Chapter 32

Information Technology in 2050

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ABSTRACT

The evolution of applied information technology (IT) over four decades is not predictable except in the most general ways, but some current trends and issues will likely persist and these can be identified and their outcomes hypothesized. A subset of such trends is considered in this discussion. IT trends that are expected to continue include increasing computational capability, improved interoperability, expanding storage capability and extending connectivity, as well as a profound evolution of software and data norms. Obvious positive consequences will include the ability to more perfectly represent the real world in analysis and simulation tools, revolutionizing engineering practice by enabling fine-grained representation of physical problems. Negative consequences may include the loss of information, quality implications associated with the spread of "grey" literature, and the inaccessibility of engineering computations to engineers. Responses to these negative consequences may include a shift in the notion of information accreditation, a drive towards formal accreditation of common engineering tools, changes in the fundamental precepts of engineering education, and the forced evolution of a paradigm shift of the notion of professionalism in IT services sectors. The picture that emerges is one of changes in practice, not just in speed and scale, but in kind.

A STARTING POINT

While we don't believe IT progress over decades is predictable, there are some groundswell changes in IT that we are experiencing today which will echo long into the future, and it is interesting to identify some of these and to speculate on where they will bring us. The constraints of space sharply limited what we could address even partially in this chapter, so we have explored some issues that are of interest to us and are as yet undecided, and suggested some outcomes that might follow. This should not be taken as an attempt at prediction, but simply as a speculation as to what might come – or might not.

It is tempting to delve into the speed and capability of computing machinery as a part of this exploration, because this is a core consideration in our day-to-day decisions as to which new piece of hardware we should buy, or which software we should load. The speed and capability evolution in both hardware and communications has driven the IT world from the time-sharing concept on mainframes to the work-station file-server model, and now to the cloud computing model (which can be viewed as essentially time-sharing re-visited). A cyclic "revolution" of computing paradigms, as a response to hardware and communications acceleration and other pressures, could repeat, and we have little doubt that "faster, better" will be a continuing theme in this sector. However, on the time scale we are now considering we suggest that this kind of change is for the most part not really a major interest area, because it is the *uses* of that machinery that are important in engineering, not their nature. So let's simply stipulate that over the time span we are considering, our hardware will be blindingly fast, physically tiny, ubiquitous and affordable. Let's assume that memory and storage are vast, cheap and robust. Let's assume that connectivity is for practical purposes limitless in space and speed. Let's even dare to hope that over this time span we will evolve a dominant operating system that is stable, dependable, and secure to the point where it isn't of much interest.

This perspective doesn't end the list of underlying technical changes we will face. There is also a range of other technical areas that will deliver fascinating extensions to present practice by 2050. There will be new ways to input data and interact with computers, including direct neural interfaces, and computer-aided problem solving will become a different experience. There will also be new ways to render results. Even now, three-dimensional renderings are possible, and this kind of technology will no doubt continue in ease of use and effectiveness. Truly photo-realistic renderings of structures and engineering works will be the expectation, not the exception, well before 2050. In this chapter, we have avoided exploring these kinds of extensions of present capability because they will tend to make what we already do faster and more effective, but will not by themselves change professional practice. Instead, we have focused on some of the larger technical trends that have the clear potential to markedly affect the practice of professional engineering.

Reluctantly, we have also decided to exclude the societal and engineering practice changes that will continue to be experienced as social networking technologies progressively drive an evolution in the way engineers interact as communities. The notions of leadership, mentoring, peer group definitions and other facets of human interaction that are fundamental to engineering practice and are being affected by IT will evolve profoundly by 2050. So will the evolution of regional and/or systematic censoring of internet connectivity, the potential for fracturing of communities based on differing computational platforms, the long-term implications of ceding data housing to generic third party service providers, the potential reconsideration of specific technologies in the face of IT-centric disasters, and others.

Processing speed is not just a consequence of hardware evolution, but of evolving practice and understanding, and we posit that this too will increase computational and application capabilities through 2050 and beyond, even though a multitude of technical, production and business challenges will be faced along the way. Some aspects of the recent acceleration in processing speed (circa 2000 – 2010) are explained less in hardware and more in how hardware is being used. Identification of parallel structures in how we cast a problem lets us attack computational problems in parallel, with enormous acceleration of throughput (apparent as "fast" to humans) without demanding a fundamental advance in actual hardware speed. Database look-up has also benefited from intellectual progress in how problems are presented to our machines, with vastly improved search algorithms and filing systems, so that speed is conferred not by faster machines, but by application of greater intellect.

