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ljimenez@jotmi.org

Universidad Alberto Hurtado
Chile

Dedehayir, Ozgur; Mäkinen, Saku J.
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DYNAMICS OF REVERSE SALIENCE AS TECHNOLOGICAL PERFORMANCE GAP: AN EMPIRICAL STUDY OF THE PERSONAL COMPUTER TECHNOLOGY SYSTEM

Ozgur Dedehayir, Saku J. Mäkinen*

Abstract

The evolution of technological systems is hindered by systemic components, referred to as reverse salients, which fail to deliver the necessary level of technological performance thereby inhibiting the performance delivery of the system as a whole. This paper develops a performance gap measure of reverse salience and applies this measurement in the study of the PC (personal computer) technological system, focusing on the evolutions of firstly the CPU (central processing unit) and PC game sub-systems, and secondly the GPU (graphics processing unit) and PC game sub-systems. The measurement of the temporal behavior of reverse salience indicates that the PC game sub-system is the reverse salient, continuously trailing behind the technological performance of the CPU and GPU sub-systems from 1996 through 2006. The technological performance of the PC game sub-system as a reverse salient trails that of the CPU sub-system by up to 2300 MHz with a gradually decreasing performance disparity in recent years. In contrast, the dynamics of the PC game sub-system as a reverse salient trails the GPU sub-system with an ever increasing performance gap throughout the timeframe of analysis. In addition, we further discuss the research and managerial implications of our findings.

Keywords: technology system, personal computer, reverse salient, computer games

* - Dedehayir, Ozgur. Tampere University of Technology. Department of Industrial Management. CITER Center for Innovation and Technology Research. PO BOX 541. FI-33101 TAMPERE, FINLAND. Email: ozgur.dedehayir@tut.fi. Phone: +358 44 5868 514. Fax : +358 3 3115 2027
- Mäkinen, Saku J. Tampere University of Technology. Department of Industrial Management. CITER Center for Innovation and Technology Research.

Introduction

Technological systems, such as the personal computer (PC) system, encompass a broad array of both social and technical components (Hughes 1994) and follow a certain trajectory of technological evolution governed by the technological paradigm (Dosi 1982). At any point along the trajectory of technological evolution lie technological imbalances (Rosenberg 1976) so that comparison of the technological capacities of two or more systemic components is bound to reveal some inequality. Such dynamics have been observed in the rapid development of the PC technological system (Bayus 1998; Gawer & Cusumano 2002), where the deployed technological performances between sub-systems have remained unequal. In this state of unevenness, the underperforming systemic component may act as a retardant hampering the development of the overall system performance i.e. reverse salients (Hughes 1983). These performance inhibiting sub-systems should become the central focus of the technological system's stakeholders that seek to resolve the underlying problems and restore desired system development. In addition, the dynamics as well as the changes in dynamics of the behavior of reverse salience is paramount to understanding and development of the technology system's overall performance.

Although literature has applied the reverse salient concept within numerous contexts (e.g. MacKenzie 1987; Mulder & Knot 2001; Takeishi & Lee 2005), our current understanding of the dynamics of reverse salience remains limited. Traditional research is especially deficient insofar as the provision of an analytical measure of reverse salience and the application of this measure in studies of technological systems is missing. We believe that measurement of a quantifiable characteristic of the reverse salient is imperative for further development of the concept and its utilization in future scholarly work as well as in arenas outside that of the academia in developing normative uses of the concept.

The purpose of this paper is to develop a means to measure the magnitude of reverse salience and in turn to study the idiosyncrasy of reverse salience in the co-evolution of the PC game sub-system with two hardware sub-systems of the PC technology system: the CPU (central processing unit) and the GPU (graphics processing unit), respectively. We begin our paper by establishing a temporal performance-gap measure of reverse salience, building on the theories of technological co-evolution and reverse salience. In the following section we describe our proposed methodology for measuring reverse salience through an empirical study pertaining to the aforementioned sub-systems. The results of this empirical study demonstrate the observed reverse salience and reveal its time evolution between 1996 and 2006, inclusively.

Theoretical Background

Technological systems are messy, complex, hierarchically nested, and comprise both technical and social elements (Hughes 1983, 1994). Technological systems include all members which are under the control of that very system, and which help shape the system through their interaction (Hughes 1994). This shaping is the consequence of problem solving and objective fulfilling activities of technological systems (Hughes 1987). The members of a technological system therefore not only interact and influence one another, but they also contribute collectively to the fulfillment of shared objectives of the system in which they are bound.

In Hughes' definition, systems are loosely structured although with sufficient integrity to assure relatedness of its constituent components. Carlsson and Stankiewicz's (1991) definition of a technological system as a "dynamic network of agents", is similar in the structural sense. Contrary to Hughes however, Carlsson and Stankiewicz attempt to demarcate the technological system boundary by elaborating on the network of agents as interacting to create, diffuse, and utilize technology inside a particular economic or techno-industrial area. This notion is in some sense overlapping with the idea of "national systems of innovation" proposed by Nelson and Winter (1982), where the technological system is bordered by the national institutional infrastructure. Notwithstanding, Carlsson and Stankiewicz' proposal has the benefit of flexibility such that, according to their definition, technological systems can be perceived as either international and of relatively large-scale, where borders extend beyond a single national system, or then as relatively small-scale and local systems such as the Silicon Valley (Carlsson & Stankiewicz 1991).

