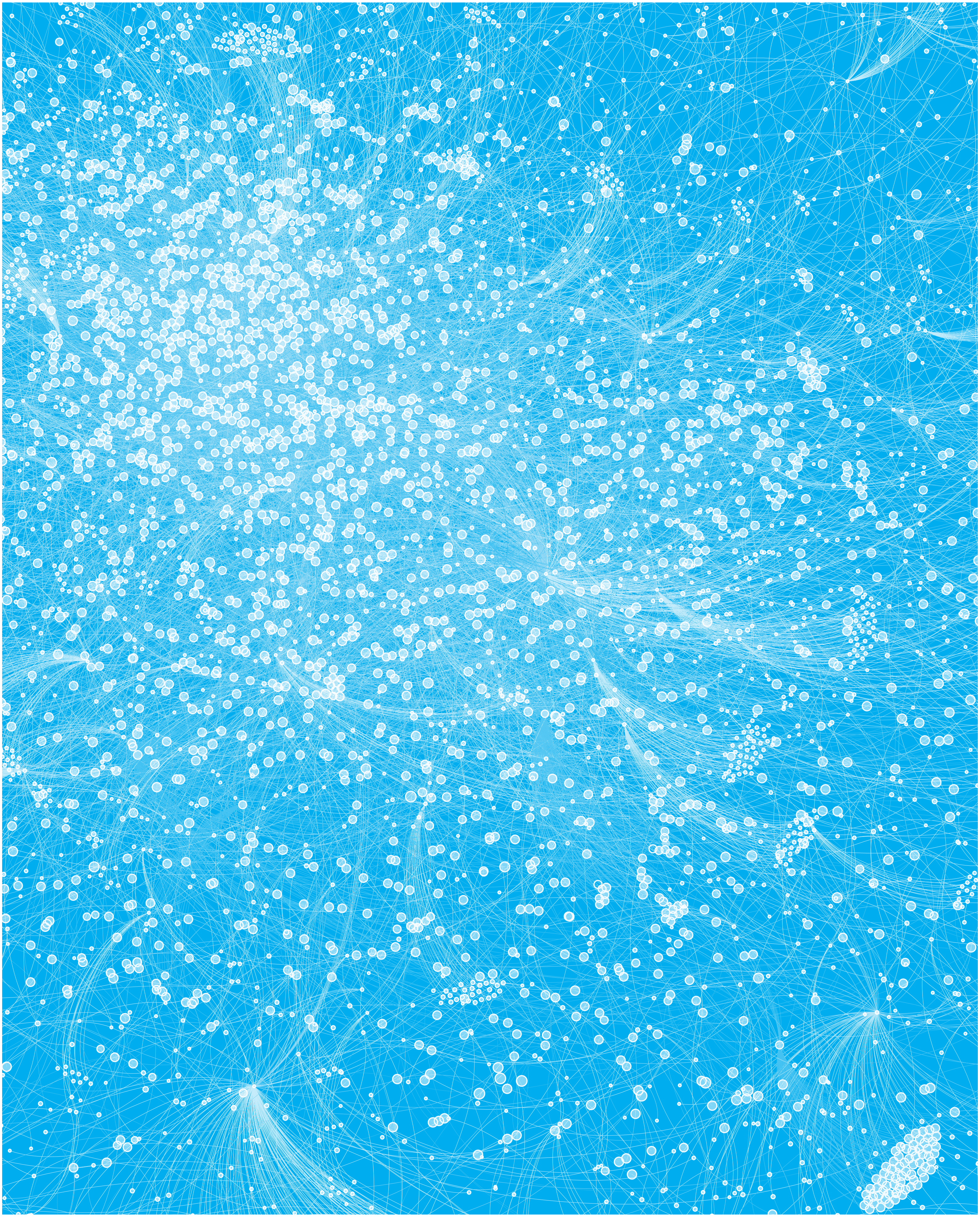

Architecture Machines and the Internet of Things

or, The Costs of Convergence

Molly Wright Steenson

Does the Internet of Things have a history? If so, it sure doesn't show it.