Unfortunately, there is also a factor that seems to be an inevitable collateral factor to the development of faster computing capability. The bloat that bogs down our hardware is staggering. An often-cited example can be found in our word processing software. Fifteen years ago the file sizes, application sizes and requirements of our basic word processing hardware required a fraction of the capability that our massive word processing products demand today, yet the benefit of the escalation in requirements for the newer products seems to be questionable. We wonder if this bloat will ever be managed. An informal poll taken by the author amongst his colleagues found that virtually no one saw benefits to a recent release of a common word processing product, yet market forces have demanded that it be adopted nevertheless.

At the end of the day, we believe it is fair to conclude that processing power will continue to evolve and that applications will keep pace with this evolution, but much of this evolution will be enabling but not fundamental in its impact. It is the expression of IT in engineering in other ways that will have a material impact on engineering practice.

IT processing power will continue to evolve and applications will keep pace with this evolution, but it is the expression of IT in engineering in other ways that will have the greatest impact on engineering practice.

LOSS OF INFORMATION

For information to be of meaning, it must be accessible and in a format that can be interpreted. The problem we now face is that accessibility and interpretation have new dimensions as a result of the IT revolution.

As things stand, information retained from centuries past can still have meaning. Much may be lost as fragile manuscripts decay or are destroyed over the centuries, but the manuscripts that survive can be made available, whether or not the content has current value. Data persistence in the electronic information age is similar in some ways and different in others, sometimes blatantly and other times subtly.

What changes in the electronic world is largely a shift in the degree of the problem, not the essential nature of the problem. The format of electronic information changes far more rapidly than its “paper” counterpart. While written documents may be readable over centuries, many electronic formats can become useless over decades for several reasons.

Media change, as anyone with a library of 5-¼ inch floppies knows, or anyone with a camera based on XD chips has learned. Even where they don't change, media themselves can degrade over time. Current CD-R technology is largely a photographic technique and the dyes in the disks, like those in a Kodachrome photograph, decay with time. Manufacturer estimates of CD/DVD life are on the order of 70 years or less. Magnetic tape has a lifespan measured in decades, paper has proven to be a multi-century medium, and burned CD/DVD lifespan has been reported as limited to possibly a few years (e.g. 2 to 5 years for burned CDs) depending on the manufacturer and storage conditions (Blau 2006). Surely storage conditions matter, but the potential for loss is not diminished with different media; in fact, because the outer "shell" in CDs or DVDs appears robust to the casual observer, we speculate that such media are more likely to be mistreated than some more visibly sensitive storage options.

Even if media are compatible, base formats can become unreadable, or readable only with difficulty or at cost. Although still widely understood, the ASCII and EBCDIC formats that provide a representation of familiar readable characters as a set of numerical values are nearing their 50th anniversary. These 8-bit encodings have evolved to form the basis of much data encoding today, and they are still "readable," decodable and translatable between each other. Although some more recent data formats are built upon these standards, some formats are proprietary enough that decoding without the manufacturer's software is practically impossible. A change in format could render in a single keystroke decades of information, collective knowledge, financial transactions, etc. unreadable. If we also in some way lose the ability to interpret older formats, then the unreadable data becomes nothing more than digital clutter, perhaps resolvable only through the equivalent of decryption methods.

Some of these issues are problematic over the long term, and some more immediately. If data are published in a proprietary format, a sometimes-costly proprietary tool may be required simply to access the data. Over the long term, the tools to access the data may no longer be available, and the prospect of reverse engineering an obsolete format emerges. This outcome can be an issue even if the agency responsible for maintaining the data has the national interest at heart. At the time of writing, the US Geological Survey (USGS) National Geospatial Program Standards website states: "Standards set the criteria and specifications to ensure that all products prepared by the USGS under the National Geospatial Program (formerly the National Mapping Program) are accurate and consistent in style and content. Most of these standards are historical and apply to products no longer produced by the USGS…" (USGS 2010). A further review of standards in the National Mapping Program Technical Standards document *Standards for Digital Elevation Models* (USGS 1998) reveals five change notices between 1993 and 1998, beginning in 1993 when the determination was made to store content on ANSI labeled 9 track magnetic tape. The USGS runs an excellent and carefully managed program, so we infer that the trail of actions by this agency speaks to the magnitude of the problem of information maintenance in the technical context. Taken together, it is fair to conclude that our electronic tools have added many complexities to the problem of information storage, and eliminated few.

