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From telephones to iPhones: Applying systems thinking to networked, interoperable products ☆

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ABSTRACT

An expanding array of consumer products have the facility to have things added in and plugged on, their firmware upgraded, and as yet un-thought of future capability supported. In short, more and more products can be connected to something and/or someone, and in doing so are slowly adapting to the current day state of modernity that is called 'the information age'. Inevitably, this brings with it changes in the way that products should be thought about and designed. The purpose of this paper is to try and help product designers and Ergonomists to get a grip on all the complexity and non-linearity that the information age brings with it, and help make themselves and their increasingly networked and interoperable products at home in it. Our case study, Apple's new iPhone, serves as a pertinent example.

1. Welcome to the information age

Are some consumer products becoming a bit more like services? Is it the case that "It's not what you sell a customer, its what you do for them. It's not what something is, it's what it is connected to, what it does."? (Kelly, 1994, p. 27). If our current case study, Apple's new iPhone, is anything to go by then one thing at least seems reasonably certain; product design is changing. Quite apart from anything else, it means that concepts which were once the exclusive province of large-scale entities and organisations, concepts like Systems Theory, suddenly become applicable to a growing number of products. The results of this shifting paradigm are fascinating, not just in terms of how information age products like the iPhone should be designed but also terms of how they should be thought about in the first place.

"iPhone is a revolutionary and magical product that is literally five years ahead of any other mobile phone," declares Steve Jobs, Apple's CEO, during a keynote speech for Macworld in San Francisco. "…it ushers in an era of software power and sophistication never before seen in a mobile device, completely redefining what you can do on a mobile phone" (Apple, 2007). For a lot of people a company like Apple represents the public face of all that Ergonomics promises for product design. It is a smiling face, literally, as is those of most Apple users who like the kind of easy interaction that Mac OS and the iPod provide. Let us be honest, the products manage this whilst still looking edgy and hi-tech, thankfully devoid of the Fisherprice jelly mould look of most stereotypically 'ergonomically designed' artifacts.

The iPhone is a significant development. Not necessarily in itself or how it specifically was designed, but in what it seems to signify. The iPhone, and products like it, show that a particular point within a wider product design paradigm shift has been reached. These are products that are located firmly in the transformation from 'industrial age' notions of products to something much more apt for the 'information age'. The information age is all around us in familiar phrases like 'the internet revolution', 'globalisation' and 'knowledge economies', so it is perhaps a shame that even a moderately detailed general critique of this particular phase of modernity would likely require a paper of its own (the interested reader is referred instead to Beniger, 1986). We can, however, start to deal with some of the consequences that flow from this paradigm shift as they relate to product design.

A number of attributes qualify the assertion that the iPhone is an incipient information age product. In some senses the intrinsic value of the iPhone lies not just in what it 'is' but what it's connected to and what it does (Kelly, 1994). The iPhone is not just a phone. It's not even a portable computer. Conceptually it is a kind of mobile porthole into an internet 'blogosphere' populated by other people, information and devices. It enables users to extract value, to harness the power of this electronic virtual world in new ways, to do meaningful 'real-life' things easily, only one of which is talking to people. It is also a slightly unusual type of technology. Far from being rigid, fixed, bureaucratic and very 'technology-like', the iPhone is instead open, flexible, adaptive, with a lot of underlying technology largely hidden from view. It

☆ This paper remarks on a number of specific consumer products but it is important to emphasise that it is not sponsored or in any way affiliated to the makers of these products. All product information, and any inferences made about them, is based on material that exists in the public domain.

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seems to be a democratic sort of device, one that supports user innovation and learning rather than squashing it under pre-set conditions of use and complicated instructions.

Back in the Expo's main auditorium, up on the stage and with growing bullishness, Steve Jobs presses the touchscreen of his iPhone. In an instant it automatically locates the nearest Starbucks, another tap on the screen and he's through to a bemused barista who's unsuspecting voice is amplified and played through the PA system where it echoes around the darkened auditorium: "Can I help you?" To the sound of laughter from the keynote audience she receives her largest ever order: "can I get five thousand latte's to go please".

2. The control revolution

If flexibility, innovation and learning are the hallmarks of information age products, then these same characteristics bring with them a number of rather frightening corollaries for product design. Principle among them is that many of the ways in which the iPhone's functionality connects to what people want to do, in other words what it actually does, its behaviour, remain as yet undiscovered by users. Apple have provided the generic capability to locate nearby coffee emporiums, and anything else for that matter. What users decide to do with that capability, how they link it to real-life things that they want to achieve, whether it's ordering one coffee for real, or five thousand for a joke, is largely up to them. This means that how their product is actually going to be used is to some extent unanticipated by Apple's designers as well. At first glance, therefore, it is tempting to see elements of the design as being out of control.

Is it truly out of control? Or is it merely a different type of control? We argue the latter. If the new vocabulary of 'firmware upgrades', plug-ins and add-ons is anything to go by, then information age products lend themselves to a form of 'through life capability' (to use a popular systems engineering term) making them able to take advantage of current as well as future developments. Most users would not give a moments thought to such things, and if they did, they would likely conjure up images of computer BIOS' and specialist, rather labour intensive procedures. Yet, like it or not, the new generation of networked interoperable products do this already, without users even being aware that it is even happening. Digital televisions, for example, satellite receivers, computers, peripherals, car engine control units and mobile phones, to name but six examples, use some sort of networked infrastructure which they are either permanently connected to (e.g. digital terrestrial and satellite broadcasts, the internet, the mobile phone network) or just periodically (e.g. the car dealer's engine diagnostic apparatus) to update their internal software. It may not be updated all that often, but the facility certainly exists for in-service problems and fixes to be addressed, and beyond that, for varying levels of extra capability to be provided. What this means is that instead of a product life-cycle characterised by 'design', 'deliver' and 'maintain', design occurs 'through-life', and often with the end user's participation. It may not be active participation, in so far as the user may not explicitly request an enhancement which the maker then provides, but emerging needs can be sensed through usage or performance data, needs that can increasingly be supported. All this means that in some senses the iPhone, and other information age products, are not 'end products' at all, at least not in the traditional sense. What has been designed is a set of initial conditions or 'capabilities' which, in concert with whatever live informational infrastructure it is connected to, will allow the iPhone to respond and adapt to its users and their environment, to be something that 'becomes' rather than something that is frozen in time. Its just that an ongoing process of user/product 'coevolution' will define exactly what.

