PART I. RECURRING THEMES

Chapter Two

NEW TECHNOLOGY DEVELOPMENTS WILL CONTINUALLY DRIVE THE INFORMATION REVOLUTION

It is clear that many current information technology trends will continue, at least over the next 15 to 20 years: computing will get faster and cheaper; communication bandwidth will increase; interesting new products (beyond cell phones and handheld personal information managers, or perhaps a merging of the two) will emerge—and so on. And yet, many previous attempts to forecast future technology developments have been woefully lacking, if not just plain wrong. Perhaps more importantly, it is difficult to predict the adoption and widespread use of various IT-enabled products and services, especially when their success depends on a critical mass of usage. Twenty years ago, circa 1983, essentially no one predicted the explosive development of the World Wide Web—indeed, although a precursor of the Internet was a fairly robust technology, there was no HTML, nothing like today's "chat rooms," and no gigahertz multigigabyte laptop computers or cell phones. And no one knows what the next "killer app" (discussed below) in cyberspace will be. So the "faster/cheaper/smaller" mantra hints at future developments, but it certainly does not predict them.

IT IS USEFUL TO DISTINGUISH AMONG DEVELOPMENTS IN TECHNOLOGY, PRODUCTS, AND SERVICES

In attempting to understand the continuing role of the information revolution and its potential differential effects on various countries, regions, and cultures of the world, it is nevertheless important to understand general technology trends and the types of products and services they will spawn. In this discussion, we find it useful to dis-

tinguish among developments in technology, products (both hardware and software), and services.[1] We view *technology* as the idea or intellectual property based on scientific principles that allows creation of a product that embodies it; for example, wireless communication standards and protocols per se are a technology. A *product* (such as a cellular telephone) may involve hardware or software, and embodies one or more technologies. *Services*, similarly, result from the application of technology, but in the form of capabilities offered to users, usually in a form resulting from storage, access, and manipulation of information. A website that helps you locate the nearest music store might be such a service. (But note that as the physical and cyber worlds become intertwined, so does the distinction between products [including software] and services [enabled by such software and hardware].)

SOME TECHNOLOGY DEVELOPMENTS CAN BE FORESEEN

It is widely believed that the exponential growth in computing power that has been seen for decades now will continue for at least another 10 to 15 years, reaching the limits of silicon technology by about 2015. That exponential growth has been referred to as "Moore's Law," an observation made originally in 1965 stating that the density of transistors on integrated circuits doubles about every 18 months.[2] That trend underlies many of the other developments that are expected.[3]

There will be a continuing convergence of voice and data communications, and another major jump in available bandwidth during the next two decades. These developments will be characterized in first-world economies by

- seamless data, voice, video sharing
- near-universal connectivity
- application convergence through the Internet Protocol (IP)
- widespread moderately wideband wireless
- optical, multiwave lines and switches, allowing bandwidths of many thousands of gigabits per second

- significant data storage density increases, to the point where terabyte stores become practical and accessible
- increasing synergies and interrelationships between silicon, bio-, and nanotechnologies, with some possible exploitation of quantum effects for computing.[4]

Machine translation among key natural languages is a long-sought goal. Its availability, for example, would allow the informational riches of the Web—predominantly in English today—to be accessed by persons whose only language is Arabic, Japanese, Chinese, or Spanish (for example). Predictions here are more difficult; the general machine translation problem is unlikely to be solved in the next 20 years, but "you can have any two of the following three desiderata: high quality, general purpose, fully automatic."[5] For many purposes and limited domains of discourse, this will be good enough for useful applications.

We emphasize in particular the importance of the very strong synergies developing between bio-, nano-, and material technologies. Beyond semiconductors, on-chip integration of logic and other components will include chemical sensors and components, electro-optical devices, and biological components as well as microelectromechanical systems (MEMS). The results, especially for sensor technology—and when combined with wireless communication developments—will be revolutionary, with an expected cornucopia of new devices and applications.[6]

PRODUCT DEVELOPMENTS WILL ALLOW INFORMATION DEVICES TO BE UBIQUITOUS, WEARABLE, AND IN CONTINUOUS CONTACT

Given developments in underlying computing and communication technologies, we expect to see a multitude of diverse, powerful, inexpensive sensors, and other devices capable of (limited-distance) wireless communication. Among them are tiny video cameras, MEMS microphones, accelerometers, gyros, Global Positioning System (GPS) receivers providing location and timing information, smell sensors, food spoilage sensors, biosensors, and polymer-based sensors. These products will provide a vastly increased coupling between the physical world and the cyber world, allowing informa-

tion systems to react much more comprehensively to (changes in) their environment, and physical systems to react to changes in the cyber world while reacting to new information from elsewhere in the physical world.[7]