What of the future, then? A likely scenario is that we will continue to progressively lose content even though much of the foregoing is generally known. A number of factors lead to this end point. Continually migrating data to new media, preserving standards and maintaining continuity of content is an expensive and demanding requirement. Public agency funding is stressed, and is likely to continue that way for some time. Some are beginning to attach costs to content they have gathered or developed, presumably in an effort to defray or recoup operating costs. Proprietary interests offer apparent solutions, but it is arguable whether the interests behind those solutions will meet future needs. Beyond this, emerging national security needs may impact the availability or access requirements for some kinds of information. A likely end point is that in contrast to the ready availability of information that we currently experience, we will enter a time of increasingly complex access problems.

This trajectory has several implications. One is that there will be a period where content access will be more complex. Another is that there will be a permanent loss of information, because for some kinds of content, records lost are records permanently gone. The extent of this erosion remains to be seen, but it can be considered for convenience in two contexts, namely data that represent primary physical phenomena, and data that are derived (designs, plans, models and so on).

Primary physical data, such as rainfall, temperature, and other meteorological data, are generally made available by public entities that have an interest in long-term data preservation and resources to properly manage that content. Although there are likely to be issues along the way, we see no inherent reason why management of these types of data in 2050 will be fundamentally different from what is experienced now. There will be a generally standard format for information, but also a constant pressure as technology changes to migrate historical content to newer forms. A danger after such migration is that there will be an incentive to destroy the original source.

For example, let’s consider the Google Books project. Copyright and revenue issues aside, scanning all known literature into referenced and searchable files is indeed a worthy endeavor, and a great service to mankind, perhaps one of the best yet conceived. The activity may preserve documents from antiquity to present and the associated information. But what of the original sources, once the electronic content is fully converted and available? Perhaps many will be destroyed to make shelf space for more physical volumes, but years later we may discover a single missing page in the electronic image. If the original is long destroyed then so is that knowledge, either lost forever or, if important enough, requiring re-constitution. Such total loss of knowledge is unlikely, but no one knows what is needed in the future, so we cannot make perfect value judgments now about what must be preserved and what can be sacrificed. It may be that this loss can be slowed, not only by consciously selecting media and behaviors that emphasize durability, but by maintaining reference copies of content as long as possible, thereby reducing the need to make copies of copies along the way. Hence this is a compelling argument that electronic content should be considered working material and somewhere a physical archive should be maintained on a medium with long lifetime and in a language that will be decipherable to future generations.

We cannot comment on how likely it is that this need will be met, but we note that the prospects seem dim. The National Aeronautics and Space Administration (NASA) may well represent one of the pinnacles of human accomplishment in their role in sending humans to the moon. They are presumably not only technically inclined but aware of the transcendent importance of the records surrounding their history of accomplishment. However, it has been reported in the popular press (Kaufmann 2007) and by NASA (2009) that they have had difficulty finding video footage of the moon landing, and had to overcome obstacles accessing and playing back footage because of the need to address obsolete recording formats and equipment. If this is the case, what hope is there that less exalted but still critical records will be maintained by agencies or owners with a lesser technical pedigree?

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Another concern is indications that some agencies may be inclined to vest the data for which they are responsible in proprietary frameworks, which in some cases could imply that they must be managed and accessed through software or services of a third party. We concur with the need to set effective standards, but note that there are implications to this kind of stance that range from added cost to the potential that data ownership is in an extreme case effectively ceded to a private entity. If that happens, the potential for a negative outcome is substantial. Future data users may have to pay a third party for access to information they need. Beyond that, the ultimate decisions for the continued maintenance of data are *de facto* ceded to that third party. Thus, in the 2050 scenario, basic data are no longer freely available, but constitute a profit-making commodity. Further, depending on the vendor, the data could in some cases disappear entirely either through a market based vendor decision or perhaps through the disappearance of the vendor and their infrastructure.

The second data context, derived data, is also problematic. Current state-of-practice puts little limitation on engineering firms or other enterprises as to how derived data are preserved and maintained. Enterprises have developed solutions based on a range of proprietary and locally developed solutions, in a range of formats and using a range of tools. In the long run, several issues may have to be addressed. One is the value of the content. Even though the system itself may save images of data dependably, the value of the images may be nil if the software it serves is obsolete and no migration pathway exists. It is not known how many enterprises have a program to refresh data in their care so that it remains viable as technology changes, or have taken steps to store the data in a format that is likely to be at least viewable in the long term. Engineering practice has not faced this issue in quite the same way in the past, because the "flat files" that were so characteristic of traditional engineering record-keeping in the past did not have the same kinds of long-term problems. They may have been susceptible to water damage, rodents, fire or other catastrophes, but they were at least viewable and generally understandable if found. Even substantially damaged physical drawings may still convey some remnant portion of the original design intent, whereas it's unlikely that a partial portion of an electronic design file in an undocumented proprietary format will retain any of the design information.