Coined in 1999, at a presentation to Procter & Gamble given by Kevin Ashton, the term "Internet of Things" (IoT) picked up valence in the early twenty-first century.[01] It connoted a universe full of objects, or "things," that sense, actuate, and respond to us. The idea of networked, sentient objects predates the naming of the Internet of Things, originating with researchers working on networked sensors in the 1980s and gaining momentum with the proliferation of wireless networks in the late 1990s. And since 2008, this idea has largely taken form: as of that year, there were more things on the internet than there were people on the planet. Gartner, an information technology research firm, estimates that by 2020 there will be twenty-six billion things on the nternet: that is, not devices with screens but everyday objects of all kinds capable of sensing, communicating, and responding to each other and to their users.[02] From environmental monitoring to home automation, from manufacturing to healthcare, from large-scale infrastructure to nanotechnology, the Internet of Things, say its proponents, will alter all aspects of our world.

Even older than IoT, the term "smart city" has been part of our lexicon for more than twenty years, for as long as the commercial World Wide Web has been in existence.[03] Smart cities promise "new generation services and infrastructure with the help of information and communication technologies (ICT)," according to one industry report, and are "differentiated in terms of their governance, technological advances, economic benefits, and social and environmental standards."[04] There are immense possibilities for technology to govern everything, from the minuscule to the monolithic. This is a different situation than what German media theorist Friedrich Kittler described in a 1999 lecture as a world influenced by the "universal discrete machine known as the computer" and "the only medium that combines … storage, transmission, and processing … fully automatically."[05] In this new universe characterized by the IoT, any *thing—anything*—can become a transmitter, a receiver, a processor. Everything is a computer, and everyone resides inside the computer.

The IoT often forgets it has users. It has no idea whatsoever about architecture. Yet the scale of IoT is the same as that of architecture, of the built environment that we navigate. It merges the architecture of the computer with the architecture of the built environment. The history of the IoT needs to be claimed in light of its mythologizing and as part of its cautionary tales. The groundwork for that history is presented here. It is a story of convergence: of architecture and computation, or of the architectures of the built environment and the architecture of the computer.

Half a century ago, architects and computer engineers began a mutual mining of each other's fields in order to express the growing complexity of their own practices. In the earliest days, architects applied cybernetics, artificial intelligence, and computer-aided design to architectural problems. At the same time, technologists used architectural metaphors to explain the increasingly complex functioning of computer systems. Engineers and programmers turned to architecture to describe the complex task of designing computers. What started out as the "organization" and "instructions" of computer design became known as its "architecture" by the late 1950s and early 1960s.

In a paper from 1945, John von Neumann characterized the design of the EDVAC computer (one of the earliest digital computers) and the instruction sets it needed to follow to carry out its operations as the "organization of logical elements." When IBM attempted to build the world's fastest supercomputer, the IBM 7030, its engineers referred to the design as "architecture." "Computer architecture, like other architecture," writes Frederick P. Brooks in "Architectural Philosophy," part of his 1962 *Planning a Computer System*, "is the art of determining the needs of the user of a structure and then designing to meet those needs as effectively as possible within economic and technological constraints." Brooks likens this process of defining the "functional characteristics" of the IBM 7030 to that of an architect designing a building, in which the architect determines the needs of the user and designs accordingly.[06] The architecture needed to reflect how it would be engineered and built, in order to assure a cost-effective and buildable system. Brooks explains, "the emphasis in architecture is upon the needs of the user, whereas in engineering the emphasis is upon the needs of the fabricator."[07] In this definition of architecture, the focus is on the organization of a system's elements with regard to the person who would be using it—a translation between the requirements of the computer's physical design and the experience of the person using it. In other publications in the early 1960s, IBM used "architecture" similarly, to refer to "conceptual structure and functional behavior."[08]

Architects turned to computing to model the complexity they found in architectural practice. As Royston Landau noted in 1968, practitioners found themselves interfacing with more systems, tackling more complicated design problems, and needing to conceptualize their work within a bigger systemic framework than they had had to manage previously.[09] They turned to computers and information processing in search of logical approaches to process the different, more complex stores of information that now fell under the umbrella of architecture. If anything, many architects found this increasing computation inevitable, a fact they approached with both trepidation and excitement. At the 1964 "Architecture and the Computer" conference, attended by a who's who of architecture, planning, engineering, and computation research luminaries, the biggest question was not whether the computer would change architectural practice but rather how it would do so. The conference served to "alert the profession to an irresistible force which will radically alter the practice of architecture whether we plan for it or not," writes conference organizer Sanford Greenfield in his preface to the proceedings.[10]

This convergence of architecture and the computer had profound implications. Working within architecture allowed both technologists and architects to ponder computation at a scale larger than punch cards and terminals. It meant that they could situate architecture as a cybernetic problem, or as an artificial intelligence question. It made architecture the locus of a new form of human-computer interaction, which took place at the scale of architecture itself. In so doing, both architects and technologists discovered the implications of building intelligence at a scale bigger than the screen, along with the problems that come when one expands a model developed for a small scale to a large system. A key example of this sort of experiment took place at the Massachusetts Institute of Technology (MIT) Architecture Machine Group between 1967 and 1984.

