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**Title:** Human Digital Twins and Cognitive Mimetic

**Year:** 2020

**Version:** Accepted version (Final draft)

# Human Digital Twins and Cognitive Mimetic

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**Abstract.** Digital twins – digital models of technical systems and processes – have recently been introduced to work with complex industrial processes. Yet should such models concern only physical objects (as definitions of them often imply), or should users and other human beings also be included? Models that include people have been called human digital twins (HDTs); they facilitate more accurate analyses of technologies in practical use. The cognitive mimetic approach can be used to describe human interactions with technologies. This approach analyses human information processes such as perceiving and thinking to mimic how people process information in order to design intelligent technologies. The results of such analyses can be presented as an ontology of human action, and in this way included in HDT models.

**Keywords:** Digital twins · Human-systems Integration · Cognitive mimetic, AI

## 1 Introduction

Digital twins – computational models of industrial objects – are becoming an important part of technological thinking [1,2]. They can be used to design, operate and maintain complex systems. They are often used to model physical objects in industry such as turbines, power stations, control systems or paper machines. However, they can also be used to assess how people interact with industrial processes.

All technology is intended to improve people's quality of life. Therefore humans should always be considered an essential part of technology systems. People are not only users of technologies; they are also targets of technical actions and organised around technical artefacts. Thus, modelling technologies should not be limited to technical artefacts; they should also take into account peoples' various roles and actions around artefacts. When digital twins include human beings in their different roles, the models can be called human digital twins (HDTs) [3].

HDTs model how technical artefacts are used. Thus, they can provide information about human differences and difficulties in the practical use of technical artefacts. HDTs can be used to obtain information about the logic of using an artefact, their usability problems as well as how people like to use them. Moreover, HDTs can model exactly how people use a particular technology. Thus, industry can use HDTs in their research on human factors and in their search for effective work and organisational practices. HDTs connect accurate pictures of the inner principles of technical artefacts with accurate pictures of how humans use or relate to the artefacts.

## 2 Cognitive mimetic approach

It is far from clear how to use digital twins to obtain relevant knowledge about people. The simplest models concern the use of controls and feedback systems. However, sophisticated systems should also provide information about how effectively people can use the systems – for example, how to design the controls so they are easy and pleasant to use. Too many industrial accidents are caused by poorly designed controls [4].

Furthermore, in many technical processes, such as those used in factories, a human operator intervenes and adjusts the physical processes based on information they obtain from multiple sources. Thus the control and feedback systems are used by the intelligent process controller of today: the human operator. Obtaining accurate pictures of the mental contents and processes that guide operators' actions also paves the way for automation and highlights their information requirements.

HDTs should model not only how artefacts work, but how people use them. One approach to building HDT models is to apply the cognitive mimetic approach, which we define as using human information processes to design intelligent systems [5]. Mimetic design involves using a source in the natural or artificial world to inspire technological solutions. Cognitive mimetics studies human shared and individual cognitive processes, as well as the mental content, representations, and constraints that establish the boundaries and forms these processes take. It analyses how people carry out intelligent tasks, and uses this information to design novel technological solutions. Cognitive mimetic researchers study how people process information while using technologies. The results of analysing human actions and performances and can be used to build HDT models.

The first example of cognitive mimicking and human information processing was perhaps Turing's model of the mathematician: the Turing machine. His focus was not on human biological structures (differently from biomimetic), but their information processing [6]. Later, Herbert Simon and colleagues began to empirically study human cognitive processes and thus extended mimetic thinking from introspective analysis to objective or behavioural [5].

Applying cognitive mimetics to HDT modelling involves explaining how (and why) people act, what they do, what kinds of difficulties they have, and how they feel about using technologies. Thus, cognitive analysis makes it possible to include all the main aspects of using technical artefacts in the model, which mimics real human information processing.

## 3 Ontology of modelling

Models of artefacts and human action can be expressed as ontologies. Ontologies are descriptions of information content; they are often considered basic units in the science of information content [7]. Ontologies are essentially conceptual systems that describe the attributes of ground concepts and their systems. The basic questions of human–technology interaction can be presented as an ontology:

1. action
    - 1.1 goal
        - 1.1.1 static
        - 1.1.2 dynamic
    - 1.2 agent
        - 1.2.1 role
        - 1.2.2 age
        - 1.2.3 skills
    - 1.3 artefact (tool)
        - 1.3.1 functionalities
            - 1.3.1.1 knowing that
            - 1.3.1.2 knowing how
            - 1.3.1.3 tacit and explicit
        - 1.3.2 functional logic
        - 1.3.3 user interface
        - 1.3.4 manipulation
            - 1.3.4.1 direct
            - 1.3.4.2 indirect
        - 1.3.5 efficiency
    - 1.4 object
        - 1.4.1 physical object
        - 1.4.2 information
        - 1.4.3 states
            - 1.4.3.1 initial
            - 1.4.3.2 goal
    - 1.5 context
        - 1.5.1 physical
        - 1.5.2 social
            - 1.5.2.1 legal
            - 1.5.2.2 interest groups
        - 1.5.3 information
2. technical interaction
    - 2.2 input
    - 2.2 output
    - 2.3 operations
3. usability
4. user experience
5. technology in life

This schematic ontology illustrates how human–technology interaction concepts can be presented. They can also be seen as issues that designers must analyse and solve. The five main categories refer to the *action* (what people do), *agent* (person who is doing something), *technical interaction* (i.e., the input, the processing logic and output), *usability* (i.e., can people use the technical artefact) and *user experience* (do people like to use the artefact). The final issue is the role of technology in human life.