Although not explicitly stated, Carlsson and Stankiewicz's standpoint portrays the hierarchical structure of technological systems by allowing for smaller systems to exist inside larger systems, and these larger systems themselves to exist as components of even larger systems (analogically similar to Russian Matryoshka or nesting dolls). This definition permits effective assessment of any technological system by merely adjusting the analytical focal lens within the hierarchical structure. Congruent with this notion, Murmann and Frenken (2006) propose a nested hierarchy of technological systems, sub-systems, and components, in their analysis of the evolution of technologies. Starting at the system level of say the personal computer, the systemic technology can be seen as a compilation of a number of first-order sub-system technologies. The CPU, operating

system, hard disk drive, RAM (random access memory), read-only memory, and cooling system are some of the major first-order sub-systems. These in turn comprise second-order sub-systems. For instance, the disk drive can be seen to integrate a motor, read-write heads, and disk. Further down the hierarchy tree, are situated the third-order sub-systems. Within the disk sub-system will be elements such as magnetic media, adhesives, and protective abrasives (Christensen 1997). Indeed, in a complex artifact system such as that of the PC there are likely to be several levels in the hierarchy. At the very end of this sequence one may specify wires and silicon granules as the components of the technological system.

The above illustrates that there are certain nuances which delineate the stances of different scholars with respect to what constitutes a technological system. Nevertheless, there are also repeating themes, of which the nested hierarchical structure of systems is one. We adopt this perspective also in our paper, borrowing in particular the more explicit description of the systemic hierarchy provided by Murmann and Frenken. In addition, we take the perspective that, not only are technological systems built hierarchically but that they also develop over time in order to fulfill goals. This notion is commensurate with Hughes' proposal declared above. In summary, we have unveiled two essential traits of technological systems as we see them: their structure, and their temporal reason for existence. There is however at least one other trait which needs consideration; the dynamics of the temporal evolution of technological systems, considering also the driving force behind these dynamics.

On the evolution of technological systems, Hughes (1987) offers the concept of "technological momentum", which captures the reciprocating nature of shaping influences between the social and the technical elements in systems. Furthermore, within his systemic framework where change causality is sourced bilaterally from technical and social actors, Hughes provides at least two mechanisms for systemic evolution. The first mechanism is the interaction of technological systems with their environments, which consist of factors not in the system's control and thus present uncertainties. Technological systems thus carry incentives to evolve by internalizing their environments over time and so minimize potentially harmful ramification of uncertainties (Hughes 1987). A second and more compelling explanation of why technologies evolve is given by Hughes, in his earlier presented claim that technological systems strive to solve problems or fulfill goals established by the system itself (Hughes 1987). This is a stance shared by Heidegger (1977) who defines technology as a means to an end, whereby ends are accomplished through the resolution of problems and reordering of the material world. Therefore, technological systems are inherently compelled to evolve as a result of their own reason for

existence; to provide ends to paradigmatic problems.

One of the important phases of systemic evolution is identified by Hughes as the period of system "growth". This is the time of expansion when the technological system strives to improve its performance, for instance with respect to economic outcomes or output efficiency. Hughes explicates that in the growth endeavor, technological systems are dependent on the satisfactory evolution of all system components' performance. Within the hierarchically nestled system observed by Hughes, the growth of technological systems is therefore necessarily reliant on the reciprocated and interdependent cause and effect processes amongst social and technical components. More accurately, the *modus operandi* of such developmental change may be described as co-evolutionary where the even co-evolution of system components carries significance in establishing desired growth (Hughes 1983).

In the context of technological systems, the idea of co-evolution is closely resembled by Dahmén's (1989) notion of "development blocks". Development blocks are a "sequence of complementarities" or a cluster of network elements, such as firms or technologies, which undergo development as a result of a series of structural tensions (Dahmén 1989). These tensions are outcomes of disequilibria between interdependent elements, reminiscent of Rosenberg's (1976) "technological disequilibrium" notion. Evolutionary momentum is hence attained within the development block through the fulfillment of developmental potential created by the technological disequilibria. The technological progress resulting from the development block follows a particular line or "technological trajectory", to use Dosi's (1982) terminology, and ends when the trajectory reaches its phase of maturity or by the technological paradigm being superseded by a new paradigm (Carlsson & Stankiewicz 1991). Dahmén's idea of development blocks therefore offers a useful portrayal of the mechanics of co-evolution within technological systems.

Hughes suggests that an imperative factor in the system growth stage is the balanced co-evolution of systemic components. Elements of the system which thus co-evolve at the necessary pace and maintain evenness contribute positively to the collective progress of that system. Conversely, a technological member at any level of the system which does not develop sufficiently prevents the technology system achieving desired growth. Hughes names these problematic members as reverse salients (Hughes 1983; 1987). Literally, a reverse salient is the inverse of a salient, which depicts the forward protrusion along an object's profile or "a line of battle" (Hughes 1987). Hence, reverse salients are the backward projections along such continuous lines. With respect to technological system development, reverse salients refer to the elements of that system which have

strayed behind the advancing performance frontier of the system (Hughes 1983). They are therefore the underperforming components which hamper the progress or which prevent the fulfillment of potential development of the collective system. In consideration of the principal goals of system development, they may also be referred to as the uneconomical and inefficient components of that system (Hughes 1983). They can be technical elements such as motors and capacitors of an electric system, or social elements such as organizations and productive units. It additionally follows that the existence of a reverse salient creates a state of “reverse salience”, the magnitude of which, we propose, is measurable and equivalent to the technological performance differential between advanced members of the system and the trailing reverse salient component.