Computing and information systems will become much more ubiquitous, with convergence of wireless telephones, personal digital assistants (PDAs), radio, voice and email messaging, smart home appliances, etc. Precursor products in this trend are the Palm series of PDAs and Research In Motion's (RIM's) BlackBerry. Developments in such small, portable, personal devices, along with sensing technology, will make wearable computers increasingly important informational aids. Aiding in these developments will be protocols for short-range wireless communication, such as the IEEE 802.11 or Bluetooth standards or their successors.

Display products will undergo dramatic improvement within the coming 15 to 20 years. The above-mentioned synergies between bio-, nano-, and silicon technologies are expected to result in "electronic paper" displays that can be rolled or folded and perhaps contain wireless links to personal or other information systems, digital displays that retain their content without requiring power to continually refresh them, and large-screen, flat-panel displays that can be "tiled" to desired sizes.[8]

SERVICES DEVELOPMENTS WILL GREATLY EXTEND ACCESS TO, AND THE USEFULNESS OF, INFORMATION SYSTEMS

There is a major shift under way in business emphasis, from products to services. Increasingly, businesses see specific products as elements or components of a broader service that the firm provides to customers. Information technologies are central to this new business model.

Kiosks Can Provide Easy Access to Some Information Services

The coming availability of "good enough" machine translation of languages and speech recognition could allow *widespread deploy-*

ment of kiosks at which a question can be voiced, and the riches of the Internet used, to provide a spoken or displayed answer. Such a kiosk may be a small structure (either temporary or permanent) in a public place, housing a display screen and computational power similar to a personal computer, and linked to a telecommunication line. It may even be reasonable to imagine the kiosk containing a small satellite dish by which Internet and other informational services are accessed, and solar cells and auxiliary batteries by which it is powered as a self-sufficient informational platform. We foresee such kiosks having more importance in developing countries, where ownership of information system access products may remain limited.

Services available from such a kiosk might—at least initially—be tailored to certain specialized areas, such as farming, weather reports, market prices for agricultural products, and so on.[9] In that manner, the complexities of translation and voice recognition might be overcome within a limited domain of discourse. The advantages of such "kiosk" information services over traditional media (e.g., radio) could be the provision of on-demand information tailored to the needs of the individual, communication in terms of maps and pictures, and perhaps locally stored information relating to an individual user that can help tailor his or her interactions across a series of them in the manner that "Favorites" or "Bookmarks" tailor usage of a Web browser to one person's preferences.

Entertainment Will Be at the Leading Edge of Novel Information Services

As is increasingly the case, *entertainment* will likely lead the way in novel services, with business-to-business e-commerce as a strong second force. As these information utilities grow, they will become backbones supporting increased lifelong learning and specialized training. Among the products and services expected to play a large role are[10]

- multiperson computer-based games, with tens of thousands of people interacting online within an "environment" simultaneously

- Web-mediated physical activity, such as interactive games requiring strenuous physical responses
- ubiquitous webcameras providing entertainment, communication (improved interpersonal interaction at a distance), and intrusive surveillance
- interactions with people of different cultures, aided by translation programs
- the ability to view athletic events from almost any vantage point
- video glasses that place images directly before a viewer's eyes
- pornography (inevitably)
- music and movies on demand, any time, anywhere
- e-books.

Information Services Will Play an Increasing Role in Health Care and Telemedicine

Health care services will increasingly be influenced by "telemedicine," in which some or all of the services will be IT-mediated. The opportunity to access information and actual care from a vastly expanded set of providers will confront both patients and health care professionals with a bewildering array of choices. This in turn may generate new dynamic brokering services. Increased use of telemedicine is one of the factors likely to increase the gap between rich and poor societies (e.g., because high, reliable bandwidth is often required); however, it is not the dominant factor. Other factors tending toward an increase in health disparities include the continuing spread of infectious and noninfectious diseases in developing countries and inadequate health care capacities and spending, with AIDS, tuberculosis, malaria, and hepatitis remaining problematic, especially in Africa.[11] Some benefits from the information revolution will accrue to poorer countries—for example, from their improved access to information and training materials. Other health benefits from the information revolution will accrue from better (computationally intensive) modeling of the interactions of various molecules and their folding patterns, allowing the tailoring of drugs at the molecular level, and even tailoring to individuals. Access to

such benefits, however, is likely to remain limited because of their expense as well as various policy hurdles—at least during the coming decade.[12]

