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Change and Control Paradoxes in Mobile Infrastructure Innovation

The Android and iOS Mobile Operating Systems Cases

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Abstract

The advent of the smartphone as a highly complex technology has been accompanied by mobile operating systems (OS), large communities of developers, diverse content providers, and increasingly complex networks, jointly forming digital infrastructures. The multi-faceted and relational character of such digital infrastructures raises issues around how change and control can be conceptualized and understood. We discuss how change and control are paradoxically related in digital infrastructures and how they affect the evolution of such infrastructures. We examine these paradoxes by examining the change in, and competition between, two mobile operating systems: Apple's iOS and Google's Android along with their related platform features and ecologies. We seek to validate a proposed theoretical framework of the dynamics of change and control through second-order analysis of the two cases. We observe that multiple factors had a significant effect on the evolution of these platforms including user interface, development platforms, business models, and value extraction principles. We observe how these factors significantly affect the evolution of mobile platform ecologies as well as speculate about the future of mobile system platforms.

1. Introduction

While the pervasive digitalization of organizational life has become the “new” reality [1] mainstream IS research has remained almost silent about the impact of the one class of IT artifacts – *digital infrastructures* – that underlies this new reality [2]. Meanwhile mobile phones have gradually been transformed from providing just telephony to powerful multimedia and Internet capable broadband computing devices. While handheld computing devices have had OS since the early 1980s [3] their role has become much more important in the last years. Indeed, the launches of

new types of smartphones have become media events [4]. Equally important are predictions that mobile phones will soon overtake PCs as the most common Web access devices [5]. Consequently, the mobile OS¹ have become pivotal *platforms* for creating service ecologies and a target for developing new services to ever-larger proportions of the world's population. Thus, it can be argued that mobile computing has become one of the most important information infrastructures in its own right – complementing and extending its fixed counterparts. All this suggests that we are rapidly moving towards fulfilling the dream of pervasive and ubiquitous computing [6].

Infrastructure can be defined as the underlying physical and organizational structures needed for the operation of a society or enterprise, and the services and facilities necessary for an economy to function [2, 7]. Accordingly, digital infrastructures can be defined as the constitutive information technologies and organizational structures, along with the related services and facilities necessary for an enterprise or industry to function. Digital infrastructures cannot be defined through a closed set of functions (unlike specific systems), or strict boundaries (unlike applications) [2, 8]. In contrast they are characterized by dynamism and longevity and their relational nature [2]. Digital infrastructures also form a new stage in the evolution of IT, reflecting the fact that IT has become deeply embedded socially [2]. IT's evolution is coordinated across diverse socio-technical worlds often with the help of numerous standards. Hence, digital infrastructures form an important distinct category of IT artifacts [8]. Being a relational construct the infrastructure cuts across many IS research topics. This challenges us to develop new

¹ A *mobile operating system* is system software that manages a mobile device's hardware and provides generic services (e.g. exception handling and memory management) to applications running on it. They often also offer more advanced services like location-based services to applications.

theoretical and methodological approaches to study IT and its effects as infrastructures continue to play a pivotal role in shaping the future uses of IT – including those of mobile services [2, 9, 10].

The notion of contradiction [11, 12] offers one way of initiating inquiries around the complex relationships between infrastructural elements located across multiple levels of analysis. For example, paradoxes of *change* and *control* have been put forward as salient phenomena for understanding the dynamic nature of digital infrastructure [2]. The paradox of change relates to the need for digital infrastructures to be stable in order to enroll new actors, artifacts and processes, while at the same time being flexible to ensure unbounded growth. The paradox of control stems from the tension when actors seek to gain the advantages of generativity from distributed processes while at the same time striving to shape or control the way generativity plays out in their own interests [2]. We use these concepts as lenses to account for evolution of mobile services and the creation of new mobile computing service ecologies.

