Me++

THE CYBORG SELF AND THE NETWORKED CITY

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BOUNDARIES/NETWORKS

Consider, if you will, Me++.

I consist of a biological core surrounded by extended, constructed systems of boundaries and networks. These boundary and network structures are topological and functional duals of each other.[1] The boundaries define a space of containers and places (the traditional domain of architecture), while the networks establish a space of links and flows. Walls, fences, and skins divide; paths, pipes, and wires connect.

BOUNDARIES

My natural skin is just layer zero of a nested boundary structure. When I shave, I coat my face with lather. When I'm nearly naked in the open air, I wear—at the very least—a second skin of spf 15 sunblock.

My clothing is a layer of soft architecture, shrinkwrapped around the contours of my body. Beds, rugs, and curtains are looser assemblages of surrounding fabric—somewhere between underwear and walls. My room is a sloughed-off carapace, cast into a more rigorous geometry, fixed in place, and enlarged in scale so that it encloses me at a comfortable distance. The building that contains it has a weatherproof exterior shell. Before modern mobile artillery, fortified city walls would have provided a final, hardened, outermost crust; these sorts of urban-scale skins remained reasonably effective at least until the 1871 siege of Paris, during the Franco-Prussian War.[2]

In the early years of the Cold War, outer defensive encasements reemerged, in extreme form, as domestic nuclear bunkers. The destruction of the Berlin Wall in 1989 marked the end of that edgy era. But still, if I end up in jail, an internment camp, or a walled retirement community, the distinction between intramural and extramural remains brutally literal. If I retire to a farm, a boundary fence stops my stock from straying. And if I locate myself within the homeland of a major military power, I take refuge behind a dubious high-tech bulwark that extends across thousands of kilometers; our extradermal armored layers have coevolved, with increasingly fearsome weapons systems, into invisible radar curtains and missile shields that create vast electronic enceintes. I surround myself with successive artificial skins that continually vary in number and character according to my changing needs and circumstances.[3]

All of my boundaries depend, for their effectiveness, upon combining sufficient capacity to attenuate flow with sufficient thickness. If I want to keep warm, for example, I can use a thin layer of highly insulating material or a thicker layer of a less effective insulator. If I want acoustic privacy, I can retreat behind a closed door, or I can simply rely on the attenuation of sound waves in air and move out of earshot. If I want to create a jail, I can construct escape-proof walls, or I can remove the prisoners to a sufficiently distant place—like the eighteenth-century British convicts transported to Australia. In sparsely populated territories, distance creates many natural barriers, while in buildings and cities, efficient artificial barriers subdivide closely packed spaces.

CONNECTIONS

But I am, as Georg Simmel observed, a "connecting creature who must always separate and who cannot connect without separating."[4] My enclosures are leaky. Crossing the various boundaries that surround me there are paths, pipes, wires, and other channels that spatially concentrate inflows and outflows of people, other living creatures, discrete goods, gases and fluids, energy, information, and money. I am inextricably entangled in the networks of my air, water, waste disposal, energy, transportation, and Internet service providers.

To create and maintain differences between the interiors and exteriors of enclosures—and there is no point to boundaries and enclosures if there are no differences—I seek to control these networked flows. So the crossing points are sites where I can survey what's coming and going, make access decisions, filter out what I don't want to admit or release, express desire, exercise power, and define otherness. Directly and indirectly, I employ doors, windows, bug screens, gates, cattle grids, adjustable apertures, valves, filters, prophylactics, diapers, face masks, receptionists, security checkpoints, customs and immigration checkpoints, traffic signals, routers and switches to determine who or what can go where, and when they can go there. So do you, of course, and so do others with the capacity to do so in particular contexts.

Through the interaction of our efforts to effect and control transfers among enclosures and our competition for network resources, we mutually construct and constrain one another's realms of daily action. Within the relatively stable framework of our interconnecting, overlapping, sometimes shared transfer networks, our intricately interwoven demands and responses create fluctuating conditions of freedom and constraint. And as networks become faster, more pervasive, and more essential, these dynamics become increasingly crucial to the conduct of our lives; we have all discovered that a traffic jam, a check-in line, a power outage, a server overwhelmed by a denial-of-service attack, or a market crash can create as effective a barrier as a locked door. The more we depend upon networks, the more tightly and dynamically interwoven our destinies become.

NETWORKS

The archetypal structure of the network, with its accumulation and habitation sites, links, dynamic flow patterns, interdependencies, and control points, is now repeated at every scale from that of neural networks (neurons, axons, synapses) and digital circuitry (registers, electron pathways, switches) to that of global transportation networks (warehouses, shipping and air routes, ports of entry).[5] And networks of different types and scales are integrated into larger network complexes serving multiple functions. Depending upon our relationships to the associated social and political structures, each of us can potentially play many different roles (some strong, some weak) at nodes within these complexes—owner, authorized user, operator, occupant, occupier, tenant, customer, guest, sojourner, tourist, immigrant, alien, interloper, infiltrator, trespasser, snooper, besieger, cracker, hijacker, invader, gatekeeper, jailer, or prisoner. Power and political identity have become inseparable from these roles.

With the proliferation of networks and our increasing dependence upon them, there has been a gradual inversion of the relationship between barriers and links. As the ancient use of a circle of walls to serve as the ideogram for a city illustrates, the enclosing, dividing, and sometimes-defended *boundary* was once the decisive mechanism of political geography. Joshua got access the old-fashioned way; when he blew his righteous trumpet, the walls of Jericho came tumbling down. By the mid-twentieth century, though, the most memorable ideogram of London was its underground network, and that of Los Angeles was its freeway map; riding the networks, not dwelling within walls, was what made you a Londoner or an Angeleno. And the story of recent urban growth has not been one of successive encircling walls, as it mostly would have been for ancient, medieval, and Renaissance cities, but of network-induced sprawl at the fringes.

More recently, the unbelievably intricate diagram of Internet interconnectivity has become the most vivid icon of globalization. Now you get access by typing in your password, and IT managers dissolve the perimeters between organizations by merging their network access authorization lists. Today the *network*, rather than the enclosure, is emerging as the desired and contested object: the dual now dominates.[6] Extension and entanglement trump enclosure and autonomy. Control of territory means little unless you also control the channel capacity and access points that service it.

A year after the September 11 attacks on New York and Washington, the implications of this were sinking in. The President's Critical Infrastructure Protection Board bluntly reported (to nobody's very great surprise),

> Our economy and national security are fully dependent upon information technology and the information infrastructure. A network of networks directly supports the operation of all sectors of our economy—energy (electric power, oil and gas), transportation (rail, air, merchant marine), finance and banking, information and telecom-

> munications, public health, emergency services, water, chemical, defense industrial base, food, agriculture, and postal and shipping. The reach of these computer networks exceeds the bounds of cyberspace. They also control physical objects such as electrical transformers, trains, pipeline pumps, chemical vats, radars, and stock markets.[7]

Connectivity had become the defining characteristic of our twenty-first-century urban condition.

CLOCKS

All networks have their particular paces and rhythms. Within the nested layers and recursively embedded networks of my world, my pulse—the sound of an intermediate-scale, low-speed vascular network—has been mechanized, regularized, externalized, and endlessly echoed back to me. Just as boundary, flow, and control systems subdivide my space into specialized, manageable zones, these constructed rhythms partition my time into discrete, identifiable, assignable, sometimes chargeable chunks. Bean counters are also minute counters; measurable, accountable time is money.

The miraculously monotone beat of the pendulum first established this possibility.[8] Ancient sundials and water clocks had marked the flow of time, and Benedictine monastery bells had formalized its approximate mechanical subdivision. Clock towers had provided European towns with faster communal heartbeats—essential, as Lewis Mumford pointed out, to the regulation and coordination of social and economic life, and eventually to the industrial organization of production.[9] Then, in the seventeenth century, Christiaan Huygens devised a pendulum clock that ticked precisely.

This innovation also initiated a shift in scale. Furniture-sized towers (grandfather clocks, standing in domestic hallways) soon began to associate timekeeping with the dwelling and the family rather than with the town and the larger community. Substituting spring-driven mechanisms for pendulums allowed clocks to become even smaller, more portable, and eventually wearable—now associating timekeeping with the individual.[10] Timepieces moved to pockets, then to wrists—provocatively, the organic pulse's most obvious point of presence. Clinging tightly to flesh, they have enabled the large-scale scheduling and coordination of individual activities; during the American Civil War, for example, the Union forces depended upon them to synchronize operations.

As artificial pulse rates have accelerated, timekeeping mechanisms have continued to shrink. Today, the gigahertz, crystal oscillator hearts of tiny computer chips are embedded everywhere. (Chips without clocks are possible, and may turn out to have some important advantages, but they are not yet in widespread use.)[11] Electronic vibrations subdivide seconds into billions of parts, pace the execution of computational tasks, discipline our interactions with computational devices, calibrate GPS navigation systems, regulate power distribution and telephone systems, measure and commodify both human and machine work, and precisely construct the accelerating tempos and rhythms of the digital era—coordinated, where necessary, by a central atomic clock.[12] They not only *mark* time, they *trigger* the execution of instructions and programs. Seconds, milliseconds, microseconds, nanoseconds, picoseconds: the electronic global heartbeat keeps quickening and gathering power—so much so that, when its coordinated microrhythms threatened to falter at Y2K, there was bug-eyed panic in the technochattering classes.[13] There was talk of "spectacular explosions, nuclear meltdowns, power blackouts, toxic leaks, plane crashes, and bank failures."[14]

PROCESSES

But there is, of course, more to the construction of time than the increasingly precise subdivision of the day. As clocks multiply and distribute themselves spatially, the relationships among them begin to matter.

Different places may simply run on their own clocks, or their timekeeping systems may be standardized and synchronized. When there was little communication between spatially separated settlements, local time sufficed, and there was no need for such coordination, but linkage by long-distance railroad and telegraph networks eventually made it imperative. In 1851 the Harvard College

Observatory began to distribute clock ticks, by telegraph, to the railroad companies. As transportation and telecommunication capacities have increased, we have entered the era of globalized network time—of GMT, time zones, and sleep cycles decoupled from the solar day.[15] Once, villagers rose with the roosters to work until sunset in nearby fields; now, jet-lagged business travelers do their email at three a.m. in hotel rooms far from home.