The concept of technological bottleneck has been used in previous literature in a similar fashion to reverse salient (Fransman 2001; Geels 2006; Geyer & Davies 2000; Keil et al 1997; Markard & Truffer 2006). However, the reverse salient more accurately describes the complex and uneven changes in evolving technological systems, in contrast to the bottleneck concept which connotes rigidity and symmetry. Yet another concept interchangeably used with reverse salience is the concept of “technological imbalance” (Ciborra & Hanseth 1998; den Hond 1998; Fransman 2001; Takeishi & Lee 2005), introduced in Nathan Rosenberg’s 1976 work “Perspectives on Technology”. Rosenberg engages his concept to elaborate on the imbalances which exist in the components of complex machines or operations. He purports that at any point in time there is varying ability of machine component parts to exceed their existing performance levels, attributable to some limiting component. This condition results in the disequilibrium of technologies within the same system. Conceptually, Rosenberg’s technological imbalance and Hughes’s reverse salient share compelling similarities. The choice of one or the other will depend on the perspective taken with respect to the technological system itself. For example, the stance on the construction and complexity of technological systems is a major determinant. If Hughes’ viewpoint is borrowed then the addition of social components to the technical increases both the size and complexity of the system. In this case the reverse salient is obviously more suitable as Rosenberg’s technological disequilibrium concept is arguably questionable in its ability to account for the effect of social systemic components. On the contrary, for technical or economically bound analysis of technology systems, scholars may effectively utilize Rosenberg’s concept (see for example; Murmann and Frenken (2006)). In this light Hughes (1983) him-

self asserts that a preference for the reverse salient rather than the disequilibrium concept is premised on the latter’s inadequacy to describe complexity in geometric unevenness. In addition, the disequilibrium does not in its core include the constraining nature of the constituent in respect to the overall systemic evolution.

For continuation of system growth the reverse salient needs to be resolved, where resolution is attained through incremental innovations (Hughes 1987). Here, comparable to Dahmén’s idea of structural tensions, reverse salience, brought about the relative backwardness of a component’s technological performance, serves as the driving force of co-evolution as the system as a whole tries to bridge the overall performance gap. Hughes’ notion of gradual improvements implies development within a single technological system, where such development is often represented as a repeating cycle or an S-curve (e.g. Andersen (1998; 1999), Foster (1986), Schumpeter (1939)). We therefore deduce that the S-curve, depicting developments in technological performance, is the outcome of the resolution of reverse salients and therefore the product of co-evolutionary processes. However, it is possible that the reverse salient cannot be removed through incremental inventions within the bounds of the existing technological system. In this case only radical inventions can succeed, subsequently leading to the creation of a new and different technological system and causing a shift to a new S-curve following a period of technological discontinuity (Anderson & Tushman 1990; Foster 1986). A historical case in point is the radical invention of the alternating-current system which overcame the low cost distribution hurdle of the electric technological system, where the direct-current system could not (Hughes 1983).

The reverse salient forms a nexus for technological system stakeholders, in particular innovating firms, which congregate around the retardant and strive to remove it through innovations. Hence, reverse salience serves as an underlying motive for organizations to deploy processes of continuous innovation, subsequently leading to the creation of new or improved technological products delivering better performance. This is in effect the description of change agents or firm clusters, referred to by Dahmén (1989) as the development block, and their activities leading to the co-evolution of technologies within technological paradigms (Dosi 1982, 1988). Grounded technological paradigms subsequently determine as well as limit the types and directions of co-evolutionary development into a set of technological trajectories, which result from the resolution of

* Figure Description: Figure one is a picture showing the size of an RFID chip.

reverse salients (Dosi & Grazzi 2006).

Historical developments in a variety of technological systems have been used in literature to illustrate reverse salience. Hughes (1983) has most famously given account of Thomas Edison's direct-current electric system and its development towards the objective of supplying electricity within a defined region of distribution. Perhaps the most notable limitation of this system's growth was its low voltage transmission distance, dictated by the cost of distributing electricity beyond a certain range. To reduce costs, Edison introduced a three-wire system to replace the previously installed two-wire alternative, and trialed different configuration of generators as well as the usage of storage batteries. While these had a positive impact they did not remove the reverse salient completely. Inevitably, the satisfactory resolution of the problem of costly transmission and distribution of low voltage electricity was provided by the radical invention of the alternating-current system (Hughes 1983).

Other authors have also offered their accounts based on the analysis of different technological systems. MacKenzie (1987) has discovered the gyroscope sub-system as a reverse salient in the ballistic missile technological development, where the systemic objective has been to increase missile accuracy. With the objective of proliferating mobile music throughout the end-user market, Takeishi and Lee (2005) have argued that music

copyright managing institutions have acted as the reverse salient in the evolution of the mobile music technology system in Japan and Korea. According to Mulder and Knot (2001), the development of the PVC (polyvinyl chloride) plastic technology system has been sequentially hampered by several reverse salient factors, including: difficulty to process PVC material, quality of manufactured products, health concerns for individuals exposed to effluent from PVC manufacturing facilities, and finally the carcinogenetic nature of vinyl chloride.

Although literature illustrates the reverse salient concept in numerous historical accounts, it sparingly employs the concept in analytical studies of technological systems. Conceptual development has additionally remained limited in the absence of an analytical tool employable in such studies.

Methodology

We firstly conceptualize a framework which utilizes the model of technological development or trajectory as an S-curve to demonstrate the temporal change in each of the components' technological performance. Secondly, by superimposing the S-curves of the co-evolving pair upon a common set of axes we compare their performance evolutions over time and ascertain performance differentials (see Figure 1).

