Infrastructure and Modernity:

Force, Time, and Social Organization in the History of Sociotechnical Systems

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Introduction

The most salient characteristic of technology in the modern (industrial/post-industrial) world is the degree to which most technology is not salient for most people, most of the time.

This is true despite modernity's constitutive babble/Babel of discourses about "technology." Technology talk rarely concerns the full suite of sociotechnical systems characteristic of modern societies. Instead, at any given moment most technology discourse is about high tech, i.e. new or rapidly changing technologies. Today, these include handheld computers, genetically modified foods, the Global Positioning System, and the World Wide Web. Television, indoor plumbing, and ordinary telephony—yesteryear's Next Big Things—draw little but yawns. Meanwhile, inventions of far larger historical significance, such as ceramics, screws, basketry, and paper, no longer even count as "technology." Emerging markets in high-tech goods probably account for a great deal of techno-discourse. Corporations, governments, and advertisers devote vast resources to maintaining these goods at the forefront of our awareness, frequently without our realizing that they are doing so. Unsurprisingly, they often succeed.

Nevertheless, the fact is that mature technological systems — cars, roads, municipal water supplies, sewers, telephones, railroads, weather forecasting, buildings, even computers in the majority of their uses[1] — reside in a naturalized background, as ordinary and unremarkable to us as trees, daylight, and dirt. Our civilizations fundamentally depend on them, yet we notice them mainly when they fail, which they rarely do. They are the connective tissues and the circulatory systems of modernity. In short, these systems have become infrastructures.

The argument of this paper is that infrastructures simultaneously shape and are shaped by — in other words, co-construct — the condition of modernity. By linking macro, meso, and micro scales of time, space, and social organization, they form the stable foundation of modern social worlds.

To be modern is to live within and by means of infrastructures, and therefore to inhabit, uneasily, the intersection of these multiple scales. But empirical studies of infrastructures also reveal deep tensions surrounding what Latour recently named the "modernist settlement": the social contract to hold nature, society, and technology separate, as if each were ontologically independent of each other (Latour 1999). Close study of these multi-scalar linkages reveals not only co-construction, but co-deconstruction of supposedly dominant modernist ideologies.

To develop these arguments, I begin this chapter by exploring how infrastructures function for us — both conceptually and practically — as environment, as social setting, and as the invisible, unremarked basis of modernity itself. Next I turn to a methodological issue that affects all historiography: the question of scale. How do infrastructures look when examined on different scales of force, time, and social organization? As Phillip Brey notes in Chapter 2, "the major obstacle to a synthesis of modernity theory and technology studies is that technology studies mostly operates at the micro- (and meso-) level, whereas modernity theory operates at the macro-level." I argue that infrastructure, as both concept and practice, not only bridges these scales but offers a way of comprehending their relations. In the last part of the essay, I apply these methods and arguments to several examples from the history of infrastructures, including the Internet and the SAGE air defense system. Ultimately, these reflections lead me to conclude (with Brey) that social constructivism, as a core concept of technology studies, and the notion of "modernity" as used in modernity theory, are strongly conditioned by choices of analytical scale. A multi-scalar approach based on the idea of infrastructure might offer an antidote to blindness on both sides.

What is infrastructure?

The word "infrastructure" originated in military parlance, referring to fixed facilities such as air bases (OED). Today it has become a slippery term, often used to mean

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[1] Most users of "computers" confront them not in their essence, as general-purpose programmable machines, but in their applications, as special-purpose, pre-programmed systems: grocery store cash registers, rental car return systems, library catalogs, Web browsers (Landauer 1995). Even more invisible to ordinary users are the ubiquitous "embedded" microprocessors contained in everything from automobiles to refrigerators.

essentially any important, widely shared, human-constructed resource. The American Heritage Dictionary defines the term as (1) “an underlying base or foundation, especially for an organization or a system,” and (2) “the basic facilities, services, and installations needed for the functioning of a community or society, such as transportation and communications systems, water and power lines, and public institutions including schools, post offices, and prisons.” In 1996-97 the US Commission on Critical Infrastructure Protection (PCCIP) chose the following as fundamental to its own definition:

- transportation
- oil and gas production and storage
- water supply
- emergency services
- government services
- banking and finance
- electrical power
- information and communications

The Commission went on to explain:

> By infrastructure… we mean a network of independent, mostly privately-owned, man-made systems and processes that function collaboratively and synergistically to produce and distribute a continuous flow of essential goods and services (President's Commission on Critical Infrastructure Protection 1997).