Computers have added additional layers of complexity to the construction of time. The first computers—constructed according to the elegant principles of Turing and von Neumann—were strictly sequential machines, executing one operation at a time; programming was a matter of specifying these operations in precise order. Everything was rigorously governed by clock increments and finite (though small) durations. But as interactive computing developed, a distinction emerged between tasks that could be performed in "real" time and those that could not. For example, computer animations of three-dimensional environments could be computed and stored for later playback, or (as in today's video games) they could be computed and presented on the fly, with no perceptible time lag. In other words, if you take advantage of fast machines to compress processes, you can elide the distinction between simultaneity and sequence. "Virtual reality" would be impossible without this.

The practice of timesharing has produced a further elision. If a processor is fast enough, it can be programmed to divide its time among multiple simultaneous processes—providing the illusion that it is devoting itself exclusively to each one. In effect, a single, sequential processor divides itself into multiple "virtual machines" that seem to occupy the same space and time. The ancient, seemingly unproblematic concept of *hic et nunc*—what's here and now—begins to frazzle.

As processors have become smaller and cheaper, and as they have been integrated into networks, it has become increasingly feasible to program parallel rather than strictly sequential processes; tasks are divided up among multiple processors, which simultaneously contribute to producing the desired result. It is even possible to imagine organizing the entire Internet as a parallel computation device.[16] At this point—particularly as network speeds approach the internal bus speeds of computers—it no longer makes sense to think of a computer as a compact, discrete object, or to distinguish between computers and networks. Eventually, we will approach the physical speed limit, and its associated paradox; information cannot travel faster than light, so spatially distributed events that seem simultaneous from one node in a lightspeed network may seem sequential from another, and vice versa.

The logical endpoint of this shift to networked parallelism is the emerging possibility of quantum computing—in which every atom stores a bit, vast numbers of atomic-scale processing elements are harnessed to execute computations at unprecedented speed, and the notoriously strange spatial and temporal logic of quantum mechanics (rather than the familiar logic of our everyday world) takes over.[17] (It isn't easy to wrap your mind around the fact of quantum systems occupying several places at once, quantum bits registering 0 and 1 at the same time, and quantum computers performing large numbers of computations simultaneously.) And, maybe, the ultimate network will operate by the quantum-magical means of quantum entanglement and teleportation of quantum states from one site to another.[18]

So we have gone from local habitation and mechanical subdivision of time to a far more dynamic, electronically based, network-mediated, global system of sequencing and coordination. The early moderns measured out their lives in clock ticks (and sometimes, as Prufrock lamented, coffee spoons); now, our webs of extension and interconnection run on nanosecond-paced machine cycles that are edging into the domain of quantum logic. The more we interrelate events and processes across space, the more simultaneity dominates succession; time no longer presents itself as one damn thing after another, but as a structure of multiple, parallel, sometimes cross-connected and interwoven, spatially distributed processes that cascade around the world through networks. Once there was a time and a place for everything; today, things are increasingly smeared across multiple sites and moments in complex and often indeterminate ways.

DISCONTINUITIES

In the fast-paced, digitally mediated world that we have constructed for ourselves, what exists between 0 and 1, a pixel and its neighbor, or a discrete time interval and the next? The answer, of course, is nothing—profoundly nothing; there's no there there. The digital world is logically, spatially, and temporally discontinuous.

Our networks are similarly discontinuous structures; they have well-defined access points, and between these points things are in a kind of limbo. If you drop a letter into a mailbox, it disappears into the mail network until it shows up at the recipient's box, and if you send an email, it's just packets in the Internet cloud until it is reassembled upon receipt. Obviously it is possible, in principle, to precisely track things through networks, but in practice we rarely care about this. We experience networks at their interfaces, and only worry about the plumbing behind the interfaces when something goes wrong.

If you transfer *yourself* through a network, you directly experience this limbo. It is, perhaps, most dramatic on intercontinental night flights. You have your headphones on, there is darkness all around, and there is no sensation of motion. The video monitor constructs a local reality, and occasionally interrupts it to display current times at origin and destination. It is best not to worry too much about how to set your watch right now, precisely where you are, or whose laws might apply to you.

The discontinuities produced by networks result from the drive for efficiency, safety, and security. Engineers want to limit the number of access points and provide fast, uninterrupted transfers among these points. So you can drink from a stream anywhere along its length, but you can only access piped water at a faucet. You can pause wherever you want when you're strolling along a dirt track, but you must use stations for trains, entry and exit ramps for freeways, and airports for airline networks—and your experience of the terrain between these points is very limited. You experience the architectural transitions between floors of a building when you climb the stairs, but you go into architectural limbo between the opening and closing of the doors when you use the elevator.

HABITATS

Decades ago, at the very dawn of the digital era, Charles Moore (the most thoughtful architect of emerging postmodernity) shrewdly understood what the simultaneous conditions of extension and discontinuity meant for our daily use of space; our habitats no longer consist of single or contiguous enclosures, but have become increasingly fragmented and dispersed. They are no longer bounded by walls, but by the reach of our networks. They are occupied by spatially dispersed organizations, ranging from multinational corporations and retail chains to terrorist networks. They are controlled and defended not at a continuous perimeter, but at separated and scattered access nodes. They are given order and meaning not by participation in strict spatial sequences and hierarchies, but by their global linkages. Our domains of knowledge and action cannot be defined as fixed neighborhoods, but must now be understood as dynamic, emergent, geographically and temporally fluctuating patterns of presence. In his influential essay "Plug It In, Rameses," he observed:

> The most powerful and effective places that our forebears made for themselves, and left for us, exist in contiguous space. They work on an organized hierarchy of importances, first dividing what is inside from what is outside, then in some way arranging things in order of their importance, so that objects give order to a location, and location gives importance to objects, as at Peking, where an axis penetrates from outside through layer after layer of increasing importance (like the skins of an onion) to the seat of the emperor himself, or as in Hindu towns where caste determined location from clean to dirty along the flow of water which served everyone. . . . Our own places, however, like our lives, are not bound up in one contiguous space. Our order is not made in one discrete inside neatly separated from a hostile outside. . . . We have, as we all know, instant anywhere, as we enjoy our capacity to make immediate electronic contact with people anywhere on the face of the globe. . . . Our new places, that is, are given form with electronic, not visual glue.[19]

COMMUNITIES

Sociologists would use more technical language to make much the same point as Moore's. They would say that I—like most urbanites today—get companionship, aid, support, and social control from a few strong social ties and many weak ones.[20] These ties, which might manifest themselves, for example, as the entries in my cellphone and email directories, establish social networks. In the past, such networks would mostly have been maintained by face-to-face contact within a contiguous locality—a compact, place-based community.[21] Today, they are maintained through a complex mix of local face-to-face interactions, travel, mail systems, synchronous electronic contact through telephones and video links, and asynchronous electronic contact through email and similar media.[22] They are far less dense, and they extend around the world, coming to earth at multiple, scattered, and unstable locations.[23] As Barry Wellman has crisply summarized, "People in networked societies live and work in multiple sets of overlapping relationships, cycling among different networks. Many of the people and the related social networks they deal with are sparsely knit, or physically dispersed and do not know one another."[24]

In the years since Moore wrote, our physical habitats have grown more fragmented and dispersed as transportation networks have extended further and operated faster. Simultaneously, the electronic glue has grown much stronger; it now includes voice, video, and data channels, broadcast and point-to-point links, place-to-place and person-to-person communication, the fixed infrastructure of the bank ATM system, the sleek portable equipment of the corporate road warrior jetting between global cities, and the cheap phone card of the migrant worker.

Wherever I currently happen to find myself, I can now discover many of the same channels on a nearby television, I can access the same bank account, and I can chat with the same people on my cellphone. I can download my email and send replies almost completely independently of location. And my online world, which once consisted of ephemeral and disconnected fragments, has become increasingly persistent, interconnected, and unified; it's there again, pretty much as I left it, whenever I log in again from a new location. The constants in my world are no longer provided by a contiguous home turf: increasingly, my sense of continuity and belonging derives from being electronically networked to the widely scattered people and places I care about.

2

CONNECTING CREATURES

You can read *Ulysses* as *Honey, I Shrunk the City*. Dublin's buildings map to vital organs—the newspaper to the lungs, the concert room to the ear, and so on—while Leopold Bloom and Stephen Dedalus circulate through the urban anatomy like sentient corpuscles, disclosing associated aspects of their biologically embodied consciousnesses at each successive location. Conversely, you can read *Finnegans Wake* as *Attack of the Fifty-Mile Man*. The sleeping body of innkeeper/city-builder H. C. Earwicker (or HCE, Howth Castle and Environs, and Here Comes Everybody) becomes one with Dublin's civic geography; his head is "the macroborg of Holdhard" (the hill of Howth Head), he stretches to the scandalously tumescent "microbirg of Pied de Poudre" (the Powder Magazine in Phoenix Park), and Dubliners are to be found "hopping round his middle like kippers on a griddle." Earwicker/Environs/Everybody's voice is the murmur of Dublin reflecting upon itself.

Now the body/city metaphors have turned concrete and literal. Embedded within a vast structure of nested boundaries and ramifying networks, my muscular and skeletal, physiological, and nervous systems have been artificially augmented and expanded. My reach extends indefinitely and interacts with the similarly extended reaches of others to produce a global system of transfer, actuation, sensing, and control. My biological body meshes with the city; the city itself has become not only the domain of my networked cognitive system, but also—and crucially—the spatial and material embodiment of that system.

LIMBS (EXTENDED)

Extra muscle first came from animals; horses and riders had all-terrain capability and great power-to-weight ratio. Walking sticks provided an early, rudimentary form of exoskeletal support. Introduction of some elementary mechanisms—wheels, beams, and containers assembled to form carts, together with smoothly paved surfaces—yielded powered vehicles and initiated the long symbiosis of vehicles, roads, and cities.

