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From facilitating interactivity to managing hyperconnectivity: 50 years of human–computer studies

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ABSTRACT

Five decades ago advances in integrated circuits and time-sharing operating systems made interactive use of computers economically feasible. Visions of *man-computer symbiosis* and the *augmentation of man's intellect* became realistic research objectives. The initial focus was on facilitating interactivity through improved interface technology, and supporting its application through good practices based on experience and psychological principles. Within a decade technology advances made low cost *personal computers* commonly available in the home, office and industry, and these were rapidly enhanced with software that made them attractive in a wide range of applications from games to office automation and industrial process control. Within three decades the *Internet* enabled human–computer interaction to extend across local, national and international networks, and, within four, *smartphones* and *tablets* had made access to computers and networks almost ubiquitous to any person, at any time and any place. Banking, commerce, institutional and company operations, utility and government infrastructures, took advantage of, and became dependent on, interactive computer and networking capabilities to such an extent that they have now been assimilated in our society and are taken for granted. This *hyperconnectivity* has been a major economic driver in the current millennium, but it has also raised new problems as malevolent users anywhere in the world have become able to access and interfere with critical personal, commercial and national resources. A major issue for human–computer studies now is to maintain and enhance functionality, usability and likeability for legitimate users whilst protecting them from malevolent users. Understanding the issues involved requires a far broader consideration of socio-economic issues than was required five decades ago. This article reviews various models of the role of technology in human civilization that can provide insights into our current problématique.

1. Introduction

As we celebrate fifty years of the *International Journal of Human–Computer Studies* it is timely to reflect on how far human–computer interaction and symbiosis has evolved in five decades: what has changed in the underlying technology; what has changed in the personal and social impact of computer-based systems; what has been realized of the potential envisioned by the early pioneers; what new technologies and phenomena have emerged that were not envisioned; what negative side-effects have become apparent that now need to be managed; and what are our aspirations and challenges for the foreseeable future.

When we signed the publishing contract for this journal in December 1967 the cutting-edge issue for computer systems research was to facilitate and utilize interactivity as we migrated back from the *batch processing*[1] of the 1950s, where the time cycle of interaction between those creating programs or solving problems and the computer's response was hours or days, towards direct *human–computer interaction* where the time cycle was seconds, emulating person to person conversation.

Licklider's (1960) vision of *man-computer symbiosis*, McLuhan's (1964) of *media as extensions of man,* Engelbart's (1963) of *the*

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[1] Early computers were 'interactive' by default but, as commercial applications developed in the 1950s, the human operator was a bottleneck preventing efficient use, and *batch processing* operating systems were developed to improve cost-effectiveness (Huskey, 1965; Weizenbaum, 1965). Such systems queued tasks and ran each to completion which precluded interactive use. Reintroducing interactivity in the late 1960s required not only the developing of *time-sharing* operating systems but also the redevelopment of compilers and applications software to operate incrementally in a way that appeared natural to human users (Talmadge, 1965).

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augmentation of man's intellect and his demonstrations of what was now possible through *graphic interaction* and Weizenbaum's (1966) of how *natural language conversation* could be emulated, had stimulated research on and development of, the next generation of interactive computer systems and applications world-wide. Conferences and books on the *Mechanisation of Thought Processes* (NPL, 1959), *Computer Augmentation of Human Reasoning* (Sass and Wilkinson, 1965), *Conversational Computing* (Orr, 1968), and the *Computer Utility* (Parkhill, 1966) had encouraged the formation of a new community of practice focused on interactivity.[2]

The technology of stand-alone interactive computers in 1968 is best represented by minicomputers and microcomputers originally designed for instrumentation and control applications such as the *PDP8,*[3] *ELBIT100*[4] and *MINIC*.[5] These offered high reliability and fast interactivity at a reasonable price and the ELBIT100 and MINIC were small enough to operate in the office or home without requiring a special environment. However, the initial human interface to these systems was ASR33 upper-case, 10cps teleprinters, and such typewriter-like terminals were the norm for several years.[6]

Experiments with time-sharing partitions on existing computer systems commenced in the early 1960s with Corbató et al.'s (1962) implementation of the *Compatible Time-Sharing System (CTSS)* on the vacuum-tube IBM709 and the transistorized IBM7090 mainframes, and BBN's implementation of a similar system on the smaller and cheaper PDP1 minicomputer (McCarthy et al., 1963; Walden and Nickerson, 2011). The techniques developed were simple and widely applicable, illustrating how "any computer can be used for on-line systems" (Cooper and Heckathorne, 1967, p. 39), and time-sharing systems proliferated rapidly (Karplus, 1967).[7] They often offered special programming languages designed for interactive development, debugging and applications, such as BASIC, JOSS, TELCOMP, BASYS, APL and so on (Schur, 1973).

1.1. Breakthroughs in the technology of interactivity

Improved person-computer interactivity and accessibility have been continuing objectives since those early years. The first major breakthrough was in *accessibility* through the development of *personal computers* (Freiberger and Swaine, 1984) such as the *Altair 8800* in 1974 (Roberts and Yates, 1975), *Apple II* in 1977 (Wozniak, 1977), and *IBM PC* in 1981 (Morgan, 1981), which were sufficiently low in cost as to make dedication of a computer to the tasks of one interactive user cost-effective.[8] Low-cost personal computers encouraged software entrepreneurs to develop text-processing capabilities that provided a *word processor* at a lower cost than specialist hardware (Bergin, 2006), and added enhanced capabilities such as WYSIWYG and proportional spacing (Rubinstein, 2006). These, and other innovations such as the *spreadsheet* (Grad, 2007; VisiCalc, 1984), in turn expanded the market for personal computers, a classical *positive feedback* process leading to exponential growth.

The second major breakthrough was in *interactivity* as the *graphic user interfaces* envisioned by Engelbart (Bardini, 2000) and implemented on the Xerox *Alto* in 1973 (Wadlow, 1981) became widely available in 1984 through the Apple *Macintosh* personal computer (Williams, 1984). This new mode of human–computer interaction was the culmination of world-wide research to improve the human interface beyond the keyboard and printer (Bardini, 2000; Bitzer and Slottow, 1966; Howard, 1963; Lehrer and Ketchpel, 1966).

The third major breakthrough was in *connectivity* as computer-computer networking was integrated with human–computer interaction in the mid-1990s when commercial services were allowed on the Internet (Abbate, 1999; Gaines, 1998), Andreessen and Bina implemented *forms* supporting interactive widgets and programmed in HTML in their *Mosaic* web browser (Andreessen, 1993; Gaines, 1999), and applications were ported to operate through the web (Gaines, 1995) where HTML (and later CSS) provided a powerful human interface programming language. Multiprocessing techniques developed for timesharing enabled servers on the Internet to provide a wide range of services to large numbers of users through client processes on their personal computers, an efficient factoring of the computational workload.

The fourth major breakthrough was in *portability* with the advent of the *smartphone* (Merchant, 2017) in 1997 as cell phone data transmission capabilities advanced to a stage that provided digital access at a reasonable cost, and enabled interactive computers to be made available as lightweight portable devices connected to the Internet anywhere that had access to the cellular network.

A fifth breakthrough has occurred in the past decade as interactivity has been extended beyond computers and people to an increasingly wide range of *smart devices* on the *Internet of Things* (Evans, 2011; Miller, 2015) as part of the *Internet of Everything* (Di Martino et al., 2018; Meridou et al., 2017). This includes not only instrumentation and control in industry, public utilities, home and office, but also

[2] I chose the citations in this paragraph from my personal library in an era where I used to date and sign each book that I purchased and hence was able to recollect what I had read that influenced our interests and research when Barrie Chaplin, John Gedye and I founded IJMMS.

[3] Manufactured by *Digital Equipment Corporation* (DEC), a major American computer company from the 1950s to the 1990s.

[4] Manufactured by *Elbit*, an Israeli company whose minicomputer was similar to the PDP8 but based on integrated circuits, packaged for the desktop and cost only $4900.

[5] Manufactured by *Microcomputer Systems*, a subsidiary of the British instrumentation company, George Kent whose microcomputer was based on integrated circuits, had an extensible microprogram that could be used to control peripherals, packaged for the desktop and cost only £2000. It was based on a machine I designed in 1966 to manage my analog and pulse-rate computers (Gaines, 1967; 1968), and prototyped at the University of Essex in 1967 (Gaines, 1969). The first commercial MINIC was purchased by University College Hospital for critical care patient monitoring and I programmed the application under a Department of Health contract. The clinician's interface comprised a teleprinter and a Tektronix 611 storage-tube display displaying plots of patient data — 8 beds monitored by a 1KBit 8-bit word computer with a 64KB drum seems a miracle in current terms, and illustrates what was possible as very low-cost interactive computers became available.

[6] The *dialogue design rules* (Gaines and Facey, 1975) that we derived from our experience in developing hospital and stock exchange systems were based on interaction through teleprinter terminals but abstracted to be systemic principles that, to a large extent, still apply today.

[7] I toured a number of industrial and university research centres in the USA in 1967, and returned with developing a time-sharing system as a major objective. I obtained a PDP9 for my laboratory at Essex University and designed and implemented an interpretive language, *BASYS*, similar to Dartmouth Basic but including string-processing similar to SNOBOL based on the Brooker and Morris (1962) *compiler-compiler*, and embedded it in a simple time-sharing process under the PDP9 operating system, later porting it to the MINIC, PDP8 and PDP11. It became our primary resources for research on interactivity, and was used in a wide variety of applications, including a time-sharing service in the City of London, clinical trials, market research, hospital administration, stockbroking and banking. Thus, by 1967 technology, knowledge and experience had advanced to a state where designing and constructing a low-cost interactive computer or a time-sharing system was very easy. As the technology advanced exponentially with Moore's law and costs declined it became easier and easier.

(*footnote continued*)

[8] A decade earlier the *ELBIT100* and *MINIC* were small enough in size and low enough in cost to be used as personal and home computers by a few individuals, but they did not have electronic displays, low-cost storage media, or widely applicable software such as word processors and spreadsheets. 'Personal computers' are essentially *systems* not just computers, configurations constituted by a constellation of innovations in low-cost microcomputers, peripherals, software, applications and opportunistic imagination.

autonomous mobile entities such as delivery drones, automobiles, trucks (Miller, 2015) and cyberwarriors (Allenby, 2018). By 2009 the number of such devices connected to the Internet surpassed the number of human users (Evans, 2011) and now greatly exceeds it.