The free-marketeering sloganism of this definition should not distract our attention from its key concept: flow. Manuel Castells, one of the few scholars to succeed in fully characterizing the close interplay among socio-technical infrastructures and the grand patterns of 20th century cultural, economic, psychological, and historical change, calls this relation the “space of flows” (Castells 1996). Given the heterogeneous character of systems and institutions referenced by the term, perhaps “infrastructure” is best defined negatively, as those systems without which contemporary societies cannot function.

Interestingly, although “infrastructure” is often used as if it were synonymous with “hardware,” none of the definitions above center on hardware characteristics. As historians, sociologists, and anthropologists of technology increasingly recognize, all infrastructures (indeed, all “technologies”) are in fact socio-technical in nature. Not only hardware but organizations, socially-communicated background knowledge, general acceptance and reliance, and near-ubiquitous accessibility are required for a system to be an infrastructure in the sense I am using here.

An important caveat is in order here. This notion of infrastructure as invisible, smooth-functioning background “works” only in the developed world. In the global South (for lack of a better term), norms for infrastructure can be considerably different. Electric power and telephone services fail routinely, often on a daily basis; highways may be clogged beyond utility, or may not exist; computer networks operate (when they do) at a crawl. I will not attempt to integrate this much different — but equally "modern" — set of infrastructural norms into this chapter, which thus suffers from a form of idealism that might also be characterized as a Western bias. Instead, I simply mark this bias where it occurs, and note that any adequate theory of modernity and technology would have to come to grips with this additional level of complexity. Other chapters in this volume — notably those of Slater and Khan — begin to move in this direction.

Infrastructure and/as environment

As I noted above, infrastructures are largely responsible for the sense of stability of life in the developed world, the feeling that things work, and will go on working, without the need for thought or action on the part of users beyond paying the monthly bills. This stability has many dimensions, most of them directly related to the specific nature of modernity.

Among these is systemic, society-wide control over the variability inherent in the natural environment. Infrastructures confer the abilities to (for example) regulate indoor temperatures, have light whenever and wherever we want it, draw unlimited clean water from the tap, and buy fresh fruits and vegetables in the middle of winter. Another is control of time and space: to work, play, and sleep on schedules we design, to communicate instantaneously with others almost regardless of their physical location, and to go wherever we want at speeds far beyond the human body's walking pace. These capacities allow us, and perhaps compel us, to approach nature as a consumable good, something to be experienced (or not), as and when we wish (Nye 1997). Infrastructures constitute an artificial environment, channeling and/or reproducing properties of the natural environment which we find most useful and comfortable, providing others which the natural environment cannot, and eliminating features we find dangerous, uncomfortable, or merely inconvenient. In so doing, they simultaneously constitute our experience of the natural environment, as commodity, object of romantic/pastoralist emotions and aesthetic sensibilities, or occasional impediment. They also structure nature as resource, fuel, or "raw material," which must be shaped and processed by technological means to satisfy human ends.

Thus to construct infrastructures is simultaneously to construct a particular kind of nature, a Nature as Other to society and technology. This fundamental separation is one key aspect of Latour's "modernist settlement."

Infrastructure and/as society

In the same way, infrastructures can be said to co-construct society and technology while holding them ontologically separate.

As Leigh Star and Karen Ruhleder observe, knowledge of infrastructures is "learned as part of membership" in communities (see also Bowker & Star 1999, 35; Star & Ruhleder 1996). By extension, such knowledge is in fact a prerequisite to membership. In the case of the major infrastructures listed above, these communities include almost all residents of societies in the developed world. The degree to which such knowledge is shared accounts, in large part, for the spectrum between familiarity and exoticism experienced in travel: societies whose infrastructures differ greatly from our own seem more exotic than those whose infrastructures are similar. Belonging to a given culture means, in part, having fluency in its infrastructures . This is almost exactly like having fluency in a language: a pragmatic knowing-how, rather than an intellectual knowing-that, such that the bewildered questions of an outsider might strike one as not only hilarious, but also unanswerable. Infrastructural knowledge is a Wittgensteinian “form of life,” a condition of contextuality in which understanding any part requires a grasp of the whole that comes only through experience (Edwards 1996; Wittgenstein 1958). In this sense, infrastructures constitute society.