The first roads were a primitive form of network infrastructure. Wheels were devices operating upon that infrastructure, and each was precisely adapted to the requirements of the other. This marked the beginning of a profoundly consequential coevolutionary process—one in which devices, systems, vehicles, and buildings have adapted themselves to the affordances of available infrastructures, while infrastructures have evolved and multiplied in response to growing demands. The hoof on the dirt track had extended, transformed, and amplified the actions of feet in the stirrups and hands on the reins. Eventually the tire on the road did the same—via mechanical and electronic linkages—for feet on the pedals and hands on the wheel. Through this sort of process, over the centuries, our limbs and muscles have continually extended and elaborated themselves.[1]

In the early industrial era, the steam engine and the horseless carriage substituted machine power for animal muscle. At first, machine power could be transmitted only over short distances, by means of mechanical linkages such as the drive trains of automobiles and the belt systems of early mills, but the combination of electrical generators, transmission systems, and motors allowed cities to equip themselves with extensive, efficient power distribution networks.[2] And as power grids have extended and linked with one another, power sources have increasingly distanced themselves from sites of consumption; Hoover Dam (near Las Vegas) exports most of its hydroelectric power output to southern California, and Hydro-Quebec supplies much of eastern North America. The electric power that is essential to modern cities has become a dynamically priced, computer-controlled commodity that is switched around through vast networks as fluctuations in supply and demand require—and as energy traders determine.

Through the nineteenth and twentieth centuries, by a process of exuberant invention, mechanization increasingly took command.[3] Today, as a privileged postmodern urbanite, I can take advantage of the resulting vast accumulation of mechanical devices to precisely apply machine power wherever and whenever I may need it, with instruments ranging in size from microscopic actuators to hand tools, appliances, vehicles, elevators and escalators, cranes, and conveyor belts, to huge industrial plants. If I operate a telerobot over the Internet, I can extend my grasp and manipulative capacity by thousands of miles. If I have the skills, I can perform telerobotic surgery on a patient on the far side of an ocean.[4] I can even tend a distant garden electronically.[5]

Where a sword might once have lengthened and hardened my hand as a weapon, I could now (as every competent terrorist knows) remotely detonate a bomb simply by attaching a cellphone to it.[6] But that is just the informal violence sector's ad hoc alternative to putting flesh directly on the line. The vast weapon systems of twenty-first-century military organizations are fiendishly extended, multiplied, and strengthened versions of the ancient soldier's legs (which have become military vehicles and delivery systems), sword hand for offense, shield hand for defense, and eyes and ears for intelligence gathering. Since wireless remote control replaced the direct grip of the hand on the weapon, and since cybernetic mechanisms were introduced to control weapon systems more precisely, electronics, software, and robotic mechanisms have increasingly taken over the action.[7] If I serve as an up-to-date military functionary, I am simply (in Norbert Wiener's prescient words) "coupled into the fire-control system and acting as an essential part of it." I become a squishy control node in an extensive and highly integrated machine network.[8] And this condition is generalizing from fire control to choreography of the machines that pervade our daily life.

By programming robotic devices I can precisely specify their future actions. I can instruct them to repeat the same actions indefinitely, to take action at a specified moment (as when a virus wakes up at midnight on a given date and wipes out your hard disk), and to respond to different conditions in different ways. And by copying programs and distributing them to multiple devices, I can repeat the same choreography at different locations. Through electronic storage and distribution of my encoded commands—particularly by means of digital networks—I can indefinitely multiply and distribute my points of physical agency through space and time.

FLOWS (CHANNELED)

Water supply and sewer networks have become geographic extensions of my alimentary canal, my respiratory system, and associated organic plumbing. The carbon-based systems that circulate solids, fluids, and gases within my bag of skin are connected to a vast, external, mostly metallic and plastic network of pipes, ducts, pumps, processing plants, and mechanical transportation devices for food, water, conditioned air, and waste disposal.[9] These extended networks collect resources in distant and dispersed catchment zones, concentrate them at storage nodes, transfer them to consumption nodes, and eventually disperse waste to disposal zones. They enable me to extend my ecological footprint (that is, the land area required to support me and assimilate my waste products) far beyond the scale that was possible before the development of extended plumbing networks—and, indeed, far beyond the point of prudence.

Under the standard arrangement, extended plumbing systems link me into the planet's natural air flow systems, water systems, and food webs, but their outputs may also be connected back to their inputs to produce miniature, closed ecosystems—a principle followed (with mixed success) in Arizona's Biosphere and in NASA projects for interplanetary spacecraft.[10] Increasingly, the flows that they channel are monitored by sensors, precisely controlled by valves and switches, filtered and tempered in a multitude of ways, and managed by sophisticated digital systems. One way or another, the pipes form linkages between small-scale metabolic processes within my skin and larger-scale processes outside it.

My sexual plumbing is constructed to interface with other, compatible sexual plumbing for the efficient transfer of genetic information in fluid format. Unfortunately, the fleshware connection can be flaky, unstable, and nonstandard (worse than a dial-up modem), but there are numerous illustrated manuals describing recommended configurations and protocols. I am a node in a body-to-body network that, sadly, turns out to be effectively organized for virus propagation as well.[11] Traditional forms of sexual union are circuit-switched and synchronous, with all the intensity and risk that this entails, but refrigerated sperm banks now function as genetic code servers. In vitro fertilization is an asynchronous transaction—the organic equivalent of downloading email, and about as arousing. Blood donations, banks, and transfusions form a similar fluid interchange network; early attempts at transfusion involved synchronous artery-to-vein links, but if I make a blood donation today, I upload to a blood bank and some anonymous recipient later downloads.[12] From the perspective of our genes and viruses, our bodies and their in vitro extensions are just temporary nodes in an evolving propagation network.

In the extravehicular mobility units (EMUs) worn by the Apollo astronauts, internal and external plumbing systems were locked in a tight, semi-permanent, crypto-sexual embrace. NASA diagrams show backpack primary life support systems (PLSSs), with supply and removal systems, intimately plugged into the bodies of the moon walkers, and controlled from chest-mounted consoles.[13] The necessary interfaces were maintained by a maximum absorbtion garment (MAG) to collect urine, a liquid cooling and ventilation garment (LCVIG) to remove excess body heat, an EMU electrical harness (EEH) to provide communication and bioinstrument connections, a communications carrier assembly (CCA) for microphones and earphones, an in-suit drink bag (IDB), and a polycarbonate helmet with oxygen supply and carbon dioxide purge valve. If you had the right stuff, you not only walked on the moon, you got to sleep with your extrabiological body double—snugly beneath two layers of inner cooling garment, two layers of pressure garment, eight layers of thermal micrometeoroid protection garment, and the outer cover.

In everyday life, of course, the linkages are a bit looser. Unless I find myself on extracorporeal life support I am only intermittently plugged in.[14] But (in developed urban environments, at least) the interface points—water faucets, supply and return air registers, domestic refrigerators, baths, sinks, and showers, garbage disposal units, gasoline pumps, urinals, and flush toilets—are never far away. The preindustrial equivalents of these points, such as the well and outhouse, or the seats of ease on a sailing ship, were generally less pleasant and sophisticated, and were kept at a distance, but their modern descendants have moved indoors to become standard, indispensable organs of buildings.[15] The large-scale construction of these intestinal extranets and the integration of their interfaces into architecture were among the heroic projects of early modernism; they were conceived (though many are now more skeptical) as progressive enterprises bringing hygiene, equality, and cohesiveness to the industrial city.[16] Eventually, as *Ulysses* obsessively emphasizes, there was no difference between shitting on a Dublin cuckstool and defecating in a London toilet. And the sewers poisoned the oysters just the same.

By the 1960s, the architectural avant-garde had begun to take note of all this. It was sensing a shift from composition of space and structure—the conception of architecture that had been expressed by Laugier's conspicuously unserviced "primitive hut"—to the construction of these pipe, duct, wire, and mechanical movement networks. (That was, of course, where the money was now going in most buildings.) Archigram in Britain, Superstudio in Italy, François Dallegret in Canada, and others produced endless images of human bodies—mostly young, photogenic, and minimally though fashionably clothed—surrounded by elegant plumbing and ductwork, large-scale mechanical contraptions, and places to connect to systems that supposedly would supply whatever you wanted on demand.[17] Renzo Piano and Richard Rogers built the Pompidou Center in Paris, with its ductwork and mechanical systems boldly exposed, Reyner Banham engagingly supplied some theory, and the imagery eventually made it to the movies in *Brazil*. In retrospect, it is easy to see that this (mostly) cheerily optimistic brand of technofetishism got half the story right; networks were, indeed, increasingly crucial.[18] What it missed—dooming its brightly colored, hard-edged images of Capsule Homes, Plug-in Cities, Instant Cities, Cushicles, Suitaloons, Manzaks, Rokplugs and Logplugs to seem closer, now, to Jules Verne than to William Gibson or Neal Stephenson—was the emerging role of hyperminiaturization, wirelessness, digitization, and dematerialization.

SENSORIUM (AUGMENTED)

Telephones, as the remaining McLuhanistas keep assuring us, are interfaces to yet another network infrastructure—one that that now stretches my speech production and reception system around the globe and multiplies its points of presence. It didn't seem quite that way at first, since the earliest models were large, heavy devices attached to walls and sometimes enclosed within celebratory booths—electrically powered descendants of the huge, earlike "listening systems" that Athanasius Kircher proposed to install in seventeenth-century palace walls.[19] They were components of buildings, and they established place-to-place networks. You were never quite sure who would pick up at the other end, and the relationship to our bodies was neither continuous nor intimate.

But later versions of the telephone were smaller and lighter, and they plugged into modular outlets; you could walk around with them, and the coordinates of the connection points became fuzzier. Handsets were scaled and shaped to the human jawbone (from front teeth to socket near the ear) and resided on desktop cradles. Now cellphones fit in a pocket, they never leave us, and (in some cultures, at least) they are never switched off. They may even be wired into our clothing and equipped with earsets (scaled and shaped to the *interior* of the ear) for hands-free use. They are more part of our bodies than part of the architecture.[20]

In much the same ways, my retinal receptors have been multiplied megafold by CCD arrays embedded in digital cameras, scanners, VCRs, Webcams, and videoconferencing systems.[21] Some of these visual receptors are handheld, others are built into vehicles (from automobiles to imaging satellites), and yet others are installed within buildings. Some even operate through inconspicuous pinholes in walls. Some work independently, but increasingly many are hooked into the worldwide, digital storage and distribution network.

