When the Whole is Less than the Sum of the Parts: Humanising convergence in interactive systems design

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Abstract

Convergence, viewed as the union of disparate technical solutions, is frequently proposed as a way of maximising value for end users: reducing the number of distinct technologies users have to purchase, learn and use. Yet few empirical studies of use and convergent technology have been reported. Though convergence as a catchphrase has had currency for over a decade now, a tension remains between those who argue for strong-specific solutions, i.e. carefully targeted 'information appliances', and those who prefer weak-general approaches, the ICT equivalent of the Swiss army knife. We describe the dynamic nature of the trade-off between usability and functional complexity that is inherent in convergence. We contrast current products as examples of 'Convergence-by-Design' with empirical data that illustrates users' practices in both combining previously non-converged solutions and separating previously converged solutions. We conclude that effective resolution of the usability/complexity trade-off involves both designers and users, and that sub-optimal resolution can trigger the workarounds that we call 'Convergence-in-Use' and 'Divergence-in-Use'.

Keywords

Convergence, Usability Knee, Divergence

INTRODUCTION

The digital clock has become the default giveaway in converged technologies (Pemberton, 2001): embedded in cookers, microwaves, radios, PDA's, mobile phones, computers etc. However, as Pemberton asks rhetorically, why not include them in shavers, or hair dryers? Are people now buying watches foremost as items of jewellery, rather than as timepieces?

Providing a use-oriented account of IT convergence has become something of a cause célèbre. Proponents for convergence (e.g. Forman and St John, 2000) argue for clear user benefits: with multi-function/single-device solutions, users will purchase, learn, use and maintain fewer technologies, the technologies will be interoperable and data and information will be integrated. Opponents of convergence (e.g. Norman, 1998; Bergman, 2000; and Buxton, 2001), point to the personal computer as evidence that a 'Swiss army knife approach' to convergence produces 'big and clumsy' technology that overwhelms the user with its complexity. The convergence sceptics counter with the single-function/many-device solution, or the 'information appliance'. Bergman (2000) describes an appliance as "*…designed to perform a specific activity, such as music, photography, or writing"*.

Though a popular topic of discussion in the practitioner press, use-oriented examinations of "*this incredibly overlooked process of convergence"* (Pemberton, 2001) are strikingly absent, and the subject of this paper.

THE CONVERGENCE TRADEOFFS

Convergence is the union of disparate technical solutions. A recent press release from Intel (2003), describing convergence as a mainstream trend, stresses the end-user benefits of the union of computing and communication. Intel's view of convergence is interesting and multifaceted. With respect to wireless infrastructure and mobile devices, Intel states *"the addition of more than 76,000 wireless networking cards a day to the world's computing infrastructure makes it clear that convergence is here to stay. And this isn't just happening in the PC area - we're estimating by 2010 there will be more than 2.5 billion wireless handheld devices capable of providing communications functions combined with the processing power of today's advanced PCs."*

Is such convergence a refined synthesis based on sensitivity to end-user needs and practices, or a technical clumping? Is it possible to converge too much, or too tightly? Can we draw out some commonalities between the convergence of form factors and convergence of the technical infrastructure? The challenge to the discipline of HCI is significant. Take the example of a 3G mobile appliance. Sacher and Loudon (2002) highlight that technical convergence brings with it a challenge to our existing interaction paradigms. Is a multimedia, multimodal 3G information and communications device best seen as communications device, thus inheriting the telephone interaction paradigm, or a personal computer, perhaps borrowing from the desktop metaphor? These two interaction paradigms influence the rules and conventions followed by both designers and users. Technically, a 3G appliance is a compelling demonstration of convergent design. However, user interactions with, and expectations of, such technology do not clearly fall into the established 'telephone' or 'desktop' models (Sacher and Loudon, 2002). For example, in the case of a 3G device, can interactions be saved as with a PC, or are they lost when the user hangs up? Perhaps modes could be used for signalling the appropriate interaction metaphor, but at what user cost? Perhaps we should develop new interaction paradigms for converged solutions, leveraging the unique value proposition offered by the new technologies, but on what basis?

In 2001, Bill Buxton proposed an inverse law of the relationship between usefulness and functionality that cautions against unfettered and unthoughtful convergence:

Usefulness ≈ 1 / Functionality n

In other words, as the number of functions climbs in a device, the usefulness to the end user declines (Buxton, 2001). More generally, unless technical synthesis is conducted with sensitivity to users and their practices, it is arbitrary, adds complexity to the technology, and may result in work-arounds, frustrations, and inefficiencies.