1.2. Interactivity today — hyperconnectivity and malevolent users

When one examines our current world of interactivity some five decades later it is apparent that the initial visions of the potential of human–computer interaction have been largely realized. Interactive computing is now embedded in our everyday life and has become *taken for granted* (Ling, 2012) as an essential component of our modes of existence. We have long surpassed Wells's (1938) vision of a *world brain* with all the advantages that he foresaw, but have encountered negative side-effects that he did not expect.

The pressing current issues are ones that arise as byproducts of the *hyperconnectivity* (Quan-Haase and Wellman, 2006) that we have achieved. The pioneers focused on the individual and social good that could emerge but may not have adequately addressed the potential for harm in a world that has become highly dependent on *information utilities* (Parkhill, 1966) that connect everyone world-wide including a growing number of increasingly skilled *malevolent users*. Combating malevolent usage has now become *the* major problem and is far from resolution (van Bavel et al., 2019; Jansen and van Schaik, 2019; Williams et al., 2018).

Many of the current issues of security and privacy were already recognized 50 years ago. I attended a session with that title at the *Spring Joint Computer* conference in 1967. Dash et al.'s (1959) *Eavesdroppers*, an exposé of illegal and semi-legal wiretapping, was cited in the papers and their discussion, and Westin's (1967) influential analysis of the issues of legislating acceptable interception of communications was published shortly after the conference. There seemed to be widespread awareness of the potential for a *surveillance society*, but rather less of the potential for fraudulent exploitation. In addition, governments were seen as the primary instigators of surveillance, and the rise of what Zuboff (2018) has termed *surveillance capitalism* where commercial organizations track the lifestyles, political views, buying habits, and so on, of a high proportion of the population and use this for behavioural manipulation was not foreseen.

I recollect one particular recommendation by a speaker from NSA: "Every user should be subject to common discipline and authority. He shall know and understand the conventions which are required of him to support the security system" (Peters, 1967, p. 284). Our studies of human skills training indicated that this was not a realistic requirement if access to interactive computing became widespread. For example, flying an aircraft required meticulous attention to procedures, and we tested for this capability to qualify those wishing to learn to fly. However, the majority of the population failed such tests. Rather than "meticulous attention to procedures," a prevalent human behaviour is that of "muddling through" (Fortun and Bernstein, 1998). The technical recommendations in the 1967 NSA paper encompass much of what we are doing today to improve computer security, but one might want to replace the quoted human factors recommendation with a more realist objective based on Norman's (1990, 1999) notion of *affordances*: "Users should be supported by affordances that enable them to achieve their objectives in a secure manner".[9]

1.3. Our problématique — protecting legitimate users from malevolent ones

The problématique of our current era is how to continue to facilitate and enhance interaction in a hyperconnected world threatened by malevolent users, whilst recognizing that patterns of interactive usage are now so widespread and ingrained that changing our intended users' habits is probably not a viable solution, certainly not a complete one (Akhgar and Brewster, 2016; Ghosh and Turrini, 2010; Hartzog, 2018; Kshetri, 2010; Tropina and Callum, 2015). We cannot take a draconian approach that undermines *functionality, usability* or *likeability* (Shackel, 1991) to an extent that usage is no longer attractive. Malevolent users are a natural and unavoidable phenomenon of the dynamics of human society, and we need to understand their motivations, activities and skills if are to prevent the harm they intend or unwittingly cause — they are also users, albeit unwanted ones.

It is not only deliberately malevolent users who are a problem. Unintentionally malevolent ones can also be highly disruptive, not only as end-users but, even more problematically, as those who control system functionality in their roles as designers or maintainers. Our everyday dependency on computer services may create serious problems when someone who has control over them is careless or incompetent and makes an error that affects large numbers of users. For example, e-commerce or financial websites that we use routinely can become dysfunctional because someone has decided to 'improve them' without understanding how they are used, or carrying out adequate user evaluations. The digital ecosystem is fragile and easily damaged. In addition, ill-considered and ill-managed attempts to *go digital* and replace systems developed over a long period of time that operate effectively through skilled people may have disastrous consequences, as, for example, with the "incomprehensible failure" (Committee on Public Accounts, 2018) of an attempt to centralize and computerize the federal payroll system in Canada.

To understand these issues requires a conceptual framework going beyond current psychological and technological schemas developed for man-machine systems in the initial stages of human–computer interaction studies. The following sections provide a range of perspectives on the dynamics of civilization and the role of technology, none of which alone can provide definitive answers, but which together form a framework for understanding much of what is happening as we move towards a hyperconnected civilization. One major lesson of the history of innovation in knowledge and technology is the need to be defensive about possible adverse side-effects and prepared to react quickly to the unexpected — often through a positive feedback cycle of further innovations (Bijker et al., 1987; Tenner, 1996; Wojciechowski, 2001). In an era of rapid technological change, we have long learned the Red Queen's lesson that *it takes all the running you can do, to keep in the same place* (Carroll, 1871, Chapter 2).

2. From individual interaction to social hyperconnectivity

We now live in a world where computer and communication technology provides us with omnipresent capabilities to access human knowledge, communicate with one another, and perceive and interact with the world in new ways. The underlying technologies and their applications are rapidly developing and changing, yet some are assimilated so readily that we quickly *take them for granted* and find it difficult to understand how we lived without them (Ling, 2012).

The personal computer, laser printer, graphic displays, Internet, World Wide Web, cellular network, smart phone and voice-actuated world of things, have been radical innovations but so rapidly assimilated that they have become an integral part of our everyday life. We have become *hyperconnected* world-wide, to one another, to the world of intelligent devices, to the world of digitized knowledge, without really noticing how profoundly our modes of existence have changed and the extent of the unexpected risks that we are incurring.

Technologies that are so readily adopted satisfy significant human needs and offer massive commercial opportunities to those that provide the products that satisfy them. The innovators focus on the intended benefits of their products that will drive widespread adoption, but there are usually also opportunities for those who are parasitic on society to

[9] In retrospect, our early developments of prescriptive *dialogue rules* (Gaines and Facey, 1975; Gaines and Shaw, 1984) are all corollaries of the notion of an affordance.

exploit them for anti-social purposes such as *spam* (Brunton, 2013), *malware* (Erbschloe, 2005), *cybercrime* (McQuade, 2008; Owen et al., 2017) and *cyberwarfare* (Allenby, 2016; Carr, 2012). Such unintended adverse side-effects may significantly undermine the benefits of innovation (Khessina et al., 2018).

These phenomena raise issues for individuals, social groups, organizations, cultures, national governments and international agencies. What are the personal benefits and dangers of adopting a new technology? How might it improve the processes of an organization and what risks are involved? How might it support or undermine cultural norms? Are there global impacts that go beyond national borders? Can the interpretation of existing legislation be extended to cover the new technology, or are new laws required?

To even begin to understand such issues let alone answer such questions, we need some basis for understanding the new technologies in terms of their impact on individuals and society. For example, McLuhan's *tetrad* model of the impact of new media provides a generic framework for the analysis of all major socio-technical change, that something is *gained*, something *lost*, something that had been lost is *regained*, and the outcomes may *reverse* into something unexpected and possibly negative in terms of the original motivation for the innovation (McLuhan and Powers, 1989). These notions may be used to analyze the social impact of any significant technical or organizational change, and the value of doing so is generally in the process of trying to think in these terms rather than the product of having done so.

The rapidity of change in the technology and the difficulty of predicting in what ways it will develop and be used suggest the need to base any analysis on fundamental traits of individuals and society rather than short-term models of the impact of technology, taking into account that individuals and institutions are dynamic and some aspects of their natures will evolve with changes in the affordances of their environments (Dutton and Reisdorf, 2019; Montgomery, 2007; Shotter, 2013; Tapscott, 2009).

3. A hyperconnectivity revolution, a hyperconnectivity age?

It would be reasonable to apply the term 'hyperconnectivity revolution' to the world wide transition to a socio-technical milieu in which a very high proportion of the population uses communication and computer technology that provides continuous access to other people, media, knowledge, devices and a wealth of computer services. However, the term *revolution* itself indicates only that we are construing some phenomenon as triggering a major social change, and has probably become so over-used as to convey little meaning.[10] Much the same comments apply to the use of the notion that after significant change we live in a distinctive *age,* a modern age, an enlightened age, a post-industrial age, a computer age, an information age, a hyperconnected age. The term focuses attention on the historic situation of the socio-cultural phenomena we wish to highlight, but has no deep meaning. It also tends to obscure the ongoing dynamics of any era of significant social change, the critical phenomena that cause us to recognize in retrospect a different age and then extend its chronology back to its presumed origins.

Despite these caveats, the phenomena of hyperconnectivity may be seen as a significant stage in the evolution of what have been termed the *information age* and the *computer age*, and it is useful to analyze these in more detail to provide a context for the hyperconnectivity revolution/age.

3.1. The information age

The term *information age* has been widely used in the literature on information technologies and their social impact (Dizard, 1985; Hammer, 1976; Slack and Fejes, 1987). However, there is little consensus on what constitutes the information age and when it commenced. Alberts and Papp (1997) in the introduction to their wide ranging *Anthology of the Information Age* note that the term is commonly used for "concluding years of the twentieth century and the beginning of the twenty first," but themselves raise issues about the meaning and chronology of the 'age.' Castells (1996) in his monumental studies of the economic, social and cultural aspects of the information age dates it to the rise of a *network society* based on computer technologies. Some writers date it later to the invention of the transistor (Riordan and Hoddeson, 1997), whilst others date it earlier to 1800 and the spread of industrialization (Beniger, 1986), to 1700 and the dissemination and organization of the knowledge arising from of the scientific revolution (Headrick, 2000), or trace it through two and half millennia from the shift from oral to written communication through the development of printing to the growth of computer networks (Hobart and Schiffman, 1998). The chronology of such early dating is largely an artefact of the availability of archaeological data because our records of ancient civilizations are based on the remnants that happen to survive the destructive influences of their local environment. The highly active biological processes of Africa destroy evidence of human civilization very rapidly. The dry desert climate of the Middle East has preserved sufficient cuneiform inscribed clay tablets from Mesopotamia (Neugebauer et al., 1945; Nissen et al., 1993; Robson, 2008; Swerdlow, 1999) for us to recognize a numerate and literate intellectual culture predating that of the Greek enlightenment by more than a millennium (Bottéro et al., 2000). Such tablets record astronomical and financial records, forecasts of harvests, mathematical and geometrical constructions, military engineering and strategy, and a range of other information processes paralleling those for which we use computers today. Prior to Mesopotamian civilizations there are tantalizing glimpses of the information processes of previous ancient civilizations through artefacts such as bone carvings (d'Errico et al., 2003) and cave paintings (Lewis-Williams, 2002) that are relics of cultures many millennia ago that found it useful to record information for purposes that we do not yet understand and may never know. What we do know is that for most of our history, our evolution paralleled that of other animal species, but at some time in the past 100,000 years humans evolved to capture and communicate information symbolically to an extent that gradually came to differentiate us from other species. These analyses suggest that we should view the acquisition, recording, processing and communication of information as fundamental to, and characteristic of human civilization, and focus on the ways in which different advances in technology have supported these processes in different eras. In particular, there may be scope for modelling and understanding the social impact of new technology in terms of that of previous technologies, including experience from ancient civilizations that may appear very remote from our own. Our technologies have co-evolved with our species (Basalla, 1988) but at a far more rapid rate. In contrast, the human condition and human interests have changed very little over the millennia and it can be argued that their analysis provides a better foundation for technological forecasting and management of innovation than does the dynamics of the rapid evolution of the technologies themselves (Gaines, 2013; Gilfillan, 1937).[11]