With these pervasive audio and video sensing systems, the lines dividing electronic conversation, accidental overhearing, deliberate electronic eavesdropping, and systematic surveillance are thin ones—more a matter of context and intention than of technology. As wireless bandwidth increases, as the video equivalents of cellphones emerge, and as sound and image capture points proliferate, the balance is inexorably shifting toward surveillance.[22]

I am becoming the focal point of a global personal Panopticon. It is not a spoked building radiating from my body (that is, a network of one-way sightlines), as constructed by Jeremy Bentham's Enlightenment imagination and elevated to iconic status by Michel Foucault, but a wildly ramifying circuit structure with artificial eyeballs at the ends of the wires.[23] There are even tiny, battery-operated wireless eyes that can be left anywhere and will transmit whatever they see to the nearest Internet reception point.[24] There are wireless video camera pills (about the size of a vitamin E capsule) that transmit images of the small intestine to a data recorder worn on a belt.[25] And as autonomous, nomadic eyes get even smaller, they will be mounted on remotely controlled micro-robots or insects (most likely cockroaches) with electronic implants.[26]

Although audio and video sensors are most evident to us in our daily lives, electronic sensing is by no means limited to the acoustic and visual domains. Air-conditioning systems depend upon temperature and humidity sensors. Vacuum cleaners and washing machines contain pressure sensors. Accelerometers, orientation detectors, inclination detectors, and vibration detectors can track motion. Strain gauges tell how a structure is behaving. Sensors for chemicals and biological agents provide the rough equivalents of our senses of taste and smell. In general, any self-contained device that detects a property and produces a signal is a sensor that I can connect to a network and use to extend my powers of observation and surveillance.

GAZE (UNRESTRICTED)

I am both a surveying subject at the center of my electronic web and the object of multimodal electronic surveillance. All of those constructions of the gaze that the post-Foucauldians have alerted us to—the gaze of desire, the gendered gaze, the consumer's gaze, the critical gaze, the reflexive gaze, and certainly the gaze of power—are extended, reorganized, and reconstructed electronically. Re-released Big Brother (or Big Other 2.0) is made from little pieces linked together; he/she is everywhere and all of us—at least when we pay attention. And combating the unwanted gaze or audience is no longer a matter of proximity and enclosure—of hushed voices, drawn veils, and retreating behind closed doors—but of controlling access to networks, databases, and messages.

Furthermore, the observer need no longer be an embodied subject hunkered homunculus-like within an enclosure, like Kircher's palace courtier, Bentham's jailer, a camera obscura peeper, or the Wizard of Oz. Nor is it necessarily a bunch of bored guys peering at flickering video screens in a security command center—the modernist imagination's icon of surveillance. It may be a dispersed observer swarm, as with cellphone-equipped, celebrity-spotting teenagers. Or, as in the U.S. National Security Agency's Echelon and Carnivore systems, the observing mechanism may be software that filters streams of audio, video, or text data to recognize and extract objects and events of interest.[27] (A stream containing the words "White House" and "attack" is likely to attract attention.) Furthermore, as digital records accumulate on the Web and in other types of online databases, they may be sorted, searched, fused, and filtered in numerous ways; surveillance may be conducted both in real time and asynchronously. These strategies overcome the Orwellian Big Brother's very human limitation—that he could only pay attention to a few things at a time.

Since the shrinkage of microphones, video cameras, and other sensing devices makes them increasingly invisible, since it is usually impossible to tell what they are connected to anyway (particularly when they are wireless), and since surveillance software seldom snoozes, our mere knowledge of the widespread existence of surveillance apparatus establishes the presumption of invisible, anonymous, unverifiable observation. Such surveillance is, as Foucault put it, "permanent in its effects, even if it is discontinuous in its action." We act as if we are observed, even when we may not actually be. That is harmless enough when invisible traffic cameras discourage me from speeding, and it can be reassuring if I know that I may need emergency assistance at any moment, but it is easy to imagine more sinister uses of this new, pervasive machinery of discipline and control. Although Foucault wrote before the digital revolution exploded, he knew in his bones what was coming; jails could morph from enclosures to networks, and in their characteristic postmodern form they could be larger and more totalizing than anything Bentham might have imagined.

SPACE (DE-PRIVATIZED)

Under these conditions, the traditional distinctions between a city's public and private spaces are eroding. When Nolli made his famous map of Rome, the difference seemed straightforward; he could show the citywide network of public spaces (streets, piazzas, and the interiors of churches) in white, with all their details, while shading private spaces in anonymous gray. In our secular age, new Nolli-style maps would, of course, depict the interiors of shops and malls rather than those of churches. They would also show zones of hypervisibility—public areas subject to video surveillance and maybe to the scrutiny of face recognition software that picks out putatively undesirable characters. Conversely, there would be zones of spatial aporia—the discreetly anonymous, secure sites of the servers and telecommunications hubs that make everything work.

I can also peer electronically from private spaces into public ones and from public spaces into otherwise private ones, creating scrambled and sometimes-paradoxical civic conditions. Security cameras provide interior private spaces with one-way views of public exteriors, while exterior displays occasionally reveal what's going on within a building—often for the benefit of those who cannot be accommodated inside. Two-way videoconferences can link public to public, connect private to private, or electronically mix public and private. New genres of electronic exhibitionism and voyeurism, such as dorm room Webcams and reality television shows, put private spaces on public display. The space of television broadcast studios is normally kept physically private (that is, closed to direct view and surrounded by strict security) while electronically presenting itself publicly. On the other hand, sports telecasts make stadiums recursively public; we can electronically watch audiences physically watching the game. Audio headsets can create private acoustic bubbles in the midst of public spaces, and video headsets can create even more dramatic disjunctions.

Wireless video cameras, which are designed to transmit to nearby base stations, blur Nolli maps in particularly insidious ways. If I am in the neighborhood, I can, if I wish, intercept these transmissions and display them on my wireless laptop computer. As I move around the city, I can surreptitiously open wireless windows at will.

The shift from naked eyeballs to networked video also changes the rules of public space layout. As the urban theorist Camillo Sitte observed, the winding streets and odd-shaped plazas of medieval cities continually provided visual surprises—not to mention opportunities for unexpected encounters and ambushes. But the streets of Haussmann's Paris and L'Enfant's Washington slice through the urban fabric in long, radiating, straight lines; rather than surprises, they provide continuous views of distant monuments, and instead of allowing for easy ambush, they are designed for efficient military surveillance, deployment, lines of fire, and control. They are, in other words, scaled-up panoptic diagrams. Now, though, these spatial moves are unnecessary; following September 11 and repeated terror alerts from the Justice Department, the Washington, D.C., Police Department began to install surveillance cameras in Metro stations, public schools, street intersections, shopping areas, and residential districts.[28] The resulting video feeds were viewable both at stationary command centers and in squad cars. With a bit more wireless infrastructure, they would, no doubt, go directly to cellphones. For the cops, camera locations suddenly became more important than street geometry, and the scope of their gaze was disconnected from urban geography. If you have electronic sightlines, you no longer need baroque street networks.

Steven Spielberg's 2002 film *Minority Report* vividly extrapolates this emerging condition.[29] In his Washington of 2052, transportation systems do not flow along L'Enfant's avenues, but employ flying machines that can swiftly go anywhere and automobiles that can drive up the sides of buildings. Electronic surveillance systems are installed in every doorway and are carried by tiny, spiderlike, heat-sensing, wireless-communicating robots that can squeeze through the cracks under doorways. Retina scans from these systems are electronically checked against databases to track the movements of citizens. And asynchronous surveillance is carried to a new level—precrime extends it to the future as well as the past.

Once, the natural condition of cities was opacity; architects created limited transparency by means of door and window openings, enfilades, open rooms, and public spaces. Today, the default condition is electronic transparency, and you have to work hard to produce limited zones of privacy.[30]

NERVOUS SYSTEM (DE-LOCALIZED)

My augmented nervous system, like that of the D.C. police, has immeasurably transcended the disposition of my flesh.[31] It has extended itself electronically by means of copper wires, fiber-optic cables, and wireless channels that connect my brain to electronic memory, processing points, sensors, and actuators distributed throughout the world and even in outer space.[32] It has been expanded to sense—where necessary—not only visible light but also infrared, ultraviolet, and very low-intensity light, to make visible the tiniest of objects, to capture sounds far outside the audible spectrum, and (through MEMS technology) to be acutely sensitive to odors, vibrations, accelerations, pressure and temperature variations, and just about anything else that may be of interest or importance to me. The firewall of my skin is crossed by electronic and electromechanical interfaces to my hands, eyes, and ears—and occasionally to other organs as well. Some of these interfaces are permanently active, others are switched on and off as required. Some are deployed at fixed locations within my surrounding environment, some are portable, some are wearable, and some may take the form of miniaturized implants.

And it does not stop there; we are on an accelerating curve. Contemplating the recently invented telegraph, Nathaniel Hawthorne began to imagine a worldwide system of artificial nerves, endlessly pulsing with electrical impulses.[33] Views from the Apollo spacecraft taught us to see the entire globe—a sparkling blue ball in the dark void—as an object of comprehensive electronic surveillance. Today's commercial observation satellites, in the words of RAND analysts, "promise to bolster global transparency by offering unprecedented access to accurate and timely information on important developments,"[34] and their military equivalents are even more capable.

Sensors of all kinds are now becoming tiny, inexpensive, and network-enabled, and they are increasingly being integrated into very large-scale sensing systems. By 2001 a committee of the National Academy of Sciences could confidently suggest, "Networks comprising thousands or millions of sensors could monitor the environment, the battlefield, or the factory floor; smart spaces containing hundreds of smart surfaces and intelligent appliances could provide access to computational resources."[35] Oak Ridge National Laboratory was pitching Sensor Net, consisting of biological, radiological, and chemical weapons detectors mounted on cellphone towers.[36] Meanwhile, William Gibson's fictional heroes inhabit a world in which neural extension is taken to the limit by dispensing with all the intermediate junk and just jacking brains directly into the global network.