In agreement with Buxton, Kiljander & Jarnstrom (2003), describing their user interface design work at Nokia, refer to the 'usability knee' (Figure 1): the point at which ease of use drops away as functional complexity increases. The challenge, to reformulate Buxton's law, is to strike the correct balance between weak-general (the PC model) and strong-specific (the information appliance view) solutions.

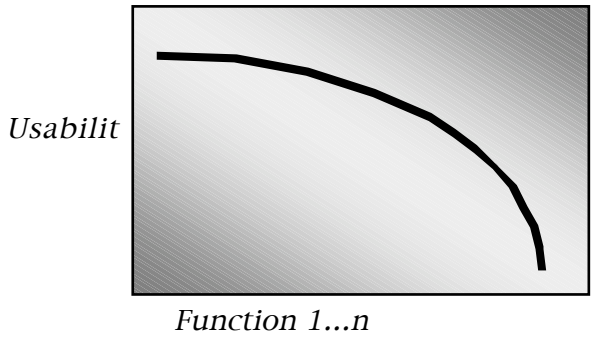

Figure 1: The Usability Knee (after Kiljander & Jarnstrom, 2003)

There are cautions if we get this balance wrong. Again, Intel state "*At a time when the 'virus of the week' seems to plague us all, making our computing devices more secure through the addition of hardware-based security must become a top priority…However, it's important to do this in a way that also respects the privacy rights of individuals.*"

Miniaturisation will further propel the move to convergence *"by packing even more new features and functions onto smaller and smaller devices"*. With 20nm wide semi-conductors by 2011, and transistors smaller than DNA molecules, size and power needs will no longer restrain 'what can be put with what'. The need for a human-centred response to the push to converge will increase in importance as technology becomes molecular and pervasive.

Both Buxton and Kiljander & Jarnstrom provide an interesting take on the convergence- balancing act but their accounts, somewhat ironically, are rather techno-centric. The relationship between usability and functionality,

putting aside precisely what we mean by these terms, is not strictly determined by designers but is also influenced by the users of technology. A technology-as-designed embodies implicit rules about expected and allowable uses but these will be modified through the practices of different users in context, resulting in technologies-in-use (Carroll et al. 2001). Consequently, the location of the usability knee will be a function of the personal cost-benefit analysis done in use. If we are to have a voice in the convergence debate, an examination of user practice in relation to converged and non-converged (diverged) technologies is necessary.

After presenting some key concepts in the next subsection, we examine convergence as embodied in recently or soon-to-be-released commercial products, Convergence-by-Design. We then examine convergence from a user perspective, Convergence-in-Use, and present empirical data from an ongoing study examining the use of multiple technologies by young people. Despite the presence of converged technologies, Divergence-in-Use can be seen in our empirical data, when users draw on multiple technologies to support a single activity. Further, the absence of converged technology does not prevent Convergence-in-Use. In the final section we pull together the two strands, speculate on the value that an understanding of Convergence-in-Use has for Convergence-by-Design, and draw out some themes and issues.

Key Concepts: Convergence, Divergence, Design and Use

What is being converged, and by whom? According to Forman & Saint John (2000) convergence can relate to content (e.g. audio, video and data), platform (e.g. PC, TV, Internet appliance and game machine) and distribution infrastructure. We have extended this classification to describe convergence occurring across four layers: *form factor,* including input/output mechanisms (Forman and Saint John's platforms); *media and modality,* used to aid representation; *data and information,* including services related to that data (Forman and Saint John's content); and technical *infrastructure*, including networking and operating system level components (similar to Forman and St John's distribution). The layers, shown in Figure 2, are a useful structural device.

