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6th OOPSLA Workshop on Domain-Specific Modeling (DSM'06)

October 22, 2006
Portland, Oregon USA

UNIVERSITY OF JYVÄSKYLÄ
DEPARTMENT OF COMPUTER SCIENCE
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Welcome to the Sixth OOPSLA Workshop on Domain-Specific Modeling – DSM'06

Preface

Domain-Specific Modeling (DSM) raises the level of abstraction beyond programming by specifying the solution directly using domain concepts. In many cases, final products can be generated automatically from these high-level specifications. This automation is possible because both the language and generators need fit the requirements of only one company and domain.

Industrial experiences from applying DSM consistently show it to be 5-10 times faster than current practices, including current UML-based implementations of MDA. As Booch[*] et al. have stated, "the full value of MDA is only achieved when the modeling concepts map directly to domain concepts rather than computer technology concepts." For example, DSM for cell phone software would have concepts like "Soft key button", "SMS" and "Ring tone", and generators to create calls to corresponding code components.

More investigation is still needed in order to advance the acceptance and viability of domain-specific modeling. This workshop, which is in its six incarnation at OOPSLA 2006, features research and position papers describing new ideas at either a practical or theoretical level. On the practical side, several papers in these proceedings describe application of modeling techniques within a specific domain. In addition to industrial projects, several authors from academia present research ideas that initiate and forward the technical underpinnings of domain-specific modeling. In particular, the 22 papers included in this proceedings highlight the importance of metamodeling, which significantly eases the implementation of domain-specific languages and provides support for experimenting with the modeling language as it is built (thus, metamodel-based language definition also assists in the task of constructing generators that reduce the burden of tool creation and maintenance). We hope that you will enjoy the workshop and find the information within these proceedings valuable toward your understanding of the current state-of-the-art in domain-specific modeling.

Jeff Gray, Juha-Pekka Tolvanen, Jonathan Sprinkle

October 2006

[*] Grady Booch, Alan Brown, Sridhar Iyengar, Jim Rumbaugh, and Bran Selic, *MDA Journal*, May 2004

6th WORKSHOP ON DOMAIN-SPECIFIC MODELING
22nd October, 2006, Portland, Oregon USA

Program committee

Organizing committee

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Using Domain-Specific Modeling towards Computer Games Development Industrialization

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ABSTRACT
This paper proposes that computer games development, in spite of its inherently creative and innovative nature, is subject of systematic industrialization targeted at predictability and productivity. The proposed approach encompasses visual domain-specific languages, semantic validators and code generators to make game developers and designers to work more productively, with a higher level of abstraction and closer to their application domain. Such concepts were implemented and deployed into a host development environment, and a real-world scenario was developed to illustrate and validate the proposal.

Categories and Subject Descriptors
D.1.7 [**Programming Techniques**]: Visual Programming.

D.2.2 [**Software Engineering**]: Design Tools and Techniques – Computer-aided software engineering (CASE), Software libraries.

General Terms
Design, Standardization, Languages.

Keywords
Computer games, domain-specific languages, visual modeling, software factories

1. INTRODUCTION

Digital games are one of the most profitable industries in the world. According to the ESA (Entertainment Software Association) [1], digital games (both computer and console games, along with the hardware required to play them) were responsible in 2004 for more than ten billion dollars in sales. These impressive numbers are a match even for the movie industry, while studies reveal that more is spent in digital games than in musical entertainment [2]

The digital game industry, however, is as surrounded by success as it is continuously faced by challenges. Software development industrialization, an upcoming tendency entailed by the exponential growth of the total global demand for software, will present many new challenges to game development.

Studies reveal that there is evidence that the current development paradigm is near its end, and that a new paradigm is needed to support the next leap forward in software development technology [3]. For example, although game engines [4], state-of-the-art tools in game development, brought the benefits of Software Engineering and object-orientation towards game development automation, the abstraction level provided by them could be made less complex to consume by means of language-based tools, the use of visual models as first-class citizens (in the same way as source code) and a better integration with development processes.

This paper explores the integration between game development, an inherently creative discipline, with software factories, which are concerned with turning the current software development paradigm, based on craftsmanship, into a manufacturing process. The focus is on how visual domain-specific languages and related assets (such as semantic validators and code generators) can be used in conjunction within a software factory to make game developers and designers to work more productively, with a higher level of abstraction and closer to their application domain.

The remainder of this paper is organized as follows. Section 2 presents current digital games development tools and techniques, and explains their lack of industrialization. Section 3 introduces a game software factory named SharpLudus, which is targeted at a specific game genre. Section 4 details the SharpLudus Game Modeling Language, the most important factory asset, along with its related assets. Section 5 presents a case study named Ultimate Berzerk. Section 6, finally, concludes about the presented work and points out some future directions.

2. CURRENT TOOLS AND TECHNIQUES

A major evolution in game development technologies has occurred since its early days. Starting from assembly language, many tools and techniques evolved, culminating in game engines. This section describes the most used game development technologies and explains why they do not yet completely fulfill industrialization needs.

2.1 Multimedia APIs

Multimedia APIs (Application Program Interfaces), such as Microsoft DirectX [5] and OpenGL [6], are programming libraries that can be used to directly access the machine hardware (graphics devices, sound cards, input devices). Such APIs are not only useful for providing means to create games with good performance, but also for enabling the portability of computer games among devices manufactured by different vendors. Therefore, by using a Multimedia API, game programmers are provided with a standard device manipulation interface and do not need to worry about low-level peculiarities of each possible target device.

Multimedia APIs set a new stage in game development, by empowering programmers with more abstraction to experience an easier game development process. They are heavily used today and certainly will last for a very long time, being used either directly or indirectly.

Nevertheless, while these libraries handle almost all the desired low-level functions, the game itself still has to be programmed. The APIs provide features that are generic for computer games development and do not offer the abstraction level desired by game programmers. For example, they do not provide features to trigger the transition between game states (phases), entity behavior modeling or artificial intelligence. In other words, the semantic gap between game designers and the final code remains too high if multimedia APIs are the only abstraction mechanism used.

Besides that, interaction with such APIs can only be done programmatically, not visually. This approach may prevent automation and productivity in the execution of some tasks (such as specifying the tiles of a tiled background map), which would have to be executed by exhaustive “copy and paste” commands and through counter-intuitive actions.

2.2 Visual Game Creation Tools

With the intention to simplify game development and make it more accessible to a broader range of communities, visual game creation tools were created and soon became very popular. They aim at creating complete games with no programming at all, sometimes by just clicking with the mouse. The end user is aided with graphical and easy-to-use interfaces for creating game animations, defining entity behavior, the flow of the entire game and to add sound, menus, text screens and other resources to the game.

A visual game creation tool can be either generic or focused on the creation of games belonging to a specific game genre, such as first-person shooters, role playing (RPG), adventure games and so on. This last category includes one of the most popular visual game creation tools: RPG Maker [7], presented in Figure 1.

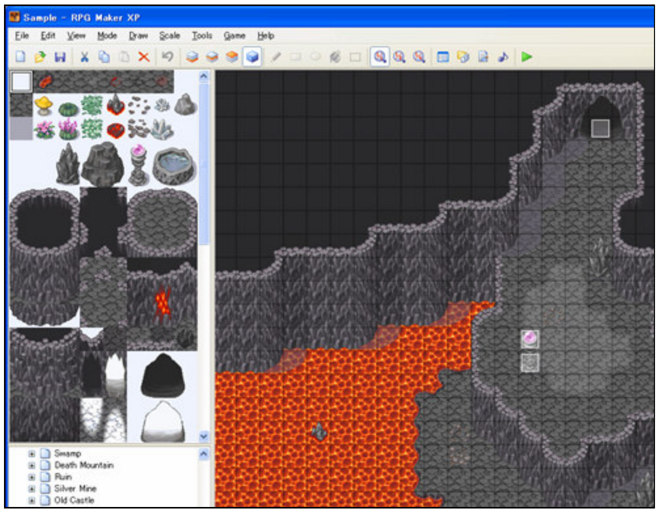


Figure 1. RPG Maker

Being able to finish the creation of a complete game with a few mouse clicks is very impressive indeed. However, although this sounds wonderful at first, the possibilities turn out to be limited. Some types of games can certainly be made, but this approach does not seem adequate for serious games [8]. Visual game creation tools currently do not address the complexity required by the creation of more sophisticated games, and this is reflected by the lack of their adoption by the game industry. Despite being very popular, most users of such tools are beginner and amateur game designers and programmers.

Visual game creation tools try to address such a problem by offering to users script languages, targeted at allowing more complex behaviors to be specified. However, while such languages certainly provide more power to visual game creation tools, they require end-users to learn a new language (perhaps their first language) and to have some programming skills. This may diverge with the original purpose of such tools (to be “visual programming” environments).

Some may say that these built-in languages are not intended to be used by all users, but only by advanced users. But once earning programming expertise, however, users might prefer to have the benefits of true object-oriented programming languages, with the support of robust integrated development environments with full editor and debugging support, instead of working with error-prone scripting languages inside an environment which was not originally conceived for codification.

Besides that, development productivity is much more than having script keywords highlighted. It is composed by a set of complementary concepts, such as refactoring, code and modeling synchronization, test automation, configuration management, quality assurance, real-time project monitoring, domain-specific guidance and organizational process integration, just to mention a few.

2.3 Game Engines

Game engines were conceived as a result of applying Software Engineering concepts to computer games development. An engine can be seen as a reusable API, which gathers common game development foundations (entity rendering, world management, game events handling, etc.) and provides to developers a programmatic interface through which game behavior can be specified. In other words, developers can be more focused on game-specific features, such as its programming logic, intelligence, art and so on.

Differently from the scenario where multimedia APIs are called directly by the computer game code, developers using a game engine are abstracted from low-level game implementation details, while still not being restricted to the limitations of an exclusively visual programming environment. As a matter of fact, the basic game functionalities provided by game engines are built on top of multimedia APIs. Examples of popular game engines are OGRE [9] and Crystal Space [10].

As with visual game creation tools, game engines can be either generic or targeted at a specific game genre. However, in order to be more effective, even generic game engines narrow their target domain by addressing only a subset of all possible computer game genres (for example, a 3D game engine has many specific issues different from a 2D isometric game engine). In fact, the main advantage of using a game engine is that, if it was built in a modular architecture, it can be reused to create a great diversity of games, which consume only the necessary game engine modules [11].

Game engines are the state-of-the-art tools in computer games development. By providing more abstraction, knowledge encapsulation and a reusable game development foundation, they allowed the game industry to reach an unparalleled productivity level. However, as with any technology, some drawbacks can be identified.

First of all, due to the inherent complexity of game engines, it should be noticed that the learning curve for mastering these tools is somewhat high. The demands for understanding the game engine architecture, interaction paradigm and programming peculiarities can turn their use into an unintuitive experience at first. That is the reason why many of today's game engines still present complexity and lack of usability as one of their most cited deficiencies.

Second, using a game engine may involve considerable costs, such as acquisition costs, training costs, customization costs and integration costs [12]. If the discussion is raised from the game developer point-of-view to the game engine developer point-of-view, additional needs for a considerable amount of resources can be identified. Since a diversity of requirements has to be satisfied, creating a game engine is a very complex and expensive task, demanding a substantial infra-structure.

In addition, one of the major difficulties in game engine development is the industrial secrecy. Since such projects involve great investments, many organizations hide their architectures and tools in order to have some advantage over their competitors [13] (for example, it may be difficult to find comprehensive studies about the applicability of design patterns in game engines [11]). Public knowledge regarding the subject, therefore, is only available through open source and academic initiatives. However, it has not been a long time since such initiatives were born, and today's game engine developers are far from having something like "game engine workbenches" to aid the creation of such tools.

2.4 Game Development onto the Next Stage

In general, game development evolution has been compliant with one of the most important software development tendencies: defining a family of software products, whose members vary, while sharing many common features. According to Parnas [14], such a family provides a context in which the problems common to the family members, such as games belonging to a specific genre, can be solved collectively.

If automation in software development is further investigated, it is possible to notice that game engines can still contribute even more to automation in game development. Roberts and Johnson [15], for example, described a recurring pattern that reveals how software development automation, in general, is carried out:

- After developing a number of systems in a given problem domain, a set of reusable abstractions for that domain is identified, and then a set of patterns for using those abstractions is documented.
- Then a runtime is developed, such as a framework or server, to codify the abstractions and patterns. This allows the creation of systems in the domain by instantiating, adapting, configuring, and assembling components defined by the runtime.
- Then languages are defined and tools are built to support the runtime, such as editors, compilers and debuggers, which automate the assembly process. This helps a faster response to changing requirements, since part of the implementation is generated, and can be easily changed.

Game engines are situated in the second of these three “pattern-runtime-language” stages. However, as Roberts and Johnson point out, although a framework (such as a game engine) can reduce the cost of developing an application by an order of magnitude, using one can be difficult. Mapping the requirements of each product variant onto the framework is a non-trivial problem that generally requires the expertise of an architect or senior developer.

Language-based tools (the third stage) automate this step by capturing variations in requirements using language expressions, encapsulating the abstractions defined by a framework, helping users think in terms of the abstractions and generating framework completion code. Language-based tools also promote agility by expressing concepts of the domain (such as the properties or even features of computer games) in a way that customers and users better understand, and by propagating changes to implementations more quickly.

Aligned with the creation of language-based tools, an emerging tendency is to make models first-class citizens for game development, in the same sense that source code already is an essential part of game development. Models can be described by visual domain-specific languages (DSLs) [16], providing a richer medium for describing relationships between abstractions and giving them greater efficiency and power than source code. By using a visual DSL, models can be used not only as documentation but as input that can be processed by tools in other stages of the development process, promoting more automation.

There is evidence, therefore, that game engines can be used together with domain-specific processes, patterns, frameworks, tools and especially languages to create a software factories approach that will situate game development in an industrial stage, by reusing these assets systematically and automating more of the software life-cycle.

3. SHARPLUDUS SOFTWARE FACTORY

In order to illustrate how games development can be turn into a more productive and automated process by means of software industrialization, a software factory named

SharpLudus was conceived. Its product line is focused on the **adventure** game genre, which can be described as a genre encompassing games which are set in a "world" usually made up of multiple, connected rooms or screens, involving an objective which is more complex than simply catching, shooting, capturing, or escaping, although completion of the objective may involve several or all of these. More information regarding the chosen domain is presented in Table 1.

Table 1. SharpLudus Product Line Definition

Feature	Description
Dimensionality	Two-dimensional (2D). World rooms are viewed from above.
User interface	Information display screens containing textual and/or graphical elements are supported. HUDs (heads-up display) can also be configured and displayed.
Game flow	Each game should have, at least, a main character, an introduction screen, one room and a game over screen (this last one is reached when the number of lives of the main character becomes zero).
Sound/Music	Games will be able to reproduce sound effects (wav files) as event reactions. Background music (mp3 files) can be associated with game rooms or information display screens.
Input handling	Keyboard only
Multiplayer	Online multiplayer is not supported by the factory. Event triggers and reactions can be combined, however, to allow two-player mode in a single computer.
Networking	High scores can be uploaded to and retrieved from a web server.
Artificial Intelligence	Enemies can be set to chase the player within a room. More elaborated behaviors can be created visually by combining predefined event triggers and event reactions, or programmatically by developers.
End-user editors	Not supported by the factory. Once created, a game cannot be customized by its players.
Target Platform(s)	PCs running Microsoft Windows 98 or higher

The SharpLudus software factory provides to developers two visual domain-specific languages (DSLs) as assets. The first one is the *Game Modeling DSL*, which together with a room designer and an info display designer allows the specification of the game states flow (info display screens, rooms and their exit conditions).

The second domain-specific language is the *HUD Creation DSL*, which allows developers to specify how useful game information (score, remaining lives, hit points, etc.) will be presented to the player by means of a heads-up display. Both DSLs are provided with validators to ensure that semantic errors are caught in design time and shown in the IDE Error List.

By using the factory DSLs, game designers can create a detailed game specification. However, contrary to common game development approaches, such a specification is a set of "live artifacts". This means that they are not only used for documentation, but they can be transformed into other artifacts by means of automation assets. For example, the VSTO [17] technology is used to create a User Manual skeleton with information extracted from the game specification, while code generators associated to the DSLs can be used to automatically create the majority of the game implementation code. Developers, however, can add their own code to the solution since the factory generated code provides extensibility mechanisms such as partial classes[1] and classes which are just ready for customization (for example, special classes for providing custom event triggers and custom event reactions).

Both the factory generated code and the developer added code interacts with a game engine, which consumes the DirectX Multimedia API. Once the solution implementation is compiled, the factory generates the game executable file and a XML configuration file, through which a high scores web server address and custom developer configuration can be specified. Finally, built-in factory organizational assets, such as the runtimes of the game engine and the multimedia API chosen, are automatically made available by the factory.

In order to illustrate how domain-specific modeling is carried out through the SharpLudus factory, Section 4 details the SharpLudus Game Modeling DSL and Section 5 explores some of its designers through the development of a real-world example.

4. GAME MODELING DSL (SLGML)

The SharpLudus Game Modeling Language (SLGML) is a visual DSL through which the game designer can specify the main game configuration (resolution, screen mode, etc.), game states (rooms and information display screens) and their flow, exit conditions and properties. The SLGML underlying concepts are also manipulated by many factory designers (event designer, entity designer, sprite designer, etc.).

According to Deursen, Klint, and Visser [16], the development of a domain-specific language typically involves the following tasks:

- **[Analysis]** (1) Identify the problem domain; (2) Gather all relevant knowledge in this domain; (3) Cluster this knowledge in a handful of semantic notions and operations on them; (4) Design a DSL that concisely describes applications in the domain.
- **[Implementation]** (5) Construct a framework (library) that implements the semantic notions; (6) Design and implement a compiler that translates DSL programs to a sequence of framework calls. Obs: considering language workbenches and visual modeling, Fowler [18] suggests an additional task to this stage: (7) the creation of a visual editor to let developers to graphically manipulate the DSL. Considering a software factory context, this research also suggests an additional step: (8) the creation of *semantic validators* to identify modeling errors in design time.
- **[Use]** (9) Write DSL programs for all desired applications and compile them.

Tasks (1) and (2) are performed as part of the software factory product line definition and product line design. The next subsections detail the other tasks, aside from task (9), which will be explored by means of a case study presented in Section 5.

4.1 Concepts Design

The *SharpLudusGame* is the root domain concepts of the SLGML DSL. As Figure 2 presents, it is related to six top-level elements, which will not be deeply detailed due to space constraints but are explained below:

- *AudioComponent:* an abstract concept representing every sound that can be reproduced in a SharpLudus game. It is specialized by *SoundEffect* and *BackgroundMusic* concepts.

[1] The concept of partial classes makes it possible to split the implementation of a single class in two files.

- *Entity:* an abstract concept which is the base unit of a SharpLudus game design. It is anything that can react with anything else in any way. It is specialized by *MainCharacter*, *NPC* (non-playable character) and *Item* concepts.
- *EntityInstance:* represents an instance of an entity, containing information such as position, speed, number of remaining hit points, etc.
- *Event:* represents a special condition that occurs to a SharpLudus game, fired by one or more *Triggers* (such as "collision between the main character and a specific item"), and that cause one or more *Reactions* (such as "add item to main character inventory"). The *CustomTrigger* and *CustomReaction* concepts, which inherit from *Trigger* and *Reaction* respectively, make it possible to create custom-made events.
- *Sprite:* represents an animation that can be assigned to entities (such as "main character walking", "main character jumping", etc.). It is composed by a *Frame* collection and it may loop after it ends.
- *GameState:* abstract concept which represents the game flow. It is specialized by *InfoDisplay* and *Room* concepts. *InfoDisplays* are used to display information (textual or graphical) on the screen, containing a *Purpose* attribute to indicate if it is an introduction, game over or ordinary information display screen (such as a menu, credits or instructions screen). Finally, each *GameState* contains an *ExitCondition* collection, which tells when the game should move from one state to another (e.g., when a key is pressed).

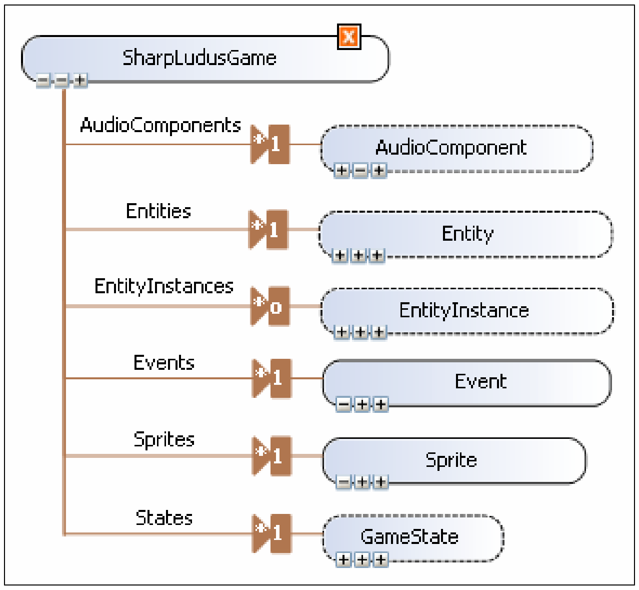
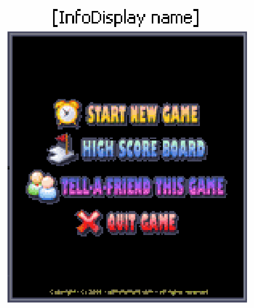


Figure 2. Top-level SLGML concepts

4.2 SLGML Syntax

Language syntax defines how the language elements appear in a concrete, human-usable form. Visual languages syntax is not only purely textual, combining graphics, text and conventions by which users may interact with the graphics and the text under the auspices of tools. Table 2 presents the visual syntax elements of SLGML.

Table 2. SLGML Visual Syntax

Graphical Representation	Description
 [InfoDisplay name] START NEW GAME HIGH SCORE BOARD TELL-A-FRIEND THIS GAME QUIT GAME	**InfoDisplay:** An information display screen is represented by a picture (shown in the left), and contains a textual decorator on its outer top, describing its name.
✓	**Intro Purpose Decorator:** This image decorator is applied to an info display, on its inner top, if the info display purpose is *Intro*.
✗	**Game Over Purpose Decorator:** This image decorator is applied to an info display, on its inner top, if the info display purpose is *GameOver*.
	Room: A game room is represented by a picture (shown in the left) and contains a textual decorator on its outer top, describing its name.
→	**Transition:** State transitions are visually represented as black arrows.

4.3 Semantic Validators

Besides aiding game designers with visual edition features, SLGML modeling experience also ensures that the DSL semantics are respected by them. This is done through semantic validators. The list below shows some examples of semantic rules associated with SLGML and enforced by means of validators:

- A game state transition must have at least one exit condition;
- A SharpLudus game should contain one main character;
- A SharpLudus game should contain only one introduction InfoDisplay;
- A SharpLudus game should contain only one game over InfoDisplay;
- An entity should contain at least one sprite;
- All game states should be reachable.

4.4 Code Generator

A C# [19] code generator was created and associated to SLGML. The generated code consumes a simple game engine developed with DirectX which was specially created for the factory. In other words, the generator receives a SLGML diagram as input and generates the following C# classes as output:

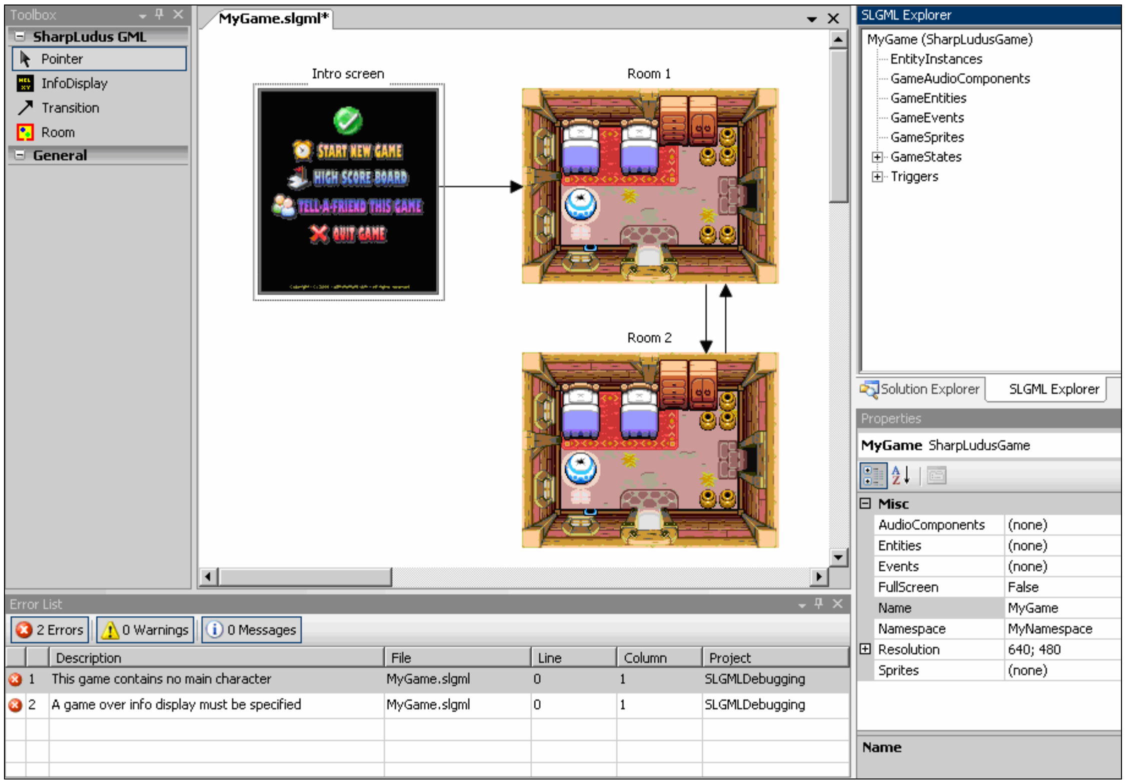
- `AudioComponents`, responsible for providing sound effect and background music objects via C# properties compliant to the Singleton [20] design pattern.
- `Sprites`, responsible for providing sprite objects via C# properties. The Singleton design pattern is not used in this case, since each sprite must be unique due to its own animation information, such as its current frame.
- One class for each *Entity* concept specified by the game designer. Such a class inherits from the `Item`, `MainCharacter` or `NPC` game engine classes.
- `EntityInstances`, responsible for providing entity instance objects via C# properties compliant to the Singleton design pattern.
- `States`, responsible for providing room and information display screen objects via C# properties compliant to the Singleton design pattern.
- The main game class, whose name corresponds to the `Name` property of the SharpLudusGame root concept. Such a class inherits from the `Game` game engine class. The code generator also creates a method in this class named `InitializeResources`, where the game configuration is set and game events are registered.
- `Program`, which contains the `Main` method and is responsible for instantiating and running the game.

Besides the generated classes, the IDE project additionally provides two initial classes which are not re-generated: `CustomTriggers` and `CustomReactions`. Developers should add their own methods to these classes in order to implement custom triggers and custom actions specified by the game designer in the SLGML model.

Figure 3 presents the complete SLGML modeling experience, hosted in the Visual Studio .NET development environment [21]. The Toolbox (at the left) presents some domain concepts that can be dragged and dropped to the SLGML designer (at the middle). The Error List (at the bottom) presents errors risen from semantic validators. The Properties window (at the right bottom) makes it possible to edit properties of the selected item in the diagram, eventually launching factory designers (sprite designer, entity designer, room designer, etc.). By using menu commands, users can launch the code generator as well as create their own code.

5. CASE STUDY: ULTIMATE BERZERK

This section presents the creation of a real-world adventure game named Ultimate Berzerk, which illustrates the use of the SharpLudus software factory. In Ultimate Berzerk, the player controls a main character, using the arrows key, to move around a maze composed by connected rooms. Once the player collects a special item (named *Weapon*), the spacebar can be used to shoot fireballs against enemies. Enemies may have special behaviors (not originally provided by the factory). The goal of the game is to collect the *Diamond* item and find the exit sign. A screenshot of the game is presented in Figure 4.



	Description	File	Line	Column	Project
1	This game contains no main character	MyGame.slgml	0	1	SLGMLDebugging
2	A game over info display must be specified	MyGame.slgml	0	1	SLGMLDebugging

MyGame SharpLudusGame

Misc

AudioComponents	(none)
Entities	(none)
Events	(none)
FullScreen	False
Name	MyGame
Namespace	MyNamespace
Resolution	640; 480
Sprites	(none)

Name

Figure 3. Complete SLGML modeling experience

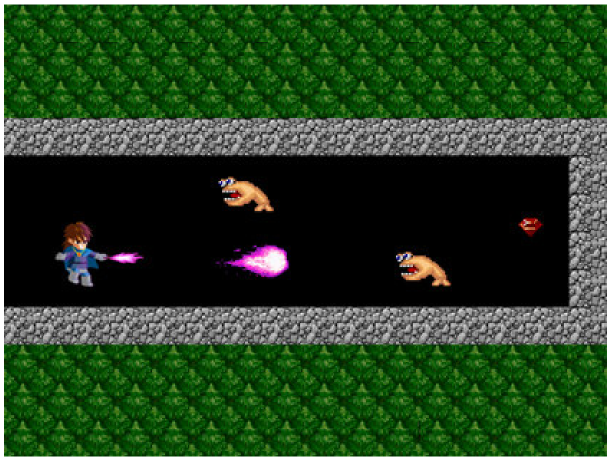
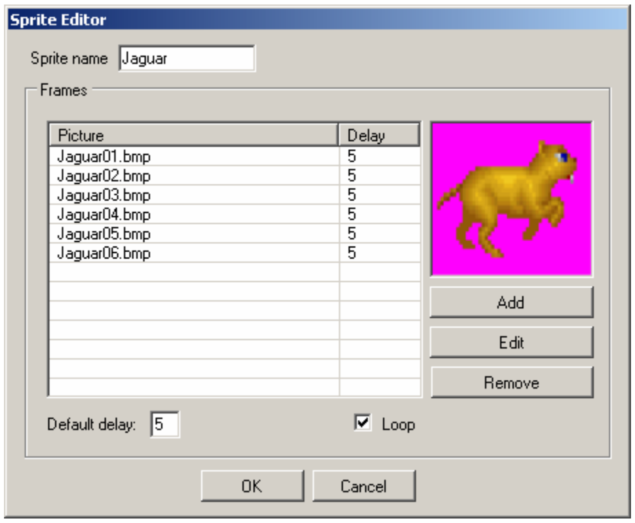


Figure 4. Ultimate Berzerk screenshot

5.1 Designing the Game

By modeling a SLGML diagram and launching factory designers from the Properties window, the game designer is able to visually create the majority of the game: sprites, entities, events, audio components, etc. For example, Figure 5 presents one of the screens of the sprite designer. This designer is launched from the *Sprites* property of a SharpLudus game and makes it possible for the game designer to specify frames and information such as if the animation will loop or not.



Sprite Editor

Sprite name: Jaguar

Frames

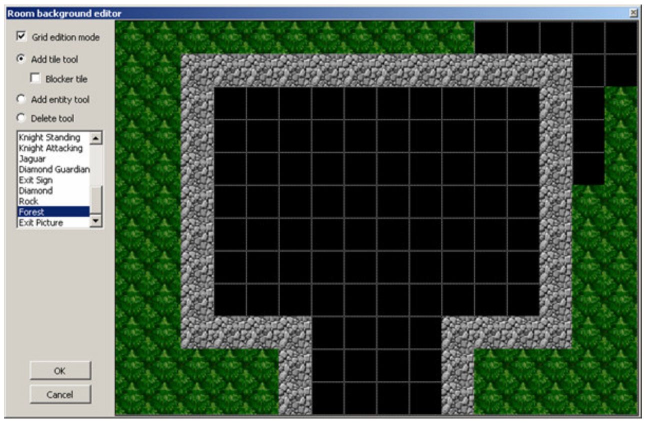
Picture	Delay
Jaguar01.bmp	5
Jaguar02.bmp	5
Jaguar03.bmp	5
Jaguar04.bmp	5
Jaguar05.bmp	5
Jaguar06.bmp	5

Default delay: 5

[✓ Loop]

Figure 5. Sprite Designer

Figure 6, on the other hand, presents the room designer, where previously created sprites can be assigned to a room as tiles and entity instances (such as enemies and items) can be added to rooms based on previously created entities.



Room background editor

[✓ Grid edition mode]

[✓ Add tile tool]

Blocker tile

Add entity tool

Delete tool

Knight Standing
Knight Attacking
Jaguar
Diamond Guardian
Exit Sign
Diamond
Rock
[✓ Forest]
Exit Picture

Figure 6. Room Designer

5.2 Custom Developer Code

Some NPCs (non-playable characters) of Ultimate Berzerk have special behaviors. For example, the enemy known as Diamond Guardian (shown in Figure 4) has a special movement in which it is bounced by room tiles of type "rock". In order to implement such behavior, factory users only need to add a class to the project named `DiamondGuardian`, mark it as "partial" and override the desired methods. This will make the final class to be the combination of the user `DiamondGuardian` class with the factory generated `DiamondGuardian` class.

It is worth noticing that when adding their own code, users will have full IDE editing and debugging support, as well as be able to make complex API calls, such as requesting information from a web service or accessing a database, for example.

5.3 Discussion: Factory Effectiveness

Although Ultimate Berzerk is a relatively simple game, with a few rooms to be investigated by the main character, its development explored many interesting SharpLudus software factories assets and features that illustrate how the factory can be used to create real-world games. Extending Ultimate Berzerk to a game with a better game-play and replay value is just a question of adding more model elements which reflect the creativity of the game designer.

The automation and productivity provided by the SLGML modeling experience, its code generator and consumed game engine is evident: in less than one hour of development effort, 16 classes and almost 3900 lines of source code were automatically generated for the development team. What is most important is that such lines of source code mainly present routine, boring and error-prone tasks, such as assigning pictures to frames, frames to sprites, sprites to entities, entities to rooms, rooms to the game, events to the game and so on.

By using the SharpLudus software factory, especially the visual designers, the development team experience was made more intuitive and accurate. At the same time, when more complex behavior was required (such as specifying the Diamond Guardian movement) the factory was flexible to allow developers to add their own code to the solution, using all of the benefits of an object-oriented programming language and being aided by IDE features such as editor support, debug support and so on. This contrasts the development experience of visual-only game development tools, where weak script languages should be used under an environment which was not originally conceived for codification.

Considering the generated code along with the consumed game engine, it can be concluded that the SharpLudus software factory is able to provide, in one hour, a development experience which would require, from scratch, the implementation of 61 classes and more than 6200 lines of source code.

6. CONCLUSIONS AND FUTURE WORK

This paper presented a study, illustrated with a real example, of how digital games development can better exploit an upcoming tendency: software industrialization. Different aspects were encompassed by such a study, being the development of a visual domain-specific language the most appealing subject.

Since the proposed approach and tools are focused on a specific domain, they may not be suitable to other types of game development contexts. Therefore, one interesting future work is the creation, based on previously acquired knowledge, of other factories targeted at other game genres, such as racing games or first-person shooters. Some domain concepts, factory designers, semantic validation rules and excerpts of the code generator may be reused, while others will need to be recreated.

Extending the SharpLudus software factory architecture and code generator to support the creation of games targeted at mobile devices, such as cell phones, seems to be quite appealing, since a recognized issue is that porting the same game to different mobile phone platforms is a burdensome and error-prone task. In such a case, once a code generator is implemented for each platform, all platforms would be able to share a single game model (specified with the SLGML visual domain-specific language) and maintenance would be made much simpler.

While the results obtained so far empirically shows that the SharpLudus factory is indeed an interesting approach, it is important to notice that deploying a complete software factory is also associated with some costs. Return of investment may arise only after a certain amount of games are produced. Besides that, despite being easy to use, software factories are complex to develop. They will certainly require a mindset evolution of the game development industry.

A final remark is that the presented proposal alone will not ensure the success of game development. In fact, no technology is a substitute for creativity and a good game design.

Game industrialization, languages, frameworks and tools are means, not goals, targeted at the final purpose of making people have entertainment, fun and enjoy themselves. Players, not the game or its constituent technologies, should be the final focus of every new game development endeavor.

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Building a Flexible Software Factory Using Partial Domain Specific Models

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Abstract. This paper describes some experiences in building a software factory by defining multiple small domain specific languages (DSLs) and having multiple small models per DSL. This is in high contrast with traditional approaches using monolithic models, e.g. written in UML. In our approach, models behave like source code to a large extend, leading to an easy way to manage the model(s) of large systems.

1 Introduction

A new trend in software development is to use model driven techniques to develop software systems. Domain specific models (DSMs), domain specific languages (DSLs), and the transformations from the DSMs to code need to be carefully designed to make them really useable.

An obvious observation is that one single model (in a single file or single repository) will not suffice for describing a complete application. Such a model would be too large to handle; it would be unreadable and thus not understandable. Although obvious, this is something that has not been acknowledged in the modelling world. Companies that apply model driven development on a large scale are having problems in managing models that are sometimes over 100 MB size. We therefore argue for building smaller, partial models, each of which is part of a complete model. This is much like the way a code file for a class is part of the complete source code for the application. Each partial model may be written in either the same or a different DSL, thus using the advantage of the fact that a DSL is designed to solve one specific part of a problem as good as possible.

In this paper we show how partial models can be used to build large, complex applications. We also show the consequences of this approach on the DSL definitions and their accompanying model-to-code transformations. We will also show how managing models for large applications is simplified by using partial models.

This paper is based on the industrial experience of one of the authors with building the SMART-Microsoft Software Factory at Ordina, a model driven development software factory using the Microsoft DSL Tools. At the time of writing this software factory included four different DSLs. Typically several dozens of DSMs are created in a project that utilizes this software factory. Although the experience was gained using the Microsoft DSL Tools, the approach can be applied in other environments (like e.g. Eclipse GMF).

This paper is structured as follows. Section 2 explains in short the development process when using a model driven software factory. Section 3 introduces the concept of partial mod-

3. The author is employed in the GRASLAND project funded by the Dutch NWO (project number 612.063.408).

els, and section 4 explains our approach to references between partial models. Section 5 explains different forms of code generation from partial models.

2 The Software Development Process

The traditional development process, not using models, DSLs, or model transformations, can (simplified) be described as follows. Decide on the architecture of the application (1). Design the application (2). Write the code, compile it, and link it (3). Run the application (4).

The model driven software factory process, as introduced in [GSCK04], using DSLs and model transformations, works in a different way. First, the software factory itself is designed as follows:

1. Decide on the architecture of the application.
2. Design the DSLs for this architecture
3. Write the transformations for these DSLs

The system developer does not need to determine the architecture any more, but starts directly with modelling the application:

1. Model the application.
2. Transform the models.
3. Write additional code (if required).
4. Compile and link the code, and run the application

This process is often done iteratively, meaning that after running the application in step 4 you go back to step 1 and start modeling the next part of the application. The development of the software factory is also done iteratively, but in the context of this paper that is not relevant. Also note that a software factory is more than just a collection of DSLs, however this paper focuses on the DSL aspect, and what's more we focus on the first part of the process: how to build a collection of DSLs and their transformations.

3 Developing a Flexible Software Factory

The first step when developing a model driven software factory, is to determine the architecture of the applications that you are going to build with the software factory. Is it, for instance, a web-based, administrative application or is it a process control system? The answer to this question determines the architecture. From the architecture we derive which DSLs are to be defined for modelling the application.

The SMART-Microsoft Software Factory is targeting web-based, administrative applications, of which the architecture is shown in Figure 1. Based on this architecture we have defined four different DSLs, each of which corresponds to a part of the architecture. We recognise the following domains: the Web Scenario DSL for the Presentation layer, the Business Class DSL for the Business classes, the Services DSL for the Service Interface and Business Processes, and the Data Contract DSL for the Data Contract. There is no DSL corresponding to the Data layer, because this layer is completely generated from the Business Class DSL. A developer who wants to build a compete system will use all DSLs together.

The different DSL are mostly independent, therefore it is possible to use a subset of the DSLs provided. We can also combine the DSLs in a different way. For example, we are planning to develop a DSL for building Windows user interfaces, which can then be used instead of the current Web Scenario DSL. This allows us to flexibly evolve the software factory.

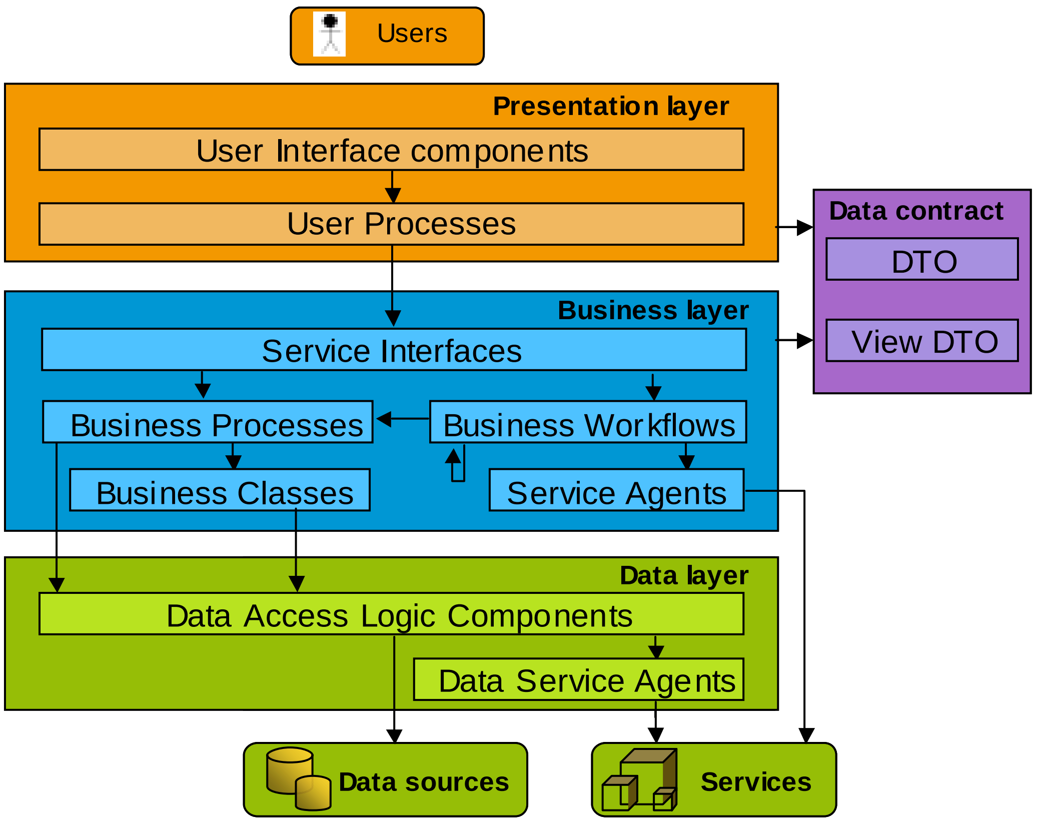

Fig. 1 The Web Application Service Architecture

3.1 Goals for Domain Specific Languages

1. A model is always executable in the sense that every aspect of a model is used to generate code. We do not consider models used purely for design or documentation, these can be built effectively with UML or tools like Visio.
2. A concept only becomes part of a DSL if it is easier or less work to model it than to code it. This keeps the number of concepts small and ensures that the DSL is very productive.
3. Models (or better said the code generated from the models) are meant to be extended by code.

3.2 Introducing Partial Models

When using the software factory to build an application, a developer determines the number and kind of DSMs that need to be built. One possibility, which we have seen used at several places, is to create one DSM per DSL. This would mean that we have four DSMs for each application. Still, for a large application this still does not scale up. For instance, if we have one DSM for the complete Web Scenario Domain, this will become an incredibly large model for any real application. The model would contain many Web Scenario elements, which each consists of a set of Web Pages and Actions. A model of such size is not readable, and certainly not understandable.

Working with one large model also introduces many practical problems relating to managing such a model in a multi-user environment. Experience with traditional UML tools has learned us that this problem has not been solved by any of them. Even when a tool allows multiple persons to work simultaneously on a model, the model must usually be divided beforehand in non-overlapping slices and the developers must be very disciplined while working with the tools.

The solution to this problem that we present here is to use multiple DSMs per DSL. We call these models *partial models,* because they do not represent the complete system. Each partial DSM is stand alone and can be used in isolation. In the case of the Web Scenario DSL, the DSL has been designed such that each DSM contains not more than one Web Scenario. If an application needs e.g. twenty Web Scenarios, twenty Web Scenario DSMs will be created. As a direct consequence of this choice each partial DSM has some unique and useful properties:

- One partial DSM can be created and edited stand alone by one user.
- The partial DSM is the unit of version control, and when the DSM is stored on file, ordinary version control systems provide ample possibilities for version control.

Our approach fits very well with the structuring of the Microsoft DSL Tools that we have been using, in which one model is stored in one file. Also, in the Microsoft DSL Tools one model is identical to one diagram, and should therefore remain small. In the remainder of this paper all DSMs are partial models, the DSLs are designed to support this.

4 Combining Partial DSMs using References

Allowing partial DSMs has direct consequences for the way that a DSL is defined. One such consequence is that we need a way to define references between DSMs. This section describes the ins and outs of references.

4.1 References between Partial DSMs

A model element from a partial DSM may be referenced in another partial DSM just like classes and their operations may be referenced in a code file. To ensure that a DSM remains a stand alone artifact, references are always modelled explicitly and are always *by name*. There are no hard links between different DSMs, otherwise we would end up with one monolithic model again. To accommodate this we have introduced a metatype *Reference to ModelElement* for each modelelement that we want to refer to in each of our DSLs. This metaclass may be subclassed to create a reference to a particular type of modelelement. Thus, a model element in a DSM may be of type *Reference to BusinessClassDto,* holding the name (or path) of a business class in another DSM.

References may link DSMs written in the same DSL, e.g. a *Reference to WebScenario* in a Web Scenario DSM, or they may link DSMs written in different DSLs, e.g. a *Reference to BusinessClassDto* in a Web Scenario DSM, that refers to a modelelement in a Data Contract DSM. An example of the first can be found in DSM 1 in Figure 2, an example of the second can be found in DSM 2.

4.2 Checking References

In a complete application the references within the DSMs should all be valid, e.g. the referred *WebScenario* in Figure 2 must be defined in another DSM. For this purpose we have developed inter-DSM validation support. With one button, a user can do a cross-check on all references to check whether the referred elements exist. This validation is based on a small run-time component, which is populated from the DSMs in the developers workspace. This component is similar to a symbol table in a compiler and only holds the minimum information needed for validation purposes.

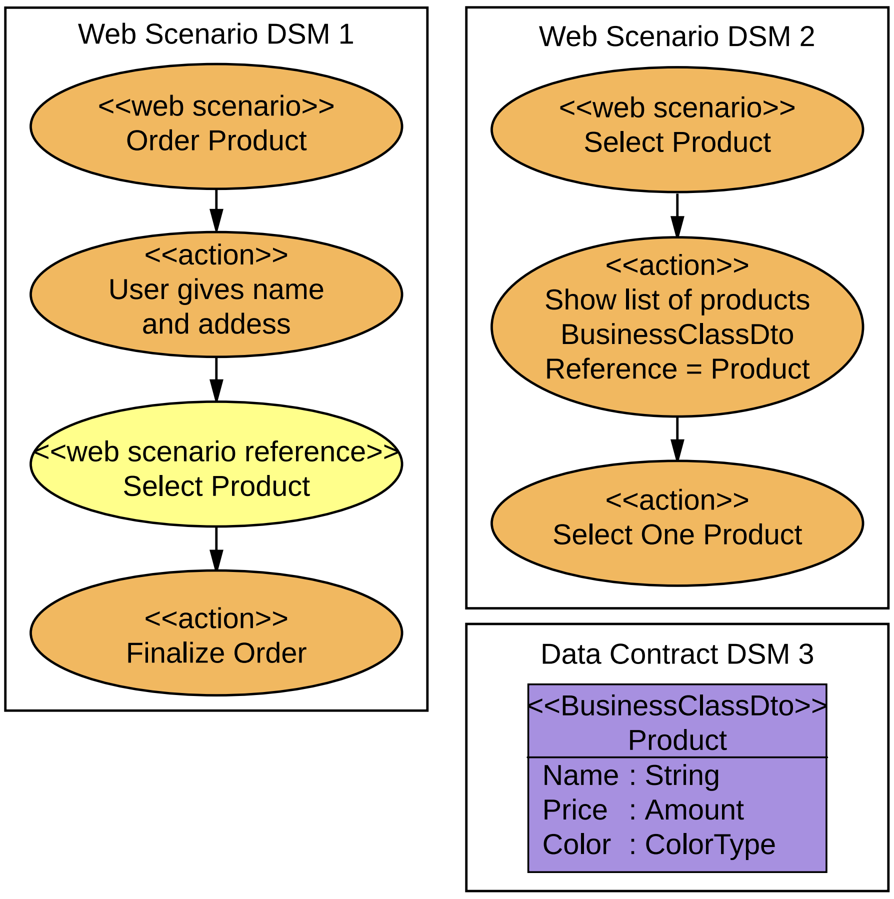
Web Scenario DSM 1
<<web scenario>> Order Product
<<action>> User gives name and addess
<<web scenario reference>> Select Product
<<action>> Finalize Order
Web Scenario DSM 2
<<web scenario>> Select Product
<<action>> Show list of products BusinessClassDto Reference = Product
<<action>> Select One Product
Data Contract DSM 3
<<BusinessClassDto>> Product
Name : String
Price : Amount
Color : ColorType

Fig. 2 Example of references between partial models

Note that a single DSM is still valid if a reference does not exist, but the collection of DSMs is not complete. The DSM with the unresolved reference can still be edited, checked in, and its model elements can be referred to by other DSMs, etc.

4.3 Dealing with Changes in References

A change in the name of a referred model element is allowed, but will make existing reference(s) dangling. This is an inherent feature, following directly from the way DSLs are designed. Tool support for coping with this kind of changes is not within the scope of language definition, instead it should be provided by the IDE. There are various options for dealing with dangling references:

- *No support*: the inter-DSM validation will result in an error message and the developer has to "repair" the dangling reference.
- *Refactoring support*: the user may explicitly perform a name change of the referred model element as a refactoring. The IDE will find all references, and change them to refer to the new name.
- *Automatic support*: when the user changes the name of a referred element, all references will change automatically.

Having no support at all does work, but is cumbersome. Automatic support has the problem that the developer does not know where automatic changes take place and he might therefore encounter unexpected results. In the Plato model driven environment that we have built in the past, we found that automatic changes also results in the need to re-test the whole system, because the changes were not controlled.

The best option seems to be refactoring support. Note that in this case renaming a model element works exactly as renaming a class in C# or Java code. Either the user changes the name, which results in dangling references, or the user requests an explicit refactoring and is offered the possibility to review the resulting changes and apply them. In the SMART-Microsoft Software Factory we have chosen the option of using explicit refactoring. The run-time component for cross-reference validation holds all the information needed to execute this.

In both automatic and refactoring support the following problem may occur. Specially in large projects, there will be many dozens of DSMs, and each DSM can be edited simultaneously by a different user. To allow for automatic change propagation or refactoring the user performing the change needs to have change control over all affected DSMs. Because we do not have a model merging feature available in the Microsoft DSL Tools, this problem cannot currently be solved.

5 Code Generation

In this section we explain different forms of code generation from partial models. As our models are meant to generate code, this is an essential part of the DSL definition. We do not use our models for documentation purposes only.

5.1 Different Types of Generation

In model driven development [MSUW04, Fra03, KWB03] multiple layers of abstraction are used. Inhabitants of the lowest layer are called code, inhabitants of all layers above the lowest are called models. There is no restriction on the number of layers that may be used, as shown in [GSCK04].

The definition of a DSL includes the code generation for that DSL. Interestingly, it is also possible to generate another model instead of code, thus making use of multiple layers of abstraction. For DSLs defined at a higher level of abstraction, it is often more easy to generate a lower level DSM than code, because the generation target itself is at a higher level of abstraction. Therefore we distinguish the following two types of generation.

DSM to Code Generation. The first type of generation is code generation from a DSM. This is the most common way of generation. Template languages like T4 for Visual Studio or JET and Velocity for Java are often used for this purpose.

DSM to DSM Generation. The second type of generation is to generate another model from a DSM. This is possible when a DSM can be completely derived from another (higher level) DSM. Often the generated DSM takes the form of a partial model. The developer can add (by hand) other partial DSMs that refer to the generated DSM, thus extending or completing the model.

5.2 Linking Partial Models or Linking Partial Code?

Another distinction that needs to be made is the moment when the partial descriptions of the application are brought together. There are two possibilities:

1. Link all partial models together to form the complete model. Transform the complete model into code.
2. Transform a single partial model into (partial) code. Link the generated code.

Within the SMART-Microsoft Software Factory we have chosen to use option 2. The code is generated immediately (and automatically) whenever a DSM is saved. Our experience is that generating everything in one step from a complete model can become very time consuming, resulting in long waiting times to conclude the code generation process. Using option 2, we can perform the transformation process incrementally, re-generating only those parts that have been changed. Also, option 2 fits much better in our philosophy that we do not need a complete model at any point in time.

However, option 2 is not always feasible. When the information in two or more partial models needs to be transformed into a single code file, only option 1 will suffice. In our case we generate C# code, which offers the notion of partial classes, which are used extensively in the SMART-Microsoft Software Factory.

5.3 Regeneration and Manual Additions

When something - either code or another DSM - is generated from a DSM we need to be able to do at least two actions:

- Regenerate whenever the source DSM changes.
- Manually add something to the generated code or generated DSM.

Besides, we must at any time be able to use the two options independently. That is, when we have manually added code or DSMs, we must still be able to regenerate the generated parts while maintaining the handwritten code or DSMs. This is implemented as follows.

Regeneration of Code. When we generate C# code, partial classes and abstract / virtual methods are used to enable the user to add code without touching the file that was generated. This allows full regeneration without disturbing the handwritten code. For other types of artifacts, the situation is more complex, often handwritten code has to be in the same file as generated code (e.g. in XML configuration files). The handwritten code is then marked as a guarded block and retained when the file is regenerated.

Regeneration of DSM. When we generate a DSM from a higher level DSM, we use the same approach as when generating C# code. One partial DSM (in one file) is generated, and this file remains untouched by developers. Handwritten additions must be modelled in separate partial DSMs. *Reference* elements (see 4.1) may be used in the handwritten DSM to refer to model elements in the generated DSM.

6 Other Views on Modeling

In the UML world the term model is often used rather loosely both for a diagram, and for the underlying collection of interrelated modelelements. However, according to the UML language definition, there can be only one model - consisting of multiple diagrams - and each diagram is a specific view on part of the underlying model. The UML offers no way to define references between different models, it assumes that you always work with one (large) model.

In the agile modeling community there is a tendency to create small models. However, these models are typically used for documentation and design, but are rarely used for code generation. The difference between this type of models and the ones presented here is that the agile models usually cannot be processed automatically to generate working code. Although human readers might recognise references between agile models, tools will not. Also, what is considered to be a set of small models, often is a set of diagrams in one UML model.

The partial DSM as described in this paper always constitutes an executable model. Within a software development project these models have exactly the same status as source code.

They are the source from which the final system is generated. Before completely building the system all references in both the source code and the (partial) models must be resolved.

7 Conclusion

We have described the development of a model driven software factory using multiple DSLs. The approach takes a non-traditional view to modelling. Instead of having one monolithic model we use many smaller models of many different types. These models are called partial models or partial DSMs. In our approach one partial DSM has the same characteristics as one source code file, which clarifies many things and leads to a different way of thinking about models. The following characteristics of partial DSMs are identical to source code files.

- Storing a DSM in a file
- Code generation per DSM
- Version control per DSM
- References between DSMs always by name
- Refactoring in the IDE if requested by user
- Intellisense / code completion for *Reference* elements

While building the SMART-Microsoft Software Factory, we found more and more advantages of our approach. Although not discussed in this paper, each DSL can be used in isolation of other DSLs. This opens up possibilities to use a subset of the DSLs whenever applicable or, for example, replace one DSL by another one in the software factory. We also see opportunities to reuse both DSLs and DSMs in a relatively easy way.

We view the approach to building a software factory using DSLs as an approach to MDA. Although MDA is often related to UML, this is not mandatory. Using DSLs fits into this approach as well. Also, we deal with model-to-model transformations as well, although we have no fixed number of levels like the PIM - PSM - Code levels in MDA.

The SMART-Microsoft Software Factory also has strong connections with the idea of developing product lines [CE00]. The software factory is a product line for administrative web applications according to a defined architecture. We have ensured flexibility for building other product lines by keeping the DSLs as independent entities. Apart from the DSLs, a Software Factory also includes other things, like a specialized process and others. This paper focuses on the DSL aspect only.

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Conceptual design of web application families: the BWW approach

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Abstract: A good analysis of the application domain is the most complex and crucial phase in information system design, regardless of its dimensions. Many well-known methodologies exist for the following development phase, but to design a specific application domain many approaches follow one another: from UML to goal-oriented approach. All these became critical when the final application will be a large web application where it is important to also model the user experience. In this case it is not possible to isolate a well-structured conceptual model of the domain where the computer technology concepts are not taken in consideration but the modeling concepts map directly to the domain concepts.
We explain here our experience of a research industrial project founded by the Italian Government about environmental monitoring. In this work, we adopt the UML-Like approach in order to obtain the domain specific conceptual model. The target is not a single application but a family of applications. After this phase, we adapt in an opportune way the BWW (Bunge-Wand-Weber) ontology to design the application domain and we evaluate which domain representation is more objective and useful for the following web information system design and development phases.

1. Introduction and background

Web application became in the last years complex application where several actor, several type of information, several technologies, several roles are involved. In order to link together these different key aspects it is very important to provide a methodological approach to helps in the design and later in the development of web application. We focus on methodologies that consider the information, navigation and transactional aspects typical of web application with several user on several devices. Very often when methodologies are applied they result strictly related to the designer experience about the domain knowledge. When the application domain is very large and several application (not only a single application) can be obtained from the design, it is important to formalize in some way the domain knowledge in order to not lies the application of the methodology only on the experience of the designer but in order to provide a common knowledge on which designer can work. In a few words it is important to take into account the conceptual design. We can see in Fig. 1 three different layers of analysis: the first, the domain layer, allows us to acquire the rigth knowledge of the entire application domain (named conceptual model); in the second, the web application layer, several design methodologies such as IDM, P-IDM and AWARE provide an engineeristic approach to the well-known web application paradigm (in order to solve the information and navigation open issues); and finally in the application layer, implementation details are taken into consideration.

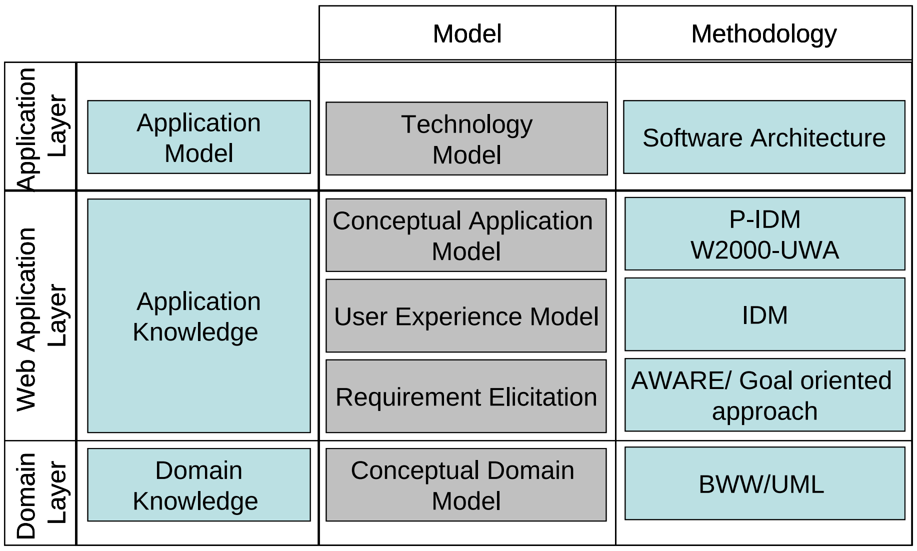

Fig. 1: Layers of analysis

In the modeling of an application family, surely a fundamental role is performed by the domain knowledge. The domain design must represent all the system complexity and, at the same time, the domain layer must be of high level of abstraction and must not take into consideration technology aspects. The conceptual model can be interpreted as the "broader view of information systems requirements engineering" [DIES00]. The conceptual model goal is to obtain a detailed domain analysis independent from the system functionalities, the processes, the information structures. Moreover the language used to describe the model must be near to the domain concepts. In practice, the conceptual model allows us *to acquire* the application domain knowledge *and to store* it using a well-defined grammar. The conceptual model will be the starting point from which to obtain the following analysis phase. Due to the conceptual model importance, it is essential to consider an efficient approach with several key aspects:

- *Complete*: it covers all the aspects of the particular application domain;
- *Objective*: it must represent the reality in its wholeness without focus on a particular aspect of the reality as it can be seen by a particular actor involved in a specific aspect of it. The conceptual model could be the model where all the actors can recognize its own particular part of the application domain.
- *Abstract*: at this modeling level it is not important to go down to the detail, but rather to remain at a high abstraction level. This allows a simple and efficient information exchange between the conceptual model and the models obtained in the next phases for instance the process model, the user experience model etc. [CHEN99]
- *Independent from the implementation technology*: to be tied up to the implementation technology results, in some cases, in designing the application domain in terms of the selected implementation technology. As a consequence, this can put little emphasis on the critical application domain aspects (because they are, for example, hard to implement) or, contrarily, can emphasize irrelevant aspects. Both factors can result in a product of poor quality.
- *Simple*: Surely a model can not be simple if the application domain is complex, so it is important to think to a methodology and to a relative notation in order to manage the application domain complexity and to represent exactly the complexity of the application domain without add another complexity level.

In order to meet all these key aspects we focus on two different approaches to the conceptual domain model:

- *The use of classical techniques within software engineering*. Due to the domain dimension and complexity, it is too hard to use a full-compliant UML approach because it force to constraint often hard to take in consideration in order to provide the key aspects considered above. For this reason we decided to adopt an UML-like approach that is to adopt the main concepts of Object Oriented customized for our purpose.

- *The use of the formal ontology*. We adapt, through a methodological approach that we propose, the classification of the concepts proposed by BWW in order to represent the domain concepts and its relationships with a well-known semantics.

In this paper we present in the section 2 an overview of the BWW approach that we propose for the conceptual model and in the section 3 we speak about the environmental domain as a case study of our research work. In the section 3.1 we discuss the conceptual model of the application domain an UML-Like approach and in the section 3.2 we discuss about the conceptual model of the same application domain with the proposed BWW approach. In the section 4 we compare the two approaches provided and finally we provide conclusion and future works.

2. The BWW approach

To achieve an objective conceptual model, not tied up to a particular technology and whose modeling primitives allow us to provide for a suitable semantics to the model, we explored two possible directions tied up to the application of the Information Systems design philosophy.
The first is proposed by Chisholm [CHI92][CHI96][LEW97] immediately rejected because it doesn't provide an objective model: the approach is based on the *common sense*, that is it leaves a lot of scope for free interpretation from who read the model without providing norms and interpretation rules.
We follow in our research work another approach: the BWW approach [WEB97]. BWW provides an effective and suitable classification of the concepts that allows from one side to not flatten the whole modeling in a few concepts (classes, relationships and so on) and from the other side to assure a good level of objectivity and the correct semantics: each part of the domain model under analysis can be associated, without leaving scope for free interpretations, with the classification of the concepts implicit in BWW. In this way the model obtained is objective: the concept classification helps to represent the application domain without focus on a particular point of view but only categorize the application domain concept in a well specific classification. Furthermore it is easy to realize and easy to use for those who will deal with the following phases of analysis and implementation. The model obtained is not tied up to any implementation technology.
Obviously we adopt the BWW approach not in the philosophy point of view but we adapt BWW concepts classification in order to define the conceptual model in a specific application domain. In this way it is possible to define the domain model direct using domain concepts.
In order to define the domain model in the environmental domain (target of our research work) we defined the BWW ontological meta-model that reflects the concepts classification proposed by BWW and, on the base of this classification, we realized the environmental domain model. The language used to define both the meta-model and the model is OWL [W3C04]. The domain model so obtained has well-defined semantics: the concepts of the environmental domain have easily been classified among those proposed by BWW. It is clear that the realized meta-model is also valid for the definition of the conceptual modeling of other application domains.

3. Case study: enviromental domain

We consider a very complex application domain: the environmental protection (understood as habitat of all the organisms and as organic structures of systems and subsystems). Environmental protection has evolved considerably in recent years. In the sixties, the public administration main goal was the control laid down by law. Today great importance is given to knowledge acquisition of the factors that heavily affect the environment quality; this choice is determined by the high growth rate of the population and by the evolution of the productive system that exercise pressure on the environment.

Today, monitoring activity and environmental control is not only developed by the government public administrations (Municipality, Provinces, Regions) but also by a number of associations and organizations and, above all, from several agencies for the protection of the environment in national and international territory.
The great number of stakeholders and the necessity to acquire the knowledge about the quality of the environment and soil, force a coherent and reliable informative exchange. To achieve this goal, organization and institution nets were born in order to facilitate the collaboration for applying a common environmental policy. The efforts to collect and to deliver environmental knowledge in the Italian and European areas do not match at regional institutional level, because the technological infrastructures do not support informative exchange. In this context, the research project GENESIS-D[1][MAIN05]. The project goal is the creation of a "framework" for the design and the development of software systems for environmental management at regional and/or sub-regional level. The software systems obtained starting from the framework Genesis-D, will be web application that will allow the exchange of environmental information among different institutional subjects such as Regions, Provinces, Municipalities, ARPA (Regional Agencies for the Environmental Protection), etc.
The problems related to the application domain model are of two types:

- The application domain is very complex so it is hard to cover all the complexity and to take into consideration all the application domain aspects without guidelines;
- The applications obtained starting from the framework will be web-based applications so the design focus is not only on the data element (represented in the form of object or relational entity) but also on the user experience (end-user and his perception of the information). This constraint force to consider the user experience design that is to take under control simultaneously of all the aspects of the application domain, to acquire and to document a deepened domain knowledge in order to highlight the differences and the shared points among different stakeholders.