We conduct a dialectic analysis to examine mobile OS from a socio-technical infrastructural perspective. In particular, we trace their evolution as critical elements that have spurred dynamic growth of mobile information infrastructures. We consider the emergence, growth and pivotal place of the current struggles around the future of mobile computing as an indicator that mobile OS have become central control points that shape the future of mobile digital infrastructures. They will after all be the interface to information, communication, entertainment, and computing for most of the world's population in but a few years [13]. Firms or other actors able to exert control on infrastructural ecosystems built around these OSs can wield incredible power across several industries [14]. To this end we explore them as relational entities – and not just entities with specific functional features. More specifically we use the investigation of the evolution and growth of mobile computing ecologies as a way to explore, understand, and illustrate how *paradoxes of change and control* are playing out around two distinct mobile OS; Apple's iOS and Google's Android. The paper demonstrates the complex and relational nature of mobile OS and the associated ecosystems as digital infrastructures. The paper also highlights the need for more comprehensive understanding of the paradoxes of change and control as means of understanding the development of such phenomena.

The remainder of the paper is organized as follows. Sections 2 and 3 outline our theoretical perspective and methodology. Section 4 characterizes the development of two mobile OS. Section 5 discusses

the main findings, and concludes by drawing-up an initial profile of the characteristics of mobile platform innovation from the perspective of digital infrastructures.

2. Theoretical Perspective

We view mobile computing as the latest step in a succession of massively scalable technological systems and related infrastructures. These infrastructures of modernity have fundamentally transformed the way that work is carried out, life is lived, and society is organized. Earlier infrastructural technologies include the roads, canals, water and sewage, railroads, telegraph, radio, TV, telephony, computing, intermodal freight, and the Internet as well as mobile communications. While all these infrastructures are manifested in physical and technological artifacts their growth and evolution highlight the essentially socio-technical nature of their evolution [15-17]. Like earlier technical infrastructures, mobile computing is deeply socially embedded. Its evolution is coordinated through diverse socio-technical worlds, such as; regulations, markets, chip designers, software application developers, and content providers [16]. Furthermore, numerous standards are necessary to coordinate action across these social worlds and are applied to and in turn influenced by mobile computing including e.g. air interfaces, protocols, mobile OS platforms, and industry practices. Put simply, the evolution of large technological infrastructures is as much a social phenomenon as a technical one [8]. Consequently, mobile computing as a technological infrastructure needs to be studied by analyzing the ongoing processes of its embedding in individual, organizational, institutional and market practices in ways, which enable and lead to new social behaviors.

Modern digital infrastructures' inherent scalability and flexibility can foster extraordinary growth in scale and scope as well as enable unexpected combinations of services and capabilities to be produced at unprecedented speed - denoted often as digital convergence [2]. Simply, the inherent flexibility of digital infrastructures is built upon the digitalization of ever more types of information and content. This endows digital infrastructures with generativity, implying that they are incomplete, underspecified and open for further developments, recombination [18, p.43]. This generativity tilts digital infrastructures towards fervent forging of novel socio-technical relationships during their ongoing use and ultimately blurs social, organizational and industry boundaries [2]. Tilson et al. [2] suggest that we can build explanations of the dynamics and generativity of infrastructural systems and their effects by viewing the key drivers in terms of *paradoxes of change and*

control. The essence of the *paradox of change* is that digital infrastructures must simultaneously have *stability* to allow “enrollment” of new artifacts, processes, and actors while possessing *flexibility* to support unbounded growth. The *paradox of control* captures the opposing logics around *centralized and distributed control* (or individual autonomy) and how they shape the services deployed, ownership of data and their definitions, control of critical resources (e.g. interfaces and platforms), and the appropriation of value. We argue that these tensions establish a continuous dynamic where endless change in socio-technical configurations impels *tussles* around certain elements of the infrastructure. These tussles drive further change as actors seek to expand or change services, establish new control points, or strive to prevent others from doing so [19, 20]. A topical example of a tussle is the recent debate around the appropriate regulatory stances and technological architectures with regard to *net neutrality* [14, 21-23]. This debate is largely driven by constant jockeying to reach preferred control points, which interacts with the need to find a generative balance between stability and flexibility. We posit that it is these dynamics (Figure 1) that largely underlie the eventual success of large-scale infrastructures. We refer readers to Tilson et al. [2] for a more in-depth discussion of this theoretical perspective.