Products are changing. Admittedly, not all products are changing, but at least some of them are, and in growing numbers; of that there can be little doubt. A growing class of networked interoperable products are beginning to shift away from "the linear, predictable, causal attributes" of the simple telephone, "to the crisscrossing, unpredictable, and fuzzy attributes" of something like the iPhone (Kelly, 1994, p. 24). The conundrum facing product designers is how to cope with the transition from the noun like qualities of a product being 'something' to the verb like properties of it being a 'process' (e.g. Law, 2003). Fortunately they are not alone. The effects of the information age have already been felt acutely in numerous 'large-scale' domains such as organizational design (e.g. from traditional organizational hierarchies to something called 'Network Enabled Capability'; Alberts, 2003; Ferbrache, 2003), systems engineering (from requirements capture to 'I'll know it when I see it'; John, 2007), even sociology (from individual 'actors' to Actor Network Theory; Czarniawska and Hernes, 2005). Products like the iPhone merely herald a new era in the domestication of these ideas. The conceptual response developed elsewhere can, within the confines of this short paper at least, be drawn down and applied to a specific, and growing class of product, currently exemplified by the iPhone.

3. Evolution…from 'is' to 'does'

Unfortunately, the conceptual journey begins with rather depressing news. According to Green and Jordan (1999), in the world of product design it is becoming increasingly difficult to compete on functionality, reliability or manufacturing costs. Technology alone is not enough any more and they argue that product design is about to reach a ceiling, if it has not already. Functionality, technical reliability and manufacturing costs do at least share one fact in common. They can be seen as industrial age concepts that relate more to what a product 'is', which is not necessarily the same as the information age concept of what a product 'does'. This paradox warrants further examination.

3.1. End products versus initial conditions

The dictionary definition of a product is "… a thing or substance produced by natural processes or manufacture" (Allen, 1984, p. 588). Products are self-evidently manufactured, but the idea of them being produced by 'natural processes' has a certain resonance. Products are not just manufactured, they are also 'designed'. Because they are designed they are subject to a range of diffuse interconnected influences, from competitive and commercial pressures to technology developments and user needs. Products, therefore, emerge out of a wider dynamic background and context, they too evolve, a form of natural process within which the designer plays a key role.

Like any product, the iPhone has its own evolutionary timeline (Fig. 1), its own inherited traits, its own product DNA and its own adapted state vis-à-vis its environment; at least conceptually. Natural evolution, as distinct from the artificial evolution of products, is an essentially 'bottom up' process. There is no 'control' or 'design' as such and complexity emerges out of lower orders of simplicity. Implicit in natural evolution is a subsumption architecture. Higher (complex) levels subsume lower (simple) levels, like building blocks (Brooks, 1986). The rules of subsumption proposed by Brooks (1986) are instructive for product design as well, as they not only underscore the importance of industrial age concepts like reliability and dependability (which are vitally important building blocks), but go further to map onto the verb-

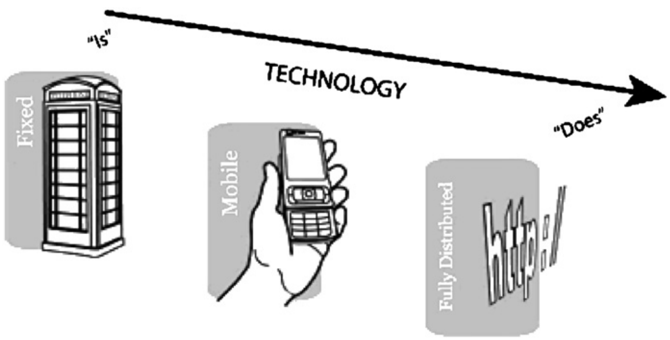

Fig. 1. The iPhone's evolutionary timeline.

like properties of information age products that are built upon these shoulders. They are as follows:

Step 1: Get the product doing simple things first and get them working perfectly (in the case of the iPhone it does everything that a phone, a GPS receiver, PDA, MP3 player, etc. normally does and appears to do them well).

Step 2: Add new layers of activity over the results of the simple tasks (in the case of the iPhone the new layer is an interface that enables these simple tasks to be integrated and combined in novel holistic ways).

Step 3: Do not alter the simple things (in the iPhone the simple things still work well and in fact are not a radical departure from the technological norm).

Step 4: Make the new layer work as perfectly as the layer below (in the case of the iPhone, watch this space).

Step 5: Repeat…

The sort of artificial ecology that products normally reside in, and emerge from, exhibits a recognizable yet peculiar form of evolution in which these rules become distorted. In product design there is a combination of bottom-up and top-down processes; there are varying degrees of controls, in fact, the so-called blind watchmaker (e.g. Dawkins, 2006) is not necessarily blind at all, there is a plan, and the designer acts as a creator. This distorted design ecology usually gives rise to a particular type of complex consumer product, a technological brontosaurus like the Motorola DynaTAC 8000X, the first mobile phone and a distant cousin of the iPhone. It is possible to argue, in subsumptive terms, that this product was limited in its ability to do some of the simple things well enough (for example, one 10 h charge only gave 35 min of talk time) before new layers were added (the 'mobile' bit of the mobile phone) and/or the simple things that may have worked were changed (for example, the addition to its standard telephone keypad of nine other keys marked confusingly with 'Rcl', 'Fcn', 'Sto', 'Snd', 'End', 'Pwr', 'Lock', 'Vol' and 'Clr' hardly helped). This is not to be critical of a pioneering product, far from it, because despite its individual shortcomings, which ultimately spelt its demise, the Motorola DynaTAC 8000X succeeded in a different, less predictable way. If nothing else it helped to create the 'initial conditions' from which progressively more complex and developed layers were built, only one of which is the iPhone.

Perhaps this is the key to product design in the information age? What if, instead of designing 'end products' (something that is made) we design instead favorable 'initial conditions' (so that something can 'become')? What if hierarchical control ('we, the designers, are designing something for you, the users', e.g. Clegg, 2000) is substituted for a different kind of 'distributed control'? A mode of control whereby the boundary between designers and users "is highly blurred, highly permeable, or non-existent" (Scacchi, 2004, pp. 6–7). Or to use Toffler's (1981) or Tapscott and William's (2007) phraseology, where consumers become 'prosumers'? What if the focus of product design shifts, at least conceptually, from 'manufacture' to something more like 'natural process'? Embedded within the iPhone's individual timeline are several key themes which suggest that insights into to these 'what if' questions are at hand.