3.1 Conceptual modelling through UML-like approach

At the conceptual modelling abstraction level it seem not correct to use a full-compliant Object Oriented approach; we define a class diagram but we can not speak about “object” as they are defined in the UML definition. In UML an object is an entity with a well defined boundary and identity that encapsulate state and behaviour [OMG]. Because in this phase we are not able to define state and behaviour we define the generic concept of “Entity” that may contain some attributes in order to characterize it. We define a static view of the overall system through the class diagram where we represent Entity and relationship between them. As it regards the dynamic view of the system, it could be defined using other UML diagram but this introduce to another important problem: the overall view of the application domain is fragmented, so a change in one diagram may make obsolete other diagrams[BOOCH].
We named this approach where we define a class diagram as relationships between Entity and without dynamic view of the system the “UML-like” approach.
In the UML-like approach the modeling process is made up though several iterations: each iteration has the goal to refine the analysis and therefore to describe the application domain in a more and more precise way. Particularly, the first step aims to provide a description of the information entities and the relationships among them. These entity are refined in order to describe the overall application domain. After this phase entities are refined (through the definition of the attributes, of their type and of the methods), in order to define a class diagram that is the model of the application domain. This process starts from the "generalization" in which the designer is forced to aggregate

[1] The leading company is Edinform SpA in collaboration with the University of Lecce and the Polytechnic of Milan

them in terms of shared attributes. At the end of this process abstract objects are specialized obtaining a full UML-compliant design useful for the implementation of the application. In a few word this process bring to a class diagram. These classes will be invoked in order to develop a single specific application. Obviously the application will be realized with an OO technology.
Taking into consideration a scratch of the environmental domain (Fig 2) we consider several objects such as: alteration biological variety, climatic change, consumption of soils, soil degradation, eutrophication, pollution, wastes production and disposal, radiation, noise, and so on. Each of these phenomena is characterized by a variation of some environmental parameters which may or may not be homogeneous. In the UML-like approach the designer describes the phenomena creating the *FIA* class (Fact of Environmental Interest) and all the parameters are grouped in the *IIP* class (Indicator, Index, Parameter) strictly related to the *Metrics* class. It is clear that in the class diagram FIA, IIP and Metrics are Abstract Classes that must be specialized when they are instanced. Using an analogous procedure, other abstract classes are identified as *Objects*, *Subjects* and *Structures* (*OSS*) to which each *FIA* makes reference. The class *OSS* contains the Subjects (physical or juridical person that can be interested or involved in facts and environmental phenomena), the *Objects* (any object or territorial structure inside which the characteristic processes of the human social lifetime are based and are developed) and the Structures. The class *OSS* is directly connected with the class *FIA* and it will be decomposed in *OST and SOI*.

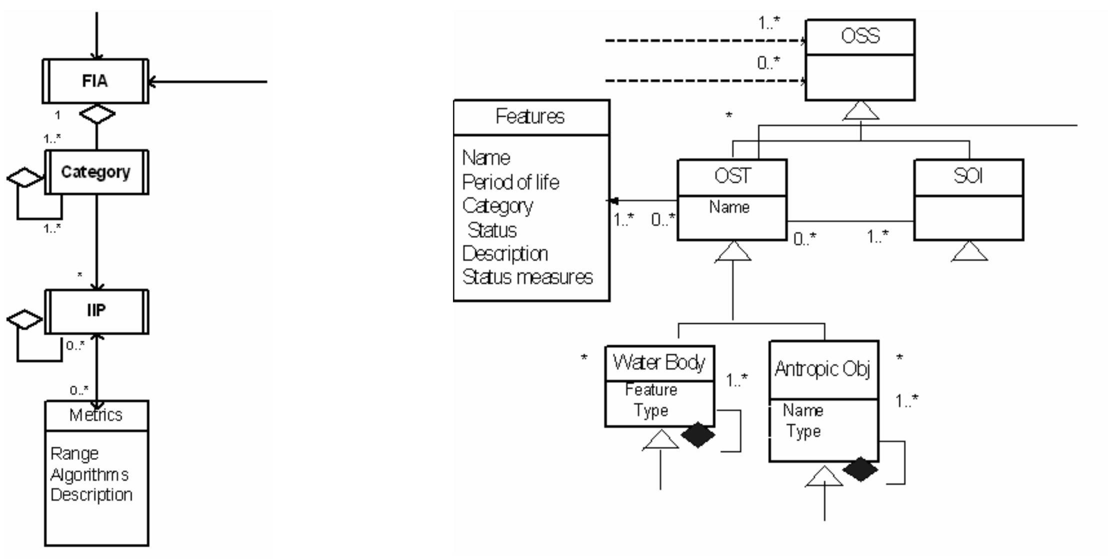

Fig. 2. A scratch of UML-Like model

3.2 Conceptual modelling through BWW

In the conceptual modelling made by BWW approach, the language used to define the model is OWL and the classification of concepts that we adopt is defined by BWW ontology. To be precise, we adapt the BWW ontology to our goal and we follow several steps in order to obtain a complete conceptual model of the domain in a well-defined language (OWL) (see fig. 3). We explain here the steps followed to define a domain-specific model using BWW concepts in the environmental domain. Obviously these steps, here applied to the design of the environmental domain, can be followed in order to model any application domain.
Having acquired the necessary knowledge of the application domain, in Step 1 it is possible to individualize the *Things* [WAND95] distinguishing them, as far as possible, from the *Classes*[WEB96](step 2). In the BWW approach the difference between *Things* and *Classes* is very subtle: the *Things* are well defined in reality in examination; they are tangible objects and therefore they are easily identified. *Classes* group together poorly defined *Things* that have some shared

properties (*mutual property*)[WAND95] (the definition of mutual property is in step 3). We, for instance, consider the *Water Basin*: it has the same properties as the *Water Body*. The properties shared between *Water Basin* and *Water Body* define a class (*Hydrographic object*): *Water basin* and *Water Body* are things and they have both mutual and intrinsic property. In the conceptual model phase it is also possible to know some mutual properties but to not know what *things* belong to this class, because their individualization requires a degree of specialization and detail in the model that would make it considerably complex and it would stray from the desired degree of abstraction.

Step	Step description
1. Analysis of things	Highlight things of the domain
2. Analysis of classes	Highlight classes of the domain
3.Mutual property	Select mutual property of each class
4. intrinsic property	Select intrinsic property of things and classes
5. Characterization of mutual/intrinsic property	Select peculiar characteristics of mutual/intrinsic property
6.Events	Define what it happens in a particular application domain
7.System	Select different parts of the same conceptual modeling

Fig.3 Methodological steps to define a conceptual model using BWW

The next step (Step 4) is to identify the related *intrinsic properties*. At this point the designer presents an initial description of the application domain; surely it is not complete but it succeeds in giving an idea of the application domain complexity.
The following step (Step 5) consists of identifying the peculiar characteristics of each mutual and intrinsic property. Particularly, each mutual / intrinsic property is tied up to both human and natural laws. This characterization of the properties introduced by BWW, has led us to reflect them in the environmental domain and to reveal *some concepts that in the UML-like approach had not been considered*. The territorial competences of the *Public Corporation* are, for instance, defined by *decrees*. The *decrees* result, therefore, in a characterization of the Intrinsic Property *territorial competences* and, particularly they are *Human Law*: this means that territorial competencies are constraints by the Human Law decree. BWW attributes allow us to take into consideration the *correct semantics* of a concept (*decree*). In the UML-like approach, because decree is an instance of a DIA (Provision Intervention Action) it will be related to this class, so it is not highlighted that decree constraint the territorial competencies. We decide to not show the concept of *decree* (Fig. 4) because it should has the same characteristics of the DIA therefore cannot be connected with the *Territorial Competencies* with the correct semantic (Fig. 4). In the BWW approach the problem is solved thanks to the “BWW Law” concept. The concept of decree that naturally fits the concept of Law is hard to represent using UML notation, in fact a study in this field say that there is not a correspondence between the concept of BWW law and any kind of representation in UML[HOPDAL02].

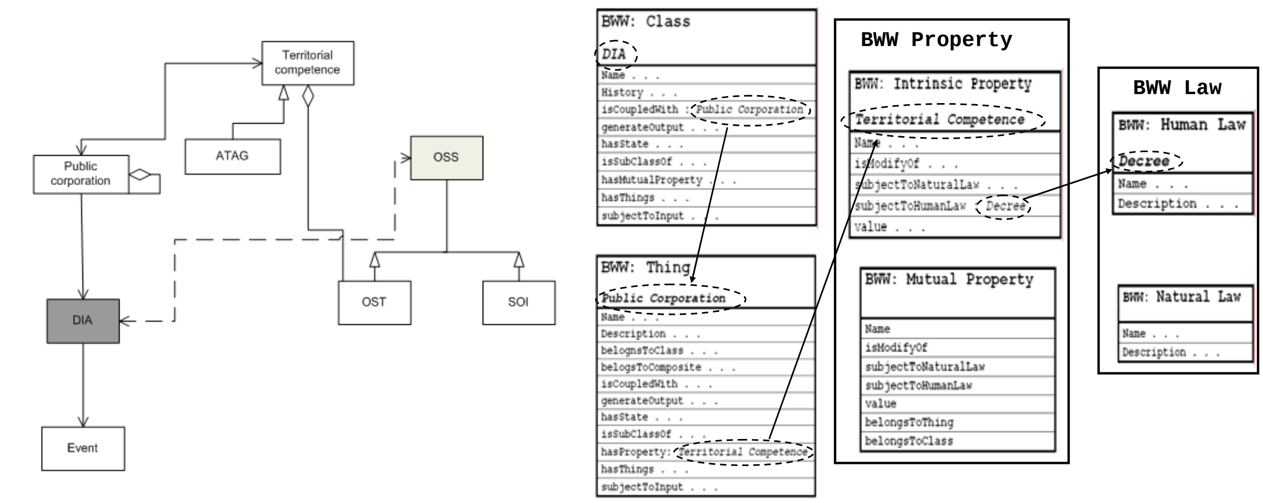

Fig. 4:The two approaches compared

The following step (step 6) is the identification of the *Events*. The concept of events allows us to define what happens in a particular application domain. BWW attributes well defined semantics to the *event*: the events are in partnership with a *thing* or class and, when they occur, change a well defined property of the Thing or of the *class* to which they are associated. The possibility to define the events induces the designer to understand thoroughly the functioning of the application domain and to identify the consequences that an event can provoke (which property the event modifies). When an event modifies the value of different properties of a same *thing/class*, the *thing/class* changes state. All the states make a *history*. In BWW the concept of history is defined to follow changes of state so the changes of state are associated to *opportune semantics*.
At this point we have a complete conceptual model of the application domain in examination and in order to organize the obtained conceptual model, it is possible (but not obligatory) to define the *systems (step 7)*. BWW defines the systems as the joining of things intending that the things belonging to the system influence the properties of each other: this is a guideline that facilitates the designer to define the subsystems and therefore to structure the model appropriately.
The conceptual model obtained, as in the case of the conceptual modelling obtained from the UML-like approach, will be the starting point for the design and implementation of specific web application: at this point, because we are not lies in any way to the object oriented approach, we are free to design and develop the web application taking the knowledge stored in the model and without any constraint about the technology to adopt.

4. Comparison between the two approaches

The UML-like approach allows us to describe a domain using an incremental method: the designer improves the analysis step by step; this option is very useful when, in an application domain such as the environmental domain, knowledge is very fragmented. In our case study, the project started with an analysis of environmental models (National, European and American models) that describe the environmental domain in general and then it has been possible to describe in detail all the information needed to produce the class diagram.
The developer can directly use the output obtained through the UML standard notation to create the framework.
The problem strictly related to this approach is that the output will be an Object Oriented model that will implement the typical constructs of this paradigm (generalization and specialization) but, although correct, it moves away from the objective reality.
The process is strongly dependent on the experience of the designer who must analyze the application domain and must be skilled at OO modeling.
The final output of UML-like approach, even if complete, is strongly tied up to the implementation logic. Furthermore, the output (the model and its notation) complex that is add to the complexity of

the application domain another level of complexity due to the fact that the semantic in the UML-like approach is flatten in the concept of entity and relationships between them.
The concept of entity is used also to model very different concepts; for instance, a *FIA* is determined by varying a particular indicator. In the UML-like modeling, the *FIA* and the indicator are both modelled as classes but the *FIA* is not a pure class but a set of values (not a-priori defined) that the indicator can assume at the time: a *FIA* is registered when some value of an indicator change. Using the BWW approach the *FIA* has been modelled as a history of the value of indicators; thus, the concept of *FIA* has the correct semantics. This example makes it clear that the application domain model (particularly the environmental domain), using an UML-like approach, compresses the different semantics into the same concept of entity (or of relationship among entity). These make not only the creation of the model difficult but also its understanding from he who must use the conceptual modeling for the following phases of analysis and implementation. The model created using UML-like approach, gives freedom to understand the model because it is not tied up to a particular semantics, therefore the model is not objective.
With BWW approach, it is possible to represent some relationships that in the UML-like vision it could be possible to characterize only by using other diagrams different from class diagram (in this case we obtain a fragmented design not useful in the conceptual modelling phase); for instance, an *OSS* creates a *FIA* that, in turn, is created when the variation of an indicator produces an alarm. The alarm condition is an input event to the *public corporation* that in response produces a *DIA* (Provision Intervention Action), a regulation that the *OSS* must respect. According with the *DIA*, *OSS* finishes the alarm and, hence, it produces another change to the indicator and so another *FIA*. In the UML-like approach it has not been possible to define this important aspect: it can describe only a relationship among *OSS*, *FIA* and *DIA* and the cause-effect relationship is not clear. We have to consider that the cause-effect relationship (in UML-like approach) could take place adding the specific methods to the objects but this is not compliant with the need to define a conceptual model of the domain without going in detail. On the contrary in the BWW approach the class *OSS* is related to the thing indicator and produces the event *FIA*. In the event *FIA* it is possible to see which properties of the thing indicator are modified by the event. The indicator produces the alarm condition (modelled through the property generateOutput of things), that is the Event source in the thing *public corporation*. The thing *public corporation*, related with *DIA*, issues the rules of *DIA*, modelled with an *Event*. At this point the *DIA*, engages the *OSS* and forces the *OSS* to conform to the new indicator value. To model this is very simple with the BWW approach thanks to the concept of "*coupled*" (that allows the joining of two classes: class modifies the value of one or more properties of the other), to the concept of *Event* and to the concept of input and output in relationship with the concept of thing. It is important that the relationship's name (*is coupled with*, *generate output* and so on) is intrinsic in BWW approach so the right semantics is given directly by the BWW approach. Last, but not least, thanks to the BWW approach the domain model is directly expressed using well defined and categorized domain concept through real world concept such as thing, classes, law and so on where the domain concept is easy to map.

5. Conclusions and future trends

The BWW approach allows the provision of the right semantics and therefore it expresses all the domain details directly using the domain concepts. The model is objective thanks to the classification of the concepts provided by BWW and it is not tied to a specific implementation technology.
The conceptual model has been immediately understood in the correct way both from the stakeholders (who, helped by the classification of the concepts, have identified their own activities and goals), and from the buyer (who has succeeded in understanding all application details without having specific skills in BWW ontology). The modeling realized through the BWW approach meets, therefore, all the requirements described above.

The UML-like approach appears particularly effective because, being a lot close to an implementation technology, allows us to directly reach the realization of a family of applications in a particular application domain. Nevertheless, the objectivity and the simplicity of the BWW approach encourage the use of this approach for the conceptual modeling of application domains of great dimensions.
Using the BWW approach, the effort and the elapsed time to define the application domain conceptual model, are smaller than those needed in the UML-like approach. In our research work the knowledge acquisition for the conceptual model of the environmental domain required 3 months and it has been realized both through interviews with the various stakeholders and through the study of several documentation pages. The team, composed of 3 units, after having acquired the domain knowledge, was split: 2 units used the UML-like approach while the third unit made the conceptual model with the BWW approach. The UML-like conceptual model required 3 months while the one using the BWW approach required just 1 month.
The case study presented in this research work where we compare the UML-like approach with the BWW approach to the conceptual design is very complex, so we think that consideration made for this case study are also valid for other case study that we planning to conclude as soon as possible.
In order to hold under control the typical aspects of web applications and therefore to manage the user experience, we design two web application starting from the conceptual modelling of the family of web application. Our efforts are focused on the definition of a methodology to obtain an IDM [PER05] design starting from the domain specific modeling of the whole application domain. To achieve this goal, it appears simpler to start from the conceptual model realized according to the BWW approach characterized by an elevated degree of objectivity that results independently from the implementation rather than to start from the UML-like model.
As future work we plain to design and implement an editor in order to help in the application of the methodology that we define.

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Building End-User Programming Systems Based on a Domain-Specific Language[1]

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Abstract. End-users of automation software systems – which are the machine operators – have the task to provide machine settings and program simple control algorithms to adapt and optimize the machine to the specific automation tasks at hand. End-user programming systems are therefore an intrinsic part of automation systems. In this paper we report on a project with the goal to build a software framework which allows realizing end-user programming systems with minimal effort. Our approach is based on a new component-based programming language Monaco for event-based machine control, a compiler-generator to realize a Monaco compiler, a virtual machine for execution of Monaco programs, and an Eclipse- and GEF-based modelling and program development environment.

1 Introduction

End-user programming as defined by [Nardi 1993] is the endeavour to give ordinary users some of the computational power enjoyed by professional programmers. The goal of end-user programming is that users are able to customize and adapt the software systems in use to their particular needs at hand, so that they can perform their work more efficiently and effectively. As we well know, programming is not a trivial task even for professionals. End-users, however, have in no way the capabilities of professional programmers and usually they are neither able nor willing to acquire such skills. Providing limited programming capabilities to users in a natural, intuitive manner is still an open issue and subject to active research [Myers and Ko 2003; Costabile, Piccinno, Fogli, Mussio 2003]. In contrast to ordinary programming environments, from an end-user programming system we expect much better user support, like domain-specific notations and presentations, user guidance, and, in addition to syntactic checks, also semantic integrity checks of user programs [Won 2002].

Our work is concerned with end-user programming in the automation domain. The end-user of the automation software system is the individual machine operator. His task is basic handling and supervision of the machine operations, usually with the help of an electronic control panel. Additionally, he is involved in configuring the machine to specific manufacturing tasks and tooling equipments. And he eventually has the task of adapting or arranging basic machine operations in defined sequences, so that a specific machining task can be performed in a most efficient way. Providing all the machine parameter settings and defining an operation sequence for a very specific manufacturing task usually requires deep knowledge of

[1] This work has been conducted in cooperation with Keba AG, Austria, and has been supported by the Christian Doppler Forschungsgesellschaft, Austria.

the domain and, due to its complexity, still represents a great challenge. Therefore, machine automation software systems usually have to come with elaborate machine configuration and end-user programming environments.

In this paper we present a project whose goal is the development of a software framework which allows building end-user programming systems in the automation domain. The background for this work is a cooperation with Keba AG (www.keba.com) which is a medium-sized company developing and producing automation solutions for industrial automation. Keba is mainly a platform provider and development of automation solutions based on the Keba platform is a multi-stage process involving several different stakeholders as follows:

- Keba develops and produces a hardware and software platform with associated tool support. This comprises a PC-based open hardware architecture, different programming languages with compilers and development environments and Java-based frameworks for building visualization systems and control panels.
- The hardware and software platform enables the customers of Keba (OEMs of automation machines) to realize automation systems for their products.
- The OEMs also build customized software systems and electronic control panels for the machine operators. Those also include customized, machine-specific configuration and end-user programming systems for machine operators.

Project experience showed that the effort for OEMs for building those end-user programming systems is tremendous. End-user systems are individually designed and always built from scratch. Keba observes increased customer demands for an easier development of customized end-user programming systems. A clear conception and a reusable software basis for building end-user programming systems are therefore heavily desirable. As a consequence, in this project we deal with the conception and the development of a software framework to enable customers of Keba to realize end-user programming systems with minimal effort. The approach, which is outlined in Section 2 in more detail, is based on a new domain-specific language for machine control, a compiler-generator framework to realize a compiler for the Monaco language, a virtual machine for execution of Monaco programs, a visual notation for the Monaco programs, and an Eclipse- and GEF-based integrated development environment (IDE).

In this presentation we show the current developments and we discuss some additional features which are required for a software platform facilitating realization of end-user programming systems. The rest of the presentation will be structured as follows: In Section 2 we present our approach in more detail. Section 3 gives a short introduction into the Monaco domain-specific language for automation control. Section 4 finally discusses additional features required for an end-user programming framework and shows how all the discussed concepts work together in the instantiation of a customized end-user programming system.

2 Approach

In this section we present the architecture and components of our software framework which together with some additional features as discussed in Section 4 will facilitate the realization of end-user programming systems.

The approach is based on the following concepts:

- A new domain-specific language for machine control – called *Monaco* (*Modelling NOtation for Automation COntrol*) – is defined which serves as a basis for building control flow programs. The language is similar to Statecharts in its expressive power, however, adopts an imperative notation which is much closer to the perception of the domain experts.

- A compiler-generator framework is used to realize a compiler for the Monaco language which constructs a parse tree object model (called *CodeDOM*) of the program as well as a writer program to write the object model back to source code.
- A virtual machine has been designed and a prototype is realized in Java for the execution of Monaco programs.
- A visual notation for the language has been defined which is usually preferred by domain experts and end-users.
- An Eclipse- and GEF-based integrated development environment (IDE) for the Monaco programming language is currently in development. The IDE allows a dual mode of programming, i.e., visual programming as well as text based programming.

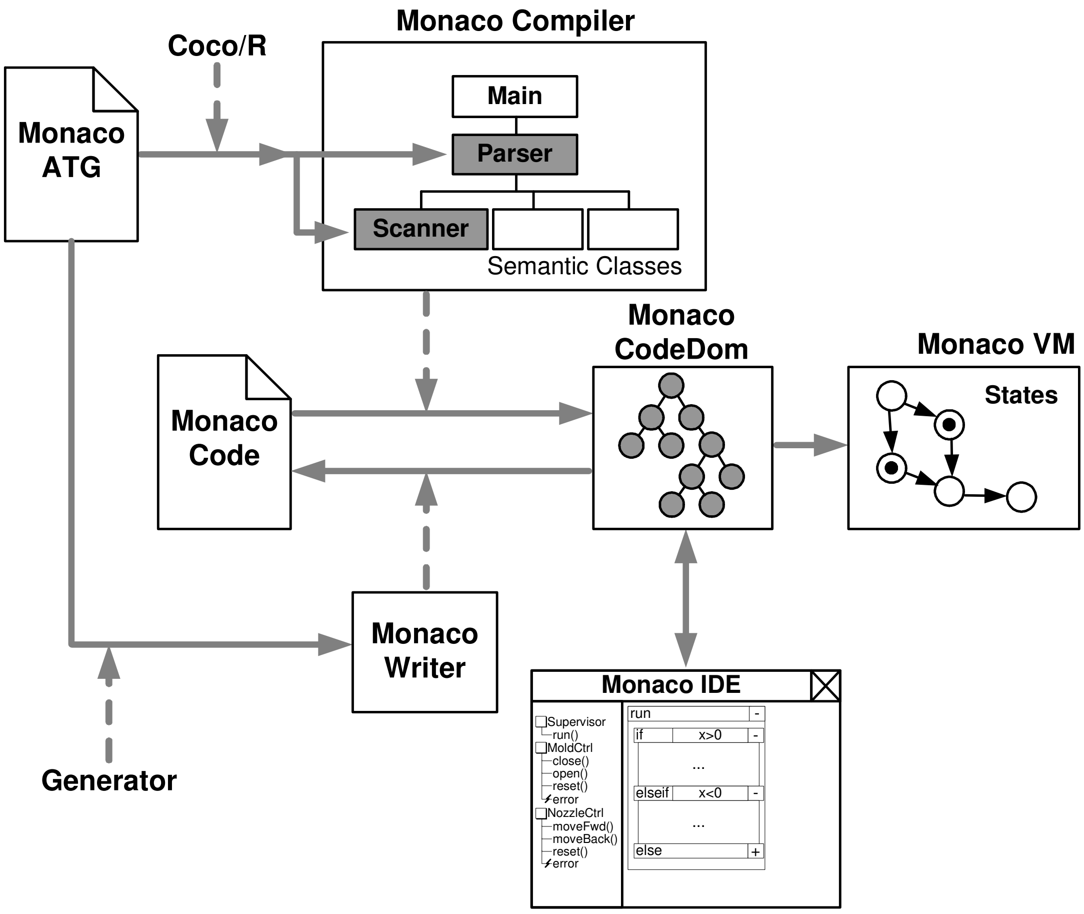

Figure 1: Architecture of domain-specific programming environment

Figure 1 gives an overview on the different components in the framework and their collaborations. The basis of the whole framework is the definition of the Monaco domain-specific language in an attributed grammar (*Monaco ATG*) which defines concrete as well as abstract syntax of the Monaco language. The attributed grammar serves as input to the Coco/R [Mössenböck 1990; Wöß, Löberbauer, Mössenböck 2003] compiler-generator which produces the *Monaco compiler* to read Monaco source code programs and generate parse tree object models (*Monaco code object model – Monaco CodeDOM*) representing the abstract syntax of Monaco programs in the form of a tree structure.

A Monaco CodeDOM then is input to the Monaco virtual machine (*Monaco VM*) which is capable of executing Monaco programs. Currently a purely interpreted version of the virtual machine in Java is available; however a version in C is envisioned to cope with real-time requirements. The execution of Monaco programs is based on a simple API to the virtual machine which basically allows parallel execution of threads, installation of (temporary) event handlers, handling of variable scopes, etc.

An Eclipse-based integrated development environment (*Monaco IDE*) is used to allow interactive development of Monaco programs. A visual program editor is used to allow visual interactive editing of Monaco programs. The visual editor operates directly on the Monaco CodeDOMs. In difference to many visual programming systems, the visual programming notation for Monaco is laid out automatically and the user has no control over positioning of program elements. In fact, the visual presentation directly reflects the source code structure, however, in a two-dimensional arrangement instead of a one dimensional as in the source code. Moreover, collapsing and expansion of block elements are heavily used (see more in Section 3.2).

Finally, a writer program (*Monaco Writer*) is generated from the Monaco attributed grammar definition which is capable of taking a Monaco CodeDOM and producing Monaco source code.

3 The Domain-Specific Programming Language Monaco

Monaco (Modelling NOtation for Automation COntrol) has been designed with the goal of bringing programming of machine control system closer to the domain experts and finally the end-users. It is not an end-user programming language itself, but is intended to form a basis to finally support end-user programming.

Current languages in the automation domain, most notably the programming languages of the IEC 61131-3 standard [IEC 2003], do not fulfill the requirements of a programming language which can be used by domain experts or end-users. Moreover, those languages do not show the characteristics of state-of-the-art programming languages from a software engineering perspective. Other formalisms, in particular the widely adopted Statechart [OMG 2004] formalism or the IEC 61499 standard [IEC 2005], would have the expressive power and can be regarded to be up-to-date regarding software engineering practices. However, the state machine notation seems to be too complex and cluttered for domain experts.

The language Monaco has been designed to overcome those shortcomings. The language is specialized to a rather narrow sub area of the automation domain, i.e., programming control sequence operations of single machines. This narrow domain includes any type of automated machines, but excludes bigger automation systems, like whole manufacturing systems. Within the multiple layers of automation systems it should cover the layer of event-based control of machine operations. Out of scope are therefore the continuous control and signal processing layer, which are supposed to form the layer below, and manufacturing execution layer, which could form the layer above.

Within this narrow domain, the language should allow expressing the desired control sequences in a natural and concise way. It has to allow expressing sequences of machine operations but also allow handling asynchronous events, exceptions, and errors. The language should allow writing reliable programs, which are easy to comprehend and maintain also by domain experts. With respective tool support, the language is supposed to form a basis for end-user programming systems.

The language design has been driven by the following main assumptions on the perception of the domain experts of automation machines. Those are:

- A domain expert views a machine as being assembled from a set of independent components working together in a coordinated fashion.
- Each component normally undergoes a determined sequence of control operations. There are usually one or several sequences which are considered to be the normal mode of operation. Those are usually quite simple. Complexity is introduced by the fact, that those

normal modes of operation can be interrupted anytime by the occurrence of abnormal events, errors and malfunctions.
- The control sequences of the different machine components are coordinated at a higher level in fulfillment of a particular control task.

The language design reflects just those assumptions by pursuing the following language concepts:

- Monaco pursues a strict component-based approach. Components are modular units (black boxes) which exclusively communicate over defined interfaces.
- The language supports hierarchical abstraction of control functionality. The component structure forms a strict hierarchy in that interaction of components only occurs with its subordinate and superordinate components. A component relies on the operations, state properties, and events from its subordinate components. It composes and coordinates the behavior of its subordinates and provides abstract and simplified views to its superordinates.
- Although the behavioral model of the language is very close to Statecharts, an imperative style of programming is used. This, in particular, allows programming of control sequences as a sequence of statements. Moreover, the language supports procedural abstraction.
- Focus of the language is on event behavior. Statements have been introduced to express reaction to asynchronous events, parallelism and synchronization, exception handling and timeouts in a concise way.

In the following section we will briefly depict the language by an example control program.

3.1 Example Monaco program

This example introduces some of the language concepts of the Monaco programming language. The example is part of a larger application in the domain of injection molding. The application is hierarchically composed of various components (Figure 2). Each of these components represents either the control unit for one part of the real machine or a control unit that aggregates the functionality of other components. This view of a machine exactly matches the end-user perception of the automation system.

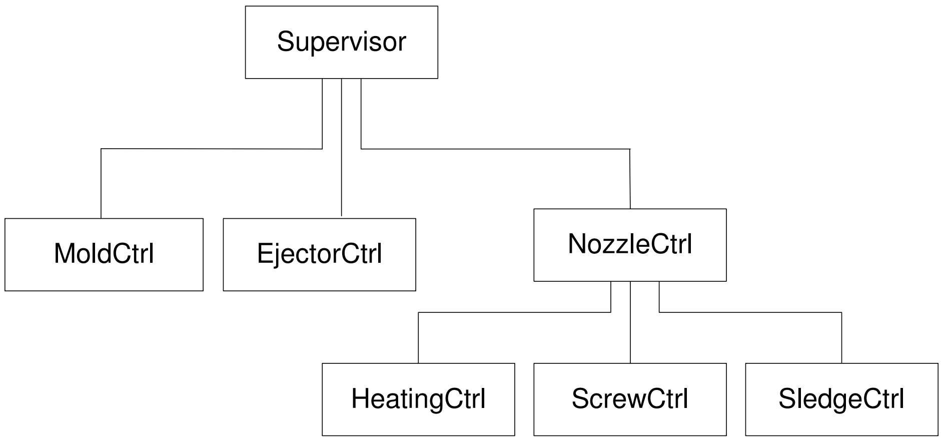

Figure 2: Component hierarchy

Each of these components implements a special interface to facilitate the assembly of those components to a system of components. The code sample shows the implementation of the upmost `Supervisor` component (Figure 3). This usually represents the level an end-user would be involved with. This component implements the interface for Supervisor controls (ISupervisor) and can be parameterized by two parameters which have to be set at start-up time. All subcomponents of the Supervisor are only defined by their interfaces to allow easy exchange of components. The component has two routines run and stop. In the following we will take a closer look at the run routine.

```
COMPONENT Supervisor IMPLEMENTS ISupervisor
  PARAMETERS
    coolingTime : INT := 1000;
    plastFirst : BOOL := TRUE;

  SUBCOMPONENTS
    ejector : IEjectorCtrl;
    mold : IMoldCtrl;
    nozzle : INozzleCtrl;

  ROUTINE stop()
  BEGIN
    mold.reset();
    nozzle.reset();
    ejector.reset();
  END stop

  ROUTINE run()
  BEGIN
    mold.open();
    ejector.moveBackward();
    nozzle.moveForward();
    LOOP
    BEGIN
      mold.close();
      IF plastFirst THEN
        nozzle.plasticize(100);

      PARALLEL
        BEGIN
          nozzle.inject();

          IF NOT plastFirst THEN
            nozzle.plasticize(100);
        END
        BEGIN
          WAIT coolingTime;
        END
      END

      mold.open();
      ejector.moveForward();
      ejector.moveBackward();
    END

  ON mold.error.FIRED OR nozzle.error.FIRED OR ejector.error.FIRED
    stop();
  END run
END Supervisor
```

Figure 3: Monaco source code sample – the Supervisor component

This routine describes the main control cycle of the automated machine. It orchestrates the subcomponents by calling routines of those subcomponents, which in turn call routines on their subcomponents or directly manipulate the machine by setting signals. Events/errors are handled at the end of the routine prefaced by the keyword ON. Event handlers must be declared using an event condition that consists of Boolean expressions and/or events. In our example any error event fired by one of the subcomponents invokes the `stop()` routine that stops all subcomponents.

This representation of a Monaco component is already quite straight-forward and, to some extent, already understandable by end-users that are not familiar with programming languages. As a next step, a visual representation of this component can help end-users not only to understand existing programs, but also to independently adapt existing Monaco components or even create new components. The next section introduces ideas about a visual notation of Monaco programs.

3.2 Visual notation of Monaco programs

Domain experts and end-users prefer visual representations of control programs. We therefore have defined a visual representation for Monaco programs and are in the process of developing an integrated development environment (IDE) based on the Eclipse RCP (www.eclipse.org) and the Graphical Editor Framework (GEF, www.eclipse.org/gef). In this section we describe the ideas behind this visual notation.

The visual notation of Monaco programs directly reflects the structure of Monaco programs. Rectangular visual elements are used for each statement and in particular reflect the block structure of the program. Each visual element can be collapsed and expanded in order to define the level of detail the user wants to see (Figure 4). Expansion of elements is not restricted to vertical expansion, but can also be used horizontally to, for example, expand event handlers defined for a block.

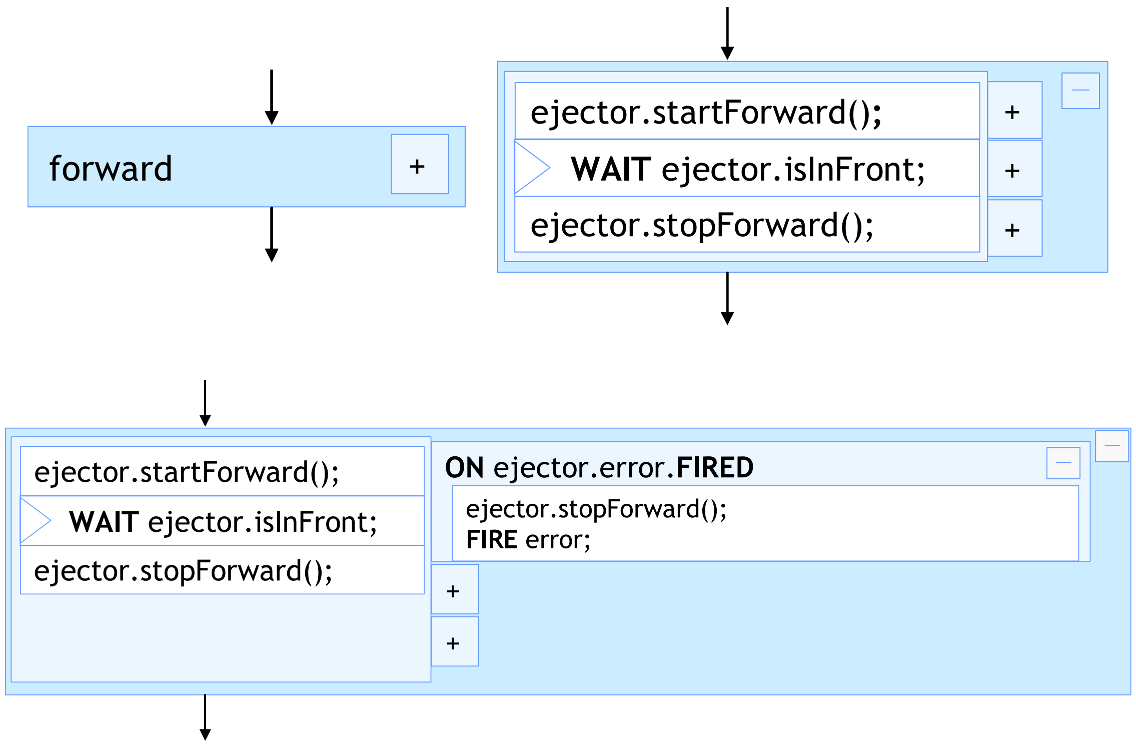

Figure 4: Visual representation of programming elements (collapsed and expanded)

A visual notation of a programming language is only meaningful if there is appropriate tool support. The Monaco IDE is capable of automatically creating a visual program editor from the Monaco CodeDOM without requiring any further positioning from the user, i.e., layouting of elements is done automatically. The duality of the language representations (textual and visual) will also be reflected in the IDE. Changes to the visual representation directly change the underlying Monaco CodeDOM which in turn updates the textual representation of the program.

4 Towards End-User Programming Systems

In Section 2 we have shown our approach for realizing a programming environment for the Monaco domain-specific language. However, for a real end-user programming system for machine control as envisioned in section 1, several features are still missing. In this section we will discuss additional features, we think are required for an end-user programming framework, and show ways for realizing those.

To support end-user programming the following features are required:

Configurable end-user presentation

Control programs should be presented in domain-specific terms and notations familiar to end-users. This includes the use of icons for program elements [Bischoff and Seyfarth 2002], e.g. components and control operations, the use of customized interactive dialogs for settings and configurations, the use of technical terms and physical units instead of program data types, and the support of the native language of the end-user.

How to tackle those issues actually seems quite straight-forward. Meta-modelling environments [Zhu, Grundy, Hosking 2004; Luoma, Kelly, Tolvanen 2004; Greenfield and Short 2004] have shown how to customize the visual presentation of modelling elements. In distinction to those systems, our approach additionally supports layout management which can be customized by the adaptation and introduction of layout managers, which are supported by the GEF framework. From interactive GUI builders and GUI components, like JavaBeans [Hamilton 1997] and Delphi [Mitchell 2002], we know how to introduce individual property editors and customization dialogs for component properties. In [Praehofer and Kerschbaummayr 1999] we have shown how a model of physical properties and units can be used advantageously in the realization of domain modelling languages.

User roles and permissions

There usually exists not only one particular type of user of a machine. User types differ in the permissions they have for changing machine settings and control algorithms. The everyday operator of a machine might be allowed to watch the operation and react to malfunctions. An advanced operator might have the permission to reconfigure the machine and make operation-specific settings. A machine expert might be permitted to reprogram the machine in a limited way. Maintenance staff then will have to change the control programs themselves, but may be prohibited to change safety critical program parts.

To cope with those different user types, one requires a user administration and permission concept and a means to clearly specify the permitted interventions. This has to go hand in hand with strong program variability mechanisms as discussed next.

Program variability

A control program for an automation machine cannot be a rigid unit but has to show considerable flexibility and variability with respect to reconfiguration, adaptation and reprogramming. Moreover, a complex control program is usually not realized for one individual machine type but for a family of similar machines. As there exists usually a product family for the machines themselves, the control programs have the characteristic of a software product line [Clements and Northrop, 2002]. Expressive concepts for modelling program variability are strongly required.

The Monaco language already supports some limited forms of variability. First, subcomponents of components are polymorphic, i.e., they are declared by an interface and a subcomponent can be replaced by another component implementing the same interface. Second, components have parameters which allow the adaptation of components in a defined and limited way. However, stronger concepts to model program variability are needed. We need means to identify program parts which can be changed and to declare the constraints thereupon.

We intend to adopt mechanisms to represent code variability as introduced by the product line engineering community [Bosch 2000; Bosch et al. 2001]. Together with the user role and permission model as discussed above, this should give the information what a particular user should be able to see from a control program, what parts the user should be able to change, and how the user can change those parts.

User guidance and semantic integrity checks

End-user programming is mainly concerned with programming the up-most sequence of control operations. An end-user, however, normally has not the capabilities to check that a sequence of operations is correct and results in a semantically meaningful and complete control program. A system which guides the user and checks the correct assembling of operations into semantically meaningful, correct, complete, and secure control algorithm would be heavily desirable.

Such an approach does not exist yet. However, recent work in formal software specification and verification [de Alfaro and Henzinger 2001, 2005] provides promising results in that direction. The application of such theoretical results in the realm of end-user programming, therefore, will be an important research direction in the future.

5 Conclusion

In this paper we have presented a framework for domain-specific programming in the automation domain. The approach is based on a new domain-specific programming language Monaco for event-based machine control. Monaco emphasized a component-based approach with hierarchical structuring of control programs and mechanisms for programming with events. It shows strong similarities to Statecharts with respect to its behavioural model, but adopts a notion similar to classical imperative programming languages. Then a visual notation for Monaco programs has been defined and a visual editor is in development.

In section 4 we have discussed additional features which we consider to be required for an end-user programming framework. Backed with the Monaco programming system and with those additional features, an end-user programming system for a particular machine is instantiated as follows:

- The basis is a Monaco program for a particular automation machine.
- User types and associated permissions are set up.
- This Monaco program is augmented with a variability model which precisely specifies the ways the program can be changed, adapted, and extended by the different types of users.
- Configuration files are introduced which define domain-specific pictures, icons, physical units, and language-specific settings to be used by the end-user.
- With all those configurations, a specific, individual end-user programming system for a particular automated machine can be instantiated without further programming.

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Dart: A Meta-Level Object-Oriented Framework for Task-Specific Behavior Modeling by Domain Experts

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Abstract

We propose an object-oriented framework for complex behavior modeling by domain experts. It is set in the context of *Adaptive Object-Models* and *Flow-Independent* architectures. It is an evolution of Dragos Manolescu's *Micro-Workflow* architecture. We add to it several abstractions needed to reify a number of concerns common to modeling by domain experts. Our aim is to make it easier for domain specialists to write behavior models in their own terms, using sophisticated interfaces built on top of the framework.

1 Introduction

An increasing number of object-oriented applications that we call Adaptive Object-Models (AOMs) [YJ02, RBYPJ05], integrate a Domain-Specific Modeling Language (DSML) [Tolvanen05] for behavior modeling. This language is dedicated to domain experts and available at run-time. In general AOMs deploy a DSML to cost-effectively and programmer-independently (1) cope with rapid business changes; (2) create a family of similar software; and (3) provide modeling and model operating functionality. More specifically, we focus on Flow-Independent AOMs (FI-AOM). A flow-independent architecture keeps the control flow outside the application domain, and thereby avoids intertwining process logic and application code, which is a hindrance to the software evolutive maintenance. The DSML embedded in an FI-AOM shares many characteristics with workflow languages and architectures [WMC99, LR2000]. They support both defining and executing processes in terms of a coordination of primitive tasks and their distribution between processing entities. What distinguishes such a DSML from a classical workflow language is that the processing entities tend to often be objects and not humans and applications. Both processing entities and primitive tasks belong to the domain's concept and task ontologies. The language targets domain experts. To emphasize these important differences and avoid confusion with standard workflow languages, we propose to call this class of DSMLs *expert languages*.

Both in industrial and academic settings, we have studied and also developed many successful FI-AOMs [AJ98, DT98, Raz00, GLS02, CDRW02, YBJ01]. Unfortunately, these applications required developing a custom expert language. In our opinion, the best approach for creating FI-AOMs is the *Micro-Workflow* architecture by Dragos Manolescu [Manolescu2000, Manolescu2002], hereafter denoted by "MWF". Several characteristics distinguish MWF from traditional workflow architectures, notably, a lightweight, modular architecture, and dealing with processes in a pure object world, i.e., all workflow processing entities are objects. This feature is crucial when developing expert languages for FI-AOMs.

However, MWF mainly targets developers. Manolescu explains the choice of the activity-based process modeling methodology by the fact that there is resemblance between the modeling abstractions and control structures in structural programming languages. Our goal is to take advantage of the extensibility and modularity of the MWF architecture in order to propose a core process modeling component which targets also business *experts*.

In the following subsections we explain our solution, called *Dart*, based on operating two separations of concerns through refactoring [Opd92], and some other amendments. Dart stands for Dynamic ARTifact-driven class specialization. It provides more flexibility and more desired features for programming by domain experts than MWF, while remaining compatible with it, but is harder to learn. We describe the design of Dart, as well as the reasons behind our design decisions using patterns (figure in *slanted fonts*). We use UML as a standard notation for presenting the *meta-level* abstractions that define Dart, as well their meta-level relationships.

We postpone the description of our motivations and also achievements to section 4. Section 2 is dedicated to the presentation of an example, and section 3 to an overview of the MWF core. Section 4 exposes our solution. Section 5 discusses our results, before concluding in section 6.

2 A simple example

For illustration purposes we adopt from [RTJ05] a simplified version of a banking system for handling customer accounts like checking or savings accounts. The system contains a class called `SavingsAccount` which provides a field called "`interestRate`" that provides the interest rate for the account, as well as other fields that are value objects, like "Money" and "Percentage". Each day a method called `accrueDailyInterest` is executed and the interest is added to the account's balance. The underlying algorithm is illustrated by Figure 1. The computation comprises five *steps*: (1) the current saving account is explicitly designated and named *Account*[1]; (2) and (3) the interest rate and the balance for that account are computed (could be done in parallel), and called respectively *Balance* and *Interest Rate*; (4) the daily interest is computed and called *Daily Interest*, and (5) finally, the daily interest is deposited on the selected account. No object is produced in this last step (result called *Void*).

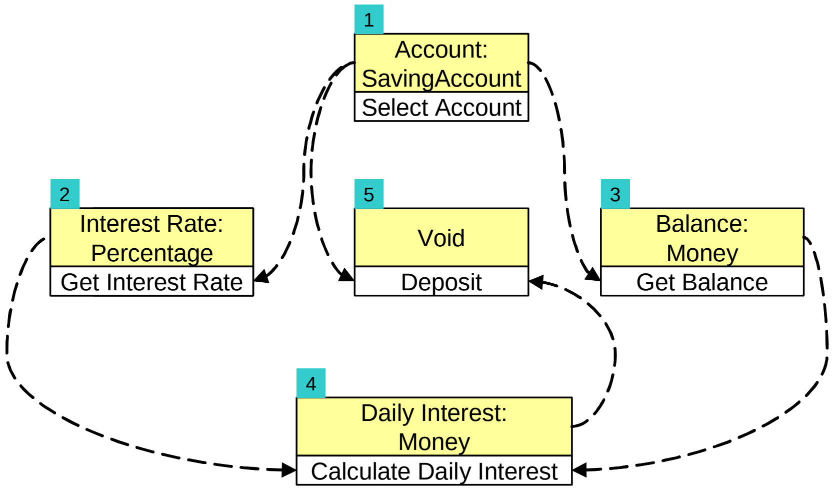
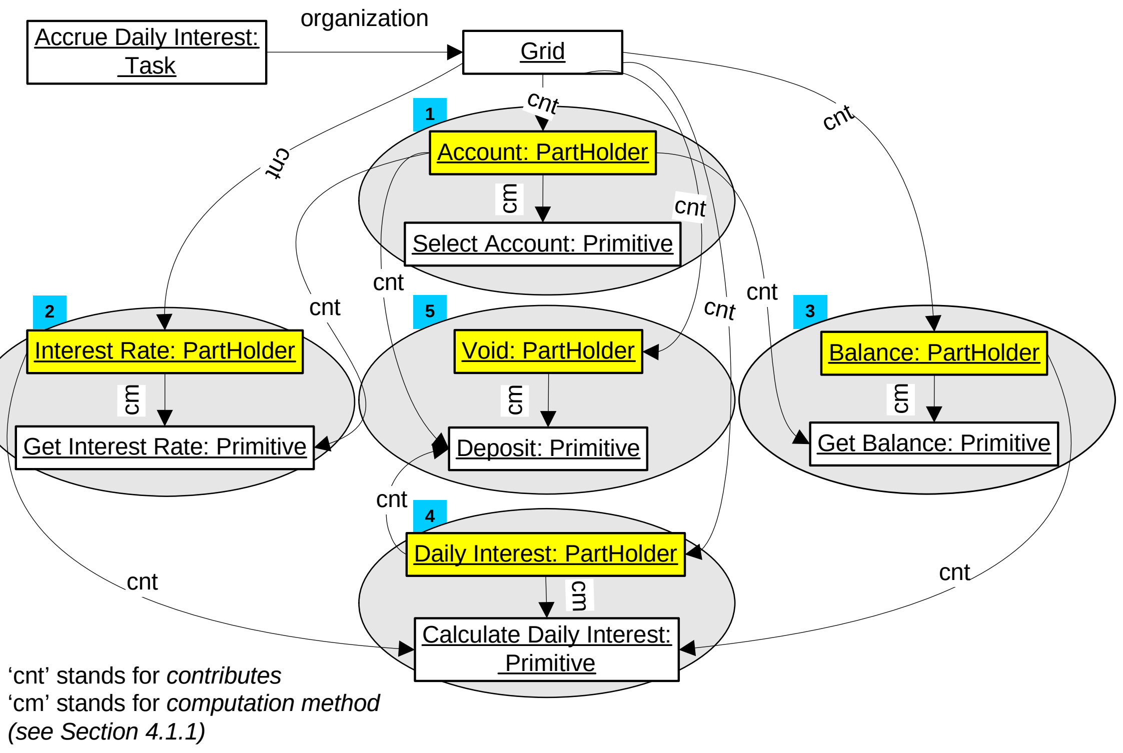


Figure 1: A visual representation of the *Accrue Daily Interest* computation.

The graphical notation for steps corresponds to the association of two rectangles. The lower rectangle (in white) symbolizes the operation and the upper one (in yellow) its result (which

[1] Could be what-ever else; the names are strings with no special semantics from the computation's point of view.

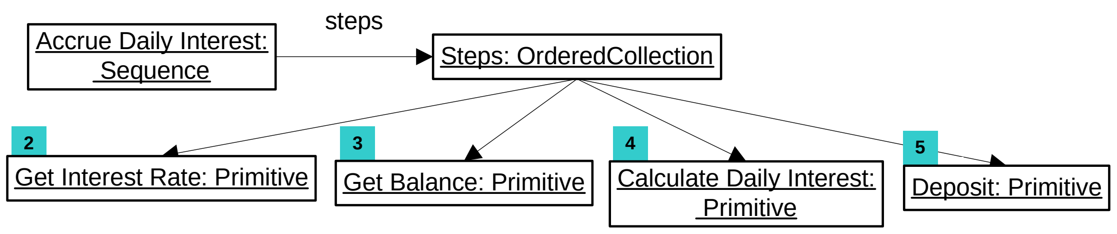
is a *part* of a whole product). The arrows are directed from parts towards operations, and denote the data dependency between steps. For instance, the arrow from the step 4's part to the step 5's operation denotes the fact that the execution of the step 5's operation requires the availability of the part of the step n° 4. This graphical notation is chosen since it reflects (1) the type of graphical interface that Dart supports (typically a spreadsheet interface), and (2) the cognitive approach of users when modeling by a Dart-based DSML (*grosso modo*, programming is done by relating together domain-specific operations and parts).



Accrue Daily Interest: Task
organization
Grid
cnt
1
Account: PartHolder
cm
Select Account: Primitive
2
Interest Rate: PartHolder
cm
Get Interest Rate: Primitive
5
Void: PartHolder
cm
Deposit: Primitive
3
Balance: PartHolder
cm
Get Balance: Primitive
4
Daily Interest: PartHolder
cm
Calculate Daily Interest: Primitive
'cnt' stands for *contributes*
'cm' stands for *computation method*
(see Section 4.1.1)

Figure 2: The Dart representation of the example in Figure 1.

The Dart representation of the same algorithm is given by the object diagram of Figure 2. The *type* of objects in this diagram is *Task*, *Grid*, *Part Holder*, and *Primitive*. These are Dart abstractions that we describe in the following sections. A secondary goal of this diagram is to illustrate the resemblance between the internal representation of algorithms by Dart, and their visual rendering on the screen (Figure 1). Figure 3 illustrates the same model represented according to the MWF through abstractions such as *Sequence*, *Ordered Collection*, and *Primitive*. We further describe and compare MWF and Dart abstractions in the following sections.



Accrue Daily Interest: Sequence
steps
Steps: OrderedCollection
2
Get Interest Rate: Primitive
3
Get Balance: Primitive
4
Calculate Daily Interest: Primitive
5
Deposit: Primitive

Figure 3: The MWF representation of the example in Figure 1.

3 The Micro-Workflow core

The MWF architecture leverages the object technology to bridge the gap between the type of functionality provided by current workflow systems and the type of workflow functionality required to implement processes within object-oriented applications. At the focal point of the architecture, the MWF core provides functionalities for workflow definition and execution.[2] This section explains the underlying design based on Manolescu's thesis [Manolescu2000].

3.1 Representation of workflow definitions

A *workflow definition* specifies the activities that the workflow processing entities must perform to achieve a certain goal. From a theoretical point of view, MWF has adopted the *activity-based* process modeling methodology, where workflows are represented in terms of activity nodes and the control flow between them. The whole constitutes a directed graph called *activity network*, which captures how process activities coordinate. This representation places activities in the network nodes and the data passed between activities on the arcs connecting these nodes, showing the data flow between activities [GPW99].

From the framework design point of view, MWF represents the nodes of the activity map corresponding to the process definition with a set of `Procedures` (e.g. Figure 3). The MWF employs several procedure subclasses that together provide a range of procedure types. Our focus here is on core abstractions, i.e., `Procedure`, `PrimitiveProcedure`, and `Sequence` (Figure 4). `PrimitiveProcedure` enables domain objects to perform application-specific work outside the workflow domain.

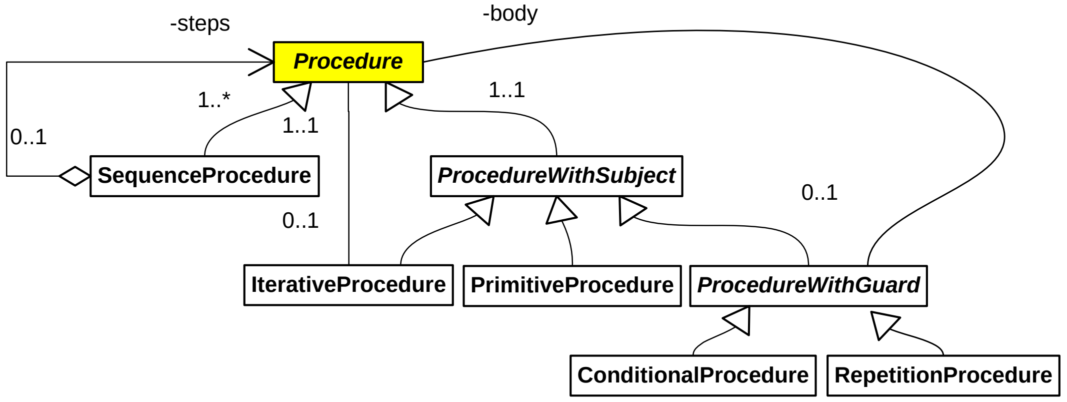


Figure 4: The MWF process component (comprises also Fork and Joint abstractions) [Manolescu2000, page 187]

As illustrated by Figure 5 using the *Smalltalk* language syntax, the implementation language of both the MWF and Dart, a primitive procedure is specified by providing the name of the method to invoke at runtime, the name of the receiver of the message, the name of the arguments, if any, and the name of the result. Names correspond to keys for storing the resulting objects and storing the arguments in the current execution context (a hash table). In this example, the message sent is called `calcDailyInterest:with:`, and the names are respectively called: `balance`, `interestRate`, `myAccount`, and `interest`. `SequenceProcedure` allows developers specifying sequences of activities by aggregating successive procedures. It is a `Procedure` subclass that has a number of steps, each of which is another procedure. `Conditional` and `Repetition` provide a means to alter the control flow. `Iterative` works on composite objects. Finally, `Fork` and `Join` spawn and synchronize multiple threads of control in the workflow domain.

[2] Other components are added by extension to support history, persistence, monitoring, manual intervention, worklists, and federated workflow.

```
     PrimitiveProcedure
             sends: #calcDailyInterest:with:
             with: #(balance interestRate)
             to: #myAccount
             result: #interest.
```

Figure 5: Instantiation of a primitive procedure in MWF.

The (simple) activity graph in Figure 3 is defined by creating a `SequenceProcedure` which holds an ordered collection of four primitive objects.

3.2 Representation of workflow executions

`Procedure` execution relies on the interplay between a `Procedure` instance and a `ProcedureActivation` instance. There are two ways to trigger the execution of a procedure object. The `execute` message allows clients from the application domain to fire off a procedure. Typically they send this message to the root node of the activity map representing the process definition. The second entry point `continueExecutionOf:` serves the workflow domain. Composite procedures send this message to execute their components. A procedure reacts to the `execute` message by sending itself the `continueExecutionOf:` message. The control reaches the internal entry point. Next the procedure checks its `Precondition` by sending the `waitUntilFulfilledIn:` message with the current activation as the argument. In effect, this message transfers control to the synchronization component. The `waitUntilFulfilledIn:` message returns when the precondition manager determines that the precondition associated with the procedure is fulfilled. Next the procedure creates a new instance of `ProcedureActivation`. Then it transfers control to the new activation by sending the `prepareToSucceed:` message. On the workflow instance side, the activation handles the data flow. First it initializes the local variables from the initial context of its type. The first `forwardDataFlowFrom:` message moves data from the procedure initial context to the activation. Then the new activation extends its context with the contents of the current activation. Finally, it returns control to its `Procedure` object, on the workflow type side. The `ProcedureActivation` is here responsible for managing data flows. At this point, the procedure has all the runtime information and sends the `executeProcedure:` message to complete execution. However, `Procedure` is an abstract class and doesn't implement `computeStateFor:` and `executeProcedure:`. Execution within the `Procedure` class ends here, and each of its concrete subclasses implements these messages in its own way. Thus inheritance allows all procedure types to *share the same execution mechanism*, while polymorphism enables them to augment this mechanism with the behavior specific to each type.

4 Refactoring the Micro-Workflow core

In the following subsections we explain our solution based on operating two separations of concerns, and also some other amendments.

4.1 Separation of structural and semantic aspects

MWF procedures combine simultaneously two important roles. First, they serve as building blocks for constructing the activity graph. Second, they hold information about the semantics of the operation. For instance, the procedure in Figure 3 is constructed by interconnecting primitive and sequence objects. The operational semantics of each step of the procedure is also held by each of these objects. We propose to separate these two roles by applying the *Bridge* [GHJV95] pattern. The result is that each step in the workflow is specified using two distinct abstractions as follows.

4.1.1 Representation of *part holders*

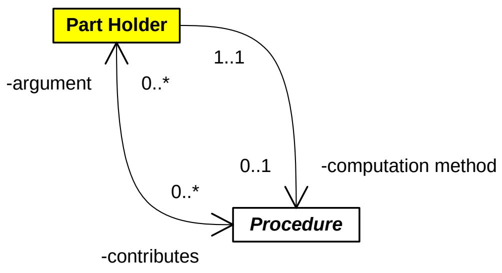


Figure 6: Design of *steps* in Dart.

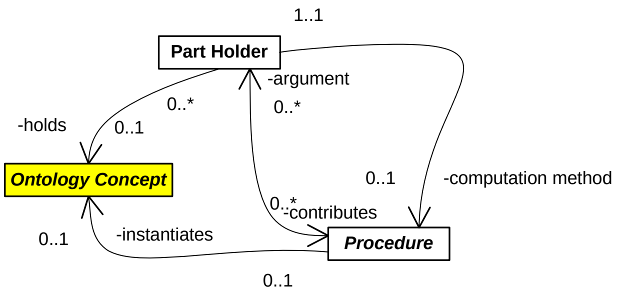


Figure 7: How *procedures* and *part holders* relate to the ontology.

As it is illustrated by Figure 6, we propose to delegate the structural role of the procedures to an abstraction called *Part Holder*. The specification of a step in a workflow, called *task* in our context (cf. the next subsection), is now achieved by associating a *part holder* ('what') to a *procedure* ('how'). The association is twofold. On the one hand, part holders are related to the (new) procedures by a relation called *computation method*. A part holder is associated to at most one procedure. For instance, as illustrated by Figure 2, step 2 in Figure 1 is represented by associating a part holder named *Interest Rate* with a primitive called *Get Interest Rate*. On the other hand, part holders are related to procedures by a relation called *contributes*. Primitive procedures may in fact require arguments. A part holder may contribute to the computation of a primitive by providing 'its' part. The inverse relation is called *argument*. A part holder may in effect serve as argument to the definition of zero or more procedures. An argument for such a procedure is selected amongst the part holders associated to other steps in the task. For instance, the part holders called *Balance* and *Interest Rate* in Figure 2 contribute to the computation of the primitive called *Calculate Daily Interest* (that computes the value of a part holder of type `Money`, called *Daily Interest*).

Further, for practical reasons it is important to be able to associate to the primitive nodes of a task definition to the object that results from their execution. This can for instance serve when fine-tuning the workflow definition by simulation. Or, when the workflow engine is used like a spreadsheet with two modes: showing the formula associated to a cell or the result of its execution. We therefore add a new abstraction, called *ontology concept*. Figure 7 illustrates how part holders and procedures relate to the *ontology*. Ontology concepts are instantiated by primitive procedures, and held by part holders. The domain ontology provides a specification of the target business product and its parts and their relationships. We assume here that the target system is provided with an explicit representation of the domain ontology, which is crucial for DSMLs in general. Dart allows expressing how a full product can be computationally obtained through partial computation of its parts.

Now, we can explain in more detail the abstractions that underlay the object diagram in Figure 2. Each part holder (yellow rectangle) is connected to a primitive by a link called 'cm' that is an abbreviation for the 'computation method'. Part holders are also connected to the primitives with the 'contributes' link. The association of a part holder and a (primitive) procedure creates a *step*. Furthermore, a grid structure contains the part holder of each step (link called 'cnt' for content). As explained in the next subsection, the grid is an example of organization and visual layout media for the steps of a task.

4.1.2 Representation of *tasks*

The notion of task refers to a logical grouping of steps, defining a meaningful, but often partial, business procedure. Part holders and procedures already maintain two relationships called computation method and contributes (see the previous subsection). These relationships interconnect steps together. For instance step 4 in Figure 2 is connected to step 5 of the same figure, since the part holder of the former contributes to the procedure of the latter. This implicit organization *de facto* represents a task. However, it is not sufficient for a neat representation of tasks. This issue is addressed by the notion of a task, which allows explicitly organizing steps.

To represent *tasks*, we first apply a variant of the *Composite* pattern [GHJV95] to the design presented in Figure 6. The result is two new abstractions (see Figure 8). The common abstraction is called *Process-Conscious Product*, and the composite is called *Task*. A task aggregates one or more steps by pointing to their part holders. In this design, steps are sequentially ordered (like in MWF). The relationships of part holders with ontology concepts and procedures remain as in Figure 7.

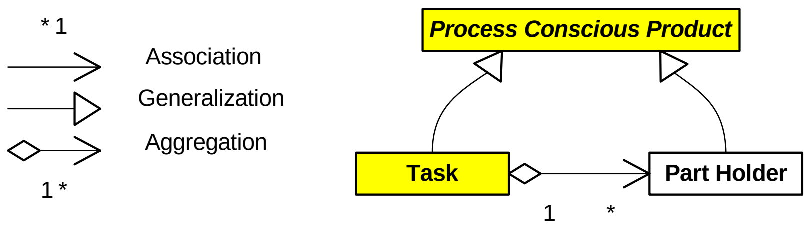


Figure 8: Preliminary representation of *Tasks* in Dart.

This design imposes an overspecification of tasks by sequentially ordering and executing their steps. For optimization and business-related motivations, steps may be organized in different structures. For instance, the steps of the task in the example of Figure 2 can indifferently, from the operational semantics point of view, be visually organized in a list, grid or free shape. Therefore, we modify the design of tasks to separate the two step-organization and step-grouping aspects (see Figure 9). Now, a task aggregates one or more steps by pointing, indirectly, through its *organization* link, to their part holders. The order of steps in a task is by default irrelevant. The full definition of a business procedure is obtained by aggregating a set of task definitions into a *Behavior* definition (see also Figure 9).

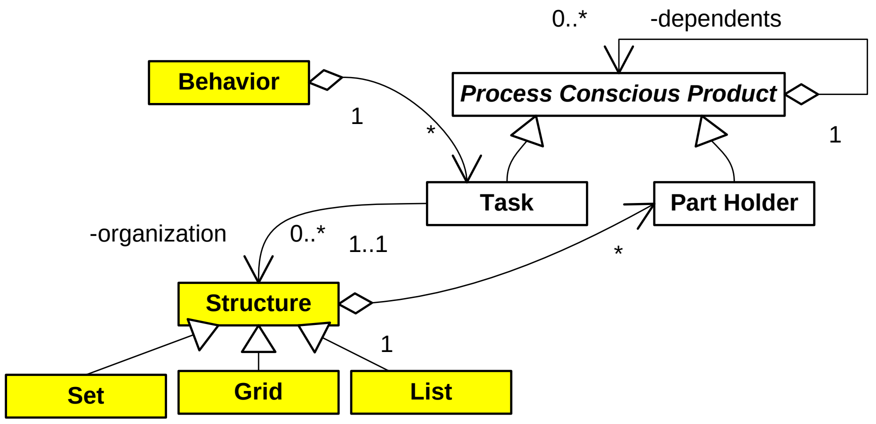


Figure 9: Design of *tasks* in Dart.

