the future of work

TECHNOLOGY FOUNDATIONS

Technology Horizons Program
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INSTITUTE FOR THE FUTURE

About the ...

INSTITUTE FOR THE FUTURE

The Institute for the Future is an independent, nonprofit strategic research group with nearly 40 years of forecasting experience. The core of our work is identifying emerging trends and discontinuities that will transform global society and the global marketplace. We provide our members with insights into business strategy, design process, innovation, and social dilemmas. Our research generates the foresight needed to create insights that lead to action. Our research spans a broad territory of deeply transformative trends, from health and health care to technology, the workplace, and human identity. The Institute for the Future is based in Palo Alto, California.

TECHNOLOGY HORIZONS PROGRAM

The Technology Horizons Program combines a deep understanding of technology and societal forces to identify and evaluate discontinuities and innovations in the next three to ten years. We help organizations develop insights and strategic tools to better position themselves for the future. Our approach to technology forecasting is unique—we put humans in the middle of our forecasts. Understanding humans as consumers, workers, householders, and community members allows IFTF to help companies look beyond technical feasibility to identify the value in new technologies, forecast adoption and diffusion patterns, and discover new market opportunities and threats.

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introduction

Over the past year, IFTF's Technology Horizons Program has been studying the technological foundations that are altering and shaping the way we measure and value work. It is here that we see an important shift in technology development, from the dualism of technology push or pull, to a more balanced approach to innovation. Basic scientific research is opening the doors to new applications that will further transform the way we work. Meanwhile, the more we learn about ourselves and the way we work, the better we'll be at developing technologies that serve our changing needs in the workplace of tomorrow.

And so, while the future of work won't likely be driven by any specific technologies, it will certainly be enabled by a confluence of many. And as usual, the largest impacts occur at the hotspots where multiple trends intersect. It's on these technology foundations that we built our framework for exploring the future of work. In the following report, Technology Foundations for the Future of Work (IFTF SR-1092 B), we shed light on seven enabling technology clusters that informed our companion report, The Future of Work Perspectives (IFTF SR-1092 A).

To begin, we looked out ten years to review the impact of new technologies that are shaping the way we work. These impacts will be felt in a variety of ways:

From Just-in-Time to Proactive Contextual Computing

We'll move from time-consuming foreground computing to ambient, proactive, contextual computing. This means that our smart, wearable systems will negotiate with embedded sensor networks and pervasive information to process patterns of our activities, patterns of places where we work, and perform tasks on our behalf.

From Sparsely Sourced Analysis to Deeply Informed Decisions

Our most important decision-making and planning practices will change substantially. Using more powerful combined-knowledge processing applications for data mining, semantic analysis, numeric analysis, pattern processing, visualization, and simulation, we are moving from making decisions based on shallow analysis and thin resource processing to deeply informed decisions and plans.

From Formal to Emergent and Cooperative Organizational Structures

New cooperation technologies, including social software and peer-to-peer architecture, will enable us to move from working in small co-located and formally aligned clusters of enterprise workgroups to larger, loosely coupled, ad hoc networks of mobile colleagues. In this new structure, we will work virtually in distributed teams cooperating on specific tasks and projects together in real time. Upon task completion, these teams will dissolve and reform in new arrangements based on the next task.

From Desk-Bound to Ubiquitous Displays

We are growing closer to a world where interaction with displays will be seamless and ubiquitous. As we move through our workspaces, our mobile personal information artifacts will be capable of seamlessly projecting a personal, common digital workspace on nearby ambient displays, on desktops, in meeting rooms and public spaces, on wearable displays, and on dashboard screens.

From Real World to Virtual World Interaction

Through a combination of pervasive connectivity, abundant computational resources, and new graphic- and media-rich telecommunications, we will be able to stay in continuous contact with colleagues and share work tasks seamlessly in both virtual and physical spaces, regardless of location. As we see the emergence of new real worlds that combine the fluid social interactivity of applications like Second Life with the spatial integrity and veracity of Google Earth, we'll be able to meet, share data, and work together with new graphical visualizations and simulations.