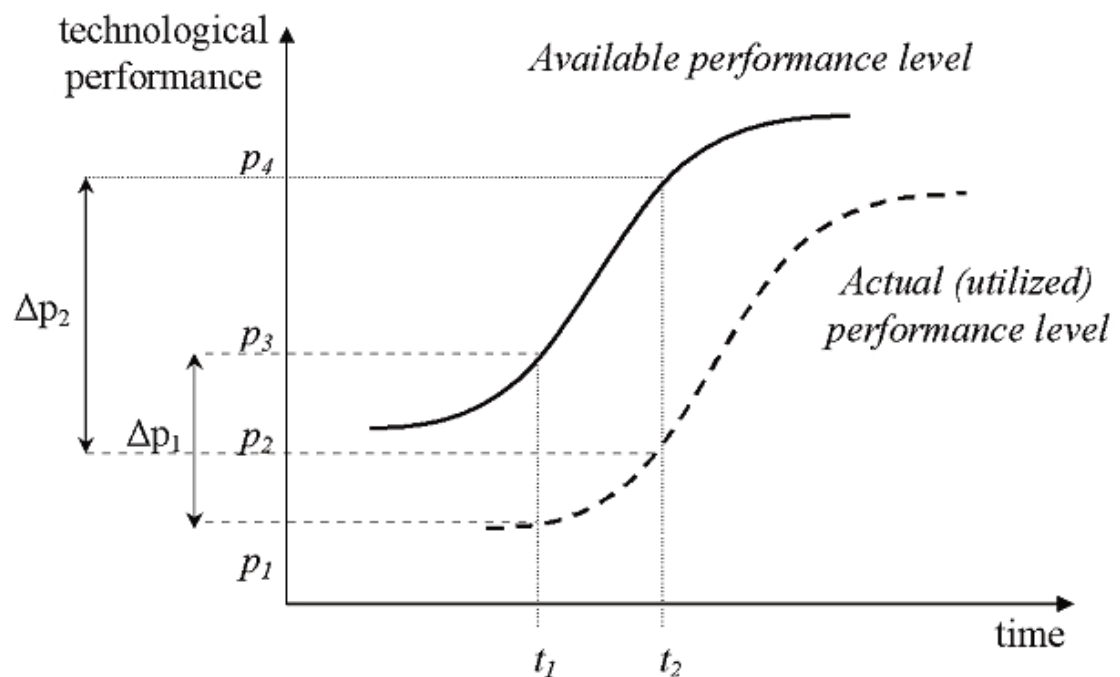


Figure 1. Superimposition of S-curves and reverse salience measured by performance-gap.

To gauge reverse salience the framework compares the actual technological performance of the lagging sub-system with the performance that is potentially attainable by it. This reflects Hughes' notion of the reverse salient, which is a systemic element's carrying potential but failing to realize that potential in full scale delivery of technology system level performance. It is also commensurate with Dahmén's concept of the development block which gains momentum through the fulfillment of its developmental potential. Here, the potential acquired by the reverse salient is equal to the disequilibrium between the co-evolving pair, generated when one member surges ahead in performance with respect to the other.

The dashed line of Fig. 1 represents the actual performance of the reverse salient component and its temporal evolution with respect to the technological potential provided to it by another technological element portrayed with the solid line in Fig. 1. This latter line essentially represents the technological trajectory of another systemic component, which is superior in performance and thus creates developmental potential for the co-evolving pair contributing to the overall performance of the technology system. The disparity between these two lines represents reverse salience, the magnitude of which is measurable by calculating the vertical separation of the lines. We refer to this separation as performance-gap and define it as the difference between the available potential and actual utilized performance levels of the reverse salient at a specific point in time. The figure indicates two performance-gap measurements, denoted by Δp_1 and Δp_2 , at time t_1 and t_2 respectively. It additionally follows that the temporal evolution of the magnitude of reverse salience can be determined by calculating sequential performance-gaps over a period of time.

In our empirical study we firstly compared the technological developments in the CPU and PC game sub-systems, and secondly the developments in the GPU and PC game sub-systems. The highly dynamic nature of these sub-systems' technological evolutions provided us a rich setting with continuously changing performance disparities. We have gathered data representing the technological performance levels of sub-systems over a period stretching between the years 1996 to 2006, inclusively.

We firstly selected processor speed as the technological performance parameter central to both the CPU and PC game sub-systems. The processor speed, measured in Hertz (Hz), is an indicator of the CPU's speed of operation, governing computational performance of the PC through its interaction with software programs such as PC games. Higher speeds mean faster data manipulation and increased computer performance resulting in enhanced user experience, especially during game play. PC game software on the other hand is developed to ensure a

designed level of functionality, when used in conjunction with a CPU delivering some required minimum processor speed. We were able to measure the technological performance of CPUs by evaluating their processor speed and PC games by assessing their minimum processor speed requirements.

Secondly, we selected graphics memory as the technological performance parameter central to both the GPU and PC game sub-systems. The graphics memory, measured in megabytes (MB), is an indicator of the GPU's ability to store and make available graphics data to the PC. Larger memory capacity means greater and faster data manipulation and increased computer graphics performance, resulting in enhanced user experience during game play. PC game software on the other hand is developed to ensure a designed level of functionality, when used in conjunction with a GPU possessing some required minimum graphics memory. We measured the technological performance of GPUs by evaluating their maximum memory capacity (in MB), and PC games by assessing their minimum graphics memory requirements (in MB).