4.2 Separation of the computation description from the execution strategy

As explained in Section 3.2, MWF procedures are deeply involved in both (1) the description of the expected computation; and (2) the implementation of the execution technique for that procedure. For instance, the primitive in Figure 5 (1) holds the information about its purpose which is calculating the daily interest; and (2) also implements the rules that govern the realization of that computation (a method invocation). By applying the *Strategy* [GHJV95] patterns, we propose to further split the *semantic* role of the procedures into two distinct roles.

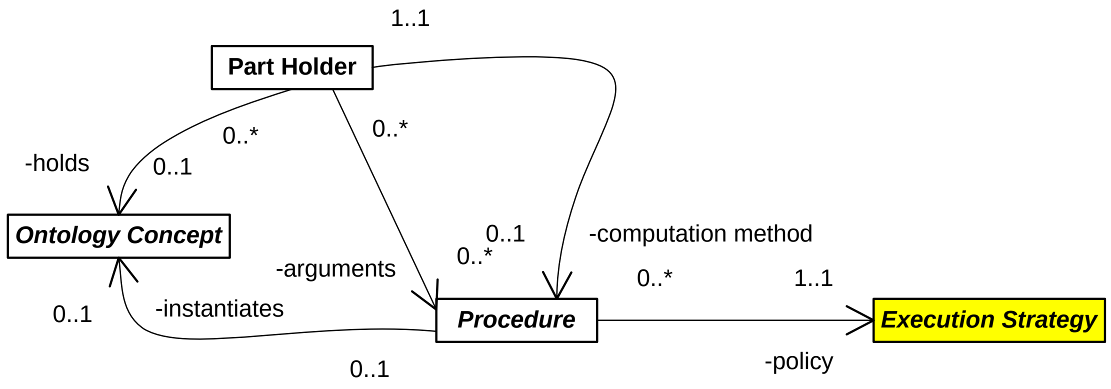


Figure 10: Design of *execution strategies* in Dart.

A new abstraction called *execution strategy* is added to Dart (see Figure 10). Procedures have now only the role of representing the computation. The operational semantics of the `executeProcedure:` method from the MWF changes now to give the control to the execution strategy which is currently associated to the procedure (and can dynamically change). The execution strategies that we have currently identified and implemented are summarized in Table 1. Execution strategies are also associated to tasks. The default behavior consists in launching the execution of task steps taking into account their organization.

Table 1: Different execution strategies currently identified in Dart.

Construct	**Execution strategy**
Primitive	Invocation of a method with its arguments.
Factory	Invocation of a static method.
Getter / Setter	Invocation of a getter/setter method.
Control Structure	Execution of the pre-condition behavior and accordingly the action behavior.
In-Pin	Fetching the ontology instance (business object) which should be hold by the associated part in the execution environment.
Constant	Returning the cached constant value.
Component	Invocation of the associated behavior definition.

4.3 Contracts

We further suggest associating to procedures, and especially to primitives, a new abstraction called *Contract* (see Figure 11). The idea consists in enriching the modeling system with a set of metadata about the modeling primitives. Contracts hold in particular information about the signature of the primitives (default name, and when pertinent, name and type of parameters and the result). For instance, the fact that our DSML for a banking system has a primitive called *Calculate Daily Interest* that needs two arguments of type *Percentage* and *Money* is stored in a contract. Table 2 provides the list of all contracts associated to the operations used in this example. Each line corresponds to a contract for a *construct* of type primitive. Contracts can further hold metadata about the medium and execution mode (the type and amount of hardware required, the name of the runtime library, etc.). The exact type of metadata hold by contracts is however application specific.

Table 2: Description of the *contracts* used in specifying the *Accrue DailyIinterest* task.

Name	Method	Inputs	Outputs
Calculate Daily Interest	`calcDailyInterest`	Money, Percentage	Money
Get Balance	`getBalance`	N/A	Money
Get Interest Rate	`getInterestRate`	N/A	Percentage
Deposit	`deposit`	Money	N/A
Select Account	`selectAccount`	N/A	Account

We consequently apply the Mediator pattern [GHJV95] to the design in Figure 9 to link the procedures to their execution strategy by the mediation of the contracts (see Figure 11). A specific type of contract should be designed for each specific type of procedure, execution context and strategy.

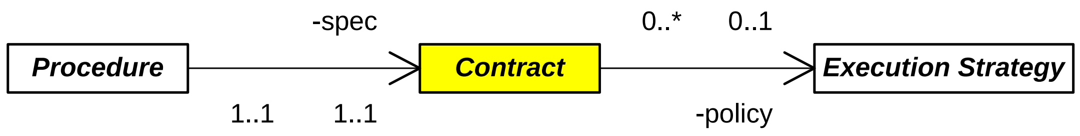


Figure 11: Associating procedures to execution strategies by mediation of *contracts*.

Table 3: Description of the different constructs of *Dart*.

Construct	**Description**
Primitive	Allows specifying a step whose value is computed by calling a ‘primitive’ function, e.g., a method, a function in a library, even a task.
Factory	Allows specifying a step whose value is computed by instantiating/selecting a specific business object.
Getter	Allows specifying a step whose value is computed by fetching the value of an attribute of a given business object.
Setter	Allows specifying a step that sets the value of an attribute of a given business object.
Control Structure	Allows specifying a step that carries an iteration or a conditional.
In-Pin	Allows creating a step whose value is received as argument. In-Pins are used in conjunction with components, in the sense that the behavior associated to a component contains steps of type In-Pin whenever some values should be passed to it at run-time. For instance, in the example illustrated in Figure 1, step 1 could be an In-Pin, allowing to the workflow to operate on any account received at run-time as argument. Such a behavior could then be *wrapped* as a reusable component and called by any part willing to ‘accrue the daily interest’ for a given account.
Constant	Allows creating a step whose value, a string, date, number or any other business object, is provided at definition time and will not change at runtime.
Component	Allows creating a step whose value is computed by executing a behavior specification.

4.4 Constructs

Now that we have modified the design of MWF procedures, we must face the challenge of adapting other MWF modeling constructs, such as the control structures, to the new design philosophy, and also adding new constructs such as parameterized tasks. Recall that our ultimate goal is a system which targets *both* developers and domain experts. Adapting and adding new constructs should therefore keep the system easy to reuse and extend by programmers, and also easy to learn and to use by domain experts.

We have achieved this goal by adopting ideas from the formula languages investigated by [Nardi93], where notably control structures are used seamlessly like primitives (an iteration or conditional is defined in the same way as an addition or an average). For space reasons we cannot describe the details of our design. Table 3 roughly describes the constructs that we have added. Figure 12 puts them in the context of our class diagram. As an example, the step 1 in the example in Figure 2 uses a *factory* construct. Other steps use a primitive one.

From the design point of view these constructs are added by specializing `Procedure` by a new abstraction called `Construct`. All modeling constructs of Dart correspond then to specializations of `Construct`. Figure 12 provides an abstract view of the final design.

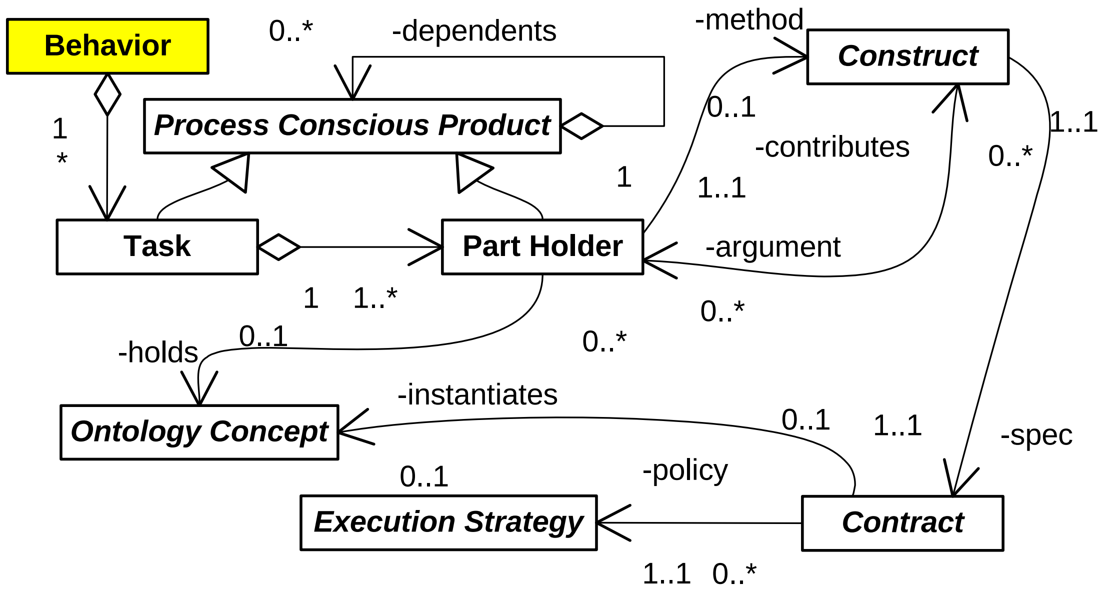


Figure 12: The Dart process meta-model.

5 Putting It All Together

The two separations of concerns that we operated by refactoring the MWF core are essentially motivated by the necessity to extend it to support End-user Programming [Nardi93]. These refactorings, together with the addition of *contracts* and *constructs* lead to a design (Figure 12) that is more consequent in terms of number of abstractions and their relationships than the MWF core (Figure 4). It is consequently harder to learn. The counterpart is that Dart provides more flexibility and more desired features for programming by domain experts, as follows.

5.1 End-user programming and adaptivity

Contracts allow an explicit description of the language constructs and primitives in a human-readable format. Conforming to the analysis of B. A. Nardi concerning task-specific languages, it becomes possible to package business knowledge in a set of well-described primitives and then present them to experts in a neat and structured manner (cf. e.g. [GLS02]). Contracts can also serve for guiding experts at modeling and model fine-tuning at execution time. For instance, it becomes possible to automatically identify that the *Calculate Daily Interest* primitive requires two arguments of types `Money` and `Percentage`. By coupling a type system to *Dart*, it becomes possible to filter choices and to avoid type mismatches when selecting arguments. Contracts allow further automating the generation of graphical interfaces for editing primitive instances. Material for online help can also be associated to contracts. At runtime, contracts help automating type checking on effective arguments and produced results. They can also automate the selection of better execution strategies according to the primitive's resource consumptions and the actual execution environment. We currently take advantage of this feature in developing ambient systems [RMSAP06].

Modeling steps by combining part holders with procedures (instead of uniquely procedures) brings several new possibilities. It allows developing modeling environments with a spreadsheet look & feel, well-known for their accessibility to domain experts [Nardi93]. Domain experts can model complex behavior by simply (1) selecting amongst the contracts, the primitive to instantiate, (2) selecting the grid cell to which the *instance* of the primitive should be *attached*, and (3) selecting the arguments for the primitive amongst other cells in the sheet. We have successfully tested this idea by developing a Web-based and Dart-compliant graphical interface for a research prototype called *AmItalk* [CRZ05].

Additionally, following the *Observer* pattern [GHJV95], *Dart* couples a dependency mechanisms with the reification of arguments (cf. the `dependents` link in Figure 12). If the part holder P1 serves as argument to the primitive that computes the value of the part holder P2, then P2 is automatically made dependent of P1 so as it computes its value upon to any *significant* change in the definition of the primitive associated to P1. This feature, also present in spreadsheets such as Excel, is also very appreciated by domain experts. It prevents them from manually keeping track of the consequences of a change in a primitive definition or value.

Adding execution strategies which are used through the mediation of contracts, allows changing the execution policy at runtime, which is no more structurally attached to the task definition. It also allows deploying task definitions on non-object execution platforms. We are also exploiting this possibility in implementing ambient systems that feature runtime adaptivity to a changing execution context. From the domain experts' point of view, this feature is appreciated, since Dart dissociates the operational semantics of the task from their definitions. In conformance with the DSM approach, it becomes possible for the domain experts to focus on the expression of the business logic in terms of an (object) workflow or task. The platform then transforms the definition and deploys it, based on the contextual data.

Our industrial experience with FI-AOMs shows that experts use both artifact and activity-based modeling. It is often a question of perspective for them, and they need to be able to switch between these two perspectives. In effect, experts need to analyze both the products and the actions, for instance from cost and resource-effectiveness point of view. Thanks to the contracts, the reification of parameters, the management of dependencies and business objects types, it becomes also possible to recursively guide experts for finding the write sequence of actions for achieving a specific product. Dart supports then the two activity modeling methodologies.

Last but not least, Dart provides a full reification of behavior modeling abstractions. Even complex control structures are fully reified. This allows domain experts defining complex procedures without low-level programming.

5.2 Ities: expressivity, modularity, reusability and extendability

The MWF primitives model also the formal arguments. However, an argument is represented as a symbol and not a full-fledged object. In Dart, arguments are represented by the part holders. This allows in particular designating as argument virtually any complex interpretable structure (*Interpreter* pattern) that implements the `value` protocol. We have used this feature in a successful metrology application [Raz00] to allow experts *embedding* mathematical expressions as arguments to other primitive calls.

Consequently, it becomes possible to hierarchically structure a computation, while keeping the same spreadsheet-like programming look & feel. For instance, an `IfElse` conditional can be represented as a "primitive" that takes two arguments which are themselves workflows. At runtime, the predicate-workflow is executed first, and the action-predicate is executed only if it returns true. Programmers can relatively easily extend *Dart* to add specific control structures, adapted to the business domains and domain experts. The *Mobidyc* system [GLS02], which reuses an implementation of *Dart*, has taken advantage of this possibility to implement a variety of control structures.

From the framework design point of view, having separated the different roles in the design of procedures makes the architecture more flexible by allowing the evolution of one aspect without being limited by the constraints imposed by the other aspect. In other terms, Dart decomposes the process model component of the MFW into several reusable, extensible and finer-grained components.

6 Conclusions and perspectives

An extension to the MWF core component dedicated to workflow definition and execution is proposed. We show that the goals of a workflow architecture that targets both developers and domain experts is achievable. Many enhancements and more flexibility (including new hooks for dynamic adaptivity) are possible.

To experimentally validate Dart, we have developed an object-oriented framework using *VisualWorks* Smalltalk, which we first used in an ecology simulation system [GLS02]. This prototype is being reused in a project related to the *Ambient Intelligence* and *Ubiquitous Computing*, where we are further deploying this architectural style for developing a macro-programming environment for *Wireless Sensor-Actuator Networks* [RMSAP06].

7 Acknowledgements

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Genie: a Domain-Specific Modeling Tool for the Generation of Adaptive and Reflective Middleware Families

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Abstract. At Lancaster University we are investigating about the two following challenges (i) how to develop new, scalable and adaptable middleware systems offering richer functionality and services, and (ii) how to do it in a more efficient, systematic, and if possible automatic way that guaranties that the ultimately configured middleware will offer the required functionality. This article is centered on how we face the second challenge. We describe Genie, our proposal of how to use Domain Specific Modeling (DSM) to support a development approach during the life cycle (including design, programming, testing, deployment and execution) of reflective middleware families. **Keywords**: Domain-Specific Modeling, Domain-Specific Languages, Model-Driven Engineering, Family Systems, Reflective Middleware.

1. Introduction

Middleware is a term that refers to a set of services that reside between the application and the operating system and its primary goal is to facilitate the development of distributed applications[13]. To pursue this goal many middleware technologies have been developed. All share the purpose of providing abstraction over the complexity and heterogeneity of the underlying distributed environment. With the advance of time other goals have been added, for example; adaptability is emerging as a crucial enabling capability for many applications, particularly those deployed in dynamically changing environments such as environment monitoring and disaster management [10, 19]. One approach to handling this complexity at the architectural level is to augment middleware systems with intrinsic adaptive capabilities [8, 18, 24]. Under these circumstances, the development of middleware systems is not straightforward at all. Application developers have to deal with a large number of complex variability decisions when planning middleware configurations and adaptations at various stages of the development cycle (design, component development, integration, deployment and even at runtime). These include decisions such as what kinds of components are required and how these components must be configured together. Tracing these decisions manually and using ad-hoc ways do not guarantee their validity to achieve the required functionality. Software engineers who work in the area of adaptive middleware development are consequently two-fold challenged in that they should (i) develop new, scalable and adaptable middleware systems offering richer functionality and services, and (ii) the approaches they use should be more efficient and systematic and should guarantee a formal foundation for verification that the ultimately configured middleware will offer the required functionality.

At Lancaster University we are researching how to meet these challenges. We use reflection and system-level component technologies and the associated concept of component frameworks, in the construction of our open, adaptive and re-configurable middleware families to face the first challenge identified above. More information about this facet of our research can be found in [1]. This article focuses on how we face the second challenge. We use DSM to raise the level of abstraction beyond programming by specifying solutions using domain concepts. We advocate working with DSM to improve the development of middleware families, systematically and in many cases automatically, generating middleware configurations from high level specifications. In this paper we describe the prototype tool Genie, our proposal of how to use DSM to support a development approach during the life cycle (including design, programming, testing, deployment and even execution) of reflective middleware families. The paper is organized as follows. Section 2 introduces the Lancaster's middleware platform and its basic concepts. Section 3 presents Genie; relevant aspects and basic concepts of Genie are discussed. Section 4 discuses aspects related with different levels of abstraction in Genie and future work. Finally section 5 gives some final remarks.

2. Lancaster's Reflective Middleware : Meeting the Family

Our notion of middleware families is based on three key concepts: *components*, *components frameworks*, and *reflection*. Both, the middleware platform and the application are built from interconnected sets of components. The underlying component model is based on OpenCOM [9], a general-purpose and language independent component-based systems building technology. OpenCOM supports the construction of dynamic systems that may require run-time reconfiguration. It is straightforwardly deployable in a wide range of deployment environments ranging from standard PCs, resource-poor PDAs, embedded systems with no OS support, and high speed network processors. Components are complemented by the coarser-grained notion of *component frameworks* [22]. A component framework is a set of components that cooperate to address a required functionality or structure (e.g. service discovery and advertising, security etc). Component frameworks also accept additional 'plug-in' components that change and extend behaviour. Many interpretations of the component framework notion foresee only design-time or build-time plugability. In our interpretation run-time plugability is also included, and component frameworks actively police attempts to plug in new components according to well-defined policies and constraints. Similar to product family area's approach, we use component frameworks to design the middleware families that can be adapted by reconfiguration. The architecture defined by the component framework basically describes the commonalities and we achieve variability by plugging in different component.

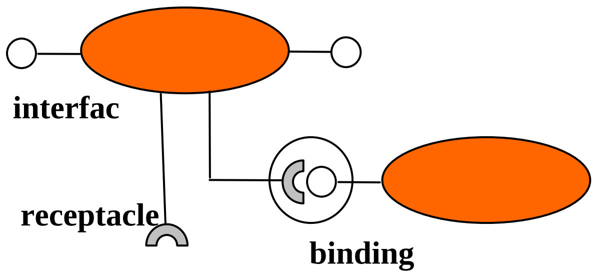


Figure 1: The OpenCOM main concepts

The basic concepts of OpenCOM are depicted in
Figure **1**. Components are language-independent units of deployment that support interfaces and receptacles (receptacles are "required interfaces" that indicate a unit of service requirement). Bindings are associations between a single interface and a single receptacle.

Reflection is used to support introspection and adaptation of the underlying component/component framework structures [7]. A pillar of our approach to reflection is to provide an extensible suite of orthogonal meta-models each of which is optional and can be dynamically loaded when required, and unloaded when no longer required. The reflective services then provide generic support for target system reconfiguration—i.e. inspecting, adapting and extending the structure and behaviour of systems at runtime. The meta-models manage both evolution and consistency of the base-level system. The motivation of this approach is to provide a separation of concerns at the meta-level and hence reduce complexity. Three reflective meta-models[1] are currently supported:

- The *architecture reflective meta-model* to inspect (discover), adapt and extend a set of components.
- The *interface reflective meta-model* to support the dynamic discovery of the set of interfaces defined on a component; support is also provided for the dynamic invocation of methods defined on these interfaces.
- The *interception_reflective meta-model* to support the dynamic interception of incoming method calls on interfaces and the association of pre- and post-method-call code.

3. Genie

Genie is a prototype for a development-tool that offers a Domain Specific Language for the specification, validation and generation of artifacts for OpenCOM-based middleware platforms. Genie enables the construction and validation of models that drive the life cycle of the reflective middleware families at Lancaster University; this includes design, programming, testing, deployment, and even execution [4]. From the models specified not only source code can be generated but configuration and deployment files, results associated with model checking and validations, and documentation.

Genie has been developed using MetaEdit+ [20]. MetaEdit+ has proved to be a mature tool that offers a simple and elegant approach to develop DSLs. MetaEdit+ offers symbol and diagram editors that allow users to develop the same graphic concepts experts, designers, and programmers use. The generation of artifacts is done using reports. Reports access models information and transform it into various text-based outputs; in the case of Genie these outputs can be XML configuration files, programming code, or test code. The new version of MetaEdit use protected blocks in the text-based output. It means (i) manual changes to generated files are preserved each time new code is generated and (ii) the programmer who adds handwritten code knows exactly where to add it. This way, unwanted changes in the generated code is avoided. It was one of the drawbacks of our approach that has been fixed. The next sections discuss some relevant aspects of Genie.l

3.1. Modeling Process with Genie

DSM provides a systematic use of Domain Specific Languages (DSLs) to express different facets of information systems. In many cases DSM includes the creation of

[1] Note that there is a potentially-confusing terminological clash here between the “meta-level” and “reflective meta-levels” terms. These two concepts are entirely distinct; nevertheless we are forced to employ both of these terms because they are so well established in their respective communities.

domain-specific generators that create code and other artifacts directly from models [16, 17]. Getting the benefits of DSM was limited as it was common to develop the supporting tool besides the DSLs and the generators. Nowadays we have modern metamodel-based DSM tools available which are used by developers to just focus on the development of DSLs and the generators. Using these tools, the process for implementing model-based development generally presents the following four phases [23]:

- Identification of abstractions and concepts and specification of how they work together
- Specification of the language concepts and their rules (metamodel). These rules will guide the modeling process that developers follow.
- Creation of the visual representation of the language (notation); this is done in the case we have a Domain Specific Visual Language.
- Definition of generators. These generators will produce source code, documentation, results related to model validation, etc.

The process in Genie essentially follows these steps (see Figure 2). More details are shown in the next sections.

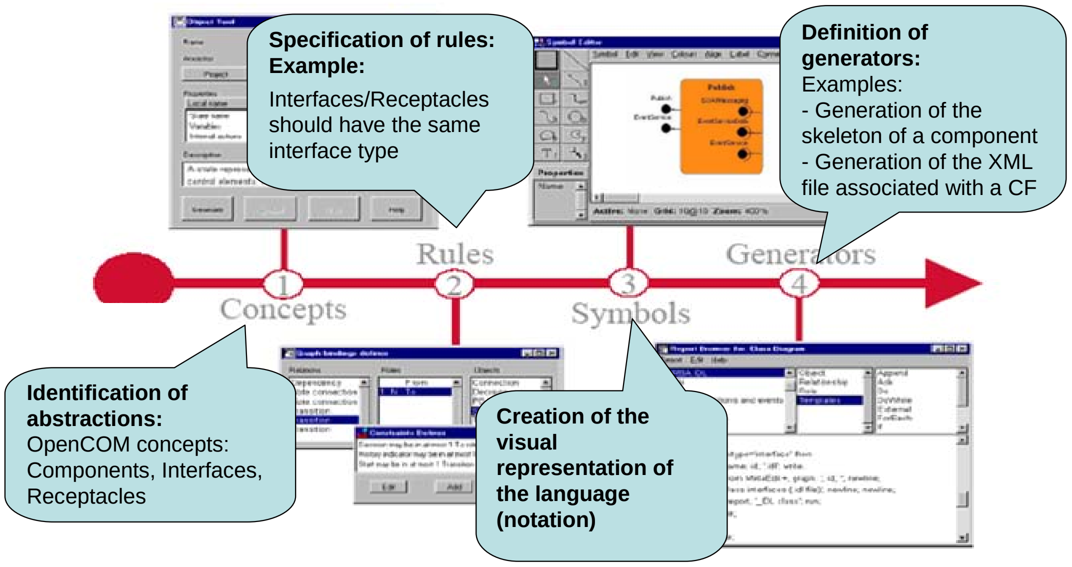

Specification of rules: Example: Interfaces/Receptacles should have the same interface type
Definition of generators: Examples: - Generation of the skeleton of a component - Generation of the XML file associated with a CF
Rules
Generators
1 Concepts
2
3 Symbols
4
Identification of abstractions: OpenCOM concepts: Components, Interfaces, Receptacles
Creation of the visual representation of the language (notation)

Figure 2: Steps for implementing a Domain Specific Modeling Language (DSML): Case study Lancaster Middleware Platform

3.2. Genie: basic Concepts

As in other program family techniques, our approach uses component frameworks to manage and accomplish variability and development of systems that can be adapted by re-configuration. A component framework enforces architectural principles (constraints) on the components it supports; this is especially important in reflective architectures that dynamically change. Reconfiguring a running system using our approach implies the insertion, deletion and modification of the structural elements represented in the component frameworks: components, interfaces, receptacles, binding components and constraints. Models associated with component frameworks are used to represent the possible variants (configurations) of the different families. Models can be effective and valuable in this sense as they can be verified and validated a priori (before the execution of the reconfiguration).

Existing models of OpenCOM-based middleware families use a wide variety of notations that depend on the domain that is being modeled. However, the basic concepts of any OpenCOM-based model use the basic notions that OpenCOM dictates (i.e. components, interfaces and component frameworks). Genie offers a common modeling notation for all the models called the OpenCOM DSL. The specification of how these concepts work together is described in the graphs associated with the components and component frameworks. An example of a model associated to a component framework is shown in

Figure **3**. The component framework specified is the Publisher [15]. In the figure we can see that components offer and require interfaces and interfaces can be bound together to connect components. Component frameworks can export interfaces from internal components. In the same way, component frameworks can require interfaces to satisfy the requirements of some of their internal components.

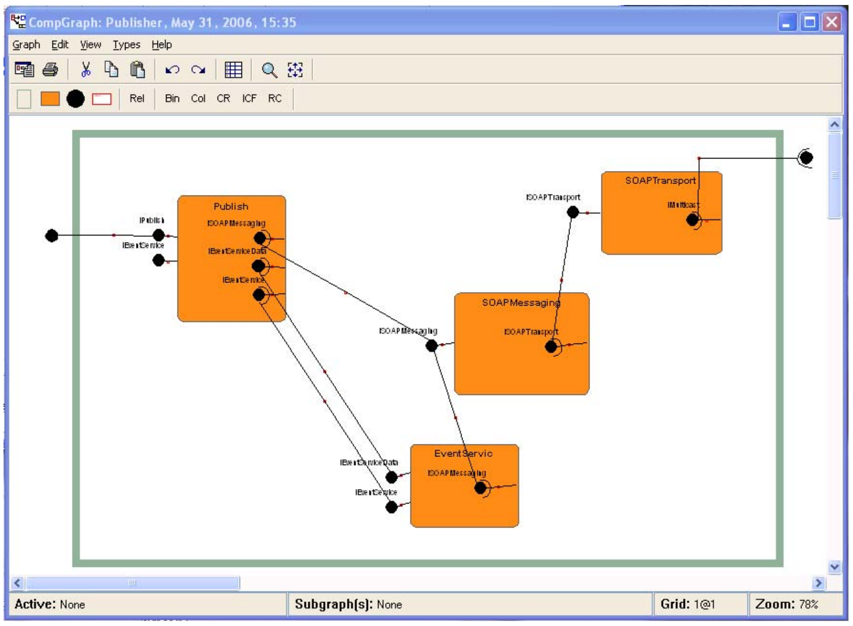
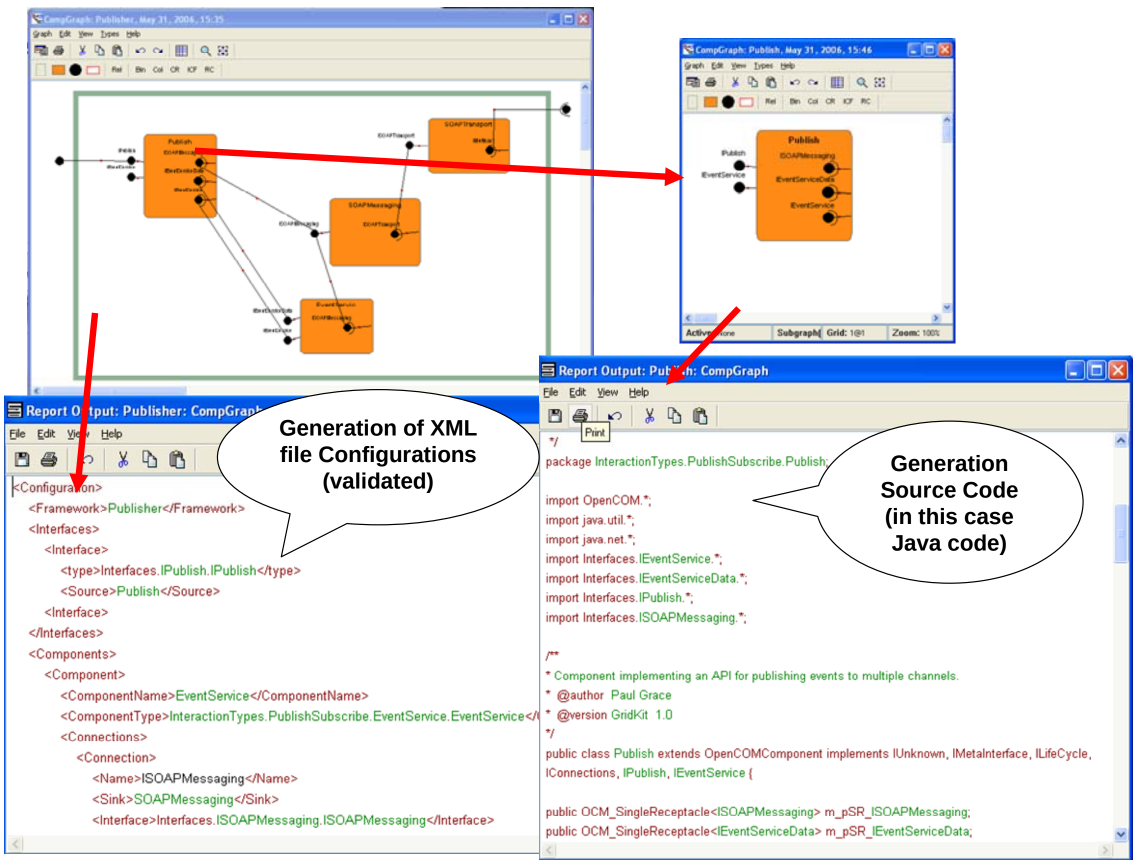


Figure 3: A Component Framework (Publisher) modeled in Genie

Many artifacts can be generated from component-framework models. Some examples of artifacts that can be generated from these models are:

- the XML files associated to policies that rule the configuration and reconfigurations of the component frameworks.
- test code that use hardcode connections of the components in the component framework. These test code is executed as isolated experiments before performing the tests that use reflective capabilities and do not use hardcode connections.
- reports of validations and checkings; for example, a report can show notifications of interface mismatches meaning that interfaces of different types are mistakenly connected. More details and examples are in Section 3.3.
- documentation

Figure 4 shows other examples and details of models, relations between models, and generation of different artifacts. Arrow (a) shows how from the graph of a component framework a component can be chosen to get more details. From the model (graph) associated to a component more details associated with required and offered interfaces, author, version, etc can be found . If the user wants to explore the interfaces associated with a component; she could open a window with the data associated with the interfaces (signature, parameters, etc.). In the same way, the user could open a window with the data associated with the author/responsible of the component. Arrow (b) shows how from the graph of a component, the skeleton code of the component can be generated and/or accessed. Finally, arrow (c) shows a policy (XML file) associated with the configuration of components shown in the graph of the component framework. These policies are stored in a Knowledge Repository that will be accessed by the middleware configurators at run-time. The configurators will read the policies to perform the re-configurations connecting and disconnecting components to perform adaptations [5].


CompGraph: Publisher, May 31, 2006, 15:35
CompGraph: Publish, May 31, 2006, 15:46
Report Output: Publisher: CompGraph
File Edit View Help
Generation of XML file Configurations (validated)
Report Output: Publish: CompGraph
Print
Generation Source Code (in this case Java code)

```
<Configuration>
  <Framework>Publisher</Framework>
  <Interfaces>
    <Interface>
      <type>Interfaces.IPublish.IPublish</type>
      <Source>Publish</Source>
    <Interface>
  </Interfaces>
  <Components>
    <Component>
      <ComponentName>EventService</ComponentName>
      <ComponentType>InteractionTypes.PublishSubscribe.EventService.EventService</
      <Connections>
        <Connection>
          <Name>ISOAPMessaging</Name>
          <Sink>SOAPMessaging</Sink>
          <Interface>Interfaces.ISOAPMessaging.ISOAPMessaging</Interface>
```

```
*/
package InteractionTypes.PublishSubscribe.Publish;

import OpenCOM.*;
import java.util.*;
import java.net.*;
import Interfaces.IEventService.*;
import Interfaces.IEventServiceData.*;
import Interfaces.IPublish.*;
import Interfaces.ISOAPMessaging.*;

/**
* Component implementing an API for publishing events to multiple channels.
*  @author  Paul Grace
*  @version GridKit  1.0
*/
public class Publish extends OpenCOMComponent implements IUnknown, IMetaInterface, ILifeCycle,
IConnections, IPublish, IEventService {

public OCM_SingleReceptacle<ISOAPMessaging> m_pSR_ISOAPMessaging;
public OCM_SingleReceptacle<IEventServiceData> m_pSR_IEventServiceData;
```

Figure 4: Generation of different artifacts

3.3. Validation of Models

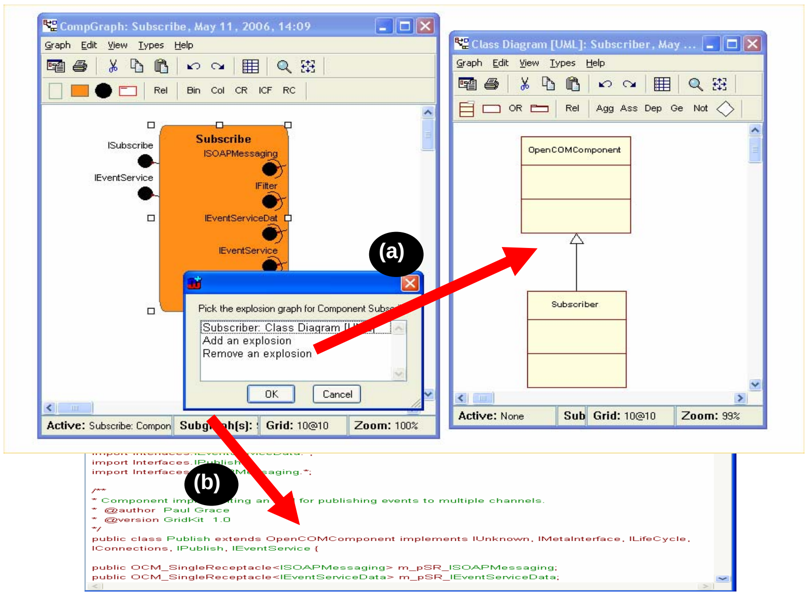
In MetaEdit+, the validation of models can be performed while the modeler is editing a model or once the edition has been completed. The second option is faster and is the option we prefer to use. Any generation of artifacts (source code, XML file, etc.) does require validation and checking. To understand the important role of validation in Genie let us focus on the case of component frameworks.

As noted above, a component framework imposes constraints on the components it supports. Consequently the basic checking is related to these architectural constraints. When designing the validations of the component frameworks we exploit known variabilities in architectural structures so that common checking infrastructure can be built once and then used by any user of Genie in the corresponding component framework. Not only does this approach decrease the cost of models validation, but it makes it easier the technology since the modeler needs just to be concern about the domain-specific aspects of the problem; in this case the behavior of components and specific domain-related constrains (architectural styles and new constraints).

An example of basic validation is the verification that all the connections between required interfaces and offered interfaces conform to the same type (therefore the configurator does not need to check these conditions at run-time). Examples of more specific validations are related to the specific constraints enforced by the component frameworks: a specific component may appear only once at the most, a connection between two components must exist, etc. These validations should be written for all the component-framework models.

4. Different levels of abstraction in Genie

OpenCOM DSL models in Genie are defined essentially in terms of configurations of OpenCOM components and individual components. These concepts are not about code but about much higher-level abstractions as shown in the previous sections. Genie offers the OpenCOM-based DSL but also allows the specification of models using UML [12]. Every OpenCOM component is specified using a UML class that inherits from the superclass called OpenCOM Component [3, 6]. In Figure **5**, arrow (a) shows how a component is inspected and shows a partial view of the corresponding UML specification. The component Subscriber is specified by the class *Subscriber* that inherits from the superclass *OpenCOMComponent*. Arrow (b) shows how, from the graph of a component, the skeleton code of the component is generated and/or accessed. Genie will traverse the UML models related to the component to generate this source code. The code generated in the example is Java code. More detail can be found in [6]



Pick the explosion graph for Component Subs

Subscriber: Class Diagram [U
Add an explosion
Remove an explosion

OK Cancel

Active: Subscribe: Compon | Subg h[s]: | Grid: 10@10 | Zoom: 100%

Active: None | Sub | Grid: 10@10 | Zoom: 99%

```
import Interfaces.IPublish
import Interfaces         M   saging.*;

/**
* Component imp        ting an      for publishing events to multiple channels.
*  @author  Paul Grace
*  @version GridKit  1.0
*/
public class Publish extends OpenCOMComponent implements IUnknown, IMetaInterface, ILifeCycle,
IConnections, IPublish, IEventService {

public OCM_SingleReceptacle<ISOAPMessaging> m_pSR_ISOAPMessaging;
public OCM_SingleReceptacle<IEventServiceData> m_pSR_IEventServiceData;
```

Figure 5: OpenCOM DSL and UML

Figure 6 shows the different levels of modeling corresponding to different levels of abstraction. At the bottom level we have the models corresponding to the *underlying code framework*. This code framework offers modules (i.e. components) that will be used from the DSL environment at higher levels. At a high level of abstraction, models defined using the DSLs, are used to generate the code that relies on the code framework. Higher levels are at a more coarse level of granularity and it is here that we deal with concepts that are closer to the problem domain. Lower-level modeling entities are about source code and implementation details. In general, programmers will work at the lower level (programming level) or generating the underlying framework code. This fits well with the vision MetaCase has for domain-specific modeling where applications are built on top of a software platform and possibly a code generation framework [2].

Future Work

It is on this specific aspect of Genie that we would like to focus our future work. We aim to introduce higher levels of abstraction in Genie to focus on different domains like grid computing [14, 21] (using more specific notions like overlay network frameworks, or resource management framework) and service discovery protocols. For example, we envisage having pre-designed and specialized components frameworks with characteristics and constraints focused on specific requirements of a class of applications (family). We are already working on the specification of models for families of service discovery protocols with a common architecture [11]. This way, we can minimize resource usage through not just component code re-use, but architecture too.

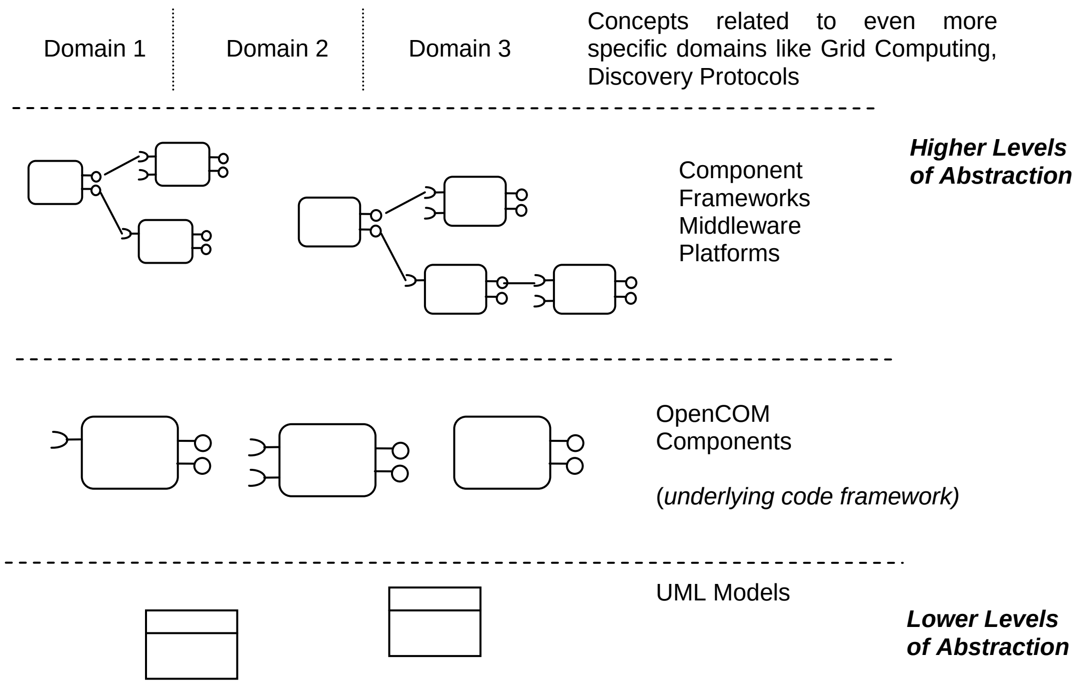

Domain 1
Domain 2
Domain 3
Concepts related to even more specific domains like Grid Computing, Discovery Protocols
Higher Levels of Abstraction
Component Frameworks Middleware Platforms
OpenCOM Components
(underlying code framework)
UML Models
Lower Levels of Abstraction

Figure 6: Level of modeling corresponding to different levels of abstraction

5. Final Remarks

Reflective and adaptive middleware platforms require the creation of multiple dynamically deployed variations of reconfigurable systems. A systematic approach is needed to model, generate and finally validate these variations. Genie represents the way in which we have met this challenge. Genie is a DSM environment prototype to support the development during the life cycle of reflective middleware families. The environment simplifies the development of middleware families offering a platform that guides the development process. Genie is proven to generate the policies for configuration of our Gridkit middleware platform [5].

In this paper, we have described the OpenCOM DSL offered by Genie, a domain specific language for the specification, validation and generation of artifacts for OpenCOM-based middleware platforms. Among the benefits of Genie are reusability of code and knowledge. Genie promotes valid code and artifacts offering a less error-prone approach.

Genie has been developed using MetaEdit+. DSM-based metamodeling tools like MetaEdit+ make it easier to construct DSL-based environments to automate software development. However, while DSL approaches raise the levels of abstraction and allow the development of systems considerably faster than UML-based approaches, UML has the advantage of visualizing code using the well understood UML models. We advocate combining both approaches [6]. DSLs and UML can give benefits by providing an intermediate representation that is validated and translated into well understood UML-based models. Following this philosophy, Genie offers tool support for different levels of abstraction using common semantics. It offers supports from the source code level up to domain-specific and higher levels, and consequently for different users. Our future work focuses on adding support for higher levels of abstractions including more specific domains and adaptability requirements [21]. We think this offers the additional advantage of better communication between participants in development projects and therefore generating potential for more successful projects.

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Incremental Development of a Domain-Specific Language That Supports Multiple Application Styles

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ABSTRACT

Domain-Specific Languages (DSLs) are typically built top-down by domain experts for a class of applications (rather than a specific application) that are anticipated in a domain. This paper investigates taking the opposite route: Building a DSL incrementally based on a series of example applications in a domain. The investigated domain of CRUD applications (create, retrieve, update, delete) imposes challenges including independence from application styles and platforms. The major advantages of an incremental approach are that the language is available for use much sooner, there is less upfront cost and the language and domain boundaries are defined organically. Our initial experiments suggest that this could be a viable approach provided certain careful design decisions are made upfront.

Keywords
Domain-specific languages, incremental design, application style, CRUD applications.

1. INTRODUCTION

Domain-specific languages (DSLs) have received a lot of attention over the last few years in the research community and in industry. They promise software development using languages that provide higher-level abstractions that are particularly tailored to a domain. The ideal approach would involve a handful of highly skilled language developers and domain experts who would collaborate and define the boundaries of a domain and come up with optimal abstractions for expressing concepts in the domain. Once the language is finalized, a "compiler" (code generator) for this domain-specific language would be developed to generate code for a target platform or language. The compiler can then be used to generate applications. The major advantage of this approach is that developers will—from the outset—work with a robust language designed by experts. The disadvantage is that it requires significant upfront investment in developing language and compiler while the usefulness of the DSL for specific applications is unknown.

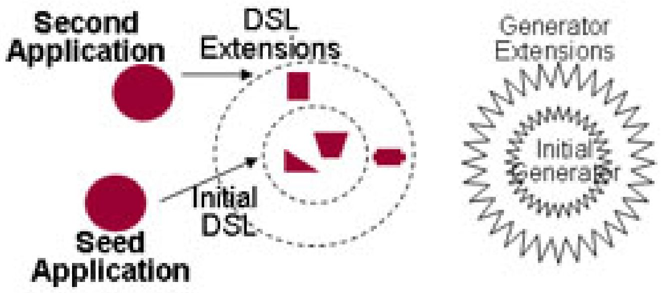


Figure 1: Incremental DSL Design Approach

In this paper we investigate an alternative "incremental" approach [12]. Rather than defining the domain or its boundaries, we choose a "typical" application that we use as a seed to develop a DSL expressive enough to describe this application. Then we attempt to add additional features to the seed application and write other applications in the domain. This may require extensions to the language and corresponding extensions to the code generator. Thus the DSL is driven by a series of examples rather than a detailed understanding of the domain without specific applications in mind. The expectation is that the language would continue to evolve until it is no longer fruitful or cost effective to extend it—thereby defining the boundaries of the domain. The advantages of this approach are that the language is available for use much sooner, there is less upfront cost and the language and domain boundaries are defined organically. Moreover, the DSL is by definition useful for at least one application. The incremental approach is depicted in Figure 1.

This paper reports on incrementally building a DSL that targets the domain of CRUD applications (create, retrieve, update, delete). We design the language to cover multiple application styles and build two code generators to cover major style and platform choices. We evolve the language in three iterations. The incremental approach appears viable for this DSL; however, certain initial design decisions must be made carefully. Further investigation is necessary to understand some of the potential disadvantages of this approach such as language drift, proliferation of languages and their corresponding code generators and the dangers of language extensions made by novices.

In the following section we introduce the domain and application we chose for our investigation. The initial DSL we developed is discussed in section 3. Section 4 describes the code generators we implemented to target multiple platforms. Language evolution with additional features and examples is investigated in section 5. Section 6 summarizes related work and we conclude in section 7.

2. DOMAIN AND SEED APPLICATION

To explore the incremental evolution of a DSL, we chose the “domain” of CRUD (create, retrieve, update, delete) applications. We deliberately left the definition of the domain vague. We chose a simple application that involves creating and maintaining data.

The application was a “distributed to-do list” manager that allows a group of people to manage their to-do list as well as to assign tasks to each other. The to-do list can contain deadlines for the tasks and may be marked complete when done. The application did not have any security features other than login. Anybody can see everyone else’s to-do’s or assign tasks to anybody.

Below are more detailed functional requirements:

- Manage one to-do list that can be viewed and edited by the members of the group. All members view and edit the same to-do list.
- Each member of the group is represented by a separate user of the application (with initial login of some sort).
- The to-do list consists of to-do items.
- To-do items have a number of attributes:
    - title (required)
    - due date (required)
    - responsible group member (required)
    - completed flag (required)
    - free-text description (required)
- The to-do list can be viewed.
- The to-do list view displays each to-do item with title, due date, responsible group member, and completed flag.
- A to-do item from the list can be selected to view individually.
- The individual view of a to-do item shows all attributes of that item read-only.
- A to-do item can be selected for editing from the individual view. All attributes are made editable at the same time. Changes can be confirmed or cancelled.
- New items can be created at any time with a form similar to the one for changing an existing item.

- Saving a new or edited item occurs transactional. If two members edit an item concurrently there will be no warning and one member will override the changes of the other member.

3. A DSL FOR CRUD APPLICATIONS

This section discusses the domain-specific language that we developed based on the seed application presented in the last section. The requirements define our seed application based on its user interface and the managed data. Therefore we decided to split the DSL into two parts, one describing the manipulated data and one for the user interface. The following subsection deals with the definition of data. Afterwards we describe the definition of user interfaces. Tool support for testing and debugging is beyond the scope of this paper.

3.1 Data: Entities and Relationships

The vocabulary used for defining data ("to-do item", "responsible group member", etc.) is specific to the application. Unsurprisingly, the requirements distinguish different kinds of data ("to-do item", "group member") that are often called *entities* and represented as database tables. These entities have *attributes* ("completed flag" etc.) that sometimes refer to other entities ("responsible group member").

Since entity-relationship models are familiar to CRUD application designers we decided to borrow their principles for the definition of data in our DSL. We use a textual representation that is reminiscent of SQL statements for table creation. However, we simplify some aspects of the language. For example, we alleviate the developer from worrying about foreign key mappings. She can instead define relationships directly with keywords like "many-to-one" that cause automatic generation of appropriate foreign key constraints. Figure 2 shows the definition of entities for our seed application.

```
GroupMember = (
      username : String  key,
      password : String
)

TodoItem = (
      autokey,
      title : String,
      dueDate : Date,
      complete : Boolean,
      responsible : GroupMember  manytoone,
      description : String
)
```

Figure 2: To-do list example application entities

By borrowing from existing concepts (entity-relationship models in this case) we allow domain experts to use a framework they are already familiar with. We believe that this can reduce the problems of learning and adopting a domain-specific language. The textual representation is very useful for automatic tools (like the code generator) while a graphical representation is probably more convenient for the developer to use.

Our definition of entities conveniently introduces the notion of types into our system. We use some common base types to define primitive attributes. Entities become types themselves that can be used to type attributes (essentially defining relationships). Note that the type of each attribute is effectively given in the requirements of our seed application (strings, dates, and Booleans). Treating entities as types will allow us to perform static checks on the definition of the user interface. It also simplifies code generation. We believe that these are big benefits of a typed approach to designing a DSL that are often worth the effort.

3.2 User Interfaces

We now come to the definition of the user interfaces. The requirements of our seed application essentially describe two things: the different views (and edits) of the underlying data and the control and data flow among them. We call the former *interactions* and the latter *compositions*. Both are understood as *processes*.

A process is defined as a part of the program that has input values and ends with an *event*. This certainly applies to interactions (see below). By extending this idea to compositions we achieve a more scalable model that allows compositions to define the flow between processes (including other compositions) because compositions and interactions have a common interface (inputs and events).

The programmer has to explicitly write the signature (inputs and events) of each process. Notice that it would be quite simple to inject code on the level of a process. For example, this code could implement a decision and therefore end with one of two possible events. Code injection on this level is simple because the interface of the injected code is defined by the process signature.

Explicit signatures can also facilitate modular code generation. If the signature can be turned into constructs of the target platform then this representation is like a “calling convention” for processes in that platform. If one process invokes the other (when control flows from one to the other according to a composition) its generated code can use this calling convention and does not have to look beyond the signature of the invoked process.

3.2.1 Interactions

An interaction communicates data to the user, optionally allows changing that data, and ends with an event that the user initiates. Thus an interaction consists of a screen that is presented to the user and the logic to query and update the presented data.

Looking at the requirements of the to-do application it is interesting to notice that users can essentially only “view” or “edit” data. Thus the nature of user interactions is generic to the domain. Conversely, the exact information presented in an interaction is specific to an application. Thus we define an interaction in terms of *what* is presented to and edited by the user. Because the language should work both for Web and desktop applications we do *not* prescribe *how* data is presented.

For the definition of interactions we had to decide how developers can express what data they want to show (or edit). For example, viewing a to-do item should show the title of the item. We chose to follow the analogy of field selection in Java and C# and use a “dot” notation. Thus if a variable called “item” is passed into the interaction then “item.title” denotes its title. Field selections can be nested, just like in Java or C#. We will call such a construct a *term*.

Displaying a piece of data can be achieved by just writing the appropriate term, starting from a defined variable. Data can be made editable by surrounding a term with “edit”. Moreover, editing has to happen inside a “update” or “insert” construct that makes certain variables subject to editing. Inside this construct, an event marked as “confirm” will commit changes into the database. Events that are not marked with “confirm” essentially discard any changes.

These concepts are again motivated by the domain. SQL distinguishes between inserting a new row and updating an existing row.[1] We combine this with the idea of “forms” in HTML that have the ability to submit or cancel any inputs made into the form by the user. However, in reflection on this work we think that the distinction between inserting and updating data could be hidden from the developer and silently addressed in the generated code.

Labels can be put next to displayed or edited terms to give the user some context about what she looks at. This is common practice in user interface design. The interactions in our seed

[1] While our language covers create and update operations, we did not need deletion for our example applications. Deletion may cause runtime errors when relational constraints are violated and could therefore motivate language extensions.

application either are concerned with an individual data element or iterate over a list of elements. We therefore define a “list” construct that implicitly iterates over the rows returned by a query. The “list” construct has a body that defines what should be displayed for each element in the list.

Similar to the definition of entities (above), the code generation for interactions is based on a textual representation. An equivalent hierarchically nested graphical representation of display and edit elements with their labels could be defined that would look very similar to graphical tools for designing desktop applications. Figure 3 shows some of the interactions for viewing and manipulating to-do items in our seed application.

Formally, an important concept in defining interactions is the scope of variables. Most variables are introduced with names for input values in the signature of an interaction. The “list” and “insert” constructs introduce additional variables (for the current and new data element, respectively) that are only available in their bodies. This means that the types of all variables are known statically. Based on the information given in the definition of entities, the types of terms can be inferred. This enables static checks to make sure that for example only primitive attributes are displayed. (It is not clear what displaying a “group member” would even mean, while displaying its username is straightforward.)

We point out that we can also rely on the types to determine automatically how terms are formatted for display and what controls are used for editing them. For example, a term that is a date should be formatted as such. A Boolean term should probably be edited through a checkbox while a term of entity type should be edited with a combo box that shows the available entries. However, additional configuration could change these defaults.

Thus we found that typing of terms not only enables static validity checks of programs written in our DSL; it also stratifies the DSL because the code

```
interaction TodoList() emits SelectItem(TodoItem),
NewItem(), NewUser(), Exit()
{
    list(select TodoItem i)
    {
        "Title"        i.title -> SelectItem(i),
        "Due"          i.dueDate,
        "Completed"    i.complete,
        "Responsible"  i.responsible.username
    },
    "New Item" -> NewItem(),
    "New User" -> NewUser(),
    "Exit" -> Exit()
}

interaction View(TodoItem item)
emits Edit(TodoItem), Back()
{
    "Title"            item.title,
    "Due"              item.dueDate,
    "Completed"        item.complete,
    "Responsible"      item.responsible.username,
    "Description"      item.description,
    "Edit" -> Edit(item),
    "Back" -> Back()
}

interaction Edit(TodoItem item) emits Continue()
{
    update(item)
    {
        "Title"        edit(item.title),
        "Due"          edit(item.dueDate),
        "Completed"    edit(item.complete),
        "Responsible"  edit(item.responsible),
        "Description"  edit(item.description),
        "OK"           confirm(Continue()),
        "Cancel" -> Continue()
    }
}
```

Figure 3: To-do list example application interactions

generator can infer the omitted information (such as appropriate edit controls and formatting) from the types.

3.2.2 Compositions

Compositions define the flow of control between processes. They essentially "wire" each event of a process to another process that is invoked when the event occurs. Events can carry parameters that are transferred to the invoked process. Figure 4 shows how the interactions of our seed application are composed.

The overall flow can be defined with hierarchically aggregated compositions. This seems helpful from an engineering point of view. For example, we used this idea to define the flow between the various interactions for displaying and manipulating to-do items in a composition that is in turn composed with the login screen to form the complete to-do list application.

We point out that a complete separation of flow and interactions as realized in our DSL is not commonly achieved in desktop or Web application frameworks. Although they typically follow a Model-View-Controller pattern [5], flow information "leaks" into the view where buttons or links point directly to their following dialog or Web page. We strictly separate the two through our event abstraction that essentially represents clicks on buttons or links.

This has in our view a number of benefits. Firstly, this approach provides separation of concerns and potentially allows better re-use of interactions or even compositions. Unfortunately we could not achieve this in our seed application even though the interactions for creating a new to-do item and editing an existing one look identical. The problem was our distinction of insert and update that is made inside the interaction. Dropping this distinction would open the possibility of reusing the interaction as discussed here.

Secondly, we can conveniently define a graphical language that lets developers "wire" processes in a kind of box-and-line diagram. In fact this is reminiscent of component-and-connector diagrams in UML2 [6] where processes are components and compositions define the connectors. Processes have exactly one "input" port and each of their events defines a separate port. This seems to suggest that CRUD applications (at least in our DSL) follow a particular *architectural style* [1].

Thirdly, we can use the wiring to bridge gaps between the event coming from one process and the input values required for another interaction. For example, we can perform conversions, run a database query or add additional parameter in between. We used this feature to verify credentials between the login screen and the rest of the seed application.

```
composition Todo(GroupMember user)
{
    TodoList      itemList;
    View    viewItem;
    Edit    editItem;
    New           newItem;
    NewMember     newUser;

    begin with itemList()
    {
        itemList.SelectItem(item)->viewItem(item);
        itemList.NewItem() -> newItem();
        itemList.NewUser() -> newUser();
        itemList.Exit() -> Exit();
        viewItem.Edit(item) -> editItem(item);
        viewItem.Back() -> itemList();
        editItem.Continue() -> itemList();
        newItem.Continue() -> itemList();
        newUser.Continue() -> itemList();
    }
}
```

Figure 4: To-do list example application composition

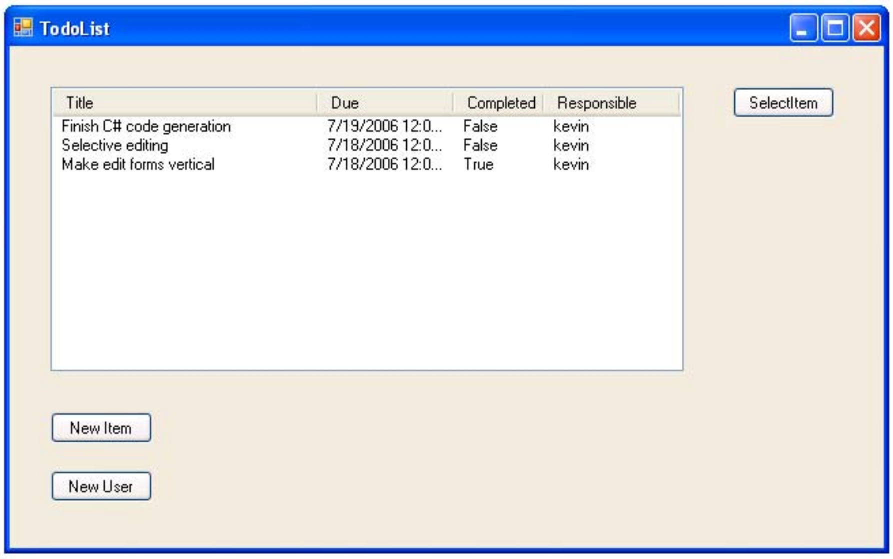
4. CODE GENERATION FOR MULTIPLE PLATFORMS

An interesting aspect of CRUD applications is that they are sometimes implemented as desktop applications and sometimes as Web applications. Desktop and Web applications have different architectures and user interfaces. We refer to these as *application styles*. Desktop applications are thick clients that interact with the user through dialog boxes and can potentially access the database directly. Web applications, on the other hand, use Web browsers as thin clients that display a typically HTML-based user interface. The actual application resides within an application server that in turn accesses the database. (Variations of these characterizations are possible, but these are in our experience typical implementation techniques.)

Our DSL supports both desktop and Web applications with their different application styles. Moreover, we are independent from a particular programming language and explicitly support both Java and C#. In particular, we implemented two code generators for our DSL. One generates C# desktop applications that communicate directly with an underlying database through SQL commands (using ADO.NET). The C# desktop applications use the .NET Windows forms library for their user interface (Figure 5). An implementation in Java would use corresponding standard Java libraries (JDBC and Swing).

The other code generator produces J2EE Web applications based on Enterprise JavaBeans (EJBs) and Java ServerPages (JSPs). EJBs provide a sophisticated way of representing and manipulating database rows through objects called Entity Beans. JSPs are essentially HTML files with interspersed Java code that are typically used for Java-based Web interfaces. The ASP.NET framework provides better support for handling state associated with Web pages than JSPs. On the other hand, .NET does not offer database abstractions that are as powerful as EJBs. We bridge these gaps by generating additional code. For example, our C# code generator creates SQL commands while our J2EE code generator relies on EJBs.

Independent from the problem of supporting multiple programming languages we had to address the discrepancies between desktop and Web applications in general. The differences in their architectures were relatively easy to handle. Conversely, their user interfaces are vastly different. We address this problem with two user interface representations specific to desktop and Web interfaces. In the case of desktop applications this representation is essentially a nesting of “panels” that contain atomic elements such as labels and buttons. In the case of Web applications the representation is HTML with special tags to represent concepts of our DSL. Thus these representations mostly capture the different natures of user interfaces (dialog boxes vs. Web pages).



Title	Due	Completed	Responsible
Finish C# code generation	7/19/2006 12:0...	False	kevin
Selective editing	7/18/2006 12:0...	False	kevin
Make edit forms vertical	7/18/2006 12:0...	True	kevin

Figure 5: Generated to-do list application dialog

The concepts of our DSL could often be turned directly into corresponding user interface concepts. For example, an event corresponds to a button in a dialog box and a link in a Web page. However, the treatment of lists posed a problem. In our DSL we allow to connect each element in the list with events that are parameterized by that element. In a Web page this can be represented as a table with links in each row. In a dialog box, this is not the typical user interface. Thus we instead let the user select an item in the list and provide one button for each event next to the list.

4.1 Code Generator Design

Both code generators use the same input language syntax and parser component. Code is typically generated in multiple steps. Each step is a transformation from one language into another. The most complicated transformations are required for generating code for interactions. Essentially we proceed in three steps.

1. We transform each interaction into a representation that reflects the desired type of user interface (desktop or Web-based). For both user interfaces this step introduces unique names for all elements in a screen.
2. The user interface representation is transformed into a language-dependent form that for example denotes the C# classes to be used for displaying certain elements.
3. This language-dependent form is then written into files.

The intermediate user interface representation output by the first step is intended to have a textual representation. It is designed to be checkable for consistency with the original interaction definition and could therefore be modified by the developer. Conversely, the subsequent steps should not be modified by the developer. Instead she can use the unique naming of elements introduced in step 1 to provide separate configuration files. The calling convention of processes (section 3.2) opens another way of injecting code.

We do not believe that all DSLs must provision these ways of influencing the code generator. We do believe that all three ways (direct editing of intermediate representation, configuration, and code injection) are viable options that have their individual tradeoffs. We think that explicit intermediate representations are particularly useful if they still carry domain concepts. Other ways of affecting a code generator become more useful once the code generation is tied to a particular programming language (because the developer can write code in that language directly).

The introduction of types into our DSL proved very helpful in making sure the code generator worked correctly. Essentially we could map types from the DSL into the target platform. The compiler of the generated code (Java or C#) could then use that information to typecheck our generated code. This helped detecting semantic errors in the code generator that are indicated by typing errors in the generated code. Of course this scheme still relies on test cases, but many code generator errors can be found before the generated code is executed. This idea of typed compilation [2] worked very well in our experience.

It is quite interesting to notice that there are alternatives to generating all necessary code. A powerful runtime could essentially perform the same tasks as a code generator but without the trouble of printing code lines. For example it is conceivable to write a C# program that takes an interaction definition and constructs a corresponding Windows forms object graph. Such a runtime would work like a virtual machine. In contrast, our code generation works like a compiler into binary code. A third alternative in the middle is to generate (hopefully less) code that plugs into an appropriate framework such as Apple’s WebObjects or Ruby on Rails.

Understanding the benefits and drawbacks of these alternatives to make informed decisions about DSL implementation strategies is an important aspect of future work. We do point out that runtime and framework approaches are fundamentally limited by language and architecture boundaries. We believe that part of the value of DSLs lies in their ability to bridge these gaps and tie different kinds of artifacts together.

5. LANGUAGE EVOLUTION

In order to find out how incremental DSL design fares we employed the following methodology.