In addition, there are seven key technology clusters that will enable these shifts:

1. Proactive Computing
2. Amplified Collaboration Tools and Processes
3. Sensemaking and Visualization
4. Device Webs and Sensor Webs
5. Ubiquitous Displays
6. Abundant Computation and Abundant Connectivity
7. Common 3D Graphical Interfaces

1 proactive computing

A simple progression of processes is likely to lead to fully proactive contextual communications. The first wave of this will include software applications that understand our human context: who we are, what we do, where we are. Context-aware software will improve incrementally over time. Today, we already enter our *personal context* into computerized calendars and to-do lists, providing information on what we intend to do, what we're doing, where we're going, and where we are. Google already delivers low-key targeted ads to us in context of each search. A simple thermostat adjusts air conditioners *in context* of human and energy requirements for each time and place in a building.

In the next ten years, many of these tasks will become automated and deeply personalized based on the available contextual information. For example, if a computer program "knows" a person's contextual requirements, then resource discovery can be an automatic search task. The program can proactively scan a smart calendar for available time, set appointments with colleagues, and search and summarize background data for meetings.

Contextual information about a place will be deeply rendered and served locally. Micro-local information will be cached on embedded wireless microservers. Invisible digital map data and geocoded web objects describing attributes of a place, an object, or a building will be accessible and actionable. Over time, the functions and activities of a place, the infrastructure and resources of a place, the settings of a thing or process, the environment of a place, or the health, history, culture, politics, and economics of a place will become selectively visible online in information-saturated spaces.

Physical things with wireless identification tags, like RFID, or with embedded computing engines will become responsive and programmable for robotic interaction and task delegation, and will operate proactively as new context processing software comes online. Whole environments, not just mobile robots, will operate automatically on humans' behalf.

Impact on Work

Our work processes will change gradually as many small-component systems come online. Over time, contextual computational processes will manage and operate complex automated tasks based on defined enterprise and personal requirements. We'll see automated systems that proactively search smart calendars for available time; arrange travel and logistics; schedule appointments with team members; adjust room environment, media, and network configurations; gather background data for meetings and tasks; and document and distribute meeting work products.

By proactively executing time-consuming processes ahead of time, contextual computing will enhance and uplift personal and group productivity and accelerate early adopters' leadership. Any work task will be enhanced by deep contextual information queued, accessible, and, where appropriate, already acted on.

2 amplified collaboration tools and processes

In the coming decade, emergent clusters of cooperation-amplifying processes and social networking developments, each with distinctive contributions to cooperative strategy, will gain importance in the workplace:

- **Lightweight communications infrastructures.** Self-organizing mesh networks define architectural principles for building both tools and processes that grow from the edges without obvious limits, distribute the burden of the infrastructure throughout the population of participants, and establish the foundation for the emergence of swarm intelligence in systems of people and devices. As the quality and connectivity of Web-enabled phones improve, it will become easier to stay plugged into our networks.
- **Collaborative computing clusters.** Like the SETI@home, collaborative computing clusters provide models for recovering currently squandered resources from distributed sources and for providing mutual security within a network of people and/or devices. They only work effectively when supported by explicit choices about when and how to foster cooperation versus competition.
- **Peer production networks.** Technologies like listservs and Wikis create frameworks for volunteer communities to accomplish productive work. The collective intelligence of these potentially unbounded communities creates new value by rapidly solving problems that would tax or stymie smaller workgroups. The diversity of the individuals working on one collaborative platform allows for an impressive variety of insight and input that a homogenous group would never produce. Wikipedia is the earliest, and most prevalent, example of this kind of peer production network.
- **Social mobile computing.** A cluster of principles and technologies—like Instant Messaging and Internet Relay Chat (IRC)—allow large or small groups of people, even if they are strangers, to act in a coherent and coordinated fashion in place and space, supported by information accessed in real time and real space. Twitter and Plazes are the next level in the evolution of these tools, allowing users to report their whereabouts or activities in real time to a network of people.
- **Group-forming networks.** Representing ways to support the emergence of self-organized subgroups within a large-scale network, group-forming networks create exponential growth of the network and shorten the social distance among members of the network. The networking site LinkedIn, a site that works like MySpace for the professional adult, is a good example of this kind of network. It allows people to link up with colleagues online and see patterns in and distance between professional connections. It also recommends available positions within the network that match the skills and industry a user declares on his or her profile page.