In the case of mobile computing the past has been littered with a number of control points that have been subject to significant tussles. The proponents of various air interfaces standards (e.g. GSM/UMTS, CDMA, iDEN, Wi-Fi, WiMax, and LTE) engaged in fierce competition seeking to establish important control points around mobile data communications [24]. Similarly, mobile network operators have had greater or lesser success in their attempts to control information and entertainment services through the creation of walled gardens [25]. More recently, mobile OS have emerged as an important platform for the deployment of mobile applications. In consequence, they have become the most salient potential control points in the evolution of massive scale computing. Thus, we are now witnessing an important battle for dominance among mobile OS each seeking to become the most important platform for the most important computing domain in the coming decade. The goals of this study are twofold:

1. To test whether, and to what extent, the infrastructural perspective and its associated paradoxes of change and control provide insight into the evolution of mobile computing and the future roles of mobile OS.
2. To examine how the paradoxes of change and control are playing out in the evolution of mobile computing and OS on mobile computing.

3. Methodology

To address our research goals we conducted a study of the evolution of mobile OS following a dual-case study design. Case studies are particularly appropriate for the sort of objectives set for this study i.e. where we search answers to ‘how’ and ‘why’ questions about contemporary events where the investigator has little or no control over the events, and where the phenomenon of interest and its context cannot be easily distinguished from one another [26]. Several mobile OS are currently deployed including; (a) those developed by traditional computing companies, such as, Apple’s iOS and Microsoft’s Windows Mobile, (b) those sponsored by device manufacturers, e.g., Nokia’s Symbian and RIM’s Blackberry OS, as well as, (c) the open source, Linux derived, e.g., Android. It is worth noting that recent entrants iOS and Android have built large market shares while once dominant Symbian, PalmOS and mobile versions of Windows have been losing market share. We have chosen to focus on the two distinctly different mobile OS: iOS and Android. They have different origins reflected in their diverse technical features and the ways they are embedded in business models. The description of Apple’s iOS is a re-analysis of Ghazawneh and Henfridsson’s case study [27], which examined the role of innovation networks and boundary objects on the governance of third-party iPhone app development. It offers rich enough case data to carve out the dynamic relationships between Apple and third-party content, service, and application providers and we have renamed their four phases. Their case is based on the rigorous review of hundreds of on-line articles, press releases, as well as some interviews and email exchanges. The Android case draws upon a similar approach as in [27] with extensive study and synthesis of a large number of published histories and interviews of people intimately involved with the OS. The case descriptions that follow are used as an initial validation of the conceptual model of the socio-technical dynamics of digital infrastructures (Figure 1). We summarize the main findings identified for each phase and map them to the numbered high-level conceptual constructs identified in Figure 1.

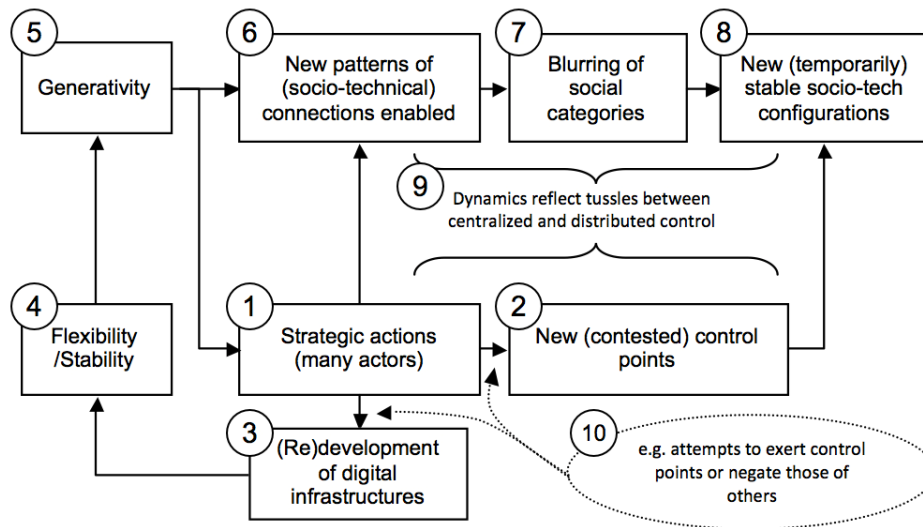


Figure 1. Conceptual Model of the Socio-technical Dynamic of Digital Infrastructures adapted from [2].