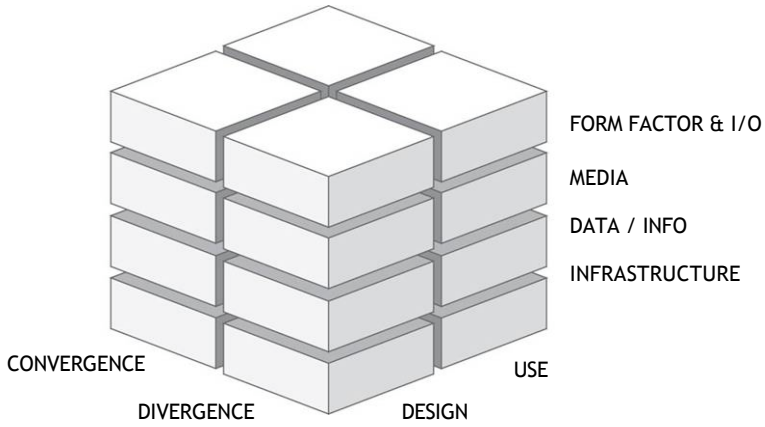

Figure 2: Convergence and Divergence by Users and Designers

Figure 2 aligns the four layers with two forces (convergence and divergence) and two actors (user and designer). The Figure suggests that either the user or the designer can converge or diverge across the four layers; simply recognising that use is not technologically determined, and an understanding of convergence based on passive adoption alone does not take into account the changes made to an innovation by users over time (Niemenen-Sundell & Vaananen-Vainio-Mattila, 2003, Carroll et al., 2003). Though designers might choose to converge form factors or network infrastructures, to a limited extent users can converge technologies-in-use.

The position of the 'usability knee' then is influenced by both the designer and the user, and can relate to any layer, or the interaction between the layers, of Figure 2. The next two sections, using examples from both the product space and empirical data from usage studies respectively, examine the influences over and consequences of convergence and divergence and try to extend our understanding of the tradeoffs inherent in technology convergence.

CONVERGENCE-BY-DESIGN

Before considering our empirical data, let us take each of the four layers of Figure 2 in turn and illustrate Convergence-by-Design.

Form factor

A recent and striking example of convergence at the form factor layer is the embedding of digital memory into the Swiss army knife. In a joint venture between Victorinox and Swissbait, the knife has acquired a 128MB USB memory key and an LED light, to complement scissors, a nail file, a screwdriver and a ballpoint pen (BBC News, 2004a).

From a technical perspective, one might argue that the similarities between the knife and the USB key, in terms of size, materials, weight, power needs etc, are suggestive of an opportunity to converge. Viewed from a use perspective however, we might question whether the designers have a clear understanding of the purpose-context mapping? In what location would you use both digital memory and a screwdriver? How big is the niche market that might include tradesmen with a need for digital memory? Does the benefit of not having to carry both a memory stick and a knife outweigh the cost of having to carry both when only one is required? Will the addition of digital memory open up new markets, as yet undiscovered?

Figure 3: The Digital Swiss Army Knife

Innovation at the level of the form factor can open up surprising new opportunities. The Swedish company Cypak has developed a disposable computer made of cardboard, Figure 4. The cardboard computer comes with 32kilobytes of embedded memory and a speaker pen (BBC News, 2004a). The company speculates that this innovation might provide an opportunity to develop the world's first disposable interactive drugs dispenser; clearly the implications of and for use are unclear.

Figure 4: The Paper Computer

Though these are perhaps the most concrete examples of convergence, convergence can and does occur at the other three levels of Figure 2.

Media and Modality

Convergence at the media layer, Figure 2, relates to the convergence of audio and video capabilities, and in the future other channels such as haptic, in a single solution (this is to be contrasted with the use of the term 'media convergence' in the popular press when discussing e.g. the AOL/Time Warner union). Media convergence can radically change the nature and role of a device, challenging the information appliance community's commitment to strong/specific solutions.

Services Relating to Data and Information

Convergence here involves the integration or federation of data, information and services from the 'supply side' or service providers and 'demand side' or end users (Clarke, 2004). Supply-side federation provides many examples of Convergence-by-Design, and we contrast this with demand-side federation, or Convergence-in-Use, considered below.

Secure identity management systems provide sophisticated exemplars of Convergence-by-Design. Such systems aim to provide access and privileges to end users via authentication schemes (Clarke, 2001). The central issue with identity management systems is 'What is one person?' and 'How are they identified?' and has been of concern for decades (Kent, 1978). For service providers the key issues concern authentication of identity, single

sign-on (i.e. one login) to one or multiple organisations to enable relevant business processes, privacy and security matters, assignment of access rights and privileges and synchronisation of changes to these things over time.

Federation of identity refers to emerging standards and specifications for single sign-on, linked access to multiple computer systems and manipulation of accounts and information across different organisations. Federated identity is dependent on the loosely coupled web services architecture based on XML (Extensible Markup Language) and SOAP (Simple Object Access Protocol) standards. This concept proposes communicating identity data through a mix of Convergence-by-Design (federation standards) and Convergence-in-Use (simple end-user web services programming) using a distributed technical architecture. This is a more flexible and widely adopted model than pure Convergence-by-Design in a complete systems integration project.