We collated data from publicly available, industry-specific databases. With regard to data on processor speeds, the data was retrieved from processor performance databases of two primary microprocessor manufacturers, Intel and Advanced Micro Devices (AMD). We acquired data on GPU technology from information available on the websites of the companies NVIDIA (www.nvidia.com) and ATI (a part of AMD since Oct. 2006) (www.ati.com), the two dominant players in the graphics processor industry. The data were accessed through the corporate web sites of these companies. The data on PC game minimum processor speed requirements as well as minimum graphics memory requirements, in turn, were collected from complementary sources: game publishers, and gaming communities Gamespot.com and Gamerankings.com, and a major on-line PC game vendor Amazon.com. Again, the databases of these sources were accessed through the web sites of these organizations. Altogether 161 CPU and 1207 PC game related data points, as well as 88 GPU and 1083 PC game related data points were collected and evaluated to reveal the technological development curves of the sub-systems and the temporal behavior of reverse salience as measured by the performance-gap.

Results

Technological development curves of the co-evolving CPU and PC game sub-systems are displayed in Figure 2. The superimposition of the S-curves clearly indicates that both trajectories follow an upward trend for a great proportion of the timeframe

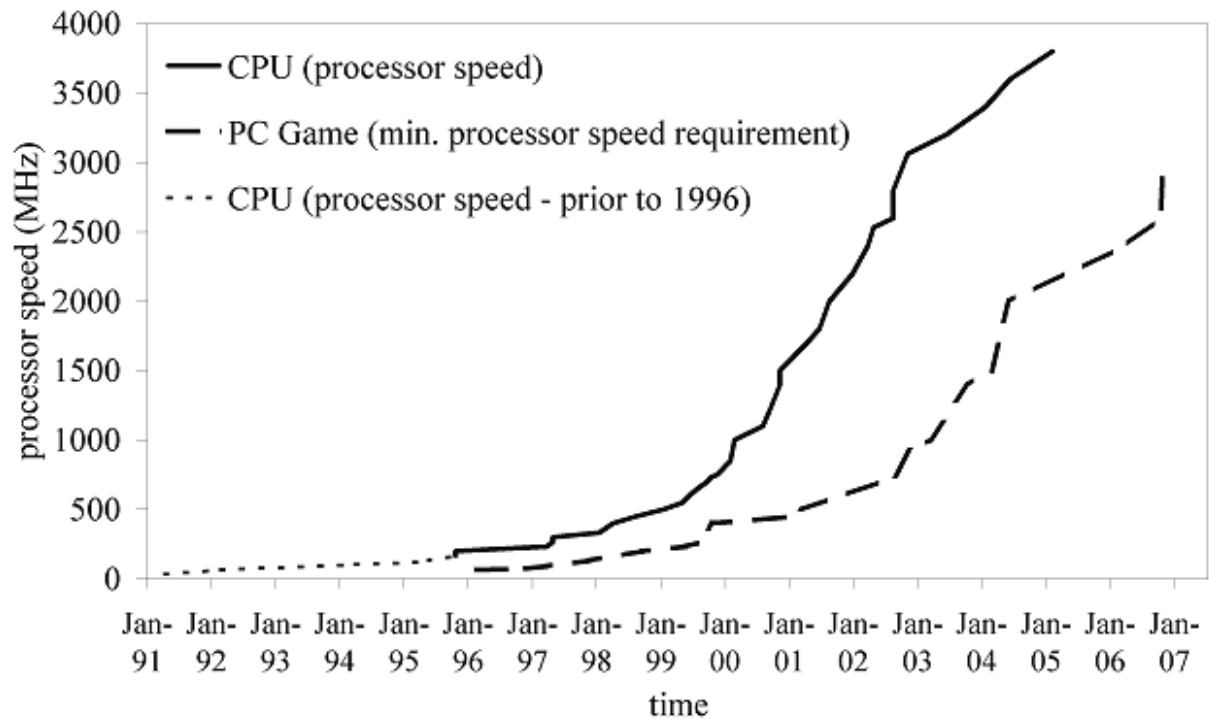


Figure 2. Superimposition of CPU and PC game sub-system technological evolution curves.