At the same time, we treat infrastructures and society as ontologically separate. For example, the causes of infrastructural breakdowns such as power blackouts or telephone outages are nearly always reported either as “human error,” which codes the problem as individual and allows the assignment of blame, or as technological failure. Although most breakdown would in fact be better explained by complex relationships between operators, systems, natural conditions, and social expectations (Vaughan 1996), social causes are rarely invoked. Power outages or traffic jams cause most of us to think of downed power lines or inadequate roads, rather than to question our society’s construction around and dependency on them. As for those few (developed-world) people who choose to live without electricity or automobiles, we generally regard them as eccentrics who have “moved backwards” or to “live in another era”; they have chosen, as it were, not to be moderns (Kraybill & Olshan 1994).

Similarly, the notion of technological failure codes infrastructure as hardware (Perrow 1984). But most such failures can be anticipated and prevented through design and/or maintenance, which in turn require highly organized social commitments (La Porte 1991; La Porte & Consolini 1991; Rochlin 1997; Sagan 1993). The remarkably low accident rates in commercial air transport, for example, reflect the success of vigilant organizations, legal apparatus, and social learning about accidents as much as they demonstrate the quality of aircraft (La Porte 1988). Yet for most travelers, the social components of safe air transport are even more transparent than the airplanes in which they fly; people worry much more about the airplane than about the ground crew, the FAA, or air traffic controllers. Thus while infrastructure in fact functions by seamlessly binding hardware and internal social organization with wider social structures, our commonsense perspective on infrastructure simultaneously creates a “black box” that enables the rhetorical separation of society from technology in the modernist settlement (Latour 1999).

Infrastructure and/as modernity

Thus infrastructure is the invisible background, the substrate or support, the technocultural/natural environment, of modernity. Therefore, the question of infrastructure seems to me better posed than Heidegger’s rather ill-formed “question concerning technology,” which he, like most others, understood chiefly as “artifact”

(Heidegger 1977). To paraphrase Langdon Winner, infrastructures act like laws (Winner 1986). They create both opportunities and limits; they promote some interests at the expense of others. To live within the multiple, interlocking infrastructures of modern societies is to know one's place in gigantic systems which both enable and constrain us. The automobile/road infrastructure, for example, allows us to move around at great speed, but also defines where it is possible to go; only a few modern people travel far on foot to places where there are no roads. When they do, it is chiefly as recreation ("being in nature"). Telephones, electric power, television, and other basic infrastructures offer many services, but also catch subscribers up in webs of corporate bureaucracy, government regulation, and the constant barrage of advertising. Control, regularity, order, system, techno-culture as our nature: not only are all of these fundamental to modernism as Weltanschauung, ideology, aesthetic, and design practice, but they are also (I want to argue) basic to modernity as lived reality.

This combination of systemic, technologically-supported social possibilities and law-like constraints leads to my first answer to the questions that motivate this book:

> Building infrastructures has been constitutive of the modern condition, in almost every conceivable sense. At the same time, ideologies and discourses of modernism have helped define the purposes, goals and characteristics of those infrastructures. In other words, the co-construction of technology and modernity can be seen with exceptional clarity in the case of infrastructure.

Scale as method

In the rest of this essay I want to explore a method for studying infrastructures that may help to clarify their relation to modernity. At the same time, this method draws attention to difficulties, contradictions, and fault lines within those concepts; thus it may help us further untangle their complexity, question their utility, and perhaps lead to reformulation of the question itself. The method involves looking at infrastructures simultaneously from a variety of scales of force, time, and social organization.