Founded by Nicholas Negroponte and Leon Groisser in 1967, the Architecture Machine Group (Arch Mac) was a hybrid laboratory for architecture and engineering research. There, students and researchers split between architecture and engineering built intelligent, computerized environments in collaboration with the Artificial Intelligence (AI) Laboratory and the Departments of Electrical and Mechanical Engineering. While located in an architecture school, Arch Mac's projects followed the same logic and research strategies as did these technical labs. The group was funded by the same Department of Defense (DoD) agencies, such as the Defense Advanced Research Projects Agency (ARPA/DARPA) and the Office of Naval Research, and supported by some of the most powerful people at MIT in artificial intelligence and computer science. These included AI Lab cofounder Marvin Minsky, still on faculty at MIT, and computer science luminary J. C. R. Licklider, who put in place the framework for what would later become networked computing and the internet.

These financial and personal relationships are an important part of Arch Mac's story. Since Arch Mac relied on DoD funding, it echoed the same dynamics as other defense-funded AI and engineering research groups. In order to understand the scope of Arch Mac's work, it is necessary to understand how DoD funding functioned and the impact it had on research imperatives.

Defense agencies operated in what historian Paul Edwards calls a "closed world."[11] They preferred to channel money within a closed, personal network. This cadre of individuals moved between DoD agencies, universities and technological institutes, and organizations such as RAND Corporation or private contractor Bolt, Beranek and Newman (now Raytheon BBN Technologies). (For example, Licklider worked at MIT, DARPA, and Bolt, Beranek and Newman between 1957 and 1968) The tight network was a way of keeping the braintrust and technological know-how developed during World War II intact during the Cold War. Until the late 1960s, general technical research could be funded by the military—it did not require explicitly military applications. But in 1970, the U.S. Senate passed the Mansfield Amendment, which restricted military funding of academic research to direct, tactical military applications.

In the same period, the big goals that AI pursued in the 1950s to early 1970s did not prove successful, causing the field to suffer major cuts. Originally, much AI research took place in the "microworlds." Such projects often involved the manipulation of stacks of blocks with natural language commands and robotic arms, and accordingly were called "blocks worlds." Microworlds were useful because they focused in on a miniature domain, abstracted from real world constraints. They were also problematic for that very reason. When microworlds fell out of favor, Patrick Winston, director of the MIT AI Lab from 1972 to 1997, encouraged researchers to develop projects with tactical military applications. In particular, this meant projects that met priorities in military command and control. Arch Mac followed suit, and we will see the ways in which the group echoed the imperatives of defense funding.

The term "architecture machine" referred to Negroponte's theories of the impact of AI and computers on the built environment. He coined the term "architecture machine" to refer to any number of intelligent, adaptive computational environments. In his 1975 book *Soft Architecture Machines*, he imagines what he calls "the distant future of architecture machines: they won't help us design; instead, we will live in them."[12] Beyond teaching architects to tinker and program, or engineers to think about applications for their work, Arch Mac investigated big questions about how computer architectures would permeate the built environment. Negroponte's statements about architecture machines were both bombastic and uncanny, a point that he himself acknowledged. "I strongly believe that it is very important to play with these ideas scientifically and explore applications of machine intelligence that totter between being unimaginably oppressive and unbelievably exciting," he writes.[13] And indeed, Arch Mac's writings, projects, and proposals would skirt the line between "oppressive" and "exciting" throughout its existence.

In the group's early days in the 1960s and early 1970s, Arch Mac worked within microworlds. Users of Arch Mac's URBAN 2 and URBAN 5 computer-aided design (CAD) systems (programs running on an IBM 360 computer) manipulated ten-by-ten-foot cubes by assigning attributes to them and engaging in a question-and-answer dialogue with the computer. URBAN 5 was supposed to be able to demonstrate its intelligence through this dialogue, which would change according to the user's context, but delivering meaningful dialogue was nearly impossible. URBAN 5 did not "admit the necessary ambiguity and the subtle intermingling of contexts that are required in order to respond to a real-world medley of events," Negroponte concedes, in 1970.[14] He deemed the project a failure.

