Digital Divides and Web Science

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Abstract: The complexity of the digital divide is described, and it is argued that in fact there are several divides, not a single one. Relevant parameters include the dimension along which the divide takes place, the function of the technology in question, and the nature of the technology in question. It is argued that only a highly multidisciplinary approach to social issues in the context of the World Wide Web, including both analysis of the Web and its social context, and the synthesis of new engineering protocols, formalisms and standards, will have any lasting effect on such phenomena. A recent initiative to create a discipline called Web Science, taking the Web as a first-order object of study, is described.

Introduction

Society and technology advance – or retreat – in lockstep. The complex interactions between people and the artefacts they create are hard to understand, still harder to predict. Most technologies are created by scientists or engineers, with idealistic conceptions of the way they will be used. Indeed, most people, scientists or otherwise, have very positive conceptions of science. In a recent survey in the UK, 86% of people think that science makes a good contribution to society, while 82% of people think that science makes our lives easier (Office of Science and Technology 2005, 28ff.).

However, it is obvious that technologies can cause as many problems as they solve. This is partly to do with the nature of the technologies themselves – the ability to process information helps villains as well as governments or the general public, for instance. But just as often, it is an adverse interaction between social structures and technologies that causes difficulty. The digital divide is a case in point: there are several benefits to be gained from information and communication technologies (ICTs), but the use of ICTs is skewed by various social, educational and financial factors, and therefore the benefits of ICTs are unequally distributed, and the (generally beneficial) technologies have the unfortunate effect of exacerbating existing social divisions.

A major factor in such adverse interactions is our lack of understanding of their dynamics. In this paper, I wish to make some methodological comments about our understanding of the World Wide Web, the most complex piece of technology in human history, and one that is already deeply embedded in various social structures, particularly in capitalist democracies, but increasingly worldwide (China's online population is already the world's second largest, and will soon overtake America's – cf. http://www.internetworldstats.com/index.html, accessed December 2007). In particular, I will argue for a conception of *Web Science* – the interdisciplinary study of the Web as a first class object of study – as a vital tool in this task. I shall begin by briefly reviewing issues pertaining to the digital divide, hoping to show that our understanding of *that* social malaise (or, more properly, *those* social malaises) requires not only an account of social divisions but also greater technical literacy than is often brought to bear on the problem. Then I shall discuss Web engineering, before bringing the two strands together in an account of the nascent discipline of Web Science.

Digital divides: a complex picture

As ICTs have become increasingly important in society, the disadvantages of not being able to exploit them have become the focus of political attention. Many political projects particular to the 21st Century seem to require some action on the distribution of ICTs as a desideratum, sometimes even a prerequisite, for their being addressed: equity, inclusion, empowerment of individuals, security in a globalised, uncertain world. The rhetoric about the digital divide has been important for at least ten years (cf. e.g. Norris 2001), and (unlike transformational rhetoric about, say, climate change) the idea of addressing it appealed to most governments almost immediately. Some cultures proved very amenable to its addressing; for instance, Singapore was able to roll out a series of programmes to become a 'digital island' (Siew & Leng 2003, Tan & Yong 2003). However, Singapore is peculiarly well-placed to even out digital divides. It has long had a political programme of securing the positions of minorities (Mauzy & Milne 2002, esp.99-113), and so could be expected to address any kind of divide almost as soon as it was identified (cf. Chua 1995, 169-183). It is a small state. It is almost entirely urban. It is a nation that needs to survive and thrive on trade, so rhetoric about the 'knowledge economy' was particularly persuasive. The governing People's Action Party (PAP) has minimal serious opposition. All arms of the establishment – the executive, Parliament, the civil service, the major industrial corporations, the PAP – are interdependent, and the people at the higher echelons have a greater loyalty to the pragmatic ideology of 'national security' than they do to their particular institution (Mauzy & Milne 2002, O'Hara & Stevens 2006b). These conditions do not obtain in many parts of the world, with the consequence that implementing programmes to address the digital divide is somewhat easier than eliminating it altogether (Loader & Keeble 2004).