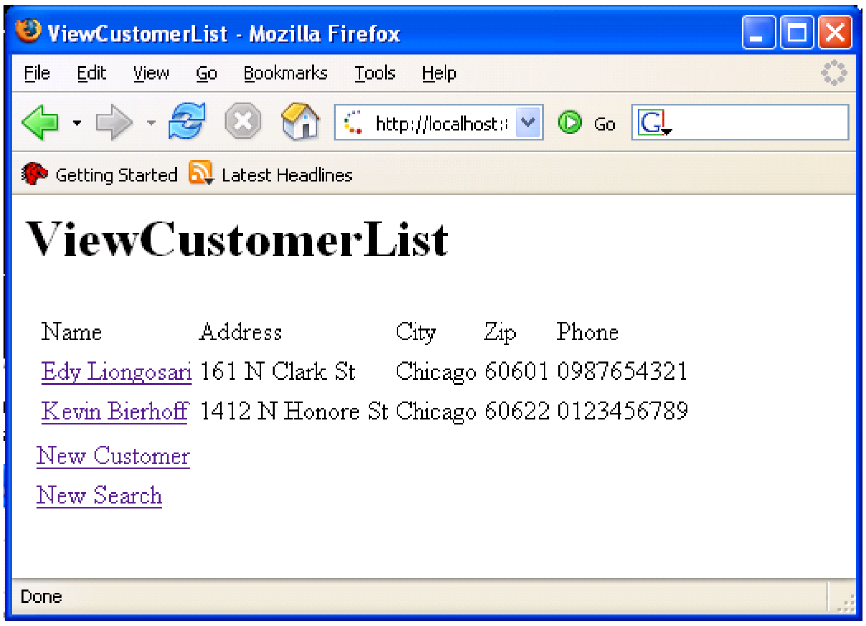
1. We chose a domain, in this case the domain of CRUD applications. The domain has the interesting feature that it spans multiple user interface paradigms and software architectures.
2. We defined informal requirements for a seed application in that domain. The application manages a simple to-do list for a group of people.
3. We implemented the application by hand with available technologies.
4. One of the authors designed a DSL based on the seed application and implemented code generators for the domain that cover the major user interface and architecture alternatives.
5. Another author then defined a new feature for the seed application that was implemented using the DSL.
6. Finally, a third author (successfully) attempted to write a completely new application in the DSL.

This section reports on how the language evolved with the addition of a new feature to the original seed application and the creation of a new application.

Additional Feature. The additional feature was to add a reporting facility to the to-do list application. It should be possible to look at the "unfinished business" of each group member, i.e. the incomplete to-do items the group member is responsible for.

This reporting facility was not immediately expressible in the DSL because Boolean constants were not part of the language and were also not allowed within "where" clauses of queries. (A "where" clause restricts the list of selected rows.) These shortcomings could be addressed easily.

New application. The new application was a "customer update" application that maintains customer records. It was a very simple application with only one entity ("customer"), five interactions, and one composition.


ViewCustomerList - Mozilla Firefox
File Edit View Go Bookmarks Tools Help
http://localhost:
Go
Getting Started
Latest Headlines
Done

ViewCustomerList

Name	Address	City	Zip	Phone
Edy Liongosari	161 N Clark St	Chicago	60601	0987654321
Kevin Bierhoff	1412 N Honore St	Chicago	60622	0123456789

New Customer

New Search

Figure 6: Generated customer update Web page

The author who proposed this application wrote it himself. Notice that he had not been involved in the development of the original DSL. He wrote the application by adapting the seed application in just 30 minutes. His implementation was correct and had only minimal syntactic errors. We think that this is a somewhat surprising result.

The only construct that had to be added to the original DSL was support for “like” in “where” clauses of queries. (Originally, we had only supported equality tests.) This supports our hypothesis that references to existing domain concepts helps in adopting a language. The author that developed the application was familiar with SQL and therefore assumed the presence of a “like” keyword (with the typically associated semantics). Again, the additional keyword could be easily added.

5.1 Code Generator Evolution

Every change to the DSL has to be reflected in its implementing code generators. In the worst case, new code generators have to be built from scratch. However, it seems desirable to evolve the code generators with the language. With our code generators and the two evolution steps described above this was possible. In fact, the necessary changes to the code generators were minimal and could be implemented in about two hours. Language changes could be reflected easily in these cases for two reasons.

1. We used a parser generator that localized changes to the language grammar.
2. Our code generators implemented the necessary transformations using visitor patterns [6]. (We used Java to implement the code generators.)

Visitor patterns implement a recursive traversal of a data structure that calls a different method in the actual “visitor” depending on the type of node currently visited. Visitor patterns allow the compiler (of the language in which the code generator is implemented) to “drive” language extensions. Whenever a new kind of node is added to the data structure definition the compiler will require a traversal method for that node. The implementation of this traversal method will in turn require a new method in the abstract visitor interface. When this new method is added the compiler will point out all the places where concrete visitors need this additional method.

Thus we could quickly find all places in the code generator that were affected by the addition of new language constructs. Modifying existing constructs is somewhat more dangerous because the compiler cannot necessarily help with finding all places that have to be changed.

We believe that the ability to evolve code generators together with the DSL they implement is crucial for the success of an incremental design approach to DSLs. More research is needed to determine how code generators can be designed to achieve this.

5.2 Incremental Language Development

Our experiences with expressing additional requirements and a different application suggest that building DSLs incrementally is possible and useful in practice. We experienced two kinds of incremental language development. Firstly, the language itself can evolve (e.g., by defining new constructs) that in turn require changes to code generators. Secondly, code generators can be built incrementally to support more and more language features. For example, our code generators do not currently support nested lists even though they are allowed by the language grammar. Nested lists are simply not needed in any of our applications and also tedious to represent. Thus the code generators “trail” the language definition.

We believe that both kinds of incremental development mentioned above are useful. Changing the language itself is inevitable when facing requirements that cannot be expressed. Supporting only a subset of the language with code generators can potentially reduce the upfront investment in building a DSL. By first implementing more common constructs, a lot of the value of the DSL is available early. It even seems possible that some constructs will never be used. Of course, when constructs are not supported the code generator should detect these cases and notify the developer about the problem.

When designing the original DSL we constantly faced the tradeoff between a simpler, more general language and a language that strictly only accommodates the seed application. This tradeoff is probably inevitable in an incremental approach. We made choices in both ways along the way. However, whenever we chose a more expressive language we still had the option of not fully supporting it in the code generation.

6. RELATED WORK

Incremental approaches to application development are commonplace in software engineering methodologies [11]. Tolvanen investigated "incremental method engineering" for individual companies [12]. We focus specifically on DSLs and investigate design challenges, in particular independence from application styles. "Bottom-up" programming is a theme in the Lisp community to build higher-level abstractions out of lower-level abstractions [6]. Some of the challenges there are similar to ours although independence from a programming language is not a goal when using Lisp macros. Finally, possible tools for DSLs such as Microsoft Visio and Visual Studio as well as the Eclipse Modeling Framework (EMF) currently do not seem to provide a great deal of help in developing or even evolving the relatively complex transformations that we implemented using visitor patterns. A more in-depth analysis of these tools and in particular model transformation frameworks is future work.

In order to understand the impact of our incremental design approach better, we deliberately did not perform an extensive literature search on existing DSLs in the targeted domain. We were familiar with Strudel [4], a Web-site management system that can generate static Web pages based on an SQL database. We build on Strudel's syntax to define interactions with label-term pairs. In contrast to our work, Strudel does not support data updates and is only intended for Web applications. Other tools similar to Strudel ([2], [10]) have similar limits. We were also familiar with the domain itself and some of the technologies commonly used to implement CRUD applications.

Luoma et al. categorized DSLs by their "looks", i.e. the principle that was applied in defining their appearance [8]. Our language probably falls into the "expert's or developer's concepts" category. It is not apparent that any of the DSLs they surveyed was built incrementally.

There has been work in the research community on using continuation-passing style (CPS) in Web applications (e.g., [6]). Our events are essentially continuations. We provide the separate concept of composition that is not necessarily achieved with continuations.

7. CONCLUSIONS

DSLs are widely said to reduce development effort by providing high-level domain-specific abstractions. The reduced development effort, however, comes with high upfront investment into designing and implementing DSLs. In this paper we investigated an incremental approach to designing a DSL that is driven by a series of example applications. We found that such an approach is viable in that it produces a DSL general enough to extend to new examples. The DSL requires less careful initial design, possibly leading to reduced upfront design effort, and evolves incrementally. Even though developed for a seed application our DSL was able to span multiple platforms, user interface paradigms, and architectures. We believe a crucial condition for the success of such an approach is the ability to evolve code generators incrementally together with the DSL they implement.

Our results are very preliminary and motivate a number of research directions. We are curious to see how our language fares when applied to more applications. Moreover, it would be insightful to try an incremental approach on other domains. Arguably the domain we chose is a "horizontal" domain that provides computational and user interface abstractions. Applying an incremental approach to a vertical domain could be very beneficial because language designers need less initial domain knowledge. In addition, we make several observations about possible tradeoffs between language design and implementation alternatives that could be investigated. Finally, an analysis of how DSL tools support developing and evolving complex transformation engines would be insightful.

8. ACKNOWLEDGMENTS

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Programmatic Building of Models Just for Pretty Printing

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Abstract

In-memory object models of programs are commonly built by tools to facilitate program analysis and manipulation. We claim that for some applications it makes sense to construct such models for the sole purpose of pretty printing, and explain the reasoning behind our claim in this paper. We also describe a tool we have created to support this approach to pretty printing; the tool derives, from an annotated grammar, both an object-oriented API for model building, as well as corresponding routines for pretty-printing built models.

KEYWORDS: code generation, grammarware, object-oriented programming, pretty printing, program representation

1 Introduction

Pretty-printing capability is required in tools intended to produce readable source code. There are a number of ways one might choose to implement pretty printing. In many tools one requires an abstract syntax tree (AST) of each processed program for analysis and/or manipulation, and in those cases it is natural to write a routine that traverses the AST to emit textual code. However, when implementing a tool that does not transform programs, but rather reads in some input and generates a *new* program based on the input, it is far less clear how pretty printing would best be implemented.

When an AST is not required for code analysis or manipulation purposes, one may choose from a number of alternative approaches to pretty printing. In this paper we explore the idea of constructing an AST-like model of the program anyway, solely for pretty printing purposes. We talk about *model*s, as in object models specifying what is to be printed. We avoid talking about ASTs, so as not to imply that we are interested in the abstract syntax of the target language; we want to know how to print an object, but not necessarily what specific target language construct it represents. We focus on model construction that is done imperatively and incrementally, by writing statements that instantiate and add objects into a model, in any desired order.

The rest of this paper is organized as follows. In Section 2, we discuss our pretty-printing approach in more detail, and consider potential applications. In Section 3 we introduce a specific implementation of the approach, by describing a tool we created to facilitate the implementation of pretty-printable model builders. We look at related work in Section 4, and conclude in Section 5.

2 Constructive Pretty Printing

We refer to our pretty printing approach as *constructive pretty printing* (CPP); with this term we try to emphasize that the defining characteristic of the approach is that one explicitly constructs, bit by bit, a model to be printed. The model objects may be of different native types, and to support incremental model building, they are likely to contain named fields into which to insert more objects in any desired order.

An alternative way to "construct" a model is to essentially just list its contents, in a declarative fashion, allowing for variability by letting lists contain non-literal expressions. This approach is widely used by Lisp programmers at least, and is likely to result in somewhat shorter model building code than in CPP. The *convenience* of writing such code depends largely on how conveniently one can express a named list in the language syntax.

A common code generation approach not involving model building is to use a *template engine* (e.g., Smarty, Velocity, Cheetah). In *template-based code generation* [6], one specifies what to generate using a textual template, but may embed directives within the text to account for variability. The directives—usually expressed in the engine implementation language—are expanded by the engine. The concept of template engines is easy to understand, and most implementations are straightforward to use. These are very desirable properties, but we still argue that alternative solutions—such as CPP—are more suitable for some applications. We believe CPP to be a good approach at least in cases where:

- One prefers to program imperatively. It is natural for people to think in terms of objects and actions.
- One wants to concentrate on abstract syntax, without worrying about delimiters and other notation that can be automatically emitted as required.
- The data to be printed is highly variable. For example, a template engine is of little assistance in printing arithmetic expressions of variable length and content.
- One wants all formatting rules in one place. A major problem with template engines is that formatting information is spread around all the templates being used, and this can easily lead to inconsistencies. In CPP, code specifying *what* to print and *how* to print it is kept separate.
- One requires indentation with variable levels of nesting. With template engines, one must be very careful with whitespace and line breaks to get the formatting right, and even then, producing variable levels of nesting gets difficult. In CPP, the semantics to decide when to indent can be in the model.

- One wants conditional line breaking. If a line is getting too long, one must know *where* it is okay to break it; again, in CPP, there can be sufficient semantics in the model.
- One simply does not want to work with strings. Code with a lot of string manipulation tends to be tedious to write and hard to read. In CPP, such code can be isolated in the printing routines.

One solution that also suits the above cases, but does not quite meet our definition of CPP, is Builder [3]. It is similar to template engines, but in the Builder case, a template is specified as Ruby code that programmatically builds an XML document for pretty printing. The formatting of the output text is left to Builder. Sample building code and the resulting output is shown below.

Listing 1: Printing XML with Builder. [3]

```
Builder::XmlMarkup.new(:target=>STDOUT, :indent=>2).
  person { |b| b.name("Jim"); b.phone("555-1234") }
```

Listing 2: Builder output.

```
<person>
  <name>Jim</name>
  <phone>555-1234</phone>
</person>
```

The Builder approach differs from CPP in that each XML element builder method, by the time it returns, will have caused the printing of the entire element—no model gets built[1]. As a result, one has to specify the entire document at once, in the order in which XML elements are to appear in the document. CPP is more flexible, but that flexibility comes with overhead in constructing and traversing models.

3 qretty

To support the use of CPP, we developed a tool called qretty. It is a Ruby library that makes it possible to dynamically derive, based on an annotated grammar of a language, an object-oriented API for building models representing expressions in the language. qretty also produces code for pretty printing the models according to hints in the grammar.

3.1 Specifying a Grammar

qretty requires a grammar specification as input. The grammar is specified in Ruby, using a provided API, and may be annotated with layout-related information. Some tools try to keep different grammar concerns such as base syntax and layout separate; GPP (see Section 4), for example, does this by having separate grammar and formatting rules for each non-terminal. We chose not to do this in qretty to avoid the extra work involved in maintaining multiple rules per non-terminal.

[1]At time of writing, support for generating DOM-like structures with Builder is planned.

Task	**CPU time (seconds)**
Grammar specification analysis (C++ grammar)	1.64
Class hierarchy generation (C++ grammar)	0.17
Model building (C++ declaration)	0.00
Pretty printing (C++ declaration, 10 times)	0.16

Table 1: qretty performance measurements. Times listed are the average of 10 rounds, run on a PC with a 2.80 GHz Pentium 4 processor and 1 GB of memory. The measured program analyzed 210 grammar rules, generated 134 Ruby classes based on the rules, built a model of a short C++ class declaration (2 superclasses, two members), and printed the declaration 10 times. The analysis time does not include parsing performed by the Ruby runtime at program startup.

Below is an example grammar specification, extracted from an as-yet-unreleased tool in which qretty is used for pretty printing C++ type specifiers; we are using the tool to convert GCC-XML generated C++ interface descriptions into a different format.

Listing 3: A grammar specified in Ruby, using the qretty API.

```
crule(:type_spec,
  seq(basic(:typename),
    opt(" ", :declarator)))
crule(:ptr_declarator,
  seq("*", opt(:declarator)))
crule(:ref_declarator,
  seq("&", opt(:declarator)))
crule(:array_declarator,
  seq(opt(:declarator),
    "[", opt(ident(:num)), "]"))
crule(:func_declarator,
  seq("(", opt(:declarator), ")",
    "(", opt(:funcargs), ")"))
arule(:funcargs,
  commalist(:type_spec))
crule(:cv_declarator,
  seq(choice(namlit(:const),
        namlit(:volatile)),
    opt(" ", :declarator)))
crule(:name_declarator,
  ident(:name))
arule(:declarator,
  basic(:declarator))
```

Listing 4: An approximate EBNF translation.

```
type_spec ::=
  TYPENAME
  (" " declarator)?
ptr_declarator ::=
  "*" declarator?
ref_declarator ::=
  "&" declarator?
array_declarator ::=
  declarator?
  "[" NUM? "]"
func_declarator ::=
  "(" declarator? ")"
  "(" funcargs? ")"
funcargs ::=
  type_spec (", " type_spec)*
cv_declarator ::=
  ("const" |
   "volatile")
  (" " declarator)?
name_declarator ::=
  NAME
declarator ::=
  ptr_declarator | ...
```

qretty includes an API for dynamically generating a set of classes corresponding to a grammar specification. Each `crule` gets its own class, whose instances get *field*s (for adding model objects) based on the named terms appearing on the right-hand side of the rule. `arule`s do not get a class; instead, their fields are folded into their containing rules. This is an important feature, as many "off-the-shelf" grammars result in deep grammar trees; one can achieve a shallower class hierarchy merely by judiciously using `arule` declarations instead of `crule` declarations.

qretty has a weakness in that it does not scale well to handle large grammars. For one thing, given a complex grammar it can be difficult to create a corresponding class hierarchy that—despite the complexity—provides a usable model building API. Also, qretty is slow in analyzing large grammars, as we noticed trying to use a fairly complete C++ grammar. For related performance figures, look at Table 1.

3.2 Building a Model

Immediately after a class hierarchy has been generated, instances of the classes can be used to form tree structures constituting models for pretty printing. qretty-generated classes have accessor methods for getting and setting child nodes, as one would expect.

Also, as described in Section 3.1, qretty knows the concept of a field, and each field has what we call a *builder setter* method, intended to make model building convenient. Depending on the receiving field, a builder setter decides whether to create a new node object. If so, it determines the type of object to create, passes its arguments to the constructor of the object, and then assigns the resulting object to the appropriate instance variable. If not, it simply uses its argument as the value to assign. The method returns the assigned object, and, if a Ruby block is passed, also passes the object to the block.

Below we give an example of model building, emulating the Builder example of Section 2. In addition to the model building code, both the used grammar specification and the produced output are shown. Two alternative syntaxes for defining a `person` are included to demonstrate how the use of Ruby blocks makes the tree structure of the model clearer.

Listing 5: Grammar specification.

```
crule(:xml_markup, opt(seplist(:person, nl)))
crule(:person, choice(seq("<person>", nl, indent(one_or_more(
  seq(choice(:name, :phone), nl))), "</person>"), "<person/>"))
mfield [:name, :phone], :pname => :@list
crule(:name, seq("<name>", ident(:name), "</name>"))
cfield :name
crule(:phone, seq("<phone>", ident(:phone), "</phone>"))
cfield :phone
```

Listing 6: Model building code and a pretty printing request.

```
model = ast::XmlMarkup.new
model.person { |b| b.name "Jim"; b.phone "555-1234" }
b = model.person; b.name "Tim"; b.phone "555-4321"
CodePrinter::pp(model)
```

Listing 7: The pretty printed output.

```
<person>
  <name>Jim</name>
  <phone>555-1234</phone>
</person>
<person>
  <name>Tim</name>
  <phone>555-4321</phone>
</person>
```

An obvious problem with qretty is that the produced model building API has no visible interface definition, forcing programmers to deduce it from the grammar specification. qretty uses runtime reflection for code generation, and there presently is no option to generate API documentation either.

At no point during or after model building does qretty validate tree structure [12], nor is there static typing support in Ruby that could be used to prevent builder code from mistakenly placing a node into a context where the grammar does not allow it. We do not perceive this as a big problem, since the preferred way for building models is via builder setters, which automatically create nodes of the correct type.

3.3 Pretty Printing a Model

qretty provides an API via which a model subtree may be pretty printed. Parameters can be passed to choose an output stream, or to specify maximum line width, for instance. The implementation makes use of a *printer method* named `qretty_print` that qretty includes in all the classes it generates. When invoked, a generated printer method matches the receiver's instance data to the corresponding grammar rule to determine what to print.

During printing, an object we call a *printer visitor* essentially walks the model depth-first, passing itself to the printer method of each node; the printer methods are expected to print themselves using the API provided by the visitor. For purposes of flexibility, qretty allows a hand-coded class to be included in a model class hierarchy, as long as it implements pretty printing in a compatible manner; in this case the right-hand side of the corresponding grammar rule need not be given in the grammar specification.

There is no support for having generated printer methods pass or make use of any context information, which makes it somewhat inconvenient to deal with language constructs that print differently depending on context. Should context information be required, one can attempt to encode it in the grammar, or implement select printer methods manually.

4 Related Solutions

There are many tools [1, 7] capable of generating APIs for operating on grammatically structured data, but we do not know of any tool apart from qretty designed to generate classes for the specific purpose of pretty printing. With such specialization, semantics not relevant in the context of pretty printing may be omitted, leading to shorter model building code. One just requires enough object semantics for correct coercion to strings for printing, and enough structural information to enable formatting.

Some grammar-based tools [10, 11] restrict themselves to so-called *structured context-free grammars* [11], which can—in generating classes—be mapped to a class inheritance hierarchy such that the presence of certain kind of non-terminals is implicit in the inheritance relationships, without concrete nodes for those non-terminals needing to appear in ASTs. For similar shallowing of models, a qretty user must enhance the grammar with sufficient annotations. qretty accepts all context-free grammars—the classes it generates do not inherit from each other, nor do they have a statically typed interface; they only form a hierarchy through builder setters' knowledge of what classes should be instantiated for which field.

GPP [8, 9] is one of the most powerful and generally applicable pretty-printing solutions around, but it does not generate a language-specific API for programmatic building of models. The GPP toolset can handle a parse tree, an AST, or—indirectly—source-code text as input, but if one has none of these, a solution similar to qretty might be helpful for building suitable input. GPP is part of the Stratego/XT [14] program transformation toolkit. There are a number of others, such as DMS [2] and CodeWorker [4], and while these all are capable of pretty printing, they are rather large systems, and might be overkill to use just for that purpose. qretty is not a reengineering tool, but it integrates easily within Ruby applications that need to generate *new* code.

CodeDOM [5] provides a fixed API for building models of programs translatable to any of multiple supported languages; qretty does not support multiple target languages for a single model. While CodeDOM has better multi-language rendering support, its weaknesses are that it does not provide elements to represent all language features of all target languages, and that CodeDOM model building code gets quite verbose. qretty avoids these problems by generating target language specific APIs designed for convenient model building.

5 Conclusion

In this paper, we have explored the idea of programmatically constructing models just for pretty printing. We listed a number of situations where applying CPP might be warranted, but any benefits must naturally be weighed against implementation effort. qretty is a tool that can help reduce the effort required, as it is capable of producing grammar-specific class hierarchies and associated pretty-printing routines. Unlike most grammar-dependent software, it even supports languages defined at runtime; a new grammar specification can be created and processed at any time, and the resulting classes can be put into an anonymous module to allow unneeded definitions to be discarded.

Aside from implementation effort, one must also consider whether it is possible to achieve convenient model building in a given case. Either the model building language or the printed language might make it hard to do so. qretty models are built in Ruby, whose syntax seemed quite acceptable for the task, but we would have liked a language feature similar to the JavaScript `with` statement for specifying the default receiver for a set of method calls.

For a friendly model building API, one probably requires memorable naming and a class hierarchy of reasonable depth. qretty's grammar specification language can assist in making class hierarchies shallower than grammar trees. Naming comes fairly naturally for some languages; in our XML example, method names directly map to element names in the XML document schema. There is no immediately obvious way to map C++ language constructs to method names, however, as we found in trying to define a C++ program model building API.

qretty is available for download [13], along with another library called `codeprint`. The latter provides functionality for printing and formatting text, offering control over indentation and line breaking, for instance, and qretty depends on it for low-level formatting tasks. The reader should note that the present bad performance of qretty excludes its use from many applications. It would be possible to drastically improve performance, at least by switching to compile-time code generation, but this is left for future work.

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Toward Families of QVT DSL and Tool

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Abstract

QVT (Query/View/Model transformation) is a modeling core technology for the development of MDD (Model-Driven Development) tools. Thus, it is strategic for a company to have QVT techniques improving productivity of development teams, especially when standards, tools, user requirements, and practices are ever evolving. The interest of introducing QVT DSL (Domain-Specific Language) is to offer higher level QVT languages in order to produce QVT tools in a faster and safer way. For assessing this position, this paper presents, at first, the case study of a view DSL for producing tools generating model diagrams. From this proof of concept of QVT DSL, this paper studies the introduction of families of QVT DSL and tool to fit to multiple project contexts.

Keywords

MDD, DSL, PRODUCT LINE, QVT, SOFTWARE FACTORIES.

1. Introduction

To produce high quality software both on budget and schedule, companies usually face productivity improvement issue. This is particularly true in the context of large-scale systems. In the current MDD context, while projects encounter evolving environment of standards, tools, user requirements, and practices, they have no other choice than to use low level QVT languages, essentially code-based, for the development of MDD tools. Then, it then becomes judicious to introduce higher level languages, for instance with wizards, easing QVT descriptions which contain sufficient information for translation toward low level QVT languages. This is the purpose of DSL dedicated to QVT.

In order to validate this category of DSL, this paper presents the case study of Diagram DSL. From a description conforming to a Diagram DSL can be deduced MDD tools generating model diagrams. The interest is such that the diagram designer does not code anything, development and maintenance tasks are easier and safer. However, this technique is limited to the production of one type of QVT DSL development. The next step is the production of QVT DSL variants meeting contextual requirements. For instance, a Diagram DSL cannot presume and contain all descriptions of diagram layout; such is the case for a serializer for which it is impossible to determine all exchange formats. Then, from core QVT assets, variations can be applied to produce the expected DSL and tool. For instance, a serialization language can be specialized into several serialization languages for meeting specific model exchange formats. This opens the way of families of QVT DSL and tool.

This paper is organized as follows. Section 2 studies the link between QVT and DSL. Section 3 presents the case study of a view DSL for producing tools generating model diagrams. Section 4 extends this result toward families of QVT DSL and tool. Section 5 presents further work and section 6 concludes.

2. Link between QVT and DSL

The MOF 2.0 QVT standard [18], a key technology for the OMG's MDA™ (Model-Driven Architecture), defines a language for model transformation, such as a PIM (Platform-Independent Model) to PSM (Platform-Dependent Model) transformation. A query is an expression that is evaluated over a model; it returns one or more instances of types defined in the metamodel of the model or defined by the query language. A view is a model derived from the base model, such as diagrams or code; a view does not modify the base model. A transformation generates a target model from a source model, such as a PIM to PIM transformation. Source and target models conform to their metamodels [10]. In this paper, we do not restrict our vision to the OMG's standard. For instance, the Epsilon Object Language (EOL) [7][13] of the Epsilon Model Management Framework provides all mechanisms for model navigation and transformation. From this standalone language, specific languages can be constructed, for instance for model merging or text generation from models. Kermeta is a metamodeling language, compliant with EMOF [17], which provides an action language for specifying behavior and for implementing executable metamodels, *e.g.* for implementing transformation languages, or action languages. AMMA (Atlas Model Management Architecture) [1], built atop EMF, is a general-purpose framework for model management. Based on ATL [2], it provides a virtual machine and infrastructure tool support for combining model transformation, model composition and resource management into an open model management framework.

A DSL, for its part, is a specialized, problem-oriented language [6], in that DSL focuses on a problem contrarily to a general-purpose language, such as UML. From a DSL to target language, a problem-to-solution transformation encapsulates complexity and hides decisions or irrelevant implementation details. During transformation, automation avoids repetitive and tedious user tasks and guarantees systematic practices. Regarding the process engineering, wizards can guide users in their development tasks and domain rules ensuring that data are reliable. Thus, DSLs are means toward easing problem expression. The objective of complementary DSLs is actually productivity improvement by industrialization of modeling chains from requirements down to the packaging of produced assets, such as models, model transformations, model views, configuration files, or documentation.

In the QVT context, a QVT DSL has for role to ease the development process where the considered domain is QVT. For MDD end-users that means QVT DSLs ease domain modeling, such as consulting model or applying patterns. For MDD users at the metamodel level that means QVT DSLs ease tool creation, for instance for designing model transformations or defining modeling processes. A DSL which is not a QVT DSL is a DSL which does not apply QVT action over a model. This is for instance the case of a profiling tool which audits models from data contained in files without QVT action.

The following, non exhaustive, table proposes a categorization of QVT DSL. The levels of QVT usages with DSL are presented in abscissa: 1/ The "Core technology" aspect covers the OMG's QVT standard and QVT languages which conform to it; 2/ The "Development" aspect covers the category of DSL enriching the QVT languages for the development of MDD tools, such as a DSL for traceability management; 3/ The "Business" aspect targets DSL for end-users, such as a Diagram DSL. In ordinate, we find the Query, View, and Transformation aspects. By crossing the two dimensions, a Diagram DSL is for instance a view DSL for business activities of development that a end-user can use in his modeler.

Development DSLs depend on core technology DSLs; business DSLs depend on development DSLs or directly on core technology DSLs. As a consequence, core technology QVT DSLs evolve more slowly and are less numerous than the others; business DSLs have on the contrary shorter lifecycles, they are more numerous and business- or project-specific. For instance, a few QVT languages implement the OMG's standard while every project can decide to customize properties for its diagram presentations.

Table 1. Categories of QVT DSL

	Core technology	Development	Business
Q	QVT languages	Model information	Model checking
V		–	Diagram Documentation
T		Merging Traceability Transformation pattern Versioning	Abstraction/Refinement Architecture Business process Domain wizard Quality of Service

3. A DSL for producing tools for model diagram generation

This section presents the case study of a QVT DSL for producing tools generating model diagrams, which has been developed by DAE, a Department of the Thales Software Research Group.

3.1 Paradigm shift from code to DSL with Software Factories

A few years ago, we started to manually develop tools generating model diagrams. After the development of several one of these, we noticed duplications, redundancies in code, and non reliable schedule. From a first refactoring emerged a diagram framework. This framework capitalized common practices; it reduced but did not prevent the same error-prone defects of manual developments. Then, we therefore decided to use MDSoFa [14], a DAE software factory tool. The objective was to realize a paradigm shift from a handcrafted to an industrialized development.

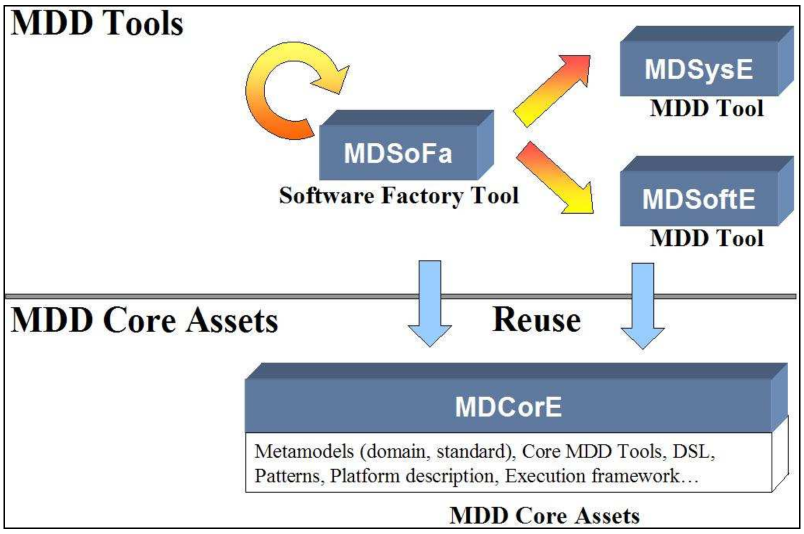

Figure 1. MDD Tool Architecture

MDSoFa is a software factory tool for producing MDD tools in series. It generates for instance the infrastructure of two large-scale MDD tools: MDSysE [8][16], a modeling tool for system-engineering, and MDSoftE, a modeling tool for software engineering. For improving reusability, MDSysE and MDSoftE, as well as MDSoFa, share a set of common core assets, gathered in a common product called MDCorE. All of these MDD tools are in line with the product line approach. MDSysE and MDSoftE are variations of MDCorE core assets. These core assets and the product lifecycle are managed by MDSoFa. A Diagram DSL has typically its place in MDCorE because it can be fitted to different MDD tool contexts.

3.2 Diagram DSL representation and usage

A first key point is to understand the relationship between a Diagram DSL and diagrams, and the relationship between a Diagram DSL and a Diagram DSL tool.

3.2.1 A 3-level architecture

Regarding the relationship between a Diagram DSL and diagrams, we have adopted a 3-level architecture (Figure 2), as MOF. The D2 level represents the language for describing a QVT domain, the D1 level a description of this QVT domain to be applied at the model level, and the D0 level the application of a D1 description at the model level. In the case study, the QVT domain is the diagram management with the following levels.

D2 – Diagram DSL	At the D2 level, the Diagram DSL represents the language for describing any type of diagrams. It is solution- and platform-independent and contains all criteria understandable by a user who wants to specify diagrams. This level is problem-oriented for specifying diagrams.
D1 – Diagram DSL instance	At the D1 level, a Diagram DSL instance describes a type of diagram. It contains the view model description for producing a type of diagram, that is model elements to be displayed with their layout properties. This description respects the language defined by the Diagram DSL. This level contains all data for generating tools producing diagrams.
D0 - Diagram	At the D0 level, we have diagrams expected by end-users in their modeler.

The Diagram DSL is described by a model which defines the grammar for model diagrams. The one we have developed contains simply four classes: 1/ *Diagram root* gives information for starting diagram generation, 2/ *Node* specifies model elements displayed in diagrams with their layout, 3/ *Navigation* specifies navigation in model, 4/ *Condition*, complementary to Navigation, specifies model element selection. Attributes represent Diagram features, *e.g.* a color of a model element type. Associations between classes declare possible relationships, *e.g.* a Node can contain Nodes, but a Node cannot contain a Diagram root. At a Diagram DSL instance, there is one Diagram Root element by type of diagram. The Nodes and Navigations describe the successive navigations in model and how model elements are displayed in the diagram.

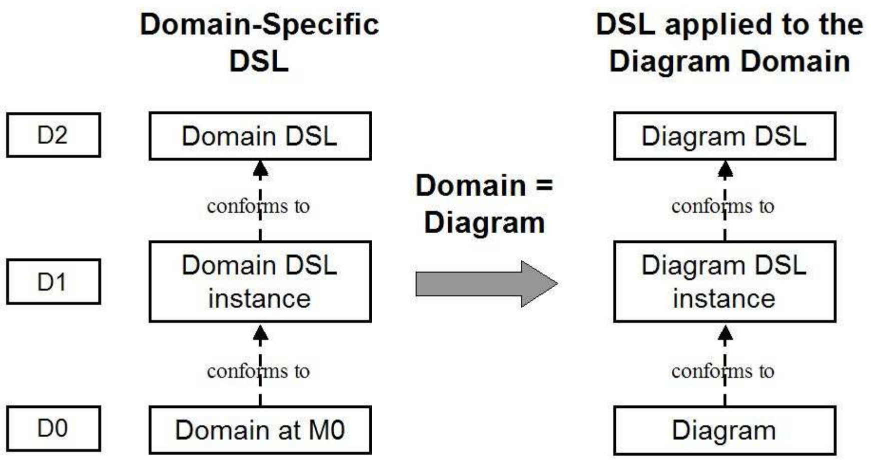

Figure 2. Diagram DSL levels

3.2.2 Diagram DSL and Diagram DSL Tool relationship

A Diagram DSL tool is the tool which puts the Diagram DSL in action. The principle for managing a Diagram DSL instance with a Diagram DSL tool is the same than for editing a domain model, such as MDSysE. Instead of editing a model, a Diagram DSL tool manages diagram DSL instances conforming to the Diagram DSL. This means the DSL tool is always consistent with the language it implements, the Diagram DSL. Thanks to this conformance and with a full generation adoption, the Diagram DSL tool can be generated from a "Diagram DSL to Diagram DSL tool" translation. Therefore, when Diagram DSL properties change, the DSL tool can be generated for a Diagram DSL / Diagram DSL tool synchronisation.

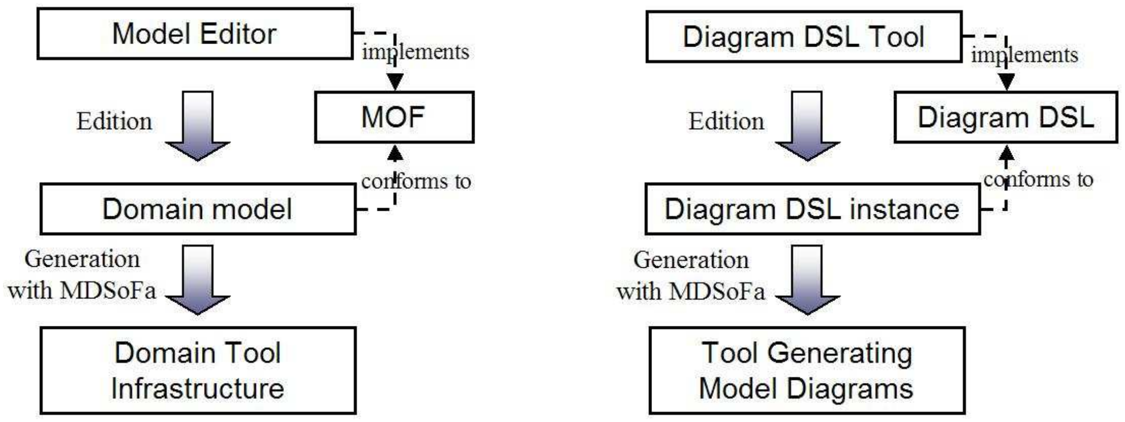

Figure 3. Analogy of domain and DSL models

3.3 Diagram DSL Lifecycle

This sub-section explains the process, which is depicted in the following figure, intending to produce tools generating model diagrams from the Diagram DSL definition.

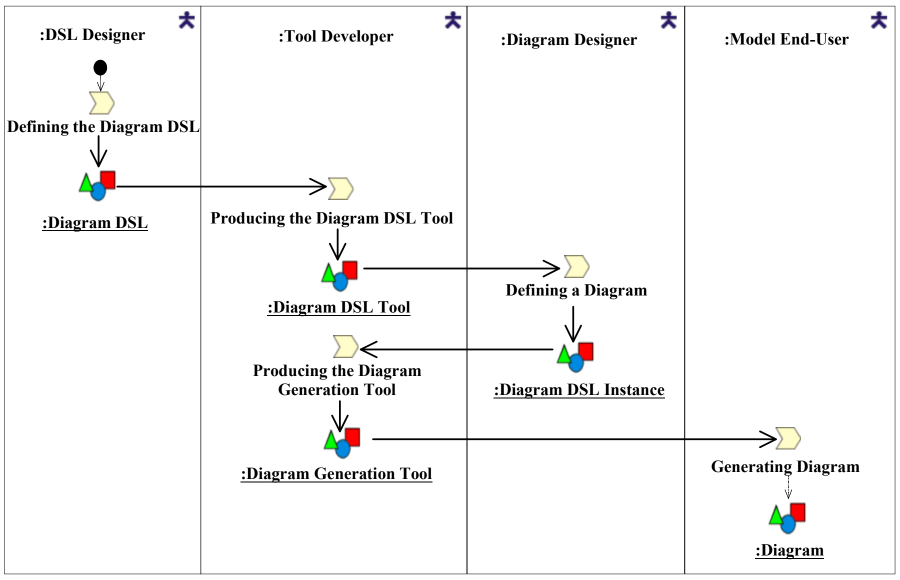

Figure 4. Diagram DSL lifecycle

3.3.1 Defining the Diagram DSL

This activity, effectuated by the DSL Designer, consists in modeling the Diagram DSL. Starting either from code, and abstracting it into the Diagram DSL, or starting directly from the Diagram user viewpoint, eliciting the Diagram DSL is not a straightforward situation. It requires several iterations before finding criteria meaningful for the Diagram Designer. These criteria must be simple, pertinent and complete enough to deduce an implementation solution.

3.3.2 Producing the Diagram DSL Tool

The Diagram DSL tool, which serves to edit Diagram DSL instances, evolves as long as the Diagram DSL does. Several presentations may exist for the same DSL. Its production can be generated from a DSL to Tool transformation or developed manually by a Tool Developer. Here again, the DSL tool must be simple and pertinent. Actually, its utility depends on its ability to increase the Diagram Designer productivity. The progress, in this way, is when the user has no code to write. Even more, it is assisted to reach faster what she/he expects to build.

3.3.3 Defining Diagram

Every Diagram DSL instance realized at this stage contains all criteria for creating and updating every kind of diagram, *e.g.* all MDSysE diagrams (interface, domain element, component, deployment diagrams, etc.). The actor of this activity is really a designer and not a developer.

3.3.4 Producing the Diagram Generation Tool

Every Diagram DSL instance is consumed by MDSoFa to produce a tool generating model diagrams. After its production, the tool is packaged, ready to be deployed and integrated in a largest tool, *e.g.* MDSysE. Diagram generation becomes a function among others.

3.3.5 Generating Diagram

During this activity, the model end-user applies the diagram tool on his model, *e.g.* interface diagrams of the model are generated. Diagrams created or updated conform to a Diagram DSL model, which conforms to the Diagram DSL. For instance, diagram layout reflects layout specifications, which conform to the properties defined in the Diagram DSL.

4. Stepping toward families of QVT DSL and tool

The case study of Diagram DSL focuses on the view aspect. It has been tested on more than 50 types of diagram and is in production with MDSysE. However, from our previous lessons learned with MDSoFa, a main point emerged: that one DSL can be, not necessarily specialized but, tailored in function of the project context. With software factories, this opens the way for families of QVT DSL.

4.1 Need of QVT DSL and tool families

Several reasons justify the need of QVT DSL families.

[N1] From the functionality viewpoint, a QVT DSL in a project context can have more or less properties that an original QVT DSL. Neither specialization nor parameterization is able to support multiple structural modifications, especially for several projects managed in parallel.

[N2] From the process viewpoint, different processes are possible for the same QVT DSL in function of the project context or the adopted methodology.

[N3] From the language viewpoint, it is illusory that one language addresses all types of modeling problems with expressiveness and accuracy simultaneously. The need is the management of variation of "abstract to concrete syntax" transformation. For low level languages, in function of user communities, from the same QVT core language can be derived various forms of programming languages: textual *vs.* graphical, declarative *vs.* imperative, etc. For high level languages, *i.e.* DSLs abstracting the most a software description, a DSL can also adopt various forms: description with formal textual language, wizard, or even with table.

[N4] From the design and implementation viewpoints, the solution can change in function of architectural or non-functional decisions. The problem to solution transformation implies to have variants of generation.

[N5] From the capitalization viewpoint, in order to meet the requirement of durability of the QVT descriptions, the need is the management of the platform variability (standards, languages, frameworks, tools).

[N6] From the reusability viewpoint, different QVT DSLs can share common features. For instance, a view DSL and a model transformation DSL can be expressed in a tree form. Then, the need is to manage common assets which can be reused in different QVT DSL contexts.

This list of needs justifies this interest of QVT families but simultaneously shows its complexity. We can continue to develop QVT tools without product line but reusability and productivity will assuredly decrease when specifications and environment evolve, or when project contexts are multiple. Managing efficiently variability of QVT DSL and tool turns out to be profitable but also a real technical challenge.

4.2 QVT DSL and tool families

The software product line is “a set of software intensive systems sharing a common, managed set of features that satisfy specific needs of a particular market or mission, and that are developed from a common set of core assets in a prescribed way” [3]. This means that core assets are created to be reused in the production of multiple products in order to reduce the cost and the time to produce an individual product [4]. A product line uses two distinct but interacting processes: 1/ the product line development process, which produces reusable assets, and 2/ the product development, which produces products. To continuously improve the core assets, the product line development process uses the feedback of the product development (promotion and improvement of core assets, architecture evolution, production process improvement, etc.).

The main activities for the product line process are: i) for the domain analysis, domain scoping, identification of the commonalities and variability among all products in the family, ii) for the domain design, architecture development, production process and definition of the production plan, and iii) implementation of the core assets for the domain implementation.

Activities of the product development have for objective the production a member of a product family. Analysis, design, and implementation activities select, integrate, and customize the core assets.

4.2.1 A QVT DSL itself as domain

The key point for QVT DSL to reap profit from experience in product line engineering is to consider a QVT DSL itself as a domain. Instead of applying variations on domains such as system or software engineering, variations are applied on QVT domains. Section 3.1 has presented the experience of product line with MDSoFa. MDSysE and MDSoftE are variations of a common domain located in MDCorE, location of MDD core assets. This common domain is defined by a model. Section 3.2 has presented the DSL Diagram defined by a model as well. The way for variations on the Diagram DSL is similar than with the MDSysE and MDSoftE domains. On the other hand, the way for generating the tool producing generating diagrams is the same than for generating the MDSysE and MDSoftE infrastructures. Representation and tooling are the same. The strength of this reflexivity is auto-consistency: end products are built in the same way than the development tool.

4.2.2 Core asset management

The level of reusability and durability of core assets comes from the ability to accept evolutions on core assets from new requirements and product evolutions. This implies a rationale management both of every core asset and the core asset architecture (modularity, asset lifecycle, interactions, etc.).

In the QVT context, a core asset can be:

- A domain description, *i.e.* a description at the D2 level for QVT DSL description, and at the D1 level for QVT DSL instance. A QVT DSL instance is a core asset when this QVT DSL instance can be tailored, or for addressing variations, such abstract to syntax concrete derivations. Refer to needs [N1] [N2][N3] in section 4.1.
- A QVT DSL tool description for QVT DSL tool families. Refer to needs [N1][N2][N3][N4][N5].
- Patterns, generations, frameworks, and tools required for building QVT DSL tools. Refer to need [N4][N5].

- The QVT environment, such as the QVT standard or platform descriptions. Refer to need [N5].

Core asset evolution is a major issue when managing core assets. Four major impacts are possible:

- Impact on domain, with three kinds of impact:
    - Intra-domain impact. Evolutions are located in the same QVT DSL, *e.g.* new layout properties in the Diagram DSL. Refer to needs [N1][N2].
    - Inter-domain impact. Evolutions are located in several QVT DSLs, *e.g.* several DSLs share common elements. Refer to need [N6].
    - Extra-domain impact. A feature is reusable by domains external to QVT DSL domains. For instance, a tree-organization can be used by Diagram and model transformation (inter-domain relationship) but also by interface description.
- Impact on feature model. In this case, the feature model evolves for taking into account new requirements or product evolutions. Refer to needs [N1][N2][N3][N5].
- Impact on architecture. Architecture must be reconsidered for domain, or feature evolutions, but also to take into account pattern, framework, or tool evolutions. Refer to need [N5].
- Impact on production plan. The production plan describes how products are constructed from the core assets. It directly depends on the previous impacts.

Regarding the architecture, Epsilon [7] is illustrative for its tree-organization of QVT languages. EOL is the core language from which other languages can be constructed atop. Epsilon is activity-oriented with languages used for instance for merging, model transformation, or code generation. This tree-organization can be reused for building a hierarchy of QVT languages with QVT DSL and tool variants. Referring to Table 1, one can find core technology, development, and business derivations of DSL but also "core technology to development", "core technology to business" or "business to business" derivations of DSL. The interest of such an organization is the robustness of the foundation: a branch meet a MDD segment (a kind of activity, a technology, a project context, etc.) and each QVT derivation is consistent thanks to a "QVT to QVT" translation.

4.2.3 Product production

A major stage is the production of product from core assets. A production plan describes how to manage this production. It takes into consideration the production method of each asset, the available resources, the linkage among the core assets, and the product line constraints.

Figure 4 describes an example of a Diagram DSL lifecycle. In order to be integrated in a product-line, each activity must declare how to fit into product production contexts. For instance, for a platform variability, the "Producing the Diagram DSL tool" needs to know the target platform, *e.g.* UML version, modeling tool, programming language. Depending on these parameter values, the right generator is selected.

4.3 Issues

Even if the core assets, the production method and the production plan are clarified, in the QVT context, a set of issues must be settled.

1/ Unification of QVT DSL. For complexity reduction and efficiency of MDD tool development, the QVT DSL architecture must be rationalized. We recommend the adoption of a reduced number of QVT DSLs, a tree-organization with few bridges, and reflexivity according to the 3-level architecture principle.

2/ Constitution of uniform QVT DSL workbench. When building MDD tools, a requirement is to have the same ergonomics and logic of action among the DSLs. With a product line, the issue is to keep this uniformity in function with the selected features.

3/ Full automation. The production plan can be a document, partially or completely automated. At a managed maturity model level, automation of the product production is maximized.

4/ Standardization. Families of QVT DSL and tools can be developed by a company for internal or external usage. Despite several open source initiatives and projects on model transformation, the lack of standard for product line prevents any QVT DSL product line in the open source segment.

5. Further Work

Our future work will focus on the development of core assets for building DSL tools, and variants of DSL tools.

6. Conclusion

This paper has presented the case study of a Diagram DSL allowing specification of model diagram. From models conforming to this DSL, DSL tools are produced for generation of model diagrams. These DSL tools are integrated afterward in MDD tools for end-users. Furthermore, in the context of software production with software factories, we figured out that this Diagram DSL could be reused for other purposes, such as model transformation. This clears the way toward families of QVT DSL and tool. We have given in this paper elements for building such families. We believe this is the next step to meet various companies and projects requirements, and to build customized QVT workbenches.

7. Acknowledgments

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Preserving Architectural Knowledge Through Domain-Specific Modeling

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Abstract

We investigate the feasibility of applying the principles of domain-specific modeling to the problem of capturing and preservation architectural modeling knowledge. The proposed solution is based on the existing architecture assessment methods, rather than architecture modeling ones, and it uses sequences of design decisions, rather than simple, unordered sets. We highlight how architecture-based development could benefit from the proposed approach in terms of both methodology and tool support.

1 Introduction

For many years, the two main objectives of software development were (and still are) how to improve the productivity of the development process and how to improve the quality of the resulting products. A recent addition to the wealth of techniques proposed to address those objectives is the approach known as domain-specific modeling (DSM). The trademark feature of DSM is the shift from the traditional practice of specifying problem solution using lower-level programming constructs, to the one at a higher level of abstraction in which the solution is spelled out in terms of concepts culled from the very domain of the problem being solved. A metamodel of the problem domain is constructed by an expert; subsequent development by less experienced developers uses this metamodel and the associated automated tools to build actual solutions. Significant improvements in software development productivity (and, to a lesser extent, software quality) can be achieved in this manner, mostly because the complexity is limited by focusing on a single, well defined problem domain [11].

In this paper, we investigate the feasibility of applying domain-specific modeling to software architecture – a highly abstract area which should be well suited for the DSM approach. Traditionally, the architecture of a software-intensive system presents a structure (or structures) comprising the elements of the system, their externally observable properties, and static as well as dynamic relationships between those elements [1]. The architecture of a system is the first, and arguably the most important, set of artifacts that sets the directions for subsequent product development and controls the quality attributes of the final product. Architecture is usually developed by established experts from both the problem domain and general system domain. The domain experts ensure that quality goals such as performance,

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reliability, security, and availability, among others, are properly addressed during the architecture definition stage of the metamodel development. The system experts cater to the requirements of feasibility and development efficiency, as well as maintainability and evolvability of the architecture and derived systems. Obviously, the process involves high-level modeling and, possibly, metamodeling. Thus, it is worth considering whether an architecture metamodel could be developed to aid in this process, and what would be the benefits (and, possibly, drawbacks) of this approach.

The remaining part of the paper is structured as follows: Section 2 demonstrates the attendant problems of current architecture modeling practice through a small example. Section 3 explores how we should model software architecture to be able to address those problems. Some implementation issues and possible uses of this approach are discussed in Section 4. Finally, Section 5 concludes this paper.

2 Components and Connectors Are Not Enough

The field of software architecture is maturing. Several modeling methodologies for software architecture development have emerged, most of which represent the concepts of components and connectors as first-class entities of the design. While those concepts are certainly closer to the solution domain than the problem domain, they did help build highly successful architectural models for different kinds of systems. Documentation-wise, architectures are typically documented as sets of views that correspond to different aspects of the architecture [2]. But despite such advances, maintenance and evolution of an existing software architecture is still a difficult and error-prone task.

A possible explanation for this is the well known concept of knowledge vaporization [4, 8, 12]. Namely, in the development process, explicit artifacts are constructed for the architecture by making a series of design decisions aimed at satisfying the requirements whilst addressing the underlying quality goals. In this process, thorough knowledge about the problem domain is gradually accumulated, but the bulk of it remains implicit in the minds of the architect(s) rather than being captured and explicitly documented. Once the development is finished, architects move on to new tasks and this knowledge fades from memory. The relevance of explicit documentation also tends to diminish, on account of changes in the requirements and/or actual implementation.

As an example, let us consider the runtime architectural view of a *prepaid* cell phone airtime top-up application which is shown in Fig. 1. The customer uses her *mobile client* to send an airtime top-up instruction in text format to the telco's *SMS_Center*. This text message is retrieved by the *TextSender* and forwarded to *TextListener*, or temporarily stored in *Telco_DB* if *TextListener* can't be reached at the moment. *TextListener* forwards this message to *TextParser*, which processes it and delivers it (together with appropriate status information) to the *Scheduler* that invokes the necessary transaction processing components *TX_proc*. The result of this processing, which involves interaction with the customer's bank, is sent to *TX_Notifier*, which formats the response and notifies *TopupWriter* to credit the customer's airtime account and dispatch an appropriate status message back to the customer.

Subsequent evolution and maintenance activities are based on the existing architectural artifacts, rather than on the knowledge that guided the design choices in the development phase. In the example above, neither the textual description nor the components-and-connectors diagram provide clues as to why the decision to temporarily log customer's instructions in *TelcoDB* was made in the first place.

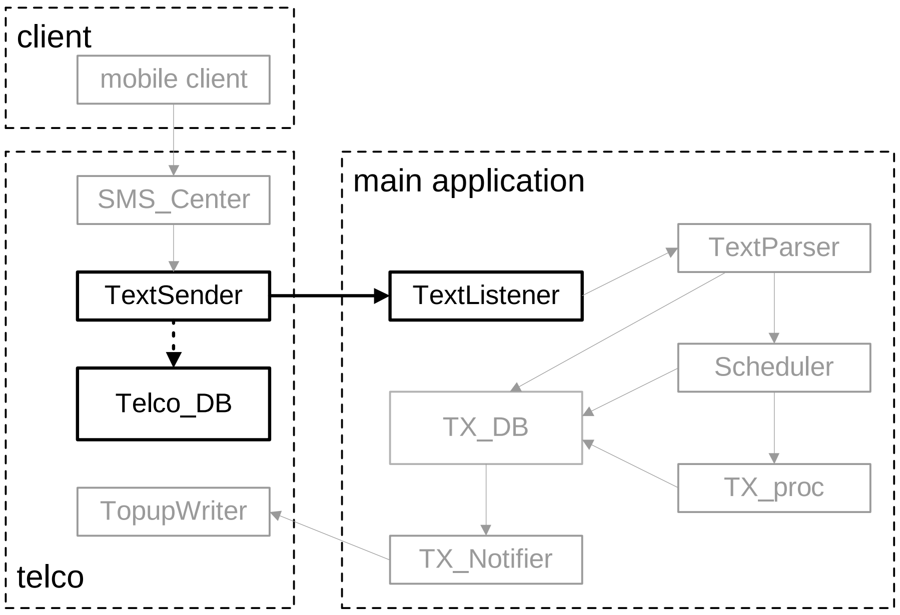

Figure 1. A runtime view of the airtime top-up architecture.

While implicit domain knowledge can be, and usually is, re-created when necessary, the process is neither quick nor easy, and it incurs a substantial risk of changing the architecture in ways that counter the initial quality goals, rather than support and align with them.

The main reason behind the loss of crucial architectural knowledge obtained in the design process and used to shape the design is simple: the current paradigm for describing software architecture models does not support that task. The only things that can be recorded are the final artifacts, but not the road that led to them. Question is, can domain-specific modeling help alleviate the problem(s) outlined above? The need to apply the domain-specific modeling paradigm to architectural modeling—for example, by representing architectural design decisions as first-class entities—has been recognized for a while [4]. In this context, a design decision is an abstraction that is closer to the problem domain than the solution domain. In fact, modeling software architecture in terms of design decisions follows a direction which is strikingly similar to the common DSM practice. The common activities of selection and interconnection of components and connectors (both of which firmly based on the solution domain) are, then, just a necessary, but by no means sufficient, ingredient of architectural modeling.

But how do we arrive at such a modeling technique? And how do we allow architectural knowledge to be captured explicitly within the model definition? According to [8], the solution is a three-step process. First, we need to devise a way to move architectural knowledge from the tacit level to the documented level. Second, we should create a formal framework for representing and reasoning about design decisions, just as has been done for components and connectors. Finally, tools should be developed to exploit a repository of such knowledge representations in order to simplify architecture evolution activities. Furthermore, there is perhaps use for an ontology of architectural design decisions that should record, store, and provide information about the varieties of design decisions and the connections between them [7].

A different solution has been advocated in [4], where architectural models are represented as a *set* of design decisions. The relationship between a software architecture and associated design decisions uses a metamodel called archium, which consists of a combination of deltas, architectural fragments, and design decisions. A delta is used to track changes in component behaviors, whilst an architectural fragment is used to scope design decisions to some set of interacting components, possibly including appropriate deltas. Although the archium metamodel development is still at the preliminary stage, it appears fair to say that it is complex to understand, and a more simplified modeling approach might be more appropriate.

Some of the issues related to representing, capturing, and using design rationale in the generic context of design rationale systems have been discussed and systematized in [9].

3 Improving the Architectural Modeling Practice

Obviously, domain-specific modeling has a role to play; but architecture-specific domain concepts have to be identified and refined to suit the task. Two main theses appear to be valid in this context.

Our first thesis is that *architecture assessment methods, rather than architecture development methods, should be used as the foundation for domain modeling of software architecture designs and related design knowledge*. This is due to the fact that architecture assessment methods, a number of which have evolved over time [3, 5, 6, 10] already focus on architecture quality attributes and related design decisions. In fact, the most complete corpus of knowledge about the design decisions that lead to an architecture usually emerges as a by-product of the assessment exercise.

These design decisions are documented and collected in the form of architectural approaches that correspond to different views. These decisions are also explored in detail to assess the fitness of a particular architecture to its stated requirements and quality goals. In this process, attendant risks, nonrisks, and sensitivity points are identified and analyzed. (In this context, sensitivity points are design decisions that shape the architecture in order to address one or more quality attributes; tradeoff points are sensitivity points where two or more quality attributes interact; finally, nonrisks are the assumptions that do not affect quality attributes in the current design, but that could become risks should some alternative design decisions be applied.) One might almost say that we already have the tool we need; but it should be used in a way that differs from the usual one.

To illustrate this point, let us look again at the example from previous Section. The final outcome—that 'text message is retrieved by the *TextSender* and forwarded to *TextListener*, or temporarily stored in *Telco_DB* if *TextListener* can't be reached at the moment'—has been decided after considering and discussing the following rationale in the following order:

i. Physical communication link between *TextSender*and *TextListener*is unreliable, therefore recording customer's instructions is necessary to avoid loss of messages in case of link failure. This decision is a sensitivity point that stems from an attempt to satisfy the quality goal of reliability.

ii. On the other hand, customer's instructions contain confidential data such as PIN issued by their bank – keeping them in the database constitutes a security risk. The decision is, then, a sensitivity point related to the quality goal of security.

iii. Since the two quality goals affected offer conflicting suggestions, we are dealing with a tradeoff point. Proper decision can only be reached by finding the optimum tradeoff between quality attributes [6].

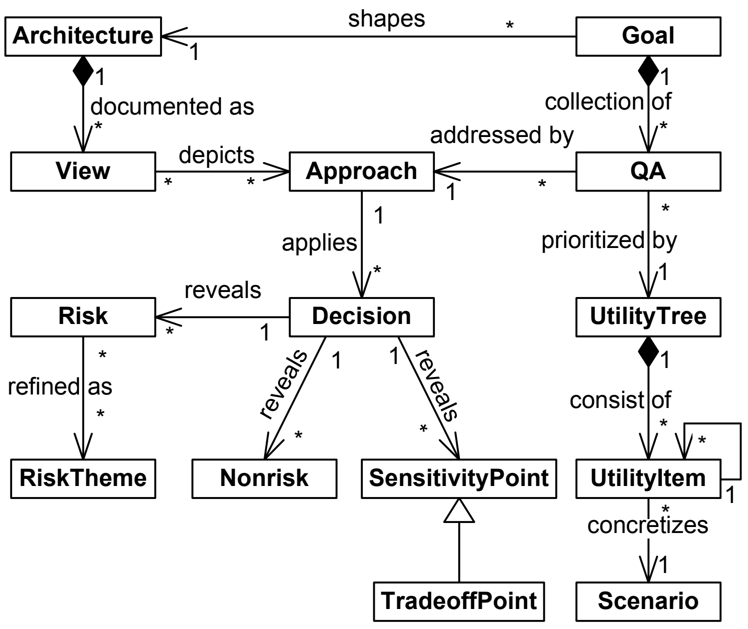

Figure 2. ATAM-based meta-model of architectural knowledge.

iv. Fortunately, *Telco_DB* is based on a particular DBMS technology that allows encryption of data items kept in a particular data area. Such items may be labeled with a expiration timeout, after which they 'disappear' from the database. A security breach of the *Telco_DB* can compromise only a limited number of such messages. This notion, then, diminishes the impact of the security risk, effectively converting it into a non-risk.

v. As a final precaution, the customers should be made aware of the fact that every instruction they issue has a predefined validity period; instructions not processed by this time will be dropped without notice. This decision is related to the quality goals of usability and reliability.

All of these decisions could easily be recorded using a suitable meta-model, and thus made available for subsequent use and refinement in the process of maintenance and evolution. The meta-model shown in Fig. 2, which draws its motivation from software architecture assessment techniques such as ATAM [6], could serve as a good starting point.

Here, we emphasize the words 'starting point'. Although techniques such as ATAM provide a good foundation for the development of a domain-specific approach to architecture modeling, they still need to be modified to maximize their effectiveness. First, facilities for capturing design decisions as first-class entities have to be present. Second, outputs generated by these methods have to be re-structured accordingly. Finally, domain-specific modeling has to be applied as early as possible – i.e., right from the start of architecture development. (As a bonus, the task of architecture assessment will be noticeably simplified if all relevant design rationale are properly recorded.)

Yet even a highly formalized meta-model such as the one shown in Fig. 2 may not allow for accurate and usable recording of *all* kinds of design knowledge. The reason is that this model captures and represents design decisions in a static manner which is inappropriate—or, rather, insufficient—for capturing the essence of the *process* through which the actual model is developed. Our second thesis is that the *shift to a dynamic representation of design decisions would allow for more productive architecture development, and at the same time facilitate subsequent maintenance and evolution*.

In other words, modeling architectures should employ a *sequence* of design decisions, rather than a simpler set structure without any temporal dependencies between its elements. The rationale for this choice is simple: first, the interdependencies do exhibit certain temporal ordering, and second, the introduction of such ordering would facilitate and promote tool-based manipulations, whilst allowing for other uses of the architecture. In this manner, the focus of architecture evolution activities can shift from secondary, descriptive artifacts (i.e., documentation) to the more appropriate target: the sequence of design decisions that led to the development of the said architecture in the first place.

4 Implementing and Using the DSM

We are currently investigating possible ways in which the knowledge about the design decisions can be formalized. A promising avenue seems to be the view/viewpoint/perspective approach described in [13]. However, a new ‘knowledge’ view would need to be created, simply because the views described so far are unable to capture architectural knowledge for the purpose of guiding the activities of maintenance and evolution at a later time. The knowledge view would seek to explicitly represent design decisions as first-class entities, including their interdependencies, alternatives, constraints, rules, assumptions, and rationales, and to do so in a temporal ordering, thereby making it amenable to machine conversion and manipulation. The tasks of documenting design activities should be made an integral part of the development process, and automated as much as possible.

We note the well known developers’ reluctance to document design decisions during development [8], and architects are no different than ordinary developers in that respect. Moreover, the introduction of another type of documentation may appear to be a step in the wrong direction. Providing automated tool support may also prove be a risky step, the more so because many such attempts in the past have failed to provide the promised benefits and gain wider acceptance. In authors’ opinion, both of these facts may be attributed to the fact that documenting, manual or automated, is not made a transparent part of the design process. As long as documenting is perceived as an additional activity of secondary importance, developers will tend to focus on higher priority activity of design. Therefore, tool support should be an integral part of the design process, and it should be made as transparent as possible. Domain-specific modeling offers the benefit of having the design and documentation activities tightly integrated and supported though the same tool, such as MetaEdit+ [11].

Uses of architectural knowledge repository can be systematized through a number of use cases, similar to the concise description given in [8]. For example, a repository of temporally ordered architectural design decisions would allow the architects to gain better understanding of the architecture, to review the set of quality attributes which were considered in the process of forming the current solution, and even investigate alternative decisions that were not accepted. Developers can also benefit from being able to find out the path that led to system architecture, rather than just being handed the architecture with little justification. (This might essentially ease—or even remove—the ‘ivory tower’ syndrome which is a major objection to the conventional architecture modeling and development practices.)

In the context of domain-specific modeling, the possibility to review the design decisions made in the process of previous development is particularly important if the original domain expert is no longer available.

Another important application of the repository of architectural design decisions is the training of architects and domain experts. In both cases, availability of a repository of architectural knowledge with a suitable tool interface would result in improved training and, ultimately, in the increase of the level of expertise available for the task.

5 Conclusion

In this paper, we outline an approach for applying the domain-specific modeling paradigm to the task of modeling architectural knowledge. We propose to model architectural knowledge and the resulting artifacts as a sequence of design decisions, and argue that this approach offers possibilities above and beyond what the current approaches are able to provide.

We are currently exploring ways to adapt existing architecture assessment methods in order to capture all required architectural knowledge for successful model evolution and training purposes.

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Domain Model Driven Development of Web Applications

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Abstract

This paper provides a brief overview of two frameworks, Domain Model Lite and Domain Model RAD, which are used to develop dynamic web applications in a relatively short amount of time. Domain Model Lite is a framework that facilitates the definition and the use of domain models in Java. Domain Model RAD is a rapid application development framework that uses Domain Model Lite for domain models and Wicket for application views. Wicket is a web framework that provides web components to construct, in an object oriented way, web concepts, such as web pages and page sections. Domain Model RAD interprets the application model and creates default web pages based on the model.