[10] A search of my personal library produced over 200 books with the term *revolution* in their title, American, English, French, Russian, writing, printing, scientific, chemical, industrial, financial, telephone, electrical, quantum, microelectronic, computer, genetic, and so on. The common feature in the diverse literatures is the recognition of a significant socio-intellectual change, an analysis of the underlying rationale and a study of the consequences, some of which are consistent with that rationale but others of which go beyond it in unintended and unexpected, sometimes unfortunate, ways.

[11] The 1937 report to the President on *Technological Trends and National Policy* in which Gilfillan's study of the prediction of inventions occurs makes salutary reading today. It addresses issues of the social effect of inventions, resistances to

3.2. The computer age

The terms *computer age* and *digital age* are often used almost interchangeably with *information age,* but reference specific technologies subject to more precise analysis and dating. If we deconstruct the notion of a computer age, while we can recognize a continuous evolution of computational technology through the ages (Williams, 1985), the electronic stored-program digital computer of today was an innovation of the intensive computer development to support military needs in the 1940–45 war (Goldstine, 1972). It was assimilated post-war to the product ranges of companies that were already major suppliers of electro-mechanical computing equipment (Cortada, 1993), but this was the natural evolution of *business as usual* rather than significant social change. Similarly, the revival of interactive access through time-sharing in the 1960s changed the way in which computers were used and led to discussion of the human–computer symbiosis and augmentation of human reasoning, but initially affected only a few scientific research communities.

The development of the silicon planar process in 1959 and ensuing development of integrated circuits including, in 1971, a complete central processor on a chip, increased the reliability and decreased the cost of computers to the extent that in the mid-1970s personal computers became consumer items (Kidwell and Ceruzzi, 1994), and computer technology began to diffuse into everyday life. The parallel development of digital networking supported communication between remote computers and their users, the increasing use of chat, email, and access to remote information sources, and, in the 1990s, the growth of the World Wide Web.

By the beginning of the millennium most of the infrastructure of the digital world as we know it today was in place, and use of, and dependence upon, networked personal computers had diffused into all areas of life. E-banking (Solomon, 1997) was common and companies such as Amazon and eBay were already heavily engaged in e-commerce (Laudon and Traver, 2017). Google was still in start-up phase, beginning to address issues of navigating the rapidly increasing volume of information available through the web but had not yet implemented its revenue generation through targeted advertising. Social networking through blogging (Stone, 2004) was in its early stages but Facebook and Twitter and their impact on socio-political processes (Farrell, 2012) were still some years away.

So when did the *computer age* commence: in the late 1940s with the advent of the first stored-program electronic digital computers; in the mid 1970s with the advent of the early personal computers; in the mid 1990s when commercial use of the Internet became permitted and web traffic from many sectors of society began to dominate; in this millennium when smartphones and social media became ubiquitous? Or do we trace it back much earlier to Babylonian aids to accounting, Euclid's mechanical solutions to geometrical problems, the development of mechanical devices computing Ptolemy's model of the solar systems, Napier's development of his computational 'bones,' and so on?

What we see in practice is an evolutionary process of continual change in computing techniques with most innovations when tested in the market place failing to achieve widespread use, but a history that is biased to record the few successes that led to the widely used technologies today and gives a false impression of inexorable progress from breakthrough to breakthrough over the millennia.

(*footnote continued*)
their adoption, unemployment from increasing productivity, and so, in terms of the innovations of a pre-computer era. However, one can see that the considerations discussed are very similar to those of today, and reflect issues of the assimilation of innovation in society that have changed little over the millennia.

3.3. Convergent evolution of computer, communication and media technologies

Hyperconnectivity is situated in the recent evolution of the information and computer ages, and reflects a new phase of *convergence* (Gaines, 1998; Yoffie, 1997) between computer, communication and media technologies. Advances in semiconductor technology did not only facilitate the development of computers, but also promoted other uses of electronics technology to support social processes such as telecommunications and mass media.

The telephone pre-dates the digital computer by some seventy years and had significant social impact (de Sola Pool, 1977), but not, for example, as much as the railways; no-one coined the term ***a telephone** age* (Perry, 1977).[12] However, in the 1990s microelectronics made possible the development of cellular phone services where small personal telephones that could be carried at all times were used to offer any place, any time access to the world-wide telecommunications network (Singleton, 1989, p. 208). Electronic digital technology also supported improved access to, and quality of, mass media, and led to the convergence of processing, storage and presentation technologies for computer and media systems.

We are now in an era where computer, communication and media technologies have converged to the extent that distinctions between computers, telephones and televisions are ones of function rather than form. Multi-functional devices differing primarily in physical size are now used to support the wide range of different activities that previously required particular specialized technologies.

Hyperconnectivity is a significant byproduct of this convergence, but we cannot understand it solely in technological terms. It is the functionality that is important, the affordances it offers for a wide variety of human psychological and social processes, the way in which it restructures the processes of the lifeworld but, to a large extent, leaves its underlying dynamics intact (Floridi, 2015). It is only when we factor out the processes that have been fundamental to the human condition for all recorded time that we can perceive how they have been affected by their assimilation of new technology.

3.4. Expectations of change as hyperconnectivity evolved

The social impact of hyperconnectivity was not unexpected. As information technologies evolved, many speculated on how they change our existing practices and industries. For example, five decades ago whilst musing over the impact of early time-sharing systems I noted that:

> If fifty percent of the world's population are connected through terminals to one network, then the questions from one location may be answered not by access to an internal data-base but by routing them to users elsewhere — who better to answer a question on abstruse Chinese history than an abstruse Chinese historian (Gaines, 1970).

Some four decades years ago in a review of the impact of the 'revolutionary' new *Videotex* (Sigel, 1980) and *Viewdata* (Fedida and Malik, 1979) systems on the printing industry I noted that:

> At one extreme we can see current videotex electronic publishing

[12] In this age of ready access to the digital archives that resemble Borges' (1944) *Biblioteca de Babel* where every combination of words occurs, it is dangerous to state that a term has never been coined — the trade journal *Telegraph Age* founded in 1883 was renamed *Telegraph and Telephone Age* in 1909. It is also noteworthy that, while the term *railway age* is still in common usage (Hylton, 2007) the term *road age* is uncommon even though the development of roads had as much, or greater, social impact than that of railways (Hindley, 1972). There seems to be no consistent basis for the choice to mark a particular era with the term 'age.'

systems as poor simulations of books with limited characters per page, poor typography, restricted graphics, and high costs. At the other extreme we can see a future where computer and communication technology is advancing at such a rate that not just the printing and publishing industries but the very structure of society itself changes (Gaines, 1982).

Some three decades ago in an extensive review of multimedia technologies just prior to the commercialization of the web, I suggested:

> It is not unreasonable to compare what we see occurring on the net with the flowering of Greek culture in the Enlightenment and with that of European culture in the Renaissance. There is a new culture on the Internet which is no longer primarily technological but instead reflects a deep and unfolding relationship between human discourse and action, and its technological support. Widespread access to the Internet means also that the culture is not geographically located, and the nature of the human-computer interface also transcends many traditional divisions based on individual characteristics. It is by no means Utopian — the net reflects humanity and is being used in a wide variety of ways that reflect both the best and the worst of human traits (Gaines, 1994b).

The technologies described in these articles from a few decades ago appear extremely primitive and antiquated relative to those of today, but their continuing development has led to the social impact that was projected. We do now have worldwide access to the social support and expertise of others, to the accumulated record of human knowledge, and to instrumentation and control technology that provides remote access to events locally and worldwide.

In the wider literature, Martin's (1978) *Wired Society* comes closest to predicting many aspects and impacts of our hyperconnected world: "the technology of communications is changing in ways which will have impact on the entire fabric of society in both developed and developing nations." van Dijk's (2012) *Network Society* provides a comprehensive account of the socio-economic impact, and Castells's (1996) *Rise of the Network Society* and associated volumes situates the origins historically.

The transition to such hyperconnectivity is momentous and the resulting web of interconnected people and technologies may reasonably be classified with previous major advances in the connectivity of what McNeill and McNeill (2003) characterize historically as the evolving *human web* of the flow of goods, people and information. However, the technologies of the human web have always been neutral to the good or evil of what they carry, and the massive rise in cybercrime and cyberwarfare shows that our new technologies also support "the worst of human traits." Our optimistic views of the benefits of information technology, which are echoed in some current articles on hyperconnectivity (Fredette et al., 2012), may have led us to be inadequately defensive about its potential for abuse (Carré and Vidal, 2018).

3.5. Regulating a hyperconnected world

Winston (1998) has questioned any revolutionary impact of new media and characterized the 'information revolution' as hyperbole, noting that, "what is hyperbolised as a revolutionary train of events can be seen as a far more evolutionary and less transforming process" (p. 1). In his analysis of the social impact of media evolution he proposes a "law of the suppression of radical potential wherein general social constraints coalesce to limit the potential of the device radically to disrupt pre-existing social formations" (p. 11), and provides detailed evidence of the phenomenon.

The adverse impacts of hyperconnectivity that have become a major concern today may be seen to arise from: the development of the technology by coders having an anti-authoritarian ethos of openness and trust (Thompson, 2019)[13] who may not have taken adequate account of adversarial ethos of many of humanity's social systems; the speed at which the new technology *went viral* in its widespread adoption; a late realization of how malevolent users might take advantage of the affordances of a hyperconnected world; a failure of existing legislation to provide a means for regulative suppression of unacceptable usage.