Successful convergence on the 'supply side' rests on the adoption of a common standard (currently two standards are emerging, the Liberty Alliance consortium and the Microsoft/IBM Web Services Federation) and a degree of trust within and between providers and users.

The secure management of a federated identity is going to be an important influence over the uptake of a growing range of personal services. Nokia, again challenging the concept of the mobile phone, propose in relation to Figure 5, *"…software that will help turn its phones into life loggers. The Lifeblog software automatically arranges all the messages, images, videos and sound clips people capture with their phones. The PC software organises information on a timeline and lets people add to the collection with images from other digital still and video cameras. Eventually the software will let people publish some or all of the information they collect to the web to let them create their own biographical blog."* (BBC News, 2004b).

Figure 5: The Mobile Blog

However, from the 'demand side' or end-user perspective, the federation of identities in devices, such as the mobile blog, may lead to an undesirable level of service and information integration. The desire of users to keep their identities private and to maintain control over the presentation of their identities to business organisations, and the need to keep different aspects of their life separate (for example work and social), may lead to a resistance to identity federation, implying a use-oriented ceiling on Convergence-by-Design. Technology should support maintenance and management of separate identities by providing functions to classify and separate blog content, i.e. facilities to support appropriate levels of Divergence-in-Use.

Infrastructure, Networks and Operating Systems

Network and infrastructure convergence is providing exciting opportunities, and again some costs are clear. The new 3G integrated mobile solutions allow a large array of services to be delivered to mobile devices, including video calling and advanced context sensitive information services. However, there appears to be some resistance to the currently power hungry and rather bulky handsets that accompany 3G capabilities. Hutchison's '3' range of form factors have struggled, not only with network coverage, but notably with Norman's earlier 'big and clumsy' challenge.

The position of the usability knee will move according to the user's sensitivity to handset size and weight, to the value of context specific information services, to the importance attached to staying at the leading edge of technology, etc. In order to understand the tradeoffs better, the next section reports on the results of an empirical study that illustrates Convergence-in-Use.

RESEARCH METHOD

As part of a larger project, we report here some findings on the coordinated use of multiple technologies by 11 young people.

Participants

The eleven participants in this project are Victorian post-graduate students in two universities, aged between 20 and 36, from either local or international backgrounds. They own or use a range of basic information technologies, mainly mobile and home phones, desktop and laptop computers. Several have MP3 players and USB keys, while PDAs and digital cameras are less common. Their technology acquisitions are somewhat constrained by their financial status as students.

Data collection

Our qualitative, multi-method approach includes focus groups and individual semi-structured interviews; observations within the university and beyond; and surveys used to establish contextual information such as educational and employment status and access to technologies and their uses. Through surveys we also capture changing patterns of behaviour and social interactions with other participants throughout the project. Interaction between participants in focus groups, where the responses of one member can spark ideas from others, has been helpful in exploring the issues (Krueger & Casey, 2000). The development of a trusting relationship between participants and research team, through which participants offer personal information, has been a critical aspect of our methodology. Opportunistic field observations provide a means of triangulation and a chance for known observers to ask clarifying questions of the participants as they use technology in their daily life (Lofland & Lofland, 1995).

Data analysis

All focus groups, conversations and observations are recorded as audio or video files, and transcribed for later analysis. To date we have gathered more than eight hours of transcripts and accompanying images that have been coded by one of the authors using QSR's NVivo software, according to codes that reflect the distinctions in Figure 2. In a recursive process, we have taken emerging themes, insights and questions back to our participants for member checking.

FINDINGS

Convergence-in-Use and Divergence-in-Use are complex behaviours, and complex influences are at work. Some of our participants honour the Convergence-by-Design decisions implicit in products and services, taking the opportunities presented by convergence to limit the range of technologies-in-use. In other cases participants break free from Convergence-by-Design, displaying Divergence-in-Use. We report this empirical data selectively, in order to illustrate convergence and divergence in relation to form factors, media, data and infrastructures.

