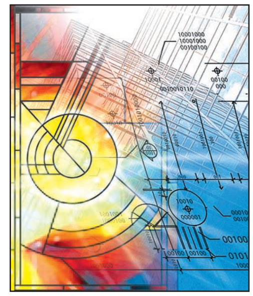
Everything Is Alive



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Two hundred years ago, it would have been difficult to comprehend the changes the now-pervasive electrical grid would make in our lives. More recently, the PC revolution distributed computing to individual desktops and PDAs.

But there was a time, long before either of these revolutions, when humans inhabited a world in which rocks, the wind, and trees seemed to have spirits and human characteristics that could influence people's everyday lives. Do you wish mankind could revive those days? What about the make believe world of cartoons, children's books, and fantasies in which animals and trees could talk? Or the Star Trek's Borg Collective, in which all Borg drones share a group mind — if one individual learns something, the collective benefits. Perhaps you lumped these ideas into the same category with telepathy, crop circles, pyramid power, and other suspect phenomena.

But what if current technology trends are leading us directly toward a brave new world in which these fantastical phenomena are real and even mundane?

Pervasive Computing Is Coming

The pervasive computing vision is a paradigm shift "back to the future." It could create a world 25 years hence where, once again, everything is alive (EiA) and can sense, act, think, feel, communicate, and maybe even move and reproduce. This might include equipment, vehicles, robots, clothing, pets, and objects such as trees and walls. The assumption behind this paradigm shift is that sensors, actuators, intelligent controllers, software, and communication devices will be virtually free and vanishingly small. They will be able to attach to their hosts transparently and intercommunicate and cooperate to help us with our tasks. This will extend the desktop metaphor so that computing is no longer just inside computers but rather inside all sorts of physical things. Wireless will replace telepathic communication — everything will be Internet-enabled and stamped with "agents inside."

In the EiA future, individual toys will have personalities and will play with children and each other; they'll help children learn to read and do their homework. The sprinkler system will communicate with your yard's plants to see how much water each needs and scan the weather channel for news of rain to adjust water rationing accordingly. While exercising at the gym after work, you'll be able to ask the weight machine to tell your oven at home to turn on at 6:30 p.m. because you're running late. As you walk to your car, you'll answer a call from your mother and have a good chat while driving to the shopping mall — all without a visible phone. The clothes racks at the mall will sense your profile and accentuate the right sizes and styles as you walk by. After you purchase a new jacket, wearable computing embedded in the cloth will begin operating on your behalf. At the grocery store, you'll just pick up the items you want and sensors in the store will automatically debit your grocery account as you leave.

The military will be an early adopter of EiA technology. In the recent past, in Operation Desert Storm, very little of the US$40 billion of equipment used could communicate and share knowledge, except to a very limited degree. In the smarter EiA future, we expect tanks to know their missions and microsatellites to work as teams. Smarter land mines will sense who is friend or foe and talk to each other to assess situations, and smarter guns will have "friendly forces" activation locks. Mosquito-sized autonomous vehicles will work with other mobile sensors to deliver smart bullets to specific targets. Soldiers' backpacks will negotiate with missions and logistics functions to ensure precision readiness — and remind the soldiers to bring extra socks. Eventually, smart dust will contain tiny sensors that can monitor and communicate their surroundings.

 1089-7801/04/$20.00 © 2004 IEEE Published by the IEEE Computer Society

Introducing Architectural Perspectives

The new Architectural Perspectives column will provide personal perspectives on areas I have spent years thinking about — scaling distributed objects, agents, and databases to Internet and Web architectures. It will look just beyond the current horizon for new directions in these areas.

During the 1980s, when the tabloids shockingly reported the headline "Heaven is Full," it became clear to me that more extensible, scalable systems would be needed in the near future and I should help do something about this. By the late 1980s, I realized modular object databases and design patterns provided ways to encapsulate some of this knowledge in a reusable manner, and, so, I got involved in component-oriented middleware, distributed object computing, hypermedia systems, and large-scale software architectures. In the early 1990s, I missed the opportunity to invent the Web, but by the mid 1990s, I was thinking about how to scale middleware to work with it. I then became interested in whether agents might represent a richer abstraction than objects and began working on how to scale agents to the Web. I also became aware that the computing world was about to explode off the desktop and into the rest of the world and, as such, we needed new ways to think about this.

This column is a forum to think about the next steps in Internet computing. This issue's topic involves the idea that the Internet could stretch to everyday items such as equipment, vehicles, toys, and maybe even natural objects such as trees, cells, and DNA. Topics for future issues might include the Semantic Web from a database perspective, e-diaries and time, privacy technology, and Web-scale architectures.

Wait — Pervasive Computing Is Already Here!