The social (e Silva, 2018), legal (Zarsky, 2014) and technological (Pelton and Singh, 2019) measures being taken to control the flow of information in a hyperconnected world represent a delayed attempt at the suppression of what is regarded as anti-social usage. It is not only authoritarian governments who wish to regulate communication through social media but also democratic ones who see some activities as contravening social norms of *privacy*, legitimate forms of *free speech*, protection of *property rights*, and so on. However, it is very difficult to craft appropriate regulations that do not themselves contravene social norms and even more difficult to enforce them given the lack of international consensus on such norms (Allenby, 2019; Wu, 2015).

There are many detailed models of human behaviour that are relevant to understanding the dynamics of individual and societal change. For example, Piaget's (1975) *équilibration* theory of *accomodation* and *assimilation* in human learning provides a psycho-social model of the phenomena that Winston describes, and may be used to study the incorporation of new technologies into the processes of the life-world that may radically change the way in which those processes are supported without necessarily significantly modifying the underlying human conditions that motivate those processes.

The following sections discuss how other fundamental perspectives on the human condition and the dynamics of the lifeworld may be used to provide a framework for understanding the way in which new technologies evolve and are assimilated into society.

4. Perspectives on technology and the human condition

The human species has in common with other species its biological origins as living creatures with a limited life span whose survival requires an environment providing food, air, warmth and shelter. Obtaining resources for survival is the primary driver of human activity as it is for other animal species. Many species have developed collaborative social structures that are more efficient at jointly addressing basic needs than is possible for an individual or family group (Hoffecker, 2013; Lewisa et al., 2013). The human species has taken this strategy much further than any other species through the development of symbolic communication and elaborate social structures (Searle, 1998). Hyperconnectivity may be seen as technological support for these human strategies, and its socio-economic impact and issues can best be understood in terms of the basic needs and processes that lead to, and are supported by, sociality and language. Evolutionary biology has made major advances in recent years, many of which have been critically dependent on parallel advances in information technology that have provided powerful new tools for all the sciences. The following sections provide biological, psychological, cultural and social perspectives on the human condition that are relevant to understand the role and impact of hyperconnectivity.

4.1. Systemic perspectives on evolution

Ayres (1994), a well-respected technological forecaster, wrote a remarkable book, *Information, Entropy and Progress: A New Evolutionary Paradigm*, that provides a coherent systemic model of physical, geological, biological, social, cultural, psychological and economic

[13] Thompson's (2019) anecdotal account of the personae and evolution of the *coding* community provides valuable insights into the experiences and value systems of those responsible for the technologies that have led to hyperconnectivity.

evolution, and, for example, models automobile manufacturing as an information process that creates a vehicle by imposing information on matter. He traces the growth of the human lifeworld back to the 'big bang' and presents it as part of a continuous evolutionary process of structure formation in the physical universe. Cybernetic/systemic models of such broad scope are fascinating and inspiring but perhaps too general to have a direct impact on any of the diverse disciplines they encompass. However, in the past twenty years advances in molecular biology have made DNA sequencing technologies available to archaeologists and anthropologists, and enabled information-flow models to be used to expose not just the systemic commonalities but also the mutual constraints coupling genetic, cultural and behavioural processes in living systems. Oyama's (1985) *Ontogeny of Information* was the first such analysis to become widely influential through the developmental systems theory community. Jablonka and Lamb's (2005) *Evolution in Four Dimensions* provides a unified model of the transmission of variation between living systems encompassing genetic, epigenetic and behavioural sub-systems and their interactions. The *extended synthesis* (Pigliucci and Müller, 2010) provided by these unified models provides a detailed account of how:

- genomes adapt to the environment through random mutation, encoding and propagating information that may enhance the fitness of future generations (Altenberg, 1995);
- epigenetic processes manage the expression of particular capabilities encoded in the 'genome library' to more rapidly propagate adaptations to major environmental change (Harper, 2005);
- behavioural adaptations are propagated through reinforcement and mimicry, both intrinsically and through pedagogy (Thornton and Raihani, 2010));
- symbolic representations of the information involved in all these processes may be used to facilitate them, amplify their effect, and enable them to be widely diffused through both space and time (Noble and Davidson, 1996).

The study of epigenetic processes is relatively recent and represents the recognition of biochemical mechanisms underlying Lamarckian transmission of adaptations effected during a parenting organism's lifetime (Gissis and Jablonka, 2011). The communication of information between all levels and partitions of living systems provides a common framework for biological symbiosis, psychological foundations of socio-cultural systems and, through the symbolic signalling system of money (Ganßmann, 1988; Singh, 2001), for economic models of those systems. Hyperconnectivity represents the current state of the art of technological support for the diverse communication processes involved.

4.2. Evolution of the human species

Our species, *homo sapiens sapiens*, diverged from *homo erectus* some 500,000 years ago, from *homo sapiens neanderthalis* some 300,000 years ago, developed some form of language some 50,000 years ago, was reduced by environmental catastrophe to a population of some 3000 in Africa some 50,000 years ago, expanded worldwide through migration commencing in the Levant, and developed agriculture and social infrastructures some 10,000 years ago, commencing the Neolithic era of modern humanity. The details are contested in a massive research literature, but the overall framework is widely accepted (Endicott et al., 2010; Liu et al., 2006; McBrearty and Brooks, 2000; Stringer, 2002). For most of our history, genetic, epigenetic and behavioural processes dominated our evolution as they do in other animal species, but at some time in the past 100,000 years information came to be communicated and captured symbolically to an extent that gradually came to differentiate us from other species. The capability to capture and transmit the knowledge created by individuals and communities is generally taken in the archaeological and anthropological literatures to be the major factor in the explosion of the human population:

> humans became behaviourally modern when they could reliably transmit accumulated informational capital to the next generation, and transmit it with sufficient precision for innovations to be preserved and accumulated (Sterelny, 2011, p. 809).

The modern civilizations of our Neolithic era have been constituted through the co-evolution of social infrastructures, symbolic communication capabilities and knowledge recording technologies (Hatfield and Pittman, 2013).

One long-standing puzzle about the evolution of social structures is that they often involve altruistic behaviour in which an individual acts in a way beneficial to the survival of a community but adverse to its own survival (Fehr and Fischbacher, 2004; Rand and Nowak, 2013; West et al., 2011). There are now a number of theories within an evolutionary framework that model the evolution of cooperation and altruism (Sterelny et al., 2013; Wilson, 2012; Young, 2015) including the development of the associated emotions of shame and guilt, social mechanisms to penalize free-loaders, and the moral and ethical rationalizations of these phenomena that emerge socially (Bowles and Gintis, 2011; Boyd and Richerson, 2009). The significance of this research for studies of hyperconnectivity is that they provide detailed models of how the norms of self-serving behaviour predicted by a simple evolutionary model become modified to those of socially acceptable behaviours. Those steeped in the associated cultures generally take this modification for granted and develop systems based on this assumption which may be inadequately defensive to those, even within their society, who do not. Hyperconnectivity can exacerbate this problem by providing ready access to a society from those of other cultures where social norms may be very different. The literature on the evolution of social norms provides a wide ranging and balanced account of the variety of phenomena that may be expected, and a foundation for developing systems that are both socially acceptable and also robust against a wide range of contingencies. In particular, since *social engineering* (Hatfield, 2018) targeted on developing unwarranted trust is a major factor in cybercrime, research on the dynamics of trust formation is significant to understanding and addressing the problem (Bachmann and Zaheer, 2006; 2013; Kramer, 2009; Lyon et al., 2016).

4.3. Technology, knowledge, communications and population growth

Human population growth does not show a smooth progression over recorded history. There have been major die-offs due to climatic factors such as the ice ages, and diseases such as the *Black Death* (McNeill, 1989), but the overall trend has been hyper-exponential. Whereas the rate of unconstrained population growth in other species is proportional to the population size, and hence exponential, for the human species it is proportional to the square of the population, and hence hyper-exponential — until the 1960s when the population growth rate dramatically declined (Korotayev, 2005). The additional multiplier is attributed to the generation and communication of technology/knowledge being proportional to the size of the population (Korotayev, 2005). In the Neolithic era there have been trends encouraging the generation and diffusion of technology/knowledge, such as the development of communities around population centres, which also increase the risk to life[14], for example, by facilitating the development and spread of disease (Cantor, 2001; McNeill, 1989) requiring the further development of technology/knowledge (Wojciechowski, 2001). Thus, there are several interacting positive

[14] In our era the environmental side-effects of excessive population growth and world wide industrialization pose the greatest risks to the survival of human civilization where "the classic signs of impending collapse are everywhere" (Ehrlich and Ehrlich, 2013; Tainter, 1988)

feedback loops involved in any model of the co-evolution of civilization, technology and population. The communication of knowledge occurs through a heterogeneous and chaotic range of processes, including its appropriation through warfare. Gunpowder and firearms technology from China was disseminated to other countries through the Mongol conquests of the thirteenth century (Andrade, 2016), and the consequent studies of chemistry and metallurgy played a significant role in the industrial revolution (Kelly, 2004). The Arab conquest of Egypt and Syria in the seventh century provided access to Greek literature, and later Arab leaders collected Greek and Indian works systematically. The Arab conquest of Spain in the eighth century gave that country access to this literature and it became a centre for its translation into Latin and dissemination throughout Europe. The crusades accelerated this process by bringing the Arab conquests under European rule and treating the material in Arab libraries as spoils of war that provided the intellectual foundations for the Renaissance and the formation of the first universities. Throughout recorded history there have been attempts to encourage and manage the communication of knowledge more peaceably, for example, through the recruitment of knowledgeable personnel from other civilizations, scholars visiting other communities, the exchange of copies of books between monastic and other libraries, the development of personal and national libraries, the development of centres of learning and teaching, and so on. The earliest records of social systems being set up to manage the communication of knowledge are those of Mesopotamia some 5000 years ago where postal systems were established to facilitate communications between the centre and outposts of the various empires (Casson, 1994, Chapter 13). Subsequent civilizations have each found the need for similar systems, and the resultant *correspondence networks* have played a major role in the management of commerce (Jardine, 1996, p. 111) and the dissemination of knowledge (Gingras, 2010; Hatch, 1998). One significant extension was the development of scholarly journals as a means of open correspondence that traded the public recognition of those creating valuable knowledge for its dissemination to the world at large (Csiszar, 2018; Meadows, 1974; Vickery, 2000). Technology began to play a major role in the storage and communication of knowledge in the earliest times as materials were developed to provide lasting records of symbolic representations of language (Poe, 2011; Woods et al., 2010). Mass-communication became possible with the invention of the printing press and moveable type that enabled large numbers of copies of printed material to be produced at a relatively low cost (Eisenstein, 1979). Technological support for real-time communication commenced with the development of electrical equipment in the eighteenth century and the telegraph system in the nineteenth century (Fahie, 1884).[15] The breakdown in the long-standing relation between population and knowledge growth some fifty years ago raises interesting issues. Some technologies have led to significant social change by substantially increasing the productivity of human labour, for example the mechanization of agriculture greatly reduced the proportion of the population required to sustain food production, and the robotization of manufacturing industry is having a similar effect on the proportion required to manufacture products. Hyperconnectivity is playing this role in increasing the productivity of the service industries (Fredette et al., 2012; Quan-Haase and Wellman, 2006).[16]

5. Frameworks for modelling hyperconnectivity

The preceding sections have situated hyperconnectivity in the broad sweep of human and information technology evolution and their interplay. This section focuses on some specific frameworks within that broader context that are useful to modelling different aspects of hyperconnectivity and its social impact.