A complicating factor in this situation is the metadata an enterprise may choose to associate with the data in their care. Often identified by keys such as project names or numbers, they may or may not be easily located in the future. The chosen metadata may not be suitable for arbitrary future searches, and may not lead to confident recovery or provenance in the event that the data are needed. Prudent practice in metadata selection and effective search engines are a remedy to part of this problem, but do not solve all things. For example, distinguishing between two similar source documents in the longer term may be difficult, so it may be relatively easy to get "close" to the right data with a suitable search engine, but impossible to find the "right" data if the associated metadata are inadequate.

A related danger in metadata-referenced information (with no solution offered by the authors other than awareness and vigilance) is that the metafile index (the pointers to the actual data) can be moved or migrated, but the source data left in-place or moved into a location that the pointers cannot find. In this situation, which we anecdotally have heard happens with regularity in small system upgrades if the loss of path is not detected early, the metadata index is no longer useful, and simply a memory that at some time in the past certain data existed somewhere.

The overall picture is that there is a reasonable likelihood that some categories of information will persist in the future reasonably well but other categories will prove to be problematic. The information equivalent of thermodynamic entropy is always at work, and the degradation of information is inexorable and progressive. If this degradation acts faster than the degradation of the physical works, an outcome could be infrastructure documented only by the infrastructure's existence, not by a reliable or accessible set of "as-builts" or other documentation. We believe that by 2050, the calculations behind and origins of many features in the ground today will have become a mystery. We hope that by 2050 the lessons learned surrounding this entropy will have led to dependable truly long term archiving of engineering information, but we don't assert that this is likely.

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A rather different direction emerging in information lies in the sources of general technical content. Traditional sources of content, such as journals and other publications, are now supplemented with a wide range of on-line resources. Wikipedia, user groups and other alternatives publish content that purport to be accurate. More than an expanded offering, electronically offered content is becoming a primary delivery vehicle.

As traditional sources of content shift to on-line formats, they tend to become more available. However, we expect that physical technical publications as we have known them will all but disappear as 2050 approaches. The multiple pressures of environmental stewardship and cost, as well as the inherent physical limitations, will eventually eliminate traditional publications except in special circumstances.

Unfortunately, we don't believe that a massive shift to e-delivery will be an unalloyed positive change. Even now, many reputable journals are not available to second generation users (those who were not initially subscribers or purchasers) for free. They are accessed either directly or through third parties for a fee that can be quite substantial. The ability to browse back through years of a journal in a library and select related content from seemingly unrelated titles is rapidly disappearing, and changes in access are evident. Even physical libraries are choosing all-electronic holdings, and new profit avenues are emerging. Consider abstracting, once a modestly lucrative sideline that is becoming more crucial as a primary way to communicate content prior to access. Abstracts don't always provide a useful indication of content and we speculate that in the near future the display of content for a short time (say a few hours) with some mechanism to prevent screen capture and printing could provide a mechanism to browse holdings rather than browse abstracts. A clever entrepreneur might be able to profit from a mechanism based on charging a connection time fee for browsing content fully rather than a per-document fee based on an abstract that may or may not provide a useful indication of content.

Whatever happens, we have no doubt that the profit motive will be present in some form, and that through 2050 there will be endless attempts to restrict or control information access and to implement ways to visit further fees on those looking for information. Whether this profit focus will benefit the originators of content or merely the incidental third party "owners" of that content remains to be seen.

Counterpressures to the attempts to assert ownership of third party information exist, and will no doubt continue. A person searching for information is therefore likely to find many answers for free from the "grey" on-line literature using a basic search engine. Finding reputable content from a more formal repository requires a different set of search skills and a willingness to spend possibly significant amounts of money to obtain content. The result, compounded by generations accustomed to finding content for casual purposes from ubiquitous on-line sources, may be a tendency to rely on "grey" sources rather than more credible content. This tendency will likely be more pronounced in professional practice than in academic contexts or agency offices where direct and free (at least to the individual) access to the formal literature is facilitated. The question that emerges is whether or not a groundswell recognition of and response to this situation of reliance on "grey" sources will emerge.