Form factors, Input-Output

Our participants, though technically sophisticated, are considered in their adoption of IT, and do wish to limit the range of devices that they carry:

> *Participant: I was thinking of getting a lap top, but I don't know whether to get … If you have too much technology in your life… Trying to do all of them at once. Just try to keep to one device.*

Convergence and divergence then are clear influences over early decisions to use:

> *Participant: I don't have a palm, maybe if I did have one I'd use it. But as XXX said once you have three devices, you're always juggling between all three.*

Though such eagerness to minimise device multiplication is frequently evident in the empirical data, it does not override more conventional usability concerns.

A mid-way point between strong/specific and weak/general solutions is possible in the form of 'tight integration'. A weaker form of convergence, tight integration is present in, for example, the synchronisation facility that exists between some mobile phones and a PC. Convergence-in-Use can be facilitated by tight integration, and results in a dynamic binding between activity (e.g. note taking) and device (e.g. which can range across handhelds, laptops and desktops), as in this example from our empirical data:

> *Participant: They synch nicely, the Desktop and a palm, so that's not an issue, and I actually turn this into a notebook, it's got a keyboard. … and people are impressed, when you go to a café.*

However, tight integration and convergence can negatively impact such dynamic binding if implemented without sensitivity to user practice. Convergence-by-Design can have unforeseen consequences for users, presenting hurdles to established practice and resulting in Divergence-in-Use:

Participant: But the other thing is if you're using computer, email or a message board or whatever it is, you can do it from any computer, whereas if you need to have whatever computer's got that little camera on it, that means that you're stuck to that place as well.

Convergence-in-Use is constrained by technology, by the user's fluency with technology, by practice, and by characteristics of the situation of use. Divergence-by-Design can result in frustrating experiences as users attempt Convergence-in-Use. A participant received an iPod for her twenty-first birthday, and described her early experiences, listening to music, storing a class presentation and using the calendar. She commented:

Participant: This is a lot more useful than just the USB key and you can have your contact list on there as well, and a calendar. The only problem is you can't edit anything that's actually on there. You have to go to a computer and download it off and upload it back on.

It should be clear that though the degree of Convergence-by-Design is important, it is not quantified according the objective capabilities of the technology. We therefore caution against a view that the drivers of convergence are restricted to a rational examination of technology. For example, participant choices at the form factor layer are instructive of the subtle social processes involved in personal image management:

Participant: I bumped into my flatmate at the train station this morning and she saw me wearing this (USB key). She said 'Oh you geek. What are you wearing that for? ' So I popped it away.

Participant concerns about rampant convergence often relate to the insecurity of 'putting everything in one place'; when a converged device is lost or stolen, or otherwise breached, the costs can be high. Context, as it relates to security, is a strong influence over the position of the usability knee in Figure 1.

When Convergence-in-Use is facilitated by either tight integration or stronger forms of convergence, participants are able to adapt and change the basic technologies. In describing a battery-operated LED pendant that the participant has attached to her mobile, she notes with some enthusiasm:

Participant: It's a thing that flashes when somebody rings my phone. It responds to the radiation. It keeps flashing a bit after, it's like there's a change in radio charge.

The form factor is a somewhat neglected area of interest for HCI, having been largely the remit of the industrial designer. However, some interesting behaviours are being observed in relation to form factor use and its symbolic significance. In our empirical data form factors are strongly associated with identity; mobile phones are reflective of and adapted to use, through downloadable ring tones and various add-ons. A more sophisticated examination of the meanings and social role of the form factor is overdue.

Media and Modality

A real challenge to a view of use constrained by ISO 9241's emphasis on the work related concepts of effectiveness and efficiency, is contained in our empirical data. To understand Convergence-in-Use we need to take a broad view of use, a view inclusive of the need to carry the form factor (not just input data) and communicate subtleties that relate to our sense of self (Strauss, 1997).

At first sight, the following example of Divergence-in-Use relates to a well-known preference for reading from paper rather than a screen (see e.g. Wright and Lickorish, 1983).

Participant: Whereas pen and paper, oh there I am, that's what I'm doing, OK. And I very much like the pen and the paper aspect. If I need to read articles for subjects and stuff, I print them out and read them like that. I just prefer it that way.

But the preceding discussion is significant:

Participant: Yeah it (paper) is another thing to juggle, but to me it's also more reliable than a palm pilot. If you forget to charge it overnight or something like that…

More than the preference for reading from paper, this participant is concerned with issues of data permanency and infrastructure reliability and these are important factors in developing an understanding of use that is broad enough to provide traction over Divergence-in-Use.