So my sensorium is no longer localized by the inexorable laws of visual occlusion and acoustic decay, the range of my exploring fingertips, and the wavelengths and scales to which evolution has tuned my original sensory equipment. It reaches to wherever there are sensors with network connections.[37] My experience of places and events depends decreasingly upon positioning my eyeballs at precisely chosen locations (as Renaissance perspective implicitly insists) and increasingly upon electronic access to a globally dispersed, multimodal sensing and reporting system. And, as this system continually gets denser, the relevant metaphor is no longer that of the all-seeing eye (as depicted, for example, on the U.S. dollar bill), but that of a continuous sensate skin. The earth itself is growing such a skin, the surfaces of buildings are beginning to evolve in that direction, and our clothing will eventually go the same way.[38]

The radical de-localization of our interactions with places, things, and one another—in space through electronic sensing and telecommunication and high-speed travel, and in time through electronic and other forms of storage—was identified by Anthony Giddens as one of the characterizing features of modernity.[39] If we lived within the walls of a preliterate, ancient city, all of our interactions would be face-to-face and synchronous, conducted in places like the agora; but we now live at the nodes of networks that allow a great many of our interactions to be remote and asynchronous. With the continued shift from enclosures to networks, we have bolted beyond modernity's spatial and temporal extensions to a condition of global hyperconnectivity.

CONTROL (DISTRIBUTED)

When I move a cursor with a mouse, I execute simple actions manually and observe the results of those actions directly in front of my nose; the feedback loop that keeps me in control, and allows me to learn from what I'm doing, operates at a scale of centimeters. When I use a television remote, I send commands electronically and get visual and audio feedback; I depend upon a direct line of sight and being within earshot, and the feedback loop operates at a scale of meters. It's the same when I operate my five-year-old's radio-controlled toy racecar; I'm in trouble if the vehicle disappears behind the couch and I lose the feedback loop. But it's different when I operate a video camera, telescope, or robot over the Internet; in this case, the feedback loop consists of bits flowing through a network, and it may be effective over thousands of kilometers.

In many contexts, form follows feedback. It is now a commonplace of control theory that swarms of bees, schools of fish, and flocks of birds are held together by short-range feedback loops. Slime mold cells follow pheromone gradients to aggregate, and to respond to global changes in their environment, at even smaller scale. These collectives are self-organizing; they don't need leaders.[40] Their spatial coherence and their complex, adaptive behaviors emerge from the capacities of simple agents to observe the movements of a few neighbors and to adjust their own movements accordingly. Swarms of SMS-equipped urban teenagers are not very different—except that the electronic feedback loops linking their actions extend beyond their line of sight, maybe for many kilometers.[41]

Kids who hang together by pinging their posses in this fashion may behave in coordinated, purposeful ways, but they only occasionally form compact, readily identifiable, directly observable physical groupings at particular locations. Most of the time, the groups are spatially dispersed and invisibly linked. It is harder (though often appropriate) to conceive of them as discrete "things" that somehow contain goals.

Markets have gone the same way. They were once enclosed within well-bounded physical places, such as market squares. Information about demands, prices, and wares on offer was visibly and audibly evident within those places, and circulated swiftly through word-of-mouth as well. The invisible hand operated at very close range. But when I purchase theater tickets through an online auction site, or trade stocks electronically, I participate in a spatially dispersed market that relies upon long-distance feedback loops carried mostly through electronic linkages. It is an extended, distributed computational mechanism, structured by complex rules and integrating both humans and machines.[42] It is certainly a real and important thing, but you cannot literally go to it or even point out its location; it does not have a stable, definite physical identity.

Games have dispersed even more dramatically. A tennis or basketball court is a rigorously standardized piece of geography designed to contain the rule-governed flow of action; an "out of bounds" condition is not to be taken lightly. The players observe the ball and one another directly, at close range, and they respond accordingly. When I participate in an online computer game, though, I don't have any idea where the physical boundaries are or how many active players there might currently be; I interact with the other players, avatar-to-avatar, in software-generated, software-ruled virtual terrain. (There may be trouble if the value of a variable inadvertently goes out of range, or if a stack overflows—but that is another story.)

In the online ur-game Spacewar (circa 1961), the virtual terrain was a simple diagram, players were few, and feedback was crude and slow. By the days of Doom (which suddenly began to clog networks at the end of 1993) and Quake, the virtual terrain was in full-color 3D, there were thousands of players, and you had to respond instantly to feedback in the form of fearsomely skinned, weapon-wielding, animated warriors. By the turn of the millennium we were seeing massively multiplayer, persistent online worlds (Everquest, Ultima Online, Asheron's Call, and more). These often grew to be larger than the physical cities inhabited by their players, and they could exhibit complex social dynamics—such as the spontaneous formation of combat clans. In the subgenre of online sports games, such as NFL 2K3, the action took place in careful simulations of famous arenas, using simulations of professional players as avatars; geographically scattered players could meet in online "lobbies" to form pickup teams. In more intellectually oriented online worlds, such as that of the Slashdot news and discussion community, the model was the seminar room rather than the gridiron, and there was less interest in visual simulation, but feedback mechanisms and self-organization played a comparably crucial role.[43]

It isn't that such complex, feedback-rich, self-organizing systems don't have identifiable units and hierarchies. In fact, they usually do. But their units and hierarchies *emerge* from the dynamics of interaction; they are not predefined, like those of armies and corporations.

When social scientists first embraced the concept of feedback, they often thought in terms of homeostasis—of closed social groups regulated by negative feedback loops and seeking stable states, as a thermostat-controlled heating system seeks a stable temperature: community as a blob of slime mold. But that is not the way it has worked out in the network era. With the electronic de-localization of my interactions, the feedback loops that guide my actions and teach me about the world may operate at all ranges—from millimeters to thousands of kilometers. They may be synchronous or asynchronous. They do not integrate me into a single, closed, stable community. Rather, they engage me (with varying degrees of commitment) with multiple, scattered, perhaps spatially indefinite, and maybe transitory social and economic structures.[44] And they implicate me with innumerable, simultaneous, spatially overlaid patterns of self-organization in complex, unstable geographies and choreographies of control.

MIND (MULTIPLIED)

My capacity for awareness, response, and agency within these structures is a variable. My local stock of neurons has (the neuroscientists gloomily assure me) been diminishing as I grow older, but the supply of silicon and software at my disposal has been growing rapidly. Consequently, the neural network inside my cranium outsources more and more mental functions. I don't do much mental arithmetic any more; calculators and computers take care of that. I don't rack my brain for half-remembered facts; I look them up on the Web. I routinely exist in the condition that J. C. R. Licklider presciently identified, way back in 1960, as "man-computer symbiosis"—except that Licklider, Doug Engelbart, Ivan Sutherland, and other pioneers of interactive computing mostly had dialogue with desktop workstations in mind, whereas I now interact with sensate, intelligent, interconnected devices scattered throughout my environment.[45] And increasingly I just don't think of this as computer interaction.

I don't directly control all the functions of the machines and devices I use; I rely on the intermediating machine intelligence embedded in my cellphone, my car, my domestic appliances, the operating system of my laptop computer, and my software agents. Mostly I cannot tell whether such intelligence is supplied by local devices, by remote servers, or by some combination of the two, and it doesn't matter—as long as there is capacity available somewhere, and the connections are sufficiently fast. Often I cannot even tell whether a verbal response I receive over the network has been generated by a person or by a machine; the Turing test has stealthily been aced.[46] And when I'm in a deathmatch on a first-person shooter like Quake, an AI opponent such as ReaperBot may be more formidable than a human one. As nodes of machine intelligence are distributed just about everywhere, as electronic interconnectivity grows, and as electronic feedback loops multiply, cities are evolving into extended minds and biological brains are becoming elements of larger cognitive systems. It is Santa Cruz guru Gregory Bateson's "ecology of mind," but with much more silicon and many more electronic interconnections than he ever imagined.

Mary Catherine Bateson, looking back upon her father's intellectual legacy, has summarized his brilliantly insightful (if sometimes frustratingly fuzzy) formulations of this idea as follows: "A mind can include nonliving elements as well as multiple organisms, may function for brief as well as extended periods, is not necessarily defined by a boundary such as an envelope of skin, and consciousness, if present at all, is always only partial."[47] Bateson himself put it: "Within Mind in the widest sense there will be a hierarchy of subsystems, any one of which we can call an individual mind."[48]

He went on to ask, "But what about 'me'"? And his answer was uncompromising:

> Suppose I am a blind man, and I use a stick. I go tap, tap, tap. Where do I start? Is my mental system bounded by the handle of the stick? Is it bounded by my skin? Does it start halfway up the stick? Does it start at the tip of the stick? But these are nonsense questions. The stick is a pathway along which transformations of difference are being transmitted. The way to delineate the system is to draw the limiting

> line in such a way that you do not cut any of these pathways in ways which leave things inexplicable. If what you are trying to explain is a given piece of behavior, such as the locomotion of the blind man, then, for this purpose, you will need the street, the stick, the man; the street, the stick, and so on, round and round.[49]

Similar spatial and functional extensions of mental systems are produced, in variously specialized ways, by the artist's pencil, the surgeon's scalpel, the diner's cutlery, the canoeist's oar, the fencer's sword, the tennis player's racquet, the boxer's glove, and the mother's Q-tip in a baby's ear. With surfboards and skateboards, feet instead of hands are the crucial connection points. Cyclists, sailors, and hang glider pilots interact with their environments at more points and through more complex mechanical linkages. Automobile drivers and airplane pilots do so through powered mechanisms, and in more advanced vehicles through electronic connections, interface devices, sensors, and servos. For several decades now, computer network users have done so through indefinitely extended electronic systems with distributed intelligence, elaborate sensor and effector systems, and increasing capacity for autonomous agency. Today, through miniaturization and wireless interconnection, these networks are becoming denser and more pervasive. In all of these cases the extended body functions as a system for perceiving one's environment in particular ways, reasoning about it, and executing actions that engage it.

It is not that there is a unified "world brain" of the sort rather crudely imagined by H. G. Wells in the 1930s.[50] But skulls and skins do not bound mental systems, and through computer networking these systems can now extend indefinitely.