We define "content accreditation" as a term for some agreed and formal mechanisms that could credibly constitute a substantiation that a particular item of information is factual and as cited without purporting to defend or endorse that information other than speaking to its authenticity. There are instances that parallel this kind of endorsement now. For example, the US Environmental Protection Agency (USEPA) has a practice of requiring specific quality control checks on secondary data (e.g. data cited in a research report but not generated as a part of that report; USEPA 2006). As the decades pass and content (all of it easily searchable) continues to accrue on a world-wide basis, the value of content accreditation will become more apparent. The attachment of an institutional endorsement to a publication will have increased value, as it will become a primary filter for what we now refer to as "refereed" or otherwise "proven" content. We suggest that the value of association of content with an accrediting institution, coupled with the shift away from traditional publication models for revenue generation, is likely to push entities that previously relied on hard-copy publication for revenue towards new profit paradigms. Will we see charges levied for naming a source, rather than for access to content?

IMPACTS ON PROFESSIONALISM

Similar to the data issues we face, there will be pressures on engineering as technical software applications evolve. In its first emergence in this profession, software tended to be the result of professional engineering efforts and was freely available. It didn't take long for profit makers to enter the field, and a rich set of proprietary tools now exists for use by engineers. The available software is commonly closed source (i.e., the code is unavailable) and sometimes even the data formats used by the software are proprietary and opaque to the user. Even where software is open to the user, knowledge of programming in the engineering profession is under downward pressure and the ability to read and understand code is increasingly limited in the profession. The concurrent increase in sophistication of engineering software means that the effort to truly understand it becomes increasingly difficult over time. Many new graduates are well versed in the use of some technology or software, but less skilled in the basic computations and principles that those tools embody. Thus, as 2050 approaches, we wonder if hands-on understanding of the theory behind the software will prevail, or not. Efforts to increase engineering education standards are underway and will likely address some of this, but the basic opacity of the tools does not seem to have a remedy.

We suggest, therefore, that in the future we will see a time where engineers will pervasively use software tools that they can't truly understand or verify in detail. The results of such tools will perforce be accepted as authoritative, perhaps backed up by simple calculations or parity checks, but otherwise accepted as-is. One then must question whether engineering will truly be practiced in a professional way, at least as understood today. There are arguments for and against the implications of software on professional functions, but their resolution is beyond the scope of this chapter. What is of interest here is how the profession will respond to the reality that some aspects of engineering functionality and judgment will be subsumed by software.

Another major change agent will be failures arising from software limitations. Today, software that is inherently flawed is tolerated to a degree we find astonishing, much more than would be accepted in humans undertaking the same function. Computational errors in water resources software have been observed and accepted for years; we accept this as a reasonable consequence of the early evolution of this field, when many lessons about numerical methods and software development were being learned. This acceptance persists. Vendors, for example, are understandably reluctant to accept liability for their products (for examples read typical End User License Agreements addressing damages arising from use of software), and users routinely sign and accept agreements for software that in turn accept that denial of liability. At some point, however, we may see an evolution in thinking, where software flaws are less accepted and where consequences are recognized as tied to the apparently inevitable use of software taken past the point where an engineer can truly control all aspects of the computation. If and when this happens, there may be a move towards accreditation of software on a par with accreditation of engineers. Steps in this direction are evident. Many entities express preferences or adopt *de facto* standards by encouraging the use of particular software packages. The US Army Corps of Engineers publishes a list that indicates which software is acceptable, preferred or mandatory. Some vendors seek peer review in an attempt to validate their offerings and promote their use. It seems a reasonable leap to consider software accreditation on a professional basis in cases where the software is linked to the professional practice of engineering.

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What emerges is a question as to how this would be regulated, monitored and pursued on a continuing basis. The groups that regulate the professional practice of engineering are not equipped to do this. We anticipate there will also likely be resistance to this evolution on the part of vendors, who have little to benefit by implicitly accepting greater risk as their products are used and in some cases may have concerns about their code being made visible or otherwise audited in ways they may not be able to control. The USEPA Environmental Technology Verification (ETV) program targeting software for verification was excellent, but some vendors absented themselves from the table even though circumstances were designed to respect their interests in privacy and protection of intellectual property.