This technique was initially sparked by Misa's ideas about the importance of scale in the history of technology (Misa 1988; Misa 1994). It also has something in common with Bowker and Star's method of "infrastructural inversion," which involves close attention to the normally invisible "bottom" layers of infrastructure, the levels of basic standards, classification schemes, and material bases (Bowker & Star 1999).[2] The general discussion in the rest of this section is followed by application to some examples in my own field, information infrastructure studies.

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[2] Here I also want to acknowledge my friend and colleague Stephen Schneider, whose insistence on the importance of scale in climate science first led me to think about these issues.

Force

I begin by considering scales of force that run from the powers of the human body (at the low end) to the geophysical.

For most of human history, transportation and production systems depended primarily on human and animal power. Many modern infrastructures, such as transportation systems and electric power, create what appear at the human scale as amplifications of natural energies, beyond what unaided human beings or animals could achieve. “Modern” societies are practically synonymous with those where such amplification is generally available. So (some) infrastructures can be characterized as force amplifiers, and the modern condition as a Heideggerian ready-to-handness of these amplifying powers. The sense of empowerment we gain from these is great indeed.

Many energy-based infrastructures thus occupy a scale of force intermediate between the human body and the geophysical. They create reliable, invisible, socially useful capacities to contain and control energy. Preindustrial infrastructures, of course, often relied directly on harnessing natural forces, such as water and wind, which also occupy this intermediate scale. A less-noticed point is that many modern energy-based infrastructures also rely, at least in part, on natural forces. Hydroelectric dams and air travel’s use of the high-altitude jet stream are only two of many possible examples. This much is relatively obvious.

However, another, larger scale of force is usually ignored in discussions of infrastructure. As the Dutch (for example) know only too well, infrastructures function only within a particular range of natural variability; the system of dikes and pumping stations that keeps the ocean from reclaiming much of the Netherlands is occasionally overcome by unusual natural events . Similarly, flood-plain residents across the globe regularly see their homes destroyed, only to rebuild them again. Earthquakes, tornadoes, global climate change, and other natural events represent scales of force beyond the range for which most infrastructures are, or even can be, designed.

At least in the United States, these events are known as “natural disasters.” Among their social effects is to bring infrastructure suddenly and painfully to our awareness. Hurricane Floyd ravaged North Carolina and other East Coast states in September, 1999; headlines about its aftermath frequently focused on the hardship, suffering, and even death resulting from failure of water and power supplies. Power failures in major US cities, during the summer of 1999 when demand for air conditioning soared due to “unusual” heat waves, were blamed for a number of deaths and near-deaths. California telephone books warn residents to stock a week’s worth of water, food, and cooking fuel, in case earthquakes take out electric power, water supplies, and/or gas lines. The severe destruction wrought by the recent earthquakes in Turkey and India, in which many thousands perished, brought hand-wringing about building codes, an important politico-legal standard for infrastructure. This list could be expanded indefinitely.

In the developed world, probably the large majority of “natural disaster”-related injuries and deaths are actually caused not directly by the natural event itself, but indirectly by its effects on infrastructures. For example, damage to roads, bridges, rails, tunnels, etc. leads to automobile and railroad accidents, or municipal water supplies contaminated by flood waters and broken sewer mains cause disease. Flooding can result as much from shattered dams and levees, or silt buildup actually caused by flood-control systems, as from heavy rainfall. Edward Tenner names these “revenge effects” of technology (Tenner 1996). The effects of such failures can be magnified by interdependencies among infrastructures. For example, natural cataclysms can cripple one infrastructure — such as the emergency services system — by taking out others, such as the telephone system and the roadway network. Indeed, we depend so heavily on these infrastructures that the category of “natural disaster” really refers primarily to this relationship between natural events and infrastructures.

Increasingly, modern societies are confronted with the forgotten relationship between built infrastructures and the assumed background of natural forces and structures upon which the former rely. Long considered essentially static, this background is now regarded not only as naturally variable, but also as subject to alteration by human activity. Global climate change, for example, is changing the parameters within which built infrastructures function, in ways ranging from changing agricultural conditions to an increase in the frequency of severe weather events. Because of its inherently forward-looking, long-term perspective, the insurance industry — a fundamental financial component of virtually all modern infrastructures — has begun to incorporate climate change in its analysis of vulnerabilities to “natural” disaster, especially in low-lying coastal regions. As a political issue, climate change represents the dawning awareness that geophysical scales of force must be included in any complete analysis of infrastructure. This recognition could be understood as a fundamental, and fundamentally new, feature of infrastructure in modernity.