5.1. The evolution of information technology

The sustained exponential growth of the number of devices on an integrated circuit chip (Mollick, 2006; Rupp and Selberherr, 2011) may be seen as the primary technological driver of convergence to low-cost, high-performance hyperconnectivity (Gaines, 1998). Exponential growth is common in many technologies, but never before by more than two orders of magnitude and then over timescales of the order of one hundred years rather than ten. Chip technology exhibits a doubling of capacity and a more than doubling of performance every two years, sustained over some fifty years, leading to the more than 10^{10} devices on a chip today. This rapid sustained quantitative growth over five decades has triggered qualitative structural changes in the nature of the information sciences and their applications. There is a simple phenomenological model of the evolution of technology as a logistic learning curve of knowledge acquisition (Marchetti, 1980). The logistic curve has been found to characterize the introduction of new knowledge, technology or product in which growth takes off slowly, begins to climb rapidly and then slows down as the innovation becomes mature and further improvement difficult and expensive. Such curves arise in many different disciplines such as education, ecology, economics, marketing and technological forecasting (Dujin, 1983; Stoneman, 1983). It has also been noted in many disciplines that the qualitative phenomena during the growth of the logistic curve vary from stage to stage (Crane, 1972; De Mey, 1982; Gaines and Shaw, 1986). Fig. 1 shows the latest version of a model of the tiered learning curves of information technologies originally developed to situate human-computer interaction in the evolution of computer systems (Gaines, 1984; Gaines and Shaw, 1986) and extended through the years to model and project the evolving infrastructure of information technology (Gaines, 1991, 1998, 2013).

The underlying learning curve for each tier may be characterized by six phases:

1. the era before the learning curve takes off, when too little is known for planned progress, is that of the inventor having very little chance of success but continuing to experiment based on intuition and faith;
2. sooner or later some inventor makes a breakthrough and very rapidly his or her work is replicated at research institutions worldwide;
3. experience gained in this way leads to empirical design rules with little foundation except previous successes and failures;
4. as enough empirical experience is gained it becomes possible to inductively model the basis of success and failure and develop theories (this transition from empiricism to theory corresponds to the maximum slope of the underlying logistic learning curve);
5. theoretical models make it possible to automate the scientific data gathering and analysis and associated manufacturing processes;

[15] The telegraph system has been termed the *Victorian Internet* (Standage, 1998) and the history of some aspects of its usage is illuminating in terms of similar aspects of hyperconnectivity. For example when we read of marriages contracted by remote parties through Skype we might note that they were also conducted more than a century ago through the telegraph system, and that the prevention of fraud through telegraphy was a major issue, as was the use of encryption to ensure secrecy — people have long-standing motivations and strategies, and repurpose new technologies to facilitate them.

[16] Quan-Haase and Wellman's original study of the role of hyperconnectivity in supporting internal coordination in a software engineering company

(*footnote continued*)
provides an example of improving productivity in an industry notorious for projects being over-time and over-budget. It would be useful to have similar studies of the wide diversity of hyperconnected communities (Ganascia, 2015), for example, those responsible for major scientific projects such as the human and neanderthal genome sequencing and the Higgs boson search, those that form to support activities such as disaster relief, those supporting less desirable activities, and so on.

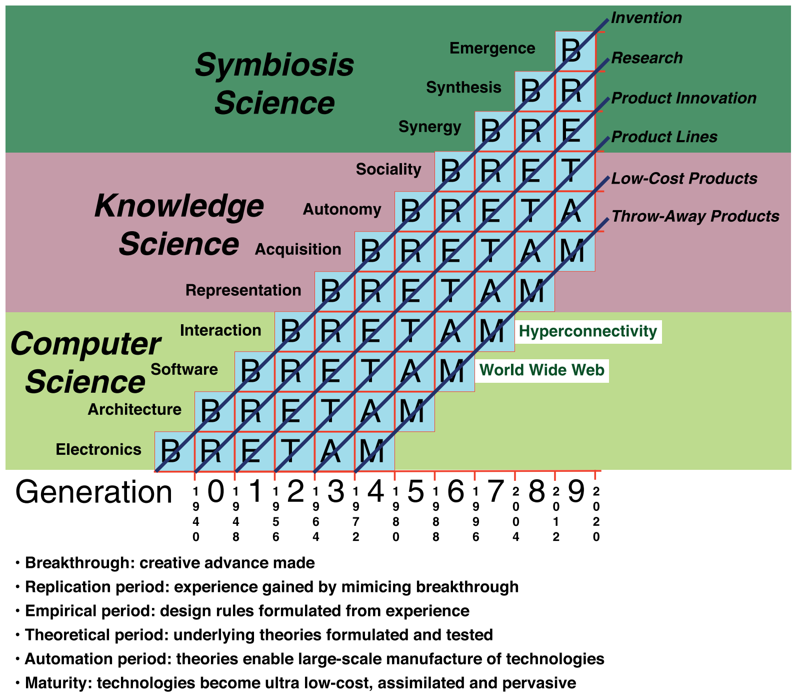

Fig. 1. The infrastructure of information technology—a hierarchy of learning curves of qualitatively distinct technologies, each of which depends on, and supports, those below and above it, and has characterized the evolution of different generations of information systems.

6. once automation has been put in place effort can focus on cost reduction and quality improvements in what has become a mature technology.

The tiers above the lowest level of electronics device technology have developed because the ultra-rapid growth in performance of the underlying technology facilitates applications that are so different in nature as to require new intellectual disciplines, each having its own learning curve. Eleven tiers have been identified to date:

- the underlying digital electronics;
- its application in computer architectures;
- programming of general-purpose computers through software;
- development of computer-people and computer-computer interactivity;
- digital representation of human knowledge;
- acquisition of knowledge from the world, people and stored knowledge;
- development of goal-directed autonomous knowledge creating processes, as virtual agents on digital networks and as mobile agents in the physical environment;
- increasing coupling of all forms of autonomous knowledge processing agents in social networks;
- supporting and enhancing the synergy between human and other agents;
- synthesis of all forms of agent into novel kinds of unified system architectures;
- emergence of a new hybrid living entity from the unification (Kurzweil, 2005; Martin, 2000).

One may characterize the lowest four tiers as constituting *computer science*; the next four as *knowledge science* (Gaines, 1986, 2000); and project those above to constitute a currently developing *symbiosis science* (Bradshaw, 2013; Gaines, 2013; Gruber, 2013; Shadbolt, 2013). There is strong positive feedback between the levels. Advances in the tiers below support increased performance in the tiers above, and innovations in the tiers above support improved processes in the tiers below — computers are used in computer-aided design of electronic devices, networked communities collaborate in the design of software and the sharing of knowledge, and so on. Empirically, from an analysis of the history of the computing and the information sciences, one may identify the time-scale of each phase, each computer generation, as some eight years. After the initial phase of *invention*, research is associated with the *replication* phase, product innovation with the *empirical* phase, product lines with the *theory* phase, low-cost products with the *automation* phase, and ultra-low cost, throw-away products with the *maturity* phase. This generates the diagonal trajectories shown where each tier of the hierarchy has its own research, development and product cycle. The *throw-away* product trajectory is particularly interesting because it corresponds to technologies becoming so low in cost that they are essentially free, either literally so, or consumables purchased routinely with little budget impact. Web browsers have long been freeware as has access to much information through the Internet. Even major hardware items with significant manufacturing costs can follow this trajectory, for example, computers, displays, printers and cell phones.[17]

5.1.1. Hyperconnectivity in the infrastructure of information technology

From a technological perspective hyperconnectivity is the extension

[17] Whilst making a powerful technology available at virtually zero cost appears intrinsically good, it can create major problems, similar to those of the *tragedy of the commons* where the low-cost availability of a resource leads to its abuse by some that substantially diminishes its value to others, a *social dilemma* (Weber et al., 2004). For example, the declining cost of telephone use has led to a massive increase in fraudulent calls that makes recognizing legitimate calls a major problem. The management of email *spam* has become a major industry in response to its fraudulent use becoming an attractive source of revenue in developing countries (Brunton, 2013; Burrell, 2012). Amazon providing free on-demand publishing and marketing offers author ease of self-publication with high royalty rates and seems a public good, as does publishers making available PDF versions of books, and software companies offering PDF editing tools. However, together, these innovations have led to a new industry of plagiarized publications with Amazon sometimes listing several variants of the same book under different authors, only one of which corresponds to the copyright owner.

of the maturity phase of the *interaction tier* where the ultra low costs of communication between people, between computers, between devices, and between all combinations of the three, has made such connectivity pervasive. From a technological forecasting perspective, what we may expect is increasing effectiveness in such connectivity where interfaces that we currently take for granted are further improved or discarded in favour of more effective ones. In order to attempt to plan or forecast future developments one needs to go back to basics and examine what is being communicated and what is the most natural and effective way of doing so. For example, at the lower levels of the technology supporting hyperconnectivity, keyboards are a relic of bygone mechanical typewriting technologies that have become an impediment to the communication of ideas. Speech provides a faster, more natural mode of input but requires improved transcription to text for storage, indexing and retrieval. In the long-term brain instrumentation may provide direct access to the ideas that generated the speech (Cochrane, 2012), but there will probably be a tortuous path of innovations *en route* (Hassanien and Azar, 2015; Peng, 2019). Similarly, displays are a form of electronic paper on which computers provide a visual image that would be more portably accessed through digital spectacles but will eventually be replaced by direct input to the optic nerve or brain (Ghezzi et al., 2011). The driving force for such technological change will be the human desire to remain connected to all relevant people, media and systems at all times in all situations, that is, to be fully and effectively hyperconnected. Continuing innovation at the levels above interaction is essential to the further development of hyperconnectivity. For example, speech recognition and natural language translation are critically dependent on advances in the knowledge level technologies. Hyperconnectivity is itself an important component of emergent brain-computer symbiosis technologies (Schalk, 2008) where new organizational structures are emerging based on the close integration of human and computer capabilities to an extent that may herald a singularity in the evolution of human civilizations (Kurzweil, 2005).

