**WHEN THINGS START TO THINK | Chapter 14: Things That Think**

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In the beginning, our collective vision of computation was shaped by the reality: large machines, with lots of blinking lights, that were used by specialists doing rather ominous things for the military or industry. *Popular Mechanics* in 1949 made the bold guess that “Where a calculator on the ENIAC is equipped with 18,000 vacuum tubes and weighs 30 tons, computers in the future may have only 1,000 vacuum tubes and perhaps weigh 1.5 tons.” Later came the fictional images inspired by this reality, captured by the Jetsons’ cartoon world that put the trappings of big computers everywhere, cheerfully filling their lives with the same kinds of buttons and blinking lights.

If we look around us now, the single most common reaction to computers was entirely missed by any of the historical visions: irritation. Computers taking over the world is not a pressing concern for most people. They’re more worried about figuring out where the file they were editing has gone to, why their computer won’t turn on, when a Web page will load, whether the battery will run out before they finish working, what number to call to find a live person to talk to for tech support.

The irritation can be more than petty. A 1997 wire story reported:

ISSAQUAH, Wash. (AP)—A 43-year-old man was coaxed out of his home by police after he pulled a gun on his personal computer and shot it several times, apparently in frustration.

Apparently? He shot it four times through the hard disk, once through the monitor. He was taken away for mental evaluation; they should have instead checked the computer for irrational and antisocial behavior.

There aren’t many people left who want to live in The Jetsons’s world. I realized this during the early days of the World Wide Web, when I unsuccessfully searched the Net to find a picture of the Jetsons. People had made home pages for their cats, and dogs, and cars, but no one was moved to create one for this most technological of cartoons. Given all of the inconveniences of the Information Age, who would want to confront computers in still more places?

Over the last few years an alternative vision of the home or office of the future has been emerging, a rather retro one. In the research community, the Jetsons’ use of information technology would be called “ubiquitous computing,” making computing available anywhere and everywhere. I’m much more interested in unobtrusive computing, providing solutions to problems everywhere without having to attend to the computers. By bringing smarter technology closer to people it can finally disappear.

Instead of making room for mice, your furniture and floors can electromagnetically detect your gestures. Icons leave the screen and through embedded smart materials they merge with the tangible artifacts that we live with. A few bulky display screens get replaced with changeable electronic inks wherever we now paint or print. The local controllers for these things self-organize themselves into adaptive networks that don’t break if any one element does. These data may go to and from an information furnace down in the basement, heating the bits for the whole house. This is a major appliance that handles the high-speed communication with the outside world, performs the computationally intensive tasks like rendering 3D graphics, and manages the enormous database of the accumulated experience of the household. Like any furnace it might need periodic maintenance, but when it’s working properly it’s not even noticed, delivering timely information through the information grates of the household.

A coffeemaker that has access to my bed, and my calendar, and my coffee cup, and my last few years of coffee consumption, can do a pretty good job of recognizing when I’m likely to come downstairs looking for a cup of coffee, without forcing me to program one more appliance. Although none of those steps represents a revolutionary insight into artifical intelligence, the result is the kind of sensible behavior that has been lacking in machines.

Marvin Minsky believes that the study of artificial intelligence failed to live up to its promise, not because of any lack of intelligence in the programs or the programmers, but because of the limited life experience of a computer that can’t see, or hear, or move. A child has a wealth of knowledge about how the world works that provides the common sense so noticeably absent in computers. Similarly, Seymour Papert feels that the use of computers for education has gotten stuck. We learn by manipulating, not observing. It’s only when the things around us can help teach us that learning can be woven into everyday experience. He’s not looking to duplicate the mind of a good teacher; he just wants a tennis ball that knows how it has been hit so that it can give you feedback. Marvin and Seymour are looking for answers to some of the most challenging questions about improving technology, and the deepest questions about human experience, in the simplest of places. They believe that progress is going to come from creating large systems of interacting simple elements.

Just as people like Marvin and Seymour began to realize that, and people like Joe Jacobson and I began to discover that we could make furniture that could see or printing that could change, some unusual companies started showing up in the Media Lab. Steelcase was wondering whether your tabletop should be as smart as your laptop. Nike was thinking about the implications of the World Wide Web for footwear. This convergence of research interests, technological capabilities, and industrial applications led to the creation in 1995 of a new research consortium, called Things That Think (TTT).