MEMORY (EVOLVING)

When such extended and distributed mental systems have the capacity to store and recall information, they don't just live in the present. They can learn from experience and grow smarter over time. Specialized memory organs may, of course, be enclosed within craniums, but they may also be inscribed on stone tablets or sheets of paper or implemented electronically in silicon or magnetic oxide.

Extracranial memories once consisted of records clustered within easy reach, like the papers on my desktop or the notes and pictures on my refrigerator door, but they are evolving into global, self-organizing networks. One part of my artificially extended memory consists of the world's scholarly and scientific literature—a collection of paper documents, most of which exist in multiple copies and locations, cross-connected by citations. I access information in this form by physically tracking down particular pieces of paper. Another part consists of the World Wide Web, that is, of hyperlinked online documents that I access either by following links or by employing the indexes constructed by search engines. The two parts are increasingly interwoven; paper documents like this book reference Web pages, Web pages cite paper documents, and some documents exist simultaneously in paper and electronic form. Every day, millions of network nodes suck information into the growing online component of global memory, millions of users construct links, and as this whole, complex, hybrid network evolves, Brewster Kahle's Internet Archive grabs and stores snapshots.[51]

The larger this exponentially expanding, continually restructuring, networked, shared collector and memory becomes, the less escapes it.[52] It can respond to major events instantly, automatically, and on a massive scale. When the attacks on New York and Washington took place on September 11, 2001, related bits immediately began to flow in—not just from the immediate vicinities, but from around the world. There was an explosive accumulation of eyewitness footage and accounts, news reports and analyses, memorial sites, tribute pages, survivor registries, commentaries, and policy analyses. A year later, when the first books on the attacks were appearing, and discussions of an architectural memorial were just getting under way, the Internet Archive already had more than five terabytes of online, indexed data on the subject.[53] (For comparison, the entire Library of Congress contains about twenty million books, or twenty terabytes of textual information.)

So we can extend mental systems by putting memory and processor chips in things, networking them, linking them to sensors and actuators, and constructing feedback loops, but it isn't *just* a matter of that. If we take Bateson's view, there is no clear distinction between internal cognitive processes and external computational ones. Furthermore, as physicists are increasingly insisting, there is also no straightforward distinction between computational processes and physical processes in general; you can think of *any* physical process as the computation of some function. (Set things up in the right way, and the whole apparatus of bits, circuits, and symbolic computation might eventually turn out to be a cumbersome and unnecessary intermediary. It may just be the wrong level of abstraction for harvesting computational capacity on a really large scale.) At the speculative edge of this discourse, John Archibald Wheeler teases us to imagine "it from bit," Stephen Wolfram conceives of unfolding reality as the enaction of an algorithm,[54] and Seth Lloyd estimates the number of logical operations performed by the universe since the Big Bang.[55] If every particle is an automaton communicating with its neighbors, physical reality at the subatomic scale is just one, inconceivably vast network.

Opponents of artificial intelligence and skeptics about telepresence frequently argue that, without a body, an information processing system can learn and understand very little about its environment.[56] They have a point; the isolated "giant brains" of the midcentury modernist imagination are insufficient. Hal doesn't hack it. But the necessary embodiment isn't just that of the naked newborn infant—though babies are on the right track. And it isn't just that of Adam, losing his innocence in a God-given garden. We perceive, act, learn, and know through the mechanically, electronically, and otherwise extended bodies and memories that we construct and reconstruct for ourselves. And, as we are beginning to see, there is no clear limit to this extension.

INDIVIDUALS (INDEFINITE)

As Bateson had begun to realize, we are not fully contained within our skins; our extended networks and fragmented habitats make us spatially and temporally indefinite entities. His central insight was that the ancient distinctions between user and tool, building and inhabitant, or city and citizen, no longer serve us well. And at a practical design level, his point becomes ever more urgent as carbon/silicon interfaces get tighter, as networked silicon intelligence embeds itself everywhere, as EmNets (networked systems of embedded computers)[57] replace stand-alone boxes of electronics, as different types of networks are integrated into multifunctional systems, and as computer and cognitive scientists increasingly theorize "societies of mind" rather than discrete, unified intelligences.[58] We will do better to take the unit of subjectivity, and of survival, to be the biological individual *plus* its extensions and interconnections.

So I am not Vitruvian man, enclosed within a single perfect circle, looking out at the world from my personal perspective coordinates and, simultaneously, providing the measure of all things. Nor am I, as architectural phenomenologists would have it, an autonomous, self-sufficient, biologically embodied subject encountering, objectifying, and responding to my immediate environment. I construct, and I am constructed, in a mutually recursive process that continually engages my fluid, permeable boundaries and my endlessly ramifying networks. I am a spatially extended cyborg.

out of control hundreds of miles above the Earth and affected bank customers could not use their ATMs." *The National Strategy to Secure Cyberspace*, draft, September 2002, <www.whitehouse.gov/pcipb/cyberstrategy-draft.pdf> (accessed December 2002), p. 44.

CHAPTER 1 BOUNDARIES/NETWORKS

1. The duality of enclosures and networks is more than just a metaphor; it is a basic fact of graph theory—the mathematical study of network structure. Consider a floor plan as a planar graph in which corners are nodes and walls are links. Construct the adjacency graph of the plan by locating a node within every enclosed room, plus the exterior zone, then representing room-to-room and room-to-exterior adjacencies by links. The adjacency graph is the dual of the floor plan graph, and vice versa. The circulation network, created by doorways through walls, is a subgraph of the adjacency graph. For more detailed, rigorous development of this point, see Lionel March and Christopher F. Earl, "Architectural Applications of Graph Theory," in Robin J. Wilson and Lowell W. Beineke, eds., *Applications of Graph Theory* (London: Academic Press, 1979), pp. 327–56.
2. The decline of the city wall is often dated from 1494, when Charles VIII of France first deployed horse-drawn artillery pieces in his invasion of northern Italy.
3. Gottfried Semper noticed that the German word for "garment" (*Gewand*) is very closely related to the word for "partition" (*Wand*). He developed an elaborate theory of the relationships among walls, textiles, and clothing in his two great theoretical works, *The Four Elements of Architecture* (1851) and *Style in the Technical and Tectonic Arts, or Practical Aesthetics* (1860–63). (See Harry Francis Mallgrave, *Gottfried Semper: Architect of the Nineteenth Century* [New Haven: Yale University Press, 1996.]) In his essay "Housing: New Look and New Outlook," in *Understanding Media: The Extensions of Man* (New York: McGraw-Hill, 1964), p. 123, Marshall McLuhan repackaged the point: "Clothing and housing, as extensions of the skin and heat-control mechanisms, are media of communication, first of all, in the sense that they shape and rearrange the patterns of human association and community." More recently, Vito Acconci has produced a series of provocative works exploring his contention that "First there is skin and bones, then clothing, then a chair and then housing." See Sarah Boxer, "Poet Turned Antic Architect Keeps Exploring Inner Space," *New York Times*, 12 September 2002, pp. F1, F5. And the discourse continues with Claudia Benthien, *Skin* (New York: Columbia University Press, 2002), and Ellen Lupton, Jennifer Tobias, Alicia Imperiale, Grace Jeffers, and Randi Mates, *Skin* (New York: Princeton Architectural Press, 2002).
4. Georg Simmel, "Bridge and Door," trans. Mark Ritter, *Theory, Culture, and Society* 11 (1994): 5–10.

5. For discussions of the pervasiveness of networks, see Albert-László Barabási, *Linked: The New Science of Networks* (Cambridge, Mass.: Perseus, 2002), and Mark Buchanan, *Nexus: Small Worlds and the Groundbreaking Science of Networks* (New York: Norton, 2002).

6. In *The Production of Space* (1974; English trans., Cambridge, Mass.: Blackwell, 1991), p. 38, Henri Lefebvre argued, "The spatial practice of a society secretes that society's space; it propounds and presupposes it, in a dialectical interaction; it produces it slowly and surely as it masters and appropriates it." Lefebvre's analysis is extraordinarily suggestive, but it shows little curiosity about the specific technologies of spatial production and even less about the effects of changes in those technologies. In *The Informational City: Information Technology, Economic Restructuring, and the Urban-Regional Process* (Cambridge, Mass.: Blackwell, 1989), p. 6, Manuel Castells extended Lefebvre's argument by identifying "the emergence of a *space of flows* which dominates the historically constructed space of places, as the logic of dominant organizations detaches itself from the social constraints of cultural identities and local societies through the powerful medium of information technologies." In *Empire* (Cambridge: Harvard University Press, 2000), Michael Hardt and Antonio Negri proposed that the "irresistible and irreversible globalization of economic and cultural exchanges" had produced "a *decentered* and *deterritorializing* apparatus of rule that progressively incorporates the entire global realm," and "manages hybrid identities, flexible hierarchies, and plural exchanges through modulating networks of command." In this volume I shall be particularly concerned with the technological infrastructure of the global space of flows, the secretion of spatial patterns by means of that infrastructure, and the specific changes that are resulting from the development of a pervasive, wireless computation and telecommunication infrastructure.

7. President's Critical Infrastructure Protection Board, *The National Strategy to Secure Cyberspace*, draft, September 2002, <www.whitehouse.gov/pcipb/cyberstrategy-draft.pdf> (accessed December 2002), p. 3.

8. For a concise history of timekeeping technologies and their increasing precision, see William J. H. Andrewes, "A Chronicle of Timekeeping," *Scientific American* 287, no. 3 (September 2002): 76–85.

9. Lewis Mumford, *Technics and Civilization* (New York: Harcourt Brace Jovanovich, 1963). See also Edward P. Thompson, "Time, Work-Discipline, and Industrial Capitalism," in Anthony Giddens and David Held, eds., *Classes, Power, and Conflict* (Berkeley: University of California Press, 1982), pp. 299–309; and David S. Landes, *Revolution in Time: Clocks and the Making of the Modern World*, rev. ed. (Cambridge: Harvard University Press, 2000).