3.2. Opaque versus transparent products

The evolutionary pre-history of the iPhone probably begins as far back as Morse code. Morse code was replaced by voice telephony, voice telephony eventually led to the domestic telephone; which in turn has led to 'mobile telephony' and ultimately the iPhone. Expressed in terms of subsumption, there is an argument to suggest that Morse Code first demonstrated the principle of electronic data transmission on any meaningful scale. This in turn led to the nascent beginnings of a telecommunications infrastructure. This infrastructure, and the capability it afforded, created new uses and new aspirations for the system, which in turn paved the way for the next layer; voice telephony. This took the proven technology (of electrical signals carried by copper conductors) to the next level, enabling voice modulated signals to be carried rather than just dots and dashes. Again, this layer 'worked' and created new affordances, affordances that helped the principle of voice telephony to spread outwards from Post Offices to private homes, and beyond, to mobile phones. Presented in this way, the iPhone's developmental pre-history is perhaps overly simplified. Of course, parallel developments in micro-processor technology, microwave communications, networking, and so forth, also occurred and can also, to some degree at least, be given a subsumptive flavor. Here too, each level afforded new capabilities and aspirations, with these processes driving the subsumptive process forward, each working layer being subsumed into the last. From 8 pin Dual In Line (DIL) chips to 250 pin grid array Very Large Scale Integration (VLSI) chips, containing many thousands of the former; from microwave analogue communications to microwave digital, and so on. Whilst there is a deliberate and undeniable simplicity to all of this, and there are undoubtedly complementary processes in action simultaneously, it remains an important and interesting factor close to the heart of systems thinking.

In product terms, what the voice telephony product 'did' was tied to a particular device, the telephone handset, which in turn was tied to a particular location, due to the 'wired' nature of the local infrastructure. The users' interactions with the product, as a result, were constrained by location, by modality and by capability; users of the product had to go to where the product was located and use it in the way that the product dictated. "The human operator supplied the initiative, the direction, the integration and the criterion. The mechanical parts of the systems were mere extensions" (Licklider, 1960, p. 5). In this case they were extensions of the human voice. What the product has 'become', however, is something far greater and more profound than something that merely 'mechanically extends the man', to use Licklider's (1960) term. In several respects the technology has become very un-technology-like due to a process that owes surprisingly little to traditional notions of top-down control, little, in fact, to traditional notions of design.

A major trend in the transition from the industrial to the information age is that some of the technology that we are all now well familiar with is itself becoming subsumed, which means that it is becoming transparent, "weaving itself into the fabric of everyday life until indistinguishable from it" (Weiser, 1991, p. 94). For the telephone network this is quite an achievement bearing in mind the extensive technological infrastructure that it comprises. As a glance out of nearly any nearby window onto the wirescape beyond will confirm, the technology has not become 'literally' invisible. The point is that whilst it would be possible to point to and isolate the function that a specific telephone pole or wire serves, from the users perspective there is simply no point (Weiser, 1991). From the user's point of view the behaviour of the system has become largely disconnected from the specific technological artifacts that support it. From the user's point of view its behaviour is what counts. So, despite its heterogeneous parts the system as a whole not only works perfectly (as per Brook's subsumption rules above) but more importantly, it behaves coherently (Law, 2003). Only when the system breaks down does it dissolve into its constituent electronic components and human interventions, but even then this lack of coherency has more meaning for the telephone engineer than it does for the user (Law, 2003).

3.3. Centralised versus distributed products

Technological invisibility goes hand in hand with another of Weiser's concepts: ubiquity. Ubiquity means, "present everywhere or in several places simultaneously" (Allen, 1984, p. 817). What a product like the iPhone 'does' has been largely set free from the technology that supports its behaviour (the technology is transparent), equally important is that it has also been set free from the boundaries of space and location. The resources required by the iPhone, such as mobile telecommunications networks, internet, wi-fi, etc., have become, or are becoming, as "dependable, consistent, and pervasive" as an electricity power grid (Chetty and Buyya, 2002, p. 61). As a result, information age products are for the most part 'always connected'. In the case of the iPhone, although the user is still tied to a specific product or device (which if the field of ubiquitous computing has anything to say will not be the case for long), that device is no longer tied to any one location, neither is it tightly constrained in terms of what it does, at least compared to the domestic telephone of old. Moving from left to right along the iPhone's evolutionary axis, the difference in innovation and learning now potentially available to the user is akin to the kind of step change difference in the power of a product that runs off a battery compared to one that plugs into a mains supply.

From analogue to digital, from electricity power grids to computer 'grids', from telephone networks to the internet, the information age is characterized by changes that are occurring at the boundaries of materialism ('is' versus 'does') and place ('somewhere' versus 'everywhere'). Behaviour is becoming detached from the places and technology required to support it. More than that, the mobile phone, through products like the iPhone, is in the process of 'becoming' something. Quite what is not yet clear but the 'servitisation' of mobile phones (to use another systems engineering term) seems well underway.

4. From evolution to coevolution…simplicity to complexity

4.1. Stretched products

According to Hollnagel and Woods (2005) technology and complexity are intertwined. Expressed in broad terms, it can be seen that any extra utility afforded by some form of technological advance is usually seized, thus "pushing the system back to the edge of the performance envelope", rather like the motorway that is being continually widened and just as continually filled (Woods and Cook, 2002, p. 141). This relates to the same definition of affordance used above under subsumption (e.g. Norman, 2002, 2007). The results of it are that products tend to be run to their limits with all that that entails for reliability, stability and complexity (e.g., a bigger, wider motorway is one that is now more complex to drive on; Hollnagel and Woods, 2005). Hollnagel and Woods (2005) call this the 'self-reinforcing complexity cycle'.

If common experience in product design is anything to go by, the cycle begins with an identified deficiency in a product created by some use that becomes 'afforded'. This apparent lack of capability is answered by expanding the product's functionality. Functionality is expanded by capitalizing on the extra capability afforded by new technology, thus creating a new product, albeit a more complex one. Consider for a moment the functionality/ease of use provided by the venerable British Telecom 700 series phone (for which a curly cord to the handset was considered an innovation) and the functionality/ease of use provided by BT's latest 1010 Digital Cordless Phone (with a 65K colour display, choice of 5 wallpapers, 50 number calls list, 150 entry phonebook, 20 number redial list, 9 polyphonic and 1 polytone ringer melodies, and an instruction booklet an inch thick: BT, 2007). More than just an 'attempt' has been made to push this product "back to the edge of the performance envelope" (Woods and Cook, 2002, p. 141); its extra capability is accompanied by a dramatic increase in task complexity.

A characteristic of this self-reinforcing cycle, one close to the heart of Ergonomics, is that the user is often left "with an arbitrary collection of tasks and little thought may have been given to providing support for them" (Bainbridge, 1982, p. 151). As a result, human adaptability is required in order for these products to work as intended, which, in turn, creates new 'opportunities for malfunction'. Hollnagel and Woods (2005, p. 5) clarify this point: "by this we do not mean just more opportunities for humans to make mistakes but rather more cases where actions have unexpected and adverse consequences". The typical response to this situation is to change the functionality of the system again. This completes the self-reinforcing cycle as shown in Fig. 2, which leads to ever more bitter complaints from Ergonomists who argue that this does not merely cause difficulties, rather it represents an optimum strategy for maximizing them (e.g. Norman, 1990).