The first decade of the Media Lab’s life was devoted to the recognition that content transcends its physical representation. A story is much more than just ink on paper, or silver halide in celluloid film; once it is represented digitally then it’s no longer necessary to create an artificial technical boundary between words and images, sights and sounds. The most important contribution from this era was iconoclasm. It was widely accepted then that it was the job of governments and industry alliances to fight over incompatible standards for new generations of television; now it’s broadly accepted that the introduction of intelligence into the transmitter and receiver means that digital television can be scalable, so that the encoding can change if the goal is to send a little image to a portable screen or a giant image to a theater screen, and a program can bring a broader context with it, such as annotated commentary or connections to current information.

In its second decade, more and more of the work of the Media Lab revolves around the recognition that capable bits need capable atoms. The 150 or so industrial sponsors are loosely organized into three broad consortia. Walter Bender’s News in the Future has content providers, asking how to search, filter, personalize, and distribute timely information. Andy Lippman’s Digital Life is looking at what it means to live in a world of information, with questions of education, and identity, and entertainment. And TTT looks directly at how the physical world meets the logical world. These three groups can roughly be thought of as the bits, the people, and the atoms. They all need one another, but each provides a community to help focus on those domains. They overlap in focused groups at the center for areas like toys or cars.

TTT comprises forty companies broadly exploring intelligence everywhere but in traditional computers. The bottom layer that I direct is developing the materials and mechanisms to let objects sense and compute and communicate. The partners include technology companies like HP and Motorola considering new markets for their chips, and things makers like Nike and Steelcase. The middle level, run by Mike Hawley, looks at how to build systems out of these elements. If my shoe, and yours, is a computer, how do they find each other anywhere on the planet? Companies like Microsoft, AT&T, and Deutsche Telekom are interested in this kind of connectivity. At the top, guided by Tod Machover, are all of the capabilities enabled by a planet full of communicating footwear.

The application companies are asking mission-critical information technology questions that are wholly unmet right now, literally keeping the CEOs up at night worrying about how to address them. Moving computing from mainframes to the desktop was a trivial step; they need it out in the world where their business happens. Disney, for example, is interested in personalization. A theme park attraction can’t respond appropriately if it knows only your average height and weight, not your language and gender. How can a one-cent ticket contain that information and be read from a distance? Federal Express has something of a mainframe model, sending all the packages to a central hub for processing. Just as the Internet introduced packet switching, routing chunks of data wherever they need to go, FedEx would like a package-switched network. How can a one-cent envelope route itself? Steelcase’s customers want the file cabinets to find the file folders: how can a one-cent file folder communicate its contents? Becton Dickinson made a billion medical syringes last year that are sterile, sharp, and cost a penny. Diabetics are notoriously bad at monitoring their insulin intake; how can a smart syringe be made for a penny? Adding much more than that destroys the whole business model.

Health care is an interesting example. Right now it’s really sick care, a system that gets invoked to fix problems rather than anticipate them. One of the biggest medical issues is compliance, getting people to do what’s needed to keep them well. Billions of dollars are spent annually just taking care of people who didn’t take their medicine, or took too much, or took the wrong kind. In a TTT world, the medicine cabinet could monitor the medicine consumption, the toilet could perform routine chemical analyses, both could be connected to the doctor to report aberrations, and to the pharmacy to order refills, delivered by FedEx (along with the milk ordered by the refrigerator and the washing machine’s request for more soap). By making this kind of monitoring routine, better health care could be delivered as it is needed at a lower cost, and fewer people would need to be supervised in nursing homes, once again making headway on a hard problem by building interconnected systems of simple elements.

It’s not possible to go to a technological consultancy and order up these kinds of solutions; they need new kinds of devices connected into new kinds of networks. The idea of things thinking is old. What’s new is the necessity and possibility of solving these problems. That’s the work of TTT.

TTT functions more as a “do tank” than a think tank. There are enormous social and industrial implications of the research, but these emerge more from understanding what’s been accomplished than by trying to figure them out in advance. While the latter order is also valuable, we find that the former is better able to answer questions that we haven’t even asked yet, and to fill needs that were not articulated because it was not possible to even conceive of a solution.