Part of the problem is that what is known glibly as 'the digital divide' dissolves when looked at closely – actually we have a multiplicity of divides across a number of dimensions. The most obvious criticism of the concept of a divide is that there are many structural divides in many societies which are reflected in differential abilities to work with ICT. I do not claim for a minute that this is an exhaustive list. In each case, members of the group on the left hand side of the '/' are, by and large, somewhat more computer literate, and use computers to a greater extent, than members of the group on the right.

- Young people/older people.
- Males/females.

- Rich/poor.
- White people/nonwhite people.
- Those with a high level of education/those with a lower level of education.
- Those who are trained in computing/those who are untrained.
- Those who create content (writers)/those who consume content (readers).
- Those who have a highly connected, networked existence/those who are relatively isolated.
- Those from the developed world/those from the developing world.
- Those from urban communities/those from rural communities.
- The English-speaking/those who speak 'minority' languages.
- The able-bodied/the disabled.
- Those from families with children/those without children.

It seems very clear that addressing any one of these problems will not necessarily mean simultaneously addressing the others. In some cases, policy vectors addressing two types of divides will be orthogonal, and indeed sometimes policies to address one divide may exacerbate another. For instance, improving the technical expertise of unskilled people in richer countries may well result of increasing the digital divide between the developed and developing worlds.

However, the dimension of the divide itself is not the only important variable. For instance, there is a further question of why the divide matters – what does the divide make harder for a citizen to do? Broadly speaking, there may well be political, personal or social functions of ICT (cf. e.g. Selwyn & Facer 2007).

Political functions of ICT help a citizen play a political role in his or her nation, providing input to, and receiving output from, government, and, in a democracy, helping make political decisions and choices. With the growth of e-government, many government services can be provided online, as can applications for benefits, tax returns and so on. In the United States, filling in tax returns is a notoriously tedious and error-prone process, and software to make a submission to the Internal Revenue Service automatically is common. As a communication medium, the Internet can be used to support democratic processes, either registering votes or providing a platform for citizens to voice opinions (cf. O'Hara & Stevens 2006a). The freedom of political life is also fostered in various ways by computing. In many countries, opaque decision-making has been replaced by online decisions transparently taken, and layers of government management removed, to reduce the number of opportunities for corruption . Technology can also be used to support privacy, to enable a citizen to preserve firewalls around his or her personal data. In unfree countries, technological know-how can allow people access to information censored at home, but widely available abroad, via proxy servers which get around government defences (cf. O'Hara & Shadbolt 2008 for more on privacy, censorship of the Internet and proxy servers).

Personal functions improve aspects of one's personal life, in more or less significant ways. Educational opportunities are increased dramatically for people connected to the Web. Similarly, the Web is a store of expertise that can dramatically alter power arrangements. For instance, the more informed the client, the less power a financial advisor has over him or her, and therefore the smaller the opportunities to make money. Furthermore, as more people consult the Web, the more disadvantaged the offline will become. In many Western democracies, patients consulting their doctors have often investigated their ailments online before they visit. As such behaviour becomes more common, doctors may begin to assume as a default that the patient is informed about his or her condition. Aspects of a person's psyche are also affected by the use of ICTs. ICTs are important for communication, especially at a distance, and also for managing memories, for instance digital photographs and home movies.

The third class of functions performed by ICTs is that of social functions. Here, apolitical but nevertheless social interactions are facilitated. For instance, science, or knowledge sharing, has been importantly improved by ICTs – indeed, the most transformative ICT, the World Wide Web, was invented precisely as a scientific instrument to share data and knowledge more efficiently. ICTs can provide people with a mobile and/or flexible working environment. They provide an alternative infrastructure for commerce and banking, greatly improving consumer choice particularly in remote regions. And the Web in particular is increasingly becoming a storehouse for community memories or histories, resulting in the creation of what is now known as the field of community informatics (Gurstein 2000).