4.2. Coevolution

A well known maxim in Ergonomics is that 'it is easier to twist metal than it is to twist arms' (e.g. Sanders and McCormick, 1992). In other words, it is easier to adapt a product to its user than to rely on them adapting to it. At one level the maxim is metaphorically and self-evidently correct. It is the raison d'être

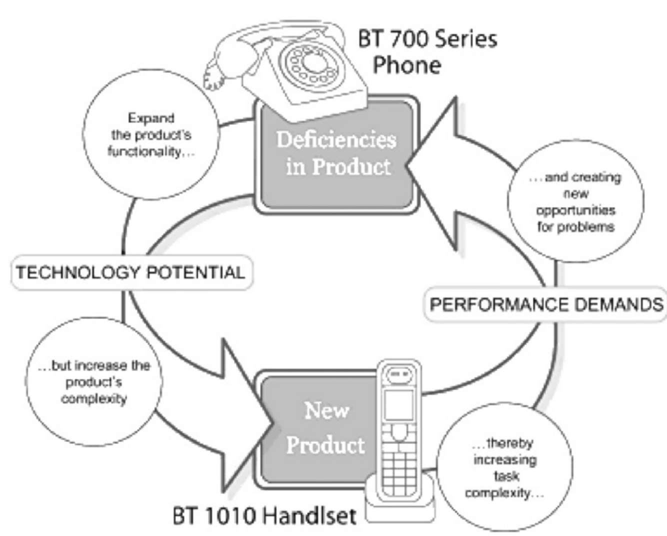

Fig. 2. Hollnagel and Woods' (2005) self-reinforcing complexity cycle.

of Ergonomics, albeit one that is somewhat redolent in industrial age thinking. When interpreted literally, it tends to presuppose that users do not adapt and that the product can be seen in isolation from its environment.

Another way of looking at this twisting metal versus arms dialectic is to see it as an almost necessarily antagonistic process, such that there is ''reciprocal evolutionary change'' (Kelly, 1994, p. 74), or a little of both metal and arm twisting. Users have their arms twisted by having to adapt to a new product, in turn, the product has a little more of its metal bent to suit new needs that arise from this adaptation, which creates more new needs, more arm twisting and more metal bending, on and on in a coevolutionary spiral until the original product becomes almost unrecongiseable. Polyphonic ringtones and wallpaper? Such things would not have even entered the heads of the BT 700 series phone's designers. In fact, what makes this kind of product archeology so fascinating is that, like the iPhone's evolutionary timeline, it says as much about what the telephone has done to users as the users have done to the telephone. Both users and product have become locked more and more into a single system, ''Each step of coevolutionary advance winds the two antagonists more inseparably, until each other is wholly dependant on the other's antagonism. The two become one'' (Kelly, 1994, p. 74; Licklider, 1960). It is an intriguing notion.

In the mid-1980s, at the birth of mobile phones as we know them today, who actually 'needed' one? One author describes the then extant situation: ''…you had to send off your fire-engine red 911 Turbo to be fitted with your new toy. The Porsche came back with a transceiver the size of a car battery in the well between the two front seats and a chunky telephone sitting on top. […] you could chat away ostentatiously, showing onlookers that *your* redundantly powerful vehicle had this *other* redundantly powerful capability too […] for who really needed to make phone calls from a car?'' (Spufford, 2003, p. 135). Who indeed. Well, it transpired that builders, plasterers, plumbers, small business people of every shade and variety, it was they who discovered that they really did need to make phone calls from their cars (or Transit Vans). ''A mobile phone cost £25 a month, plus 25p a minute when you were talking, but if it meant you picked up a couple of extra jobs a week, because customers could find you, you'd be well ahead'' (Spufford, 2003, p. 135). They became the early adopters parexcellence and the ''use of mobile phones was beginning to push along the S-curve to the next phase of the market'' (Spufford, 2003, p. 135).

Aspects of this success can be traced back again to ideas about subsumption, it does not explain everything of course, but the process is clearly active. Whist in some senses the mobile phone represented a radical departure in that it relied on cutting edge technological developments and new infrastructure, just as much as much as it did on new legislation, in another sense it was still 'just a phone'. It is perhaps instructive to compare it to other forms of telecommunication technology that were less successful, for example telex and fax machines. Both of these examples needed a critical mass of other telex and fax machines to communicate with in order to make them useful, and so consequently did not spread all that far from business use. But precisely because a mobile phone was 'just a phone' it could ring any other phone (Spufford, 2003). So actually, in some senses, it was merely a new layer of distributed technology overlain on the fixed infrastructure of the existing telephone network. The old subsumed layer worked perfectly, the new layer merely required some subtle arm twisting as users, from city traders to plumbers, adapted to the new technology and the technology to them.

As mobile phone ownership approached full market saturation in a way that telex and fax machines could only dream of, and as users and mobile phones became increasingly locked into a single system, the metaphorical twisting of arms required some more metal to be twisted. This took the form of the European Groupe Speciale Mobile (GSM) standard, the digital mobile telephony standard designed to support the kind of interaction and service afforded by this and parallel developments in the world of telecommunications. Buried deep within the technical specification for GSM was Short Message Service (SMS). SMS was originally conceived as a way for service providers to communicate billing information to users, yet it did include provision for users themselves to send short (160 character) 'texts' to each other, although no one really conceived that people would want to do this. After all, no-one really 'needed' to? According to another well-known artifact of the information age, ''The first commercial SMS message was sent over the Vodafone GSM network in the United Kingdom on 3 December 1992, from Neil Papworth of Sema Group (using a personal computer) to Richard Jarvis of Vodafone (using an Orbitel 901 handset). The text of the message was ''Merry Christmas'''' (Wikipedia, 2007). As it turned out, for the service providers it was Happy New Year as well.

The technological metal had been bent in response to user needs; users in turn adapted to the new version of the technology in a phenomenal way, to such an extent, in fact, that the effect of the simple SMS facility became magnified out of all proportion to the almost accidental way in which it came about (Smith, 2006). The 'initial conditions' that SMS created gave rise to over 500 billion 'texts' being sent in 2006, more than 100 for every man, woman and child on the planet, in the process generating more than £25 billion for service providers. Not bad for a feature that was not even 'designed' that way, such is the potential power of coevolution.