Data, Information and Services

Subtle, transient and intangible aspects of use are most evident at the foundational layers of Figure 1, the 'Data and Service' and 'Infrastructure' layers. Service integration is affecting our young participants positively:

Participant: I use Internet banking for almost everything. … I do all my banking via Internet, I pay all my bills, via my credit card, and pay my credit card through Bpay and systems like that.

Our participants struggle with the fragmentation of their online identity, especially as it relates to personal identification numbers (PIN) and passwords.

Participant: For my Internet banking I use a different password from everything else. That's because once when I first tried to log in, I was entering the wrong password. I was so sure it was that one. I forgot I had changed it to another, so the Internet banking got blocked, I had to go to the bank.

For end users the key issues in identity management concern the management of multiple identities for different roles, use of pseudo-identities and anonymous identities in certain situations, privacy and security concerns and identity stability over time.

Consequences of a failure to manage Convergence-in-Use in relation to identity appropriately can range from amusing, through embarrassing to very serious:

Participant: There's a thing called life journals. They're like blogs and you private them… Sometimes if you forget to do that, other people get to read it that are not meant to. One girl was bitching about another girl and then everyone else read it and ganged up and there was a whole big war...

There are success cases in the empirical data, cases where Convergence-by-Design aligns with and supports use naturally:

Participant: Well, Palmie's [PDA] right next to my bed, it doesn't have to be on, that's my alarm clock as well…games, as well…strategy games, kind of thing. And…when I wake up at 3 o'clock in the morning with a thought, it goes on the Palm…schedule of things, has lots of work things that this person is doing and also lots of fun things, and in fact is going out too much and getting stressed by it all, should cut down a bit.

Another example relates to the iPod.

Participant: Well it plays music and you can also put files on there as well, you can use it like a USB key, so I've got a presentation, that I'm doing this afternoon on PowerPoint, at the moment it on there that I'll just transfer across to the computer and run it tonight cos it's 20 G worth of space it's a lot more useful than a USB key…

An interesting example of Divergence-by-Design relates to the unique PIN attached to mobile phones.

Participant: The only reason you need to share information with other people is because the systems aren't in place to do it in the first place. You have a mobile phone for instance and you can put a PIN number in your mobile phone so only you can use it. If the mobile phone has the facility to have more than one PIN, you wouldn't need to give your PIN number out….

Convergence-in-Use can be seen in the preference for usability (a single pin for everything) over the security benefits of unique PINs and passwords:

Participant: frequently I used to forget (password), so now I have all the same passwords, for the uni, for my bank, for my credit card… if…someone gets into my password, then that person could have access to my emails, everything.

Infrastructure, Networks, Operating Systems

Though unsurprisingly not so clear in our empirical data, infrastructure issues are an important consideration in the convergence/divergence debate. Our participants battle with the lack of integration that comes from Divergence-by-Design at the infrastructure layer:

Participant: …files are on the USB stick as well as on email, a bit of a pain due to version control issues.

In this section, we have considered convergence and divergence as activities end-users actively engage in. This is a rather unconventional perspective, but we hope now clearly seen as relevant and important. In the next section, we revisit Figure 1 and suggest that the location of the 'usability knee' can be understood in the patterns discussed above.

DISCUSSION AND CONCLUDING COMMENTS

There is a complex dynamic between Convergence-by-Design and Convergence-in-Use that is neither linear nor deterministic, i.e. it is not necessarily the case that Convergence-by-Design facilitates Convergence-in-Use. Rather, Convergence-by-Design can enable effective, efficient and highly satisfying interaction with composite technologies, exploiting natural synergies in peoples' activities and the contexts within which those activities play out. Convergence-by-Design can seamlessly facilitate use or present hurdles to effective and efficient use; thus causing Divergence-in-Use, as seen in the workaround when a paper copy of a diary is made to gain the 'big

picture' not well supported by converged small screen PDAs. Figure 6 extends Kiljander & Jarnstrom's (2003) notion of the usability knee, in order to illustrate the key themes we see in our empirical data.