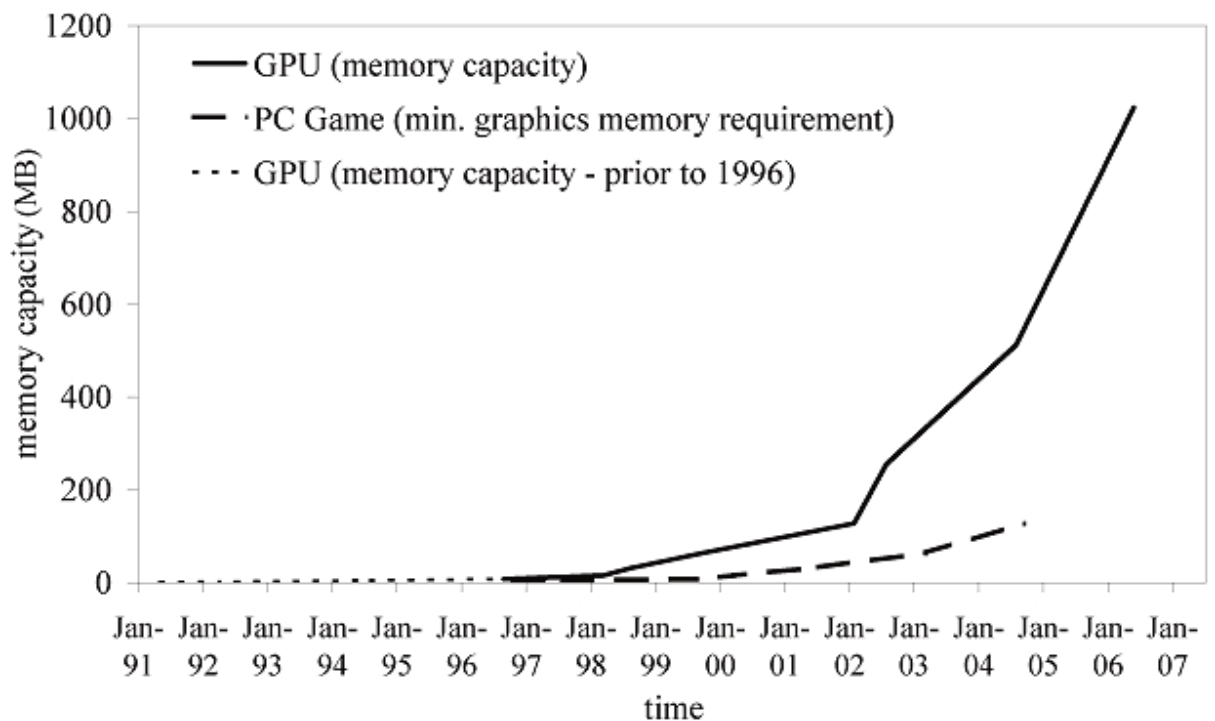


Figure 3. Superimposition of GPU and PC game sub-system technological evolution curves.

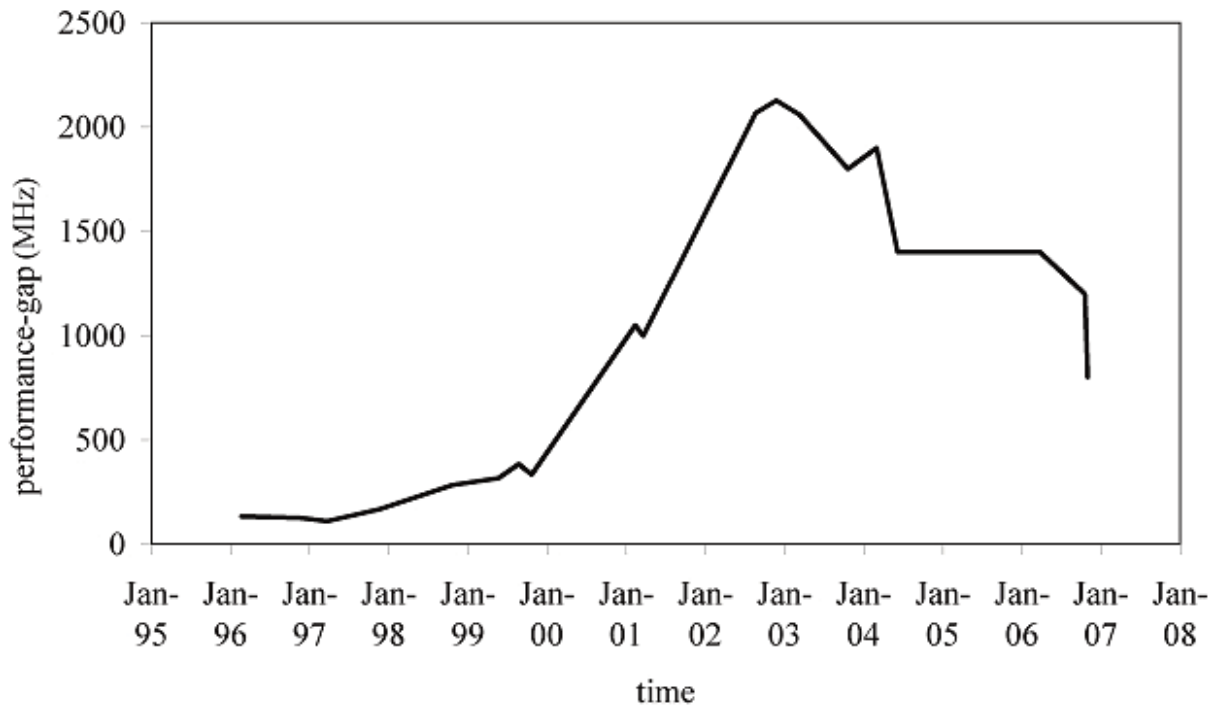


Figure 4. Temporal behavior of reverse salience measured by performance-gap for CPU.