10. In his speculations on the evolution of machines, Samuel Butler suggested that large clocks would go the way of the big lizards. "Examine the beautiful structure of the little animal, watch the intelligent play of the minute members which compose it; yet this little creature is but a development of the cumbrous clocks of the thirteenth century—it is no deterioration from

them. The day may come when clocks, which certainly at the present day are not diminishing in bulk, may be entirely superseded by the use of watches, in which case clocks will become extinct like the earlier saurians, while the watch (whose tendency has for some years been rather to decrease in size than the contrary) will remain the only existing type of an extinct race." (Samuel Butler, "Darwin among the Machines," in *A first Year in Canterbury Settlement and Other Early Essays* [London: Jonathan Cape, 1923], p. 210.) Butler could not anticipate, of course, that tiny vibrating quartz crystals would one day make mechanical watches seem like bulky and expensive dinosaurs.

11. Ivan E. Sutherland and Jo Ebergen, "Computers without Clocks," *Scientific American* 287, no. 2 (August 2002): 62–69.
12. See David J. Bolter, *Turing's Man: Western Culture in the Computer Age* (Chapel Hill: University of North Carolina Press, 1984), and James Gleick, *Faster: The Acceleration of Just About Everything* (New York: Vintage Books, 1999), for discussions of accelerating subdivision and pace in the digital era.
13. In his October 1998 *Computerworld* column, for example, Edward Yourdon asked: "What if Y2K leads to massive corporate bankruptcies, heralding a long-term economic recession/depression? What if it leads to breakdowns in international communications, or a shut-down of the world's airports for six months?" This was over the top, and Y2K eventually passed with little incident. But the potential for some significant level of Y2K disruption had been real enough, and it had only been averted through a massive effort to identify and eliminate Y2K bugs.
14. Edward Yourdon, "What Comes after 1/1/00," *Computerworld* 32, no. 42 (1998): 89.
15. In 1884, at the International Meridian Conference in Washington, D.C., the globe was subdivided into twenty-four time zones, and the Royal Observatory at Greenwich was chosen as the prime meridian.
16. David P. Anderson and John Kubiatowicz, "The Worldwide Computer," *Scientific American* 286, no. 3 (March 2002): 40–47.
17. Seth Lloyd, "Quantum Mechanical Computers," *Scientific American* 273 (October 1995): 140–45; Seth Lloyd, "Quantum Computing: Computation from Geometry," *Science* 292 (2001): 1669; and George Johnson, *A Shortcut through Time* (New York: Knopf, 2003).
18. Carlton M. Caves, "A Tale of Two Cities," *Science* 282 (1998): 637–38.
19. Charles W. Moore, "Plug It In, Rameses, and See if It Lights Up, Because We Aren't Going to Keep It Unless It Works," *Perspecta*, no. 11 (1967): 32–43. Reprinted in *You Have to Pay for the Public Life: Selected Essays of Charles W. Moore* (Cambridge: MIT Press, 2001), pp. 151–60.
20. Mark Granovetter, "The Strength of Weak Ties," *American Journal of Sociology* 78 (1973): 1360–80.
21. Traditional, place-based communities were described, in many cases idealized, and contrasted with life in the big city in some of the landmark works

of sociology. See, in particular, Emile Durkheim, *The Division of Labor in Society* (1893; New York: Free Press, 1964), Ferdinand Tönnies, *Community and Society* (1887; East Lansing: Michigan State University Press, 1957), and Louis Wirth, "Urbanism as a Way of Life," *American Journal of Sociology* 44 (1938): 3–24.

22. Barry Wellman, *Networks in the Global Village* (Boulder Colo: Westview Press, 1999).

23. There is a growing empirical literature on the role of electronic interconnections in sustaining (or weakening) social networks. See, for example, Keith Hampton, "Living the Wired Life in the Wired Suburb" (Ph.D. diss., University of Toronto, 2001); Philip E. Howard, Lee Rainie, and Steve Jones, "Days and Nights on the Internet: The Impact of a Diffusing Technology," *American Behavioral Scientist* 45, no. 3 (2001): 383–404; Robert Kraut, Vicki Lundmark, Sara Kiesler, Tridas Mukopadhyay, and William Scherlis, "Internet Paradox: A Social Technology That Reduces Social Involvement and Psychological Well-Being," *American Psychologist* 53, no. 9 (1998): 1017–31; and Norman Nie, "Sociability, Interpersonal Relations, and the Internet: Reconciling Conflicting Findings," *American Behavioral Scientist* 45, no. 3 (2001): 420–35.

24. Barry Wellman, "Designing the Internet for a Networked Society," *Communications of the ACM* 45, no. 5 (May 2002): 91–96.

CHAPTER 2 CONNECTING CREATURES

1. In his 1865 essay "Lucubratio Ebria," Samuel Butler developed the idea that modern machines were extended limbs, and that these extensions evolved rapidly. "Every century the change in man's physical status is greater and greater. . . . Were it not for this constant change in our physical powers, which our mechanical limbs have brought about, man would have long since apparently attained his limit of possibility; he would be a creature of as much fixity as the ants and bees; he would still have advanced, but no faster than other animals advance." (Samuel Butler, *A First Year in Canterbury Settlement and Other Early Essays* [London: Jonathan Cape, 1923], p. 217.) Furthermore, he argued, command over such limbs was a privilege of class and power: "He alone possesses the full complement of limbs who stands at the summit of opulence, and we may assert with strictly scientific accuracy that the Rothschilds are the most astonishing organisms that the world has ever yet seen. For to the nerves or tissues, or whatever it be that answers to the helm of a rich man's desires, there is a whole army of limbs seen and unseen attachable; he may be reckoned by his horse-power, by the number of foot-pounds which he has enough money to set in motion. . . . Henceforth, then, instead of saying that a man is hard up, let us say that his organization is at a low ebb, or, if we wish him well, let us hope that he will grow plenty of limbs." ("Lucubratio Ebria," pp. 219–220.)

2. Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore: Johns Hopkins University Press, 1983).
3. This process was to be exhaustively documented in the immediate postwar years by Sigfried Giedion in *Mechanization Takes Command* (Oxford: Oxford University Press, 1948). Giedion worried, as he meticulously enumerated wave upon wave of inventions, about "how far mechanization corresponds with and to what extent it contradicts the unalterable laws of human nature."
4. Telerobotic surgery, which had been a research topic for some years, became a practical reality on 7 September 2001, when a surgeon in a Manhattan office performed a gallbladder operation on a patient in Strasbourg. See Jacques Marescaux, Joel LeRoy, Michel Gagner, Francesco Rubino, Didier Mutter, Michel Vix, Steven E. Butner, and Michelle K. Smith, "Transatlantic Robot-Assisted Telesurgery," *Nature* 413 (2001): 379–80.
5. The Telegarden is a telerobotic art installation, located in the Ars Electronica Center in Austria, where Internet-connected remote users may plant seeds and water the flowers. See telegarden.aec.at and Ken Goldberg, ed., *The Robot in the Garden: Telerobotics and Telepistemology in the Age of the Internet* (Cambridge: MIT Press, 2000).
6. The idea of wireless remote detonation emerged in the very early days of wireless technology; by 1899 Nevil Maskelyne had demonstrated that gunpowder could be exploded by wireless remote control. When terrorist bombs exploded in Kuta, Bali, in October 2002, it emerged that SMS text messages to cellphones strapped to the bomb parcels had probably been used to detonate them. See Wayne Miller and Darren Goodsir, "Wanted: Police Name the Bali Six," *Age* (Melbourne), 18 November 2002, <www.theage.com.au/articles/2002/11/17/1037490052933.html> (accessed December 2002).
7. Manuel de Landa, *War in the Age of Intelligent Machines* (New York: Zone Books, 1991); James Der Derian, *Virtuous War: Mapping the Military-Industrial-Media-Entertainment Network* (Boulder, Colo.: Westview, 2001).
8. Norbert Wiener, *Cybernetics: or, Control and Communication in the Animal and the Machine* (New York: J. Wiley, 1948). In recent military discourse, this point has been articulated as the Revolution in Military Affairs doctrine. See Nicholas Lemann, "Dreaming about War," *New Yorker* (16 July 2001): 32–38.
9. For an overview of "the metabolic requirements of a city" and systems to serve them, see Abel Wolman, "The Metabolism of Cities," *Scientific American* 213, no. 3 (1965): 179–90.
10. The Biosphere was originally constructed, in the 1980s, to explore the possibility of long-term human survival in a closed environment. In the late 1990s, Nicholas Grimshaw's Eden Ecological Center, in Cornwall, was a less doctrinaire, more architecturally sophisticated exploration of the same theme.
11. Fredrik Liljeros, Christofer R. Edling, Luis A. Nunes Amaral, H. Eugene Stanley, and Yvonne Aberg, "The Web of Human Sexual Contacts," *Nature* 411 (2001): 907–8.

12. Dog-to-dog transfusions were attempted in the seventeenth century, following William Harvey's analysis of the functions of the heart and blood circulation system, and experiments with animal-to-human transfusions followed. In 1908 the French surgeon Alexis Carrel sutured an artery of a human donor to a vein of a recipient. By World War I, blood storage technologies had emerged, and military blood depots had been created.
13. For an excellent, detailed description, see Craig C. Freudenrich, "How Spacesuits Work," *Marshall Brain's Howstuffworks*, <http://www.howstuffworks.com/space-suit.htm/> (accessed December 2002).
14. Extracorporeal life support (heart/lung) systems generally include catheters to hook you up, connective tubing, a blood pump, an artificial lung, a heat exchanger, and monitoring devices.
15. The classic analysis of this move is Reyner Banham, *The Architecture of the Well-Tempered Environment* (Chicago: University of Chicago Press, 1969). For a French, post-'68 theoretical reading, see Dominique Laporte, *History of Shit* (Cambridge: MIT Press, 2000). And for valorization of the sanitary engineer and an argument that indoor plumbing turns the home into an "inseparable part of the urban body: the individual organ (the home network) becomes a member of the social body (the city's public network), so that the continuous link between private systems and equipment, and public network induces the shaping of a socially rooted and individually introjected image and model," see Alberto Abriani, "Dal sifone alla città," *Casabella*, no. 542/543 (1988): 24–29 (English summary, "From the Syphon to the City," p. 117).
16. Stephen Graham and Simon Marvin, *Splintering Urbanism: Networked Infrastructures, Technological Mobilities, and the Urban Condition* (London: Routledge, 2001); Matthew Gandy, "Water, Space, and Power," in *Concrete and Clay: Reworking Nature in New York City* (Cambridge: MIT Press, 2002), pp. 19–76.
17. For a retrospective view of Archigram, see Peter Cook, ed., *Archigram* (New York: Princeton Architectural Press, 1999).
18. In a retrospective discussion of the Plug-in City (Cook, *Archigram*, p. 39), Peter Cook commented: "The Plug-in City is set up by applying a large scale network structure, containing access ways and essential services, to any terrain. Into this network are placed units which cater for all needs."
19. Illustrations of these were published in Kircher's *Musurgia universalis* (Rome, 1650). For a recent discussion, which locates them in the history of surveillance systems, see Dorte Zbikowski, "The Listening Ear: Phenomena of Acoustic Surveillance," in Thomas Y. Levin, Ursula Frohne, and Peter Weibel, eds., *CTRL {SPACE}: Rhetorics of Surveillance from Bentham to Big Brother* (Cambridge: MIT Press, 2002), pp. 32–49.
20. The Singapore term "hand phone" comes closer to expressing this quality than the North American "cellphone." And it raises the question of how far *I* extend—to the tips of the fingers that grasp the phone, to the transmitting antenna, or to the receiving earpiece? The Greek term *kinito soma* also makes the association with the body (*soma*) explicit.