And the sponsors need partners to build a business in these emerging areas, but usually a great deal of negotiation is involved before they can work together. Just as we learn a lot from student projects that don’t succeed, TTT provides a context for sponsor companies to try out new business models before the lawyers get involved.

The most immediate consequence of TTT for me has been how it has reshaped the Media Lab. When I came, most people typed at computers, and there were a few desultory machine tools sitting neglected in a corner. The Media Lab now has some of the best fabrication facilities of all kinds on the MIT campus. Even more striking, every group in the building now has an oscilloscope. This is the basic instrument used for developing and debugging electronics; its presence shows that people are designing and modifying their own hardware. Basic computer literacy is quickly coming to include machining, and circuit design, and microcontroller programming.

Very few people are left just sitting in front of a computer. Or are even left in the building; pursuing these ideas has entailed following them to other spaces. Not to home-of-the-future projects, which have generally been rather deadly affairs designed and inhabited by middle-aged white males in suburban settings, but to environments that reflect people’s personal passions, whether a networked Volvo driving through Cambridge, or a smart space in the Smithsonian museum, or a probe on the summit of Mount Everest.

The biggest surprise is how quickly the work is progressing. When TTT started it was an elusive concept, a quirky domain out of most everyone’s field of view. In just a few years it has zoomed into the mainstream, rapidly becoming almost as familiar as an earlier strange notion, multimedia. This pace in turn raises a few questions. The first is when TTT will “happen.”

I don’t expect there to be an epochal day when heavenly trumpets blare and TTT gets turned on. It’s leaking out now, and like so many other technological revolutions, its real arrival will come when the question is no longer interesting. Many early products have been announced or are in the pipeline, and we’ve seen that people are very quick to incorporate these kinds of capabilities in how they live.

At one of the first TTT meetings, Mitch Resnick’s group made smart name badges. These could be dipped into buckets containing answers to provocative questions, such as where you see society headed, or what you would read on a desert island. Then, when you met somebody, your badges would compare notes and light up a colored bar graph. A long green line meant that you agreed on everything, something that’s nice to know. A short red or green line indicated a weak overlap. Most interesting was a long red line, showing that you disagreed on everything. These ended up being the most interesting ones to find, because you were guaranteed to have a lively discussion about anything. This kind of information was so useful that during the course of the meeting people incorporated it into the familiar gesture of shaking hands, squaring up and exposing their chests to make sure that the displays were easily seen. All of this happened without any discussion or explanation.

Another project, Tod Machover’s Brain Opera, explored the implications of smart spaces for creating an opera that people enter into instead of watching from a distance. The audience shaped the composition through a room full of sensing, computing, communicating objects. At the premiere at Lincoln Center, Joe Paradiso, the technology director, came upon someone in great frustration pounding on a structural girder. Everything else in the environment had responded in interesting ways; this person had a hard time accepting that the girder just held up the building. As more and more things gain the ability to interact, a steel beam that is all body and no brain will indeed come to be seen as deficient.

The next question is what TTT will mean for the future of the Internet. Right now the Net is groaning under the explosion of new hosts and new users. Available bandwidth decreases as it gets shared among more and more people, and the routing of data becomes less and less reliable as it becomes harder to keep track of what is where. What will happen to these problems when the number of people using the Net is dwarfed by the number of things?

Not too much. A great deal of effort is going into upgrading the Internet to handle real-time audio and video, for the killer Internet application: telephony, or videoconferencing, or movies on demand (pick your favorite). But your toaster doesn’t need to watch movies. Most of the devices being connected to the Net are bit dribblers, things that send a small amount of useful data rather than a continuous multimedia stream. These things easily fit into the margins around the heavy users of bandwidth.

If TTT can happen, then what about privacy? The most Orwellian fears for the future were not paranoid enough to worry about the very real possibility that even your eaves may be doing Big Brother’s eavesdropping, or to wonder whose side your shoes will be on.