And, of course, the type of technology with respect to which societies are divided can also vary. To take one example, in the Western democracies, the usual situation is that primary Internet access is via a bulky static PC, or at least a laptop, while the mobile Web is an expensive luxury suitable primarily for entertainment, games or sports results. In the developing world, the situation is exactly reversed. With unreliable power and telecommunications fixed infrastructure, and the relative expense of PCs, the mobile Web is rapidly becoming the method of choice of getting online. PCs here are the luxury. But subsidising the development of the mobile Web, from the point of view of a critic in the developed world, would be a case of widening, not closing, a digital divide. And in general, there are different types of technologies that demand different skills, different sizes of supporting community, and different outlay on hardware – making for potentially hard decisions for people who need or want technologies for particular problems. Is the right technology a mobile phone with SMS capability, or access to a proxy server, or Web 2.0 content creation tools, or peer-to-peer systems, or the Semantic Web, or pervasive sensors, or privacy-enhancing technologies such as firewalls? Much will depend on the problem; each technology presents different obstacles and choosing one will create an opportunity cost with respect to the others.

The Web: a piece of engineering and a social structure

So the number of digital divides is large. Even if we can think of, say, 15 social divides, 15 functions of technology and 15 technologies that may be useful, that will be 15^3 = 3,375 different digital divides to be explored, investigated and addressed. Of course, exact quantification here is a joke, not a serious option, but the point has to be made that the position with respect to digital divides is highly complex – and that is before we get into detailed policy debate about what, if anything, should be done about it.

My aim in this paper is not to make any prescriptions. It is clear that in some areas of social interaction, greater facility with technology can be extremely important. As I have argued elsewhere (O'Hara & Stevens 2006), there are areas where digital technologies can make a difference to someone's ability to pursue his or her ideas of the good. ICTs are important for promoting development, deliberative democracy and privacy. Policy-wise, I have argued for a prioritarian rather than a target-driven approach – those furthest from acceptable access to ICT should be prioritised in policy decisions. But my aim in this paper is to draw some conclusions about how to address the wider picture.

In the very brief discussion of digital divides in the previous section, the various dimensions were in different disciplinary provinces. Types of divide, methods for measuring them, and indeed policy prescriptions fall under the aegis of the social sciences. Functional accounts of the divides (what can the disadvantaged person not *do*?) are political questions. The technological dimension demands technical expertise. To understand the full picture with respect to a complex social issue like the digital divides requires an understanding of society, computer engineering, individual users, the economics and incentives of technology use, and the properties of large-scale networks. There are usually several degrees of freedom with respect to the remedy of divides with technology: do we fill any expertise gap with training, or simpler, more responsive interfaces? Do we build more tools? Do we merely need to develop new protocols to govern the passing of information? For instance, one common complaint about the World Wide Web was that it promoted an asymmetry between trained writers and the mass of readers; the development of AJAX (Asynchronous Javascript And XML), a suite of techniques for Web development used behind the scenes has played a more important role in addressing that particular divide (by helping create the content-creation-and-sharing paradigm often called Web 2.0) than any amount of training courses for creating and uploading webpages.

And we ought to add here that a further factor complicating the situation is that the Web scale – tens of billions of webpages, colossal quantities of data in the databases of the deep Web, hundreds of millions of users – undermines many assumptions about ICT use. The mere fact of the existence of a community of this size alters the facts about what solutions will work and where.

The interaction between a technology and its embedding community is clearly complex, but there is a tacit assumption that the two are orthogonal, and that each is an exogenous influence on the other. But engineering and society are more tightly linked than that assumption allows, particularly when a technology has a wide user base. Figure 1 shows the cyclical links that we can detect in the development of Web technology (the diagram is intended to refer only to the WWW, but is probably of more general application).