5.2. Technology and the human condition

As already noted, the technology to support human needs has evolved very rapidly, particularly since the scientific revolution and in the information age, but the fundamental needs themselves have changed little over the millennia. One can better understand the social impact of new technology by focusing on the needs that the technology might address, and forecast the likely future development of the technology by considering how it might better satisfy those needs. A useful perspective from which to analyze the impact of technology on the human condition is that of Maslow's (1971) *hierarchy of human needs* which provides a pragmatic, systemic classification of the dynamics of human motivations and priorities. The logic of his hierarchy is that upper level needs are of low priority until lower level ones are satisfied. We need to satisfy basic biological needs for sustenance, warmth and shelter before we are concerned with safety needs for protection from environmental hazards, and predators, and only when we are safe are we concerned with social needs such as belonging, esteem and realization of our own potentials. Too rigid an interpretation of the hierarchical relations is subject to debate (Lederer et al., 1980) but the structure provides a useful basis for classification of human needs and the social, and technological, infrastructures that support them. Fig. 2 is the most recent variation of a model developed to analyze issues of *trust in technology* (Gaines, 1987). The first two columns show Maslow's hierarchy of needs together with those social systems that have evolved to support the satisfaction of those needs. The next two columns show the beneficial and adverse impacts of technology on these processes.

5.2.1. Hyperconnectivity in the hierarchy of human needs

Hyperconnectivity is a significant component of information technology at all levels of Maslow's hierarchy, providing the same technical

Needs hierarchy	Socio-economic infrastructure supporting needs	Beneficial impact of technology	Adverse impact of technology
Transcendence	Moving beyond and subsuming mental, cultural, social and physical *realities*	Increased access to a variety of cultures & experience	Destruction of non-technological cultures
Self-actualization	Realizing personal potential; facing life as it is; aesthetics; peak experiences	Increasing availability of time for personal development	Alienation from a de-humanized society
Esteem	Role in family, work and community; other recognized achievements	Extension of individual capabilities	Deskilling of respected job roles & achievements
Belonging	Family, work, religion, politics, entertainment, communities	Tele- & physical communications, mass media, hyperconnectivity	Undermining family structure, job displacement, cyberfraud
Safety	Social norms; police, military, medical, insurance	Tele- & physical communications, arms control, robots in risk jobs	Tecnology disasters, biotech accidents, cybercrime, cyberwarfare
Biological needs	Agriculture, energy, housing, ecology, finance, physical communications	Automation, higher productivity, clean processes & energy production	Over-population, pollution, environmental destruction

Fig. 2. The role of technology in Maslow's hierarchy of human needs.

functionality but having qualitatively varying social impacts as it addresses different forms of need. For example, the two lowest levels in Fig. 2 involve primarily connection to the *Internet of Things* (Floerkemeier et al., 2008; Uckelmann et al., 2011). Hyperconnectivity supports engagement with, and management of, the physical world, such as domestic appliances (Brown et al., 2013), remote access to security cameras, empowering the disabled (Domingo, 2012), healthcare (Turcu and Turcu, 2013), safety monitoring in mines (Niu et al., 2012), autonomous vehicles (Miller, 2015), cyberwarfare (Carr, 2012), and so on. The middle two levels involve primarily the needs to belong to social groups and to build social capital. Hyperconnectivity supports these through a range of social media involving self-disclosure (Chen, 2012), grooming and gossip (Tufekci, 2008), scholarly discussion (Veletsianos, 2012), customer support (Gallaugher, 2010), marketing (Orsburn, 2012), and so on. The top two levels involve the needs to realize one's full individual potential and to go beyond that to comprehend, and transcend the bounds of the cultures that have both supported and constrained one's lifeworld. Hyperconnectivity supports these by providing access to other cultures including mediated experience of their functioning, access to tools that support participation in creative communities world wide, and so on (Floridi, 2015).

5.2.2. Strategies for satisfying needs — finding, producing, trading, stealing

Maslow's hierarchy provides a useful framework for analyzing human needs but not a model of the dynamics of the means by which people and societies attempt to fulfil them. A socio-economic perspective on the general strategies adopted to satisfy human needs is provided in Snooks' (1996; 1998) monumental series of books on the *laws of history*. He identifies the major strategies through which societies acquire resources as *family multiplication, technological change, commerce* and *conquest*. He uses this framework to model of the cycles of strategies adopted in the development of ancient and modern civilizations and enables one to trace through the ages the social, communication and knowledge processes involved that support farming, manufacture, commerce, warfare, crime, medicine, technology and science.

The underlying conceptual dimensions of Snooks analysis have been recognized from the earliest times, for example, they form the top level distinctions in Plato's analysis of expertise in the *Sophist* as *production* or *acquisition*, and his further division of the latter as *mutually willing exchange* or *by taking possession* (Plato, 1997, 219a4–d7). Snooks detailed historical models have been criticized (Sanderson, 2001) but his abstract conceptual framework that resources may be acquired to satisfy basic needs by *finding them, producing* them, *trading* them, or *stealing* them provides a systemic model that is very useful in the analysis of social dynamics, including those of hyperconnectivity in cyberspace.

Snook's treatment of warfare as a well-established strategy for resource acquisition is echoed in Allenby's (2016, 2019) analyses of cyberwarfare that model it as an a natural evolution of conventional warfare to take advantage of the new affordances for espionage and disruption that have become available in our hyperconnected era. Cyberspace has become a major battlefield for the continuing friction between major nations using their information technology resources to achieve their political objectives at a lower cost than through conventional warfare.

5.3. Technology and the worlds of human experience

Maslow's hierarchy focuses on the basic needs that motivate human action rather than the means by which they are addressed. A general framework for analyzing the roles of technological, social and knowledge resources as systems that have evolved to satisfy human needs is provided by Popper's (1974) ontology of conceptual worlds:

- **World 1**: the physical universe;
- **World 2**: the cognitive and communication processes of individual and organizational agents;
- **World 3**: the knowledge created as a byproduct of World 2 processes and captured symbolically to exist independently of its originators.

Maslow's hierarchy may be viewed as an ontology of *needs* crossing Popper's ontology of *worlds*.

In the early years of computers, Popper's notion of World 3 was used to model our expectations of the digitization of human knowledge to make it more actively available, of what became the current World Wide Web of documents, journals, books, audio and video recordings, datasets, and so on (Gaines, 1978). The ontology has also proved valuable in modelling person-computer interaction (Gaines, 1988) and organizational knowledge processes (Gaines, 2003). Nowadays hyperconnectivity technologies are also supporting the human communication processes of World 2, and mediated interaction with World 1.

Fig. 3 shows an extension of Popper's three worlds model to model the ontological structure of human experience which was originally developed to explain aspects of organizational knowledge processes (Gaines, 2003). It illustrates how human activities are unified across conceptual worlds, and adds an explicit *World 4*[18] to capture the tacit assumptions presupposed in our models of each of the other worlds. Recognition of the existence of such presuppositions is important, that our world models are intrinsically biased and incomplete, and that any conclusions we draw from them involve assumptions of which we may be unaware and which others may not share.

The central region presents a three-layer model of human agents and their supporting infrastructures, whether roles, people, groups, organizations or societies. At the bottom are the subconscious processes of interaction with the environment, of percepts, acts, reflexes, sensation, transducers, and so on. At the top are the symbolic processes of reason, of rationality, reflection, planning and so on. In the middle are the tacit processes of *practice* (Wenger, 1998), of *culture* (Hall, 1959), *habitus* (Bourdieu, 1990) and *field* (Searle, 1998) characterizing mental and social, action, mimicry, reward and punishment.

[18] World 4 might be envisioned as the slow-to-change, tacit foundations of World 3.

5.3.1. Hyperconnectivity across worlds

There is not only a convergence of technologies leading to hyperconnectivity but also a convergence of the domains to which we are hyperconnected. This is important because needs at one level may be supported by activities at another. For example the satisfaction of basic biological needs may be substantially enhanced by innovation in theories, and the development of those theories may be substantially enhanced through the development of new transducers providing better quality data.

We can factor hyperconnectivity as supporting:

- *intra-world communication in World 1*, for example, the integrated robotic production line of closely coupled machines, city-wide integrated traffic control systems;
- *intra-world communication in World 2*, for example, the networked organization, whether it be commercial, governmental, military, terrorist, political or hobbyist;
- *intra-world communication in World 3*, for example, the Google search engine (Langville and Meyer, 2006), the IBM *Watson* question answerer (Ferrucci et al., 2010); grid computing for bioinformatics (Talbi and Zomaya, 2008) and the SETI network (Shuch, 2011);
- *inter-world communication*, for example, between World 3 and World 1 such as automated data collection and event detection in the Hubble telescope and Higgs Boson projects, or between World 2 and World 1 when one checks an array of traffic webcams to see if there are problems along routes one might take, or between World 2 and World 3 when one initiates a bot search of digital libraries for a particular configuration of ideas;
- *unified-world communication*, where in future one will distinguish between the worlds less and less as one becomes more and more a part of hyperconnected networks of things, people and knowledge, playing a variety of roles in different cultures and activities.

By their very nature the tacit presuppositions of World 4 present obvious problems of analysis and support. However, *crowdsourcing* (Howe, 2008) multiple perspectives from different cultures provides resources for tracing conflicts in assertions to possible differences in underlying assumptions that are not explicit and of which the originators may be unaware. As Derrida (1988) has emphasized, one can never break out of the box of all presuppositions but hyperconnectivity to many sources and cultures may make it easier to move from one box to another and develop new perspectives that may suggest innovative solutions to otherwise intractable problems.