I believe that in the same way that bringing more technology closer to people is the way to make it disappear, it is also the path to protecting privacy. Cryptography is an arms race that the encoders can always win over the decoders. The effort to encrypt a message more securely grows far more slowly than the effort to crack the code. Because of this, the government has tried to mandate encryption schemes such as the Clipper chip that have official back doors that permit “authorized” agencies to decrypt them. These have failed, because software encryption is too easy to implement for it to be prevented. A favorite T-shirt at MIT contains a few lines of computer code implementing a widely known secure cryptosystem; the shirt is officially classified as a munition that cannot be exported from the country. Leaving the United States with this shirt, or even a laptop with encrypted passwords, violates the unenforceable law. The real limit to personal use of cryptography has not been regulatory, it’s been inconvenience. Your personal information cannot be routinely protected unless the things around you know how to do that.

Even forgetting encryption, the official eavesdropping agencies are drowning in the torrent of data flowing through networks. A wiretap was originally just that, a wire attached on or near another one to pick up the signal. Setting one up merely required access to some part of the wire. That no longer works on a high-bandwidth digital network. It’s hopeless to try to pick one phone call out of a billion bits per second passing through an optical fiber. This means that legal eavesdroppers are reduced to pleading for convenient access to the data. Their demand took the form of the Communications Assistance for Law Enforcement Act (CALEA), passed in 1994, mandating manufacturers of telephone switching equipment to install ports for legal government surveillance of calls passing through the switches.

Like cryptography, this is a battle that the eavesdroppers can’t win. It’s far easier to generate data than it is to analyze it. As the network bandwidth increases, as the number of nodes connected to the network increases, and as efficient use of the network replaces easily intercepted messages with signals that appear to be random, the technological challenges presented to the eavesdroppers are going to surpass even what can be solved by legislation. The answer to Big Brother may well be little brother, a world full of communicating things providing a Lilliputian counter to the central control of information.

In the end I think that the strength of these technical arguments is going to turn privacy from a regulatory issue to a matter of personal choice. Right now the price of your insurance is based on your crude demographics, rather than your personal details. If you drive safely, and you let your car insurance company have access to data from your car that confirmed that, then you could pay less than the bozo who cuts you off. If you eat well, and you’re willing to let your life insurance company talk to your kitchen, then you could be rewarded for having a salad instead of a cigarette. The insurance company would not be in the business of enforcing any morality; they would be pricing the expected real cost of behavior. These kinds of communication can be encrypted without revealing irrelevant but sensitive identifying information, such as where you’re driving or when you’re home. And the ability to turn insurance from a static document into an on-line tool does not mean that you have to participate; complete privacy will remain available, but it will cost more because the insurance company has less to go on to price your policy.

It’s as irritating to lug along at 55 mph in the middle of the Arizona desert as it is to be passed at 155 mph on a winding rain-slicked German autobahn. Setting speed limits is a political process that necessarily results in an unhappy compromise between competing interests and varying needs. Driving faster carries a cost in pollution, road wear and tear, and safety. All of these things have qualifiers, such as the straightness of the road, the condition of your car, and your driving experience. If you’re willing to share this information with the road then speed limits can be dynamically chosen and contain useful information, rather than the current practice of setting universally ignored rates based on the lowest common denominator. Privacy alone is not an absolute good; what matters is making a sensible tradeoff between private and shared interests. Connecting things provides a way for these tradeoffs to become matters of personal rather than national policy.

A final question about TTT is what it implies for the stratification of society, locally and globally. If the haves are already diverging from the have-nots, what’s going to happen when there are all these new things to have?

In thinking about this essential question, it’s important to recognize that technology rarely causes or fixes social problems; those are a consequence of much larger social forces. In 1747 James Lind, a British ship surgeon, figured out that British sailors were dying at sea from scurvy because they didn’t have fresh fruit (containing vitamin C). Packing limes let the ships stay at sea much longer, projecting the might of the British Navy much farther. Was that advance in nutrition good or bad? Sailors’ lives were saved, other lives were lost from the wars they then fought, lives were saved from the order imposed by the ensuing empire, more lives were lost getting rid of the empire. It’s too simple to credit or blame that history on vitamin C.

Granting that, there are modest grounds to think that TTT can help rather than exacerbate the existing divisions. There’s a new foundation growing out of the Media Lab, called 2B1, to develop and deploy information technology for children in developing countries. It’s almost, but not quite, a Media Lab Peace Corps. Instead of drilling wells for water, 2B1 will provide bit wells for information.