4. Mobile Operating Systems Case Studies

The following two sections each present the analysis of a mobile operating system – first iOS then Android.

4.1 Apple iOS

4.1.1 Phase I: 2007-2008: Browser Applications

Apple's initial strategy for third party apps (1 in Figure 1) for the iPhone was to have developers create web apps that could be accessed via the iPhone's built in Safari Browser. This approach built upon existing Web 2.0 and AJAX technologies but needed customization for the device's small screen and other characteristics (3,4 in Figure 1). The iPhone also built on its own iTunes platform originally developed for its successful line of iPod media players (3,4). Many existing content and service providers (e.g. Google, Flickr, Newspapers, YouTube, Twitter, and Facebook) ported their offerings to the Safari browser (1,5,6). The buzz around the iPhone made Apple an important player in mobile communications and -computing (7) and widened access to content and service offerings to mobile platforms (6,7). New tools were developed by third parties to better exploit the potential of the limited capabilities (5). This led to what was arguably a new, albeit very temporarily, stable configuration of the evolving Apple ecosystem (8).

From a control perspective the browser based approach allowed third parties to offer services without having to make deals with Apple, who retained total control over the creation of native

iPhone applications with full access to the iPhone's capabilities (1,2,10). However, developers and entrepreneurs criticized the restrictions (1,2,9) and doubted that this approach would reinvent the mobile phone business (visions of 6,7). Hackers bypassed Apple's control mechanism by opening up the iPhone (an act referred to as jailbreaking) to allow native apps from third parties, thus attacking a major (contested) control point (2,10).

Apple's decision to open up the platform and release an iPhone SDK represented a clear change in its evolving strategy (1) and its digital infrastructure (3,4) in response to tussles around centralized and distributed control (9) and other actors' efforts to challenge them (10).

4.1.2 Phase II: 2008-2009: Native Applications

In this phase Apple introduced a new SDK that allowed developers to write native applications (1) building on many iPhone (and iPod touch) APIs – thus greatly expanding the potential of its evolving digital infrastructure (3). The increase in flexibility of the iPhone platform (4) unleashed a new round of generativity (5) by third-party app developers. Apple added to its existing infrastructure by launch its App Store (3) as the sole official distribution channel for apps from third-party developers (10). VCs invested in start-ups creating apps for the iPhone (1,5). By early 2009 there were 25,000 apps, 50,000 registered developers, and 800 million app downloads (6) [27]. Apple became a more important player in the mobile computing and media industries (7) and its role and business model became more established (8).

While Apple opened up the iPhone to native apps developed by third parties it retained several technological and legal control points. By retaining

control of the SDK it determined what functionality would and would not be made available (2). The control points remained somewhat contested (9,10) as some developers objected to Apple not making certain functionality available via APIs (e.g. push notifications, background functionality, payment APIs, multitasking, and Flash support) (9). The App Store not only expanded Apple's infrastructure but also allowed it to extract value (30% of developer's revenue from the sales of apps) and exert censorship on the types of apps allowed (no porn, illegal content, or malicious apps), protect the network (no bandwidth hogs and restricted VoIP to LAN connections), or deny competitors the opportunity to deploy competing platforms on the iPhone (e.g. Adobe's Flash) (10). These restrictions being possible because of the "take it or leave it" nature of the legal agreement with developers and the 'obligatory passage point' represented by the App Store that did not exist for more traditional OS that could not enforce such restrictions (6).

4.1.3 Phase III: 2009-2010: Generativity Boost

A third version of the operating system and the SDK were released with over 100 new features and 1,000 new APIs [27]. Some of the changes were responses to the previous third-party developer concerns (9). Overall the changes can be viewed as a refinement of Apple's strategy (1) and digital infrastructure (3) from Phase II. Some centralized control of technological capabilities was relinquished (2) to support the expansion of the platform's flexibility (4) and generativity (5). However, the net result was bolstering of the platform's legitimacy by the expansion of the ecosystem built around the SDK the App Store and its associated legal agreements: 85,000 applications, 125,000 developers, and 2 billion downloads by Sept. 2009 (8) [27].