Digital twins (of physical processes) can connect to many categories and attributes by providing a parallel complementary picture of the target or artefact. It is also important to keep in mind that the user's picture of the system is not necessarily the same as that of designers or managers. For example, an operator in a paper mill understands the technical system in a different sense than a chemical engineer designing the overall process. Thus it is not possible to reduce many complex and dynamic factory processes to pure physical or engineering knowledge.

# 4 Air traffic controllers – a case analysis

The case of air traffic controllers illustrates how these ontologies could be applied to create digital twins in order to investigate how technologies can improve their task. The main objective of the controllers' actions is to maintain the vertical and horizontal distances between airplanes so they do not enter into a "conflict situation" in which they may collide. This main objective explains and justifies all the other partial objectives. When a controller asks a pilot to climb to a particular altitude, his ultimate objective is to prevent the aircraft from entering a conflict situation with another aircraft in the immediate future. In this way, it is possible to analyse how the controller's cognitive decision-making processes manage the information he is perceiving and to predict the future positions of the aircraft. Based on these predictions of future positions, the controller is not able to understand the action of asking the pilot to change altitude.

The devices used by the controller must be analysed from the point of view of how he or she interacts with them. The functionalities that are included in the radar of a control position are those that the controller needs to perform its task. However, these functionalities must be designed to ensure the controller has an effective, efficient, satisfactory and positive experience when interacting with them. The control positions are designed to suit the preferences of each individual controller. Therefore, where digital twins mimic the control task, individual differences and references must be taken into account.

As for the objects of the actions, it is necessary to take into account the fact that the control acts on both "proximal" and "distal" objects. Proximal objects are, for example, the representations of the aircraft on the radar screen, while distal objects are the aircraft themselves. Psychologically speaking, actions on proximal vs. distal objects involve different types of cognitive processing.

The physical and social context in which the controller acts is very important. The physical context, for example, is very different for a tower controller and a route controller. The tower controller has a direct perception of its objects (the airplanes), while a route controller can only perceive nearby objects (the objects on the radar screen).

Finally, the social context is essential to air traffic controllers' work, since they work with the pilot and other controllers – called "collaterals" – who are responsible for other sectors of the airspace. Depending on the circumstances in a control position, there may be two controllers, the "executive" and the "planner". Therefore, issues of social and organisational psychology are very relevant in control tasks.

## 5 Uses of human digital twins

Constructing digital twins can be based on in-depth cognitive science, which allows technical designers to construct well-designed human–technology interaction processes. This also makes it possible to consider users' minds. An important approach to modelling the mind was developed based on Turing's as well as Newell's and Simon's thinking within cognitive psychology. Cognitive researchers began to consider the human mind as an information processing system [6, 7]. Following this hugely influential way of thinking, one can suggest that constructing HDTs could be based on the idea that they are information processing systems.

The cognitive mimetic approach can be applied in this context. Cognitive mimetics analyses human information processes such as perceiving and thinking to mimic how people process information for designing intelligent technologies. Building human-digital twins (HDTs) with parallel human information processing models could thus make use of the ideas in cognitive mimetics. Thus, research on (and the concept of) information processing could unify people and research artefacts into a single model.

HDTs would facilitate a number of possible improvements to design and development processes. For instance, one can follow usability and user experience problems based on knowledge collected in digital twins, or study individual and group differences in working with technologies.

For example, if two work shifts on a factory line have essentially different outcomes, this must be based on how the operators work rather than how the machines are performing. Thus, HDTs can make it possible to analyse how to improve the conditions and work habits and thus to improve the use of technical artefacts.

HDTs may improve design communication and how expertise is organised. One difficulty associated with constructing technologies can be differences in educational backgrounds. As human researchers are used to the ways people think in psychology or sociology, technical people may have great difficulty understanding how people operate technologies. The opposite may be equally difficult, as human researchers are often not very competent with mathematics, materials, properties of machine elements and phenomena such as friction, which are commonplace issues for technical people. HDTs can therefore make communication easier.

Finally, a key idea in cognitive mimicking involves supporting the design of artificial intelligence (AI). One may ask whether twinning is a proper way to use cognitive mimetics. Digital twins are models of industrial processes, and thus they need not have any role in AI design. However, digital twins maybe used to describe information processing, and thus HDT modelling can be used to develop AI solutions for existing work processes.

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