Time

Another, related scalar dimension is time, which I will discuss as ranging between the human (hours, days, years) through the historical (decades, centuries) to again the geophysical (millennia and beyond).

The specific character of human time is one reason why infrastructures fade into invisibility between moments of breakdown. Human time scales are set by our natural (animal) characteristics: the horizon of death, the salience of extremes, the fading and distortion of memory, the slow, faltering process of learning, and our restless, present-centered, single-focus attention, among many others.[3] Outside rare moments of creation or major transitions, infrastructures change too slowly for most of us to notice; the stately pace of infrastructural change is part of their reassuring stability. They exist, as it were, chiefly in historical time.

[3] Speed, which may be understood as the application of force amplification to the problem of human time, is another aspect of modernity produced through infrastructures. I lack the space to treat this here, but see for example Virilio (1986) and Rabinbach (1990).

Partly because of this, infrastructures possess the power to shape human time, shaping the preconditions under which we experience time's structure and its passage. Famously, the telegraph created a sense of simultaneity across huge distances, prefiguring McLuhan's "global village," while electric power extended working hours into the night.[4] Transportation infrastructure fixes the relationship of time to space, transforming human experience of both. Societies build infrastructures, of course, but because of their endurance in time, infrastructures then become the more important force in structuring society. This point is similar to Giddens' concept of "structuration," which he once defined as "how it comes about that social activities become 'stretched' across wide spans of time-space" (Giddens 1984, xxi).

Yet on geophysical, or even long-term historical, time scales, infrastructures are fragile, ephemeral things. The Roman aqueducts still stand, but most have carried no water for many centuries. The global telegraph network, mainstay of world communications even into the 1960s, has been largely replaced by the telephone. On this long view, time shapes them, rather than the other way round. In geophysical time, cataclysms far larger than anyone now living has experienced have occurred with monotonous regularity, while even apparently gentle forces, such as continuously dripping water, exceed the capacities of technological control (for example, in the still-unsolved problem of long-term nuclear waste storage).

Thus—returning to my point in the preceding section—the irregularity with which "natural disasters" occur can be seen (on human force and time scales) as one vehicle for constructing properties of a modernist "nature" (as dangerous, unpredictable, and/or inconvenient), thereby separating nature from infrastructure and framing technology as control. Yet in geophysical time, this same irregularity becomes a fundamental, predictable property of nature, deconstructing the separation between them by illustrating the permanent imbrication of infrastructure in nature.

In other words, we might say that infrastructures fail precisely because their developers approach nature as orderly, dependable, and separable from society and technology — an understanding that is in fact a chief characteristic of modern life-within-infrastructure. Yet nature recalcitrantly refuses to agree to this modernist settlement. Alternatively, we could say that on long-historical and geophysical time scales, breakdown is a natural property of infrastructures, or instead a property of nature as infrastructure (on which all human-built infrastructures ultimately depend). Thus modernity can also be depicted as a condition of systemic vulnerability.

Consciousness of this vulnerability runs deep in modern thought. It is no accident that modern apocalyptic fear stems chiefly from two sources: nuclear war, on the one hand, and ecological catastrophe, on the other. The former represents, in a sense, the ultimate scientific/technological force amplifier. At its height during the Cold War — an utterly modern conflict of two gigantic systems whose military infrastructures permeated

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[4] The epochal character of these changes led Marvin (1988) to the correct insight that the perceived pace of technological change in the late 19th century was in fact faster even than today's. See also Kern (1983).

entire societies — widespread (and well-justified) fear of accidental nuclear war brought home the normality of breakdown, even in an infrastructure built with essentially unlimited resources (Borning 1987; Bracken 1983). More recently, fear of global warming represents the permanent imbrication of industrial infrastructures within the planetary carbon metabolism. This again drives home the falsity of the modernist settlement; technological systems consume carbon, but they rely on nature to cycle it out of the atmosphere and back into the soil (and to produce it in the first place). As a global infrastructure, the fossil-fuel economy is simply a part of this larger process. Nature is thus, in some sense, the ultimate infrastructure. Ecological awareness, especially in its planet-management variants, explicitly recognizes this inseparability. We might imagine Beck's "Risk Society" (Beck 1992) as a description of an emerging post-modernist settlement, which functions by rendering the natural and the sociotechnical commensurate via the omnipresent category of risk .