Despite the complexity of the problem, given the increasing reliance on software, the increasing substitution of software for human judgment and the eventual need to associate liability with more than the engineer, we feel it is inevitable that the hurdle of software accreditation will be faced by 2050, if not resolved by then.

REAL WORLD REPRESENTATION

Another change in capability driven by IT that has the potential to profoundly affect professional practice can be found in the convergence of several factors related to the way we define the physical world around us. Two of them are a radical increase in the ability to address and access locations around the earth, and an evolution in the ability to deploy sensing devices to the point where they are cheap enough to deploy, in quantity, as elements of any physical project.

Addressing is fundamental, because the ability to resolve elements of the physical world is dependent on the ability to locate and monitor them. We have stipulated that internet connectivity and speed will not be limiting, so the question is whether or not fine-grained addressing is stressed in 2050. The currently dominant addressing scheme for the internet has served well, but it will be exhausted (saturated) well before 2050, not long from the time of writing this chapter. It will be replaced by a successor that has a vastly greater ability to uniquely identify locations around the earth; this process is under way now. Continued evolution over the next decades makes it clear that it is realistic to expect that by 2050, every conceivable physical item of interest to engineers at a gross physical level will be addressable. We note that this may occur not through the application of internet technology, but rather through the application of other connectivity mechanisms, and it is moot as to which option eventually emerges. At the same time, sensing technology is increasing rapidly in its ability to identify locations and conditions at a location. Satellite technology, airborne sensing, Radio Frequency Identification (RFID) technology (www.rfidjournal.com), and many other evolving sensing methods point to a future ability to sense conditions at any point and time to a degree that makes the essentially perfect knowledge of the state of a physical system a realistic possibility.

Coupling processing speed, storage, sensing and addressability, it is possible to foresee the construction of engineering applications by 2050 that are today only concepts and possibilities. Rather than the often somewhat crude systems that currently characterize practice, the potential exists that large-scale systems will be manageable based on real-time sensing, processing and intervention at a highly accurate level. Rule-based planning will be reduced in significance, and methods that rely on physical prediction will become the norm. Rather than static assumptions, dynamic behaviors will be accommodated in engineering analyses of physical systems. Feed-forward control capabilities that have hitherto only been possible by engineers in plants and factories will be extended to natural systems. Numerous other examples of paradigm changes will accompany pervasive communication coupled with connectivity and sensing, but the essential point is the impact on routine engineering practice will be substantial. This evolution has only just begun, but by 2050 it has the potential to dominate engineering practice.

We note that the value of real-time control of natural systems is predicated on the ability to predict the responses of a system to human intervention, and that many biological systems have response times that are measured in years or decades. Given the number of variables and the complexity of scientific research before these responses are fully understood, we expect that there are decades of research into natural systems that must occur before real time control can be perfected. It is our speculation that by 2050, the IT infrastructure to accomplish this will be fully available, but the natural sciences basis for physically based interpretation and prediction will still be evolving. We therefore expect that real-time control will be pervasive and unencumbered by IT limitations, but still developing where long period natural system responses (multiple years or decades) are concerned.

CONCLUSION

The future of IT is impossible to predict except perhaps to note that it will expand in speed and capacity and decrease in cost very substantially between the time of writing and 2050. This expansion will bring with it both enhancements and losses in engineering practice. Many currently available sources of information will be lost, and there may be a consequent shift in the notion of information accreditation. Fees for basic data, either direct or as a result of the need to purchase applications to access those data, may be common and significant. Engineering software will continue to evolve and there may be a drive towards formal accreditation of common engineering tools and a limitation of the ability to independently (i.e. without using certified tools) practice engineering. The ability to fully represent the real world in analysis and simulation tools will undergo a change that revolutionizes engineering practice in this area by enabling fine-grained representation of the real world, perhaps limited only by the rate of increase in scientific knowledge as opposed to engineering capability. We will therefore experience changes in practice not just in speed and scale, but in kind. The human skill sets required to manage and work effectively in this changing environment will evolve; syntax, sources and organizational models will change, but the ability to apply intellect and propositional logic will not. Knowledge workers of the future will require much of the fundamental skills of today, but will extend their abilities to encompass specific needs that result from the evolution in pervasively used information technology.

Some of these hypotheses are troubling, and some exciting. Whatever the case, the likelihood of many of them rests on our willingness to accept a particular outcome. In this regard, the future is ours to determine. Perhaps the greatest value of these speculations is that if we don’t like the look of where we might end up, we can be inspired to forestall some of the more negative future histories in favor of better ones.

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