4.1.4 Phase IV: 2010-: Platform Integration

Apple added another form factor to its mobile platform with the launch of the iPad in early 2010 in versions with and without cellular wireless connectivity, but without support for telephony. The iPhone OS (renamed iOS) and the SDK were upgraded to support all three types of devices, and in the case of the iPhone and iPod, several generations of hardware (1,3,10). The ecosystem continued to expand: 185,000 apps, and 4 billion downloads by April 2010 (8) [27]. A fourth version of the OS and SDK offered 100+ new OS features and 1,500+ new APIs, including a number of features requested by third-party developers (9,4,5). Apple further refined and extended its strategy (1) by using the new device and OS version to establish a distribution channel for electronic books (iBooks), established a hub for casual gaming (Game Center), and an in app

advertising platform (iAd), thereby creating and refining control points (2).

More controversially the App Store review process was used to restrain some competitors from gaining strategic advantage from Apple's platform, for example, updating its agreement with developers to bar the use of non-Apple controlled development tools (2). Thus, Apple is willing to unilaterally change its agreement with its developers (6) to retain what it considers to be key control points (2), in this case to negate intermediation by another actor hoping to build a cross OS development environment (2,9,10). Another example is the charge of a 30% fee for in-app subscriptions. Such arrangements exhibit Apple's attempt to embed iOS and its ecosystem in institutional and market practices (1,6,10) very different to those that surround desktop/laptop OS.

4.2 Android

4.2.1 Phase I: 1991-2003: Open Source OS

Although we will not delve too deeply into computing history the story of Android relies on the development of the free and open source OS built around the Linux kernel. The Linux kernel itself started life in 1991 and is built on earlier free operating system initiatives (e.g. GNU, BSD and Minix). From its hobbyist beginnings Linux has become a mainstay on corporate servers. The open nature and low cost of Linux have made it popular as an embedded operating system for electronic devices – including on mobile phones. For example, Montavista founded in 1999 to commercialize embedded Linux has thousands of customers. As early as 2003 Motorola released Linux based handsets [28]. The last few years have seen a rapid rise of the Linux derived Android operating system we discuss next.

4.2.2 Phase II: 2003-2008: Google Acquisition

Andy Rubin started "Android Inc" in 2003 with other entrepreneurs and telecom executives. The goal "was to design a mobile handset platform open to any and all software designers" [29]. Rubin was also a founder and a CEO of Danger Inc. that produced the T-Mobile Sidekick – one of the first phones to integrate Web, IM, mail, and other applications. The Sidekick had a software development kit (SDK) but its application market never rivaled that of Symbian, Palm, or Windows Mobile. So, while the Sidekick did not provide a broad generative platform, it did demonstrate an alternative business model connecting network operators, device manufacturers, and service providers. In describing Danger's approach to aligning its business model with operators' by sharing service fees Rubin said, "*We were giving devices away and taking a share of the revenue*" [29].

Google's founders, Page and Brin, attended a talk in early 2002 that Rubin gave at Stanford on the development of the Sidekick [29]. In 2005 the Android startup was negotiating a round of venture capital investments, and Rubin e-mailed Page of the interest in potential investment. Within a few weeks Google had acquired Android [29]. Since its founding Android had kept its cards close to its chest only describing itself as making software for mobile phones [30]. The development of a new operating system was only an unsubstantiated rumor.

By mid-2005 there were reports that Google was shopping a Linux based mobile operating system to handset manufacturers after persistent rumors that Google was developing a "Googlephone" [31]. This created interest among potential developers on the web [32], and spurred speculation about advertising-based services entering mobile computing [33].

Google went public with its new Android OS in November 2007. The OS was announced as the first offering of the new Open Handset Alliance that included 34 initial members drawn from operators, device manufacturers, semiconductor vendors, and other technology vendors. Android was touted as being "*made available under one of the most progressive, developer friendly open-source licenses, which give mobile operators and device manufacturers significant freedom and flexibility to design products*" [34]. (5,6)

In the US the largest wireless network operators, AT&T and Verizon feared that Google could snatch away future revenue from mobile advertising and loosen their ability to control what phone features customers can access [35] (9). T-Mobile in the US had been talking with Google since its acquisition of Android in 2005 – the same operator that had offered the Sidekick. It became the first operator to offer an Android-based device; the T-Mobile G1 produced by HTC. The smaller T-Mobile was more willing to challenge wireless industry orthodoxy and cede some control in return for access to a better OS and popular applications like Google's search and Maps [35] (1). The T-Mobile G1 hit the market in October 2008 but was neither a critical- or market success [36] and there was a real risk that Android would fail to gain traction.