Arising from the mutually antagonistic relationship between evolving user needs and evolving technology is coevolution, which, if the example of SMS is anything to go by, is a force to be reckoned with. Whereas evolution describes the iPhone's own individual technological adaptation, coevolution is a jointly optimized adaptation that meets the mutual requirements of users and the capability of technology (e.g. Brand, 1974). Coevolution binds user needs and technology potential together; neither force exists in isolation. As a result, there is an imperative to consider the causes of coevolutionary change, both interaction push (the metaphorical twisting of arms) as well as technology push (the twisting of metal), in addition to the processes of change (e.g. the self-reinforcing complexity cycle) as well as the presence of change itself. It is also important to consider that a likely consequence of the information age is that coevolutionary processes will accelerate. However, before we move on to consider the consequences of this we should dwell for a moment on the graphical depiction of coevolution and the shift to information age products shown in Fig. 3, which is taken from the domain of organizational design and the work of Alberts et al. (1999). Here it can be seen that an interactional *y*-axis has been added to the iPhone's evolutionary timeline and the effect of coevolutionary arm and metal twisting, of interaction and technology push, spirals forward in time. The interesting fact about this coevolutionary spiral is that it leads not to chaos, as one might anticipate from the lack of control and predictability, but to order. ''By incrementally extending new structure beyond the bounds of its initial state, [an information age product] can build its own scaffolding to build further structure. Spontaneous order helps create more order. Life begets more life, wealth creates more wealth, information breeds more information, all bursting the original cradle. And with no bounds in sight'' (Kelly, 1994, pp. 22–23). It is perhaps a shame, then, that 'order' is far from synonymous with simplicity and stability; quite the reverse in fact.

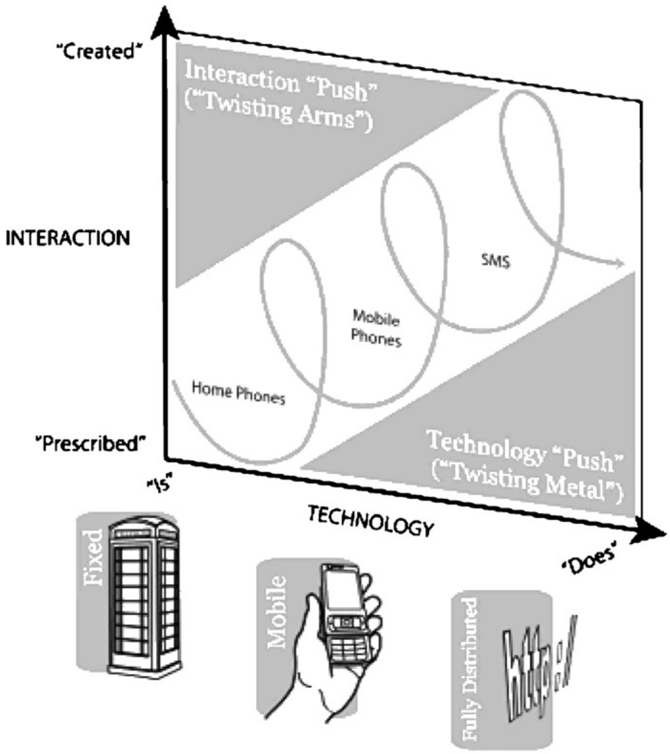

Fig. 3. Interaction push, technology push and product coevolution.

4.3. Complexity

To paraphrase the sociotechnical systems literature, the "single most descriptive term for [product] environments is change. This characteristic in itself is the basis for innovation of alternative [products], since the implicit assumption of [an industrial age product] was high stability or placidity of the environment" (Davis, 1977, p. 263; Trist and Bamforth, 1951). BT's original 700 series phone, for example, has a simple, well-defined capability designed for an enduring context of use. It is an end product in all senses of the word. The iPhone, on the other hand, has a degree of through-life capability. Whether its innate flexibility and adaptiveness is seen explicitly as this or not, the iPhone is designed for an altogether more dynamic environment. It is possible to go further and say that information age products exhibit the property of 'agility' (e.g. Ferbrache, 2003, p. 104). They are able to reconfigure (or to be reconfigured to some extent) in response to the evolving demands of the environment. British Telecom's new BT1010 handset is not alone, for example, in granting buyers a currently existing state of functionality as well as, according to BT's website, allowing buyers to "take advantage of the future services that BT has planned!" (BT, 2007).

A product's agility in response to environmental change is all very well but because products and users are increasingly inseparable coevolutionary partners, agility serves to create further change. Not just an increasing rate of change but also in terms of what it is ultimately changing towards; greater order, yes, but also greater complexity (e.g. Emery and Trist, 1965, p. 13). The problem with complex entities and environments is that they begin not to "…function in the linear ways in which we are used to thinking and analyzing." (Smith, 2006, p. 40). Actions "are both persistent and strong enough to induce autochthonous processes in the environment" (Emery and Trist, 1965, p. 29). The self-reinforcing coevolutionary cycle is one such autochthonous process, a type of positive feedback loop which means that "the consequences which flow from […] actions lead off in ways that become increasingly unpredictable: they do not necessarily fall off with distance, but may at any point be amplified beyond all expectation; similarly, lines of action that are strongly pursued may find themselves attenuated by emergent field forces" (Emery and Trist, 1965, p. 29). As a result of all this, product design in the information age presents itself as a daunting prospect. Fortunately there is good news. The significant product design opportunities embedded within complexity arise "paradoxically from the same conditions because it is exactly this non-linearity that presents the possibility of obtaining a disproportionate leverage from a given action" (Smith, 2006, p. 40). Evolution and coevolution appear as the watchwords for realizing this aim, SMS appears as a dramatic case in point.

5. From closed systems to open systems…rationality to non-linearity

5.1. Products as systems

Systems thinking is "…a framework for conceptualizing or viewing the world" (Carvajal, 1983, p. 230). In this regard the networked, interoperable consumer products that are the topic of this paper are conceptually no different from any large-scale system to which 'systems thinking' is normally applied. Although rarely seen in this way, certain types of product can also be seen as "…a set of interrelated elements" (Hall and Fagen, 1956 cited in Carvajal, 1983) and a "regularly interacting or interdependent group of items forming a unified whole" (Merriam-Webster, 2007).

What is a system? What form does it take? Let us assume that the iPhone is an interacting group that forms a unified whole. Mobile telecommunications, GPS, WiFi, Bluetooth functionality, all of these heterogeneous parts link together to create an iPhone 'system'. This structural definition of a system has two axes, vertical and horizontal (Fig. 4), which means that systems can be analysed at several levels (Molina, 1995). As we move upwards we traverse different layers of interconnectivity, from the links between the iPhone's inner functionality (GPS, WiFi, Bluetooth, etc.) to the links between other local devices (established via Bluetooth perhaps) to the links established within a much wider telecommunications and internet infrastructure. In each case the system becomes an ever larger interacting group of parts. Thus we can look at the iPhone as part of a super-system (i.e. a system of systems) or as a micro-system (within itself). Super systems subsume micro-systems; subsumption being what this vertical axis is really all about (Fig. 4).