I was struck by many things when a large group of representatives of developing countries came to visit the Media Lab for the first time. I expected there to be a great deal of sensitivity about cultural imperialism, or cultural pollution, in presuming to connect African villages to the Internet. Instead, in many different ways, people expressed the belief that the world is changing quickly, and it is far more elitist to insist that developing countries progress through all of the stages of the Industrial Revolution before they’re allowed to browse the Web. They want to participate on an equal footing with the rest of the world. The loss of local culture is a valid concern, but then the Web has also served to foster the creation of community among nearby people who had not had a means to communicate among themselves before its arrival.

The technological challenges they’ve presented line up almost perfectly with the work of TTT. A computer in the middle of the veldt must need no spare parts, has to run without an electrical outlet or telephone line, can’t require calls to technical support, must be usable without a manual, and be insanely cheap and indestructible. Such a thing is not in the direct lineage of a desktop PC; it requires a range of new technologies.

Life in the veldt already provides a model for what this might eventually look like; biology is the master designer of adaptive systems that fix themselves. Extrapolating the history of the Media Lab from bits to atoms leads rather directly to biology.

For the foreseeable future we’ve got a lot of work to do to create around people inanimate technologies that they can trust. Beyond that, it’s impossible not to speculate about implanting them in people. Your body is already the ultimate wearable computer; why not move the heads-up display to your retina? Striking work is being done in augmenting people’s sensory and motor disabilities in this manner, but I don’t trust anyone yet to be able to do these things on a purely discretionary basis. It’s not until the technologies outside of people become so useful and reliable that I couldn’t live without them that I would consider trying to live with them. I’m not ready to see a dialog box reading, “You just crashed, OK?” and then have to take a nap to reboot.

If the present work of TTT succeeds, implants are the natural next step, equally intriguing and frightening. Even more so is what could come after that, editing the genome so that you grow the right parts. The genome already guides the fabrication of such exquisite machines as the eye and the hand (as well as more problematical hacks like the knee). What’s so privileged about our current eye design? We now do know a lot about optics, and chemistry, and could design eyes that have a broader spectral response, say, or that could look backward as well as forward. There are no longer serious ontological debates about the design of the eye as proof of the existence of a God, but we haven’t taken seriously the converse that if the design of the eye does not represent divine intervention, and we don’t intend to replace one deity with another by defying evolution, then the eye is open to mortal improvement. And who says we just have to upgrade our existing senses. Growing up I was disappointed when I realized that it appeared that I didn’t have ESP, but I do know how to use a cell phone to talk around the world. How about adding radios to brains?

The attendant ethical, social, and scientific challenges are staggering, but the point stands that our current construction represents one evolved and evolving solution and that it is open to improvement. Evolution is a consequence of interaction, and information technology is profoundly changing how we interact; therefore, it’s not crazy to think about an impact on evolution. If I’m far from being ready to let someone implant a chip, I’m certainly nowhere near being willing even to entertain seriously a discussion of aftermarket additions to the genome, but I have to admit that that is the logical destination of current trends. I fear, and hope, that we eventually reach that point. You’ll be able to tell we’re getting close when the Media Lab starts hiring molecular biologists.

In between the dimly glimpsed, terrifying, and thrilling possibility of an evolution in evolution, and the present reality of an overhyped digital revolution, lies a foreseeable future that is increasingly clear and appealing. In retrospect it looks like the rapid growth of the World Wide Web may have been just the trigger charge that is now setting off the real explosion, as things start to use the Net so that people don’t need to. As information technology grows out of its awkward adolescence, bringing more capabilities closer to people is proving to be the path to make it less obtrusive and more useful. The implications of this change are on display in the laboratory now, and given the combination of industrial push and consumer pull it’s hard to believe that they will not soon be equally familiar elsewhere.

Now that media has become multi, and reality has become virtual, and space is cyber, perhaps we can return to appreciating the rest of reality. As a technologist so frequently annoyed by technology, as an academic developing products, as a member of the species wondering about the evolution of the species, I can’t imagine a more exciting mission than merging the best of the world that we are born into with that of the worlds we’re creating.

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