Verizon Wireless had been reluctant to engage with Google on Android and the relationship was further strained when Google joined an auction for mobile spectrum [37]. However, Verizon recognized the growing success of Apple's iPhone with AT&T and saw its App Store as a significant threat. Verizon's expensive attempts to market the LG Voyager and Blackberry Storm smartphones as viable alternative to the iPhone had been

unsuccessful and the company realized that they needed to engage in partnership with Google to compete [38]. They teamed up with Motorola, who was in dire need of a successful phone, and the Motorola Droid phone, launched in October 2009 (1), was finally an Android success that helped establish it as a viable mobile platform. Verizon promoted it heavily as an iPhone competitor. The Samsung Galaxy S phone soon followed as another hit that spread the popularity of Android to Europe and key countries in Asia. [38].

4.2.3 Phase III: 2008-2010: Shifting Control

The Android operating system is licensed using an Apache 2.0 open source license. Therefore, it is available to anyone who wishes to use it without any licensing costs with or without Google collaboration. This can result in sub-par products such as tablet devices trying to deploy versions of the OS not optimized for that form factor.

That is not to say that Google does not exert a level of control. For example, device manufacturers cannot use the Google name on a device without having it certified as compliant with Google's Compatibility Program [39]. Furthermore, device manufacturers cannot license Google's closed source applications for Android, including access to Android Market, without such certification. Google has also chosen to work with specific manufacturers and operators to launch new versions of Android (e.g. in the US T-Mobile was the first operator to get the new Samsung Nexus S with the then latest "Gingerbread" version of Android in late 2010). Such time to market advantages in the high-tech device market is invaluable for some and a "virtual death sentence" for others [40].

Unlike iOS devices most Android devices can access apps from multiple "stores." Some websites emerged to supply apps to non-Google approved devices that could not access Android Market – at least not officially. More recently Amazon has opened an Android App Store to compete with Google's Android Market [41] (1,2).

Google has been criticized for delays in releasing source code for Android 3.0 (Honeycomb) [42]. Critics argue that Google is not living up to its obligations under Android's open source license [43] thus putting smaller device manufacturers at a major disadvantage (2,9). There are reports of Google taking a more active role in preventing fragmentation of the Android platform by insisting on approval on change to Android code – with access to the most up to date software contingent on compliance [40]. The paradox of change and control are summed up by an analyst quotes as saying that while manufacturers "might balk at tighter Google control but in the long

term, it is in their interest” [44]. Thus, we see different control points (2, 10) and tussles (9) emerging from dissimilar socio-technical configurations (8).

4.2.4 Phase IV: 2010-: Growth

By most measures Android has been a great success. In late 2010 Android replaced Symbian as the world’s leading smartphone platform. In Q1 2011 36.2 million Android based smartphones were sold across 179 devices (36% market share compared with Nokia’s 27.4%, and Apple’s 16.8%) [45]. The building up of the Android based ecosystem or infrastructure involved more actors (1, 2) than the iOS case, for example with operators and payment processors splitting the 30% commission on app sales. This has led to similar levels of flexibility and generativity (4, 5) and industry level reconfigurations (6,7,8).

At the time of writing there were in the order of 200,000 apps on Android Marketplace (about half the number on Apple’s App Store). The lower barriers for submitting to the Android Marketplace with some applications of poor quality, along with the \$100 million Android app store revenue against Apple’s \$3bn can both be seen as a “*vote for Apple’s more curated model*” [38], and a poorer resolution of the paradox of control and generativity, where Apple’s App Store can be seen as both generative and controlled (4,5).