Introduction

There are many Open Source Java web frameworks [1]. The most popular is Struts [2] from the Apache Jakarta Project. Struts relies more on external configuration files and less on Java code to speed up Web application development. It is an action based framework. As a consequence, the control part of Struts is rather elaborate for developers and is not suitable for rapid development of web applications.

There is a new web component based framework called Wicket [3]. A web component, such as a web page or a page section, is in the center of preoccupation in Wicket. The control part of Wicket is largely hidden from developers. Thus, Wicket is appropriate for rapid development of web application views.

A web application, as any other software has two major parts: a domain model and views. Although, a Wicket component requires a model for the component data, the actual model is outside of the Wicket realm. Wicket developers usually use Hibernate [4] to represent domain models and to persist them to relational databases. Hibernate is a complex object-relational mapping framework that uses several XML configuration files to support the mapping. However, the interaction of Wicket with Hibernate is not obvious. In addition, a Wicket developer must learn a complex framework before providing even some simple data to web components. Hence, Hibernate is not an appropriate choice for rapid application development.

I have developed a domain model framework, called Domain Model Lite or dmLite [5], to provide an easy support for small domain models, which are usually used in rapid web development. Its name reflects the framework objective to provide an easy to learn and easy to use framework. I have developed, in nine spirals, a simple web application with Domain Model Lite and Wicket [6], to allow less experienced developers to learn the basics of Domain Model Lite and Wicket quickly. In addition, I have developed a web component framework, called Domain Model RAD or dmRad [5], to produce rapidly a web application based on the given domain model.

Domain Model Lite

A domain model is a model of specific domain classes that describe the core data and their behavior [7]. The heart of any software is a domain model. When a model is well designed and when it can be easily represented and managed in an object oriented language, a developer can then focus more rapidly on views of the software, since they are what users care about the most.

There is a class of small projects where there is no need to elaborate on different design representations, such as sequence and collaboration diagrams in UML. In a small application, a domain model is the core part of the application software. Domain Model Lite has been designed to help developers of small projects in representing and using application domain models in a restricted way. The restrictions minimize the number of decisions that a domain modeler must make. This makes Domain Model Lite easy to learn.

In most cases, domain model data must be saved in an external memory. If a database system is used for that purpose, the software requires at least several complex installation steps. Since Domain Model Lite uses XML files to save domain model data, there is no need for any special installation. In addition, Domain Model Lite allows the use of a database.

Domain Model RAD

Domain Model Lite has a companion rapid web application development framework, called Domain Model RAD, which can be used to make a default Wicket application out of a domain model. Domain Model RAD uses the domain model configuration to find the model entry points and to provide a web page for each entry point, either for the display or for the update of data. An entry point is a collection of entities and it is presented in a web page as a table, a list, or a slide show of entities. This choice and other view presentation properties are defined in the XML configuration of the domain model**.** The traversal of the domain model is done by navigating from an entry entity to neighbor entities following the parent-child neighbor directions.

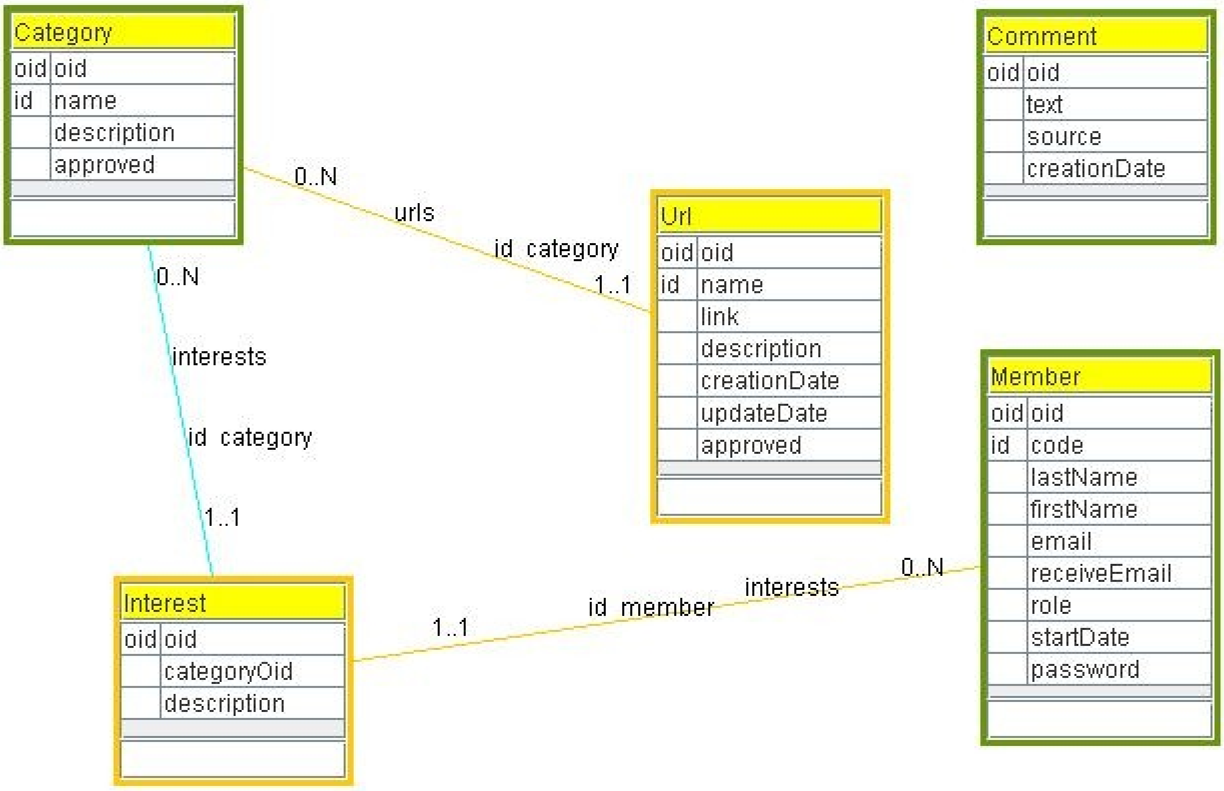
A default application may help developers validate and consequently refine the domain model. In addition, Domain Model RAD has a collection of web components that may be easily reused in specific web applications to display or update entities. For example, the component called `EntityUpdateTablePanel` is used to display entities as a table with a link to update the selected entity and a link to display child entities of the selected entity. The following is a list of the most important web components.

```
EntryUpdateTablePanel
EntityAddFormPanel
EntityUpdateConfirmRemovePanel
EntityEditFormPanel
EntryDisplayTablePanel
EntityDisplayTablePanel
EntityDisplayListPanel
EntityDisplaySlidePanel
EntityDisplayPanel
EntityDisplayMinPanel
EntityDisplayKeywordSelectionPanel
EntityDisplayLookupTablePanel
```

Domain Model

A domain model is a representation of user concepts, concept properties and relationships between concepts. The easiest way to present a domain model is through a graphical representation [8]. The following is a domain model of web links (or urls) that are of interest to certain members.

The Urls domain model concepts are: Url, Category, Member, Interest and Comment. Url describes a web link. Urls are categorized. Members express their interests in categories of web links.



A concept is described by its properties and neighbors. The Url concept has a name, a link, a description, a creation date, the last update date and whether it is approved or not. The Url concept has only one neighbor, the Category concept. However, the Category concept has two neighbors: the Url and Interest concepts. A relationship between two concepts is represented by two neighbor directions, displayed together as a line. A neighbor direction is a concept special (neighbor) property, with a name and a range of cardinalities. The Category --> Url direction is named urls, its minimal cardinality is 0 and its maximal cardinality is N. Note that cardinalities are characteristics of the (source) concept. Thus, they are expressed close to the concept, which is opposite in UML. A Url has exactly one category.

A concept is represented in Domain Model Lite as two Java classes, one for `Entity` and the other for `Entities` (or `OrderedEntities` if an order of entities is important). The `Entity` class implements the `IEntity` interface, and the `Entities` class implements the `IEntities` interface.

```
public interface IEntity extends Serializable {
	public IDomainModel getDomainModel();
	public ConceptConfig getConceptConfig();
	public void setOid(Oid oid);
	public Oid getOid();
	public void setCode(String code);
	public String getCode();
	public Id getId();
	public void setProperty(String propertyCode, Object property);
	public Object getProperty(String propertyCode);
	public void setNeighborEntity(String neighborCode, IEntity
		      neighborEntity);
	public IEntity getNeighborEntity(String neighborCode);
	public void setNeighborEntities(String neighborCode,
		     IEntities neighborEntities);
	public IEntities getNeighborEntities(String neighborCode);
	public boolean update(IEntity entity) throws ActionException;
	public IEntity copy();
	public boolean equalContent(IEntity entity);
	public boolean equalOids(IEntity entity);
	public boolean equalIds(IEntity entity);
}

public interface IEntities extends Serializable {
	public IDomainModel getDomainModel();
	public ConceptConfig getConceptConfig();
	public Collection getCollection();
	public IEntities getEntities(SelectionCriteria selectionCriteria)
		     throws SelectionException;
	public IEntities getSourceEntities();
	public void setPropagateToSource(boolean propagate);
	public boolean isPropagateToSource();
	public IEntities union(IEntities entities) throws SelectionException;
	public IEntities intersection(IEntities entities) throws
		      SelectionException;
	public boolean isSubsetOf(IEntities entities) throws
		      SelectionException;
	public boolean add(IEntity entity) throws ActionException;
	public boolean remove(IEntity entity) throws ActionException;
	public boolean update(IEntity entity, IEntity updateEntity)
		     throws ActionException;
	public boolean contain(IEntity entity);
	public IEntity retrieveByOid(Oid oid);
	public IEntity retrieveByCode(String code);
	public IEntity retrieveByProperty(String propertyCode, Object
		      paramObject);
	public IEntity retrieveByNeighbor(String neighborCode, Object
		      paramObject);
	public Iterator iterator();
	public int size();
	public boolean isEmpty();
	public Errors getErrors();
}
```

The Category concept has two classes: `Category` and `Categories`. The Category concept is an entry point into the domain model. An entry point concept has a green border. Thus, the Url concept is not an entry point. That means that urls can be reached only through its category. However, an object of the `IEntities` type that represents all urls of all categories may be created by a specific method. The `Category` class describes the Category concept and the `Categories` class represents all categories. A specific category may have from 0 to N urls. The urls for that category, and other urls for other categories are represented by the `Urls` class. The `Url` class is used to describe the Url concept. In the context of the Category -- Url relationship, the Category concept is a parent, and the Url concept is a child.

Every concept in Domain Model Lite has two predefined properties: oid and code. The oid property is mandatory, while the code property is optional. The oid property is used as an artificial concept identifier and is completely managed by Domain Model Lite. Its value is a time stamp and it is unique universally**.** In addition, a concept may have, at most, one user oriented identifier (id) that consists of the concept properties and/or neighbors. A simple id has only one property. In an entry concept, all entities must have a unique value for the concept id. However, in a non-entry child concept, the id is often unique only within the child parent. The Url concept id consists of the name property and the category neighbor (direction). Thus, a url name must be unique only within its category.

Entities as Plain Old Java Objects

The Category concept has two classes: `Category` and `Categories`. For the sake of space, only the Category concept and its relationship to the Url concept, will be considered in this example. The example is used to show the flavor of Domain Model Lite.

The `Category` class extends the `Entity` abstract class, which implements the `IEntity` interface. It contains three properties and one child neighbor with the corresponding `set` and `get` methods. All properties are typed by Java classes and not by Java base types. A `Boolean` property has also an `is` method that returns a `boolean` base value for convenience reasons. The class constructor passes the domain model to its inheritance parent. The neighbor is created in the class constructor. The neighbor `setUrls` method sets the current category as the neighbor parent.

```
public class Category extends Entity {

	private String name;
	private String description;
	private Boolean approved;

	private Urls urls;

	public Category(IDomainModel domainModel) {
		super(domainModel);
		urls = new Urls(this);
	}

	public void setName(String name) {
		this.name = name;
	}

	public String getName() {
		return name;
	}

	public void setDescription(String description) {
		this.description = description;
	}
	public String getDescription() {
		return description;
	}

	public void setApproved(Boolean approved) {
		this.approved = approved;
	}

	public Boolean getApproved() {
		return approved;
	}

	public boolean isApproved() {
		return getApproved().booleanValue();
	}

	public void setUrls(Urls urls) {
		this.urls = urls;
		urls.setCategory(this);
	}

	public Urls getUrls() {
		return urls.getUrlsOrderedByName();
	}
}
```

The `Categories` class extends the `OrderedEntities` abstract class, which in turn extends the abstract `Entities` class, which implements the `IEntities` interface. The class constructor passes the domain model to its inheritance parent. The `getCategory` is a convenience method that uses the Domain Model Lite `retrieveByProperty` method. The `getApprovedCategories` method shows how a selection of entities is done in Domain Model Lite. The `getCategoriesOrderedByName` method shows how entities are ordered. Both selection and order produce a new specific entities object.

```
public class Categories extends OrderedEntities {

	public Categories(IDomainModel domainModel) {
		super(domainModel);
	}

	public Category getCategory(String name) {
		return (Category) retrieveByProperty("name", name);
	}

	public Categories getApprovedCategories() {
		Categories approvedCategories = null;
		try {
			SelectionCriteria criteria =
				SelectionCriteria.defineEqualCriteria(
					"approved", Boolean.TRUE);
			approvedCategories = (Categories) getEntities(criteria);
		} catch (SelectionException e) {
			log.error("Error in Categories.getApprovedCategories: "
					+ e.getMessage());
		}
		return approvedCategories;
	}

	public Categories getCategoriesOrderedByName() {
```

```
            Categories orderByName = null;
            try {
                  CaseInsensitiveStringComparator cisc = new
                     CaseInsensitiveStringComparator();
                  PropertyComparator nameComparator = new
                      PropertyComparator("name", cisc);
                  OrderCriteria criteria =
                      OrderCriteria.defineOrder(nameComparator);
                  orderByName = (Categories) getEntities(criteria);
            } catch (OrderException e) {
                  log.error("
                      Error in Categories.getCategoriesOrderedByName: "
                      + e.getMessage());
            }
            return orderByName;
      }
}
```

Domain Model XML Configuration

A domain model must be configured in an XML configuration file [9]. This configuration reflects the model classes. However, it provides more information about the domain model default behavior used heavily in Domain Model RAD. The model XML configuration is loaded up-front and converted into Domain Model Lite meta entities. The following is a minimal version of the configuration.

```
<models>
  <model oid="2001">
    <code>Urls</code>
    <packagePrefix>org.urls</packagePrefix>
      <concepts>
        <concept oid="2020">
          <code>Category</code>
          <entityClass>org.urls.model.component.category.Category
          </entityClass>
          <entitiesCode>Categories</entitiesCode>
          <entitiesClass>org.urls.model.component.category.Categories
          </entitiesClass>
          <entry>true</entry>
          <fileName>categories.xml</fileName>
          <properties>
            <property oid="1">
              <code>name</code>
              <propertyClass>java.lang.String</propertyClass>
              <required>true</required>
              <unique>true</unique>
            </property>
            <property oid="2">
              <code>description</code>
              <propertyClass>java.lang.String</propertyClass>
            </property>
            <property oid="3">
              <code>approved</code>
              <propertyClass>java.lang.Boolean</propertyClass>
              <required>true</required>
              <defaultValue>false</defaultValue>
            </property>
          </properties>
          <neighbors>
```

```
            <neighbor oid="1">
              <code>urls</code>
              <destination>Url</destination>
              <internal>true</internal>
              <type>child</type>
              <min>0</min>
              <max>N</max>
            </neighbor>
          </neighbors>
        </concept>
        ...
    </concepts>
  </model>
</models>
```

Web Applications

I have developed two different web applications for the same Urls domain model. The first web application uses Wicket for the application views [10]. The second web application uses Domain Model RAD for the application views [11]. Thanks to Domain Model RAD, only a small portion of the application is specific, which means that there is significantly less Java code in the second application.

Conclusion

I have developed a domain model framework, called Domain Model Lite, to provide an easy support for small domain models, which are usually used in rapid web development. Besides, I have also developed a web component framework, called Domain Model RAD, which makes it possible to produce quickly a web application based on the given domain model. With Domain Model Lite, a web application developer does not need to learn a complex framework, such as Hibernate, in order to create and save a domain model. With Domain Model RAD, a web application developer may create a small application quickly. For example, I have developed the Public Point Presentation web application in three spirals: ppp00 [12], ppp01, and ppp02 [13]. The ppp00 spiral has been created with almost no programming [14], while the ppp02 spiral has only a few specific classes.

Web Links

[1] http://java-source.net/open-source/web-frameworks
[2] http://struts.apache.org/
[3] http://wicketframework.org/
[4] http://www.hibernate.org/
[5] http://drdb.fsa.ulaval.ca/dm/
[6] http://drdb.fsa.ulaval.ca/urls/
[7] http://www.dsmforum.org/
[8] http://drdb.fsa.ulaval.ca/mmLite/
[9] http://drdb.fsa.ulaval.ca/dm07/web/config/specific-model-config.xml
[10] http://drdb.fsa.ulaval.ca/urls08/code.html
[11] http://drdb.fsa.ulaval.ca/dm07/code.html
[12] http://drdb.fsa.ulaval.ca/ppp00/
[13] http://drdb.fsa.ulaval.ca/ppp02/
[14] http://drdb.fsa.ulaval.ca/ppp00/code.html

Generative Programming for a Component-based Framework of Distributed Embedded Systems

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Abstract. COMDES-II is a component-based software framework which formally specifies the modeling concepts and constraints for distributed embedded systems in different aspects, such as component structures, interaction, hierarchy, etc. The paper presents an overview of the design philosophies of COMDES-II in the related aspects and a generative programming approach developed to enable the engineering applicability of the framework. The dedicated generative programming approach involves the formal definition of COMDES-II modeling language by means of meta-models which are instrumented by a meta-modeling tool – Generic Modeling Environment (GME), and the development of a specific code generation technique using CodeWorker tool to implement the automatic synthesis of system codes from system models.

1 Introduction

Complexity of software in embedded applications is continuously increasing, this situation is caused – primarily – by growing computational power of general-purpose microprocessors, which eliminates the need for special dedicated hardware solutions and therefore moves the emphasis from hardware to software design. An embedded software system is characterized by its tight interaction with the physical environment, restricted running resources (e.g. RAM, CPU, etc.), robust and strictly safe execution under hard real-time constraints [1]. These domain-specific features mandate the investigation of proper *domain-specific modeling* (DSM) techniques for various application domains of embedded systems, whereby the modeling concepts and abstraction rules of software that are provided in the solution space should accommodate the critical aspects in the problem space, such as system concurrency, environmental physicality, time, etc.

Component-based design (CBD) can be regarded as one of the most suitable design paradigms (if not the most suitable) for domain-specific modeling methodology. Due to the great profits brought by reusability of components, higher level of system abstraction (modeling systems rather than programming systems), an embedded software system can be efficiently and intuitively constructed from the prefabricated and reusable components. Moreover, from a software engineering point of view, CBD is an effective way to bridge the gap between the conceptual system design models and the concrete system implementation [2], provided that a proper *generative programming* approach is developed.

Generative programming is a software engineering methodology that automates the generation of system implementations from higher level abstractions represented as textual or graphical models [3]. In this context, *meta-modeling* and *model-driven development* (MDD) techniques provide great advantages for modeling domain-specific software systems at higher abstraction level, and on the other side, *code generation* and *model transformation* are the general approaches adopted to implement the automatic synthesis facilities for systems.

This paper intends to present such a generative programming method for a domain-specific, component-based software framework aiming at the development of distributed embedded systems – *COMDES-II* (Component-based Design of Distributed Embedded Systems, version II) [4]. The focus is placed on the design philosophy and the meta-modeling approach of framework components in the component design aspect, and the code generation technique related to the component implementation aspect (as shown in Fig. 1).

The meta-models of COMDES-II components are represented as the special UML class diagrams provided by the meta-modeling tool *GME* (Generic Modeling Environment) [5, 11], a configurable toolkit that supports the creation of domain-specific modeling and program synthesis environments. The constraint language *OCL* (Object Constraint Language, a subset of UML 2.0) is also supported in GME, which can be used to help specify the complex static semantics of component models in COMDES-II.

For the development of code generation technique, the *CodeWorker* [12] tool is employed. CodeWorker is a versatile parsing tool and a universal generator, which provides a scripting language adapted both to the description of any input format and to the writing of any generation templates [6]. COMDES-II models are parsed by an extended-BNF script to create a parse tree, which is subsequently processed by template-based scripts that drive the code generation. The generated code and the reusable component execution algorithms are finally composed into the executable code by means of the GNU Compiler Collection (GCC) [13].

This engineering approach involving the graphical modeling of COMDES-II components and the automatic synthesis of component codes can be conceptually illustrated as in Fig. 1.

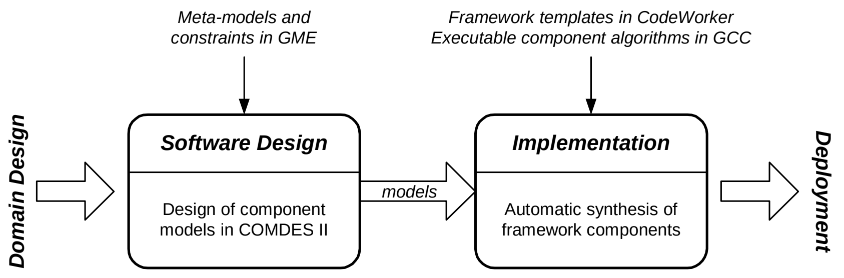
Meta-models and constraints in GME
Framework templates in CodeWorker
Executable component algorithms in GCC
Domain Design
Software Design
Design of component models in COMDES II
models
Implementation
Automatic synthesis of framework components
Deployment

Fig. 1. The generative programming approach for COMDES-II components

Firstly, a component is designed in its application domain, at relatively high level, e.g. a controller of control system in MATLAB/Simulink [14]. Next, the domain component model that satisfies application requirements can be transformed into the COMDES-II framework model, e.g. by automatic mapping from Simulink components to COMDES-II components. The transformed framework components may have some supplementary information which will guide the implementation generation. Ultimately, the synthesized code can be deployed into embedded devices and tested against real environment.

The paper is organized as follows: Section 2 gives a brief introduction about the design philosophies of COMDES-II. Section 3 presents the meta-level definitions of COMDES-II components through an example. Section 4 describes the code generation technique developed under CodeWorker tool to automatically synthesize the framework code from the corresponding component models, and the concluding section summarizes this engineering approach for COMDES-II framework, discusses the related research and future work.

2 The COMDES-II Framework

COMDES-II is a component-based framework with its focus on the distributed control systems, as a result the framework places its root in the control engineering domain and borrows a number of software concepts that are popular in this domain, such as function blocks, state machines, etc. [7].

COMDES-II provides specific modeling techniques in the solution space by emphasizing two significant aspects of an embedded software system: 1) the openness and hierarchy of system architecture, and 2) predictable and deterministic system behaviour, by taking the following problem space issues into account:

- *Component structures, interaction and hierarchy*
- *System architecture, concurrency*
- *Environmental physicality (e.g. external events etc.) and time*

The framework employs a two-level architectural model to specify the system architecture: at the first level (system level) an embedded application is conceived as a composition of *actors* (active components) that exchange signals asynchronously through a content-oriented, producer-consumer model of communication. An example of the system developed under COMDES-II for Production Cell Case Study [8] is shown in Fig. 2.

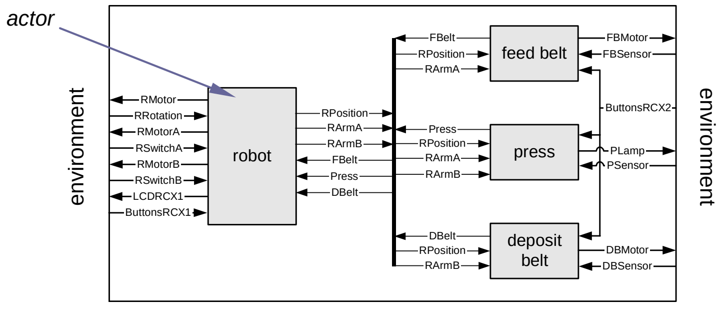

Fig. 2. Actors interaction in COMDES-II

At the second level (actor level), an actor contains multiple *I/O drivers* and a single *actor task* (execution thread). I/O drivers are classified as *communication drivers* and *physical drivers*, which are associated with the actor task by the *dataflow* connection relationship. As an example, the internal structure of feed belt actor shown in Fig. 2 is illustrated as in Fig 3.

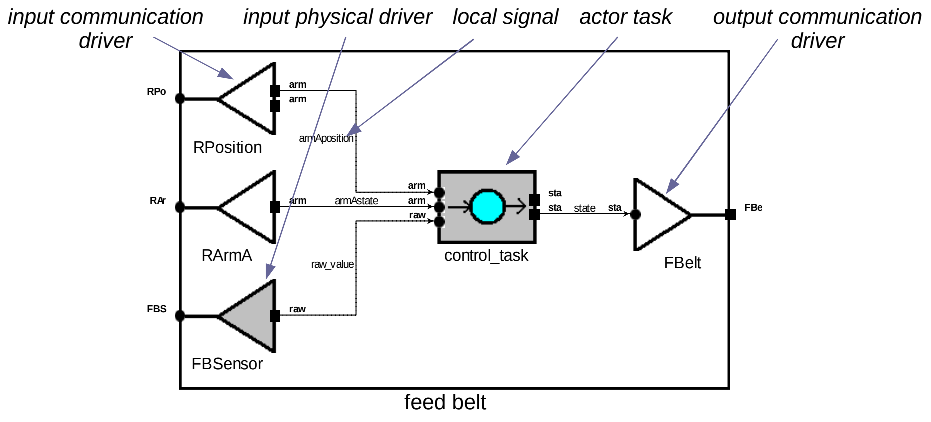

Fig. 3. Internal structure of the feed belt actor

The I/O drivers of an actor are assumed to be short pieces of code executed atomically (zero time) at precisely specified time instants referred to as *execution triggering* instant and *deadline* instant respectively, hence the execution triggering instant of an *actor* is also the *releasing* instant of the *actor task*. The actor tasks and I/O drivers are scheduled by the real-time kernel *HARTEX*$_{TM}$[1] [9], which employs a preemptive priority-based *timed multitasking* (TM) technique [10]. TM guarantees the execution time of an actor is constant – nevertheless the actor task may be preempted by higher priority tasks in arbitrary times – as long as the task finishes execution before its deadline. This execution pattern of actor tasks is referred to as *split-phase* execution and illustrated by the diagram shown in Fig. 4.

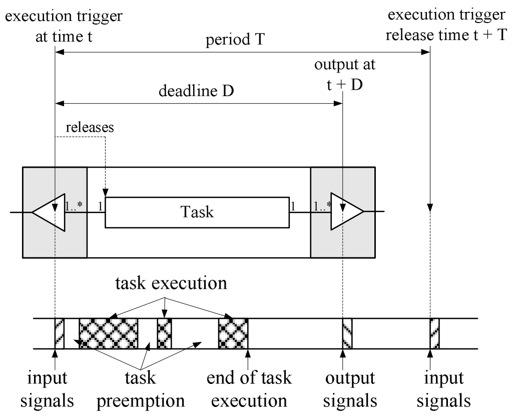

Fig. 4. Split-phase execution of actor tasks under timed multitasking

An actor task can be hierarchically composed from an aggregation of different *function block instances* (passive components). Function block (FB) instances are instantiations of reusable FB *types*, which can be categorized into four FB *kinds* (meta-types) - *basic*, *composite*, *modal* as well as *state machine* FBs. A basic FB contains attributes, operations and associations that are common to all kinds of FBs, such as inputs, outputs, parameters, etc. Hence the definition of basic FBs is a root class which can be extended to define the other kinds of FBs. A more detailed description of each kind of FBs is referred to [4]. And as an example, the FB instances contained in the feed belt actor *task* (named control_task) are shown as in Fig. 5.

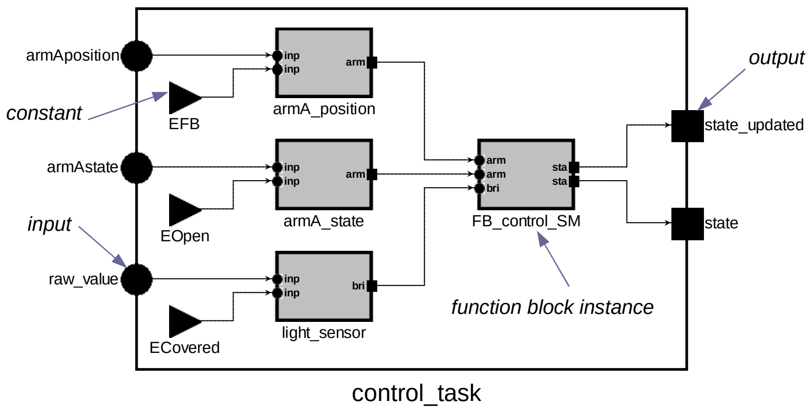

Fig. 5. Internal structure of the feed belt actor task

The concrete operation dynamics of this actor and its constituents will not be explained here since they are irrelevant to the focus of discussion, and we hope the diagram is intuitive enough to demonstrate the architectural and hierarchical features of COMDES-II framework.

[1] *HARTEX*$_{TM}$ is a hard real-time kernel developed by Software Engineering Group, Mads Clausen Institute for Product Innovation, University of Southern Denmark (SEG, MCI/SDU).

A FB type is a software component with an *execution record* containing its attributes and a set of *operations* defining its possible behaviour. A generic component model for all kinds of COMDES-II FBs is conceptually illustrated as in Fig. 6.

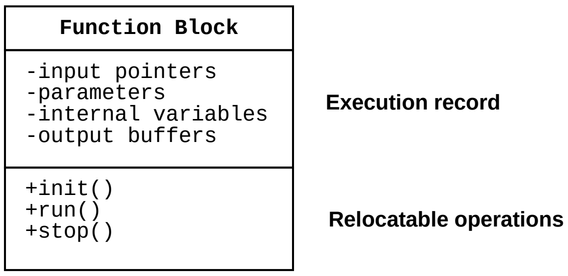

Fig. 6. Component model for COMDES-II FBs

The execution record is actually the FB interface containing the information like input pointers, parameters, internal variables and output buffers of a specific type of FB. FB execution record can be instantiated as well as reconfigured for the related FB instances of a given type. The operations are reentrant and relocatable functions performing some kinds of algorithms on an execution record, by accepting a pointer as the argument referring to the corresponding execution record of a specific FB instance.

In COMDES-II, the interface of a specific FB type can be automatically synthesized into the C files from the corresponding FB graphical design model. The operations of a given type of FB are predefined algorithms and implemented as C routines. The prefabricated operation and interface files of FB definitions are stored in the FB repository, in which the operation files are delivered as executable routines, e.g. as object files (.obj files).

3 Meta-level Definitions of COMDES-II Components

The description of COMDES-II framework presented in the previous sections is informal, which is helpful to intuitively understand this DSM framework though, it is yet insufficient to implement a DSM language that is compliant with the framework rules and constraints. A DSM language of COMDES-II enables the modeling of components and application systems under the framework, and in order to develop such a language, the meta-models formally describing the syntax and static semantics of the targeting domain modeling language should be defined with a consideration of various problem space issues (e.g. hierarchy, time etc.). Generally speaking, the formalization of modeling languages to be the corresponding meta-models is a recursive process which can be conceptually presented as in Fig. 7.

Meta-modeling COMDES-II framework involves the formal specification of following abstractions in different aspects:

- Meta-modeling *HARTEX*$_{TM}$ kernel and actors to accommodate the physicality (handling external interrupts), actor task concurrency (primitive priority-based scheduling), actor interaction (actor communication, actor synchronization etc.) and timing aspects (timed multitasking).
- Meta-modeling various kinds of function blocks in terms of function block structures, function block interaction and hierarchy (e.g. a model function block can contain other function block instances).
- Integrating the meta-model of *HARTEX*$_{TM}$ kernel and actors with the function block meta-models to accommodate the architectural aspect of the framework.

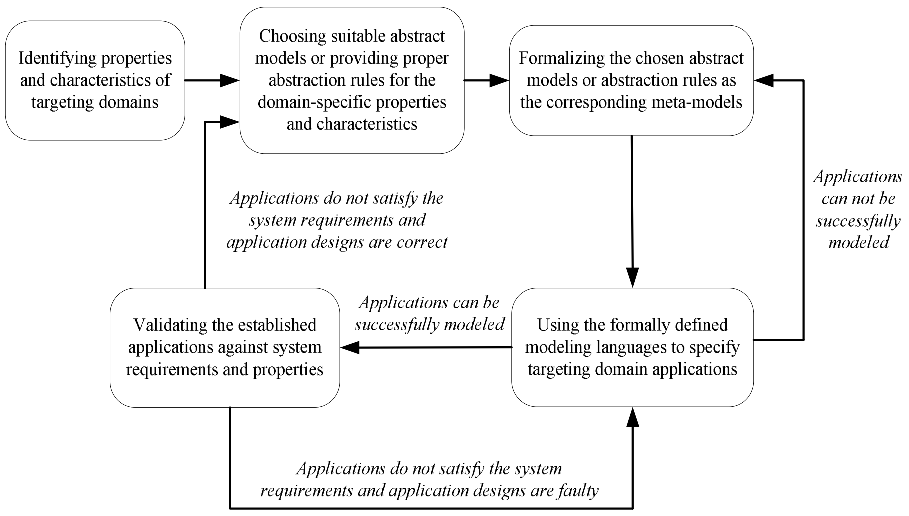
Identifying properties and characteristics of targeting domains
Choosing suitable abstract models or providing proper abstraction rules for the domain-specific properties and characteristics
Formalizing the chosen abstract models or abstraction rules as the corresponding meta-models
Applications can not be successfully modeled
Applications do not satisfy the system requirements and application designs are correct
Validating the established applications against system requirements and properties
Applications can be successfully modeled
Using the formally defined modeling languages to specify targeting domain applications
Applications do not satisfy the system requirements and application designs are faulty

Fig. 7. General meta-modeling process

In order to better understand the above meta-modeling approach, an example for formalizing the models of state machine FBs (SMFBs) is given. A SMFB in COMDES-II employs a dialect of the finite state machine model with event-driven semantics to specify the sequential behavior of a system. The graphical representation of FB_control_SM function block instance in Fig. 5 is presented as in Fig. 8.

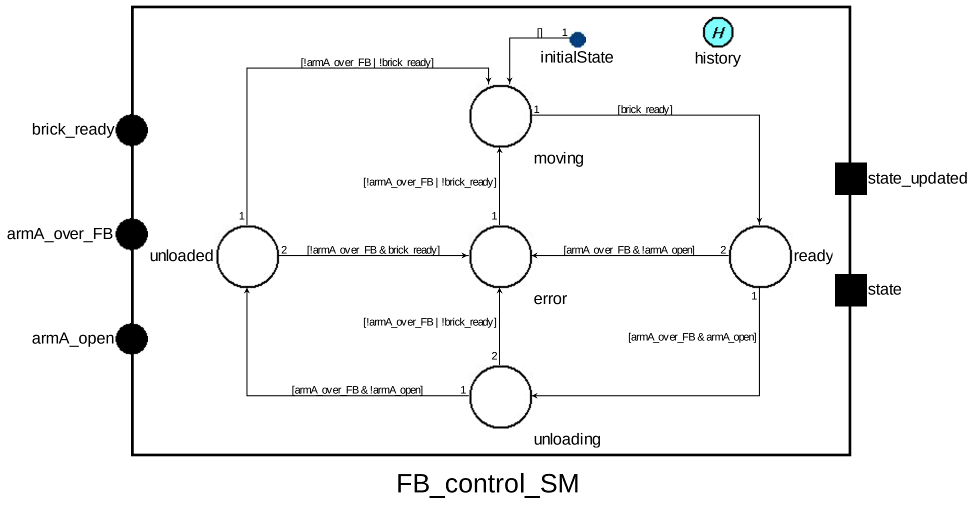
[] 1
initialState
history
[!armA_over_FB | !brick_ready]
1
[brick_ready]
moving
brick_ready
armA_over_FB
armA_open
[!armA_over_FB | !brick_ready]
1
1
unloaded
2
[!armA_over_FB & brick_ready]
[armA_over_FB & !armA_open]
2
ready
error
1
[!armA_over_FB | !brick_ready]
[armA_over_FB & armA_open]
2
[armA_over_FB & !armA_open]
1
unloading
state_updated
state
FB_control_SM

Fig. 8. FB_control_SM function block instance

This function block instance contains three inputs and two outputs, which are the common elements that all kinds of function blocks have and therefore are inherited from the basic function block definition. Additionally, an event-driven state machine model specifying the sequential behavior of the host actor is also integrated. The state machine model includes a dummy initial state pointing to the actual initial state of the machine, a graphical label with the name history meaning that the state machine is historic, a number of states as well as state transitions which are labeled by events, guards and transition orders. Transition order is a number indicating the importance of the transition, i.e. which transition should be fired when multiple transition triggers associated with the current state are evaluated as true (transitions are evaluated starting from 1).

The above informal abstractions of the state machine function block can be formalized by a meta-model as illustrated in Fig. 9.

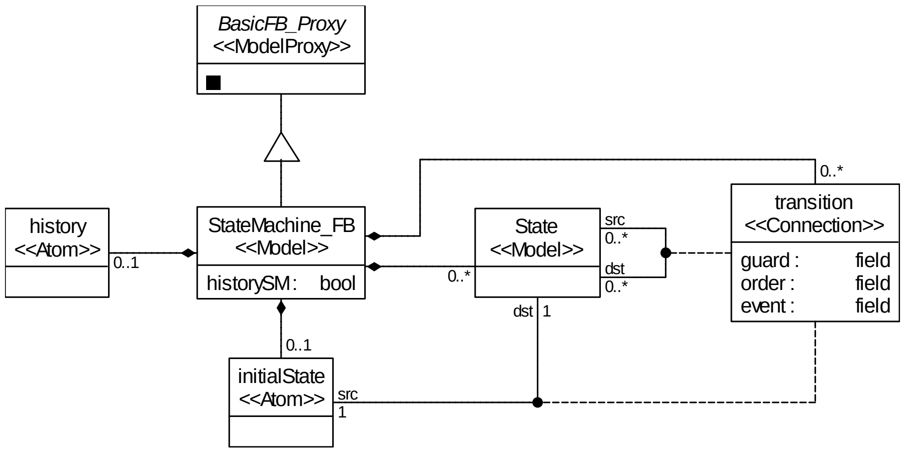

Fig. 9. Meta-model of state machine function blocks

In addition to the meta-model defined as a class diagram, some extra constraints specifying the static semantics for the state machine model are also defined in OCL, which are summarized as in Table.1. The meta-model in form of class diagram together with the constraints expressed in OCL provide a complete formal definition for the corresponding kind of function block.

Table 1. Example of constraints in OCL

Syntactic Constraint	OCL Expressions	Applying Object	Checking on Event
The state machine is reactive.	`self.models("State")->forAll(s | s.connectedFCOs("dst")->size >= 1)`	StateMachine_FB	CLOSE_MODEL
The state machine is deterministic.	`self.connectionPoint("src").target().attachingConnections("src","transition")->select(c : transition | c.event = self.event and c.guard = self.guard)->size = 1`	transition	CONNECT
All states are reachable	`self.models("State")->forAll(s | s.connectedFCOs("src")->size >= 1)`	StateMachine_FB	CLOSE_MODEL

4 Code Generation Technique of COMDES-II Framework

Implementation of COMDES-II system is achieved in two stages: firstly, CodeWorker generates source code files from GME models; secondly, GCC composes the generated source files with prefabricated codes into the final executable implementation. Execution of the first stage is controlled by an application written in Java accessing CodeWorker functionality via its Java interface, whereas the second stage is conducted by the Makefile generated in first stage.

COMDES-II implementation is built, or configured from predefined and reusable components stored in a repository. For each application component instance a data structure

(FB execution record) is generated, whereas the accompanying component algorithms (FB operations) are prefabricated in advance. In this way, during application synthesis no component executable code is generated.

In order to match the limited resources of embedded systems, COMDES-II framework is implemented in C language, which could be seen to some extent as a portable source code as long as the GCC tool chain is employed. Because some parts of the C code (e.g. FB operations) are only CPU architecture dependant and are compiled into an executable object codes for a particular CPU architectures, e.g. avr5 – ATmega128. Some parts, as usual, are dedicated to a particular hardware platform (e.g. hardware I/O drivers) and are written by an expert once (Fig. 10). In this way, portability and native platform performance is achieved rather easily, assuming existence of GCC tool chain for the platform of interest.

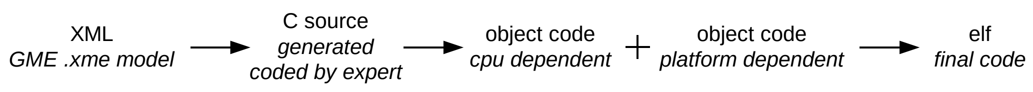

Fig. 10. Portability of COMDES-II system

An overview of the generation process is given in Fig. 11, with three different scenarios:

- Application synthesis (green, solid line) – models, which provide all necessary information, drive the configuration of an application.
- Component generation (blue, dashed line) – component execution record is generated, and then supplemented with the algorithms written by software expert. Final implementation is stored in a repository of reusable components in a form of executable object file.
- Reconfiguration (red, dotted line) – rather than generating the reconfigured application as a whole, only the updated part is created, which provides for faster application modification.

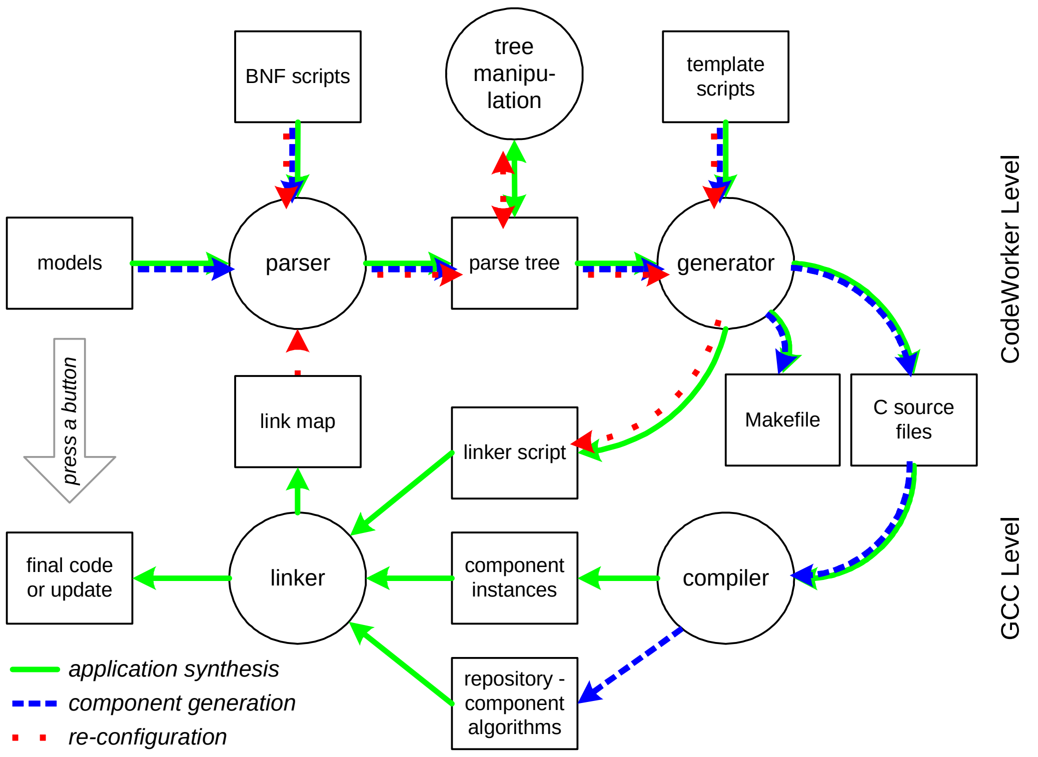

Fig. 11. Automatic synthesis of COMDES-II system

5 Conclusion

COMDES-II is a component-based framework aiming at the software development in the domain of distributed embedded systems. The framework provides the modeling methods for domain-specific features of an embedded system in different aspects, including component structures and interaction, system concurrency and functionality under the hard real-time constraints, etc. The provided design methods in these aspects enable COMDES-II a framework accommodating both the open system architecture as well as the predictable and deterministic system behaviour.

In the paper a generative programming approach for COMDES-II has been presented, which involves the meta-modeling of framework modeling language and the development a dedicated code generation technique. A complete formal definition of the COMDES-II components carried out in GME consists of a meta-model specified as a class diagram and a set of constraints expressed in OCL, which is exemplified in the paper with a concrete state machine function block instance. Automatic synthesis of application implementation is a process consisting of parsing of models and generating source files in CodeWorker, next, compiling and linking of all codes in GCC. Ultimate result is the configuration of applications from reusable and reconfigurable components.

Throughout the development of the generative approach we follow a motto: *let the best tool do the job, the tool that is designed for the job*. And therefore we adopt: GME – rapid development of DSM editor prototypes, CodeWorker – generation of any output and GCC – compiling and linking of codes. There are also other options of tools which can be used to develop the graphical DSM editor, for instance, Eclipse EMF/GMF/GEF frameworks [16], or MetaCASE MetaEdit+ [15].

Eclipse EMF/GMF/GEF frameworks provide an excellent model-driven approach for creating domain-specific models from their meta-models, and allow developers to establish a very flexible graphical environment for editing the models, however, developing such a graphical editor is really a labor-intensive task. MetaEdit+ is a commercial meta-modeling product developed by MetaCASE, which offers a Symbol Editor that facilitates the customization of model visual effects and a promising code generation tool for easy automatic synthesis and documentation. However, the meta-modeling process in MetaEdit+ is not as straightforward as that in GME or Eclipse EMF, and moreover, only the cardinality constraints of relationships are supported in MetaEdit+, whereas the Object Constraint Language (OCL) is not implemented. GME enables a powerful meta-modeling capability by providing a number of unique meta-modeling concepts, such as sets, references and aspects etc., additionally the OCL language is fully implemented. Automatic synthesis of program is also possible in GME through user-defined plug-ins and Builder Object Network (BON) API. A deficiency of GME is that the graphical representation of models can not be dynamically changed, due to its fixed Model-View-Controller architecture.

The presented software framework has been experimentally validated through two case studies: the Production Cell Case Study [16] and the Steam Boiler Control Specification Problem [17]. The envisioned future work includes the development of a graphical editing toolset in Eclipse, and the meta-model as well as model transformations from GME to the developed graphical environment. Such transformations can be realized by using dedicated model transformation languages, just like GReAT – *G*raph *Re*writing *A*nd *T*ransformation language – for model transformations in GME [19].

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Techniques for Metamodel Composition

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Abstract

The process of specifying an embedded system involves capturing complex interrelationships between the hardware domain, the software domain, and the engineering domain used to describe the environment in which the system will be embedded. Developers increasingly turn to domain-specific modeling techniques to manage this complexity, through such approaches as Model Integrated Computing and Model Driven Architecture. However, the specification of domain-specific modeling language syntax and semantics remains more of an art than a science. Typically, the syntax of a DSML is captured using a metamodel; however, there are few best-practices for metamodeling and no public collection of reusable metamodel b to address common language specification requirements. There is a need for an advanced, comprehensive language design environment that offers tool support for a wide range of metamodel reuse strategies and the preservation of metamodeling best-practices. We outline existing techniques for the reuse and composition of metamodels, and propose a new metamodel composition technique we call Template Instantiation.

1 Introduction

In its current state, the definition of new domain-specific modeling languages via metamodeling is more of an art than a science. Metamodeling best practices are not well understood or documented. Most DSMLs are built completely from scratch, using only the metamodeler's personal experience in language definition to guide the process. Consequently, we see a need for libraries of reusable metamodel fragments or patterns to serve as DSML building-blocks. Metamodel reuse will bring to the realm of DSML specification benefits analogous to those that software reuse brought to the realm of software engineering:

- The avoidance of duplication of effort
- The emergence of high-quality reusable metamodel fragments
- The recognition of key metamodeling patterns and best practices
- A significant reduction in the time-to-market for new DSMLs

The cornerstone for metamodel reuse is tool support for a variety of metamodel composition techniques.

We envision a unified, comprehensive modeling language design environment which provides direct support for every language design task. The full scope of language design extends far beyond abstract syntax specification through metamodeling. Especially for embedded systems modeling, there is a strong need for domain-specific modeling languages with unambiguous semantics and built-in analysis capabilities. Consequently, a comprehensive language design environment will also fully support the specification of formal structural and behavioral semantics, semantic mappings, property-preserving model transformations, and links to external formal analysis tools. Wherever possible this environment should ease the language design process by enabling at least partial automatic generation or composition for each of the aforementioned elements. Strong support for the reuse of syntactic metamodel fragments and patterns will greatly help in this effort, because each composable metamodel fragment can have associated structural semantics, semantic mappings, and model transformations that can also be composed and reused. Of course, reusable syntactic pattners will also help language designers rapidly construct new languages including time-tested, quality modeling styles and patterns of expression.

The Model Integrated Computing toolsuite [9] includes tools that can be used to address the capabilities mentioned above. The Generic Modeling Environment (GME) includes a metamodeling environment for the specification of DSML abstract syntax, and also has some support for the composition and reuse of metamodels [3]. The Graph Rewriting And Transformation tool (GReAT) is used to build model transformers [2]. The current MIC solution for the formal specification of DSML behavioral semantics is called *Semantic Anchoring* [10][11]. Semantic Anchoring mandates the use of GME for defining language syntax by formal metamodels, GReAT for creating semantic mappings using formal model transformations, formal models of computation represented as *Semantic Units* for capturing behavioral semantics, and the formal Abstract State Machine [6] framework for expressing and executing the formal semantics specifications built using the Semantic Units. Recent research advocates the use of Horne Logic to specify DSML structural semantics, and describes the *4ml* toolsuite for the generation and analysis of structural semantics from GME metamodels [7][1].

This paper focuses on the reuse of DSML syntax via metamodel composition. In Section 2 we review existing metamodel composition techniques, each of which should be supported in a comprehensive language design tool. In Section 3 we propose a new metamodel composition technique we call Template Instantiation. We also include a proof-of-concept demonstration of this technique using a metamodeling template instantiation tool built for use with GME. In Section 4 we discuss some ideas for future investigation regarding the relationship between the reuse of metamodels and the reuse of semantic specifications.

2 Current Metamodel Composition Methods

In this section, we describe three general techniques for metamodel composition and discuss when each may be best applied. We also provide illustrative examples of the different techniques using primarily the GME metamodeling language, MetaGME [4].

2.1 Metamodel Merge

A metamodel may be thought of as a namespace for a set of modeling constructs. When composing two modeling languages together, name collisions between the two composed metamodels need to be dealt with in an intelligent way. Typically, name collisions between the elements of two metamodels implies that the domains of those modeling languages intersect in some way; however, this "concept collision" may occur even between modeling constructs with different names. Any time two DSMLs include modeling constructs that capture a shared set of real-world entities, those concepts can be used as "join points" to stitch the two languages together into a unified whole. We refer to this metamodel composition technique as Metamodel Merge.

MOF 2.0, the OMG standardized metamodeling language [8], dictates an algorithm for merging metamodels that fuses together the meta-objects with the same name and metatype from each metamodel. MOF terms this operation a *Package Merge* because it operates at the Package level and recursively impacts all of the elements contained within the merging packages. The new metamodel resulting from a MOF Package Merge maintains no dependency relationships, such as inheritance, importation, redefinition, or type conformance, with the metamodels merged to create it – each element belonging to the new metamodel is newly-created according to the Package Merge algorithm. The MOF specification provides specific rules for merging each of the different MOF metatypes, which we will not review in depth here. However, Package Merge can be generally understood as a recursive unioning of model elements matched by name and metatype.

MetaGME enables Metamodel Merge through the use of three types of class inheritance and a special *Class Equivalence* operator. Class Equivalence is used to show a full union between two classes. The unioned classes cease to exist as distinct metamodel elements, instead fusing into a single class. This union encompasses all the attributes and associations, including generalization, specialization, and containment, of each of the fused classes. The union process is very similar to merging classes through MOF Package Merge, except that the operation takes place at the class level instead of the package (or metamodel) level, the two merged classes do not need to have the same name, and the use of the Class Equivalence operator does not produce a new derivative metamodel.

It is possible simply to use inheritance as a weaker mechanism for merging metamodels - the "is-a-kind-of" specialization relationship is similar to, but weaker than, the "is-equivalent-to" Class Equivalence relationship. In addition to the regular notion of class inheritance supported in both MetaGME and MOF 2.0, MetaGME also defines two special inheritance operators, implementation inheritance and interface inheritance. In implementation inheritance, the child inherits all of the parent's attributes, but only the containment associations where the parent functions as the container. No other associations are inherited. Interface inheritance allows no attribute inheritance but does allow full association inheritance, with one exception: containment associations where the parent functions as the container are not inherited.

Figures 1-3 provide an example of the metamodel merge with MetaGME. Figure 1 shows part of a DMSL for modeling the properties of software components and their deployment onto abstracted hardware components for execution, and Figure 2 shows part of a DSML for modeling the details of hardware components. It might make sense to merge these two DSMLs and get a combined language that can capture details about both the hardware and the software of a particular system. In Figure 3, the Class Equivalence operator (the hollow diamond) is used to fuse the top-level concepts from each language dealing with hardware. The new class resulting from this fusion will have a new name (specified on the Class Equivalence object) and include the SecurityEnclave attribute from the ProcessingModule class.

2.2 Metamodel Interfacing

The metamodels of two DSMLs capturing two conceptually distinct but related domains may be composed to explore the interactions between the two domains. Performing this composition requires the delineation of an interface between the

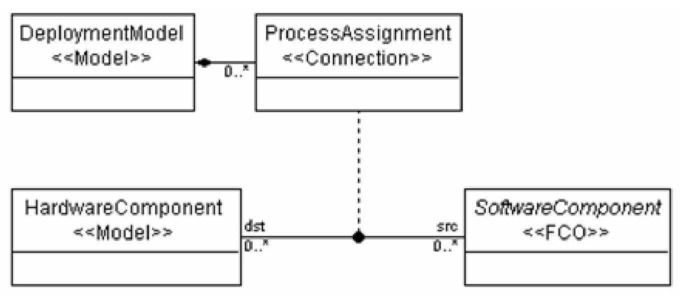

Figure 1: Software deployment metamodel fragment

two modeling languages consisting of new modeling entities and relationships that do not strictly belong to either of the composed modeling languages.

For an example use case, imagine that we had a language for modeling system requirements and a separate language for modeling hardware and software. It would be useful to interface these two languages to enable the traceability of requirements to the hardware and software components that satisfy them. Figure 4 below displays the additional metamodel fragment needed to interface the two DSMLs. In this figure, Requirement originates from one metamodel while HardwareComponent and SoftwareComponent originate from a second metamodel. The interface between the two metamodels when composed consists of a new model view, TraceModel, which can contain references to Requirements, SoftwareComponents, and HardwareComponents. A new type of connection, RequirementTrace, is also defined to relate the requirements to the components that satisfy them.

2.3 Class Refinement

Class refinement may be utilized when one DSML captures in detail a modeling concept that exists only as a "black box" in a second DSML. This technique is employed similarly to metamodel interfacing, but the relationship between the two composed modeling languages is given by the hierarchical containment of the constructs of one metamodel within a single construct of another metamodel.

For example, consider a simple DSML for modeling the topologies of electronic components of automobiles as depicted in Figure 5. Eventually, the details or behaviors of the components may need to be elaborated, so it may become necessary to further refine the Component language construct. Suppose we want to view the automobile model as a system of concurrent communicating finite state machines. In that case, we would need to refine the Component model using the constructs from the FSM metamodel shown in Figure 6. The composition of the

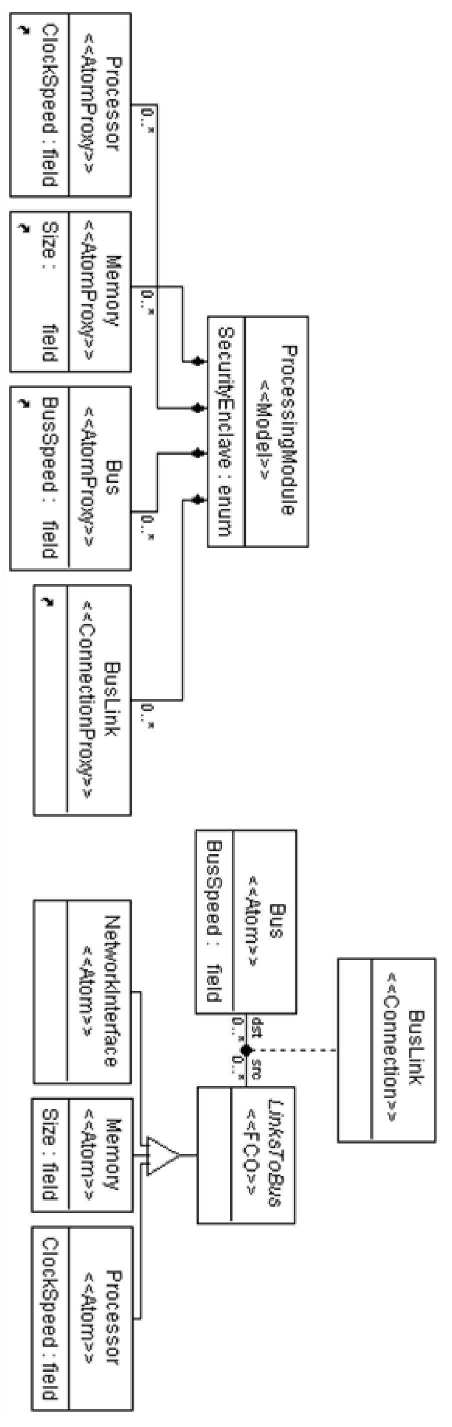

Figure 2: Hardware component metamodel fragment

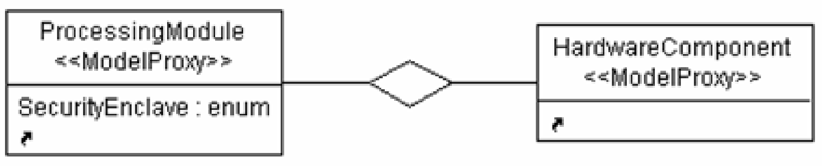

Figure 3: Class merge

two metamodels is shown in Figure 7.

3 Template Instantiation: A New Metamodel Composition Method

Template Instantiation is a new metamodel composition technique we propose to overcome a limitation of the previously-discussed techniques. It is intended to support the multiple reuse of common metamodeling patterns or styles in a single composite metamodel. In Template Instantiation, we record common metamodeling patterns as abstract metamodel templates, then instantiate (replicate and concretize) those templates in domain-specific metamodels. Our previous experience with the definition of modeling languages has resulted in the discovery of a number of commonly-occuring metamodeling patterns. These candidate metamodeling templates include (but certainly are not limited to):

- Composition hierarchies of composite and atomic objects
- Modular interconnection, in which composite objects are associated through exposed ports (a specific incarnation of this pattern would be component-based modeling)
- StateCharts-style modeling
- Data Flow graphs
- The proxy metamodeling pattern, in which a reference type is defined for an class with the same attributes, composition roles, and associations as the class itself

Each of the above patterns repeatedly occur in new DSML specifications, and some may potentially be used multiple times in the same metamodel, so they are good candidates for metamodeling templates.

The previously-discussed metamodel composition techniques are not suited toward the multiple reuse of metamodel fragments within the same composite

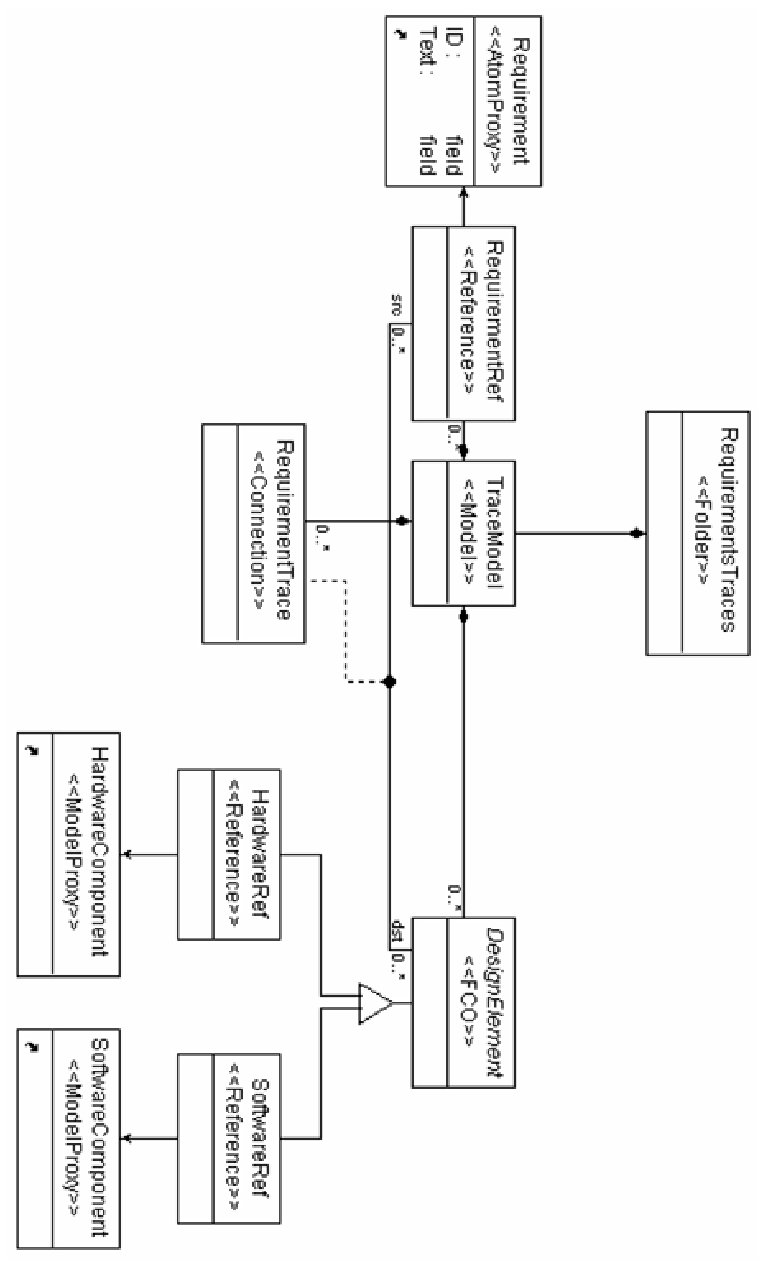

Figure 4: Metamodel Interfacing

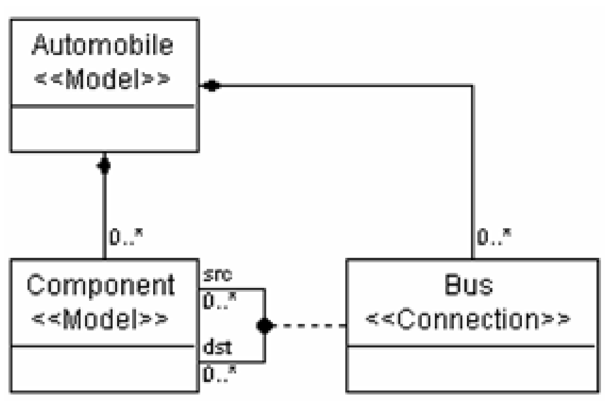

Figure 5: Automobile electronic component metamodel

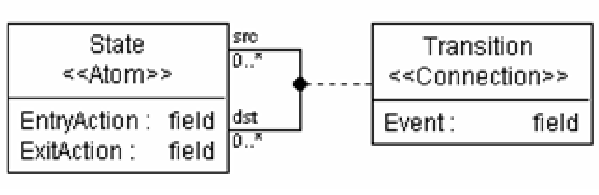

Figure 6: FSM metamodel for capturing component behavior

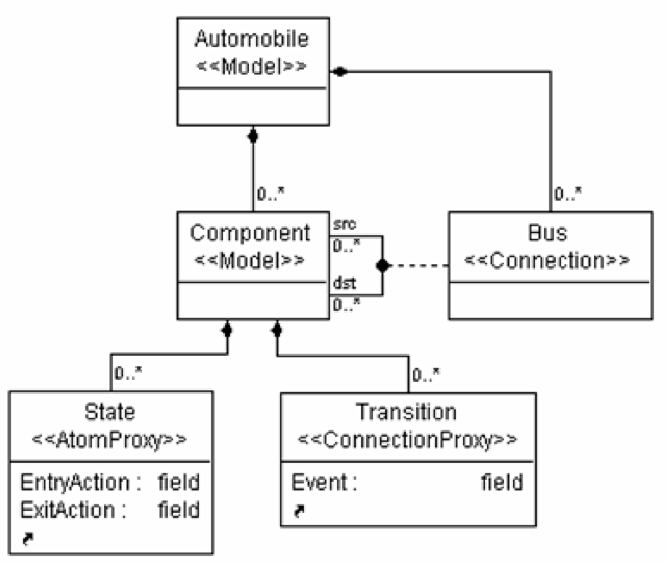

Figure 7: Automobile electronic component refinement

metamodel. To demonstrate this limitation, we can consider a simple example: using Metamodel Merge to incorporate hierarchy into the metamodel shown in Figure 8. This metamodel captures a Data Flow language where the internal behavior of the Data Flow Actors is captured using FSMs. Now, suppose we want to be able to define hierarchical Actors that contain whole Data Flow graphs, and we want the FSMs in this language to be hierarchical as well. We will attempt to do this by merging in the abstract Hierarchy metamodel depicted in Figure 9. The composition using Metamodel Merge (inheritance, in this case) is shown in Figure 10.