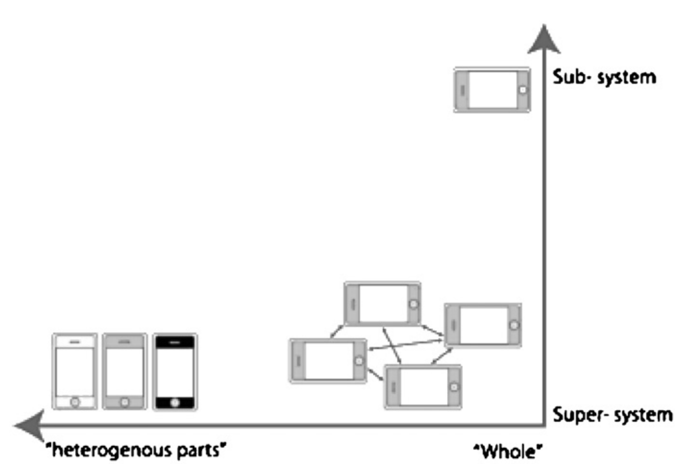

Fig. 4. Sub-systems, super-systems, systems of systems.

The horizontal axis, on the other hand, is more about the heterogeneity of the parts than the decomposed uniformity of a 'whole'. Whereas the vertical axis is comprised of layers of building blocks, the horizontal axis is comprised of vertical slices. In effect, this means that the conceptual building blocks are different shapes and sizes. In Fig. 4, running from right ('whole') to left (heterogeneous parts) the point is made that whether subsumed or otherwise, individual parts differ in all manner of ways. For example, the way in which one person uses their iPhone may be quite different to the next, thus the role that each of these iPhones plays in a larger super-system is probably quite different. The structural perspective considers systems from a very 'real-life' perspective (as real-life iPhone's disposed geographically and linked through a real-life telecommunications network). It is possible to divide up the systems theoretic cake according to more abstract 'functional' criteria as well. A system can be divided up according to purpose, to location, to behaviour, in fact to almost anything. In each case the end result is a quite different sort of system, one that does not necessarily conform to any kind of physical correlate.

The key point in all of this metaphorical cake slicing are the twin notions of "a complex whole" formed from a "set of connected things or parts" (Allen, 1984). Without trying to gloss over the practical implications of bringing real-life systems into being (which is undeniably complex), conceptually at least, the 'things' or 'parts' of a system can be almost literally anything. Systems can be "composed not only of people but also of machines, animals, texts, money, architectures—any material that you care to mention" (Law, 2003, p. 2), networked interoperable products and iPhones included. Systems thinking is simply a way of enabling such diverse phenomena to be linked together to form a kind of heterogeneous network, which can then be described with a universal language.

Product design is very good at doing the 'parts' of a system, yet it is sobering to think that it was Aristotle in circa 300BC who first stated the well-known maxim "that the whole is characterized not only by its parts, but by the relations between the parts…" (Ropohl, 1999). Innovations like the internet, and any product that has a connection to it and/or to other devices, brings with it the added imperative to consider these relations between parts and the 'whole' that arises when parts are linked in this way. In a sense the information-age raises the systemic level at which products need to be considered, in other words the designer needs to include more of the world in their design. Because of this, a product can become greater, or indeed far less than the sum of its parts because "…above all, the set of relations determines the very character of the system…[and]…the structure of the system determines its function" (Ropohl, 1999, p. 4). Metcalfe's Law brings home the point that lies behind even looking at information age products like the iPhone in this way, because "as the number of [parts in a system] increases linearly the potential 'value or effectiveness' of the [system] increases exponentially" (Alberts et al., 1999). The emphasis is on 'potential'; such an outcome is far from guaranteed based on merely connecting things up. Information age products like the iPhone do, however, have more parts, more interconnections, and 'potentially' more value. The flip side is that the more parts which are integrated, the greater the knock on effects for reliability and traceability. The lofty aim of applying systems thinking to networked, interoperative products is to recognize these problems, grant them a framework within which they can exist and be modeled, then ideally move forward to try and harness the synergistic potential of systems and their interconnections.

5.2. Objects versus networks

Systems theory's most recent past hails from a world far removed from product design: biology (e.g. Bertalanffy, 1950). Just as the concepts and metaphors of systems theory have been successfully applied to large systems and organizations we argue that the same insights are becoming increasingly relevant to certain types of products as well. Thus we can proceed from a more general characterisation of what systems thinking is to what it might mean.

The extent to which a product's 'parts' and 'interconnections' can be specified determines whether it has the systemic properties of an 'object' or a 'network'. The characteristics of an 'object' bring to mind a 'simple contraption' like the old 700 series phone (e.g. Kelly, 1994). The characteristics of a 'network' are better aligned with the flexible, adaptable, information age attributes of the iPhone. Looking at the iPhone's evolutionary timeline it can be noted that the products on the left of the axis seem to exhibit object-like properties. They are:

- concerned with the attainment of a relatively specific goal,
- have well-specified criteria for deciding on optimum means to ends and
- a "high degree of formalization" (Scott, 1992).

According to Scott (1992) this is the definition of a closed or of a rational system. To clarify, this is a system containing parts that have well specified input/output characteristics and interconnections with known properties and flows. An electrical circuit diagram might be a good visual metaphor for this type of system, where the outputs of one component form the input for another, the behaviour of the component being similarly well defined. The interesting point here is the imposition of closed systems thinking to parts of the system, namely the user, who are potentially concerned with the attainment of numerous goals, have poorly specified criteria (if any) for deciding on optimum means to an end, and a concomitant low degree of formalization. The original BT 700 series phone, for example, embodies this control theoretic logic in its design. Users pick up the cream coloured 1970s handset, dial a number on the rotary dial and speak into the perforated mouthpiece. The output characteristics are also definable, in so far as they are represented by the sound of a voice coming out of the earpiece. The first user is linked to the second user, functionally, by a simple two way informational link. And that is pretty much it. It is possible to delve into greater detail but this description is the essential essence of the human interaction with the product, an interaction that can be easily represented using Hierarchical Task Analysis (HTA), for example. If such an analysis were compared to that for an iPhone the number of tasks would be considerably fewer, and the conditions that cue those tasks similarly limited, not only in number but to the extent to which they refer to the external environment (if at all). For all practical purposes normal use of the 700 series phone exploits the full, albeit limited capabilities of the product and there is only one way to achieve an end state (which is the way the product designer has provided). The closed system metaphor, therefore, extends outwards from the technical parts of the product to include the users interaction with it. One could argue that there is relatively little harm in imposing the logic of the machine onto human users with a device as simple as a 700 Series phone. The logic runs something like this:

- *Rationality*—the user, like the device, can be assumed to behave rationally. There is a well defined end state and optimum prescribed ways of reaching those end states, which the user will follow rationally and consistently.
- *Linearity*—"the whole will be equal to the sum of the parts; […] the outputs will be proportionate to the inputs; […] the results will be the same from one application to the next; […]

there is a repeatable, predictable chain of causes and effects" (Smith, 2006, p. 40). This applies equally to both the human (socio) elements of a system and the machine (technical) parts.
- *Stability*—end states, routes to end states, the context of use and the needs and preferences of users are static and enduring. In other words, the time dimension can be ignored.