- **Social software.** Providing the tools and awareness to guide people in intelligently constructing and managing informal cooperative structures and processes to specific ends, social software amplifies, extends, and makes explicit many of the informal cooperative structures and processes that have evolved as part of human culture. Internet forums are an excellent example of this, particularly with the popularity of Lussumo's easy-to-implement Vanilla forums. Anybody with the required Web space can download the open-source software (getvanilla.com), set up a discussion forum for whatever topic(s) they want, and then approve members and designate moderators. Approved members log in to post discussion topics and comments. Last.FM applies social software to the music world by allowing users to create profiles that publicly display the track metadata "scrobbled," or transmitted, from iTunes and other music players. Users can add friends, track their listening habits, write journal entries, announce that they are attending certain live shows, and see who else may be attending the same shows. A user can also download Last.FM's radio software to listen to recommendation-based stations generated from that individual's listening habits. Other features include recommendations from friends and "Similar Artists" groupings that enable a user's discovery of artists they might like based on what the user already likes.
- **Social accounting tools.** These tools suggest methods and structures to measure social connectedness and establish trust among large communities of strangers. As a result, they build reputation along dimensions that are appropriate to a specific context and create a visible history of individual behavior within a community. AskMetafilter, a section of the community weblog MetaFilter, allows users to post a single question soliciting advice from other members of the community. Community members post comments that they hope will answer the original poster's question, and the original poster can mark an answer as "Best Answer" when he or she is satisfied with a response. Because the community is a large and active group of people with different interests, backgrounds, and skill sets, questions usually find an answer from somebody. All of a user's recent posts can be tracked, creating a visible history of comments and advice. AskMetafilter even allows anonymous users to post a question and solicit the advice of the user community.
- **Knowledge collectives.** A particularly powerful cooperative process, knowledge collectives model the structures, rules, and practices for managing a constantly changing resource as a commons. They secure the commons against deliberate or accidental destruction and degradation, multiply its productivity, and make it easily accessible for wide-ranging uses. The news-ranking site Digg is a knowledge collective where registered users submit a blog or an article that they find interesting. Once submitted, users vote on that article, or "digg" it. The more votes an article has, the more people within the collective have deemed it newsworthy. Comments are also ranked so a user can digg an insightful comment and "bury" ones that are incendiary or just plain destructive. When a comment is buried, it's no longer visible. This system of digging and burying allows the users to enforce a general code of conduct on the site while preventing it from becoming inaccessible to the outside.

Impact on Work

Emerging digital technologies present new opportunities for developing complex cooperative strategies that change the way people work together to solve problems and generate wealth. As these strategies become second nature, they will have transformative effects on the modern workplace. Diversity will not be about color or creed, but about working and learning styles of amplified individuals. Human resources will need to adjust to manage this new form of radical diversity.

- A new crop of tools will change how we cultivate and conceive of collective intelligence. The previous generation of knowledge management tools, requiring extensive training to use competently, forced users to change and adapt their working habits to the system, focused on particular projects and groups, and were closed proprietary systems. The new tools, however, are ethnographic and bottom up. Since they are inherently sociable, they augment social processes of sharing. While many community and workgroup resources leave knowledge invisible and untapped, new cooperative technologies will better harness group resources to make them common and accessible.
- In this sociable view of collective intelligence, the new core competency in the workplace—and the economy at large—will be the ability to make logical connections. Both tools and people will become skilled at identifying and facilitating new links between ideas, web sites or articles, and people.
- Enabled by cooperation technologies, a number of new organizational forms offering new structures for production based on cooperation rather than competition will emerge. These marketplace experiments, from eBay to Wikipedia, from Linux to Apache, from SETI to Folding@home, will pose surprising challenges to traditional economic practices by shifting from top-down organizational structures to emergent ones formed from the bottom up.

3 sensemaking and visualization

We have already arrived at a place where we have access to a staggering amount of digital information, due largely in part to pervasive technology. More knowledge than ever is at our fingertips. Humans and machines will only continue to accelerate the creation and storage of this growing amount of data and media to be searched, harvested, and rendered.