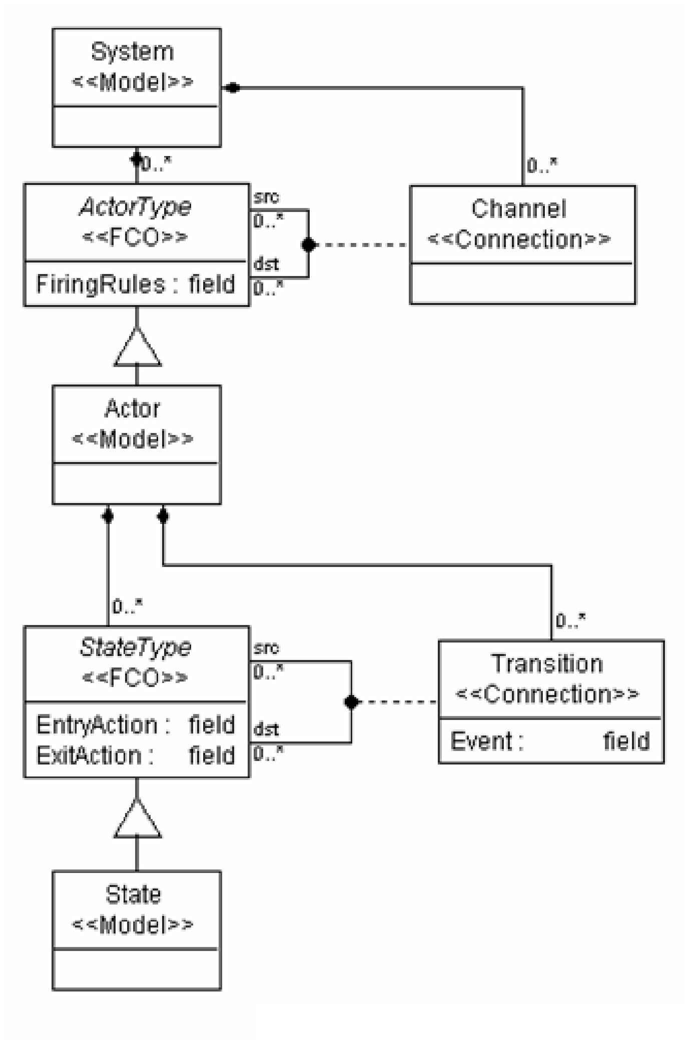

Figure 8: Metamodel for Data Flow with embedded FSM

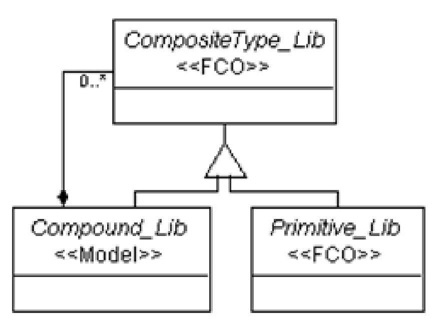

Figure 9: Hierarchy metamodel fragment

Unfortunately, in the metamodel resulting from the merge the composition has had an undesired side-effect: according to Figure 10, FSM States can contain Data Flow Actors! In fact, any time Metamodel Merge is used to merge in the same metamodel in multiple places, as was done in this simple example with the Hierarchy metamodel, these kinds of unintended consequences can occur. Furthermore, neither Metamodel Interfacing nor Class Refinement may be usefully applied in this example. What we really need is a way to make use of the hierarchy pattern without explicitly and repeatedly importing a metamodel that captures hierarchy. We need a templated approach.

Unlike the other metamodel composition techniques discussed here, Template Instantiation does not operate by importing an external set of entity types into a target metamodel. Instead, it automatically creates new relationships between the pre-existing entity types in a target metamodel to make them play roles in a common metamodeling pattern. Tool support is key for Template Instantiation. We outline the following process for using this metamodel composition method:

1. The user indicates that they would like to instantiate a particular template within a domain-specific metamodel.

2. A Template Instantiator tool looks up the appropriate template. The template is actually an abstract metamodel fragment specifying a set of roles (the classes) and relationships between the roles.

3. The Template Instantiator queries the user to determine which class in the user's metamodel should play each role proscribed by the selected template. If the user's metamodel contains no class suitable for playing a given role from the template, they may select “None”.

4. The Template Instantiator updates the user's metamodel with the instantiated template by constructing new relationships between the classes in the

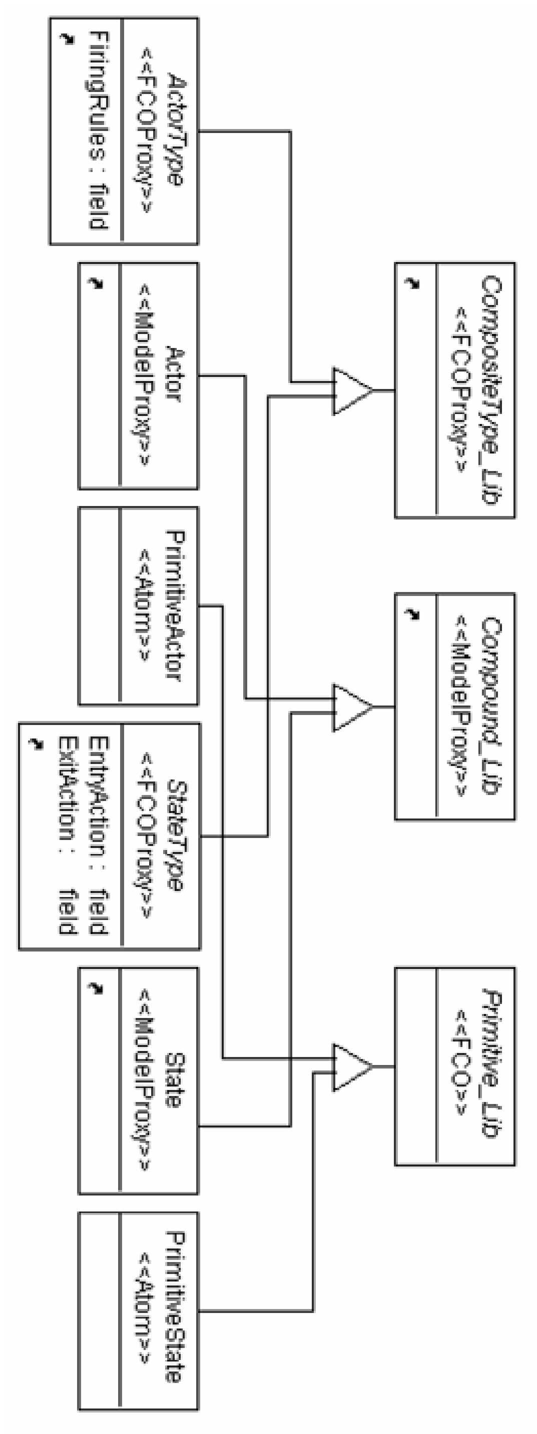

Figure 10: Adding in hierarchy using Metamodel Merge

user's metamodel. The unbound template roles (those for which the user selected "None" in step 3 above) are also included as new classes with place-holder names indicating the role to be played. It is up to the user to edit these newly-added classes as appropriate for the language's intended domain.

We have implemented a simple prototype Template Instantiator tool for GME. For our tool, metamodeling patterns can be captured as templates using the standard GME metamodeling language. Each pattern should be captured in a separate modeling project. Our Template Instantiator guides users through the selection of the template to be used and the assignment of template roles to domain-specific language concepts, then automatically edits the user's domain-specific metamodel as appropriate to instantiate the template. Our prototype may be downloaded from [13] for experimentation.

Let's try applying Template Instantiation for our hierarchy example above using the GME Template Instantiator. We need to run the Template Instantiator two times, once for the FSM part of the language and once for the Data Flow part of the language. In the first run of the Instantiator, the user selects class StateType to play the roll of CompositeType_Lib, the class State to play the role of Compound_Lib, and leaves the Primitive_Lib role unbound. In the second run of the Instantiator, the user selects the ActorType class to play the role of CompositeType_Lib, the Actor class to play the role of Compound_Lib, and again leaves the Primitive_Lib role unbound. This results in the metamodel depicted in Figure 11. To finish out the metamodel, the user merely needs to replace the place-holder classes, ActorType_Primitive and StateType_Primitive, with appropriate domain-specific classes. The final result does not have the unanticipated side-effects caused by using the Metamodel Merge technique, and merges in the hierarchy capability in the way the user intended. Furthermore, by employing a template, the user has taken advantage of the experience and best-practices knowledge of the metamodeler who made the template.

4 Related Work

A foundational metamodeling paper by Brinkkemper [5] describes most of the the basic issues of modeling language composition (or in Brinkkemper's terminology, method engineering) that we review. Brinkkemper considers the composition of both abstract syntax and static semantics (well-formedness rules). However, his definition of metamodel composition is not expansive enough to include MOF's Package Merge technique or our Template Instantiation technique.

Other previous work by Zhang [14] developed a generic framework of model

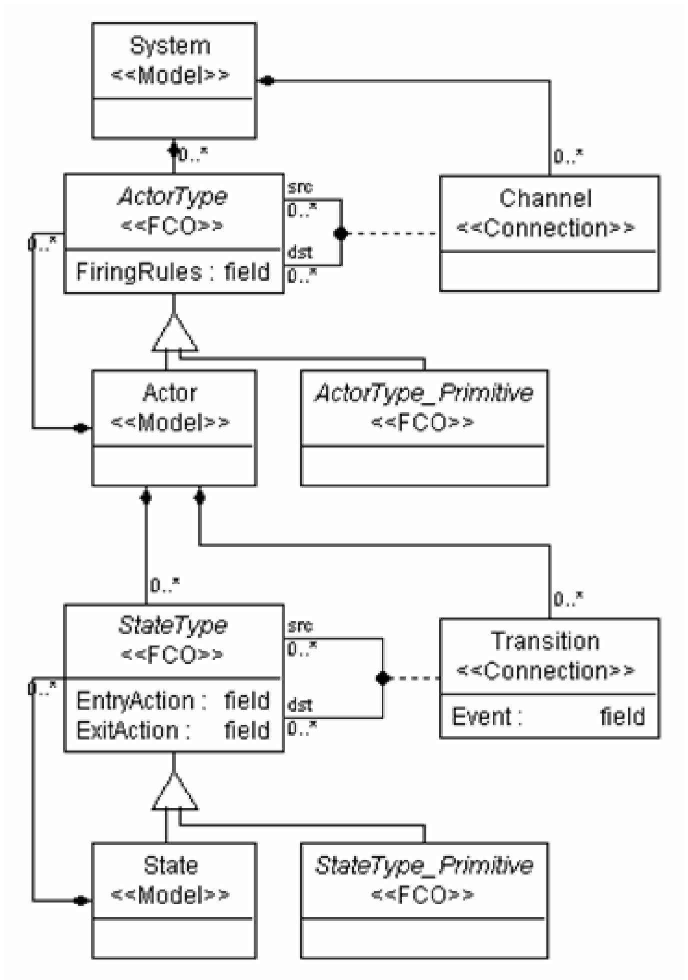

Figure 11: Adding in hierarchy using Template Instantiation

reuse that was applied to the native reuse capabilities of the metaprogrammable modeling tool MetaEdit+ [12]. His framework defines several categories of reuse:

- **Functional:** the reuse of roles, primarily through inheritance
- **Conceptual:** the reuse of conceptually related model fragments through mapping or transformation
- **Instantiation:** the reuse of model fragments across distinct but similar domains using a series of model migration rules expressed at the metamodel level.

The primary proof-of-concept for Zhang's framework is the development and reuse of a MetaEdit+ metamodel fragment for modeling components. Although the framework is discussed and evaluated in the context of MetaEdit+, it could be adapted to apply to any metaprogrammable modeling tool because it is generic with respect to the metamodeling formalism used and the details of how the reuse is actually accomplished.

While Zhang focuses on the general ways in which individual model artifacts may be reused, the Metamodel Merge, Metamodel Interfacing, and Class Refinement techniques we reviewed above focus on the details of how multiple metamodel fragments may be composed or related in the context of class diagrams-style metamodeling. Our Template Instantiation technique can be classified as a specific incarnation of Zhang's Functional Reuse - both share a strong focus on entity roles.

5 Future Work: Composite Metamodel Semantics

The formal specification of modeling language semantics is a key current issue for model-based engineering. A wise approach to the specification of semantics is to rely on well-established formal models of computation, such as finite state machines, data flow, and discrete event systems. Semantic Anchoring is one such approach for the formal specification of DSML semantic domains and semantic mappings. It mandates the use of canonical, executable models of computation for semantic domains and the use of graph transformation algorithms for semantic mappings. Because models of computation capture widely-used, standardized, formal patterns of execution, they are ripe for reuse. The question of reuse is especially important when languages with heterogeneous semantics are considered - that is, languages with semantics defined by some combination of interacting models of computation. In the sections above we described the ways in which modeling language syntax may be composed, but what can the composition of syntax tell us about the execution semantics of the resulting unified modeling language? If it is possible to compose and reuse syntax specifications, how can semantic specifications similarly be composed and reused? It seems intuitive that if the syntaxes of two semantically-anchored languages are composed using one of the techniques outlined in this paper (for example, Metamodel Merge), then the structural part of the composite semantic domain can be created using the same technique. Further work is needed to bear this idea out.

One of the key requirements to make the Semantic Anchoring approach practical is the availability of a library of reusable Semantic Units to act as composable semantic domains for DSMLs. However, even with such a library to draw on, the semantic mappings must currently still be done completely by hand. In the comprehensive DSML design environment we envision, users will enjoy tool support that enables the automatic generation of these mappings from DSML syntax. Of course, this can only be possible where the syntax itself contains clues regarding its intended semantics. One way of providing these clues is to create a library of syntax fragments corresponding to the library of Semantic Units, where each syntax fragment has a pre-specified semantic mapping onto a Semantic Unit. By "mixing in" the syntax fragments with a DSML metamodel through Metamodel Merge composition, users could effectively tag each domain-specific modeling concept with information about its role in the intended language semantics. The use of these mix-in syntax libraries would also help encourage the specification of DSML syntax that maps cleanly onto available Semantic Units.

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On Relationships among Models, Meta Models and Ontologies

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Abstract

In this position paper, we discuss the relationships among domain specific models, domain specific ontologies, meta models and a meta model ontology, in order to provide seamless semantics for both of models and meta models. By using the same semantic framework, we can detect semantic inconsistency included in models and meta models by using inference rules on the ontologies.

1 Introduction

Meta modeling techniques play an important role of developing model description languages suitable for problem domains, and they define abstract syntax of the model description languages. In fact, the UML meta model defines abstract syntax of all kinds of UML diagrams. However, meta models can express the logical syntactical structures of domain specific models (simply models, hereafter) only, and cannot specify the semantics of the models. There are many studies to combine modeling techniques with the formal methods having rigorous semantic basis, e.g. Class diagram and Z, and they provide transformation rules of a model description into a formal description like Z. In a broader sense, the transformation can be considered as an interpretation and the semantics basis of the formal description provide the formal semantics for the model description. However, these approaches are for general purpose and do not consider domain-specific properties. In particular, semantics where domain specific properties are embedded, i.e. domain-specific semantics is very significant for domain-specific modeling description languages.

On the other hand, there are a few works to provide the formal semantics for meta models, not for models. MEL (Method Engineering Language) [4] is a language to describe meta models and it gives the semantics to a meta model by using an ontology called method ontology. In [12], the schema of the rules to transform a model description such as a class diagram into a formal description like Z are defined with graph grammar and it presented that the semantics of a meta model can be considered as these transformation rules. However, in these works, none of logical relationships to the semantics of the models as instances of the meta model could be found. The semantics of the meta model should be seamlessly connected to the semantics of the models.

In this position paper, we propose the usage of ontologies for domain specific semantics of models and for the semantics of meta models. By using two types of ontologies, we give semantics to both of a meta model and models as the instances of the meta model simultaneously. As a result, we can formally infer various properties of the meta model and the models in the same framework.

The rest of the paper is organized as follows. In the next section, we introduce the basic idea and clarify the relationships among models, domain-specific ontologies (domain ontologies), meta models and the ontology of meta models called meta model ontology. In our framework, a domain ontology play a role of a semantic domain for the models, while the meta model ontology provides a semantic basis on the meta models specifying abstract syntax of modeling description languages. To show the beneficial effects of our technique, we illustrate an example of consistency checking between a class diagram and a sequence diagram in the domain of Lift Control. By using this example, sections 3, 4 and 5 present the details of the semantic relationships between meta models and a meta model ontology, between models and domain ontologies, and between the meta model ontology and the domain ontologies, respectively. In section 6, we list up research agenda for future work.

2 Basic Idea

Ontology technologies are frequently applied to many problem domains nowadays [6, 14]. As mentioned in [11], we consider an ontology as a thesaurus of words and inference rules on it, where the words in the thesaurus represent concepts and the inference rules operate on the relationships on the words. Each concept of an ontology can be considered as a semantic atomic element that anyone can have the unique meaning in a problem domain [13]. That is to say, the thesaurus part of the ontology plays a role of a semantic domain in denotational semantics, and the inference rules help a model engineer (an engineer for developing models) in detecting lacks of model elements and semantically inconsistent parts during his or her model-development activities [8]. As mentioned above, we develop two types of ontologies; one is an ontology of meta models and another is an ontology of a problem domain, called domain ontology. A model is an instantiation of a meta model and it is semantically interpreted by the domain ontology. A domain ontology is an instantiation of the ontology of meta models. Figure 1 depicts the relationships among these ontologies, a model and a meta model. Models are instances of a meta model and their logical and syntactical structures should obey the meta model. For example, a sequence diagram shown in the left part of Figure 4 is an instance of the meta model of sequence diagrams shown in the left bottom part of Figure 3. Constraints appearing in the left part of the figure are imposed on the instances. For example, Constraints #2 attached to Meta Model are for the instances of the meta model, while Constraints #1 are for the instances of the model, i.e. M0 layer in MOF. Semantic mappings appearing in Figure 1, including a simple example, will be mentioned in section 2.

As mentioned in section 1, an ontology plays a role of a semantic domain in denotational semantics. Basically, our ontology is represented in a directed typed graph where a node and an arc represent a concept and a relationship (precisely, an instance of a relationship) between two concepts, respectively.

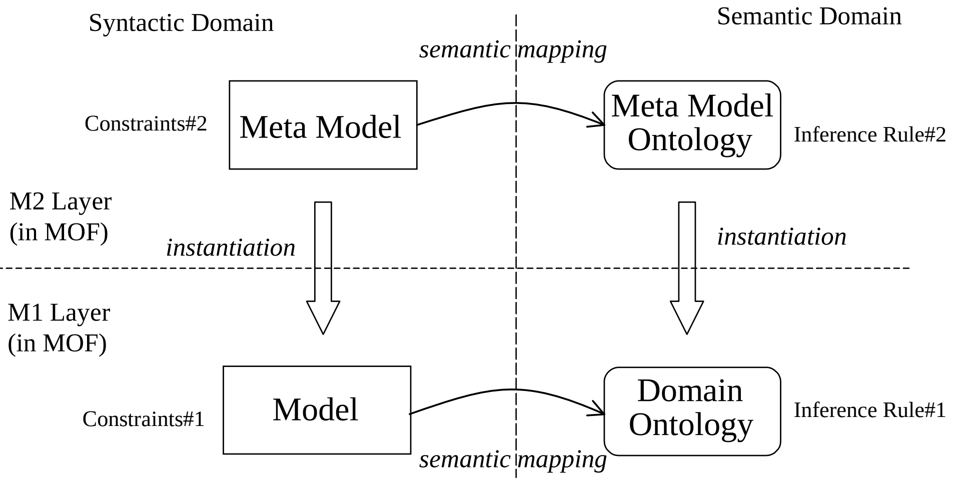


Figure 1: Relationships among Ontologies, a Model and a Meta Model

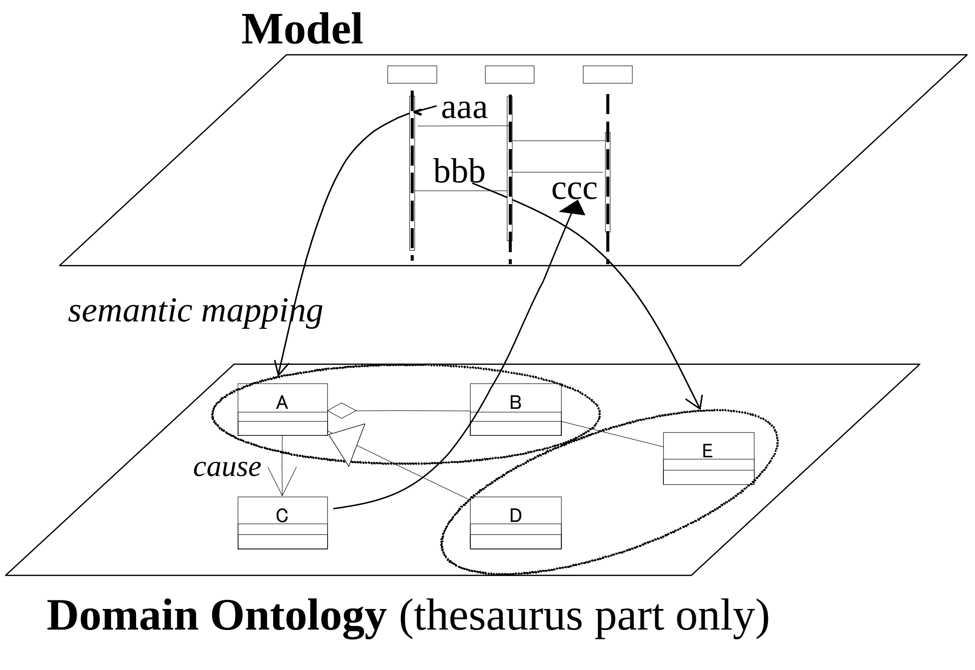


Figure 2: Mapping from a Model or a Meta Model to an Ontology

Below, let's consider how a modeling engineer uses a domain ontology for completing a model. During developing the model, the engineer should map its model element into atomic concepts of the ontology as shown in Figure 2. In the figure, the engineer develops a sequence diagram, while the domain ontology is written in the form of class diagrams. For example, the message "aaa" in the sequence diagram is mapped into the concepts A and B and an aggregation relationship between them. Formally, the engineer specifies a semantic mapping $\mathcal{F}$ where $\mathcal{F}$(aaa) = $\{$A, B, an aggregation between A and B$\}$. The sequence diagram may be incrementally improved, and logical inference on the ontology suggests to the engineer what part he or she should incrementally improve or refine. In the figure, although the model includes the concept A at the item "bbb", it does not have the concept C, which is caused by A. The inference resulted from "C is caused by A" and "A is included" suggests to the engineer that a model element having C, i.e. a message "ccc" should be added to the sequence diagram. In our technique, it is important what kind of relationship like "cause" should be included in a domain ontology for inference, and they result from an ontology of meta models as will be discussed in the next section.

3 Meta Models and Meta Model Ontology

The technique mentioned in the previous section can help a meta-model engineer (engineer for developing meta models) in constructing a meta model of semantically high quality. Suppose a simple example of a meta model consisting of simplified versions of Class Diagram and Sequence Diagram of UML. Following this meta model, another engineer, i.e. a model engineer constructs a class diagram of the information system to be developed, and then develops the sequence diagrams, each of which defines an scenario of the interactions among objects belonging to the classes appearing in the class diagram. The left part of Figure 3 illustrates the meta model written with Class Diagram. For simplicity, we use Class Diagram for specifying meta models. Although context-free aspects of abstract syntax of models can be defined with Class Diagram, some of context-sensitive aspects cannot. For example, the constraint that the same class name cannot appear more than once in a class diagram cannot be specified in Class Diagram by itself, and therefore we use first order predicate logic to express this kind of constraints. The above example constraint can be represented as follows;

$\forall c1, c2 \in Class \cdot ((name(c1) \neq name(c2)) \vee (c1 = c2))$

where $Class$ denotes a set of classes appearing in the class diagram and is from the meta model Class Diagram. This constraint is an example of Constraints #2 in Figure 1. Although the usage of OCL is natural to specify these kinds of constraints, we actually have used Prolog for implementation because of its query functions and interfaces to Java.

A meta model ontology can give the meaning of the elements of a meta model in the same way as the technique mentioned in the previous section. The right part of Figure 3 depicts a part of a meta model ontology, which is a simplified version of [7]. During developing a meta model, a meta-model engineer maps its elements into a part of the meta model ontology. In the example of the figure, the meta-model engineer maps Class and Object in the meta model into the concepts Class and Object respectively. Attribute is mapped into a set of $\{$State, Data$\}$, because attributes in a class play roles of the states of the object belonging to the class and of the local data that the objects have. Let $\mathcal{G}$ be the semantics mapping of the this example, and we can have

$\mathcal{G} : MetaModelElements \mapsto 2^{MetaModelOntologyElements}$

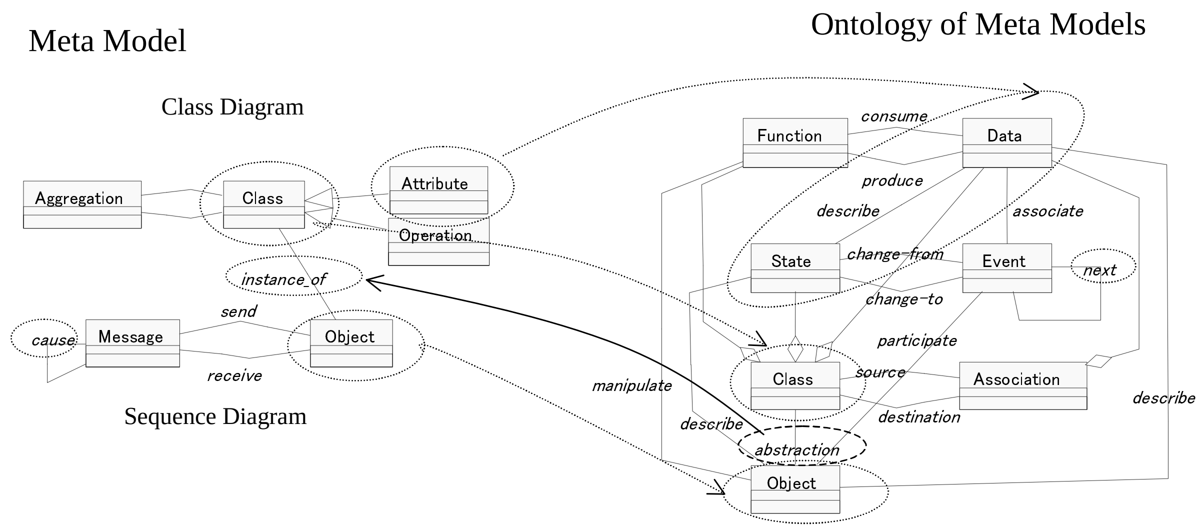


Figure 3: Meta Model and Meta Model Ontology

$\mathcal{G}$(Class) = Class, $\mathcal{G}$(Object) = Object, and $\mathcal{G}$(Attribute) = {State, Data},

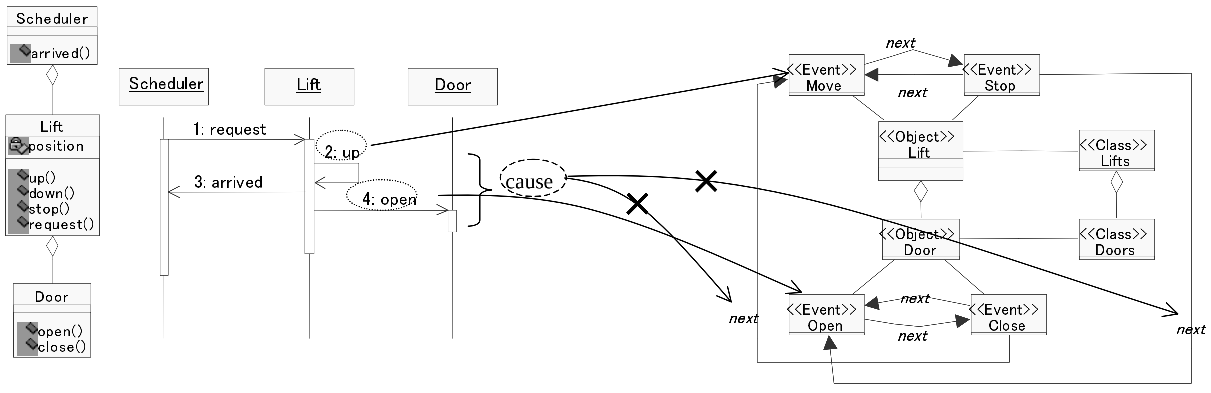
where $MetaModelElements$ and $MetaModelOntologyElements$ are a set of meta model elements such as Class and Message, and a set of elements of the meta model ontology such as Function and State, respectively.

Note that the example meta model is the result of assembling the meta models Class Diagram and Sequence Diagram by adding a new association *instance_of*. If a meta-model engineer did not add this new association, he or she got two isolated meta models as a result. This resulting meta model was not considered as a useful one, because a model engineer can construct class diagrams and sequence diagrams independently. The benefit of assembling Class Diagram and Sequence Diagram is the semantic relation between Class in Class Diagram and Object in Sequence Diagram to specify the behavior of instances of classes with sequence diagrams. The inference rule that a consistent meta model should not include isolated elements can be formalized with predicate logic and its detail was shown in [3]. This inference rule is an example of Inference Rule #2 in Figure 1.

The above example is a syntactical aspect of meta models. By establishing a semantic mapping meta model elements into the ontology, we can avoid producing semantically meaningless meta models [3]. The meta model ontology has several inference rules to keep semantic consistency on meta models. In this example, the inference rule “If both Class and Object concepts are included in a meta model, the association whose type is *abstraction* among them should be also included in the meta model” suggests to add a association that can be mapped to *abstraction*. See the figure 3. This mechanism is the same as the logical inference of on models that domain ontologies have, mentioned in the previous section.

4 Model and Domain Ontology

The left part of Figure 4 illustrates a model following the meta model of Figure 3, consisting of a class diagram and a sequence diagram. This example is a part of Lift Control System and the right part of the figure shows a part of a domain ontology of Lift Control System domain.



Model (Class Diagram + Sequence Diagram) Domain Ontology in Lift Control Systems

Figure 4: Model and Domain Ontology

We will explain stereotypes attached in classes of the domain ontology in the next section. The model engineer maps the messages "up" and "open" in the sequence diagram into Move and Open concepts of the ontology, during developing the model, as shown in Figure 4. And he or she tries to map *cause* relationship between the messages "up" and "open" into the association of type *next*. However, no events but Stop can be executed just after Move is executed because the domain ontology of Figure 4 specifies that Move has only one outgoing *next* relationship to Stop. Thus the inference rule on the ontology suggests that there are no *next* relationships between Move and Open and some events should be added to keep semantic consistency of execution order *next* relationship. Obviously, in this case the engineer should add the message Stop between "up" and "open", which a Lift object sends to a Door object. The used inference rule is "If there is a *next* relationship between the concepts A and B in the domain ontology, then the elements mapped to A and B in the model, if any, should have the association mapped to *next* among themselves. This is also an example to detect semantic inconsistency, mentioned in section 2.

5 Meta Model Ontology and Domain Ontology

The meta model ontology can be considered as a meta model of domain ontologies. The stereotypes attached to the elements of a domain ontology express instantiated concepts of the meta model ontology. In the example of Figure 4, the element Move has the stereotype <<Event>> and it is an instantiation of Event in Figure 3. By providing the instantiation mechanism from the meta model ontology to domain ontologies, we can get the following two benefits.

1. The meta model ontology helps a domain engineer in developing domain ontologies, and it can play a role of a development methodology for ontologies like Object-Oriented Methodology for software development.

2. Although semantic processing may be possible in an extent, the efforts of establishing the mapping from elements to an ontology still remain human activities. Because only human can understand the meaning of a model and a meta model. However, some supports to develop the mapping are possible by using the combination of relations among the meta

model ontology, the domain ontology as its instance and the mapping from a meta model to the meta model ontology. In Figure 1, if all of the instantiation relations and semantic mappings are isomorphic, we can infer the semantic mapping from the model into the domain ontology, by using the other relations and other semantic mappings, i.e. the instantiation from the meta model to the model, the instantiation from the meta model ontology to the domain ontology and the semantic mapping from the meta model to the meta model ontology.

We will illustrate the second benefit, by using Figure 5. Suppose that a meta-model engineer produces a meta model combining Class Diagram and Sequence Diagram fragments and establishing the semantic mapping from *cause* association in the meta model into *next* relationship in the meta model ontology. The *next* relationship is instantiated to the "next" relationship between Stop and Open events in the domain ontology. In this situation, a model engineer develops a class diagram and a sequence diagram of Lift Control System following the meta model. He or she adds the messages "stop" and "open", which has the instance of *cause* association of the meta model, and then tries to map them into some elements of the domain ontology. Since the message concept in the meta model is semantically mapped into Message in the meta model ontology and Message is instantiated to Move, Stop, Open and Close in the domain ontology, the model engineer can select the suitable ontological elements out of these four elements. After the model engineer has mapped "stop" and "open" into Stop and Open respectively, he or she pays attention to the *cause* relationship between "stop" and "open". This case is simple, because the candidate of the mapping is only one, i.e. the mapping from *cause* to the "next" from Stop to Open, as shown in the figure. Another example is to establish the mapping from *instance_of* to *abstraction* between Lifts and Lift as shown in the figure, and it can be automatically decided.

As shown in these examples, the model engineers can be supported to establish the semantic mapping, in addition to detect semantic inconsistency by using inference rules on ontologies.

6 Research Agenda

This report discussed the relationships among domain specific models, domain ontologies, meta models and a meta model ontology, and illustrated their application. We showed a technique to give semantics to both models and meta models by using ontologies and illustrated that the logical inference rules on the ontologies could automatically detect semantic inconsistency included in the models and the meta models. We classified the ontologies into two types; domain ontology and meta model ontology, and the same technique of semantic mappings helps model engineers in providing the meaning of the models. Currently, we are elaborating the meta model ontology and developing the supporting tool for semantically inconsistency checking of models. The details of research agenda in this direction can be summarized as follows.

1. Elaborating the meta model ontology. We have diverted a simplified version of method ontology mentioned in [7] as our meta model ontology. However, we need more elaborated version rather than it. There are several excellent works to construct ontologies in the domain of information systems development and software engineering processes [10, 5, 14] and we may use their results. Another approach is the application of text-mining techniques to methodology manuals written in natural language to extract the concepts and relationships so that wide varieties of meta models can be semantically described by using them.

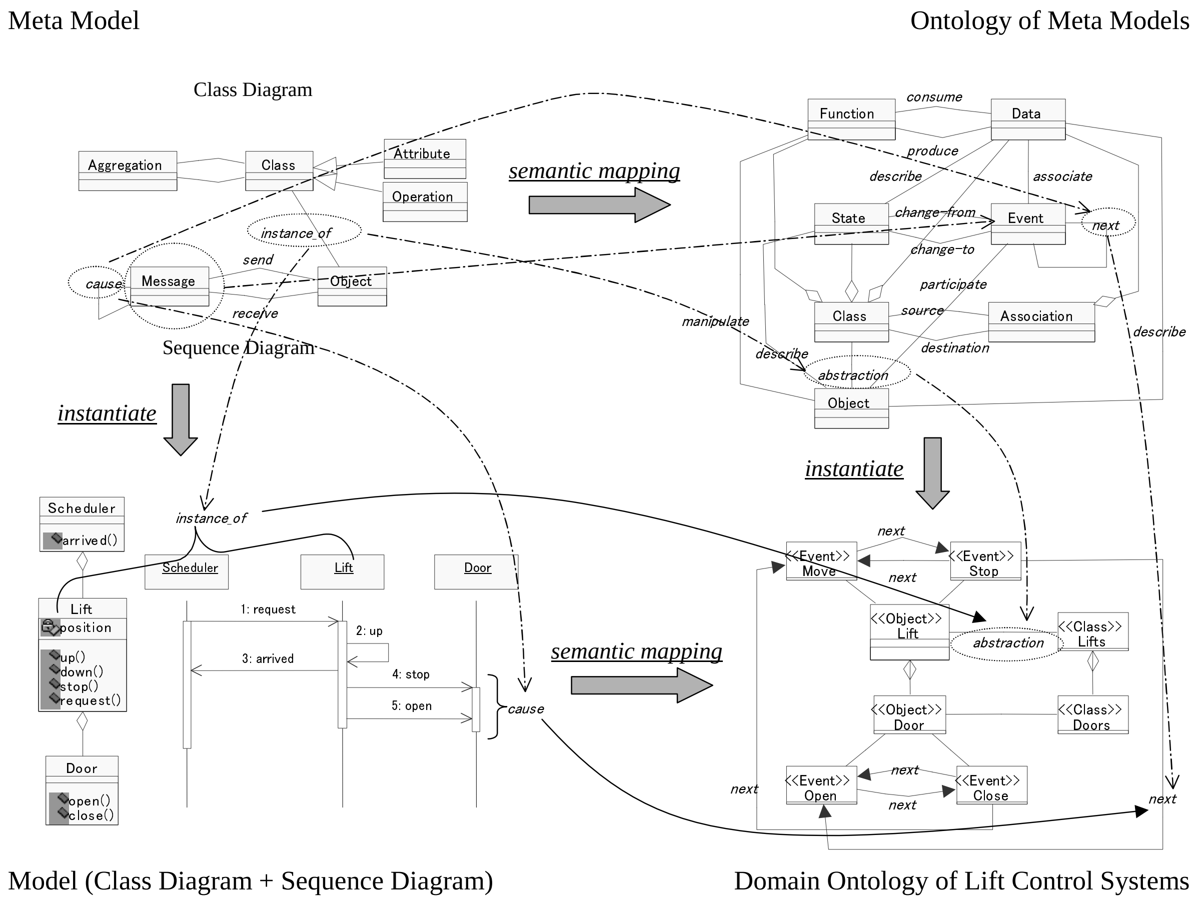


Figure 5: Meta Model Ontology and Domain Ontology

2. Supporting tool. Our inference rules are being described with Prolog because it can have application interfaces to Java like tuProlog [2]. Thus it is easier to develop GUI of the tool using Java and to extend inference rules. As a standard, description logic and its reasoning engines become more popular to specify ontologies and their inference rules. After establishing the ontologies and rules, we can shift our formalism from Prolog to description logic.

3. The supporting techniques to develop domain ontologies. Although we have a meta model of domain ontologies, developing various kind of domain ontologies of high quality by hand is a time-consuming and harder task. Adopting text mining approaches are one of the promising ones to support the development of domain ontologies [1, 9].

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Roles in Software Development using Domain Specific Modelling Languages

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Abstract

Domain-specific modelling languages (DSMLs) successfully separate the conceptual and technical design of a software system by modelling requirements in the DSML and adding technical elements by appropriate generator technology. In this paper we describe the roles within an agile development process that allows us to implement a software system by using a combination of domain specific models and source code. We describe the setup of such a process using the MontiCore framework and demonstrate the advantages by describing how a group of developers with diverse individual skills can develop automotive HMI software.

1 Roles in a DSML-based development

Domain-specific modelling enables developers to separate previously connected development activities for a software system. Thus it allows them to concentrate on a single task at a time which leads to better results [4]. Furthermore, the development becomes more efficient, as parts of work can be reused from other projects more easily. In accordance to [4] we identify (in a simplified fashion) the following three activities during development:

- Domain specific modelling languages (DSMLs) are developed, reused or existing ones are enhanced to express the desired models of the problem domain.
- Code generators are implemented that transform models to an executable solution.
- The project specific knowledge or problem description is expressed in the DSMLs and the generators are used to map these models into a running solution.

These development activities are usually applied by different people according to their individual skills. By different code generators or even direct execution of the DSL instances the models are first class artefacts within the development. They can be used for different tasks like documentation, automated tests and rapid prototyping [16]. Therefore it is worthwhile to separate the activities mentioned above and assign them to specific roles:

- A *language developer* defines or enhances a domain specific modelling language (DSML) in accordance with the needs of the product developers.
- A *tool developer* writes code generators for the DSML which includes the generation of production and test code as well as the analysis of the content and its quality. In addition tool developers integrate newly-developed or reused language processing components and generators to form tools used within the project.
- A *library developer* develops software components or libraries and simplifies thereby the code generator because constant reusable software parts do not have to be generated. Therefore this role is closely connected to the *tool developer* but requires more domain knowledge. One aim of a library is to encapsulate detailed domain knowledge and provide a simplified interface that is sufficient for the needs of the code generation.
- The *product developers* use the provided tools for different activities within the project. Mainly, they specify a solution using their domain knowledge expressed in DSMLs to directly influence the resulting software.

The language developer not only defines the syntax of the modelling language respectively the newly added concepts in that language but also describes its meaning in terms of semantics, ensures that the new concepts are properly integrated in the existing language and provides a manual for their use. It is important that the semantics of a language is not only defined by describing how the generator handles it [9].

In conventional non-agile project settings both roles, language and tool developer, are not part of the project team. In cases where a commercial off-the-shelf tool is used, they are completely unavailable. However, the experiences we made so far indicate that it is recommended to integrate these tool based service activities into the project, leading to a more agile form of development.

The running system produced by the code generator allows the product developer to gain insights into the system's behaviour and thus gives the developers immediate feedback. Then the product developer might provide new feature requests and in turn the tool and language developers change the generator implementation or the DSML itself. In accordance to an agile development process, we argue that all developers should be able to easily adapt and immediately compile the resulting system after each change to judge the influence of the applied change easily. This requirement corresponds to the agile principles of *immediate feedback* and *continuous integration* [2]. This is only possible, if the language and tool developers are available within the project. Furthermore, in smaller projects the aforementioned roles might be taken by single person, thus the language, tool, library and product developer roles are unified.

The advantage of the development steps and roles is the strict separation of the description of a solution on a conceptual level and its technical realisation. This is an example of the well know principle *separation of concerns* [5] and permits the ability to independently evolve and possibly reuse all artefacts. The approach gains its benefit from the fact that technical solutions, stored in libraries and code generators change less often than the requirements for a certain application.

Our experience is based on the development of the MontiCore framework [8] which we use to develop DSMLs and tools which process these DSMLs. MontiCore itself is developed in an agile way, where the requirements of certain DSML descriptions (the input of MontiCore) often lead to changes in the generator itself and therefore evolve the MontiCore framework. MontiCore can be automatically rebuilt after any change in a MontiCore artefact and tests with different type of granularity ensure the quality of the result.

Our agile model-driven method uses a lot more concepts of other agile methods like *Extreme Programming* [2]: on-site customer, test-first, early feedback, etc. However, instead of a code-centric approach we concentrate on executable models that we use for production and test code generation. The main idea as described in [3] is to detect errors as soon as possible and to get early feedback from customers. Furthermore, the test cases we generate run in full automation, which makes the development process really agile. An on-site customer can act as a product developer that is not only able to develop the system in an appropriate way but can also define tests using the same notation [19]. All roles should develop their artefacts in a test-first manner regardless if they use or develop DSMLs or write source code. This makes an explicit test role unnecessary.

To explain such a development process in more detail we have developed a tool chain for a Human-Machine-Interface (HMI) in an automotive context. Two DSMLs are developed and used by different roles to produce an HMI based software.

The rest of the paper is structured as follows. Section 2 describes the MontiCore framework which enables an agile development of domain-specific modelling languages and the tool support for such a development process. Section 3 describes an illustrative example for the roles in the process where DSMLs are used for the development of an automotive sub-system. Section 4 relates our approach to other publications and Section 5 concludes this paper.

2 DSML-Framework MontiCore

As an intermediate step towards a fully model-based software development process we currently advocate a development process that uses code and models at the same time and, more important at the same level of abstraction. Several kinds of models and source code together express solutions in a problem-adequate way. This means, the developers do not round-trip engineer and switch views between code and models, but use models and handwritten code as descriptions of orthogonal parts. Developers do not look at or modify any form of generated code.

In [7] we have shown how to combine Statecharts and Java source code that exceeds the approach current CASE tools provide. The developer modifies only the handwritten source code and the Statecharts without considering the generated source code. This imposes syntactic constraints between source code and Statecharts, like called events in source code must be accepted by the Statechart and events have fitting parameters, which are directly displayed on basis of the Statechart and the handwritten source code. This makes a generation tool much more useable, compared to a situation, where errors have to be traced back from the generated source code to the model.

This approach is different from the OMG MDA[13] approach, because MDA describes the usage of models at different levels of abstraction and basically one-shot model transformations to transform each models from one level down to a less abstract level. The last transformation then results in source code that forms the software system. Manual changes in the generated models resp. source code are generally allowed and therefore, repeated generation becomes difficult if not impossible. Figure 1 sketches the generation/transformation process as seen by MDA that is also similar to a classic CASE tool approach compared to our process (b) where constraints are checked between models and source code. The handwritten source code is transferred to the generated source code and changed automatically where technical details are needed to interact correctly with the source code generated from models.

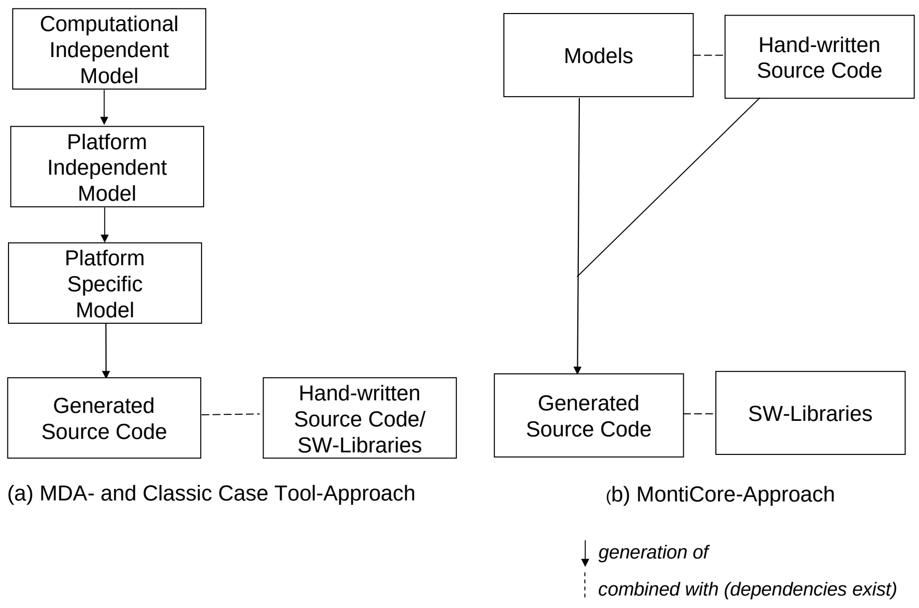
Computational Independent Model
Platform Independent Model
Platform Specific Model
Generated Source Code
Hand-written Source Code/ SW-Libraries
(a) MDA- and Classic Case Tool-Approach
Models
Hand-written Source Code
Generated Source Code
SW-Libraries
(b) MontiCore-Approach
generation of
combined with (dependencies exist)

Figure 1: Comparison of MDA and the proposed approach

Executable UML [14] describes an approach where a well-defined subset of the UML is used to model a system. MontiCore completes this approach by additionally integrating a programming language as another kind of model and providing facilities to create new kinds of models.

MontiCore allows the language developer to define a modelling language by specifying the concrete syntax in form a context-free grammar. It uses this definition first for generating a lexer/parser pair with the parser generator Antlr [15]. In addition, it generates the internal representation (abstract syntax, metamodel) of the language as derivation from the grammar in form of Java classes. Through an extension mechanism within MontiCore grammars the standard derivation process can be flexibly adapted.

The language developer can express additional constraints and features that simplify the integration of the resulting products in the DSLTool framework of MontiCore. This framework provides standard solutions for tasks like file and error handling, execution order, tree traversal, template processing [12] or target code formatting. These techniques are a solid basis for the tool developer to define model transformations, code generation, analysis algorithms and syntactic checks based on the proper semantics and the intended use of the DSML. These solutions are offered to simplify the development of specific DSML tools within the agile development process.

Consequently, MontiCore can be seen as a generator on the one hand and as a language processing support environment on the other hand. The development of the MontiCore framework itself is a proof of concept for this approach, because the framework is implemented using a partial bootstrap process.

3 DSMLs for HMIs

This section demonstrates a practical example that uses the proposed MontiCore method for developing Human-Machine-Interfaces (HMIs) in cars. HMIs provide a user interface for the comfort functions of a car and are able to provide various feedback to the user.

Nowadays most car companies use their own HMIs with differences in look and feel, functions, and handling. Even cars of a single company have various configurations with different features. Taking the project setting of developing an HMI software for a certain car manufacturer with the agile MontiCore process, we have identified different activities in the development process and associate them with our identified roles.

The cooperation of the different artefacts can be found in Figure 2. The mentioned diagram types and languages are explained in the following.

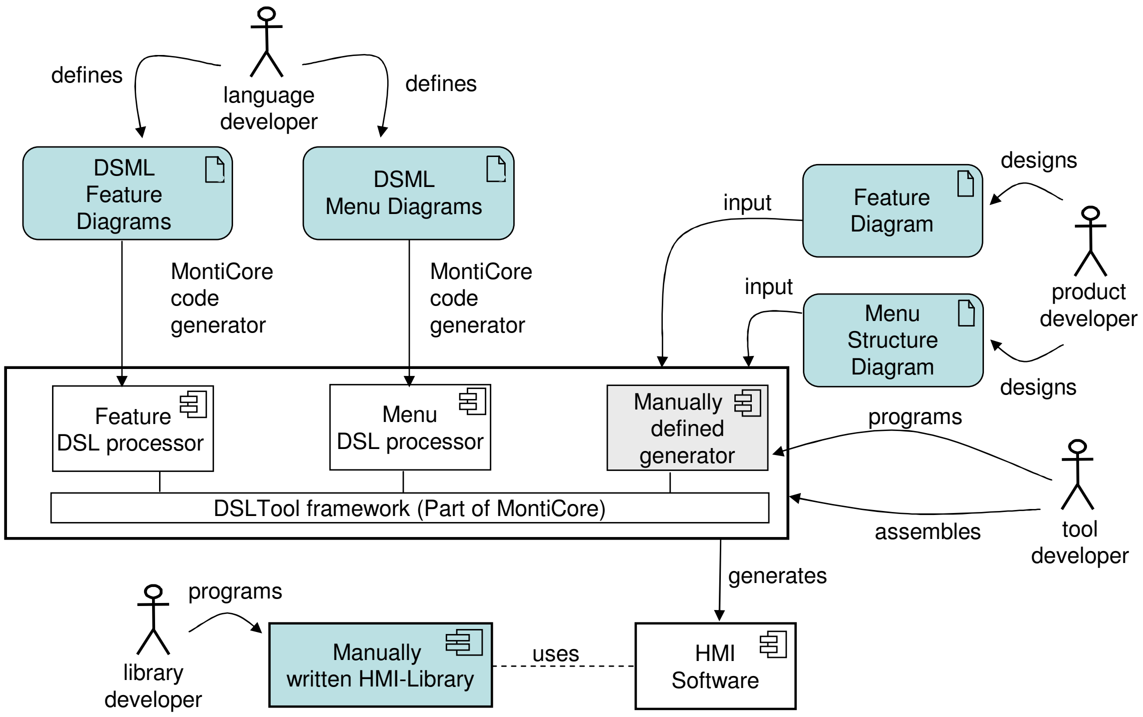

Figure 2: Generator structure for the HMI

After discussions with the product developers a *language developer* designs a DSML definition for *Menu Diagrams* that describe the menu structure of an HMI. This form of description is specific for HMIs in cars and uses concepts like menus, dialogs, status boxes and user inputs that correspond directly to the concept used by the manufacturer.

Another task for a *language developer* is to introduce *Feature diagrams* [4] to the project. These diagrams allow to model common and variable features and interdependencies between them. Figure 3 shows such a *feature diagram*. It is essentially a tree of features, that can either be mandatory or optional depending on the style of the edge: a black (mandatory) or a white (optional) circle. The edge decoration denotes alternative features. For the easier integration in the text-based tools in our proposed development process a textual notation for feature diagrams is used.

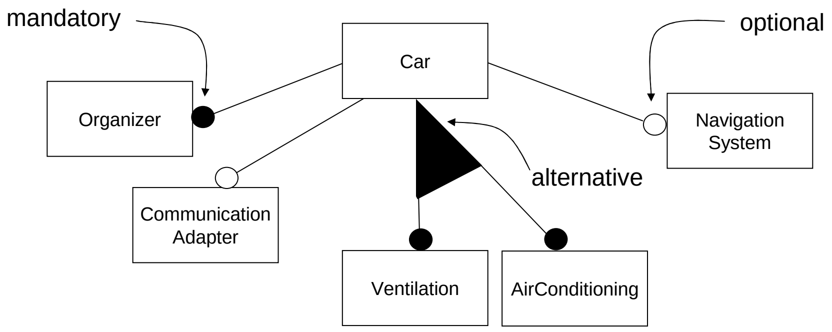

Figure 3: Feature Diagram

A *tool developer* builds a tool that comprises both languages. MontiCore is used to generate the language processing components and the DSLTool framework is configured to simplify the internal workflow and the input file handling of the tool. In addition a manually written code generator for HMI code is added to complete the tool.

The implementation of the generator is simplified by a *library developer* who develops an HMI-library that contains certain reusable code parts to program HMI software. The code generator simply configures the HMI library to form a specific HMI software.

The *feature modeller* describes feature sets which specify possible configurations of a type series and therefore is an instance of a *product developer*. An *HMI-developer* designs a menu structure for certain type series of cars. The HMI-developer therefore is another instance of a *product developer*. By using the developed tool and choosing a certain configuration for the car, he can directly generate the resulting software and simulate the result without further help of IT experts.

4 Related Work

Frequently *metamodelling* is used to create the abstract syntax of a modelling language. The Meta-Object Facilty [26] is the metamodelling technique standardised by the OMG where the metamodel is written as a simplified UML Class Diagram and OCL is used to define constraints on the abstract syntax. The MDA approach provides various ideas of integrating models into the development process which are primarily described as an input for one shot generations and therefore makes an agile process with continuous integration difficult. Due to the transformational nature of the approach the additional role *transformation definition engineer* is needed [11].

The Eclipse Modelling framework (EMF) [21] is another commonly used metamodelling framework. The meta-metamodel named Ecore can be used to create metamodels with the EMF framework itself, but also an import from a UML tool or textual notations like [10] and

[22] are possible options. Instances of the DSML can be created by a generic EMF editor. More sophisticated graphical editors can be either handwritten or created using the Graphical Modelling Framework (GMF) [24]. No strictly defined role based development process is proposed for the use with EMF.

The Generic Modeling Environment (GME) [23] is an integrated development environment for domain-specific modelling. The described MontiCore process could be adapted to be used with GME. A language developer would describe the abstract syntax of a language by a metamodel and define a graphical concrete syntax. GME is similar to MontiCore because a tool developer is supported by the environment to develop code generations or model interpretations. These artefacts can be reused inside GME to support product developers with an individually configured tool.

MetaCase's MetaEdit+ [25] uses a menu based editor to define metamodels. Models can be created through a graphical editor by drag and drop, inputs such as model names are made in input fields. MetaEdit+ uses its own *Report Definition Language* to navigate over a model instance and create code from it. The MetaEdit+ tool supports a variety of development processes and therefore does not go deep into process definition.

The *Domain-Specific Language Tools* [20] initiative from Microsoft also aims at the design of graphical DSMLs. The development is divided into three parts: definition of the metamodel, definition of (graphical) design, and definition of constraints. The meta-metamodel offers classes, value properties, and relations such as embedding (composition), reference (aggregation) and inheritance. Constraints are expressed in C#, code generation is supported by the *Template Transformation Toolkit* which allows an iterative access to DSL instances. Supported target languages for these templates are Visual Basic and C#. Sketches of an appropriate development process do exist e.g. in [6].

In [1] different roles for a model-driven development in general are presented. In comparison to our approach a more conventional software process is advocated with a separation in a meta and a project team. The paper mentions additional roles for testing and system analysis which are fulfilled by all developers in agile projects with activities like test-first design and constant feedback.

5 Conclusion

In this paper we have explained how an agile development process that uses code and models at the same level of abstraction can be used to efficiently develop a software system. We explained the different roles developers play in the realisation of a software when DSMLs are used to separate technological and application specific aspects. This technique also simplifies the integration of domain experts into a development team by giving them domain specific tools to express their knowledge without the need to go deeply into software issues.

The MontiCore framework strongly simplifies the development of DSMLs by providing an infrastructure the developer can rely on. This simplification is assisted by easy to use and quickly executed tools that enable a much more agile development process. Therefore, instead of a strict separation of tool and product developers, we are able to integrate those into the same project. In addition, we define new roles in a DSML-based project that will be carried out by developers respectively domain experts.

In the future we will further enhance the features of the MontiCore framework to be able to quickly develop more complex DSMLs. Furthermore, we will provide a number of predefined DSMLs that will serve as a basis for specific DSML definitions. Among others, we will develop a framework which supports UML/P [18, 17] as a special UML profile to model properties of a software for both, production and test code generation.

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Lightweight Domain-Specific Modeling and Model-Driven Development

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Abstract

Domain-specific modeling (DSM), especially when accompanied with powerful tools such as code generators, can significantly increase productivity in software development. On the other hand, DSM requires a high initial investment due to the effort needed for designing a domain-specific modeling language and implementing code generators. In this paper, a lightweight DSM approach that uses somewhat more generic languages and developer-guided transformations borrowed from model-driven development is discussed. It is concluded that the lightweight approach can be used as a bridge to full-blown DSM or in a context where sufficient economies of scale do not exist to justify the investment required by the latter approach.

1 Introduction

Domain-specific modeling (DSM) is commonly advocated as a means to raise the level of abstraction in software development and to achieve higher levels of productivity than with conventional languages. DSM languages borrow their vocabulary from the problem domain, letting developers concentrate on defining the problem instead of implementation-level details. Model transformations and code generators are then used for deriving an actual implentation in a computer-assisted fashion.

Model-driven development (MDD) is a related approach where abstract models are incrementally refined through model transformations, starting with a problem domain centric model, the final goal being the production of a solution-centric platform-specific model. Mainstream MDD research is, however, tightly coupled with OMG's Model Driven Architecture (MDA), where a generic modeling language, UML, is usually utilized instead of domain-specific languages.

In this paper we investigate the relationship between DSM and MDD, more specifically the use of *somewhat* domain-specific models in a context where a highly specific language does not (yet) exist, and the introduction of concepts and constructs related to the implementation domain using refinement and transformations. We refer to this approach as *lightweight hybrid DSM/MDD*. A simple mobile robot will be used as a running example.

The structure of the rest of this paper is as follows. In Section 2 we define the scope of the discussion more precisely and compare the lightweight approach to full-blown DSM. Section 3 introduces a running example and discusses a somewhat domain-specific modeling language for real-time control systems. In Section 4 it is shown how a somewhat domain-specific high-level model can be combined with an architecture, and eventually transformed to an implementation. Section 5 concludes the paper with some discussion.

2 Lightweight Domain-Specific Modeling

Domain-specific modeling languages are usually built around a tool chain that includes automatic code generation for a certain implementation platform. Provided that DSM languages, modeling tools, and code generation tools are well designed, significant increases in productivity can often be achieved. With MetaEdit+ [4], for instance, five- to ten-fold productivity increases compared to conventional coding have been reported [6].

The tradeoffs associated with the above approach are the high initial investment required for designing a domain-specific language, and the inflexibility with regard to the target platform. The latter disadvantage is of course partly due to the use of a code generator that normally only supports a certain target platform, but also to the fact that DSM languages tend to reflect a certain target architecture. In other words, DSM languages often include concepts that do not actually originate in the problem domain, but in the solution domain. In fact, the vagueness of the term *domain* is a known issue, and at least two different points of view have been identified: "domain as the real world" and "domain as a set of systems" [11].

For example, Tolvanen mentions [10] a MetaEdit+ based DSM language whose *"modelling concepts are directly based on the services and widgets that Series 60 phones offer for application development."* This reflects the "domain as a set of systems" view and is of course a valid and efficient approach when only Series 60 SmartPhones are targeted, but consider a setting where a company wants to produce the same application for both Series 60 and Microsoft Windows Smartphone platforms. In this situation, using a somewhat more generic specification language and perhaps adopting the "domain as the real world" view would make sense.

While we do not question the efficiency and usefulness of the full-blown DSM approach in many applications, in some cases a lighter, "modular" approach might be required, where slightly more generic specifications are refined in a systematic manner towards an implementation. Such an approach might have to do with lower levels of productivity increase than actual DSM, but it might be applicable in situations where DSM is not a feasible solution or defining a full-blown DSM language is simply not realistic due to the lack of experiences on the specific domain. Our proposal is based on a method framework called *specification-driven development* [8] and our experience with using a *somewhat* domain-specific specification language, DisCo [2, 1], for high-level specification in a context where architectural styles are utilized in the process of producing a more detailed design of a system [8].

DisCo is actually a formal specification language for reactive systems. Thus, if it is viewed

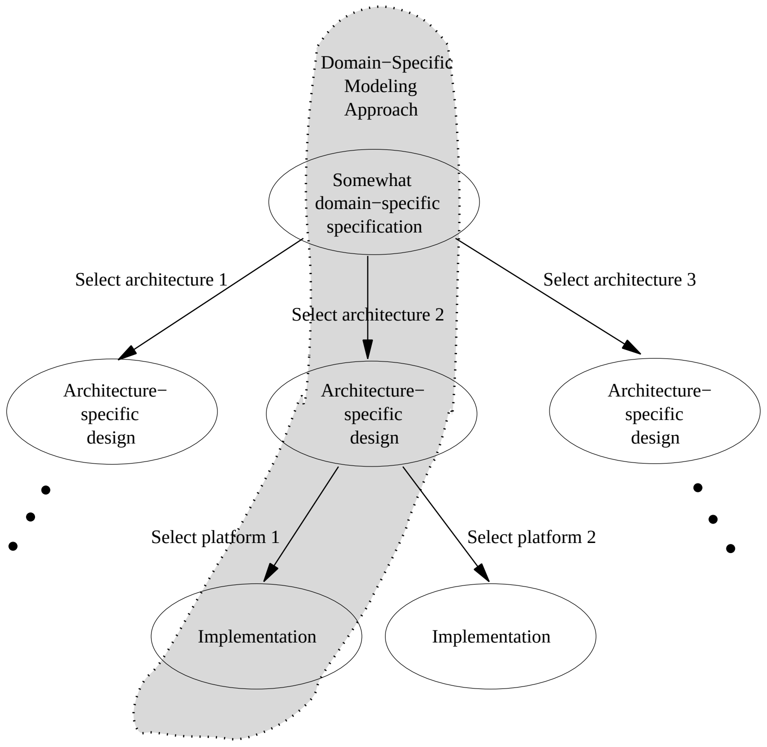

Figure 1: Lightweight hybrid DSM/MDD compared with full-blown DSM.

as a domain-specific language, the problem domain is quite large: for instance, distributed enterprise business logic fits the definition of a reactive system, as does a mobile robot control application. The defining characteristic of a system whose modeling DisCo is suitable for is that it is in continuous interaction with its environment. Real-time properties may or may not be included. DisCo is not, however, as generic as UML, as the specification of a stereotypical transformational program such as a compiler using the language would not be feasible.

The proposed lightweight hybrid DSM/MDD approach and its relationship with full-blown DSM development are illustrated in Figure 1. In the lightweight approach, a somewhat domain-specific specification-level language is used for high-level modeling, and the resulting model is then transformed into an architecture-specific design model, ideally using some kind of a transformation tool. The idea is that the sort of transformations required for this step are less laborious to define than a full-blown code generation strategy for a DSM language because the transformation process is developer-guided. Furthermore, a more generic but still somewhat domain-specific language has a wider scope of applicability, and therefore it can be used in a context where defining a fully tailored language would be overkill.

In contrast, a full-blown DSM approach (whose scope covers the grey area in Figure 1) requires that architects and domain experts define a tailored specification language and specify how the different constructs are mapped into code, or even implement a code generator manually. Such a language-and-tool-chain is restricted to a particular combination of a problem domain, architecture, and implementation platform. The raise in productivity can indeed be high, but there are situations in which the approach is not applicable, for instance

- if only one or a small number of similar projects are planned, and the high initial investment required by DSM cannot be justified, or
- if precise enough estimates about performance issues cannot be done without first writing some sort of a specification, and if the results of this evaluation affect the choice of architecture and/or implementation technologies, or
- if several different implementation platforms are targeted.

In short, the lightweight hybrid DSM/MDD approach is perhaps more suitable than full-blown DSM for pilot type projects and environments where sufficient economies of scale do not exist. Additionally, the approach can be used in the initial phases, before a full-blown DSM toolchain has been implemented, to aid in defining the scope and concepts of a DSM language, and selecting the right architecture and implementation platform to commit to.

3 Example: High-Level Model of Digibot

We will illustrate lightweight hybrid DSM/MDD using a simple mobile robot as an example. The mobile robot is based on Tutebot, a simple robot introduced by Jones and Flynn [3]. While the original Tutebot was implemented using analogue electronics, our version is digital and therefore called Digibot. A more verbose discussion on the Digibot model can be found in [8], where also animation and model-checking are used for validating and verifying the specification.