Products that exhibit the characteristics of an 'object' seem to make certain underlying machine like assumptions about the nature of human users. Thus, complex products like the BT1010 phone, designed as closed systems, often have to rely on a prescribed form of human adaptability in order to make them work as the designer intended. Of course, such a prescribed form of adaptability sits uncomfortably with an ergonomic view of the world. But beyond that there is a much more fundamental paradox in that what start out as highly rational products quite often degenerate into irrationality. To paraphrase George Ritzer (1993, p. 22) from a product design perspective: "*Instead of remaining efficient* [object-like products], *can degenerate into inefficiency as a result of* [the bureaucratic design of their interfaces] *and the other pathologies we usually associate with them.* [These products] *often become unpredictable as* [users] *grow unclear about what they are supposed to do and* [...] *do not get the* [outcome] *they expect.* [...]*...All in all, what were designed to be highly Rational* [products] *often end up growing quite irrational*" (Ritzer, 1993, p. 22).

Information age products can be different. Users can often do many things with the same product, reaching the same end states from different initial conditions and in different ways (the sociotechnical principle of 'equifinality'; Bertalanffy, 1950). Information age products are not concerned merely with the attainment of specific goals but also unspecified one's, one's for which an interconnection between product and user must surely exist but its precise nature is more difficult to define in advance. Information age products also link users more to the kind of real-life tasks they want to perform, which means that if human adaptability is required then it is because of coevolutionary needs rather than an artificial prescribed form of adaptability. Rather than a circuit diagram, with known properties, as we move up the vertical/structural axis from micro-systems to systems of systems, a more appropriate visual metaphor might be a block, venn or influence diagram, who's properties and links are no less extant but more loosely specified. This type of product exhibits the property of a network rather than an object.

5.3. Open systems, steady states and equifinality

The idea of a network brings along with it several useful concepts, the first of which is the idea of an 'open system'. "A system is closed if no material enters or leaves it; it is open if there is import and export and, therefore, change of the components" (Bertalanffy, 1950, p. 23). "The 'open' perspective implies that the social and technological dimensions of [products] must be designed not only in relation to each other, but also with reference to evolving environmental demands" (Mitchell and Nault, 2003, p. 2). Open systems have boundaries with other systems (users and the environment) and there is some form of meaningful exchange between them. This is an exchange that is not constrained by machine-like assumptions which, from an open systems perspective, may as well be no exchange at all. This appears to be one of the iPhone's strong suits.

"A closed system must, according to the second law of thermodynamics, eventually attain a time-independent equilibrium state, with maximum entropy and minimum free energy" (Bertalanffy, 1950, p. 23). A BT 700 series phone can exhibit 'time-independent states' with 'maximum entropy'. Why not? What these systems concepts make a 700 series phone look like is 'developmentally frozen'. It performs one simple task in one simple environment, it cannot be changed or updated, there are no 'firmware upgrades', no plug-ins and no add-ons. With a real-life change in the environment from analogue to digital telephone exchanges, the 700 Series was rendered obsolete and users had to purchase a new phone.

An open system, on the other hand, "may attain (certain conditions presupposed) a time-independent state where the system remains constant as a whole...though there is a constant flow of the component materials. This is called a steady state" (Bertalanffy, 1950, p. 23). Steady state behaviour is an attribute of information age products: "*They grow by processes of internal elaboration. They manage to achieve a steady state while doing work. They achieve a quasi-stationary, equilibrium in which the enterprise as a whole remains constant, with a continuous 'throughput', despite a considerable range of external changes*" (Trist, 1978, p. 45). The behaviour and capability inherent in the iPhone is, to a significant degree, dependent upon the live, dynamic, informational infrastructure that it is connected to. If the telecommunications network was turned off, and with it the constant import and export of information, then the iPhone would become just as much of a closed system as the old 700 Series phone did with the switch from analogue to digital. Networked interoperable products' capability is based around a continuous throughput of data. Its capability exists as a steady state, a "stable instability" (Kelly, 1994, p. 78). This, then, is the difference between products that are integrated and those that are designed on the basis of interoperability. Without labouring the deep theoretical concerns of open systems thinking too heavily, a new implicit theory seems to apply to such products:

- *Irrationality*—"People using the new [product] interpret it, amend it, massage it and make such adjustments as they see fit and/or are able to undertake" (Clegg, 2000, p. 467). In the words of Hollnagel and Woods (2005), they will adapt themselves and the product to suit their needs and preferences. This creates new and unexpected goals which, although useful for users, are quite often divergent from the normative, rational behaviour anticipated by designers.
- *Non-linearity*—Industrial age closed systems are often designed from the top down. In systems terms, parts and interconnections are well defined and they are thus designed to be 'homopathic', that is, the 'whole' is designed to be equal to the sum of the 'parts'. Information age products can exhibit heteropathic effects, that is to say they can be more than the sum of their parts, capability can be emergent and therefore not traceable to any one cause or individual part. To use Johnson's (2005, p. 1) definition, these emergent properties are "unexpected behaviours that stem from interaction between the components [people] ...and their environment". This is a bottom-up approach to capability and design.
- *Equifinality*—End states, routes to end states, the context of use and the needs and preferences of users are dynamic and changeable. "There are different ways of achieving the same purpose" (Majchrzak, 1997) from different initial conditions and by different means.