An idea for a technological solution to a perceived problem, or a technological method of taking a perceived opportunity, is decomposed into a set of technological fixes *and* a set of assumptions about the user base. When the technology is built, we have a functioning system. So far so predictable, and at this microcosmic level the technology is manageable. However, if the user base grows, and large networks of heterogeneous users appear, then the macrocosmic effects can be very complex indeed and highly unpredictable. Analysis of these networks, against a background of particular social values, present policymakers and engineers with further issues – which may demand technological solutions, and thus the cycle begins again, with synthesis and analysis alternating.

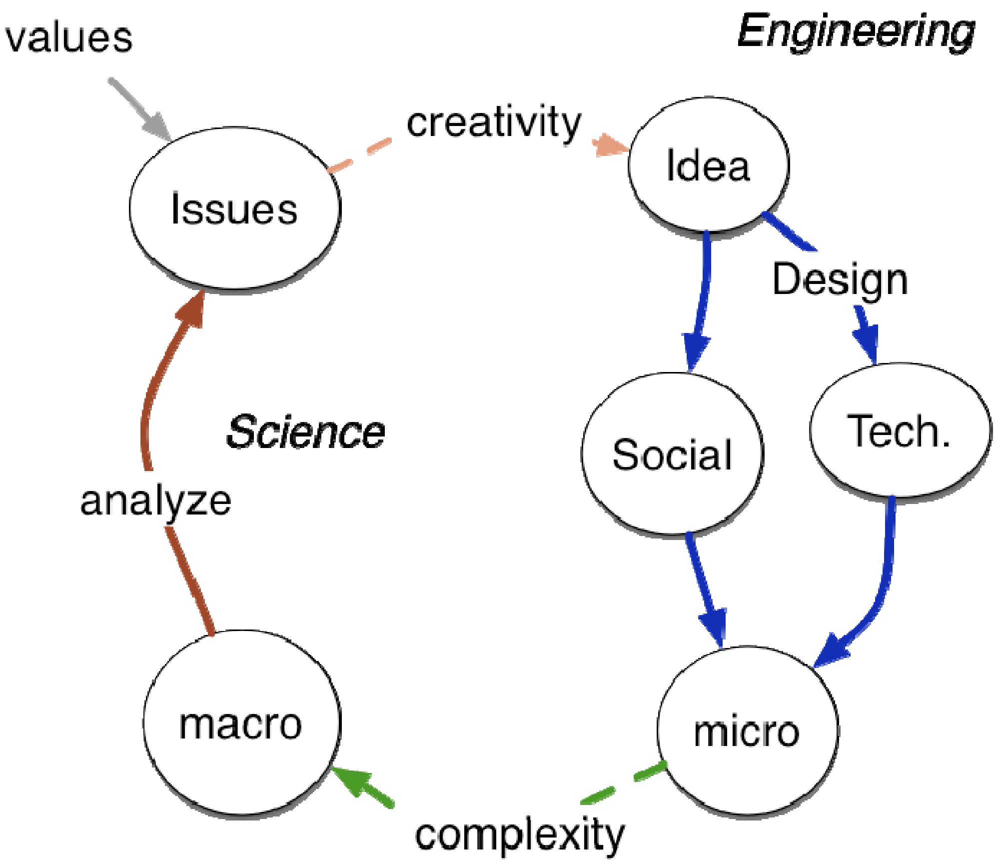

Figure 1: The cycle of Web engineering (from Berners-Lee 2006)

So, to take an example, email came about as a solution to a problem (the need for simple and effective communication between academics) and an opportunity (the existence of the underused Internet infrastructure). A technical solution – store-and-forward SMTP (Simple Mail Transfer Protocol) – was developed, against a set of social assumptions, about a friendly community of academics acting in good faith. Hence security and privacy were not perceived by the developers of SMTP as burning issues. But once email began to be used by a large number of people (1.4 billion hosted mailboxes as of 2007 – Radicati & Champagne 2007), unpredicted social effects began to be detectable – perhaps most notably the emergence of spam email. Hence another set of technologies, spam filters and the like, began to be developed in response.