Google has proven that great search heuristics and algorithms can provide useful results running simultaneously on a platform of thousands of CPUs. While it does have great software and thousands of computers, Google does not own the data on the Web, nor does Google use large, private data systems to provide any complex combined analysis of information from the Web at large. In the future, we will all have network access to easy-to-use, massively powerful decision-making and planning tools running on common utility supercomputer grids. These grids will be spread across thousands of computers distributed across the Internet.

There are six component-technology clusters supporting the change from sparsely sourced to deeply informed decision making and planning:

- **Data mining** is, according to usability.com, "The use of statistical and visualization techniques to uncover trends and relationships within massive databases. Data mining is common with financial data, medical data, census data, and across the web as a whole. The trends sought after are often non-obvious and require substantial data manipulation, either through a directed search to test a particular hypothesis or through less bounded exploration to find unexpected results."
- **Numerical modeling** is a specifically mathematic analysis applied to utilizing and harvesting floods of numeric data. One example of this would be to calculate position data and physics of a real-time, high-resolution animated simulation of complex phenomena. Another example would be harvesting and managing real-time information from thousands of sensors embedded in things like RFID chips on items in a warehouse or on a factory assembly line.
- **Semantic processing** is the foundation of programs that understand language, and will be increasingly useful in performing tasks that demand a sophisticated knowledge of the specific language of a project or task domain. XML and follow-on semantic Web programs enable language to be self-identifying by carrying pointers to Web resources that are able to automatically translate or otherwise act on the data. Over the next few years, enterprises will develop and adopt structured vocabularies, ontologies, and schemas of enterprise knowledge and metadata (data about data—usually invisible to an end user). This will allow unprecedented levels of useful insight and actionable knowledge to be created and harvested from different, previously unconnected, databases and network-served resources.

- **Knowledge visualization and simulation** are specific graphical and tactile user-interface techniques for interacting with massive and complex knowledge. The greatest benefit of visualization is its ability to communicate concepts difficult to adequately describe or grasp in words: things that are too large (a galaxy), too small (an electron), too slow (an eon), too quick (a nanosecond), too complex (an engine), an ecosystem (a weather system), or too abstract (an equation, a heuristic, a process, a trend, or an analytic model). Knowledge visualization and computer simulations give us the ability to operate and manage otherwise unimaginable tasks.
- **Pattern processing** is the mathematical analysis of two-dimensional images like sensor patterns, photographs, satellite pictures, facial expressions, video images, and voice-prints. As we continue to learn how to better process patterns, our computers will be able to interpret meaningful information from an otherwise opaque environment. Pattern processing is an integral part of voice recognition and biometric authentication techniques for confirming our identities based on retinal patterns, genetics, voice, and fingerprints.

Impact on Work

Compared to our limited capabilities today, working people will have unprecedented powerful capabilities to access, manage, manipulate, and visualize abstract processes and vast datasets. Subsequently, each decision and plan we make will be based on a much deeper understanding of relevant data. Mathematics will become a necessary resource for sorting this information by redefining our workflow processes. Machines will not replace humans but they will be necessary mediators between data overflow and human analysts. The employee of the future will have sharp analytic capabilities, able to make sense of the filtered data.

4 device web and sensor webs

We are just beginning to move from a world where our computer and communications resources are tethered to a desktop or limited to a portable interactive “brick” and into a new world—a visible world—where we’ll be wearing a complex variety of intelligent artifacts interacting with environments. Powerful networks of devices, sensors, and “place” servers like the ones listed below will be embedded in these environments.

Wearable Devices

Identity manager/ID badge
Digital wallet for purchases
Digital key ring
Personal data storage
Personal data viewer
Keyboards and keypads
Mobile IP phone/net communicator
Location sensor
Media players/recorders
Cursor pointer/remote control
Personal health sensors

Embedded Devices and Sensors

Identity recognizers, biometric interfaces
Motion and gesture sensors
Input interfaces
Digital locks
Commerce processors
Network interfaces
Range and position sensors
Media players and recorders
Biological and environmental sensors

Impact on Work

When it comes to workplace infrastructure, most companies will have to make a major shift in thinking during the next decade. The traditional concept of workplace will transform from wired desks to wearable wireless personal networks. Workers' bodies will become the dominant infrastructure of knowledge work. The physical and cyber landscapes will merge, enabling a major shift in workers' sensory perception and driving a new kind of nomadic work pattern. Instead of cyberspace being distinct from the material world, workers will perceive the two as fused. Instead of peering at cyberspace through the screen, they will find it embedded in the objects of their daily life and perhaps even in their own bodies.