Hyperconnectivity binds Popper's diverse conceptual worlds together in a way that has never previously been possible. It facilitates the emergence of a unified world of the virtual and the real, of agents and artefacts, where many of the distinctions we have made in the past are no longer appropriate and new ones need to be made.

5.3.2. Dynamics of the ecology of knowledge

Wojciechowski (2001) models the dynamics of the growth of knowledge in World 3 and its interactions with Worlds 1 and 2 as an *ecology of knowledge.* He emphasize the positive feedback process whereby more knowledge must be created to combat the adverse side-effects of the application of prior knowledge, and develops twenty-five *laws of knowledge*, for example:

- **Law 1**: The number and variety of causes of stress are proportional to the amount of knowledge;
- **Law 2**: The perception of the complexity of the consequences of knowledge is proportional to the development of knowledge;
- **Law 6**: Humans' ability to determine the development of humanity is proportional to their knowledge;
- **Law 10**: The need for communication is proportional to the size of a society, the number of groups within the society, and the amount of knowledge available;

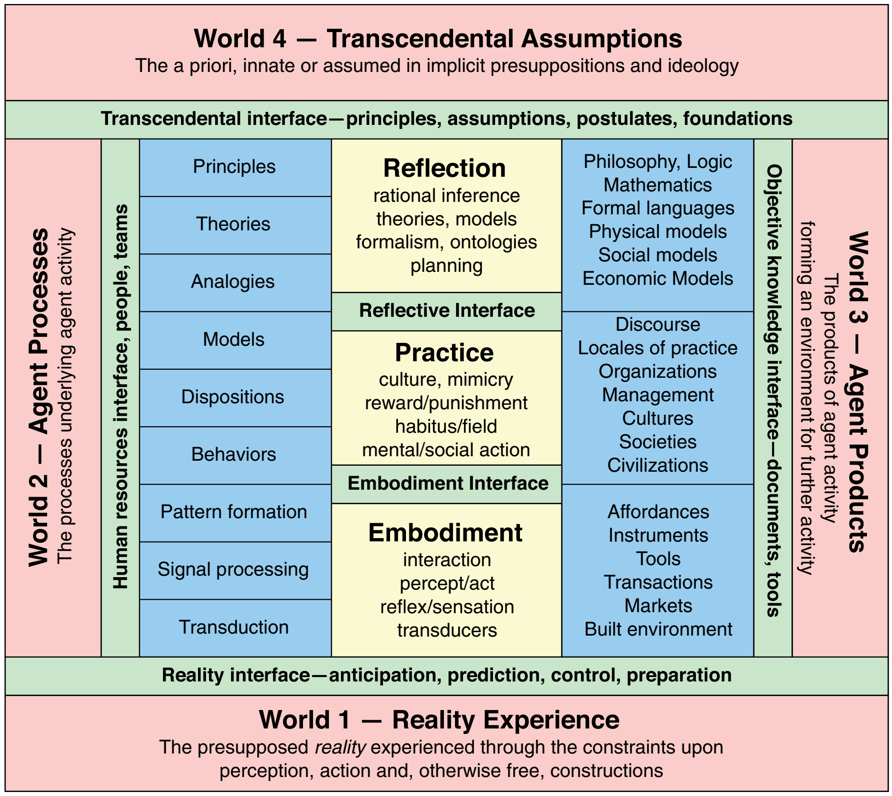

Fig. 3. The ontological structure of the worlds of human experience—a hierarchy of agent processes and products in Popper's Worlds 2 and 3, predicting and controlling experience in World 1, and dependent on tacit assumptions in World 4.

- **Law 19**: The development of a society is proportional to its storage and use of information;
- **Law 25**: The capacity to do good or evil is proportional to knowledge.

Such considerations suggest that the evolution of human capabilities leading to the growth of knowledge is not intrinsically a 'survival trait.' Bickerton (1990) notes that one possible outcome of the power of intelligence is species destruction. Wojciechowski's overall message is that knowledge is produced for its benefits but often has negative side-effects whose management requires the development of further knowledge — another positive feedback loop, and one that is dominant now in the search for solutions to the problems of cybercrime.

5.3.3. *A collective stance to human agents and their technologies*

The recognition that human agents, whether individual, organizational or societal, may, in many respects, be modelled in the same way suggests that we:

> adopt a *collective stance* to humanity and see it as a single organism, a neural network that is distributed in time and space by recursive partitioning into parts similar to the whole. The parts into which the human organism is recursively partitioned include societies, organizations, groups, individuals, roles, and neurological functions. Many concepts that apply to individuals may be applied to social systems without recourse to metaphor or analogy for systemically they are the same (Gaines, 1994a, p. 45).

This approach to modelling collectivities is now well developed in a variety of literatures and disciplines, such as the evolution of cooperation towards a *global brain* (Bloom, 2000), a *superorganism* (Kesebir, 2012), a *collective intelligence* (Lévy, 1997), and so on. The collective intelligence model has also been applied in the management literature to the improvement of team performance (Fisher and Fisher, 1998), and the Quan-Haase and Wellman (2006) study provides empirical data on the role of hyperconnectivity in supporting collective intelligence.

Licklider's (1960) provocative metaphor of *human-computer symbiosis* may be formalized and extended within this framework by abstracting (mutualistic) symbiosis to be a "mutually beneficial relation between autonomous systems" and conceiving human and computer systems as agents having manifestations in each of the worlds. Society, knowledge and technology have been analyzed as autonomous collectivities in that they are human products that, once created, develop through use in ways that the creator neither intended or conceived (Popper, 1974; Winner, 1977; Wojciechowski, 2001).

Hyperconnectivity provides powerful affordances for novel forms of collectivity to form rapidly and spread widely (Rainie and Wellman, 2012), and, whilst it basically supports well-known human propensities, it does so on a scale never previously experienced and has evolved a new culture, perhaps a new species, of 'digital apes' (Shadbolt and Hampson, 2018). The impact is particularly significant for the young as they begin to develop social networks that are constitutive of their own personae, and experience cultures for which their home and educational environments may have provided little preparation (Boyd, 2014).

5.3.4. *Transaction cost models of collectivities and hyperconnectivity*

Coase (1937) developed an economic model of the value of forming collectivities having common goals and mutual trust in terms of the lowered cost of transactions between members of such collectivities compared with those between unrelated entities. His *transaction cost economics* accounts for the formation of firms, markets and legal systems (Coase, 1988) and has been generalized to model the processes underlying the formation of a wide range of human institutions (Pitelis, 1993; Rao, 2003; Suematsu, 2014; Williamson, 1996).

Transaction cost analysis provides a valuable systemic framework for modelling and quantifying both the positive and negative impact of hyperconnectivity on human societies and individuals. It has been applied to modelling the development of social capital on social network sites (Richter et al., 2010), analyzing the development of trust between initially unrelated parties on the Internet (Etzioni, 2019), studying whether the Internet does reduce transaction costs to such a low level (Pesch and Ishmaev, 2019) that it creates a *weightless world* (Coyle, 1998), analyzing cyberwarfare as having lower transaction costs than conventional warfare in delivering disruption to nations deemed enemies (Allenby, 2016), and many other phenomena of our hyperconnected world.

Many of the negative aspects of hyperconnectivity discussed above may be modelled as transaction costs incurred through simplistic linking of disparate, possibly adversarial, collectivities having little basis for mutual trust. The Internet evolved rapidly with little central control because it satisfied major social needs, and is still a largely self-governed supranational entity outside existing jurisdictions (Abbate, 1999; Kahin and Keller, 1997; Pastor-Satorras and Vespignani, 2004). In the early years these were its strengths in enabling new forms of commerce and new collectivities having very low transaction costs and transcending national boundaries (Wriston, 1997).

However, the Internet bypasses the barriers between socio-political collectivities that have been developed and refined, often over long periods of time, to manage the interactions between them in a way that is agreed to be mutually profitable or, at least, minimizes transaction costs. These barriers serve to contain geographically local activities within well-defined jurisdictions where they may be monitored by responsible authorities, and managed to conform to the norms of the societies in which they take place. The current Internet makes these barriers permeable such that criminals in one nation may commit crimes in another that has no jurisdiction over their activities. Worse, the authorities having geographical jurisdiction over those committing the crimes may have an adversarial relationship with that where the crimes are taking place and actively encourage them as a form of cyberwarfare. They feel justified in this, and other uses of the Internet to disrupt other countries, because they view an *Internet-freedom* agenda as itself being a *weaponization* of the technology to undermine their forms of society (Morozov, 2011).

Coase's (1937) pre-computer analysis of the formation of organizations may be seen as presaging much of the impact of developing the Internet, good and bad. For example, he notes the role of the telegraph and telephone in facilitating transactions at a distance and hence supporting larger organizations. His reasoning applies even more strongly to the advent of an Internet linking virtually every institutional entity world-wide, suggesting that we have all became part of one or more supraorganizations. However, he also discusses the limitations to organizational size being when the transaction costs within it equal or exceed those with entities outside, suggesting that some of our problems with hyperconnectivity may have come from over-extending connectivity without the development of appropriate organizational structures.

Many current approaches to alleviating the adverse impacts of hyperconnectivity may be conceptualized as developing new organizational structures to manage it. Barriers are being erected in cyberspace, similar to territorial boundaries, in order to regulate transactions between entities from different cultures having limited mutual understanding, little basis for trust, or adversarial relations. Several nations have developed national intranets with controlled access to the global Internet (Morozov, 2011), and nearly all nations are implementing censoring of content and services appropriate to their cultures and political structures (Warf, 2011).

What is emerging is a distributed structure of barriers at the national, service provider, institutional, community and individual levels. Nations have enacted privacy laws to address how sensitive data in large databases may be used and distributed (Flaherty, 1989) and have become very sensitive to the storage of such data outside the jurisdiction which can monitor and ensure compliance with these laws. Service providers and institutions are providing spam and malware protection, strengthening their intrusion protections, and being forced to take responsibility for the content whose dissemination they facilitate. Communities are undertaking *cybervigilantism* (Chia, 2019; e Silva, 2018; Trottier, 2017) to identify and discourage content that they deem inappropriate. Individuals are being made aware of the nature of the activities of malevolent users and being encouraged to take appropriate precautions to evade such attacks. New technologies are being developed to provide barriers to such activities that combine and extend all the various forms of protection that have been developed over the years (Egele et al., 2008), such as *network security devices*[19] that are themselves powerful computers dedicated to malware and intrusion prevention for all devices on a LAN, and computer architectures that use high-speed encryption and key-churning techniques to counter control-flow attacks (Gallagher et al., 2019).