The cycle can go around several times. The development of the Web, the use of HTTP and HTML, were fine as long as the name of the game was knowledge sharing between a relatively small community of high energy physicists who were prepared to link to good papers in good faith. But as the amount of information on the Web grew, there came a social problem – how to find content. The invention of the PageRank algorithm underlying the Google search engine was a particularly elegant solution, with technical aspects – the use of the Eigenvectors of the Web's link matrix – and social ones – incentives to link, plus an advertising-based business model. But that solution led in turn to the issue of Google spoofing, of artificially linking to one's website to push up its PageRank. This demands further responses from Google, and their algorithm undergoes a constant top secret evolution.

The problem for technologists and policymakers is that this socio-technical engineering cycle is very little understood in general, and with respect to ICTs in particular. When an ICT becomes as influential as the World Wide Web has done, then trying to understand the cycle is an important venture. This is the aim of a new initiative to understand the development of the Web, which has been called *Web Science* (Berners-Lee et al 2006a, 2006b).

Web Science

Web Science is conceived as an amalgam of science *and* engineering: both, because the Web is open both to study and incremental change. Although the Web is extremely large, and the range of content that it supports is beyond any single person's purview, it is nevertheless dependent on a relatively small set of protocols, or methods of constraining how computers communicate with each other. And so, although it is a large, complex piece of technology, it remains a human creation, and is alterable. It has of course come under study in a number of disciplines, and a number of engineering approaches have helped its development. But it is rarely a primary object of study – it is studied as a communication system, a political space, a scale-free network, a graph, an arena for legally-constrained interactions, and so on. The point of Web Science is to institute the study of the Web as a first-class object in its own right.

One effect of the multidisciplinary study of the Web (as opposed to the interdisciplinary study) is that it tends to be studied as an exogenous world. The investigator takes the Web as a given and tries to track its dynamics or properties. But actually, it is an endogenous space that can be engineered in particular directions (although possibly with unintended consequences alongside the intended ones – and understanding the potentiality for unintended consequences is one of the aims of Web Science).

The Web as a first order object of study is probably best characterised as *a decentralised information space constituted by protocols*. Its radical decentralisation – links can be made between any pair of resources, not just documents but even data – is perhaps the most significant aspect of it. It entails that there can be no editing or moderation of the space. It has several very different properties from managed information spaces. First of all, the lack of moderation and the decentralisation means that the Web will scale. Managed information spaces, with hierarchical structures, will find it hard to increase beyond a certain size, because as scale increases, the demands on the editors or moderators will increase at a higher order. So, for instance, checking that content is acceptable is possible, indeed desirable, for a particular website, but if a similar process was required for the Web as a whole, there would be a huge waiting list to post content, and it could not function as it currently does, with almost instant responses detectable to new phenomena of interest. Furthermore, the very much larger scales that the Web will support changes the nature of intelligent processing. In a managed information space, intelligence comes from smart processing of a relatively small amount of information, using techniques developed in fields such as artificial intelligence or expert systems, whereas on the Web, intelligence often results by processing very large quantities of information, using relatively straightforward data mining or statistical techniques for processing. Scale plus decentralisation provides an awful lot of power.

Secondly, unlike the tendency for managed spaces, the information on the Web is highly heterogeneous. Varying representation formats are used. Reliability, and consequently trust, is very variable. The Web is very open to the reuse of data in new and unintended contexts, which is where much of its value stems. But reuse of data can require bringing together information from several databases developed using different methodologies and representations, which means that quite often the information pulled down from the Web is less 'clean' than in a managed space, such as a single database, or a suite of databases developed and managed by the same organisation, within existing and understood quality assurance guidelines.

Thirdly, the economic principles governing the Web are somewhat different from other information spaces managed by single organisations, individuals or small consortia. On a traditional understanding, information adds value through *scarcity*. Intellectual property is protected by its creator or sponsor being given monopoly rights via copyrights or patents (or careful protection of a trade secret), and is able to make money either by exploiting a competitive advantage that monopoly use of the information supplies, or by gaining a revenue stream through licensing to others. On the other hand, the Web adds value to information through *abundance*. The rich informational context that the Web provides makes information more valuable by placing it into unforeseen contexts. The more information there is to provide such contexts, therefore, the greater the potential value-added.