Online Education Will Have Increasing, but Specialized, Effects

In *educational services*, the greatest impact of the continuing information revolution is likely to be in lifetime learning and specialized training. These areas are burdened with few regulatory constraints, and there is already keen competition among providers of such educational services. Other important changes will occur in postgraduate education, where online education will allow students to customize their degree programs, enjoying lectures from and consultations with professors at multiple universities.

University undergraduate studies and K–12 education are likely to be less affected over the next 15 to 20 years because of a variety of social, political, and other factors, but they may be dramatically affected somewhat later. Especially at the K–12 level, inertia, entrenched unions, unfamiliarity with and inability to use new technologies, the costs of acquiring equipment and building infrastructure, and (for public schools) political interference will all constitute serious barriers to adoption of new IT-based teaching techniques. K–12 education also has a significant social and emotional maturation component that cannot yet be provided by distance learning.[13]

Micropayment Schemes Will Emerge to Handle Small Online Payments

Payment schemes such as *micropayments* will be increasingly important in allowing e-commerce services to charge small amounts (less than the cost of processing a credit card payment) for small services performed, such as reading a document or downloading a small file. "Dynamic brokerage" services will provide a decentralized capability for matching highly specific customer requests for packages of services with suitable offers of these services from a wide range of suppliers. This requires creating a standard vocabulary for articulating requests for services and for describing services offered. The availability of micropayment services is likely to cause restructuring of

some existing businesses, such as a move toward "pay per use" for downloading information, rather than reliance on subscriptions. These services may also expand commerce to many small entrepreneurs or individuals providing access to specialized information for pennies per transaction—perhaps the equivalent in the information sphere of eBay's expansion of commerce in an auction format to millions of individuals.

MARKETS WILL DECIDE WHAT POSSIBLE PRODUCTS AND SERVICES BECOME ACTUAL AND WIDESPREAD

Although technology's progress makes many products and services possible, markets ultimately decide which will become so widespread as to have an effect on societies and cultures around the world. Some important market criteria that can determine the widespread adoption of a product or service are

- ease of use
- backward compatibility
- perceived advantages from use
- low- or no-cost ownership
- affordability
- noncritical failures
- state of the economy (affecting disposable income)
- importance and criticality of adoption compared with viable alternatives
- dependence on market penetration for a successful business model
- dependence on critical mass of users.

But it is also important to realize that the various applications of IT can be treated as either private goods, which are left to the market, or as public goods. The United States tends to treat most applications of IT as private goods. Other nations (e.g., India) are treating IT not only as a private good but also as a public good. They are not leaving it to the market to determine what happens regarding IT developments

and applications. These differing approaches can lead to tensions between countries or regions regarding intellectual property rights, which may slow the globalization of information technology. Observers in the United States or other Western countries should take some care to temper their assumption of reliance on the market with other societies' approaches and viewpoints. As a result of these differences in approach, other nations may use IT in different ways than does the United States.[14] Possible implications for the United States include markets that are less global than expected for informational goods and services.

The Emergence of "Killer Apps" Can Greatly Affect Markets and Create Markets

It is also useful to distinguish between the market for invention (e.g., through support of university research or research and development budgets within corporations) and that for innovation (e.g., from access to and availability of venture capital).[15] How IT-related products emerge from basic research, go through revolutionary change, become breakthrough products, or undergo gradual evolutionary change—or do not do so successfully—depends to a large extent on the market for invention, and for innovation, within a society:

- If a society has weak markets for both invention of new technology and for innovation of new products, it will tend to produce gradual evolutionary change.
- A society with a weak market for invention, but strong in innovation, can produce breakthrough products.
- A society with a strong market for invention, but weak in innovation, will likely produce basic research but no entrepreneurs.
- A society with strong markets in both invention and innovation can produce revolutionary change.[16]

The wild card in applications and services is what is known as a "killer application"—one that makes a new market because everyone views it as a "must have" product or service. Examples are the VisiCalc spreadsheet that greatly stimulated purchase of Macintosh personal computers (followed by Lotus 123 that stimulated purchase of IBM-compatible PCs), and Napster and its "peer-to-peer" cousins

that created explosive Internet sharing of MP3-formatted music files. It is difficult to predict where future killer apps will emerge, but massive online, simultaneous, coordinated game-playing by thousands or tens of thousands of participants is one possible candidate.