It has been quite a conceptual journey to reach this point. It may still be difficult to perceive the link that we have tried to establish between systems thinking and products. Paradigm shifts are seldom easy. To be fair, consumer products in general, and the iPhone specifically, are by no means a pure expression of an information age product. To the perceptive designer, though, there

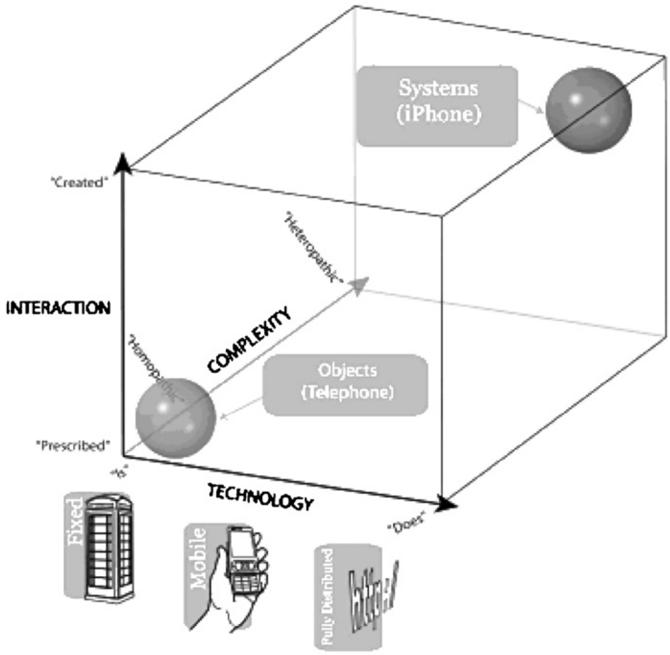

Fig. 5. From industrial to information Age products (based loosely on NATO, 2006).

appears to be enough about many current products to argue that at least some of their characteristics lend themselves to this alternative way of thinking. Some practical questions to ask might simply be: Does my product have a USB or RS232 port? Is it connected to something or can it be? Is it the sort of product where users can explore and discover its functionality? Is there a defined end state and route to that end state or is the product more flexible than that? Does the product have one defined 'capability' or does it have many? If the answer to any of these questions is in the affirmative then it has attributes that can be exploited by information age product design.

The enduring dialectic throughout this paper has been 'from' something 'to' something else. From 'is' to 'does', from 'simplicity' to 'complexity', from 'linearity' to 'non-linearity'. If each of these transitions are ascribed an intersecting axis then a three-dimensional space is created that describes in more detail where the networked interoperable products like the iPhone have come from and where they might be heading to (Fig. 5). One set of implicit theories, dominant design paradigms and conceptual languages applies to where the iPhone has been. The purpose so far has been to establish a foothold into the new implicit theories, emergent paradigms and conceptual languages applicable to where the iPhone, and all information age products like it, are heading towards.

6. From complex products 'doing' simple things to simple products doing complex things?

As consumers of electronic products we have become used to a dominant design paradigm: that of the closed, bureaucratic, inflexible, complex, technology laden product which, despite all that, really only permits the user to perform relatively simple and arbitrary individual tasks and only then with arduous effort. As this all too common experience testifies, although labeled 'implicit' these industrial age theories (in the loose sense) exert a strong influence and it is against this prevailing backdrop that the iPhone stands out. The label 'implicit' refers to the fact that these commonly held beliefs are ubiquitous, not that attempts to build on them and to move forward are fruitless. On the contrary, the question now, having established a conceptual foothold, however tenuous, is how to actually design information age products. How can this conceptual language be turned into something more practical, something that can be used to exploit the characteristics of the information age rather than fall victim to it. Once again, experience in other domains is instructive.

What might a 'good' information age product look like? It would not look like the Motorola DynaTAC 8000X, the iPhone's distant predecessor, which despite its very modest level of functionality had a complex bureaucratic mode of operation and a button infested interface. The DynaTAC is a far cry from most contemporary mobile phones that feature perhaps only three or four buttons (in addition to a number pad) that function as multi-modal hotkeys tied to a colour LCD. A far cry indeed from the iPhone, which dispenses with a keypad altogether and only has one button: on/off. The idea of outward simplicity (built on subsumed and transparent inner complexity) rests on the idea that for all its vicissitudes, the information age is not really, in itself, the problem. Rather it is the design of the product. Specifically, "the rate at which uncertainty overwhelms [a product] is related more to its internal structure than to the amount of environmental uncertainty" (e.g. Carvajal, 1983). With a product facing up to the challenges of the information age, Sitter et al. (1997) might offer two broad strategies:

"The first option is to restore the fit with the external complexity by an increasing internal complexity." This usually means the creation of more functions or the enlargement of existing functions and/or greater investment in vertical integration (p. 498). This is the typical technology-centric Law of Stretched Systems in action again. The alternative strategy, however, is to "…deal with the external complexity by 'reducing' the internal control and coordination needs." This option can be called the strategy of simple products 'doing' complex, real-life tasks. The paradox is that a good information age product is one that deals with external complexity *not* by a corresponding increase in its complexity (at least as far as the user is concerned) but by actually *reducing* complexity and features, by the technology becoming transparent, ubiquitous and flexible. The iPhone has been chosen because it is a good example of this. Although the iPhone is a cutting edge technology users have a better than normal chance of knowing what it is, what it does, and what to do in order to make it do it. There is no reason why all future networked products, whether they are blue-tooth fridges or the latest computer operating system, could not adopt the 'simple product doing complex tasks' maxim and be as equally recognisable and useable. Perhaps it can be hoped that excessive functionality and button infested displays are a thing of the past.

7. Conclusions

The information age is making technology transparent and ubiquitous, blurring the distinction between users and designers, increasing complexity and increasing the tempo of product design (e.g. Alberts et al., 1999). It is both a cause and consequence of a fundamental 'productivity paradox' in this and other domains. Stated simply, in spite of all the time, effort and expense that feeds into the design and development process, the resultant organizations (e.g. Ritzer, 1993; Davis, 1977), systems (e.g. Bar-Yam, 2003), major projects (e.g. Morris and Hough, 1987) and, we argue, networked interoperable consumer products, are often substantially less effective than intended (Clegg, 2000). The fundamental irony in all of this is that whilst the prior industrial age created the many long held and cherished beliefs that have led to all the success and progress achieved to date, it has become, or perhaps is in danger of becoming, the only remaining impediment to future progress (Berman, 1983). The purpose of this paper has been to bring these issues into the consciousness of both product designers and Ergonomists, to help them get a grip on these ideas and to start thinking about them. The good news is that what seems to be the optimum strategy for making ourselves at home in this information age, for managing increased complexity and non-linearity in the environment and marketplace, is not to design, at least from the users point of view, a corresponding increase in a product's complexity and non-linearity. Quite the opposite in fact, for the emergent product design strategy seems to one of simple products that enable users to do more complex things. Ergonomics sits squarely on the boundary between an interoperable products and the pervasive networked infrastructure they are connected to. The open systems behaviour of user and device, therefore, critically depends on it.

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