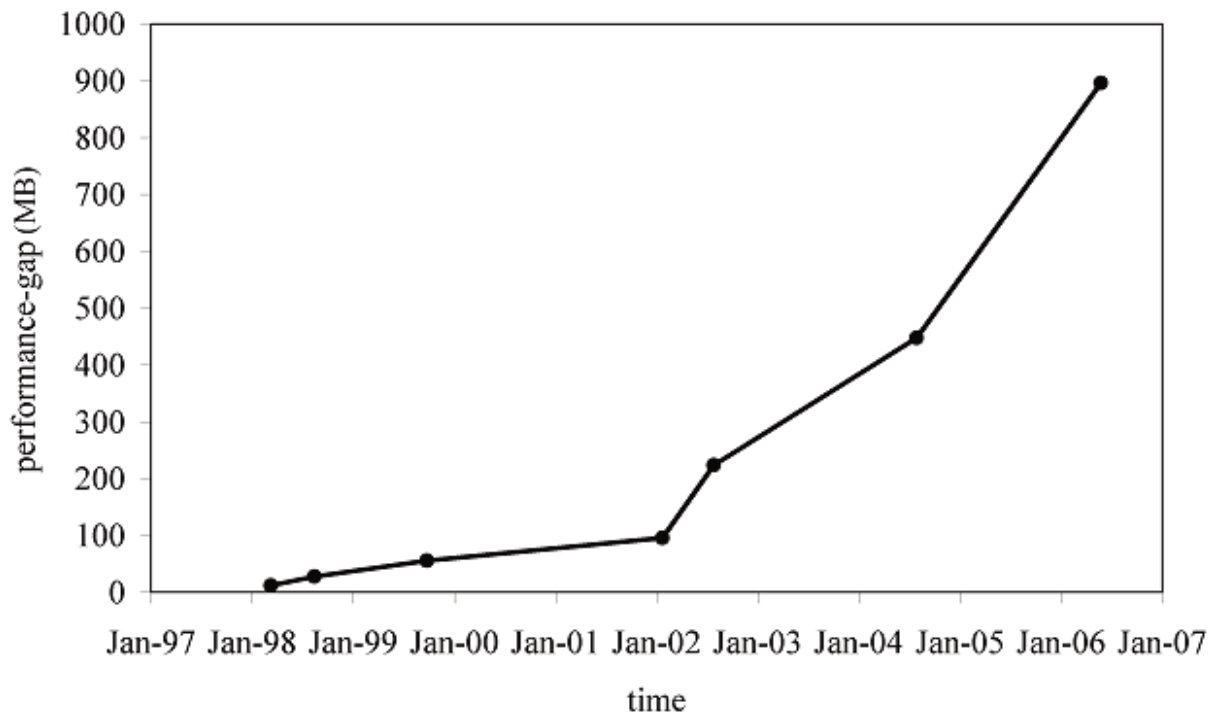


Figure 5. Temporal behavior of reverse salience measured by performance-gap for GPU.

considered. This trend can be more elaborately explained as a relatively slow one for the early phases followed by a steep ascent, commencing approximately in the year 2000 for the CPU sub-system and in the year 2003 for the PC game sub-system.

Technological development curves of the co-evolving GPU and PC game sub-systems are displayed in Figure 3. The GPU sub-system, more so than the PC game sub-system, demonstrates a steep incline from the year 2002 onwards.

In addition to the individual developmental curves, Figures 2 and 3 reveal the PC game sub-system as the reverse salient in its co-evolution with both the CPU and GPU sub-systems, continuously trailing the technological performance of the latter throughout the timeframe of analysis. Utilizing the measure of performance-gap we observe the varying degree of reverse salience over this timeframe in Figure 4.

The temporal behavior of reverse salience with respect to the CPU displays a period of increasing performance-gap, between the years 1996 and 2003, followed by a marked period of diminishing performance-gap until the year 2006. The decreasing technological disparity between the co-evolving sub-systems in recent years, underlines the PC game sub-system's utilization of the development potential made available to it by the CPU sub-system.

In contrast, the performance-gap measure of reverse salience with respect to GPU in Fig. 5 illustrates an ever increasing technological disparity between the co-evolving sub-systems, underlining the PC game sub-system's growing inability to utilize the development potential made available to it by GPU sub-system.

Discussion

Reflecting on the definition of reverse salience as a state of unevenness which limits the development of technological systems, we conclude from our results that the overall PC system providing gaming performance to end-users has not reached its full potential within the evaluated timeframe. The difference in dynamics of reverse salience between the different co-evolving technological sub-systems inside the technological system was evident in our analysis of temporal evolution of the magnitude of reverse salient.

The disparity between the technological potential and its use is because the full utilization of technology for the delivery of user experience takes place only at the time that the minimum re-

quirements specification of PC games meets certain technology performance level of the technology frontier, established in this instance by CPUs and GPUs, respectively. Likely explanations of this observation are many but one which is fairly salient is born from the role of the end-user market as an intermediary in the co-evolution of the considered technologies. The argument here is that games of higher technological performance are purposefully restrained from being developed and introduced to the market to allow time for the diffusion of complementaries such as CPUs or GPUs (Teece 1986). In this sense, the argument follows that once a critical mass of hardware would have penetrated the market, the likelihood of PC game sales reaching desirable levels increases favorably for game developers, partly as a result of the network externality phenomenon (Katz & Shapiro 1985). If this standpoint would provide a plausible explanation of the continuing technological disparity witnessed, we would expect to find, *ceteris paribus*, some pattern in the temporal behavior of reverse salience. Although difficult to conclude with confidence, the idiosyncrasy of reverse salience displayed in Figure 4 (more so than in Figure 5) could potentially represent a cyclical pattern, which suggests some moderating connection between the market and the two co-evolving technologies. Extending the present study over the coming years is recommended to verify or refute this proposal.

There are naturally other factors which may explain the observed reverse salience. Rather than emphasizing causes within the PC game sub-system for instance, we may find them associated with the CPU or GPU sub-system instead. Here, we could argue that the observed idiosyncrasies of reverse salience are in fact brought about by the incessant technological progress of these hardware components, undeterred by the underdevelopment of the PC game technology. A more substantial driver of CPU and GPU performance may therefore lie outside of the greatly simplified co-evolutionary process studied in the bounds of this paper. This point addresses one potential limitation of the study, in that its scope, while appropriate for the development of measurement means, is possibly too narrow to allow for the identification of causalities of measured results.