It might seem that EiA is a macro trend that is inevitable within 25 years. What is interesting is that it is already happening all around us in small, incremental ways. We are adapting to the transition without blinking, almost without seeing the progression, treating each change as independent. Just by keeping your eyes open over the next few weeks, you'll likely notice many examples of EiA that range from the mundane to the experimental.

Every day, technology adds another commonplace pervasive gadget to our lives. When I was growing up, these were transistor radios, color TVs, and calculators. Then the rush began: chips in coffeemakers and digital clocks, VCRs, cordless and mobile phones, beepers, remote controls, motion-sensor lights, laptops, palmtops, digital cameras, laser pointers, smart cards, mobile Internet connections, high-definition big-screen TVs, pervasive email, the Web, search engines, Webcams, in-flight phones, and remote keyless entry car locks. Doors have been sensing people and opening as they approach for some time. Now sinks, toilets, and cats' litter boxes are also sensing presence and taking appropriate action. *Softball Sales* magazine even sells a pitcher's ball with a built-in speed-indicator LED ("not for use in batting practice").

Many other examples of EiA's advance are all around us: smart homes, smart highway technology, factory automation, smart weapons, surveillance. It almost seems that if we can think of an application, we can build it (except perhaps where real commonsense intelligence is required, still a difficult AI problem).

In Vehicles

OnStar provides several vehicle- and GPS-related services. If your car airbags deploy, OnStar will contact emergency help and give them your exact location. If your vehicle is stolen, its tracking system will help police pinpoint the car's location. If you lock your keys inside, a signal broadcast from the OnStar center can unlock the door. As well, Garmin's StreetPilot GPS combines satellite tracking GPS and street map displays. In an even more impressive use of this type of technology, the small radio- and GPS-controlled aircraft *Liama* aerosonde was the first pilotless plane to cross the Atlantic Ocean in the late 1990s.

In Toys

In 1998, Tiger Electronics debuted the Furby — a furry toy containing a microprocessor and six sensors. The toys speak the "Furbish" language, which contains 200 words, and can learn English words such as *hungry* and *sleepy*. They also can wink, wiggle, babble, burp, sing, eat, respond to attention, sleep, and make spontaneous outbursts; what's more, they had no on–off switch. In January 1999, they were banned at secure government facilities because they record and later repeat what they hear. Now, many kinds of toys can talk to each other; Lego has put robot development and programming in children's hands with the customizable Mindstorm functioning robots; and, each year, hundreds of people watch the RoboCup, which is the World Cup of mechanized soccer-playing robots.

In Remote Sensing

Individuals already can afford to videotape their entire lives. Ads for one-inch video cameras are commonplace, and cell-phone cameras are so pervasive that they are being banned from locker rooms and the workplace. Iridium communication satellites can connect mobile callers from Mount Everest to the Sahara, part of the ongoing formulation of a worldwide cellular phone system. Stores have long used hidden cameras to catch shoplifters. Recently, the 90 communities in 14 US states that use cameras at traffic intersections to issue citations have reported noticeable decreases in intersection crashes.

In Remote Control

Calling home to check your answering machine is an everyday low-end example of remote awareness. On a grander scale, remote users (usually scientists, sometimes the public) regularly access expensive lab equipment at labs known as collaboratories.

Mobile robots extend human reach into new environments. For example, NASA's Sojourner crawled across the Martian landscape, analyzed rocks, and radioed the information back. NASA's Jet Propulsion Lab is funding work on an interplanetary Internet Protocol, known as InterPlaNet, and developing an architecture for how the interplanetary Internet will evolve. Such a protocol would let robots and colonizers talk to each other and to Earth.

In Battle

The military has developed binoculars that contain GPS, range finders, and communications; when a soldier sights and ranges an enemy, the binoculars send a message to the command post to fire. The military is also developing comprehensive architectures for permitting fleets of semiautonomous vehicles to team together in future combat systems. It has already effectively used unmanned aerial vehicles (UAVs) in Iraq, and developers are working on butterfly-sized surveillance vehicles.

The World Itself Is Alive

Already we have developed a variety of means to monitor and reason about the world around us. For example, we can measure lead isotopes 206 and 207 in Greenland ice cores and date-correlate them to Roman mining in Rio Tinto, Spain, between 600 BC and 300 AD. Core samples from Greenland Ice Sheet Project 2 and the Gulf of Oman indicate a drought that lasted from 2200 BC to 1900 BC which could have contributed to the collapse of Middle Eastern civilizations such as the Old Kingdom of Egypt, Minoan civilization of Crete, and Indus Valley civilizations. Meanwhile, we track the weather with ever-increasing accuracy, map large areas with sub-meter accuracy, track schools of fish via sonar (overfishing many fishing grounds as a result), and tag and electronically track sharks, wolves, manatees, drug runners, and even children.