5 ubiquitous displays

Another effect of the visible world will be the way information is displayed and shared within the workplace. Ambient displays are already widely prototyped in image labs worldwide, and as we move into a new world of ubiquitous computing, a wide range of displays will become even more useful as costs are lowered and more robust products become available:

- **Tabletop workspace.** Horizontal flat displays that support multiple users sharing and moving around a common work surface.
- **Smart walls.** Large format displays that seamlessly display users' personal work environments over broadband wireless connections.
- **Web signs.** Digital signs that are actually flexibly programmable Web displays for specific purposes.
- **Public display boards**. Similar to Web signs yet more general function displays for news and mobile workers' transitory interactions as they pass by.
- **Floating augmented reality.** Eventually viewable through lightweight head-mounted displays or perhaps, in the far future, through direct neural connections.
- **OLEDS and OLEPs.** Organic light-emitting diodes and organic light-emitting polymers will be used in the future for paper-thin digital displays, e-paper, and textile displays.
- **Chair-top work surfaces/control pads.** In time, even our seating will have embedded digital controls for interacting with ambient displays.

Impact on Work

Ambient displays will expand collaborative productivity of existing workspaces and open public and shared spaces for seamless personal productivity. As we move through our workspaces, our mobile personal information artifacts will be capable of seamlessly projecting a personal digital workspace on nearby common ambient displays, on desktops, in meeting rooms and public spaces, on wearable displays, and on dashboard screens.

6 abundant computation and abundant connectivity

Today, application capabilities are limited by desktop CPUs; handheld, lightweight computing processes; and limited, uneven bandwidth to network resources. In the future, users will have ubiquitous broadband access to almost unlimited supercomputer power, in grids of thousands of individual CPUs. These clusters will be harnessed as necessary to casually solve and regularly execute computationally intense tasks like contextual computing, knowledge visualization, simulation, and pattern processing. The following are key component technologies of utility supercomputing:

- **On-demand supercomputing (grid computing).** The National Science Foundation, IBM, Sun, HP, Oracle, and most notably Google, are prototyping operating environments for thousands of individual CPUs to be combined anytime as an on-demand utility supercomputing resource. This is, in fact, exactly what Google Web search has been designed to do from the beginning.
- **Broadband infrastructures.** Over time, our entire fiber-optic backbone infrastructure will be upgraded, resulting in massive improvements in throughput by combining and transmitting multiple signals simultaneously at different wavelengths on the same fiber. This technique is called Wave Division Multiplexing (WDM), or Dense Wave Division Multiplexing.
- **Ubiquitous wireless broadband.** Within five to ten years, it is unlikely that any user will ever be out of range of a wireless broadband interface to on-demand supercomputing capabilities. We're already seeing many extensions to Wi-Fi and, like Wi-Fi, these new networks can be configured economically, working independent of current wireless carriers. Beyond Wi-Fi (802.11a,b,g,n), the next stage is Wi-Max (802.16), offering 70 megabits over tens of kilometers. Following Wi-Max we'll see WMANs (802.20), wireless metropolitan area networks of 1 megabit for mobile user, and then Cognitive Radio (802.22), promising gigabits of service over five to ten kilometers.
- **Mesh radio.** Operating as a switch or router, a radio or wireless device allows the casual ad hoc organization of custom secure networks independent of traditional carriers and LAN infrastructures.
- **Ultra wideband.** Wireless technology for gigabits-per-second wireless signals spread across bands and spectrum. See IEEE 802.22.

- **Software-defined radios.** High performance digital signal processors (DSP) are able to operate as radios on various bands. They're defined programmatically by software instead of hardware for each radio band so that general-purpose devices can be deployed and tailored for communications to specific and different wireless environments.