21. Thomas J. Campanella, "Eden by Wire: Webcameras and the Telepresent Landscape," in Ken Goldberg, ed., *The Robot in the Garden* (Cambridge: MIT Press, 2000), pp. 22–46.

22. The Japanese mobile carrier NTT Do Co Mo introduced G3 cellphone service in October 2001. The new G3 phones transferred data at about forty times the rate of earlier systems, crossing the threshold of feasibility for wireless videophones.

23. Michel Foucault, "Panopticism," in *Discipline and Punish*, trans. Alan Sheridan (London: Penguin, 1977), pp. 195–228. See also Gilles Deleuze, "Postscript on the Societies of Control," *October* 59 (1992): 3–8; and Levin, Frohne, and Weibel, eds., *CTRL {SPACE}: Rhetorics of Surveillance.*

24. By the spring of 2002, the inexpensive X10 wireless video camera had become a popular consumer item, and had opened up the possibility of drive-by electronic peeping by intercepting its 802.11b signals. See John Schwartz, "Nanny-Cam May Leave a Home Exposed," *New York Times*, 14 April 2002, pp. 1, 27.

25. Lou Hirsh, "Wireless Camera Takes Fantastic Voyage," *Wireless NewsFactor*, 11 January 2002, <wireless.newsfactor.com>. For these tiny, video-toting tourists, the intestinal tract is an amusement park ride, and the rest of the body is just mysterious poché.

26. The biorobot research team at Tokyo University, directed by Isao Shimoyama, has experimented with electronically controlled cockroaches, carrying tiny backpacks, for this purpose.

27. Details on these systems mostly have to be gleaned from investigative journalists and the Web pages of watchdog organizations. See, for example, Duncan Campbell, "Inside Echelon: The History, Structure, and Function of the Global Surveillance System Known as Echelon," in Levin, Frohne, and Weibel, eds., *CTRL {SPACE}: Rhetorics of Surveillance*, pp. 158–69.

28. "Washington Plans Unprecedented Camera Network," Reuters, 13 February 2002.

29. There's a nod, in this, to Orwell, who also set his *1984* surveillance society several decades in the future.

30. For a lively analysis of this condition, together with some provocative arguments that general transparency is not necessarily a bad thing, see David Brin, *The Transparent Society: Will Technology Force Us to Choose Between Privacy and Freedom?* (Reading, Mass.: Perseus Books, 1998).

31. For a snapshot, circa late 1990s, see Brian Hayes, "The Infrastructure of the Information Infrastructure," *American Scientist* 85, no. 3 (May–June 1997): 214–18.

32. Adrian J. Hooke, "The Interplanetary Internet," *Communications of the Association for Computing Machinery* 44, no. 9 (September 2001): 38–40.

33. "Is it a fact . . . that, by means of electricity, the world of matter has become a great nerve, vibrating thousands of miles in a breathless point of time?

Rather, the round globe is a vast head, a brain, instinct with intelligence!" Nathaniel Hawthorne, *The House of the Seven Gables* (1851).

34. John C. Baker, Kevin M. O'Connell, and Ray A. Williamson, eds., *Commercial Observation Satellites: At the Leading Edge of Global Transparency* (Santa Monica: RAND Corporation, 2001), p. 1.

35. National Academy of Sciences, *Embedded Everywhere: A Research Agenda for Networked Systems of Embedded Computers* (Washington, D.C., National Academy Press, 2001), p. x.

36. Erin Hayes, "Detecting Terror: Lab Develops New Ways to Identify and Fight Terrorist Attacks," ABC News, 16 December 2002, <http://abcnews.go.com/sections/wnt/DailyNews/antiterror_technology021216.html> (accessed December 2002).

37. Paul Saffo, "Sensors: The Next Wave of Infotech Innovation," *1997 Ten-Year Forecast* (Menlo Park, Calif.: Institute for the Future, 1997). See also *Sensors*, <www.sensorsmag.com> (accessed December 2002), for coverage of emerging sensor technology. For a 2003 update see Gregory T. Huang, "Casting the Wireless Sensor Net," *Technology Review*, July/August 2003, <www.technologyreview.com/articles/huang0703.asp> (accessed June 2003).

38. The skin metaphor is becoming increasingly prevalent. See, for example, Neil Gross, "The Earth Will Don an Electronic Skin," *Business Week*, 30 August 1999, pp. 68–70.

39. In *The Consequences of Modernity* (Palo Alto: Stanford University Press, 1990), Anthony Giddens develops the argument that the institutions of modernity are characterized by such de-localization.

40. For detailed developments of this theme, see Mitchell Resnick, *Turtles, Termites, and Traffic Jams: Explorations in Massively Parallel Microworlds* (Cambridge: MIT Press, 1999); and Eric Bonabeau, Marco Dorigo, and Guy Theraulaz, *Swarm Intelligence: From Natural to Artificial Systems* (New York: Oxford University Press, 2000). For an attempt to apply concepts of feedback, self-organization, and emergence to urban design, see Steven Johnson, *Emergence: The Connected Lives of Ants, Brains, Cities, and Software* (New York: Scribner, 2001).

41. For snapshots of this phenomenon, as it manifested itself in the early 2000s, see Joel Garreau, "Cell Biology: Like the Bee, This Evolving Species Buzzes and Swarms," *Washington Post*, 31 July 2002, p. C1, and Howard Rheingold, *Smart Mobs: The Next Social Revolution* (Cambridge, Mass.: Perseus Books, 2002).

42. For extended development of the idea of markets as computational mechanisms, see Philip Mirowski, *Machine Dreams: Economics Becomes a Cyborg Science* (Cambridge: Cambridge University Press, 2001).

43. For a detailed discussion of Slashdot's feedback mechanism, see Johnson, *Emergence*, pp. 152–62.

44. The identification of emergent online communities has become an academic cottage industry. See, for example, Gary William Flake, Steve Lawrence, and C. Lee Giles, "Efficient Identification of Web Communities," in *Proceedings*

of the Sixth International Conference on Knowledge Discovery and Data Mining (Boston: ACM Special Interest Group on Knowledge Discovery and Data Mining, 2000), pp. 156–60.

45. J. C. R. Licklider, “Man-Computer Symbiosis,” *IRE Transactions on Human Factors in Electronics*, HFE-1 (March 1960): 4–11. See also J. C. R. Licklider and Robert W. Taylor, “The Computer as a Communication Device,” *Science and Technology*, no. 76 (April 1968): 21–31.
46. In the 1960s, Joseph Weizenbaum’s Eliza system demonstrated that a system did not need deep intelligence to look smart in simple online conversation. By the late 1990s, Richard Wallace’s ALICE chatbot could fool most of the people most of the time. It wasn’t an intelligent entity, but it played one on screen.
47. Mary Catherine Bateson, foreword to Gregory Bateson, *Steps to an Ecology of Mind* (Chicago: University of Chicago Press, 2000), p. xi.
48. Bateson, *Steps to an Ecology of Mind*, p. 466.
49. Ibid., p. 465.
50. H. G. Wells, “World Brain: The Idea of a Permanent World Encyclopedia,” contribution to the *Encyclopédie Français*, 1937, reprinted in H. G. Wells, *World Brain* (New York: Doubleday Doran, 1938).
51. <www.archive.org> (accessed December 2002).
52. On the dynamics of the Web, see Bernardo A. Huberman, *The Laws of the Web: Patterns in the Ecology of Information* (Cambridge: MIT Press, 2001).
53. The Internet Archive’s collection is at <web.archive.org/collections/sep11.html> (accessed December 2002). See also <911digitalarchive.org> (accessed December 2002), and Genaro C. Armas, “Sites Archive 9/11 Communications,” Associated Press, 19 August 2002.
54. Stephen Wolfram, *A New Kind of Science* (Wolfram Media, 2002).
55. Seth Lloyd, “Computational Capacity of the Universe,” *Physical Review Letters* 88, 237901 (2002).
56. These arguments are frequently grounded in the philosophical positions of Heidegger and Merleau-Ponty. See, for example, Hubert L. Dreyfus and Stuart E. Dreyfus, *Mind over Machine: The Power of Human Intuition and Expertise in the Era of the Computer* (New York: Free Press, 1986); Hubert L. Dreyfus, *On the Internet* (London: Routledge, 2001); and George Lakoff and Mark Johnson, *Philosophy in the Flesh: The Embodied Mind and Its Challenge to Western Thought* (New York: Basic Books, 1999).
57. National Academy of Sciences, *Embedded Everywhere*.
58. Marvin Minsky, *The Society of Mind* (New York; Simon and Schuster, 1988).

CHAPTER 3 WIRELESS BIPEDS

1. Marshall McLuhan, “Housing: New Look and New Outlook,” in *Understanding Media: The Extensions of Man* (New York: McGraw-Hill, 1964), pp. 123–30.