SOME TENSIONS ARISING FROM THESE DEVELOPMENTS WILL AFFECT THE GROWTH AND SPREAD OF IT-RELATED PRODUCTS AND SERVICES

A number of individual and societal tensions arise from the developments outlined above.

Optical Communication Technologies Are Highly Disruptive to Existing Telecommunication Industries Worldwide, and Other New Communications Developments Could Be as Well

It is increasingly clear that ultra-high-speed all-optical communication networks are a highly disruptive technology. It is likely that many present-day leaders in computer and communications industries will be threatened with extinction.[17,18]

The communication industry, especially in Europe, is also facing massive "3G" (third-generation) investment costs (for licensing and network infrastructure), yet the 3G wireless services promised have not yet sparked great consumer interest. At the same time, a grassroots "Wi-Fi" (wireless fidelity) revolution is taking shape in portions of the unlicensed spectrum, based on the IEEE 802.11b standard; this is threatening to undermine parts of the business plans of traditional telephone companies. Wi-Fi may be an enabler for a future "killer app."[19]

The possible rise to substantial use of IP-based telephony could be an additional disruptive influence.[20]

Open Source Versus Closed Source: Proprietary Standards Battles Will Continue

There are major battles to be waged between advocates of "open" versus "closed" worlds of protocols and standards. It is unclear where the balance will be found.[21]

Intellectual Property and Digital Rights Issues Are Creating Major Tensions

Among the many social tensions are increasing threats to intellectual property rights—for example, from new business models such as those exemplified by Napster and Gnutella. These issues are coming to a head with widespread sharing of songs in MP3 format and the likelihood of increased sharing of digital movies in MP4 format—both developments being fought with legislation and lawsuits by the Motion Picture Association of America and the Recording Industry Association of America. And it is likely that many of the new IT products and services will, as is often the case, primarily benefit those with the resources to obtain and exploit them. How these battles are fought (in courts, in legislatures, in the marketplace) and decided will not substantially affect underlying technology developments, but they will affect the types of products and services that each society or culture will have available.[22] The major tensions arising from these issues are likely to be between countries whose IT-based industries and services depend on enforcement of intellectual property rights, and other countries and regions not having comparable IT-based industries requiring protection.

A PERIOD OF INFORMATION TECHNOLOGY CONSOLIDATION IS BOTH LIKELY AND HEALTHY

The U.S. economy, in particular, has recently experienced a "dot-com crash" and is currently watching the implosion of the telecom industry. The events of September 11, 2001, created additional major disruptions in the U.S. economy, with some effects worldwide. There is a drastic reduction in the availability of easy venture capital money for the establishment of new IT-related companies. Tremendous amounts of slightly used, or even new, IT and telecom equipment are being auctioned off and sold from companies that failed, further depressing the market for new IT goods. All these factors compound, resulting in a period of slower growth of new companies and consolidation of existing ones. Given the frenetic nature of the "dot-com bubble," we regard these developments as healthy, overall, for the future development of IT technology, products, and services. During this consolidation, there are issues to be sorted out with some rational planning and decisionmaking: spectrum allocation for new

wireless products; potential fundamental restructuring of the telecom spectrum; "fair use" policies for intellectual property being transmitted and used in cyberspace; patenting policies for software and business practices encoded in software; the extent to which Microsoft's operating system monopoly will be modified; standards for security and various guaranteed levels of service on a next-generation Internet; and so on. Working through these issues at international, federal, and consortium levels will take some time but can lead to a stronger foundation for substantial, yet sustainable, IT growth in the coming decades.

NOTES

[1]A similar distinction, but one varying in some aspects—including the use of the term "artifact" in place of "product"—was described in the proceedings of the first conference in this series. See Hundley et al. (2000), Section 10. This distinction also formed the basis of much of the discussion within the second conference upon which much of the discussion in this chapter is based. (See Anderson et al., 2000.)