Impact on Work

Users will have ubiquitous access to broadband networks in buildings, outdoors, and while mobile. Utility computing will enable people to have unprecedented capabilities to access, manage, manipulate, and visualize abstract process and vast datasets. There will be little or no limitations on users' capabilities to work on complex tasks or to collaborate with colleagues in real time in multimedia, regardless of location. The workplace will no longer be tethered to a single space, cutting down on costs of business travel. One impact of this will be increased sustainability.

7 3D graphical interfaces

As virtual worlds like Google Earth, Microsoft Virtual Earth, NASA WorldWind, ESRI ARCglobe, and Computer-Aided Design systems like Autodesk begin to share data across legacy 3D GIS &CAD environments, new purely virtual worlds like Linden Lab will launch 3D social applications in the real world—virtual worlds based on geospatial coordinates instead of Second Life's random geography. Meanwhile, mobile augmented reality developers will likely build geocoded 3D frameworks to hang links on for services like Nokia's MARA prototype (http://www.technologyreview.com/Infotech/18291/). Consensus 3 D geowebs like GEON (http://www.geongrid.org/about.html) will also be the basis for the worldwide sensorwebs and for visualizations and simulations for transdisciplinary problem solving like macro-ecology, climate models, zooanotic or animal-borne diseases, and emergency response.

Instead of multiple 3 D geowebs, we'll begin to see harmonized 3 D data and media structures for producers and service operators. These structures will produce and share 3 D data for computational environments; places, buildings, and things; and people and avatars across enterprise, Web, and geospatial context.

During the 1990s, NASA's Digital Earth programs—initiated by Vice President Al Gore—developed a prototype Digital Earth Reference Model (DERM) for cross-agency use by members of the Interagency Working Group on Digital Earth. Although that work has now been abandoned to collect dust on a shelf—out of date, given the future requirements—efforts to revive the project have begun, considering a consensus reference specification for a 3 D geoweb: a standard Digital Earth. Google, no doubt, sees Keyhole Markup Language (KML) as the foundation. KML is Google's proprietary spatial markup language, recently released to the Open Geospatial Consortium (OGC) for standardization. Other large players like Microsoft and the dominant enterprise GIS software company, ESRI, are building their own frameworks. Still, geospatial communities—U.S. government, OGC, W3C, and SIGGRAPH—and graphic arts and gaming communities—like x3 D effort within the Web3d consortium—are beginning to converge on an integrated perspective for sharing 3 D data structures.

Over time, a meta-level, layered architecture will be developed for unified earth and geo-related computing, refining a model that includes the following topics into an ideally coherent and rigorous framework for optimally sharing and using data across all Web, geospatial and scientific contexts alike:

- Geodesics, where experts are still refining descriptions of the shape of the earth, and where new coordinate systems are argued.
- Sensor data generation and labeling.
- Geodata and hypermedia coding/decoding/transcoding.
- Open source networked geodata—libraries and feeds—of raw sensor data (streaming media, tiles, 3 D objects, 2 Dvectors, polygons, points, text, etc.).
- Geo metadata models: formal ontologies and logical description as frameworks for mining informal users' tag systems.
- Geo server and middleware models for efficient saving, searching, and sharing of all kinds of geodata.
- Sensemaking inference and other spatial intelligence.
- Rendering software for combining many sources of geodata into unified useful views for many kinds of interaction.
- User software/sharing/saving/serving/searching/rendering.

As a coherent dialog evolves between constituent communities in loosely connected dialogs, consensus interoperable models for a 3 D real world virtual world will coalesce.

Impact on Work

Currently, 3 D data is not commonly used in many business processes mainly because it's hard to create and share across domains and applications. Over the next ten years, creation of useful 3 D data for visualizations, simulations, and collaboration will become much easier. Our capabilities to effectively utilize abundant computational resources and vast knowledge bases will increase dramatically as we learn to use new user interfaces for manipulating 3 D objects, data, and media in our social interactions using real-person avatars; for managing and interacting with 3 D location intelligence; for interacting with autonomous sensor networks processing real time geodata; for managing and exploring large transdisciplinary problem spaces like real time logistics and manufacturing, public health ecosystem interaction models, large-scale emergency response, large-scale science like planetary meteorology, and large-scale ecosystem modeling.