This new, different world demands detailed study, to ensure its continued usefulness to society and to prevent its collapse through the identification of potential vulnerabilities. We need to identify the invariants of the Web experience, and then work to preserve them. Such invariants include: decentralisation; the use and maintenance of the Universal Resource Identifiers (URIs) which allow resources to be named and referred to in context-independent ways (one common type of URI is the standard *Web address* seen in one's browser bar, such as http://www.eu2007.pt/UE/vEN/); the use of open standards, publicly available to allow anyone to access and write software that interfaces to them (the World Wide Web Consortium, which is the main international standards organisation for the Web, ensures that its specifications can be implemented on a royalty-free basis); and the neutrality of treatment of the packets of information that are transported round the Web.

By coupling the analysis and synthesis of the Web more tightly, it is hoped that future problems could be engineered out at an earlier stage. Spam email might have been addressed in the early implementations of SMTP, for instance. Teasing out the interrelationships of large-scale macro social effects and small scale protocol definitions, is the aim of Web Science. As argued above, a social problem such as the digital divide is a highly complex phenomenon – but also, when one examines it closely, fragments into a series of linked phenomena, key parameters in the descriptions of which include deep technical understanding. Understanding, and hence addressing, digital divides demands *both* social science research *and* technical engineering research.

Indeed, there is virtually no limit to the disciplines which can contribute to Web Science, from mathematical analyses of graphs and networks, to artificial intelligence work on knowledge representation, to the microeconomics of knowledge acquisition, to the sociology of trust, to media studies, to security systems, to evolutionary dynamics, to social network analysis, to human cognition and information processing (Figure 2, and Berners-Lee et al 2006a).