These socio-technical approaches are limited in the contributions they can make to the *social engineering* issues of end users being persuaded to disclose sensitive data or undertake actions damaging their selves or institutions through techniques that take advantage of unmerited trust (Junger et al., 2017) or carefully nurture it through a series of targeted transactions (Krombholz et al., 2015; Mouton et al., 2016). Protecting systems from cybercrime that bypasses organizational and technical protections by targeting the trust processes of their users has become a major human factors problem in our era (van Bavel et al., 2019; Jansen and van Schaik, 2019; Nam, 2019; Williams et al., 2018).

Social engineering attacks may be mitigated by establishing strong organizational controls that are embedded in computer systems, for example, by having a carefully-defined structure of institutional authorities that is enforced through the actions permitted at the user interface, by having actions logged and reported in an easily-assimilated form to those responsible for overall security of sub-system operations, by having identity verification for intra-organization communications, and by training users to accept these controls and support them.

Such protection must also apply to access by offsite teleworkers, customers and suppliers, and must be implemented in such a way that employees do not feel that their own privacy is being violated or become alienated by an over-bureaucratic organizational ethos. The design objective should be to improve functionality, usability and likeability, and any implementation should be assessed to ensure they are not undermined.

The impact of malevolent users cannot be entirely eliminated, only managed to be less damaging, and the protections need to be continuously maintained and extended as malevolent users have access to the same knowledge and technologies as those defending against them. From a transaction cost perspective, the equilibrium level is where the marginal costs of protection approach the marginal costs of residual malevolent use. The Internet is by no means 'weightless' but its role in society will continue to expand as long as its benefits exceed its costs — including those of protecting against malevolent users.

6. Future research directions

One may distinguish two broadly defined directions for future research on hyperconnectivity, one concerned with the technology and the other with the social impact.

The technology is primarily that of the *interaction tier* of the BRETAM infrastructure model (Fig. 1) which encompasses human-human, human-computer, computer-computer, and computer-world interfaces. There are strong pressures to improve the brain-computer

[19] A number of such network security devices are already available commercially at prices targeted on the domestic market, and if one searches Google Scholar for these terms one retrieves a large number of recent patents indicating widespread ongoing research and development of the technology in the expectation of major market opportunities.

interface and remove mechanical devices that impede high-bandwidth communication.

As the brain-computer interface develops the psychological problems of information overload (Strother et al., 2012), managing the focus of attention, keeping track of multiple tasks, backtracking to previous states, and so on will require continuing research on the nature of these psycho-neural processes and their effective support. The *ambient commons* (McCullough, 2013) will evolve from the physical to include the virtual with decreasing distinction between them, the demands on human attention will increase, and the support for the meta-cognitive management of the interface will become critical.

While the evolution of information technology is rapid, it is intrinsically limited by the rate at which it can be assimilated by people and economically controlled by its utility to society. The *digital/net generation* (Montgomery, 2007; Tapscott, 2009) has already made major adaptations in many aspects of their lives and modes of existence to accommodate advances in information technology.

There is concern that that these adaptations encourage *browsing* with shorter attention spans rather than in-depth reflection (Schuurman, 2013). However, these are trends that have long been part of the human response to information overload (Blair, 2010), and may be seen as necessary to take advantage of a hyperconnected world. Information overload, its consequences, its management and technological support for that management, will continue to be a central topic for hyperconnectivity research (Eppler and Mengis, 2004).

Dependent upon purpose, background knowledge and personal inclinations, what is information overload for one person may well be a highly desired rich environment for another. Development of an extensive and exemplified taxonomy of hyperconnectivity applications is one important research task, as are empirical studies of those applications.

Characterizing those who will function well in various forms of hyperconnected world is another significant area of research. The major differences in human personality that reflect individual reactions to stimulation, such as introversion-extraversion, have been well-studied (Cain, 2012; Kagan, 2010), and have *prima facie* relevance to reactions to different aspects of hyperconnectivity.

Personality variables have been related to the use, and non-use, of social media (Baker and White, 2011; Yanru et al., 2012), as have rationales for usage (Bertolotti, 2011; Tufekci, 2008; Yanru et al., 2012), although a meta-analysis of personality studies suggests that the correlations are low (Huang, 2019). There are also other typologies that may have relevance to the usage of hyperconnectivity, such as Holland's (1996) for vocational guidance, and it would be interesting to have research studies involving these also.

The negative aspects of hyperconnectivity, and the means to defend against them will continue to be a major and growing area of research. A review of culture and the evolution of human cooperation notes:

> Honest, low-cost communication provides many benefits — coordination is greatly facilitated, resources can be used more efficiently, hazards avoided; the list is long. However, once individuals come to rely on the signals of others, the door is open for liars, flim-flam artists and all the rest (Boyd and Richerson, 2009, p. 3283).

Dishonest communication may be the result of ineptitude or laziness rather than deliberate misrepresentation, for example, citations that are erroneous in scholarly documents may be plagiarized by other scholars without checking, propagate widely and be such that checking multiple, apparently independent, sources does not make the error apparent (Simkin and Roychowdhury, 2012). Published materials may be made available to others in good faith but may be erroneous or otherwise of low quality (Porcello and Hsi, 2013). However, whether deliberate or accidental, the propagation of false information undermines the integrity of a hyperconnected world and the research on improving the management of access to dubious quality material will require continuing effort and innovation.

A starting point for any analysis of cybercrime and cyberwarfare should be that crime/warfare, the acquisition of resources by stealing them or taking them by force, is a normal, rational and expected mode of human behaviour in evolutionary biology (Boyd and Richerson, 2009) and socio-economic modelling (Snooks, 1996). A major research issue in those disciplines is to explain the evolution of human cooperation, of honest, trustworthy, supportive interaction.

The explanation is generally in terms of the evolution of social norms relating to the 'three Rs': *reputation, reciprocation* and *retribution*:

> If cheaters are despised by others in their group, and, as a consequence, suffer social costs — lose status, mating opportunities, the benefits of mutual aid when ill or injured — then they may be motivated to cooperate, even though prosocial motivations are entirely absent from their psychology (Boyd and Richerson, 2009).

Support of these norms in hyperconnected worlds will be a continuing research topic (Ahonen and Wright, 2008; Clark et al., 2006; Rouvroy, 2008), both for those who wish to sustain the norms and those who wish to violate them. For example, reputation, or social capital, is established through a track-record of valuable, trustworthy service to others, but its value depends on correct identification of the reputable agent (Al-Karkhi et al., 2012; Seigneur and Jensen, 2005). Hence, technology needs to provide reliable means to enable agents to establish the identities of other agents.

Reputation, reciprocation and retribution do not in themselves necessarily result in useful behaviour but can stabilize *any* pattern of behaviour within a group, institution or society (Boyd and Richerson, 2009). This can lead to some very unusual cultures (Henrich et al., 2010). Hofstede's 1983 extensive studies of the differences between national cultures, and studies deriving from them (Kirkman et al., 2006), also provide useful insights into cultural similarities and differences but are primarily targeted on organizational management issues

Defensive provision of connectivity within a culture needs to take account of the norms of that culture, and support of that between cultures needs to be very much more defensive. Continuing cross-disciplinary research is on hyperconnectivity that is both effective and safe needs to take into account parallel research on the evolutionary dynamics of cultures.

From a technology perspective, research on system design needs to focus at least as much on *robustness* as *performance, cost, functionality*, and so on. Robust systems are those which continue to be able to perform reliably despite failures of some subsystems (Barley et al., 2009; De Felice and Petrillo, 2018; Huhns and Holderfield, 2002). In particular, dependencies on subsystems that are prone to failure or attack, such as the Internet[20] and data storage should be mitigated by redundancy, local caching, backup, malfunctioning detection, and so on. This includes human users as subsystems that are themselves potential sources of errors, attacks by phishing, and so on. The computer industry has long been addressing these issues and much of the technology for robust system design is available but its use requires greater general awareness of the existing and growing risks of our over-dependency on systems in our 'hyper-complex habitat' (Shadbolt and Hampson, 2018, 61–65) that are fragile, not only to malevolent users but also to environmental events such as severe storms and earthquakes.

7. Conclusions

The major advance in human-computer technologies in the past five decades is that the initial objective of improved human-computer interaction has been achieved to such an extent that a majority of the world's population is now mutually connected through the medium of digital computer and communication systems — we have become

[20] Clark's (2018) *Designing an Internet* provide important insights into the weaknesses of the current system and the options for addressing them.

hyperconnected to the physical world, to knowledge and to one another.

As a technology, hyperconnectivity is the outcome of the convergence of communication, media and computer technologies in the mature phase of their development where their extremely low cost makes them almost universally available.

As a social phenomenon, hyperconnectivity is the latest stage in the evolution of human social connectivity that has been a core necessity of the development of human civilizations for at least five thousand years.

The technologies of hyperconnectivity are evolving rapidly in a way that is difficult to forecast although one may expect impediments to effective communication to be increasingly bypassed with an eventual target of direct brain-to-brain and brain-to-computer interaction.

The human needs that motivate human strategies requiring connectivity have changed little over recorded history, and the social impact and issues of hyperconnectivity can be best understood in terms of those needs and strategies.

The human species is unique in having evolved systems for symbolic communication and storage that have enabled much larger social units than the family group to develop and function in a stable fashion that gives advantage to the individuals forming the group and sustains the group itself beyond the lifetimes of particular individuals.

Honest, trustworthy, supportive interaction within a group is enforced and reinforced through the social norms of the group, notably reputation, reciprocation and retribution.

Groups are generally part of a hierarchy of larger groupings which themselves have social norms intended to result in honest, trustworthy, and supportive interaction, but these norms generally become weaker as one moves up the hierarchy.

The central role of hyperconnectivity in human communication with others, computers, stored knowledge, and the mediated physical world, implies that these social issues will play a major part in the assimilation of the technology in society.

Hyperconnectivity is playing a major role in increasing the productivity of increasingly knowledge-based societies, but it also introduces equally major dependencies and risks of intentional, or unintentional, abuse that can undermine the functioning of those societies.

Defence against those risks is already a major consideration in the development and application of the technology, and this concern has become pivotal in the evolution of the technology and its applications.

System design needs increased attention to *robustness* despite subsystem failure, whether it is due to hardware/software faults, human error, malevolence, or environmental disturbance.

For human-computer interaction research, a major objective of this era is *maintaining and enhancing functionality, usability and likeability whilst protecting legitimate users from malevolent or incompetent ones*.

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Conflict of interest

None

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