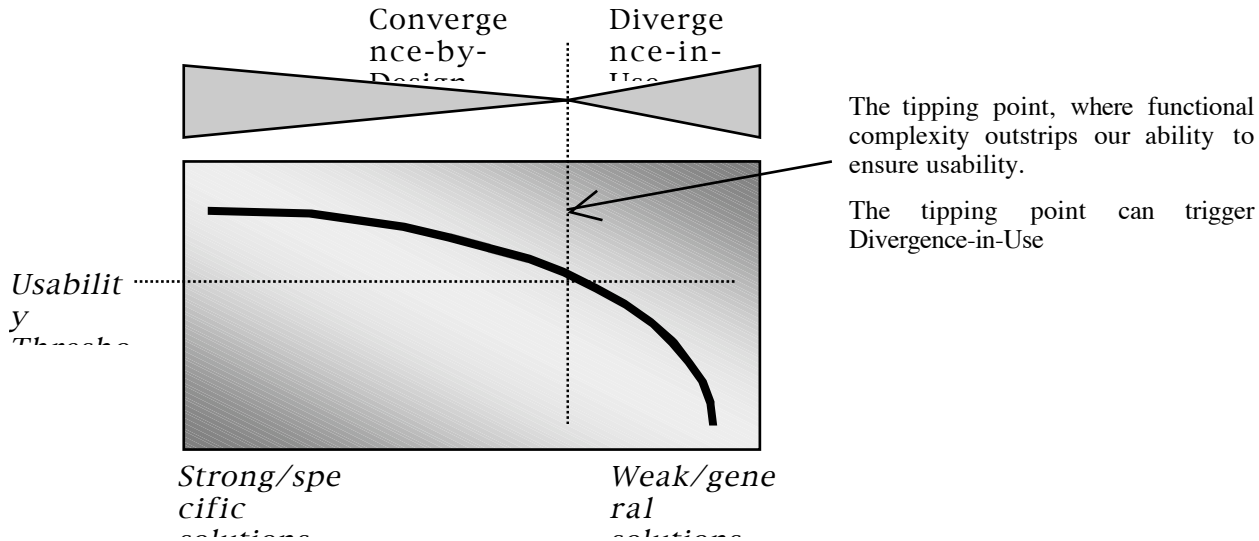

Figure 6: The Convergence Tipping Point

Figure 6 summarises the major ideas in this paper. Adding functional capabilities to an artefact generally increases complexity, and if extended far enough the artefact falls beneath the usability threshold, in some cases tipping the user into Divergence-in-Use. It should be stressed that Divergence-in-Use is not necessarily negative, nor is Convergence-in-Use always to be seen as a positive, but rather design for convergence needs to be informed about the tipping point if it is to be oriented toward users' and their practice.

Using Convergence-in-Use to influence Convergence-by-Design

A use-oriented framework for convergence design will need to reflect a refined understanding of the location of both the usability threshold, and the tipping point as it emerges in use. This paper has been a preliminary step in developing that understanding. Future work will need to develop both theoretical accounts of, and methods and techniques for practitioners that guide:

Horizontal Convergence: that is convergence within the layers of Figure 2. Horizontal convergence may be most straightforwardly exemplified in PDA/mobile phone converged form factors. Horizontal Convergence needs support in judging the *breadth* of convergence. We need to provide support in integrating technologies up to but no further than the usability threshold.

Vertical Convergence: Good convergent design should converge up to the appropriate layer on Figure 2. Vertical Convergence needs support in judging the *depth* of convergence. For example XML is useful in producing accessible (i.e. platform independent) systems, due to its power in drawing on integrated networks, data repositories and services whilst stopping short of requiring convergence at higher presentational layers.

Good convergent design converges the right parts of the system to the right extent and in the right way. Signs of resistance if we get it wrong are evident, for example in relation to the converged PDA/mobile phone end users may want to maintain clear boundaries between work and social activities. During social activities the mobile phone becomes a device to support communication, whilst the PDA, with its work calendar and long list of work contacts remains primarily a device of the working identity. Our understanding of Convergence-in-Use asks us to consider designing so that the PDA can 'stay at work' when socialising. We should design with flexibility in mind.

This paper has presented a layered model of technology convergence and shown how the model can be used to understand the interactions between convergence and divergence in both design and use across each of four layers. The model has provided a useful lens through which to interpret empirical data collected in fieldwork that examines the use of multiple technologies by young people, and demonstrates the complex dynamic between Convergence-by-Design and Convergence-in-Use. Interactions of various components in Figure 2 provide an understanding of convergence, in terms of horizontal convergence within layers and vertical convergence across the layers. Unlike earlier traditions of convergence, as they relate to non-computing artefacts, the layers of Figure 2 illustrate a unique opportunity (Buxton, 2001) to lower the usability threshold by using the intelligence in the network infrastructure to manage the convergence overhead at the level of the media and the form factor. Ongoing work in the project is extending these ideas further.

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