British scientists James Lovelock and Lynn Margulis proposed the Gaia hypothesis in the late 1960s, which makes a case for the Earth itself being alive (not just the entities in its biosphere) as physical processes interact with life processes in feedback loops to stabilize the environment. In *Darwin Among the Machines: The Evolution of Global Intelligence* (Perseus, 1998), George Dyson argues that a conscious mind will evolve naturally in the digital universe, rather than as the result of design, and that humans will play the role of neurons.

EiA Building Blocks

Perhaps the world is not (yet) alive in the sense of some of these theories. But biotechnology, microelectromechanical systems (MEMS), and Web-object-agent technology are moving us in the EiA direction.

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Biotechnology

For billions of years, nature has been perfecting little "machines," such as enzymes, that construct other machines. People are just beginning to understand how these grow, reproduce, and heal themselves, but we are making progress. We also are learning from these biological networks how to make complex computer networks more self-healing and survivable. Also, we are increasingly able to mine data from the world around us. For example, Iceland is engaged in a state-mandated experiment to integrate detailed genetic, medical, and genealogical information about its very homogeneous DNA pool of 270,000 residents into a set of linked databases — its aim being to better study genetic diseases.

MEMS

Size matters. The miniaturization of Big Ben to create the mass-produced pocket and wristwatch, and the transformation of the 100-foot ENIAC computer into PDAs are just points on a progression that is already moving toward the age of nanotechnology. IBM's Scanning Tunneling Microscope was the Kitty Hawk that demonstrated how to place atoms like tiny Lego blocks, arranging 35 xenon atoms to spell IBM in 1989. Now, MEMS technology marries hair-sized computer chips with tiny sensors, probes, actuators, lasers, motors, nozzles, valves, gears, and drive shafts. In *The Best of Annals of Improbable Research* (W.H. Freeman, 1997), a MEMS toaster is described that saves on counter space and "implies the existence of fundamental toast particles." MEMS researchers predict a technological avalanche. Plausible applications are everywhere in biotechnology, medical, defense, and electronic games: ultralight planes could use arrays of MEMS rather than flaps for precision maneuvering; molecule-sized machines could be built into paint to activate a fire retardant when heated; dexterous probes could perform surgery through pin-hole slits; and glowing MEMS in airplane struts or machine girders could indicate cracks.

Internet and Web Technology

In the past ten years, the Internet, the Web, email, and wireless technologies have connected the world of PCs, laptops, and PDAs. The Web has matured to provide an information and electronic-shopping paradise. Search engines let us find content, chat rooms let us find companionship, thin browsers in smart phones give us windows to remote applications, and knowledge once hidden in write-once organizational memories is now being organized for use. The Web world is constantly changing, and we can see the beginnings of higher-level organization. It is already becoming easier to connect data sources to the Web and write Web services, and ontology tools are emerging for organizing a world of categories. Are we on our way to a Web-based collective?

What's Missing?

Our perspectives must change. We might see the inevitability of the EiA macro-trend, but we don't have a framework to understand where it will take us, or how we can use it to accelerate, shape, or control progress. If the evidence described earlier is just the tip of the EiA iceberg, then we are beginning to need a map of the iceberg. This means we must adjust our focus to see how MEMS and biological trends are related to that of computing infrastructure. What would help us progress faster?

One idea is to develop an architectural framework for thinking about EiA. Along this line, we could collect and categorize examples, systems, and technologies to provide a better mosaic view of progress. Identifying key technologies would be a good step — likely, these are a stack starting with distributed hardware components and building through ad hoc networking to agents to sharing over a Semantic Web. As we've learned from the Internet, we'll need layer-independent standards. We'll also need to understand even more about metadata — physical objects and their parts will need to contain self-describing metadata about their identities, interfaces, and histories.

A complementary idea would be "grand-challenge" problems that galvanize groups to accelerate progress. There will be many, possibly hundreds, of these. For example:

- *Pets that talk.* There is much talk on the Web about telepathy with pets, but what if we could sense and translate tail-wagging behaviors to speech and provide wireless connectivity so we could talk to pets from afar (cell phones for pets)?
- *Macro and nano extensions of the Internet.* If we already are exploring interplanetary Internets, why not also encompass radio-frequency identification tags so we can address and communicate with the next generation of tagged EiA objects? Can we further extend this to nervous system networks to address individual cells or DNA strands?

At heart, this revolution is coming. Currently, we think of cellular phone technology as connecting people across the world. In the next generation, both people and things will routinely and seamlessly communicate with each other.

Craig Thompson is professor and Acxiom Database Chair in Engineering at the University of Arkansas and president of Object Services and Consulting. His research interests include data engineering, software architectures, middleware, and agent technology. He received a PhD in Computer Science from the University of Texas at Austin. He is a senior member of IEEE.