Paradoxically, however, failures justified more funding for blocks worlds. Minsky and MIT Professor Seymour Papert wrote in a 1970 ARPA proposal, "we feel they are so important that we are assigning a large portion of our effort toward developing a collection of these microworlds and finding how to use the suggestive and predictive powers of the models without being overcome by their incompatibility with literal truth."[15] In fact, they were useful precisely because they operated without regard to "literal truth," or reality. Minsky and Papert write that each microworld "is very schematic; it talks about a fairyland in which things are so simplified that almost every statement about them would be literally false if asserted about the real world."[16] This is less of a concern when the blocks world is housed in a laboratory, or on a screen: but blocks worlds did not scale, as was apparent in Arch Mac's Seek project, exhibited in the "Software" show at New York's Jewish Museum in 1970.

Seek manipulated and organized blocks to "show

how a machine handled a mismatch between its model of the world and the real world."[17] The project consisted of a pen containing a bevy of two-inch mirrored blocks, which the steel and Lucite robotic hand of Seek, guided by colored wires and a coiled cord, attempted to stack. The pen also contained a colony of gerbils. Seek, however, was not apprised of these rodent residents. The exhibition catalog reads, "Unbeknownst to Seek, the little animals are bumping into blocks, disrupting constructions, and toppling towers. The result is a substantial mismatch between the three-dimensional reality and the computer remembrances which reside in the memory of Seek's computer. Seek's role is to deal with these inconsistencies."[18] Unfortunately, the system suffered from the same problems that plagued URBAN 5. "Today machines are poor at handling sudden changes in context in environment. This lack of adaptability is the problem Seek confronts in diminutive," writes Negroponte.[19] Indeed, in diminutive the model failed for many reasons, and not just because it was a blocks world. Seek also tended to kill the gerbils.[20]

Seek serves as a pointed example for criticizing microworlds in their abstractions and reductions. While microworlds provide manageable frameworks for exploration, applying the lessons they offer to larger-scale environments becomes a thornier issue. Rodney Brooks, MIT AI Lab director from 1997 to 2007, argues that the microworld construct is "a dangerous weapon" because it does not scale: "There is no clean division between perception (abstraction) and reasoning in the real world," he writes.[21] "Eventually criticism surfaced that the blocks world was a 'toy world' and that within it there were simple special purpose solutions to what should be considered more general problems."[22]

Arch Mac built an all-encompassing media environment, the Media Room, in the mid-1970s. Rather than sitting at a computer terminal keyboard or operating upon a world composed of blocks, the Media Room put the user inside the computer. Negroponte calls this "being in the interface."[23] The soundproofed, living room–sized apace had dark pile carpet on the floor and walls. Spanning the wall in front of the user was a large light-valve screen. At the center of the room, an Eames lounge chair was equipped with joypads (like joysticks only in the form of touchpads). Two smaller touch screens were positioned within reach of the user, along with a ten-inch-square data tablet.[24] The Media Room provided ways to experience simulations more real than real, claimed the group. Using the joypads on the lounge chair, denizen could drive down the streets of Aspen with the Aspen Movie Map, a sort of Google Street View at the scale of the room. They could move through the interfaces of the Spatial Data Management System, a forerunner to the graphical user interface. Or, they might move a fleet of ships by voice and gesture with Put That There, or navigate the first digital layered maps in Mapping By Yourself, an augmented reality and handheld mapping system.

In the Media Room, computer architecture and spatial architecture converged. In line with the notion of "integration," the Media Room was a space to explore "supreme usability," a conflation of the human, the interface, and the built environment. It combined comfort and ease, on the one hand—"that one can be oneself in the company of machines," as Negroponte writes in one proposal—with technological integration, on the other.[25] Where usability relates to the ergonomics and affordances of user interfaces, supreme usability is ergonomics on a larger scale, architecture and the machine aligning the human amid dynamic streams of information, military logistics, and the simulation. "We look upon this objective [supreme usability] as one which requires intimacy, redundancy, and parallelism of immersive modes and media of interaction," Negroponte and Richard Bolt write. "The image of a user perched in front of a monochromatic display with a keyboard, is obscured by the vision of a Toscaniniesque, self-made surround with the effervescence of *Star Wars*."[26] A limitless *Star Wars*, it would seem: in a report on the Media Room, Negroponte writes, "As soon as each wall is a floor to ceiling display, or in the limiting case the place is a hemisphere, the room has no presentational extent. Instead, spatiality is only limited by the movements of input, itself confined to the real space of the human network."[27]