[2]The original statement of Moore's Law had transistor density doubling every 12 months, but the pace has been a doubling every 18 months in the recent past, and that is taken to be the form of the law now.

[3]See, for example, the International Technology Roadmap for Semiconductors (2001 edition) at http://public.itrs.net/Files/2001ITRS/Home.htm (accessed April 7, 2003). An overview of the technologies contributing to higher-speed, smaller computing chips is contained in a set of briefing charts accompanying a speech, "Beyond the Wall: Technologies for the Future," by Karen H. Brown, National Institute of Standards and Technology (February 26, 2001), given at the International Society for Optical Engineering's (SPIE's) 2001 Symposium on Microlithography. The charts are available at http://www.nist.gov/speeches/SPIE_022601.pdf (accessed April 7, 2003).

[4]See the Karen Brown charts cited in the previous endnote.

[5]This quotation is from Anderson et al. (2000), p. 11. The discussion at that conference distinguished between "shallow" translation, between sentences of actual languages, and "deep" translation, in which the source language is translated first to some semantically explicit interlingual representation and from there to the target languages. The shallow approach tends to use dictionary lookup of words along with some simple cues—and the results are of relatively low quality. The deep systems can achieve higher quality but are more expensive and require a constrained domain of discourse, such as a kiosk with travel information in a specific locale or translation of training manuals for a specific company's products.

[6]See Antón, Silberglitt, and Schneider (2001). See also the brief discussion in the Science and Technology section of NIC (2000). We return to this subject in Chapter Fifteen.

[7]See Antón, Silberglitt, and Schneider (2001).

[8]See Mann (2001). Also available at http://www.technologyreview.com/articles/mann0301.asp (accessed April 7, 2003).

[9]Such kiosk-based information services would also be accessible through other devices such as home-based PCs, small portable wireless devices, etc. that have network access.

[10]These services will depend on access devices such as those mentioned earlier.

[11]See the section on Health in NIC (2000).

[12]For example, in the United States, health care policy has not yet made telemedicine a legitimate way to deliver even the most basic services.

[13]These views are based on a U.S. perspective; the situation may well differ in other nations.

[14]See the additional discussion of societal factors in adoption of technology in Chapter Six of this report.

[15]In this discussion, we distinguish between *invention* of technologies and *innovation* of products and services. This is, of course, an oversimplification.

[16]These statements are taken from Anderson et al. (2000), p. 55.

[17]This process is already well under way in the telecommunications industry. The reasons for the trend are documented in detail in issues of the subscription newsletter, *The Cook Report on the Internet* (Cook Network Consultants, 431 Greenway Ave., Ewing, NJ 08618). The basic argument is that optical, multiwave transmission lines and optical amplifiers and switches will make possible all-optical networks with a quantum jump in communications bandwidth, to thousands of gigabits per second. This trend, even in its early stages today, is creating a major glut of bandwidth, leading to a "race to the bottom" of firms trying to sell this capacity in order to recoup the investment. The bankruptcy of some existing telecom firms, and their strategy to undercut the pricing of others to gain some revenue, is only exacerbating the situation.

[18]In the computer industry, all-optical fiber and switching networks have not yet caused major disruptions, but they will. The transmission speeds that these networks will provide, thousands of gigabits per second, are greater than the main memory bus speeds of current workstations. This will give rise to major changes in computer architectures, operating systems, and networking protocols. Application software will also change, probably becoming much more distributed as communications capabilities expand and costs decrease dramatically. These changes, potentially as disruptive as the transition from mainframes to microcomputers in the 1970s and 1980s, will threaten present-day leaders in the computer industry with extinction. (See the white paper by David J. Farber, "Predicting the Unpredictable: Technology and Society," reprinted as Appendix A in Anderson et al., 2000.)

[19]See Stone (2002). Also available at http://www.businessweek.com/technology/content/apr2002/tc2002041_1823.htm (accessed April 7, 2003).

[20]See Cook Network Consultants (2003), especially pp. 15–37, for a discussion of IP-based telephony, often termed "Voice over Internet Protocol," or VoIP. Romero (2003) provides a briefer description of the current situation.

[21]See, for example, Edwards (2001). Also available at http://www.darwinmag.com/connect/opinion/comment.html?ID=375 (accessed April 7, 2003).

[22]A thoughtful analysis of intellectual property issues in the information age is contained in Lessig (2001).