The performance-gap measure of reverse salience in the comparison of GPU and PC game sub-systems on the contrary displays exponential increase, which in the presence of market moderation would not be expected. This is due in part to the fact that sequential levels of graphics technology increase in a step-wise fashion, and typically in two-fold rather than in smaller increments (e.g. 8 MB to 16 MB, and 16 MB to 32 MB). As a result, the computed performance-gaps have tendencies to increase with larger values over time, in the absence of radical technological leaps in PC games. In light of these outcomes we

believe that the moderating role of the market can be a fairly plausible explanation of the witnessed reverse salience in our empirical study. Notwithstanding, the additional influence of other factors should not be dismissed. Additionally, it is arguable that technological systems are inherently messy and complex (Hughes 1987), such that the scope of studies necessary to uncover underlying drivers for system co-evolution must be of significant breadth. Nevertheless, the appropriateness of the scope of study remains a point of consideration for future studies of reverse salient behavior within technological systems.

Conclusion:

Technological system growth is marked by periods of unevenness between technological components or states of reverse salience. The will of stakeholders to overcome states of reverse salience drives the evolution of technological systems, and in reciprocating fashion the evolution of technological systems reveals further states of reverse salience. Our paper has considered the technological co-evolution of the CPU and PC game sub-systems, and the GPU and PC game sub-systems, which are nested inside the greater PC technology system. In line with the concept of reverse salience in evolving socio-technical systems, as well as the notion of structural tensions within development blocks, we have proposed a means to measure the magnitude of reverse salience in the co-evolution of system components – performance-gap – and showed its use in identifying temporal evolutionary patterns in our empirical study. We built this measure upon the theoretical concepts of technological systems, technological co-evolution and reverse salience in technological systems. The reliability of our measurement method is attained by following the sequential steps stipulated in the methodology section of this paper. The validity argument is derived from Hughes' definition of a reverse salient as the component of a system which underperforms technologically when compared to other components within that system. Thus, any state of reverse salience is most suitably projected by the comparison of different components' technological performances, and the magnitude of reverse salience measured by the disparity between these technological performances.

Our findings firstly indicated the PC game sub-system to be the reverse salient in the PC system's delivery of gaming performance to end-users. Using performance-gap as a measure of reverse salience, we also underlined the increasing technological disparity between the GPU and PC game sub-systems over time, but the partially cyclical pattern in the technological gap between the CPU and PC game sub-systems. These results

not only prove the analytical measure of reverse salience to be a quantifiable characteristic positively complementing the reverse salience concept utilized by scholars thus far, but also demonstrate the application potential of the developed measures in the analysis of technological systems' evolution. In highly dynamic systems where knowledge pertaining to the idiosyncrasy of systemic evolution is heavily sought, our research most importantly underlines the increasing effectiveness with which firms can strategically engage in innovating solutions through the ability to gauge the magnitude of reverse salience.

Our research work also yields beneficial implications for continuously innovating and R&D (research and development) oriented organizations positioned in evolving technological systems. Most importantly, the ability to gauge the magnitude of reverse salience in technological sub-systems is likely to increase the effectiveness with which these firms strategically engage in innovating solutions. A firm's continuous innovation process is thus improved with the availability of vital information embedded in the reverse salience measure. More specifically with respect to the gaming industry, our findings show that PC game product performance is not governed by the magnitude of reverse salience, which leads us to conclude that game developers may be advised to launch products with a focus on other factors to guarantee success than innovating products based on higher technological performance.

The complexities of interaction between members of the analyzed technology system rendered the revealing of underlying causes of the observed results difficult, especially within the confines of this concise paper. We believe that complementary studies can identify these causes. Additional investigations are also recommended to establish the past and future characteristics of the S-curves of the subsystem technologies analyzed as well as the temporal behavior of reverse salience, where these would be of interest to those concerned with the case at hand. With respect to the measuring method itself, although we have argued the validity of the performance gap measure, it is nevertheless essential to strengthen this claim. The further validation of the measuring means can be achieved by applying the method with respect to other subsystems within the same technology system.

In conclusion, we believe that our presented study and its outcomes pertaining to the developed measure of reverse salience in the PC technology system are applicable in organizational practice as well as in further academic research. Conceptually, we perceive the established method to be reliable and externally valid due to its malleability to other contextual requirements. We propose that the application of the performance-gap measure of reverse salience could be especially beneficial for

the study of technology systems, when revealing the dynamics of co-evolution and reverse salience is imperative in understanding the observed pace of that system's growth, and consequently in resolving the reverse salient to ensure delivery of desired system objectives.

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About the Authors

Ozgur Dedehayir, M.Sc., is a Ph.D. candidate at the Tampere University of Technology (TUT), Finland. Currently he is a researcher at the Center for Innovation Technology and Research (CITER), at TUT. He holds a M.Sc. (Ind. Mngt.) from TUT and a B.Sc. (Eng.) from the University of Melbourne, Australia. His research interests include theory of technology and technology management.

Saku J. Mäkinen, PhD, is a Professor of Technology Management at the Department of Industrial Management, TUT. He received his M.Sc. in Electrical Engineering and his PhD in Technology Strategy from TUT. Dr. Mäkinen has previously been at the Department of Marketing, Faculty of Business Adminis-

tration, National University of Singapore and at the Australian Graduate School of Management at the University of New South Wales, Australia. His research interests include technology strategy, innovation management, and technology and industry co-evolution. He is Head of the Department and Director of the Center for Innovation and Technology Research (CITER, <http://www.tut.fi/citer>) at TUT.