This description calls to mind the camera obscura that art historian Jonathan Crary situates in "its relation of the observer to the undemarcated, undifferentiated expanse of the world outside."[28] Arch Mac and Media Lab researcher Andy Lippman uses this notion of limitlessness in his corollaries for effective interaction: the "impression of an infinite database."[29] The user has to have the idea that there are not just one or two possibilities but rather many potential ways to navigate, myriad choices to make: otherwise, it is not interactive. In an infinite database, the simulation knows no bounds. In the warm and exciting integration provided by supreme usability, the Media Room simplifies complex information, while masking the dynamics—perceptual and power both—that lie beneath.

Arch Mac was rolled into the MIT Media Lab, which opened in 1985 with $40 million in mostly corporate, private funding, under a new moniker: media. Inherent in Negroponte's term "media" is political scientist Ithiel de Sola Pool's concept of "convergence." A technological condition in which computing devices become more compatible, convergence referred to the alignment and unification of content, media, delivery, and governance. In his 1983 book *Technologies of Freedom*, Pool characterizes it as follows: "A process called the 'convergence of modes' is blurring the lines between media, even between point-to-point communications." He writes,

> A single physical means—be it wires, cables, or airwaves—may carry services that in the past were provided in separate ways. Conversely, a service that was provided in the past by any one medium—be it broadcasting, the press, or telephony—can now be provided in several different physical ways. So the one-to-one relationship that used to exist between a medium and its use is eroding.[30]

Pool's particular interest in convergence was in the implications of electronic communications on politics and the economics of media ownership, but Arch Mac sheds light on another form of convergence, not just of humans and machines, nor of military and consumer applications, but also of the architectures of computing and lived space. The one-to-one relationship with the built environment, with the infrastructures we don't see, and the everyday interfaces that we do, becomes more complicated as the computational powers within them increase. Arch Mac's research provides early proof of the promise and problems of these forms of convergence.

It may be easy to scoff at Arch Mac's grand pronouncements regarding the future of architecture machines and how they would change the world in which we live, but the fact is that in the more than forty years since they were made we have not come much further. Consider the statements of Google CEO Eric Schmidt at the World Economic Forum in Davos, Switzerland, in January 2015. Schmidt talked about the "disappearing Internet"—so pervasive, it is no longer visible. Schmidt tells his audience, "Imagine you walk into a room, and the room is dynamic. And with your permission and all of that, you are interacting with the things going on in the room. … A highly personalized, highly interactive and very, very interesting world emerges."[31] This statement represents a gross abstraction: it glosses over issues of privacy, responsiveness, and generativity. Looking back to an even earlier moment, in 1991 Xerox PARC Chief Scientist Mark Weiser introduces the term "ubiquitous computing" in a *Scientific American* article. "The most profound technologies are those that disappear," he writes. "They weave themselves into the fabric of everyday life until they are indistinguishable from it."[32] Weiser's concept of nearly twenty-five years ago is far more nuanced than Schmidt's more recent description of the disappearing internet.

What Google, Cisco, IBM, or even a feisty startup have to gain from the success of the IoT is clear: there are billions of dollars at stake. The current total market value of smart cities—with their investment in smart buildings, homes, energy, healthcare, industrial automation, transportation, education, and security—is expected to grow from $411 billion in 2014 to more than $1 trillion in just five years. That projected total rises to nearly $40 trillion over the course of the next twenty years.[33] But the stakes revealed by the convergent history of architecture and the IoT are equally evident. As in Negroponte's blocks worlds, the effects of a bad model will become magnified at the scale of the city, with its billions of networked objects, and its users will be humans, not gerbils. How smart is the smart city?

Perhaps it is not so smart after all. Our fine-grained details become coarse when they meet big data, when decision technologies that respond to this data become embedded in the world around us. To return to John von Neumann's characterization, computer architectures organize the logical elements of the machine—the architecture machine. We find that uniting the user with the machine creates sticky problems and that users still do not fare well. From inside the architecture machine—as designed by the architects of the smart city or the Internet of Things—there is no exit.

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