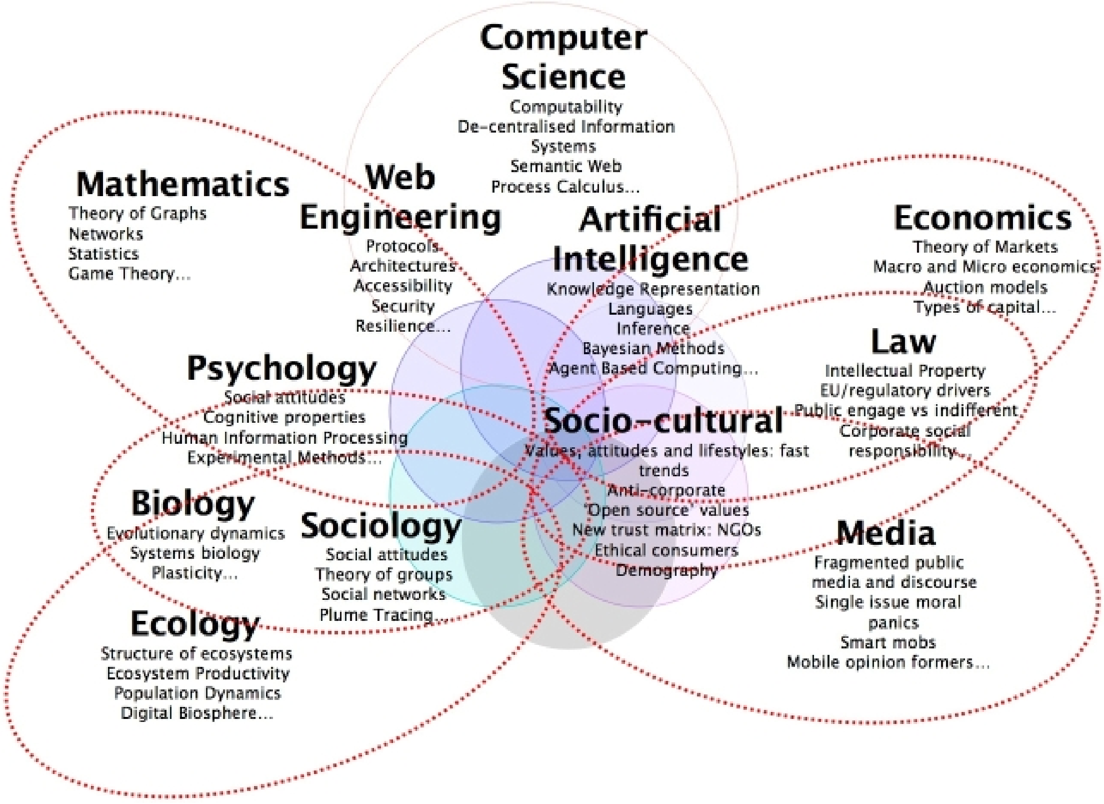

Figure 2: Disciplines relevant to Web Science (from http://webscience.org/)

To this end, the *Web Science Research Initiative* (WSRI – http://webscience.org/), a joint venture between the Massachusetts Institute of Technology and the University of Southampton, has recently been established to try to develop the Web Science discipline. In particular, it is focusing on defining a curriculum to teach the relevant skills to a new generation of researchers and engineers. It is hoped that WSRI, under the directorship of Tim Berners-Lee, Wendy Hall, Nigel Shadbolt and Daniel Weitzner (with James Hendler as associate director), will help provide the momentum to spread Web Science as a methodology able to address serious social issues such as the digital divide.

Conclusions

The Web is the largest, most complex piece of technology in human history. But though it dates from 1989, its form and purpose are striking reminiscent of other schemes for understanding and relating knowledge, such as Vannevar Bush;s Memex (Bush 1945), or even Diderot's *Encyclopédie*. Diderot's definition of '*Encyclopédie*' in the *Encyclopédie* is instructive: the interrelation of all knowledge, with the aim of 'collect[ing] all the knowledge scattered over the face of the earth, to present its general outlines and structure to the men with whom we live, and to transmit this to those who will come after us.' Diderot describes a liberal philosophy of releasing information, and fulminates against 'narrow minds, deformed souls, who are indifferent to the fate of the human race and who are so enclosed in their little group that they see nothing beyond its special interest', and who would rather, 'instead of enlightening the foreigner, [would] spread darkness over him or even plunge the rest of the world into barbarism' (Diderot 1995).

The effects that Web has had are at least as powerful as those Diderot intended for the *Encyclopédie*. The Web is a genuinely transformative technology, and trying to address social change without an understanding of the engineering issues is probably a doomed undertaking. Certainly, as Loader and Keeble have argued, with most if not all such initiatives, individuals and groups benefiting tend to be those who are affluent and already computer literate, while there is little evidence-based research to show that the social inequalities associated with ICT adoption have been challenged significantly (Loader & Keeble 2004, 41), while equally many projects are led by the technology, rather than by the needs of the people involved (Loader & Keeble 2004, 39). Target-driven, or technologically-led projects tend to fail to match aims against those established in communities 'bottom up', while an understanding of technology is essential for ensuring that a community's aims as articulated are feasible and attainable within technological constraints.

If addressing macro social effects of technology is not directly possible, then a closer association between technologists, social scientists and policy makers, under the banner of Web Science (rather than as an *ad hoc* grouping) may be a methodological step forward. It is to be hoped that such a step would allow digital divides to be addressed in a realistic manner, while still preserving the invariants of the Web experience.

The interdisciplinary study of the Web as a first class object should yield greater understanding of the interaction between it and the world. But also it would allow study with a view to incremental change – the Web is an endogenous space, and can be altered as a result of evidence-based research. The outputs of Web Science are deliberately intended to be engineering ones (Berners-Lee et al 2006b). As Karl Marx, who knew a bit about the interrelationships of society and technology, once said: "The philosophers have only interpreted the world in different ways. The point, however, is to change it." Marx has fallen into disfavour recently, for understandable reasons – but in the context of the Web, the scope of his ambition is within our grasp.