Like Tutebot, Digibot wanders around a room, traveling straight ahead until it encounters a wall or some other obstacle. It has two sensor switches attached to the front bumper, one on the left and one on the right. Depending on which side touches the obstacle, Digibot shall back up in an arc towards the left or the right before starting to travel straight ahead again. Thus, the robot will travel a route that resembles that in Figure 2.

3.1 DisCo Specification of Digibot

In a full-blown domain-specific development approach a tailored modeling language with concepts related to timers, sensors, actuators, motors, etc. would probably be utilized for specifying Digibot. Ideally, a code generator would then produce a complete implementation for a certain hardware platform, such as an Atmel AVR based controller card.

In contrast, we use DisCo as a specification language that is biased towards reactive real-time systems, but does not prescribe a single implementation platform or even a general architecture – there are modeling constructs for concepts such as deadlines, minimum separation, and atomic event, but no architecture-specific constructs. The specifications can be implemented using hardware as well as software.

DisCo specifications are arranged in *layers* that are superimposed on each other. Each layer typically specifies an *aspect* of the problem, and rules of superposition guarantee that safety

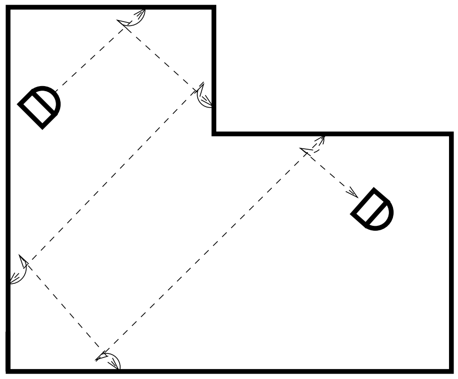
Figure 2: Route of Digibot.

```
layer abstract_robot is
  constant MIN_STOPPED: time := 0.5;

  class Robot(1) is
    mode: (STOPPED, MOVING);
    allowed_to_move_at: time := 0.0;
  end;

  action move(r: Robot) is
  when r.mode'STOPPED ∧ now ≥ r.allowed_to_move_at do
    r.mode := MOVING();
  end;

  action stop(r: Robot) is
  when r.mode'MOVING do
    r.mode := STOPPED() ||
    r.allowed_to_move_at := now + MIN_STOPPED;
  end;
end abstract_robot;
```

Figure 3: Layer abstract_robot.

properties (of the form *"something bad never happens"*) are preserved by construction. Layers can introduce *classes*, *actions*, and some other constructs, and they can refine classes and actions introduced in previous layers.

Digibot is specified in DisCo using three layers. The first layer called abstract_robot, depicted in Figure 3, specifies an abstract robot as a device that can only move or stop. The layer defines a constant time interval MIN_STOPPED that specifies the minimum duration of inactivity between periods of movement. This anticipates the capability to change direction that is to be added later on; i.e. the robot must not change the direction of rotation of its electric motors too quickly to avoid causing damage to them. The literal constant '1' in parentheses after the class name Robot indicates that there must be exactly one instance of Robot. State machine mode inside the class specifies that the robot can either be stopped or moving, and the time-valued variable allowed_to_move_at is used for implementing a minimum separation between distinct periods of movement.

Actions move and stop specify the behavioral part of the layer. The guard of action move specifies that, when stopped, the robot may begin moving when the minimum duration of inactivity has passed. The change of state is implemented using a simple assignment statement in the action body. Action stop is enabled whenever the robot is moving. The mode of execution is nondeterministic: any action whose guard evaluates to true in the current state can be exexuted. In addition to the change of state, the action body stores to the variable allowed_to_move_at the earliest

```
layer directional_robot is
  import abstract_robot;

  extend Robot by
    extend MOVING by
      dir : ( FORWARD, BACKUP_LEFT,
              BACKUP_RIGHT);
    end;
  end;

  refined forward(r : Robot) of move(r) is
  when ... do
    ...
    r.mode'MOVING.dir := FORWARD();
  end;

  refined backup_left(r : Robot) of move(r) is
  when ... do
    ...
    r.mode'MOVING.dir := BACKUP_LEFT();
  end;

  refined backup_right(r : Robot) of move(r) is
  when ... do
    ...
    r.mode'MOVING.dir := BACKUP_RIGHT();
  end;
end directional_robot;
```

Figure 4: Layer directional_robot.

instant of time at which the robot is again allowed to move.

Layer directional_robot (Figure 4) adds the notion of direction of travel to the abstract specification. When moving, Digibot is assumed to be heading forward, backing up towards the left, or backing up towards the right. This is specified by extending state MOVING by three sub-states that indicate whether the robot is moving forward, backing up towards the left, or backing up towards the right. In addition, three refinements of action move are given. They correspond to the three different directions of movement, and activate the appropriate sub-state. Note that the base action move ensures that each of these versions must respect the real-time constraint discussed above. After the refinements, the pure move action will cease to exist.

This far, Digibot is just a nondeterministic entity that can execute any sequence of stopping and moving actions as long as the sole real-time constraint is honored. To add the actual control part to the robot, layer robot_with_sensors is given in Figure 5. The time constants BACKUP_DL and STOP_BACKUP_DL define maximum time intervals for starting to back up after running into and obstacle, and stopping the backup phase. These constants are used in actions. Class Robot is extend with a state machine indicating backup mode, i.e. whether Digibot is about to back up in either direction. The contact actions modeling the closing of sensor switches are refinements of stop, i.e. sensor switch contact triggers an immediate stop. The actions modeling backing up are enabled in the corresponding backup mode, and they reset the backup_mode state machine to state NO in addition to removing the deadline for starting the backup phase and setting a deadline for stopping the backup phase. The specification also needs an ordinary stop action that brings the robot to a halt after backing up. The guard of action forward is refined to require that the robot is not currently in either of the backup modes.

Digibot is of course a very simple and small example, and does not demonstrate the full power of DisCo as a modeling language. For instance, timed automata could well be used for specifying the same system while still keeping it manageable. The advantages of layerwise refinement and adding one aspect at a time start to show in larger systems and systems that include unbounded ranges and structures or dynamic creation of objects.

```
layer robot_with_sensors is
  import directional_robot;

  constant BACKUP_DL: time := 1.0;
  constant STOP_BACKUP_DL: time := 3.0;

  extend Robot by
    backup_mode: (NO, LEFT, RIGHT);
    halt_dl : time;
    backup_dl: time;
  end;

  refined contact_left (r : Robot) of stop(r ) is
  when ... r.mode'MOVING.dir'FORWARD do
    ...
    r.backup_mode := LEFT() ||
    r.backup_dl @ BACKUP_DL;
  end;

  refined contact_right(r : Robot) of stop(r ) is
  when ... r.mode'MOVING.dir'FORWARD do
    ...
    r.backup_mode := RIGHT() ||
    r.backup_dl @ BACKUP_DL;
  end;

  refined backup_left(r : Robot) of
          backup_left(r ) is
  when ... r.backup_mode'LEFT do
    ...
    r.backup_mode := NO() ||
    r.backup_dl @ ||
    r.halt_dl @ STOP_BACKUP_DL;
  end;
  refined backup_right(r : Robot) of
          backup_right(r) is
  when ... r.backup_mode'RIGHT do
    ...
    r.backup_mode := NO() ||
    r.backup_dl @ ||
    r.halt_dl @ STOP_BACKUP_DL;
  end;

  refined stop(r : Robot) of stop(r ) is
  when ... now ≥ r.halt_dl do
    ...
    r.halt_dl @;
  end;

  refined forward(r : Robot) of
          forward(r ) is
  when ... r.backup_mode'NO do
    ...
  end;
end robot_with_sensors;
```

Figure 5: Layer robot_with_sensors.

4 Adding an Architecture to Digibot

In our approach, combining a specification and an architecture results in a *design*. A design model is a solution domain oriented description of the structure and processing of a particular system. To be complete, it has to take into account both behavioral and structural aspects. Application-specific data and behavior is imported from the specification, while a suitable architectural style is used as the source of more generic structural and behavioral elements.

We shall discuss two different architectural styles that can be applied to the Digibot specification. They are a hardware-based style, and an interrupt-driven software based style.

4.1 Hardware architecture for Digibot

An architectural style for hardware implementation of DisCo specifications (further discussed in [5]) is best described in terms of certain elements. The elements are: combinatorial block for computing the guard of an action, scheduler, sequential block corresponding to an object, and sequential block corresponding to a subsystem. A generic architecture resulting from such components is depicted in Figure 6.

The operating principle of a system based on the architecture is the following: the combinatorial blocks $G_{A_i}, i \in [1, n]$ constantly evaluate the value of each action guard. The results are input to a synchronously operating scheduler that selects one enabled action per each clock cycle

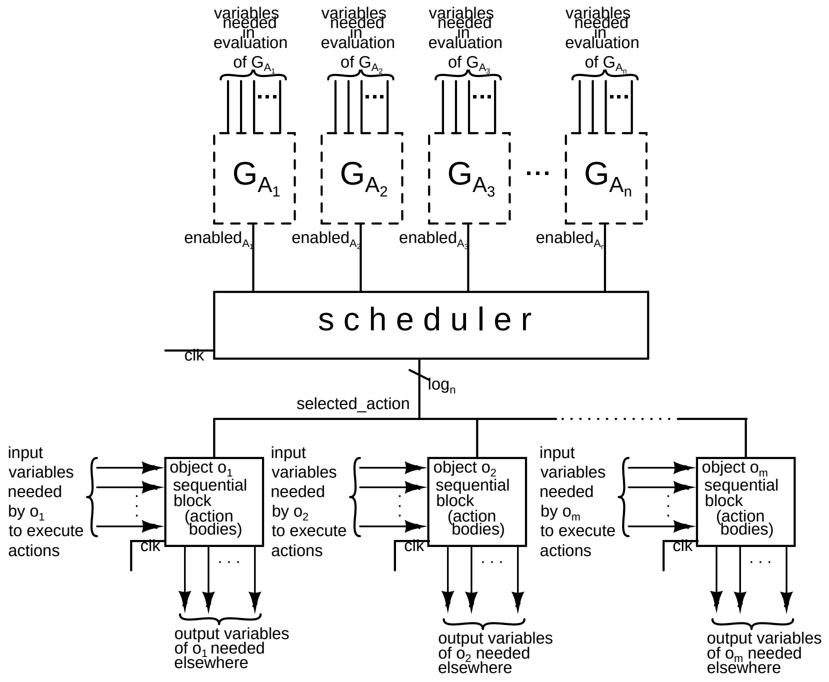
variables needed in evaluation of G_{A_1}
variables needed in evaluation of G_{A_2}
variables needed in evaluation of G_{A_3}
variables needed in evaluation of G_{A_n}
G_{A_1}
G_{A_2}
G_{A_3}
G_{A_n}
enabled$_{A_1}$
enabled$_{A_2}$
enabled$_{A_3}$
enabled$_{A_n}$
scheduler
clk
log$_n$
selected_action
input variables needed by o_1 to execute actions
object o_1 sequential block (action bodies)
input variables needed by o_2 to execute actions
object o_2 sequential block (action bodies)
input variables needed by o_m to execute actions
object o_m sequential block (action bodies)
clk
output variables of o_1 needed elsewhere
output variables of o_2 needed elsewhere
output variables of o_m needed elsewhere

Figure 6: Hardware style.

according to some scheduling strategy. The selected action is then communicated to the object blocks using a bus that can be implemented e.g. using $log\ n$ one-bit signals. Each synchronously operating object block then executes its share of the action body, and the cycle is then repeated from the beginning.

Each guard of a basic action maps to a combinatorial network (shown in the top part of Figure 6) that takes as its input signals corresponding to all the variables that the action guard depends on, and outputs a single bit indicating whether the action is currently enabled or not. This mapping is usually straightforward, as it in effect means the transformation of a logical formula to a logic network.

The outputs of the combinatorial networks are input to a scheduler component that picks the next action to be executed. The scheduler operates synchronously, triggered by a an edge of a clock signal. The scheduler might also have additional inputs that are used in the computation (for example, some of the signals representing variables of the system), and it can utilize many different kinds of scheduling strategies. Finally, the scheduled action and all needed input variables are communicated to the sequential blocks that correspond to objects that synchronously execute action bodies. Each object block is responsible for executing those parts of the body that result in state changes in its own variables. The object blocks must also output the values of those variables that are needed elsewhere.

Transforming a DisCo specification to such a hardware-based design can either be carried out manually or with the aid of an experimental compiler [7]. The approach is discussed further in [9], [5], and [7].

4.2 Interrupt-Driven Architecture for Digibot

The *interrupt-driven* style is a software-based architectural style suitable for the implementation of real-time control applications. It is widely used for small-scale embedded systems, and especially useful if there is no operating system that supports processes or threads. The architectural style is very simple and can be described as follows: *1)* There is a main loop that is often empty or performs some background tasks. *2)* Interrupts are generated by timers and input/output events. *3)* When an interrupt occurs, control is transferred to an interrupt handler for that particular interrupt. *4)* The actual application functionality resides in the interrupt handlers.

The interrupt-driven style can be used for implementing relatively simple DisCo specifications. It is particularly useful for specifications that contain real-time aspects, and where actions are effectively triggered by the passing of time or by events that are conceptually controlled by the environment. Examples of events of the latter kind are inputs coming from sensors.

When applying the interrupt-driven style to a DisCo specification, one first needs to identify the variables, events, and timing constraints that are used to trigger interrupts, and determine which actions are executed on which interrupt. An action may model an external event that generates an interrupt; for example the closing of a sensor switch. Potentially nondeterministic timing constraints often map into deterministic timer interrupts: for instance, if action A sets both a minimum separation and a deadline for action B, this can be realized by setting a timer that expires somewhere in between these time instances and causes an interrupt. Actions that are not interrupt-triggered can be placed in the background loop of the program, their guards implemented using conditional statements. However, often in control-oriented specifications such actions do not exist.

5 Conclusion

Lightweight hybrid DSM/MDD is an approach where a somewhat domain-specific specification languages are used in conjunction with transformation techniques and tools that enable computer-assisted implementation of specifications. Compared to a full-blown DSM approach based e.g. on a tool such as MetaEdit+ [4], the lightweight method requires a smaller initial investment and offers flexibility with regard to choosing an architecture and a target platform. On the other hand, the process of deriving an implementation based on a specification requires more developer intervention, and thus the productivity increase is probably lower.

Lightweight hybrid DSM/MDD can be used as a bridge from generic methods and tools to a domain-specific workflow, as it allows incremental development of the modeling languages, model compilers and transformators that are required for a full-blown DSM toolchain. A specialized DSM language and automatic code generators can be based on experience and partial transformators that have been developed when applying the lightweight approach.

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How to represent Models, Languages and Transformations?

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Abstract

One of the main goals of domain-specific languages is to enable the developer to define completely new languages for special domains in order to get the advantages of programming on a higher level of abstraction. Nowadays languages are represented in different ways: by metamodels specified in some data modelling technique or by formal grammars. This position paper examines the influence of the representation of languages on language construction and transformation.

Introduction

In the last few years domain-specific languages (DSL) have been getting more and more attention in the software industry. DSLs could be a technique to develop software in shorter time and in better quality. DSLs promise to be a good solution to the problem of reuse not only on technical but also on architectural and design level. The usual way of handling this kind of reuse is the adoption of design or architecture patterns. DSLs can be seen as executable patterns. DSLs and generative techniques give the chance of defining the variability in specific software domains. Best practices, such as patterns, can be included as static parts in the generators and variable parts of a software system can be specified in some kind of model or language [GP]. Thus, DSLs present new perspectives on the development of software product lines.

But DSL development is still hard because domain and language development knowledge are required [WaH]. To make a DSL usable three tasks have to be carried out:

- Definition of an abstract syntax
  Most DSL-tools (also called language workbenches [LW]) allow the definition of the abstract syntax as a metamodel [MOF]. This metamodel is defined by a data modelling technique (the meta-metamodel) similar to class diagrams or ER-diagrams.
- Definition of a concrete syntax
  To make the language usable some concrete syntax has to be defined. Many language workbenches like the Microsoft DSL-Tools focus on graphical languages [MSDT, SWF]. For every language element there has to be a graphical icon that represents the abstract model element. Finally some kind of development environment needs to be provided. In the case of textual languages the syntax can be described by a grammar. A grammar describes both concrete and abstract syntax by specifying terminals, non-terminals and production rules.
- Definition of semantics
  Possibly the most important part of language specification is the formulation of semantics. An informal description of the language may be given in natural language by describing the domain itself. But the actual definition of these semantics is done by implementing the generator backend. Thus, the semantics of the DSL is defined by giving a translation (translational semantics) into some target language which already has some behaviour definition for its elements (operational semantics).

The generator backend is most often realized by one of the following three kinds of approaches [LOP]:

- Templates
  The most preferred approach to code-generation in language workbenches is the use of template techniques. As the name suggests code-files in the target language are the basis. Expressions of a macro language are inserted that specify the generator instructions. Often ordinary programming languages are used to specify the behaviour of the generator, e.g. C# in the Microsoft DSL-Tools [MSDT]. Other template languages like openArchitectureWare's functional Xpand language [oAW] specify a specific path through the model graph in each template by using recursion.

- Patterns
  This approach allows specifying a search pattern on the model graph. For every match a specific output is generated. This approach is used in BOTL [Botl1, Botl2] or ATL [ATL03].

- Graph-traversing (visitor approach)
  This kind of code generation approach specifies a predetermined iteration path over the syntax graph. For every node type, generation instructions are defined which are executed every time such a node is passed. This kind of generation approach is mainly used in classical compiler construction and textual languages.

Most language workbenches offer poor assistance for the specification of the generator back-ends. Ordinarily there are only little syntax-highlighting (only for the generator language but not for the target language) or code-completion features. The reason lies in the independency of the generator backend from the target language and the missing definition of the target language.

Today many languages are developed that are incomplete in the sense that manual coding is still needed to get an executable program. The adoption of DSL technologies is useful especially when the target code doesn't need to be touched after generation. Otherwise the developer using the DSL must still have full knowledge of the platform and the architecture of the generated code. In this case the benefits of the DSL's higher level of abstraction don't really take effect. In the early days of compiler construction generated machine code was also manually modified. This inconvenient practice was no longer necessary when the optimization techniques evolved in compiler construction. The same effect will probably take place when DSL techniques are further developed. But nowadays the reasons for manual coding in generated code are not performance issues but the difficulty to specify languages that are capable of expressing more than architectural and design decisions (like component or service structures). It would often be useful to be able to write logical or arithmetical expressions in a DSL. But it is cumbersome to specify this in a metamodel. Such common language constructs would be useful in many domains so the demand for reuse of language concepts arises. Manual modifications in generated code should be forbidden not only because of convenience reasons. It is a prejudice that generated code is less maintainable than hand written code. Manual interference may possibly destroy the architectural decisions specified in the DSL and its generator. Also, some typical technical round-tripping problems [RTE] could be avoided. For example, manually written code is lost when the generator needs to be run again due to changes of the model. Common solutions to this problem often lead to poor designs and bad program structures because of the inappropriate use of the target language's concepts (e.g. inheritance). This problem becomes obsolete if complete code could be generated out of DSL specifications.

In most language workbenches graphical languages are formulated as data models as the metamodelling technique of the workbench. These are usually simplified class diagrams or entity-relationship models (ER-models). In the vocabulary of the Meta Object Facility [MOF] this would be the meta-metamodel. Textual languages on the other hand are usually defined by their grammar, e.g. in Backus-Naur-Form (BNF).

The next section will compare these different representations of languages. Class diagrams can easily be transformed into ER-diagrams. Due to that we will not distinguish between these data modelling techniques anymore and only talk about ER-modelling and relational models in the next sections. After that we will describe the effects of a uniform meta-metamodel on the generation and transformation techniques. At last we want to address the composition of languages out of language components.

Data Modelling vs. Grammars

As mentioned above the big difference between classical compiler construction and language workbenches is the formulation of the metamodel. Compilers use formal languages whereas generators use ER-models. The problems compiler construction is facing arise because of the linearity of text. It is difficult to encode and decode information into a linear representation (parsing). Recognizing and reconstructing the information which is encoded into text makes it necessary for every compiler to solve the word problem to decide whether a given program is syntactically correct and in order to reconstruct what the programmer had in mind when writing the program.

An interesting question concerns which is the better or more expressive way of formulating metamodels. We will examine this topic using a small example. Figure 1 shows a simplified part of an abstract syntax tree of an ordinary imperative language.

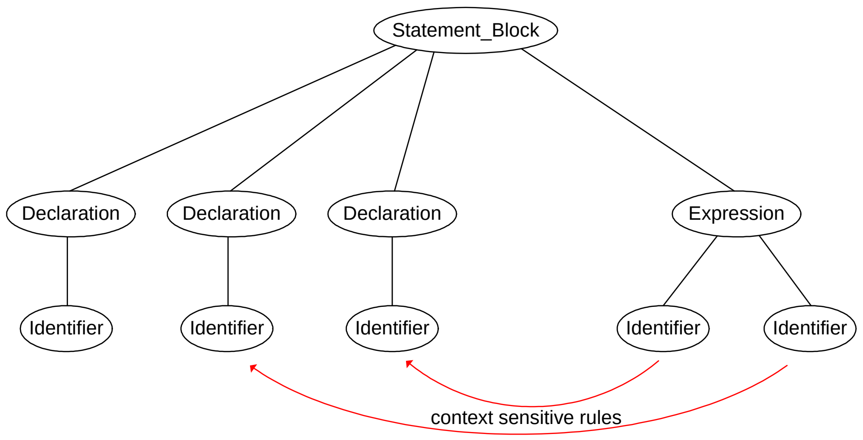

Figure 1: A simplified abstract syntax tree

This simple example shows the definition and the use of identifiers. An ER-schema whose stored data represents the same information as the syntax tree (without the context sensitive rules) would look like this:

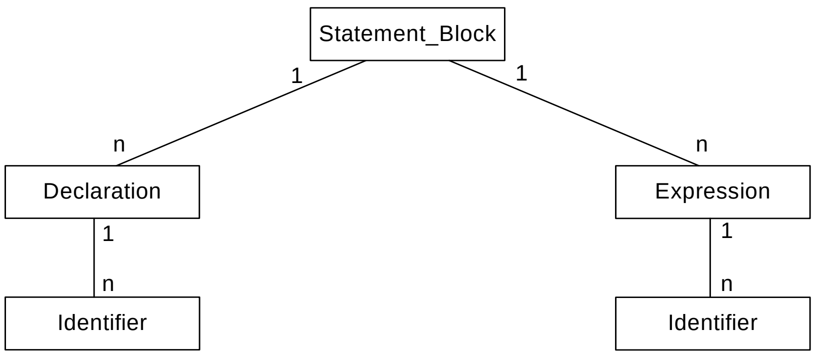

Figure 2: An ER-model as a metamodel for the syntax tree in Figure 1

But a better way of expressing all the information needed for the concept of usage and declaration of identifiers would be the following:

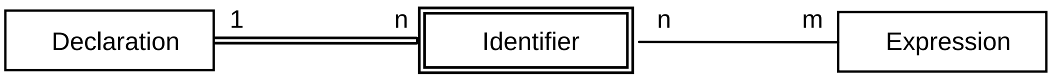

Figure 3: An ER-diagram representing the declaration and usage of identifiers

This shows a simple example of the weaknesses of compiler construction: It is impossible to express all the information needed in context free grammars. In almost every (non-trivial) language there are context sensitive rules that must be integrated and checked by manually coding the compiler. A similar example would be the definition of interfaces in Java or C#. If a class implements an interface it has to implement all the methods declared in this interface. This rule is also context-sensitive and cannot be expressed in a BNF notation of these programming languages. In every case where information (identifiers or method-signatures) is specified more than once in programs a relational structure can be found that eliminates this redundancies and expresses both, the information within the syntax tree and the context-sensitive information. This is possible because a database schema is not only capable of storing trees but also universal graph structures (with typed nodes).

The presence of context-sensitive rules of course lowers the maintainability of the compiler. Using context sensitive grammars is not possible either, because they are not easy to handle and the word problem (check if a given word is part of a language) cannot be solved efficiently. The examples above already show the assumption that ER-models are more expressive than context free grammars. But the expressiveness of ER-models is limited, too. In the second example (interface implementation) there could also be the restriction that the interface-methods implemented by the class must be declared as public. This exceeds the expressive power of ER-modelling and constraints formulated in predicate logic would be needed.

Our goal is to define a way to translate context-free grammars into ER-schemata and optimize them towards the context-sensitive rules. By using normal form theory we will try to find a way to store programs without redundancy. More research is needed to formalize this topic. Further work will discuss this in more detail. Now we want to have a look at the advantages that could possibly be gained by using a relational representation of a language.

Benefits of relational metamodels

Keeping these advantages of data-modelling compared to grammar-based definition of languages in mind, the question arises if this technique could also be used in ordinary programming languages. The formulation of a programming language as an ER-schema and the storage of programs in a relational database would demand an extra definition of concrete syntax in a textual or graphical way.

Formulating languages as relational data schemata can make the use of a parser unnecessary because the programs would directly be stored as abstract syntax graphs and the construction of the program could be done syntax-driven. If a graphical program representation is preferred, the operations of dragging and dropping language elements onto the drawing board have to take care that either no incorrect models can be produced or at least that no incorrect model can be stored or executed by the generator backend. In the case of a textual representation of the programs ordinary parsing-techniques may be used before storing the abstract syntax graph or structured editors could be applied like it is done in the Meta Programming System [LOP]. Programming in this kind of relationally represented language would at last be a sequence of insert, update and delete operations whereas DSL composition would be done using add, alter and drop table operations.

Another advantage of storing programs in a relational format is much easier refactoring. For example, in a conventional programming language, a simple renaming of a method declaration would cause the programmer to identify and consistently change all of the usages of this method. This phenomenon is comparable to update anomalies known in database theory. In an ER-schema of a programming language, a method call could be realized by references (numeric primary key) without storing the method name twice [Sim06, Sim96].

Versioning systems (like CVS, Subversion) work on simple pattern matching practices and are unable to identify the reason of conflicts. With ER-based programming languages merge conflicts could be solved much more easily because the versioning system has all the details necessary to determine the exact reason for the conflict. Not only differences in the text lines can be shown, but detailed information on what the differences really rely on (e.g. a new method is declared or an old one has been moved). The developer could be informed of conflicts in a much more detailed way and do a kind of “semantic merge” [LW, Sim06, Sim96]. It is no longer possible to destroy the syntactic correctness of the code base by doing merging operations. Even scenarios are imaginable where developers work synchronously on the same copy of code stored in a central database. For every statement the author could be stored. Two developers would immediately notice when working on the same piece of code. This could avoid merge conflicts totally.

Data modelling is much easier than dealing with grammars. Software engineers are usually experienced at building data models. One of the main ideas behind DSLs is to give the programmer the ability to modify his own tool, the programming language. Compiler construction know-how is not very common in average software companies but if the modification of a language could be done via simply changing a relational schema this idea would get better acceptance. Some simple modification could be the implementation of company specific coding conventions by restricting the programming language used.

Model Transformation

After this reasoning about the way of defining metamodels, these observations should now be examined towards their influence on the generator backends and model transformation capabilities. DSL-workbenches generate just plain unstructured text, and it is not ensured, that the generator output really fits the grammar of the target language. The used generation techniques do not respect the target language syntax (respectively its metamodel). A formal mapping between the source and target language elements is very important because it specifies the semantics of a newly developed DSL. If not every word in the new language can be translated into an equivalent and syntactical correct target language word, how is the semantic of these words defined? In our opinion the semantics of DSLs must be specified as translational semantics. This leads to the need for syntax respecting code generation. By specifying a translation to a target language that has operational semantics a newly developed language implicitly gets a formal definition of its own semantics.

To ensure the syntactical correctness of the output of a transformation it would be necessary to define a separate transformation language for every pair of source and target language. Such a transformation language would consist of the syntax definitions of the source and the target language and some language elements needed to be able to define the mapping. The synthesis of such a transformation language is always the same process and could therefore be automated.

Usually people distinguish between model-to-code and model-to-model transformations. One of the difficulties in syntax-respecting model-to-code transformations relies on the different representations of models and code. Models are usually defined relationally and code by its underlying grammar. Actually four kinds of transformations should be distinguished:

1. ER-defined language to Grammar defined language
2. ER-defined language to ER-defined language
3. Grammar defined language to Grammar defined language
4. Grammar defined language to ER-defined language

If a language workbench would have a (relational) representation of a target language (e.g. a 3rd generation programming language) then the task of model-to-code generation could be treated equally to model-to-model transformations and techniques like ATL [ATL03] or QVT [QVT] could be applied. Several other concepts for model-to-model transformations have been submitted to the QVT request for proposals of the OMG [QVTr].

But these model-to-model transformation techniques have a different methodology than template based code generation. It is questionable if these would really fit the needs because most examples of model-to-model transformations just show transformations between models that have almost the same level of abstraction. Code generation on the other hand often has to deal with a huge gap between the levels of abstraction of the source and target language.

```
Component c → insert Java-Class(Name = c.Name, Visibility = public) jc {

   insert Constructor(Name = jc.Name);

   Port (Type == "sender")  p    → insert Method(Name = c.Name+"_"+p.Name){…};
   Port (Type == "receiver") p   → insert Method(Name = c.Name+"_"+p.Name){…},
                                   insert Method(Name = "CS"+c.Name+"_"+p.Name){…},
                                   insert Attribute(Name = "isCalled_"+p.Name, Type = boolean);

   DataElement d → GenAttr;
}

GenAttr : DataElement d → insert Attribute(Name = d.Name, Type = string);
```

Figure 4: Example of a fictitious transformation language

The example for a transformation language illustrated in Figure 4 can be read equally to ordinary template approaches and is inspired by the Xpand language used in openArchitectureWare [oAW]. The left hand side of the transformation rules can be thought of as model elements over which is iterated in a for-each-loop and the right hand side as the body of the loop which ordinarily generates the textual output. The right hand side specifies the abstract syntax elements that should be inserted into the target model when the rule is executed.

In contrast to approaches like ATL [ATL03], this kind of transformation is traversal based rather than pattern based. The transformation specifies a spanning-tree in the syntax graph of both the source and the target language, which is constructed by the right hand side of the transformation rules. So the transformation can be executed as a depth-first search over the abstract syntax graph of the source language word and at every node parts of the abstract syntax graph of the target language word are constructed. A real complex transformation may need several of these passes. An important thing about the specification of the transformation is that it is done in a declarative manner. Unlike text generation the transformation doesn’t create a concrete syntax representation of the resulting target language word but its abstract syntax graph.

This transformation language is composed out of the source and target language and elements for defining the transformations. It is very context-sensitive because the transformation rules have to take care of the source and target language syntax and mapping constraints. But if it can be shown that a word is in the transformation language, this word is a complete definition of translational semantics for the source language.

Especially in cases where the source and target languages have a huge difference in their level of abstraction the transformation language in this example is not very useful, because many target elements have to be generated from single source elements and the transformation gets very hard to read. Ordinary templates have the advantage that the concrete syntax of the target language gives a good impression of what generator output is to be expected [PTM]. The example of the textual transformation language above is just meant to show in which manner transformations should be expressed. Of course the transformation language itself could (just as every other language) be represented as an ER-schema and a good GUI-concept could ease the task of specifying transformations by offering only the appropriate elements like code completion does in modern IDEs.

The definition of the semantics of the transformation language itself can be defined in a bootstrapping way by formulating a transformation from the transformation language to a programming language (with operational semantics) in the transformation language.

Language Composition

One of the big goals of this approach to code generation/model transformation is to make it possible to identify the dependencies between target elements and source elements to identify free elements. In the example the DataElement that corresponds to the attribute doesn’t need information (fields) of the component in whose context it is generated. You can say that in this simple example the DataElement concept is independent of the component concept.

This could be a first conceptual step toward a composition of languages in a building blocks approach. By introducing new blocks of an existing language (e.g. arithmetic expressions) into a new language, all of the transformation rules that do not depend on other elements of the existing language can be taken over into the generator of the new language. So this is an approach to semantic conserving DSL-composition. Through similar concepts the development of complete DSLs can be done with less effort.

Conclusion and further work

In this position paper we have shown a new perspective on the differences between models and code. The main difference lies in the representation of their metamodels by relations or grammars. After that we explained what advantages could be expected, if ordinary programming languages are formulated as relational models. Translations between relationally represented languages have been proposed and discussed towards the goal of developing transformations that verify the syntactical correctness of the target words. This kind of transformation could also be an exact definition of the (translational) semantics of a newly developed language.

In the future we will work on an implementation of a relational programming IDE with a transformation language like the one presented. It has to be formally shown where relational modelling is situated in the Chomsky hierarchy.

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Model integration in domains requiring user-model interaction and continuous adaptation of meta-model

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Abstract

Possible architectures for meta-models for domain specific model driven development are compared in the context of a domain – exploration engines for patterns in the dynamics of financial markets – that require interaction between domain expert and model, continuous development of the meta-model and yield the necessity to provide the domain expert with means to express rather abstract mathematical concepts. The focus will be on the decisions for structural integration versus dynamic integration, and for integration within an object oriented meta-model versus integration by mapping between formal grammars. It will be argued that structural integration within an object oriented meta-model is the most promising approach for the particular task.

Motivation

Domain specific modelling is a concept for increasing productivity in software development by integrating the development of models based on domain specific concepts and executable models. Ideally, the domain expert should not need to bother with the development of an executable implementation model from their domain model as the mapping will be predefined in the meta-model. However, in practice it will often be more or less impossible to define the mapping in advance, yielding the question how can the architecture of a meta-model be designed to support model integration and allow for continuous development of the meta-model at the same time. Moreover, it will often be an important task of the model to interact with the user and assist them with the design of the solution, yielding the demand for something like a design-time executable functionality of the model.

Tools for research in the financial markets are examples of these types of situations: Many experts believe, that the dynamics of speculative markets show recognizable patterns that can be exploited by interpreting initial segments of the patterns as triggers for own action [Sw95]. The working hypothesis is that such patterns are statistical side effects of invariance in the momentums of a dynamic system that is constituted by superposition of interactions between many agents and occasional perturbations, such as national bank interventions. Such systems are unlikely to be predictable by a closed theory. Yet they will often expose considerable constraints on the set of possible trajectories through state space that allow negative assertions on trajectories [Ba91]. Although assertion of such constraints is logically negative – the system will *not* do this or that - they may yield exploitable assertions in particular situations – e.g. "If development of some ratio x/y becomes directed after a period of strong fluctuations, then it will not pass a threshold t without a previous outburst into the opposite direction, where t depends on the strength of previous fluctuation by …." This will say nothing about future development most of the time but may be sufficient to identify profitable trades occasionally, which is enough to justify considerable efforts.

The logical structure of assertions on constraints is that of statements with quantifications on sets of trajectories through state space of a complex system. Such statements – e.g. the one cited above – need to be expanded into sets of empirically testable formula by crawling parameter spaces and generating closed formulas for empirical verification. That motivates the idea to provide the domain expert with the computational power of exploration engines that generate and test manifolds of hypotheses on market dynamics. Domain expertise is needed to identify interesting hypotheses. Taking into account that the domain model will already be formalized, the question arises, whether this job may be a candidate for automatic model transformation. This yields the idea to use model driven development techniques for providing the domain expert with the facilities for *generic rapid exploration engine development* (greed). Essentially solutions in this domain are models of AI-systems (admittedly rather dull AI), that search for patterns in the dynamics of a complex system.

The key observation concerning requirements for greed is that the development of the domain model is actually the goal. The implementation serves as a vehicle for the domain expert to explore the domain and the executable basically serves as an instrument for development of the domain model. This situation has a number of consequences:

- The objects to be developed in the domain will show 'rich' behavior. The behavior of such machines needs to be definable in much more domain-specific concepts than those of traditional programming languages.
- The designer will often switch between different levels of abstraction, e.g. between definition of a meta-strategy for exploration of trading strategies and specification of parameter sets for instantiation of model-level trading strategies as instances of the meta-level types.
- The process of development will often be interactive in the sense, that the domain expert's ideas for specification of new exploration engines will be inspired by observation of previously designed ones.
- There is no chance to develop the complete domain meta-model and it’s mapping to corresponding executable implementation models in advance, even if this would be desirable. The development strategy thus must support integrated development on domain view-, implementation- and meta-model-level.

On the other hand, aspects like adaptability to different target platforms or interoperability are irrelevant here and no trade-off should be accepted in favor for such aspects.

The needs sketched above constitute the context for considerations concerning an adequate architecture of the meta-model for domain specific modelling in the respective domain. In this paper the focus will be on two aspects of the meta-model:

- Is the meta-model based on structural integration in the sense of a single model principle[Pa02] or does it work with separate domain- and implementation models and explicit transformation?
- Is the integration of views defined within an object-oriented meta-model or on basis of a mapping between formal languages?

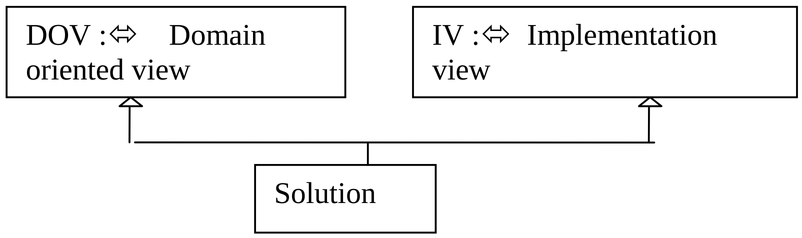
To proceed with, the consequences of these two logically independent questions will be sketched out and the structural integration within an object oriented meta-model for projects like greed will be argued.

Views

Many scenarios for MDD can be described in terms of integration of design models that specify the solution in domain-specific concepts and platform/language-specific implementation models [St05]. The transformation is done automatically or semi-automatically by code generators which specialize given domain model for a particular platform by adding information needed for a complete implementation model. MDD concepts therefore often focus on generalization / specialization relations between models. This looks very natural when starting from the idea that model driven development and domain specific modelling serve to increase productivity by providing the designer with an environment that allows them to describe their model using domain-adequate concepts rather than low-level abstractions. [Gr04, St05, To06] The automatic generation of the implementation – or at least a skeleton thereof – can then be seen as a specialization of the design for a particular platform or machine – e.g.: a domain model of functions for a smart phone can be automatically expanded into an implementation model for a particular device through a tool chain that itself can be developed using a meta-CASE tool.

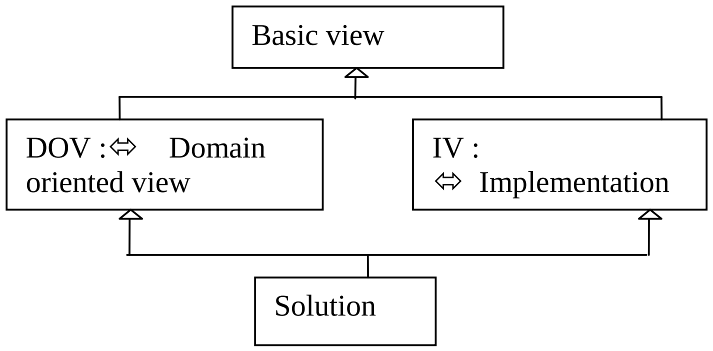
Strictly speaking, it is often a simplification to call the implementation view a specialization of the domain view because the former contains information which is not contained in the latter – from diagram layouts to references to formula, video clips illustrating game-theoretical considerations through visualization of computer simulations, or whatever kind of things which are important for the domain model developer but not executed at runtime. Notwithstanding that this point may be irrelevant for much of the practical work in model driven development, it is important for the meta-level issues of concepts for the integration of development in different views. For this purpose domain and implementation view actually need to be conceived as different generalizations of the underlying complete solution without presupposing that one view were a specialization of the other:

Diagram 1: General scheme of views



Since domain view and implementation are not orthogonal abstractions of the integrated solution, it may make sense to derive both views from a common base:

Diagram 2: General scheme of views with common basic view.



Moreover, there will often be more than two relevant views, not only in the trivial sense of expanding and collapsing regions of code in an IDE, but also in a non-trivial sense. For the sake of simplicity, the following considerations will nevertheless be formulated on base of the assumption of only two views:

- The domain view: This is the solution as the domain expert sees it, formulated in domain specific concepts.
- The implementation view: This is a description of the solution in a form, which allows transformation into an executable program with means that are considered stable for the purpose of development of solutions within the domain.

The implementation view does not need to be a complete standard-language solution, but may still presume arbitrary complex frameworks, libraries, compilers, code-generators or other tool chain elements. To the extent that these prerequisites are considered as an invariant part of the meta-model, their development nevertheless does not need to be integrated with that of the solution - but is an independent task. It may be noted, though, that confidence in the sufficiency of the tools as they are at the beginning of the project need not be unlimited.

Structural vs. dynamic view integration

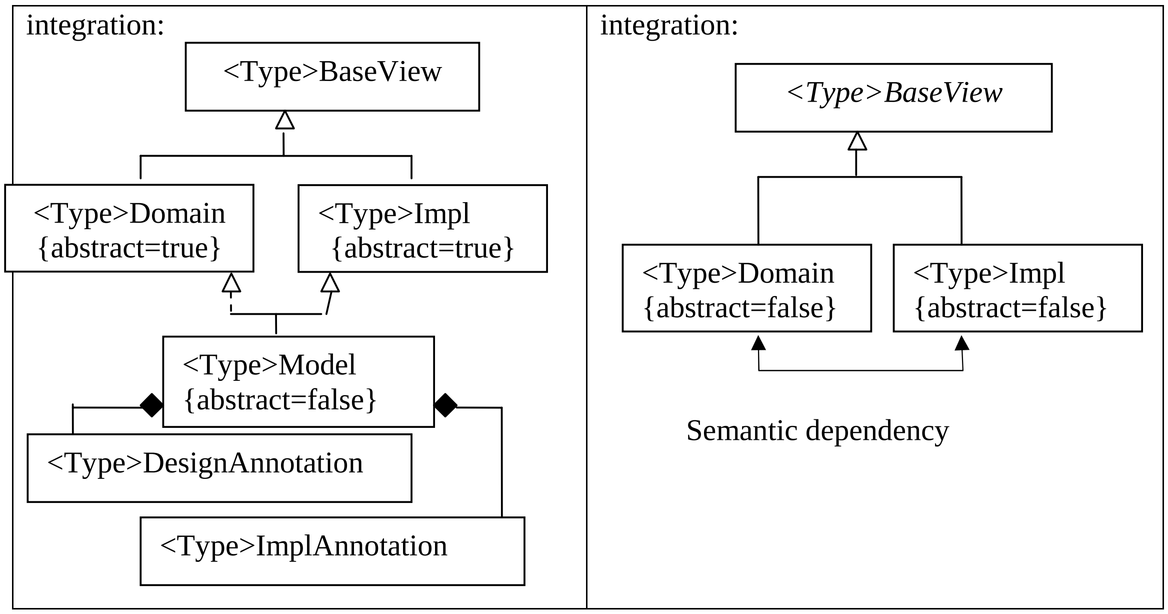
Obviously, a pair of different abstract models must fulfill many constraints in order to have an interpretation as two views on the same solution. Outside model driven development environments it's the task of the software engineer to maintain consistency with little support for preventing the notorious tendency of model views from drifting apart. Model driven development aims at providing mechanisms for integration of development of different views in a way that helps to prevent consistency. One of the basic decisions is, to determine the need to separate the domain and implementation model with a mechanism for propagation of information between the two, or to adopt the single model principle [Pa05].

The single model principle is characterized by the existence of only one model at any time. The different views present different aspects of this unique model. The integration is defined by the structure of the relation between the integrated model and the individual views. This motivates the term 'structural' integration.

Alternatively, different views may be built from model elements with different individual identity. This implies a potential for semantic incoherency. Therefore a mechanism is needed, that is able to transform a pair of incoherent views into a coherent pair of modified views by modification of either one or both views, using either one or both views as input. The possible mechanisms range from one-way code generation to complex bi-directional synchronization mechanisms. In any case there are explicit transformations from one model state to another one. This motivates the term 'dynamic' integration.

The main differences may be summarized as follows:

Structural integration	**Dynamic integration**
Shared properties of model elements in domain and implementation view exist as properties of underlying elements of an integrated model. Views therefore only provide access to differently filtered properties of the same unique model.	Domain view and implementation view actually correspond to two separate models which consist of disjoint sets of model elements with different identity. Correspondence between both views thus means that constraints for values of properties of different objects are fulfilled.
Scheme for the structure of meta-model classes representing a <Type> for structural	Scheme for the structure of meta-model classes representing a <Type> for dynamic


integration:
<Type>BaseView
<Type>Domain {abstract=true}
<Type>Impl {abstract=true}
<Type>Model {abstract=false}
<Type>DesignAnnotation
<Type>ImplAnnotation
integration:
<Type>BaseView
<Type>Domain {abstract=false}
<Type>Impl {abstract=false}
Semantic dependency

The structural integration scheme for construction of model elements corresponds to a single model, extended by two types of annotations, whereas the scheme for dynamic integration corresponds to construction of two structurally independent models, which need mechanisms for reaching consistency by explicit transformations.

Structural as well as dynamic integration may be combined with either object oriented or grammar oriented representation, as will be demonstrated below.

Dynamic integration allows for isolation of the views' meta-models as such and the transformations between them. The meta-models of different views may be captured in two grammars or two meta-model type systems. Transformations may then be represented by templates or by specialized synchronization methods. There are natural slots for adaptation of mappings between domain- and implementation meta-model through adaptation of templates. Dynamic integration is flexible and may boost productivity [Ko05, To06].

However, the arguments for explicit transformation depend to some extent on the completeness of code generation. If this is 100%, then the arguments are convincing [To06]. In a scenario where the domain meta-model is unlikely to be completely understood in advance, this is probably not realistic. This can lead to subtle problems like consolidation of incoherent views – the type of problems which sometimes pops up in form of the notorious 'generated code – do not modify – modified nevertheless' files. This poses the question, whether conditions for integration of simultaneous development of different (editable) views may be better in the structural approach is worth a second consideration.

Another interesting feature of the structural integration idea is, that it allows for maintenance of an executable interface, e.g. if the model elements implement something similar to the component interface of Microsoft's CTS. This will facilitate providing the domain expert with design time support, something very important in a scenario where the domain expert actually uses model driven development techniques to generate tools needed to build the domain model.

Since greed will become well understood only through doing solution development, it needs to be possible to organize integrated development of solutions and the meta-model of both views and their relations. Also is it more important to support the domain expert in building the domain models themselves than boosting productivity in terms of production of implementation from design – which is a consequence of the somewhat paradoxical situation where domain model development is performed through implementation model development, so that the latter actually becomes a vehicle for the first.

Object oriented vs. grammar oriented integration

The term 'language' is often used in a more general way than that of formal logics and includes graphical languages and general rules for handling and combining symbols [Fo05] [St05]. Nevertheless the question remains, what kind of thing a model element is considered to be with respect to its role in view integration: Is it considered as an instance of a meta-model class? If so, then it can show behavior, manifest itself as an instance of different interfaces or base classes, which exhibit different abstractions, change state, maintain references to other model elements and so on. Or is the model element considered a production of a formal grammar? In this case, it may appear in the input stream of a parser or the output stream of the code generator but cannot show behavior and there will not be a class hierarchy.

Both approaches can coexist and it is possible, to switch between them: a model that exists in form of XML-code may be transformed into a DOM, and a model, that exists as an interwoven lattice of objects may be persisted as a XML file. Yet, even if grammar-oriented and object oriented meta-models coexist, it must be decided which of the two representations will be used for integration of different views. The distinction between object oriented and grammar oriented integration can be summarized in the table below:

Object oriented integration	**Grammar oriented integration**
Model elements are considered instances of meta-model classes for the transformation between views.	Model elements are considered productions of formal grammars for the transformation between views.
The models are general graphs containing of nodes and references. Relations between elements are represented directly by associations or by class-class relations.	Relations between elements are represented indirectly. The algebraic structure of the web of relations extends the set of production rules of the formal grammar.
Shared properties of model elements of both views are represented by object oriented mechanisms, e.g. by deriving classes of both views from a common base class or by realizing views as interfaces of an underlying integrated model.	Shared properties of model elements of both views are represented by relations between the views' languages, e.g. by defining these languages by application of filters to an underlying integrated model language.
Explicit transformations are based on message exchange between model objects.	Explicit transformations are based on parsing, merging and code generation.

Both object oriented and grammar oriented integration techniques are compatible with structural as well as with dynamic integration:

- Object-oriented + structural: Concrete types in the meta-model type system are complete solution types. The domain- or implementation specific types are abstract type or interfaces implemented by the solution type. Shared properties of the domain-

and implementation type are represented as properties of a common base-class of these abstract types.

- Object-oriented + dynamical: In this case the domain- and implementation types are concrete. Domain and implementation specific information is thus represented by different object instances that must have methods for synchronization. Shared properties are either redundant in both views or there are references to specialized shared-property types.
- Grammar oriented + structural: Here the code of the solution is a production of one formal grammar. The languages of the views are defined by homomorphisms from the complete solution language in- or onto the languages of the individual views.
- Grammar oriented + dynamical: The view models are represented in domain- or implementation specific languages, the latter often being a standard language. Coherency of views is assured by parse, code-generation and merge algorithms.

The grammar oriented approaches have a long tradition of mathematical analyses [Ha71] [Ag05]. Formalizations of object oriented approaches have recently been motivated by the demand for a theoretical base for object oriented MDD [OMG01].

Grammar oriented integration yields an explicit representation of relations between views in templates or grammar files. The object oriented alternative represents the relation between views in the class system of the meta-model. This is a trade off between the flexibility and transparency of grammar oriented techniques on the one hand, the power of object oriented concepts and the support for the development of object oriented meta-models – which also are object oriented solutions – by modern IDEs on the other hand.

Discussion

Structural versus dynamic and grammar-oriented versus object oriented MDD-approaches yield four combinations with different advantages and drawbacks.

Object oriented structural integration allows optimal support for the domain expert through interaction with the model elements and helps to integrate synchronous co-evolution of the application and it’s meta-model. The most obvious disadvantage is the necessity of strong domain-expert – meta-modeler interaction and continuous participation of the latter in solution development, implied by the definition of domain/implementation-mapping in the Meta model’s type system.

Dynamic integration within an object oriented meta-model simplifies the task of addressing different target platforms from the same domain model, compared with structural object oriented integration. The drawback is, that it is more difficult to maintain coherency between domain and implementation meta-model, if neither is stable from the beginning.

Structural integration within a grammar oriented meta-model is theoretically well understood but the concepts of grammar-to-grammar homomorphism and/or tree-rewriting are rather abstract. Tool support for practical work is also less elaborated than modern IDEs for object oriented software development.

Dynamic integration on a grammar based meta-model can increase productivity a lot if a high degree of completeness in code generation can be achieved. The precondition for this is, that the domain meta-model is understood in advance. Also, while it is possible to provide the domain expert with design time support through the development environment, it is somewhat complicated to integrate functionality provided by the generated implementation model into design time support functionality.

Conclusion

Recalling that the task is to build a development environment for the domain expert within which generated implementations are immediately available to provide them with design time support and that knowledge will be insufficient to define a complete meta model in advance, the preceding consideration suggest a recommendation for object oriented and structural integration. This approach appears to be most suitable for a project like greed, where the domain expert shall be supported with the means to explore their domain with machines that are generated from the ideas that they can formulate in terms of domain specific concepts and where the meta-model continuously has to be adapted to new requirements.

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The Practice of Deploying DSM
Report from a Japanese Appliance Maker Trenches

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Abstract: *Domain-specific modeling (DSM) and code generation technologies have been around for decades yet are not widely used when compared to traditional software development practices of using general purpose languages ("C", Java...) and design techniques (sketches, UML, OOP...). This is surprising considering the availability of mature tools capable of generating product quality application code, configurations, documentations, test suites and other artifacts, from a unique source, a domain-specific model [1]. Why is it so? The problem may lie in the difficulty of integrating DSM into legacy processes and mindsets. Based on real experience in the domains of home automation and embedded device networks developments, we present some key aspects of deploying DSM. After describing our context of modeling and the rationales behind our decision to use DSM, we describe our solutions to the problems of promotion, process integration, usability and sustainable deployment of custom programming languages. We conclude with the recognition that most challenges to deploy DSM are not technical but human by nature, and we elaborate on the perceived advantages of using Cognitive Dimensions to help build better software modeling languages.*

Introduction

The home and building automation divisions of Matsushita Electric Works, Ltd., Japan (MEW) are contemplating a steady increase of software development costs combined with growing difficulties to satisfy quality requirements for appliances. These problems are caused by the constant growth in scope, size and complexity of the features implemented by way of embedded software, while the fundamental practices and tools have not significantly evolved.

More embedded features	Same old development tools
- Internet connectivity - Multi-media - Ubiquitous computing - Plug-and-play behavior - Peer-to-peer networks - Mesh networks - Application mashups	- Text-based editor - Low-level programming language "C" - Limited use of patterns - Ad-hoc approaches to problem solving

Table 1: Poor practices for today's challenges

MEW has engaged several projects to address this challenge, the so-called "Software crisis":
- CMM-based software process improvement (SPI)
- Definition of common development platforms and modules
- Deployment of software automation practices and tools.

This paper discusses the later project. We start with an explanation of our rationales for selecting domain-specific modeling (DSM). We subsequently describe our promotional approach based on the resolution of measurable problems related to the use of software in products. We then discuss the issue of process integration and propose a life-cycle for software development with DSM. Next we analyze the problem of devising visual languages that do not get in the way of the practitioners, and we introduce the concept of *escape semantics* that allows for creative modeling and collegial language construction. Finally we present a test-driven approach to facilitate the deployment of families of custom languages.

The Context of Modeling and the Decision to Use Domain-Specific Modeling

At MEW, new technologies and disciplines are created in the Advanced R&D Lab before being transferred to product divisions to help these enter new markets. The phases of creating appropriate new technologies and deploying these in time to product divisions constitute two major challenges (cf. {C} for creation and {D} for deployment in Diagram 1).

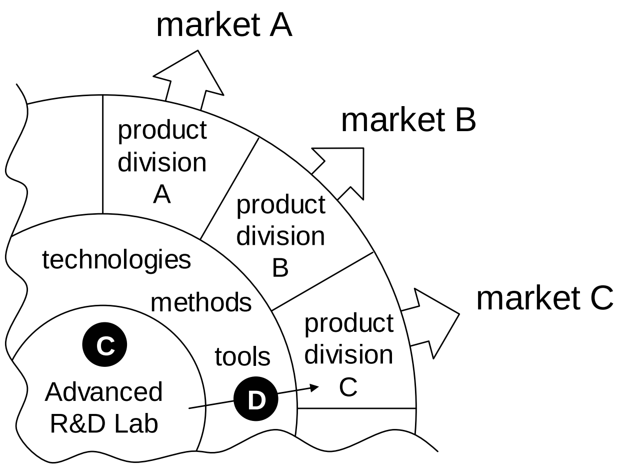

Diagram 1: Position and role of the R&D lab

MEW had mixed experiences with past attempts to use CASE tools and UML-based modeling to facilitate the new technology creation phase {C}.

The following table lists the most significant attempts at using modeling tools to develop better software. Although these were local successes, each one failed to go beyond the category of early adopters.

Tool type	Design method	Generation	Platform	Application
commercial	state-transition matrix	"C"	8-16bit CPU No RTOS	Room control
	UML		16-32bit CPU RTOS	IP routing and filtering
in-house development	sequential functional charts	ASM	4-8bit CPU No RTOS	Remote sensors and actuators

Table 2: Past experiences of software modeling

The first reason of failure to deploy software modeling invoked by practitioners is specific to off-the-shelf commercial tools: for full code generation, it is necessary to use the tool vendor's underlying framework which raises questions of suitability (does the vendor's framework perform correctly within the product specifications), adaptability (recurrent cost of porting the vendor's framework to new hardware platforms), availability (MEW products for home and building automations have a typical lifespan of 10 to 20 years), and loss of differentiation factor (use of same framework as competitors who purchased the same vendor's tool).

A second reason is specific to UML: practitioners consider UML's object-oriented notations too far apart from the "C" procedural world in which they evolve. Instead of class-centric designs, practitioners think in terms of concurrent tasks, interlock mechanisms, software stacks, data formats and communication protocols.

A third reason is the lack of support over the long period of product developments. It happens innovators did not have sufficient organizational support to pursue the promotion long enough neither to integrate their new methodology into the organization's development process. Active promotions of these methodologies were abandoned after their initiators were assigned new responsibilities.

After previously promising methods felt short of expectations, users built-up natural defenses against novelty and focused instead on known-practices: assembly language and "C" programming. With these, the team can program on the bare metal, be in control of the detailed implementation, so that predictable behavior can be produced.

A corporate language has evolved naturally over the years to express requirements, designs and implementations matters. It has notations, conventions and semantics that map precisely the problem domains, and it evolves incrementally when the problem domain changes as described in following table.

Problem domain change	Consequence / Response
Application of Building Automation technologies to the Home Automation market	Downsizing of specifications. Reuse of selected sensors, actuators and communication mediums. Porting of selected software modules and hardware components to lower-end hardware platforms.
Home appliances get connected to the Internet	Addition of Internet protocol stacks for machine-to-machine and machine-to-human communications (TCP, HTTP, SMTP/POP...).
Reduction of single points of failure	Addition of peer-to-peer features to move from top-down hierarchical control to grid-like computing.

Table 3: Examples of corporate response to some domain changes

This corporate language survived all the changes and it evolved just-in-time at the pace required by practitioners to be used for internal communication and development purposes. It is well-understood not only by developers, but also across the board by testing divisions, marketing people, sales people and managers. Models are written in the form of diagrams with free-form graphic tools, or simply tables with text editors.

Format	Defines
Table	Message format, Product specifications, I/O map, Memory map
Graph	Network system architecture, Device role, User-interface, Data-flow, Hardware layout
Sequence diagram	Communication protocol, Feature implementation
Sequential functional graph	Input-driven decision logic (decision-tree)
Stack	Software modules stack
Bag	Features selection

Table 4: Some concepts found in MEW models (N=13 projects)

We concluded that past failures to deploy software modeling practices were caused principally by the strategy of targeting the fragmented problem of new technology creation with uniform methods (cf. {C} in Diagram 1), the requirement to use notations and concepts apart from the practitioners' concerns, and the lack of organizational support.

Furthermore, although the methods employed to create new technologies are not always optimal, practitioners generally succeed to complete their technical development. However, practitioners often have troubles getting their new technology deployed to product divisions and spread to many development groups, which results in underused software modules. In other words, previous modeling promotion efforts aimed at improving what was working (creation), failing to provide solution for what was not working (deployment).

With that respect, we decided to focus our new software modeling project on the issue of deploying new technologies to product divisions (cf. {D} in Diagram 1), and to use the on-going CMM-based process improvement effort as our organizational support. To adapt to the needs of stakeholders from various backgrounds, we selected Domain-Specific Modeling (DSM) for its versatility and adaptability. To enable quick development of solutions with few resources, we selected a DSM tool with a metamodeling facility (language definition and visual editing) based on configuration rather than programming. To reduce the risk of losing support over a long period of time, we selected a commercial tool from a well-established vendor. The promotion of general purpose modeling was delegated to our Software Engineering Group (SEG) within the software process improvement project.

DSM Medicine

In the course of our DSM developments, we found evidences of a wide range of problems that can be solved with DSM technologies, although these are not necessarily defined in terms of application code generation. Hereafter we list the problems we encountered, and we briefly describe the DSM solution we proposed to the respective stakeholders.

Stakeholder	**Activity**	**Needs**	**DSM Solution**
Product engineer	Development of systems of systems	Complex system configuration	Generation of configuration files from system model
		Too many misuse cases to take in account	Automated discovery of misuse cases from models
Product developer	Porting of existing software to new hardware (re-targeting)	Quality issues	Injection of generated code into code templates
Product tester	Development of test suites	Test suite development is costly	Automated generation of test suite from models
		Possibility to overlook test cases	
Development team	Product development	Late requirement changes	Provide agility by way of visual modeling and code generation as visual models are closer to the requirements than source code
Development manager	Pass-over of a working software to the product division	Up-to-date design documentations	Generate up-to-date design and architecture documents from the model
R&D planning office	Measure of gap between current development practices and foreseeable market needs	Visibility of current development practices	A central model repository that can be scanned (a special model compilation) to extract information such as usage frequency of a module, of an operating system, of a combination of domain concepts…

Stakeholder	**Activity**	**Needs**	**DSM Solution**
Core technology developers	Develop new technologies for tomorrow's products	Reduce learning curve of innovative technologies to help deploy these to the developers	Reduce learning curve by embedding new APIs and guidelines into the code generator, and by providing a familiar visual language atop of it.
Software Process Improvement Group	Promotion of best coding practices	A method to enforce code layouts, naming conventions, folders conventions, etc…	Automated code generation according to well-defined rules.
Software Security Group	Reduction of software security risk	A method to avoid dangerous code structures (scanf…)	Automated code generation that complies with the corporate security policy
		Difficulty to analyze risks induced by design	A special model compiler that derives risks from the model
Top management	Strategic planning	Costly software development	Software automation
		Difficulty to enforce reuse of common platforms across the company	Automated selection of reusable models

Table 5: A selection of problems that can be addressed by way of DSM

Note that care should be given to select pains (problems) which resolution can be measured to demonstrate progress to both practitioners and management. Our pain killing method is composed of six steps:

- Get embedded into the practitioner team
- Observe the way people work to understand their context
- Ask practitioners for the few problems that most disrupt their core activity
- Select the problems that can be measured
- Present the DSM solution as a pain killer
- Deploy the DSM solution and verify the problem reduction with the practitioners

Process Integration of Modeling

Contrary to what happened with past efforts to promote general purpose modeling, where practitioners questioned the ability of specifying their software particularities, or the opportunity of replacing in-house frameworks with the tool vendor's, we found no such resistance to our DSM effort. The perceived reason is that DSM tools adapt to the methodology in place, allowing us to use the domain concepts and frameworks that practitioners have been developing for years. This seems to corroborate Seth Godin when he writes [2] "a key element in the spreading of the idea is the capsule that contains it. If it's easy to swallow, tempting and complete, it's far more likely to get a good start".

In order to clarify the positioning of DSM into the corporate process, we defined the three activities of creation {C}, deployment {D} and evolution {E}. As illustrated in the following diagram, new technologies are first created using appropriate software engineering techniques {C}, and later deployed to the product domain with the help of DSM {D}. Finally, necessary evolutionary steps {E} are engaged to keep both technologies and DSM capsules up to date with the constantly changing market needs.

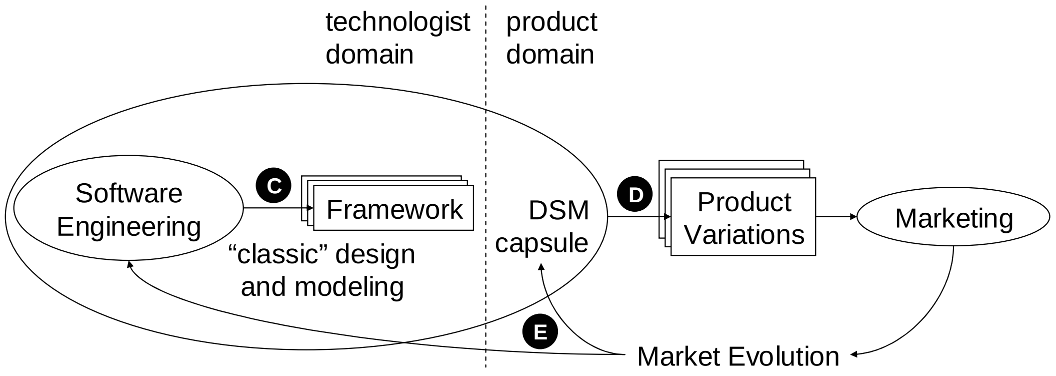

Diagram 2: DSM capsule fills the gap between technologists and marketers

When looking from a lifecycle perspective (cf. Diagram 3), the creation activity {C} corresponds to new product developments, while deployment activity {D} represents domain-specific modeling. Finally, the evolution activity {E} maps to the incremental changes applied to both framework and modeling tool to follow the domain changes. Furthermore, this view reveals a well-established practice we have no plan to change: during the fundamental research phase practitioners often use off-the-shelf DSM tools for algorithm research purposes (ex: Simulink®).

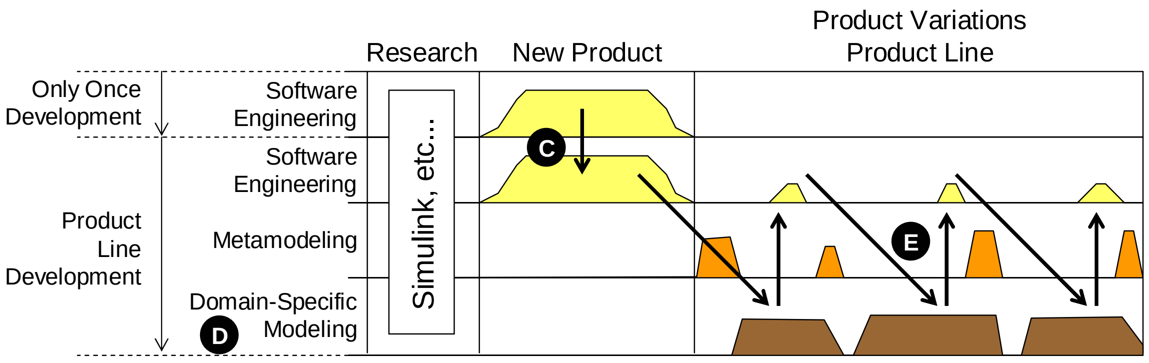

Diagram 3: Life-cycle for software development aimed at deployment with DSM

Agile Modeling

Language agility is critical to the tool-smith, because lack of language agility puts the DSM tool at risk of being abandoned by practitioners for more convenient methods. After all, what matters most to practitioners is producing a working product, not using modeling tools.