5. Findings and discussion

The first objective for this paper was to “*test whether, and to what extent, the infrastructural perspective and its associated paradoxes of change and control provide insight into the evolution of mobile computing and the future roles of mobile operating systems.*”

While the study is restricted to two mobile OS and focuses on the relationships with third party developers it shows that the high-level conceptual model in Figure 1 offers a plausible representation of the dynamics of digital infrastructure evolution. However, it is also evident that these platforms’ evolution does not follow one simple predictable trajectory. Rather the dynamics are fundamentally path dependent as they are influenced by their own trajectories, those of competing platforms, as well as by the evolution of the wider technological (e.g. processing power, maturity of capabilities in silicon, touch screens, etc.) and social (e.g. markets, business model maturity, regulatory clarity, developer networks, etc.) ecologies within which the ecosystems evolve. So, while the high-level model in this initial exploration seems to fit well, the specific

dynamics are complex. Indeed they are much more complex than is possible to reflect in the brief case studies presented above. Both the iOS and Android ecosystems feature popular user-downloaded apps and have resulted in explosive growth in third-party developed applications on touch-based smart phones [46]. Yet they do so by deploying significantly different business models, and control strategies, and so far with greatly varying economic results. Despite rapid growth across Apple’s, Google’s, Nokia’s, and RIM’s app stores from 2009 to 2010, Apple’s App Store has managed to secure over 82% of the revenue [47]. The technological advancement of all these platforms indicates highly complex and non-linear relationships among the elements in our model (Figure 1), as the success of the leaders would otherwise have been easier to replicate.

The paper’s second objective was to “*examine how the paradoxes of change and control are playing out in the evolution of mobile computing and operating systems on handheld computing devices.*” At one level this objective has been addressed by the descriptive case studies themselves. Here, we present additional observations about how each case played out as well as how they interacted with wider industry and technical contexts.

A prior theoretical perspective such as network economics is certainly reflected in the growth of multi-sided markets described here [48, 49], an aspect studied by Tuunainen & Tuunainen [50] characterizing the development of services on mobile platforms as a multi-sided market.

Platforms become more valuable as their number of users, developers, and device manufacturers increase. However, the drivers of the success of any particular ecosystem are many and certainly not confined to ecosystem size as exemplified by the fast decline in the market shares of the formerly dominant Symbian, PalmOS, and Microsoft’s mobile OS.

The dynamics of the evolution of the mobile platforms emerged from the actions of, and interactions among, several types of actors. There is traditional competition between the ecosystems built around each operating system. Better technologies, improved user interfaces, more attractive business models for participants, or the quality of development environments have certainly influenced the growth of user and developer networks. In each ecosystem there have been both competition and tussles for control [19], and the demonstration of the ability of some to extract the financial fruits of the efforts of many. Several firms can play the same role in their ecosystem and subsequently seek to gain advantages through direct competition. Tussles can also occur when firms play complementary roles in the

ecosystem and are vying to capture value and therefore encroach on each other's domain. For example, the ongoing tussle between Apple and content providers regarding the 30% tax on in-app subscriptions [51] involves how complementary resources of different players are valued and what their relative strengths are.

The tight centralized control of the Apple App Store ecosystem of iOS, SDK and APIs has been an instrument for the company to serve its own interests while striving to build the ecosystems around its operating system and devices. The App Store "obligatory passage point" for the marketing and sales of Apps and much content and other socio-technical control points bolstered by legally binding agreements under Apple's sole control marks a control regime, which is perhaps a key-element in its success as the company insists on acting as a highly regulating force. This was probably crucial in the start-up phase when a clear understanding by end users of the relative advantages of adopting the technology was particularly important. The importance of a strong central anchor-point in mobile platform development has been documented, even if this strong central player does not exercise its ability to control [52]. Indeed one of the key roles of the platform owner can be ongoing management of the control and generativity paradox [53].

It is here that the *paradox of control* is evident as Apple's offerings and centralized control provides many attractive features for users, developers, and content providers while also constraining some uses and business models in ways that favor Apple in its tussles with the other actors. Nevertheless, Apple has not gotten all its own way as other actors, particularly developers, have been able to influence changes in the OS and the conditions surrounding its use. It remains to be seen how the tussle between Apple and newspaper publishers and ebook distributors will play out. However, it is emerging as an exemplar of a new kind of tussle, where a deal is clearly beneficial to all parties, but where there is fierce competition around who extracts the joint value created.