References

Tim Berners-Lee (2006). *Looking Back, Looking Forward: The Process of Designing Things in a Very Large Space*, inaugural lecture, University of Southampton, http://www.w3.org/2007/Talks/0314-soton-tbl/#(1) (accessed December 2007).

Tim Berners-Lee, Wendy Hall, James A. Hendler, Kieron O'Hara, Nigel Shadbolt & Daniel J. Weitzner (2006a). 'A framework for Web Science', *Foundations and Trends in Web Science* 1(1), 1-134.

Tim Berners-Lee, Wendy Hall, James A. Hendler, Nigel Shadbolt & Daniel J. Weitzner (2006b). 'Towards a science of the Web', *Science*.

Vannevar Bush (1945). As we may think, *Atlantic Review* July 1945, http://www.theatlantic.com/doc/194507/bush (accessed December 2007).

Beng-Huat Chua (1995). *Communitarian Ideology and Democracy in Singapore*, London: Routledge.

Denis Diderot (1995). 'Encyclopédie', in Isaac Kramnick (ed.), *The Portable Enlightenment Reader*, New York: Penguin Books, 17-21.

Michael Gurstein (2000). *Community Informatics: Enabling Communities with Information and Communications Technologies*, Hershey, PA: Ideas Group Publishing.

Brian D. Loader & Leigh Keeble (2004). *Challenging the Digital Divide? A Literature Review of Community Informatics Initiatives*, York: Joseph Rowntree Foundation, http://www.jrf.org.uk/bookshop/eBooks/1859351980.pdf (accessed December 2007).

Diane K. Mauzy & R.S. Milne (2002). *Singapore Politics under the People's Action Party*, London: Routledge.

Pippa Norris (2001). *Digital Divide: Civic Engagement, Information Poverty and the Internet Worldwide*, Cambridge: Cambridge University Press.

Office of Science and Technology, Dept of Trade and Industry, United Kingdom (2005). *Science in Society: Findings from Qualitative and Quantitative Research*, MORI, http://www.ipsos-mori.com/polls/2004/pdf/ost.pdf (accessed December 2007).

Kieron O'Hara & Nigel Shadbolt (2008). *The Spy in the Coffee Machine: The End of Privacy As We Know It*, Oxford: Oneworld.

Kieron O'Hara & David Stevens (2006a). *inequality.com: Power, Poverty and the Digital Divide*, Oxford: Oneworld.

Kieron O'Hara & David Stevens (2006b). Democracy, ideology and process re-engineering: realising the benefits of e-government in Singapore, *Proceedings of the Workshop on e-Government: Barriers and Opportunities, World Wide Web Conference 2006*, Edinburgh, http://www.w3c.org.hk/www2006/papers/re-eng_sg.pdf (accessed December 2007).

Sara Radicati & Joseph Champagne (2007). *E-mail Platforms for Service Providers Market 2007-2011*, The Radicati Group Inc, http://www.radicati.com/brochure.asp?id=481 (accessed December 2007).

Neil Selwyn & Keri Facer (2007). *Beyond the Digital Divide: Rethinking Digital Inclusion for the 21st Century*, Bristol: Futurelab, http://www.futurelab.org.uk/resources/documents/opening_education/Digital_Divide.pdf (accessed December 2007).

Lim Siew Siew & Low Yin Leng (2003). E-government in action: Singapore case study, inGregory G. Curtin, Michael H. Sommer & Veronika Vis-Sommer (eds.), *The World of E-Government*, New York: Haworth Press, 19-30.

Jeffrey B.H. Tan & James S.L. Yong (2003). Many agencies, one government – Singapore's vision of public services delivery, in James S.L. Yong (ed.), *E-Government in Asia: Enabling Public Service Innovation in the 21st Century*, Singapore: Marshall Cavendish Business Publishing, 267-308.