The following diagram illustrates the gap between present needs, practices and available tools. Due to the metamodeling delay necessary to define visual languages, editors and compilers, the DSM tool lags behind practices, so it is at risk of being perceived as constraining, especially for practitioners used to drawing with free-format whiteboards, pen and paper and general purpose diagram tools like Microsoft© PowerPoint.

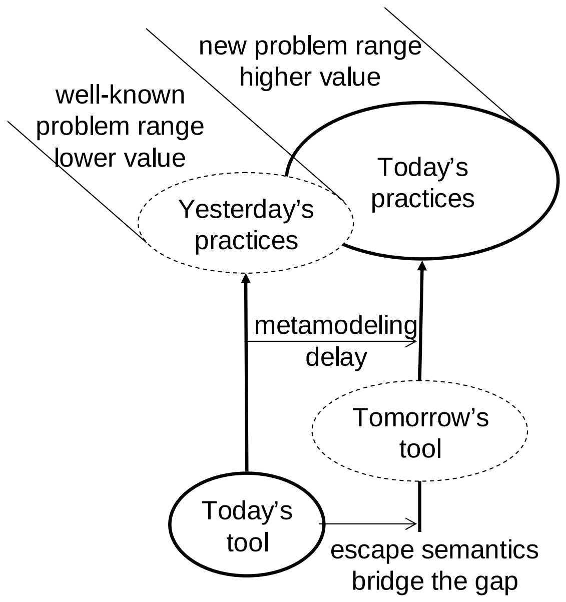

Diagram 4: Reduce the gap between tool and practices

To address this issue we implemented *escape semantics* in our languages, with the purpose of improving the modeling tool's stickiness by making it applicable to new problems not taken in account at language-design-time. The *escape semantics* allow for free-form modeling within boundaries set by the tool-smith, letting the modeler augment the official notation as necessary, typically when devising designs for new market segments. This opens the door to a collegial form of custom language construction where the DSM tool-smith and the domain expert initiate the reflection and practitioners add their thoughts and knowledge from field applications.

We identified several *escape semantics* that can empower the tool user:

1. *Joker objects* to augment the official language with new concepts
2. *Joker links* to augment the official language with new kinds of relationships
3. *Overwritable list-boxes* that can be augmented on the fly with new entries
4. *Code generator aspects* to let tool users augment the model compiler
5. The ability to extend model concepts with properties created on the fly

We noticed that young practitioners are more inclined to "invent" new notations to represent the world as they see it, while senior practitioners have been trained to the corporate notation and limit their usage of *escape semantics* to fixing purposes. Typical usage patterns of *escape semantics* we identified include:

- Add a concept that had been overlooked by the tool-smith and expert.
- Augment the expressiveness of an existing language to enter a new domain.
- Adapt existing models to new corporate regulations.

Following is a real example of *escape semantics* occurrence. A Field-bus Definition language had been defined to declare the type, cardinality and mapping of data points found on communication protocols used to interface sensors and actuators. Because this language was too simple to describe Full2Way field-bus, Mr. Tanaka proposed the addition of a union relationship by using one *Joker object* (yellow box) and three *Joker links* (red dashed lines) to represent the fact that terminal unit data points (*tu*) and lighting dimmer data points (*dimmer*) are interchangeable.

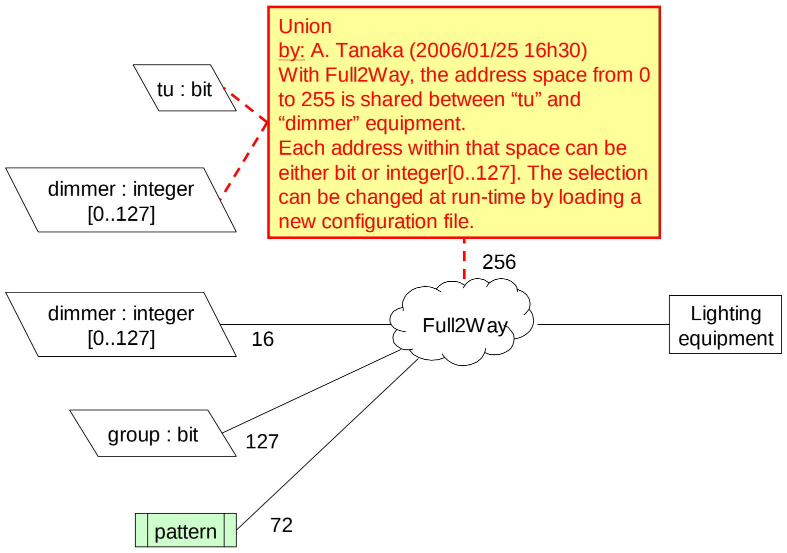
Union
by: A. Tanaka (2006/01/25 16h30)
With Full2Way, the address space from 0 to 255 is shared between “tu” and “dimmer” equipment.
Each address within that space can be either bit or integer[0..127]. The selection can be changed at run-time by loading a new configuration file.
tu : bit
dimmer : integer [0..127]
256
dimmer : integer [0..127]
16
Full2Way
Lighting equipment
group : bit
127
pattern
72

Diagram 5: Using *escape semantic* to convey the meaning of union which does not exist in the language yet

In addition to language adaptability via *escape semantics*, we find necessary to design the languages for modeling flow. That means reducing the number of double-clicks, text-field editions, list and menu navigations necessary to draw a complete model.

As a rule of thumb, all activities introduced by the DSM but not found in sketching should be minimized, because practitioners will compare modeling with tool to sketching models. Some form of automation can be introduced into the modeling language to protect the modeling flow:

- Default values (object name, property value) allow separating the creative activity of drawing pictures from the activity of specifying attributes. This can be facilitated by following the principle of convention over configuration [3] in the language design.
- Special values *undefined* and *unknown* allow practitioners to make progress in modeling a problem even thought some specifications remain unclear.

- Connecting the DSM tool to corporate IT system to avoid duplicate input of information

Sustaining Deployment of Many Custom Languages

By introducing home-made tools into the product development process, the DSM tool-smith is exposed to several risks, including but not limited to:

- A broken visual editor does not load old models
- The visual editor does not support current modeling practices
- A broken code generator produces malfunctioning software
- A valid code generator has not been updated to support changes in the target framework

These risks are worsened by several factors specific to DSM:

- Most domain-specific languages (DSL) are proprietary and maintained by a limited team
- Proprietary DSLs suffer from limited scrutiny and peer-reviews
- Proprietary DSLs have a limited user base and are applied to a limited number of applications when compared to main-stream languages like UML, “C”

To address these issues we implemented some test-driven practices from the agile software development community.

For example, the opposite diagram illustrates our solution to test the correctness of `(modeling tool, frameworks)` pairs by generating executables from well-known models and by running these against well-known data sets. Doing so, the tool-smith can periodically verify all well-known model compilation cases after each modification of existing DSLs, reducing the risk of releasing broken model compilers to the user.

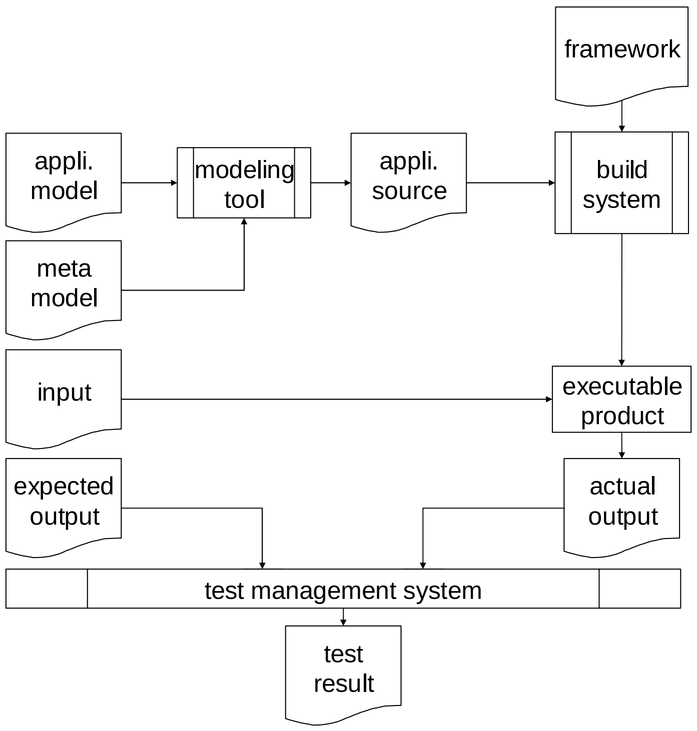

Diagram 6: Test-driven language development

Another step consists in checking the models repository for occurrences of *escape semantics* by way of *daily model analysis*. For example, the tool-smith could be emailed an alert on his mobile phone whenever a user would have used *escape semantics*, due either to some limitation in the modeling language, or to lack of knowledge from the practitioner, which either is bad news. This mechanism could prove to be a powerful communication means between the tool-smith and his users.

Finally, we use Scrum to manage the development of visual language editors and code generators. The product backlog proved to be a very practical tool to negotiate work items between the tool-smith and the stakeholders. For that purpose, we slightly customized the backlog format by adding columns *Example models* and *Generation samples*. Backlog items with more *Example models* and *Generation samples* are given priority because the more variation samples, the better DSL we can devise. The message is well understood by stakeholders who naturally do their homework to find or create more samples to get their problem higher in the list. Holding monthly Sprint Reviews open to all stakeholders and interested persons is also an efficient way to demonstrate progress, to keep stakeholders and users interested and involved, and to expose other practitioners to the DSM, fostering inquiries and requests for help.

The DSM Tool-smith's Commandments

We propose to summarize this paper in the form of seven principles for the DSM tool-smith:

- *You shall find the measurable pain of each user.*
- *You shall promote DSM as the medicine for each user's pain.*
- *To product and solution developers, you shall give DSM. To technology developers, you shall offer well-known software engineering practices. To all you shall give Agility.*
- *You shall keep your tool up-to-date with your user's changing practices.*
- *You shall offer escape semantics to your users.*
- *You shall design your languages for ease of modeling.*
- *You shall daily-test your languages and code generators.*

Conclusion

We described key aspects of MEW's approach to deploy domain-specific modeling (DSM) in the developments of systems of embedded devices, and we proposed practices to support the DSM tool-smith. We found that most challenges are not technical but instead human and organizational, and we interpret this as a testimonial of the maturity of DSM tools, but also as recognition of the lack of associated methods and practices.

Usability of home-made DSM tools remains the most challenging issue, because these tools are typically developed internally by a limited pool of software engineering specialists who lack expertise in ergonomics.

To address this problem we are exploring the discipline of human-computer interaction (HCI), and we found in Cognitive Dimensions (CD) [4] a promising candidate as some cognitive dimensions map precisely to several topics we discussed in this paper. For example, *premature commitment* and *viscosity* relate to our effort for preserving *modeling flow*, when *secondary notation* relates to our *escape semantics*. And *progressive evaluation* could correspond to the ability of simulating models with *undefined* and *unknown* values.

Further research will tell whether Cognitive Dimensions can help build DSM tools that are not only efficient in solving technical problems, but also comfortable to work with.

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A Model-Based Workflow Approach for Scientific Applications

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Abstract

Productive design of scientific workflows often depends on the effectiveness of the communication between the discipline domain experts and computer scientists, including their ability to share their specific needs in the design of the workflow. Discipline domain experts and computer scientists, however, tend to have distinct needs for designing workflows including terminology, level of abstraction, workflow aspects that should be included in the design. This paper discusses the use of a Model-Based Workflow (MBW) approach as an abstract way to specify workflows that conciliate the needs of domain and computer scientists. Within the context of GEON, an NSF cyberinfrastructure for Earth Sciences, the paper discusses the benefits of using a Gravity Map MBW generated from an ontology about gravity. The Gravity Map MBW is based on terms derived from the gravity ontology that was developed by geophysicists; it does not include some of the workflow properties that tend to make workflow specifications look too complex for discipline domain experts to understand; and it provides a framework for developing strategies to derive executable Gravity Map workflow encodings with only limited interaction from computer scientists.

1 Introduction

Workflows specify the composition of software services, including data and control flow, to achieve a particular result or complete a task. In the case of scientific applications, the design of a workflow typically requires the involvement of at least two domain experts—one from the scientific field of interest (e.g., a geophysicist or biologist) to specify how scientific products (e.g., maps, graphs, data analysis reports) may be derived from datasets and another from a computer scientist, who understands the process of composing a workflow and encoding the derivation in a format that machines can execute.

Productive design of scientific workflows often depends on the effectiveness of the communication between the discipline domain experts and computer scientists—in particular, on their ability to clarify and reconcile their specific needs in the design of the workflow. Because domain experts and computer scientists have distinct terminology to describe workflow elements, including requirements, effective communication is a challenge. For instance, domain experts may base their workflow descriptions on objects of complex types that the computer scientist may not know how to translate to primitive types that are supported by executable workflow languages such as OWL-S [1] and MoML [2].

A domain expert's workflow description is often more abstract than a computer scientist's encodings of a workflow. Additional communication problems arise when the domain expert is expected to understand and further refine workflow specifications prepared by computer scientists. At the same time, computer scientists need to understand the entailments of the domain expert's abstract workflow if computer scientists (with the help of software systems) are supposed to translate the abstract descriptions into executable workflows. For instance, domain experts may be concerned with the specification of partially ordered sequences of services even if such sequences of service do not provide a perfect matching between services' inputs and outputs. In this case, abstract specifications may require further refinement by computer scientists to be executed, e.g., the workflows may require additional steps such as translation services to match input and output information from services.

In this paper we discuss the use of a **M**odel-**B**ased **W**orkflow (MBW) as a means to increase productivity during the design of workflows in support of scientific applications. Following the reasoning from the **D**omain-**S**pecific **M**odeling (DSM) community [3], MBW is also about using a level of abstraction for modeling workflows that is consistent with the target domain, and then using such models (at best) to automatically generate executable workflows, that is, workflow implementations, or (at least) to guide the development of workflow implementations. In this paper we focus on the latter. We present the **W**orkflow-**D**riven **O**ntology (WDO) approach[1] to describe the domain and how WDOs can be used to create MBWs. In a scientific domain with the WDO approach in combination with the service-oriented paradigm, we claim that we diminish the intervention of computer scientists on the software development process by providing tools for domain-experts to produce specifications using the expert's discipline-specific terminology that the computer scientist can employ to create the service-oriented modules necessary to achieve the intended results.

The remainder of this paper is organized as follows. Section 2 describes the technologies involved in representing and executing scientific workflows. Section 3 presents our approach for building model-based workflows and is exemplified through a use case. Section 4 discusses further benefits of model-based workflows when compared to approaches to develop scientific workflows. Section 5 summarizes the paper and identifies future work.

2 Background

Service Oriented Architectures (SOA), in combination with *scientific workflows* and *ontologies* are being used in efforts such as GEON to create cyberinfrastructure [4] that will provide the necessary tools to drive the next generation of scientific research. By developing service-oriented components, the scientific community is developing independent and distributed modules of functionality that are accessible and reusable through the web. Service-orientation enhances the design of low-coupled components by hiding implementation details from users and exposing only an interface specification that serves as a contract between service providers and service users. Ontologies are used first as "an explicit specification of a conceptualization" [6]. Later, they are used to support the composition and matching of services.

Scientific workflows are used to specify the composition of such service modules to achieve some complex scientific endeavor. There are many workflow specification languages and execution engines. Here we mention two: MoML and OWL-S. MoML or the **Mo**deling **M**arkup **L**anguage is the language used by the Kepler Scientific Workflow engine [5] and is a simple markup language that allows the specification of workflows that include actors and a director. Each actor carries on the execution of a step in the workflow, and the director gives the semantics of the control flow. With the Semantic Web as its basis, OWL-S [1] is a web service ontology that is based on the **O**ntology **W**eb **L**anguage (OWL). OWL-S provides a service provider with constructs to describe properties and the functionality of a service in an unambiguous manner that is interpretable by a machine. OWL-S is composed of three different parts: the service profile that provides additional information about the services, such as functionality, inputs and outputs; the process model that provides information about

[1] http://trust.utep.edu/ciminer/wdo/

how services are composed into a workflow; and the grounding that presents details about how to access the service.

Ontologies are used to describe knowledge about a domain such that its representation can be interpreted and reasoned about by a computer. **W**orkflow-**D**riven **O**ntology (WDO) is an ontology design approach to represent knowledge about scientific domains that thus make them amenable to creating scientific workflows [7]. WDO-specific tools such as the WDO Assistant are used for capturing knowledge. Use cases typically drive the specification of ontologies [8]. In the WDO approach, abstract workflow specifications drive the elicitation and specification of classes and their relationships. For example, domain experts begin the knowledge acquisition process by identifying a *product* and from the *product* identify *methods* that can generate the product. Further, domain experts can identify *data* that are required as input for the identified methods. We claim that abstract WDO-derived workflow specifications are indeed the use cases for WDOs. Such use cases are the basis to create Model-Based Workflows (MBWs) and these are further described in Section 3.2 below. Furthermore, a WDO is an OWL ontology and as such it can be used to represent knowledge that is not workflow-specific, including domain knowledge.

3 Approach

Once a scientist has represented knowledge about a domain of interest by using the WDO approach, the scientist can extract abstract workflow specifications from the WDO that can serve as a guide to implement an application to produce desired information. These abstract workflows are referred to as **M**odel-**B**ased **W**orkflows (MBWs), and are created with the aid of workflow generator assistant software that can interpret the knowledge represented in a WDO. The scientist would identify the information desired from the WDO and the assistant software would then build an MBW to obtain the information based on the concepts and relationships defined in the WDO.

The next section discusses a use case that is used to exemplify the approach, followed by a description of an MBW.

3.1 Use Case

Assume that a geoscientist wants to obtain a *Contour Map* of *Bouguer Anomaly Gravity Data* for a given region of interest. The scientist starts by obtaining a WDO that represents knowledge from the geophysics domain; more specifically about "gravity data." By using assistant software, the scientist identifies *Contour Map* as the intended information desired, and the assistant software produces as many MBWs as possible from the captured knowledge that identify the abstract steps to produce the map. One of the possible MBWs, referred as the *Gravity Map MBW*, is shown in Figure 1.

To show the relationship to the WDO, the workflow in Figure 1 is divided into two main sections. The left-hand side represents the classes of type *Information* that are associated with the workflow, and the right-hand side represents the classes of type *Method* that are involved in the transformation of the information required to achieve the desired outcome, i.e., a contour map. The left-hand side of the diagram is divided further into three sections: *Product*, *Processed Dataset* and *Data.* The distinction between these classes and their intention is explained elsewhere [7].

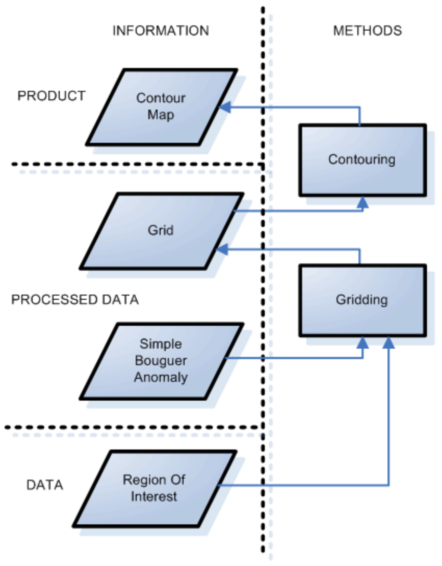

Fig. 1: The Gravity Map MBW generated from the Gravity WDO to produce a *Simple Bouguer Anomaly Contour Map.*

The arrows in Figure 1 shows the data flow of the workflow as the information is transformed starting from information of type *Simple Bouguer Anomaly Contour Map* to *Grid*, and finally to *Contour Map*. The information is transformed through the application of the *Gridding* and *Contouring* Methods, respectively.

3.2 Model-Based Workflows (MBWs)

MBWs are the resulting specifications obtained from a WDO to produce some information desired by the scientist. They are referred to as MBWs because the specifications use the knowledge represented by an ontology, and as a result, the terminology is based on the target domain, not computer science terminology.

Scientific workflows typically involve the sequential transformation of information from a simple information type towards a more complex information type such as an end product. Each step is of the form:

$$\text{Output Info} \leftarrow \text{Method (Input Info List)}$$

Output Info defines the type of the information that will result once the *Method* of a step finishes execution. When an *Output Info* type is used as an *Input Info* type in a subsequent statement, it means that the resulting information from this statement is used as input to the subsequent step. Any *Input Info* types that are not bound by previously executing steps require that the user inputs the corresponding type when the execution reaches the given step.

This simple "type-binding" mechanism illustrates the data flow of the workflow specification. The different types of information that will flow through the workflow are: datasets, products, and any other domain-specific concept defined in the WDO to clarify details about the workflow execution.

For example, consider the "Contour Map" use case presented in the previous section. The MBW produced by the assistant software would be as shown in Figure 2. All the concepts in the workflow specification are derived from the Gravity WDO.

Grid ← Gridding (Simple Bouguer Anomaly, Region of Interest);
Contour Map ← Contouring (Grid).

Fig. 2: Model-Based Workflow specification to create a Simple Bouguer Anomaly Contour Map.

Currently we are in the process of formalizing MBW's as an ontology. It is our intension to utilize OWL as a base framework and to have a tight integration between MBW's and our concurrent work on WDO's. The ontology that will be used to represent MBW's will include constructs to specify basic sequential control flow, as well as concurrent control flow to allow workflow specifications with partial order method execution.

4 Discussion

A vision of cyberinfrastructure efforts such as GEON [4] is to provide scientists with tools that would allow them to access and use resources to further their research, education, and professional goals. A short term goal and the focus of this work is to allow domain and computer scientists to communicate better to produce the desired software systems required for scientific endeavors in a more efficient manner. The longer term goal is to provide sophisticated tools that would allow scientists to accomplish their tasks with limited interaction with computer scientists, if any.

Position1: MBWs provide a base for interaction between domain and computer scientists to facilitate communication towards implementing a workflow.

MBWs allow domain scientists to specify their tasks using terminology with which they are familiar, while at the same time assisting computer scientists to understand what needs to be done to implement such specification. After a workflow specification is extracted from the WDO and represented as one or more MBWs, the domain and computer scientists work together to select and refine the MBWs, resulting in an executable specification of a desired system functionality.

The conversion process from an MBW to an executable specification is not straightforward, since the MBW is at a higher level of abstraction and, as a result, will lack details necessary for implementation. For instance, in the *Gravity Map MBW* presented in Section 3.1, the scientist uses the term *Region Of Interest* as input for the *Gridding* method. This requires interaction between the domain and computer scientists to map the abstract data type to one or more primitive data types, e.g., *Double*, *Integer*, and *String*. In one context, a scientist may desire to represent the *Region Of Interest* as two points, i.e., the upper-left and lower-right coordinate values (*Latitude*/*Longitude*) of a rectangular area. The computer scientist may decide to represent the coordinate values with a *Double* primary data type. In a different context, the scientist may decide that the best representation of the *Region Of Interest* may be the name of a county or state. In this case, the computer scientist may choose to map the *Region Of Interest* to a *String* primary data type. In any case, with the help of MBWs, domain experts can specify and refine workflow specifications without specifying a type for the *Region Of Interest* concept or composing a complex type for this concept from the primitive types of a workflow language. Furthermore, existing implementations of the *Gridding* method may only handle *Region Of Interest* represented as a *Latitude*/*Longitude* coordinate value and a *Radial Distance* value. The domain and computer scientists would then have to decide whether to adapt to the existing resource restrictions, or to create additional resources to convert the current needs to match the signature of the existing resources.

Position2: While executable code cannot automatically be generated from MBWs, MBWs guide the code development process.

OWL-S is one executable language that can be used to implement workflows from service-oriented components. Like other executable workflow languages, OWL-S is a sophisticated language that a domain scientist may find discouraging to learn, thus emphasizing the importance of Domain-Specific Modeling approaches. The process of creating an OWL-S workflow or composite service consists of 1) identifying the individual service components to be used in the workflow, and 2) creating the composition process for the workflow.

OWL-S supports a mechanism to create semantic descriptions for service components through "profiles". Following the SOA approach, it is the job of the service provider, who has knowledge of the implementation details of the service component, to provide the description "profile" to the service user, who remains unaware of the implementation details. Once the domain and computer scientists have refined the requirements of the service components to be involved in the implementation of the MBW, the identification of service components is done by matching the requirements to profile descriptions of service components.

The composition process creation follows directly from the composition of methods involved in the MBW, in addition to any intermediary service components that the domain and computer scientists might have identified through the MBW refinement phase. For example, in the contour map use case, the workflow components are the *Gridding* and *Contouring* services, executed sequentially in that order, as described in the MBW.

While tools exist that automatically generate executable scientific workflows from models, e.g., Kepler [5] generates MoML code from a graphical model, such tools do not support Domain-Specific Models, and as a result, lack the consequent benefits of DSM.

Position3: MBWs open doors to additional work that will eventually result in scientists being able to produce workflows with only limited interaction from computer scientists.

Additional complementing work can facilitate the workflow generation process for the scientist. One area that shows promise is *preferences* [9]. Preferences are useful whenever a user has to make a decision, and is an approach that can be used to filter through potentially many options. Preferences may apply both at the model level, as well as at the implementation level. For example, in the contour map use case, the scientist has to decide what is the best representation of the *Region Of Interest* for the context at hand. Once this decision is made, it can be documented as a preference to automate a similar decision for future development in the same context. Similarly, preferences can be captured for the decisions made by the computer scientist that map abstract information types to primary data types. The combination of preferences at all levels of abstraction brings the MBW approach closer to the ideal situation of automating code generation from domain-modeling.

5 Summary

This paper introduced the use of Model-Based Workflow (MBW) approach to facilitate the design of scientific applications. Derived from Workflow-Driven Ontologies built by domain experts, MBWs are described in terms that the experts can understand. Thus, domain experts can be more active in the process of improving workflow specifications and less dependent on their ability to communicate to computer scientists. Although MBWs are very abstract with respect to their implementations, they can still be used as a framework for computer scientists to build executable workflows.

Previous work on expert systems has dealt with the problem of communicating domain knowledge to computer systems. Liou [10] breaks the expert system development effort into four primary tasks: acquiring knowledge from experts; representing that knowledge in a computer-readable form; implementing a prototype of the system; and verifying and validating the system. Even though our goal is not to develop expert systems but to develop scientific workflows, the tasks involved in expert system development contain some parallelism to our work. Our concurrent work on WDO's [7] addresses the issues of knowledge acquisition and knowledge representation through the use of OWL ontologies. WDO's also contemplate validation by allowing domain experts to review and provide feedback about the workflow generation process. The work discussed in this paper deals with prototype building based on the captured domain knowledge. Finally, other work on property specification and runtime monitoring of properties [11] complements the task of verification.

6 Acknowledgements

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Bootstrapping Domain-Specific Model-Driven Software Development within Philips

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Abstract
Philips recognizes the importance of model-driven software development (MDD). Unfortunately, there seems to be a lack of mature tools that would support domain-specific MDD and allow their deployment in an incremental fashion. This paper describes the ongoing MDD research efforts at Philips, introducing VAMPIRE[1] − a light-weight model-driven approach to domain-specific software development. The VAMPIRE MDD framework is developed by Philips Research and it is currently being deployed at several Philips product divisions. The paper elaborates on the VAMPIRE modeling environment, focusing on its meta-modeling facilities, editors, and generators. Further, we summarize the lessons learned during the process of deploying our MDD framework into the product divisions.

1. Introduction

To be a successful player in a competitive business environment such as consumer electronics, medical systems, or healthcare solutions, one needs to deliver integrated and interoperable software-intensive systems, and fulfill the ever-growing demand for new and improved features in ever-decreasing time to market. Moreover, the whole range of product families is required to exhibit a similar look and feel towards the end-user. These requirements affect the product's hardware as well as its software. The proliferation of software in Philips products has been substantial and the amount of software still continues to grow at a great pace. As a consequence, the whole process in which the software is designed and constructed needs to address the aforementioned requirements efficiently.

The struggle to increase the software productivity and reliability has accompanied software development efforts since the very beginning. Among the remedies that proved to be (at least partially) successful was the raising of the abstraction level for writing code. Throughout the evolution of programming languages and design techniques (e.g. procedural languages, object-orientation, and design patterns) one can clearly see an increase in the level of abstraction at which software was written. The booming proliferation of software across many fields makes the demand for software higher than

[1] Visual Agile Model-driven Product-oriented Integrated Research Environment

ever before. The demand currently exceeds the ability to produce software by a large margin, and this “software-gap” steadily increases in time.

To address this issue, the conventional development means need to be augmented by new approaches that would enable to raise the level of abstraction even further, while bringing the software engineering discipline closer to the actual domain where it is to be applied. The combination of a higher abstraction level closely coupled with the domain knowledge introduces a so-called model-driven development (MDD) − a paradigm shift in software engineering that has the potential to become a solution to the software-gap problem. To make this happen, we need to gradually move from writing code to creating domain-specific models and generating code and other related artifacts, such as documentation, etc., from them. Using small domain-specific modeling languages, as opposed to a universal modeling language such as UML, brings the modeling discipline much closer to the domain experts and at the same time enables simpler maintenance and evolution of such models, which contributes to the desired productivity increase as well as to the agility of the model-driven development.

The rest of the paper is structured as follows. Section 2 introduces the VAMPIRE modeling framework, section 3 elaborates on VAMPIRE’s meta-modeling features defined by the *Meta Object Model*, section 4 focuses on model editors , and section 5 explains the ideas behind our code generator. Section 6 summarizes the lessons learned during the process of applying this framework in Philips product divisions. Finally, section 7 gives an overview of related work, and section 8 presents our conclusions.

2. VAMPIRE modeling framework

VAMPIRE is a light-weight model-driven approach to domain-specific software development. The VAMPIRE framework is being developed by Philips Research. It primarily aims at raising the level of abstraction at which the software for Philips products is produced, trying to increase productivity and reliability. The main idea is to capture the domain knowledge by means of models and to develop (parts of) applications by instantiating these models and generating the code, documentation, and other artifacts. VAMPIRE consists of a collection of loosely-coupled tools and in some sense represents a minimalist approach that allows us to apply MDD now and not wait till tools that would fit our needs appear.

The VAMPIRE framework is based on a very simple pattern, involving *object models*, *editors* and *generators* (see Figure 1).

Object models define the essential entities in the domain(s) of interest. There need not be a single object model capturing a complete application domain, but there can be several small object models such as models capturing the variation points of specific products.

Editors enable manual construction of model instances conforming to an object model. The editors allow users to construct these model instances in an intuitive and domain-specific way and completely hide the underlying implementation technology.

Generators facilitate the generation of various artifacts from model instances. The generators allow (parts of) the software development process to be automated, i.e. to be “driven” by the models.

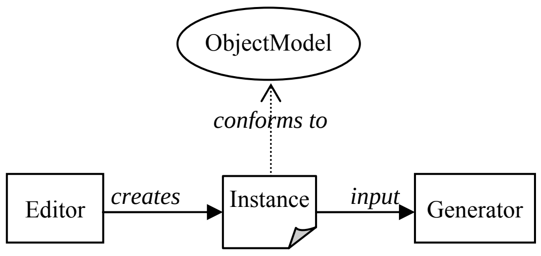


Figure 1: VAMPIRE modeling pattern.

Setting up an MDD approach like VAMPIRE requires the definition of a *meta-model* − a modeling language defining the class of models that the framework supports. In VAMPIRE, this is represented by the *Meta Object Model* (see section 3) which is used to formally describe models of a certain domain. These models can be viewed as *abstractions* of entities within the given domain. In VAMPIRE, a model constitutes a network (graph) of *types* that capture domain knowledge in a certain area (e.g., medical systems). Object models thus serve as *languages* for defining instances of models and are therefore also referred to as *domain-specific languages* [1]. An important feature of VAMPIRE is that it considers models not just as abstractions but as concrete objects from which artifacts such as executable code and documentation can be automatically generated.

The models we develop for our product domains are relatively small in size, usually not exceeding 50 mostly product-specific type definitions. However, given the fact that there are many related products (creating groups of so-called product families) it is often the case that various (related) models need to be reused, combined, or their elements simply have to refer to other models' elements.

In VAMPIRE, it is possible to combine models in different ways. Models can reference types in other models, thus building separate but linked models. Models can extend existing models, which allows the sharing of common parts (model inheritance). Finally, types can be extended with different aspects, which facilitates building models incrementally while separating concerns (Aspect Oriented Modeling).

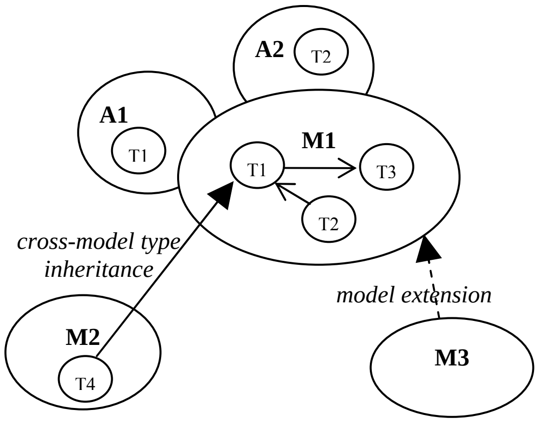


Figure 2: Aspect orientation and model reuse.

Figure 2 depicts three models (*M1*, *M2*, and *M3*). Models typically contain several interrelated type definitions, e.g. *M1* contains types *T1*, *T2*, and *T3*. As mentioned, models can be extended by various aspects. An aspect is also a model; it defines (extensions to) types that are combined with the types of the model to which the aspect is associated. For instance, aspect *A1* defines *T1* which is combined with the definition of *T1* from model *M1*; this mechanism to some extent resembles partial-classes from C# 2.0 but then at model level. The advantage of aspect orientation is the clear separation of concerns. One can simply define different aspects to already existing models, e.g. XML serialization details can be captured as an independent aspect.

Models can be also combined with, extended, or reused by other models. For instance, model type *T4* from *M2* refers to (inherits from) a type *T1* from *M1,* and model *M3* inherits all types from *M1*.

3. Meta Object Model (MOM)

The Meta Object Model (MOM) is defined as a combination of different aspects. Current aspects include the model itself, documentation and XML serialization. The documentation aspect supports the annotation of models with summaries, status, etc. The XML aspect allows for customization of the XML language of the instances. This even makes it possible to model existing XML languages like XML Schema (XSD), SVG, XML and XSLT. By so doing, the generation of such an XML file is reduced to a model transformation followed by a save-to-file operation.

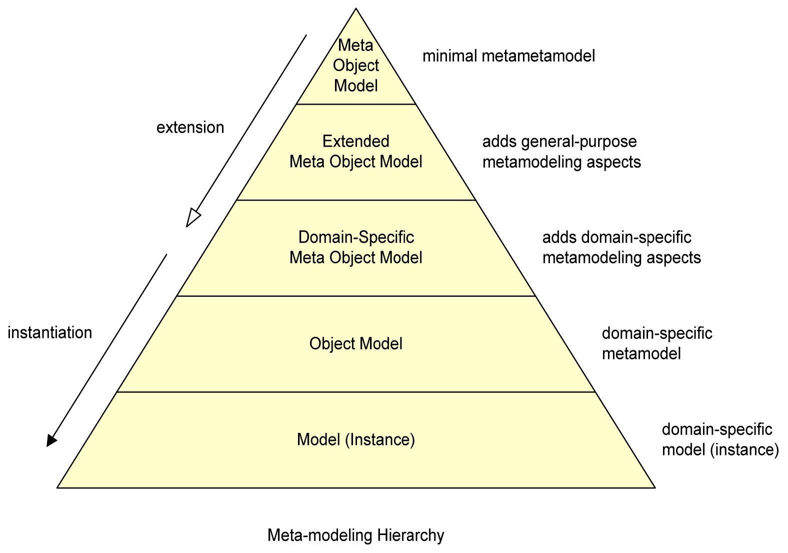
The MOM is an instance of itself which brings great flexibility. It is possible to transform any object model to a MOM instance and vice versa. This enables building tools such as validators to perform additional semantic checks, normalizers that resolve model extensions by creating a single self-contained model, and so-called defaults-resolvers that add or remove default values, which makes navigating through the MOM instances easier from the code. In the code, any MOM instance can be accessed by the graph it represents. When saving an instance of an object model, the graph representation is mapped to a tree-structure imposed by XML. This is done by a special model construct that allows indicating at which location a definition of a certain item is expected and at which other locations in the model references to that item may exist. A stubs-resolver replaces all reference stubs by real references, so that at any location the item's definition becomes transparent to the programmer.

Since the MOM is a generic meta-model, it is very small with just 5 basic constructs: *class*, *union*, *list*, *enumeration* and *value type*. Classes contain attributes that can be optional. This makes it possible to test for the presence of (and even remove) an attribute from a class object. The MOM currently supports single-inheritance, but the work on supporting multiple-inheritance is in progress. This is possible because the generated C# code is fully interface-based and multiple interface inheritance is supported in C#.

Unions represent a special kind of forward type declaration. They define (closed) sets of classes or other unions; the instance of a union type is in fact an instance of exactly one type within the defined set. From the modeling perspective, unions can also be seen as a (type) choice. Unions do not have attributes of their own and support a weak form of multiple inheritance.

Lists are modeled closely to the generic list type of C# 2.0. Enumerations contain literal values. Value types are types that restrict some other basic types, e.g. the name of a C# identifier may subtype string with the restriction that it does not contain spaces.

The generated C# programming library enables a MOM-oriented reflection. So in code it is possible from any model instance to access and explore its object model, which brings more flexibility for writing artifact generators (see section 5).



Meta Object Model
minimal metametamodel
extension
Extended Meta Object Model
adds general-purpose metamodeling aspects
Domain-Specific Meta Object Model
adds domain-specific metamodeling aspects
instantiation
Object Model
domain-specific metamodel
Model (Instance)
domain-specific model (instance)
Meta-modeling Hierarchy

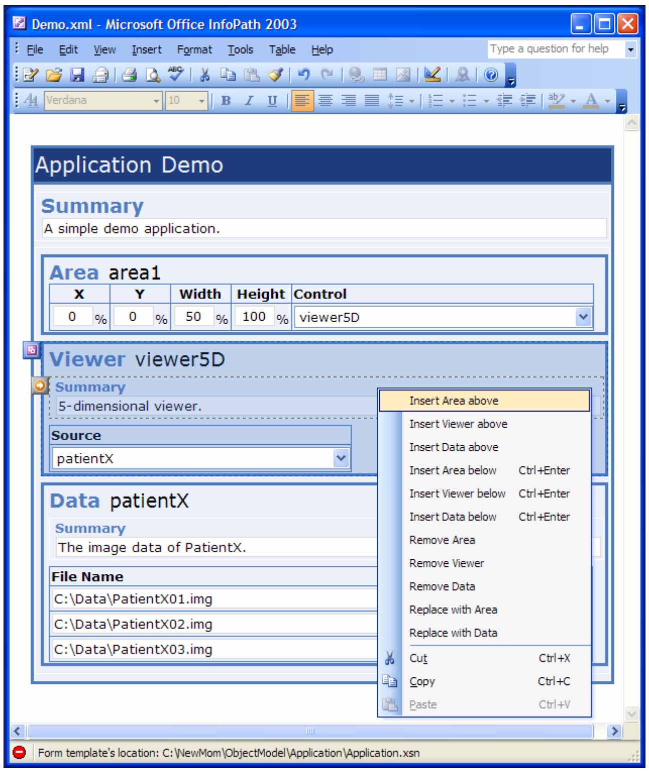
Figure 3: The MOM meta-modeling pyramid.

The MOM is extensible. Since it is described in itself, an extension to the MOM is achieved in 2-pass iterations. In the first pass the MOM is extended and new code is generated from it. In the second pass the code generator is extended to start using the new constructs. Extensions that are independent of the C# model are even simpler and can be added at any time. Therefore, extending the MOM with new aspects, e.g. layout metadata for a graphical editor is very easy. Figure 3 illustrates the extension pyramid of MOM. It starts with the MOM itself as the basic building block followed by general–purpose meta-modeling extensions such as serialization; this layer can be (optionally) extended with domain specific meta-modeling extensions. These meta-modeling facilities are then used to describe concrete domains in terms of Object Models and their instances (Models).

4. Editors

The first letter from the VAMPIRE acronym stands for "Visual", emphasizing that the visual aspect plays a crucial role in the MDD way of working. The fact that models and their instances are edited visually (as opposed to writing code or hand-crafting XML files) makes the learning curve much less steep and the actual process of modeling much more appealing. The visual aspect also contributes to the desired agility of our approach, as it is much easier for people to reason and change models if they are represented visually.

There are several approaches to model / instance visualization, browsing, and editing. These approaches range from more generic table-based model editors (such as the one depicted in Figure 4) to more diagrammatic or pictorial editors. The latter have the potential to offer more (domain) specific elements in the visualization, but of course then they become model dependent and therefore need to be individually tailored for every single application domain.



Application Demo

Summary

A simple demo application.

Area area1

X	Y	Width	Height	Control
0 %	0 %	50 %	100 %	viewer5D

Viewer viewer5D

Summary

5-dimensional viewer.

Source: patientX

Data patientX

Summary

The image data of PatientX.

File Name
C:\Data\PatientX01.img
C:\Data\PatientX02.img
C:\Data\PatientX03.img

Form template's location: C:\NewMom\ObjectModel\Application\Application.xsn

Figure 4 InfoPath-based Application Editor.

The VAMPIRE framework offers an extensible set of loosely-coupled generic tools for editing and browsing models and their instances. Most of these tools are currently based on existing XML-enabled editing suites such as InfoPath[2] or XMLspy[3].

The generic editors provided by the framework can be made more domain-specific by extending the default generators. Future development includes a customizable suite of diagrammatic and pictorial tools for visual model editing.

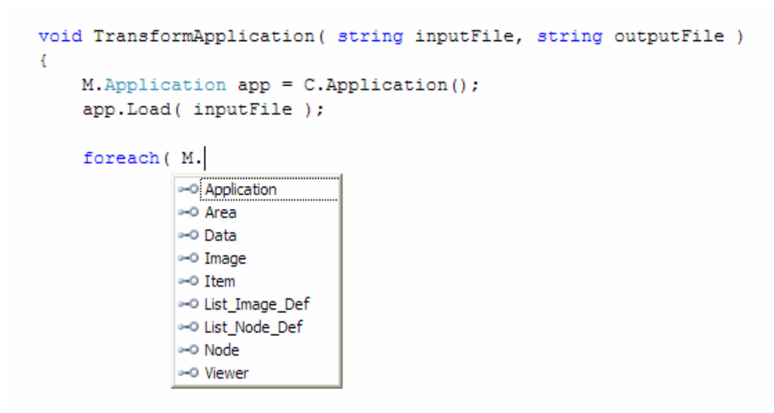
5. Generators

The VAMPIRE framework includes a C# code generator which takes an object model as its input and produces a C# library of types occurring in the model together with a set of interfaces for access and manipulation. The library is fully interface-based implying that instances of model types can only be accessed / modified by interfaces [6].

The generated code provides an easy-to-use programming model for instances of an object model, where all constructs defined in the object model, are also available in C# using Intellisense of VS.NET (see Figure 5). This strongly-typed approach of model instance to C# conversion brings the benefit of compile-time checks and an early discovery of potential inconsistencies (which may occur especially when models are instantiated by humans).

[2] http://www.microsoft.com/office/infopath

[3] http://www.Altova.com/XMLSpy



```
void TransformApplication( string inputFile, string outputFile )
{
    M.Application app = C.Application();
    app.Load( inputFile );

    foreach( M.
```

Figure 5: Model-aware Intellisense support.

Multiple views in the code provide a value-oriented, object-oriented, and an attribute-oriented way of working. The adopted interface-based approach allows switching between the different views. Construction methods are generated for the types to reduce the lines of code you have to write in a generator.

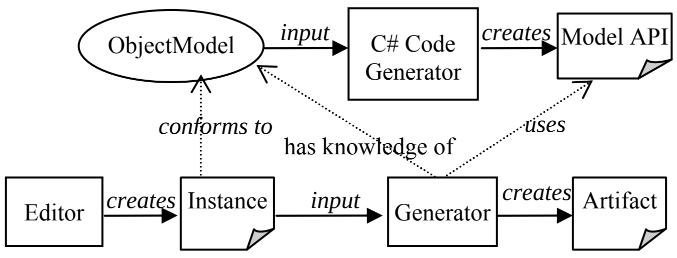


Figure 6: Artifact Generator.

Every model has its own XML representation for which an XML schema file can be generated. The generated C# code provides load and save methods for the instances of the model that conform to their XML representation. The default XML representation makes efficient use of XML attributes, elements or anonymous constructs.

Besides the C# code generator, the VAMPIRE framework offers a number of other tools such as XML schema generator, HTML documentation generator, and a generator of an SVG graphical model browser. On top of the “built-in” generators (which are generic for all instances of the MOM), one can write domain-specific generators that create domain-specific artifacts. Figure 6 shows such a generator; the generator uses the model API created by the C# generator and processes the instances of the model, creating domain-specific artifacts.

6. Applying VAMPIRE

In the past three years we have successfully applied our approach in several domains which, because of the proprietary nature of the products involved, we can only describe briefly in this paper.

During this time the approach has reached a maturity level where it can be transferred to other departments within Philips. Some departments are going to use the approach to research new models and description languages, while others will use the development environment to implement tools for their customers. Because of the fast development of models and transformations more time can be spent focusing on the content instead of the tooling.

The complexity of using MDD in existing software-intensive product lines is mainly identifying those parts in the software architecture that can be replaced by models with generated code. Certain skills, and a different way of thinking about software in general, are required. A trained eye sees possibilities for code generation almost everywhere, which requires switching between several meta-level views.

A typical target for applying MDD is the class of software that exists in many varieties in one product line, or software that changes a lot over time, e.g. with every new release. It may also be applied to develop architecture description languages (ADLs) [7].

Below we shortly summarize the lessons learned during the last few years when we were trying to introduce the VAMPIRE framework in Philips. This (not exhaustive) list can be seen as necessary prerequisites without which it would be very hard to apply MDD within an industrial environment like the Philips product divisions.

- Incremental deployment of MDD.

  It is important to be able to introduce MDD in small evolutionary steps (as opposed to a sudden 100% MDD conversion). This is important especially in an environment which possesses a long history of products and usually has many obligations to third parties w.r.t. that.

- Very simple meta-modeling facility.

  It is necessary to realize that the ultimate user of MDD will eventually be a (technically savvy) domain expert rather than a “purist” programmer[4]. Therefore, the learning threshold for embracing the MDD approach must be as low as possible and the actual models must be close to the domain where they are to be applied.

- The ability to combine/reuse/extend models.

  Multitude of related products require their models to be also related. The agility of MDD brings even more benefits if one is able to reuse and combine existing models.

- Support the rapid development of generators (using MDD).

  Tools like an efficient C# code generator or editor generators must be present in the framework to increase its usefulness, its ease of use, and ultimately to make it embraced by the community of modelers and developers.

- Software development paradigm shift.

  The introduction of any paradigm shift takes time. We have to change the way in which developers perceive software, the way they think about development, and prove that the changes will bring benefits in the long run. Developers are often reluctant to change the way they work. MDD focuses on developing tools that generate (parts of) the end-product, instead of developing the product manually.

[4] Excellent software developers will still be needed to develop MDD tools like (domain-specific) generators etc.

We believe that MDD has the potential to improve the way we create software and above all to make this process more efficient. However, as any new technology, also MDD must overcome the inertia of existing approaches, and even if all the technical ingredients are in place, it also requires the management support and their devotion to make the change happen.

7. Related work

In this short comparison we chose to focus on two MDD initiatives advocated by OMG and Microsoft, respectively. We note that there are a number of other model-driven frameworks and approaches that VAMPIRE can relate to. However, to our knowledge no existing approach offers an aspect-oriented way of modeling combined with (pure) interface-based C# code generation, features which are very important in our application domain.

MODEL DRIVEN ARCHITECTURE (OMG)

The OMG promotes model-driven architecture [2, 3]. In simple terms, their approach states that applications are developed by creating platform-independent models (PIMs) in UML. PIMs conform to domain-specific meta-models defined by UML profiles or by means of the meta-object facility (MOF). Model transformations map PIMs to platform-specific models (PSMs) and from there to code, etc. Tools exchange data by means of the XML Metadata Interchange (XMI) language. The OMG itself does not develop tools and the tool support is (to be) delivered by third parties.

MDA in some sense represents an MDD vision that other approaches can relate / comply to. VAMPIRE too adopts some of the MDA ideas, however, we consider our approach being more of a bottom-up nature (starting with a concrete domain) than top-down nature of MDA (having the universal language that needs some tailoring).

S*OFTWARE FACTORIES / DSL (Microsoft)*

Microsoft's *software factories* initiative [4] and the associated DSL tools [5] are very close to our approach therefore we compare it in more detail. The Microsoft approach uses a meta-language to define domain-specific languages (DSLs), which is not very different from our Meta Object Model. One important difference though, is that the VAMPIRE framework facilitates various ways of combining and reusing models; this feature is, to our knowledge, missing in DSL. The type of reflection provided by VAMPIRE and DSL also differs. While VAMPIRE allows for reflection at model level, DSL provide reflection at C# level only.

Another difference is that DSL use a tem7plate-oriented approach to artifact generation while VAMPIRE uses a (full-fledged) code-based approach. The former fits well in simpler types of artifacts such as documentation reports; however, writing templates that generate C# code is much more tedious, especially since (at the time of writing) supporting tools like Intellisense or the syntax highlighting are missing.

On top of that, DSL tools are still undergoing radical changes (to the better we believe) and their meta-model and APIs are not yet stable enough for use in production quality code. We continue to monitor the developments of the DSL tools and do not exclude the possibility to port our VAMPIRE framework onto this platform some time in the future.

8. Conclusions

In this paper we have described the essence of the VAMPIRE framework developed at Philips Research. Our approach targets both new product architectures as well as existing software intensive product lines, where the handwritten code can be incrementally replaced by generated code from models.

The framework is based on a pattern involving *models*, *editors*, and *generators* and the paper elaborated on these MDD "ingredients" in more detail. We have also summarized the lessons learned from applying our framework in Philips product divisions. Below we list some of the distinguishing features of VAMPIRE.

- By incorporating Aspect-Oriented Modeling and supporting multiple inheritance, VAMPIRE provides an easy way to build new models on top of existing ones, facilitating model extensibility and reuse.
- The generators are implemented as loosely-coupled tools associated with different model instances, and can also be combined into file- or memory-based generator pipelines, where output of one generator serves as input for another one.
- Flexible XML serialization format allows for modeling of existing standardized XML languages such as XML Schema. Creating output in such a standard XML language is as easy as building a model-to-model generator.
- Using a minimalist approach, we tailored VAMPIRE to the needs of our industrial applications. However, the framework proved to be powerful and extensible enough to be applied in different (unrelated) contexts.

In our experience, MDD has the potential to make the process of software creation much more efficient. In order to achieve that, the MDD way of thinking needs to be adopted by the developers and domain experts, some of whom will actually become application modelers.

Acknowledgements

We would like to thank our colleagues both from Philips Research and Philips product divisions for providing their valuable feedback on this work.

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Domain Specific Model Composition Using A Lattice Of Coalgebras

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Abstract

This paper presents a semantics for domain-specific modeling in support of system-level design of reactive, embedded systems. At the core of the approach is the use of a lattice of coalgebras to define the semantics of individual models and reusable specification domains. The lattice provides formal support for assessing the correctness of specification transformation. Additionally, using pullbacks and functors within the lattice provides semantic support for specification transformation and composition. Although developed for the Rosetta specification language, the lattice of coalgebras provides general semantic support that could be used to define any system-level design language.

1 Introduction

The Rosetta system-level design language and semantics [1, 2] are designed explicitly to support the needs of system-level design for reactive, embedded systems. To achieve this, Rosetta supports domain-specific, heterogeneous specification by providing a collection of *domains* that define vocabulary and semantics for domain specific design *facets* and a *domain lattice* that organizes domains to support abstract interpretation, transformation and composition of specifications. In this paper we present a semantic infrastructure supporting these system-level design activities.

2 Domain Specific Modeling Semantics

Facets are the fundamental unit of Rosetta specification representing one aspect or view of a multi-aspect system using domain-specific semantics. Information such as component function, performance constraints, and structure are represented using facet models. Facets use a domain-specific semantic basis appropriate for the information being represented explicitly supporting heterogeneous modeling.

Figure 1 shows two facet models describing power and function for a simple signal processing component. The power model defines a simple activity-based power consumption model that observes changes in the output value. The function model defines the interface of a functional model whose body is omitted for space consideration. The system-level design objective is to define a single model that satisfies both specifications.

```
facet power
  (o::output top;
   leakage::design real;
   switch::design real)::state_based is
  export power;
  power::real;
begin
  power' = power + leakage +
             if event(o) then switch
                else 0
             end if;
end facet power;
```

```
facet interface function
   (i::input real; o::output real;
    clk :: in bit;
    uniqueID::design word(16);
    pktSize::design natural
   ):: discrete_time is
  uniqueID :: word(16);
  hit :: boolean;
  bitCounter :: natural;
end facet interface function;
```

Figure 1: Rosetta specification fragments defining power consumption and functional models for a TDMA unique word detector.

2.1 Coalgebraic Semantics

Jacobs [3] observed that coalgebras provide an excellent basis for defining computations that are event driven and non-terminating. Every coalgebra ψ has the form:

$$\psi :: \mathcal{X} \rightarrow \mathcal{F}(\mathcal{X})$$

where $\mathcal{X}$ is the carrier and $\mathcal{F}$ defines constraints on the carrier. Running a coalgebraic system involves unfolding $\mathcal{X}$ with respect to ψ using an anamorphism defined for all such coalgebras. Specifically, given $\mathcal{X}$ the next state is $\psi(\mathcal{X}) = \mathcal{F}(\mathcal{X})$, the next is $\psi(\psi(\mathcal{X})) = \mathcal{F}(\mathcal{F}(\mathcal{X}))$, and so forth. This is precisely the semantics we want for event-driven, continuously operating systems. The application of ψ is associated with a system event, causing a state change when that event occurs.

It is useful to contrast the coalgebra with an algebra having the form:

$$\phi :: G(b) \rightarrow b$$

where b is the carrier and G defines constraints. Here, evaluation is takes the form of a fold of G over b using a catamorphism. Given any *finite* number of applications of G, the value b can be calculated. Thus, if we use an algebraic model, we are restricted to examining only finite prefixes of potential state sequences.

The semantics of a Rosetta facet is denoted by coalgebra defining observations on changes over an abstract state. The facet's signature defines the coalgebra signature while its terms define its transformation by placing constraints on abstract state observations. For example, when denoting the power facet from figure 1, $\mathcal{F}$ is next observed by facet declarations while a is the facet state. Thus, given a state a, the sequence of states is observed as a, $next(a)$, $next(next(a))$ and so forth as expected. The terms in the facet constrain $next$ providing a definition of the sequential computation. The application of $next$ is constrained to occur only when an event is observed on the system output. This is embodied by the predicate event used in the definition.

The signature of coalgebra denoted by the power facet in figure 1 has the form:

```
<o,leakage,switch,power,s,next> :: 𝒳 →
    (state_time  → top)
    × (state_type → real)
    × (state_type → real)
    × state_type
    × (state_type → state_type)
```

where o, leakage, switch, and power are observations on $\mathcal{X}$ defined in the facet while s and next are defined by the state_based domain. The corresponding types of those observations comprise the product.

What we are defining in the facet is the observation of the next $\mathcal{X}$ as observed by next. Examining the denotation of the power term reveals the coalgebraic nature of the facet:

```
power(next(s(𝒳)) = power(s(𝒳))
                    + leakage(s(𝒳))
                    + if  event(o(s(𝒳))) then switch(s(𝒳)) else 0 end if;
```

Here, the next function is being defined by embedding it in the observer power, commonly called a destructor. As long as $\mathcal{X}$ does not change, the observation remains the same. These characteristics – defining functions in destructors and observing state change – lead us to a coalgebraic semantics over the more traditional algebraic semantics [3].

In a Rosetta facet coalgebra, $\mathcal{X}$ is always held abstract with no associated concrete type. It is never directly visible to the specifier or even to the Rosetta facet that observes it. Instead, a Rosetta facet's state is denoted as an observation of $\mathcal{X}$. For example, if s :: state_type defines a state in some domain, then its value in the coalgebra is denoted $s(\mathcal{X})$ :: state_type – a function over the abstract state. If an item x :: integer is defined in a facet from the domain of s, then it is denoted $x(s(\mathcal{X}))$ :: integer.

Because facet state is simply an observation of $\mathcal{X}$, it is possible to define multiple state observations with multiple semantics. As sequencing of state is the critical element distinguishing models-of-computation, defining different state observations results in multiple, heterogeneous models-of-computation. When models defining different state semantics observe the same abstract state, then those observations may be related. This is precisely what is needed in system-level design where the distinction between modeling domains is rooted in the underlying computational model.

2.2 Specification Composition

The primary specification composition mechanism in the Rosetta semantics is defined by the category theoretic *pullback* construction. In the traditional specification literature where algebraic specifications dominate presentations, the *coproduct* and *pushout* define specification composition [4]. As Rosetta models are coalgebraic, their duals, the *product* and *pullback*, define model composition. Intuitively, the pushout forms the union of two algebraic specifications defined around a collection of shared declarations. The pullback forms the intersection of two coalgebraic specifications, again defined around a collection of shared declarations. Making $\mathcal{X}$ the minimum shared declaration ensures that specifications involved in the pullback reference the same abstract state. They may observe that state differently, but they observe the same state.

Given two Rosetta models f_1 and f_2 a product is formed as the disjoint combination of f_1 and f_1 much like a record. In contrast, a pullback forms a product around a common, shared specification, d. We say that d is shared between specifications because when properties from f_1 and f_2 refer to declarations in d, they refer to the same element. Properties placed on symbols of d from each specification mutually constrain d implying f_1 and f_2 are no longer orthogonal.

In our power modeling example, we would like to understand how the function being performed impacts power consumption. Thus, a pullback is formed is formed from the power specification and the original function specification. This product model formed by the pullback is defined as a new Rosetta facet in Figure 2.

```
facet power_and_function
    (i :: input real; o :: output top; clk :: in bit; uniqueID::design word(16);
     pktSize :: design natural; leakage,switch :: design real) :: discrete_time is
  gamma(power(o,leakage,switch))
  * function(i,o,clk,uniqueID,pktSize);
```

Figure 2: Creating the composite specification by forming the product of the functional specification with the application of gamma to the power specification.

The product treats the discrete_time domain as a shared specification among the power and function models. The specification objects that t, delta and next refer to are shared between the specifications. Edges that indicate state change and power consumption are common to both components implying that processing in the functional specification results in power consumption in the power model. Any property defined on these items in one specification must be consistent with definitions in the other –

they are literally shared between the specifications. Other symbols remain orthogonal, but when referenced in properties relating them to shared symbols they are indirectly involved in sharing properties across domains.

2.3 The Domain Lattice

Because Rosetta facets are first-class items, they must have an associated type, called a *domain*. In figure 1 the domain of the function facet is discrete_time while the power facet is of type state_based. Rosetta domains encapsulate vocabulary and semantics for domain specific specification style. Each domain encapsulates units of semantic declarations, a model of computation, and a domain specific modeling vocabulary for reuse among similarly structured specifications.

Domains are simply distinguished facets that represent specifications that are extended. When a new domain is defined, it extends another domain in a manner identical to facet definition. The new domain is aptly call a subtype or subdomain of the original domain. For example, the discrete_time domain is defined as a subtype of state_based. The concepts of state and change present in the state_based domain are inherited and refined within the state_based domain. The distinction between defining a domain and defining a facet is the domain can be further refined to define facets or other domains.

The set of legally defined domains together with the homomorphism relationships resulting from extension define a partially ordered set $(D, \Rightarrow)$ referred to as the *domain lattice*. The domain lattice obeys the formal definition of a lattice requiring the definition of meet ($\sqcap$), join ($\sqcup$), the minimum domain the maximum domain. **null** defines primitive Rosetta semantics including $\mathcal{X}$ and is the least domain in D with all domains inheriting from it. Similarly, **bottom** is the greatest domain and inherits from all domains, making it inconsistent.

For any domain pair D_1 and D_2, $D_1 \sqcap D_2$ and $D_1 \sqcup D_2$ are defined as the least common supertype and greatest common subtype. The existence of **null** and **bottom** ensures that every domain pair will have at least one common superdomain and subdomain. Thus, $(D, \Rightarrow)$ defines a lattice.

2.4 Specification Transformation

A *functor* is a function specifying a mapping from one domain to another. The primary role of functors is to transform a model in one domain into a model in another. Viewing each domain and facets comprising its type as a subcategory of the category of all Rosetta specifications, a functor is simply a mapping from one subcategory to another corresponding to the classic definition of functors in category theory.

When defining domains by extension, two kinds of functors result. Instances of concretization functors, Γ, are defined each time one domain is extended to define another. Abstraction functions, A, are the dual of concretization functions and are known to exist for each Γ due to the multiplicative nature of extension. So, Γ instances move down in abstraction while A instances move up. Each arrow in the domain lattice moving from one domain down to another defines both an instance of Γ and A. However, A and Γ do not form an isomorphism because A is lossy – some information must be lost or A cannot truly be an abstraction function.

3 Implications of the Domain Lattice

A major application of Rosetta functors is to add or remove detail to support predictive analysis and specification composition. Thus, it is critical to assure that functor application results in correct models. To achieve this, we view functor application from the perspective of abstract interpretation [5] where programs and specifications are statically analyzed by focusing only on necessary details. An abstraction is *safe* when the model resulting from it is faithful to the original model.

Because Rosetta focuses on domain-specific specification composition, we need to verify the safety of functors moving specifications within the lattice. More specifically, we want to verify that by moving a specification or model between Rosetta domains we do not sacrifice correctness. One technique common in the abstract interpretation community is establishing a *Galois connection* [6] between domains in the lattice.

A Galois connection (C, α, γ, A) exists between two complete lattices $(C, \sqsubseteq)$ and $(A, \sqsubseteq)$ if and only if $\alpha : C \rightarrow A \wedge \gamma : C \leftarrow A$ are monotone functions that satisfy $\gamma \circ \alpha \sqsupseteq \lambda c.c$ and $\alpha \circ \gamma \sqsubseteq \lambda a.a$. Typically, α is an abstraction while γ is an associated concretization. Within the Rosetta domain lattice, the initial focus on the functors A and Γ formed when one domain is extended to define another. This gives the Galois connection we are initially interested in the form (D, A, Γ, D).

The extension of one domain to form another gives us a concretization functor, Γ, that defines a homomorphism between domains. Because Γ is multiplicative, we know from lattice theory that an inverse abstraction functor, A, exists and can be derived from it. With A and Γ and the homomorphism, we can define a Galois connection between any Rosetta domain, D_0, and any of its subdomains, D_1, as $(D_0, A_1, \Gamma_1, D_1)$. Knowing the Galois connection exists we are guaranteed any transformation between D_0 and D_1 using Γ of A is safe. We are also guaranteed that the original model is an instance of the abstract model and the abstract model is truly an abstraction.

We also know that the *functional composition* of two Galois connections is also a Galois connection [6]. Formally, if $(D_0, A_1, \Gamma_1, D_1)$ and $(D_1, A_2, \Gamma_2, D_2)$ are Galois connections then $(D_0, A_2 \circ A_1, \Gamma_1 \circ \Gamma_2, D_2)$ is also a Galois connection. Not only can we assure safety between any domain and its subdomain, but we are also guaranteed safety of any transformation within the entire Rosetta domain lattice that follows abstraction links.

4 Related Work

The use of products for specification composition is well established in the literature for both specification [4] and synthesis [7]. Although the coalgebra and pullback are less frequently used, there has been work using coalgebras to define composable specification systems [8] and the use of coalgebraic specification is seeing acceptance in the specification community [9]. Brevity prevents complete discussion of coalgebraic techniques – see Jacobs' and Rutten's excellent tutorial for more details [3].

UML meta-models define semantics that has been exploited for domain specific tool development and model-integrated design [10]. The model-integrated approach reflects our approach to model refinement and abstraction as the central features in design synthesis and analysis respectively. The model-integrated approach uses UML as its modeling language, although like the coalgebraic semantics presented here it should not be limited to UML models.

Viewpoints are a software specification technique applied to domain specific modeling [11]. Viewpoints are less formal than Rosetta and focus primarily on software systems. However, interaction between models searching for inconsistencies has been explored extensively giving Viewpoints a similar system-level focus[12].

An alternative approach using operational modeling is the Ptolemy [13] project. Ptolemy (now Ptolemy Classic) and Ptolemy II successfully compose models using multiple computation domains into executable simulations and software systems. Ptolemy II introduces the concept of a system-level type [14] that provides temporal information as well as traditional type information. Like Rosetta, Ptolemy II uses a formal semantic model for system-level types. Unlike Rosetta, Ptolemy models are executable and frequently used as software components.

5 Discussion

This paper provides an overview of the approach to domain specific model composition embodied in the Rosetta specification system. With a formal semantics for heterogeneous models supporting composition and transformation functions, it becomes possible to define heterogeneous models, compose them and generate abstract analysis models. Further details are available in *System-Level Design with Rosetta* [2] one of several overview papers [15].

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