The *paradox of change* in the iOS context was addressed by largely incremental and additive changes to its capabilities. This left prior interfaces stable and thus did not fundamentally undermine prior applications. While some level of maintenance is required in many apps as the operating system evolves, Apple's App Store provides a mechanism that greatly simplifies the propagation of these updates. Furthermore, the establishment of the App Store was carefully fashioned as incremental change to end-users. The pre-existing capability for downloading content to iPods through iTunes was

extended to include mobile apps. Thus Apple was able to implement a significant change whilst relying on a stable socio-technical configuration (8) as far as the end-user was concerned.

The paradoxes of control and change interact in as much as resistance, for example, hacking and complaints from developers, to Apple's control mechanisms and interfaces have driven change in the socio-technical configuration of the platform. Similarly changes to the interfaces (e.g. APIs) and control mechanisms (e.g. legal agreements) have altered the inter-actor relationships and the locus of control. It could even hypothetically be argued that Apple was forced by jailbreakers to abandon an intended strategy to only allow web-based iOS apps. If so, this ecosystem displayed more readiness for change towards distributed production and consumption of mobile apps as they could be conceived of as simply one more content category in addition to songs, movies, and eBooks.

Of course the timing of technological developments and strategic actions also influenced how the mobile OS developed. The relative limitations of earlier generations of hardware left older mobile OS with legacy architectures, UIs, and development environments that have struggled to capture the imagination of users and developers in the same way that Android and iOS have in the last couple of years. Conversely it is only last few years that mobile devices with Unix based OS with touch interfaces like Android and iOS have become feasible. It remains to be seen if the more open nature of Android can be harnessed to greater levels of generativity without falling victim to the sort of fragmentation that created challenges for the evolution of Symbian.

There are distinct limitations inherent in this small study. A fuller study would consider the evolution of other mobile platforms (e.g. Symbian, RIM Blackberry OS, Microsoft Windows Mobile, PalmOS/WebOS, Maemo, MeeGo, Bada, and Moblin, as well as Java and BREW). The cases could be expanded to include more consideration of the relationships with a wider set of actors. In addition, the methodology for the creation and coding of the case studies would need to be further developed to build more rigorous support for the infrastructure focused theoretical perspective developed in [2]. Nevertheless, the model has withstood this initial attempt at falsification [54] even when basing part of the analysis on a case developed to explore an alternative theoretical perspective. We provide at least some validation support for the initial framework for understanding these sorts of complex infrastructural phenomena. The elaboration of a

framework that recognizes the inherent complexity of the dynamics around digital infrastructures will surely be important as mobile information systems could be among the most the most important of humanity's global infrastructures.

A wider study would also allow us to explore the effect of differing paths for mobile OSs in the light of the influence of prior industry affiliation [51, 55]. The nature of the overlap between pure competition among ecosystems and the intra-ecosystem tussles could be explored in cross case interactions such as the presence of "Goggle Apps" across many of the ecosystems while Google also drives the development of Android. This generalizes to questions around the role of the diverse business models of some of the focal actors within the most important current ecosystems, such as, Nokia, Google, and Apple.

This early analysis of two examples of mobile platforms using the digital infrastructures framework proposed in [2] clearly demonstrates an underlying complexity of relationships between change and control beyond simple linear explanations. The complexity of change and control arrangements can best be described in terms of paradox, and the two digital innovation paradoxes suggested throw light on the dynamics of digital infrastructure innovation.

While ecosystem tussle over control may follow complex and non-linear patterns of development, these can be seen in the light of episodic change [56], which are infrequent, discontinuous, and intentional. The changes in control arrangements can perhaps be characterized in terms of processes of unfreezing, transition, and refreezing [56, p.366]. In the case of digital infrastructure innovation, digitalization has fuelled the unfreezing of previously stable control arrangements amongst stakeholders [2, 57], and resulted in potential re-arrangements where platform owners may seize control and redefine control arrangements. The Apple case represents the more radical case of unfreezing and reconfiguring control arrangements. It also demonstrates that a highly complex mobile device could provide an easy-to-use experience, and subsequently serve as a key element in a tightly controlled, yet generative, ecosystem. Apple has been able to refreeze control arrangements through the extensive application of centrally managed control points, and through this establish control where it came up for grabs [58].

6. References

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