Social organization

To force and time, let me now add a third scalar dimension: social organization. In contrast to its relatively straightforward application to time and force, the notion of "scale" applies to social organization only as a heuristic; the size of organizations is only one of numerous, not necessarily related variables governing their relative importance. Still, for my purposes here it works as a rough, intuitive guide. The "scale" of social organization runs from individual families and work groups to governments, economies, and multinational corporations. It is multiply and crucially cross-cut by categories such as gender, ethnicity, and other identity-constituting social formations. Here I will begin to introduce empirical studies (the purpose of this volume) directly.

As I noted above, infrastructures exist on historical time scales. Under my definition, they also exist on large social and economic scales. Most are built and maintained by very large organizations (e.g. telephone and power companies, national and international regulatory bodies, etc.). They may connect millions, even billions, of individual and corporate users, who may employ them on a daily basis for a lifetime or more. Yet from the perspective of these users, infrastructures also exist on much smaller temporal and social scales. In some sense, every household is an individually-configured infrastructure for a family or small group, built primarily by selecting commercially available components whose connectibility is ensured by standardized interfaces (e.g. wall outlets, telephone jacks, and TV cable). Small, ephemeral social groups, such as those constituted by email lists or neighborhood telephone directories, may function largely or entirely through large-scale infrastructures.

Scales of social organization require a different terminology than the ones I used to describe force and time, so I will adopt Misa's useful categories:

- micro: individuals, small groups; generally short-term[5]
- meso: institutions, e.g. corporations and standard-setting bodies, generally enduring over decades or longer
- macro: large systems and structures such as political economies and some governments, enduring over many decades or centuries

Here as above, I will argue that a micro-scale approach to infrastructures produces one view of their role in modernity, while a macro-scale approach produces a quite different one. Each scale tells us something about the condition of modernity, yet the tensions among scalar views simultaneously call into question the category of "modernity." They also suggest a serious problem with the currently popular social constructivist approach to science and technology studies.

Meso scales: large technical systems

Let me begin with a meso-scale view. A number of empirical studies have treated aspects of the history and sociology of individual infrastructures, including highways (Goddard 1994; Lewis 1997; Seely 1987), the telegraph (Blondheim 1994; Standage 1998), radio (Douglas 1987), air traffic control (La Porte 1988; La Porte & Consolini 1991), and more recently the Internet (Abbate 1999; Hauben & Hauben 1997; Segaller 1998). The best and most successful of these have examined railroads (Chandler 1977; Yates 1989), electric power (Hughes 1983), and telephone systems (Fischer 1992).[6]

However, only a few such studies seek to address issues of infrastructure formation and development per se. The most systematic attempts began in the mid-1980s under the aegis of a loosely organized "large technical systems" group of European and American sociologists and historians (La Porte 1991; Mayntz & Hughes 1988; Summerton 1994). Hughes, the dean of American historians of technology and a prominent figure in the large technical systems group, set the agenda by arguing that on historical time scales, large technical systems tend to follow a well-defined developmental path. Initially, an unorganized, diffuse set of inventors and tinkerers create new technological possibilities. At some point, "system builders" see a way to organize these possibilities into a complete system with an important function, as Edison conceived a lighting system from generator through cable to light bulb, or as Morse imagined a trans-Atlantic network made from telegraph keys, cables, and code. The vision of system builders must be simultaneously social and technical, since commercial success depends on understanding not only how a system might be built, but also what it might be good for and what might make it attractive to customers or clients (who usually already have

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[5] Small size does not always correlate with short duration. Families, for example, are a basic social unit which can endure coherently in time over extremely long periods. Nor does large size guarantee long survival.

[6] For reviews of these literatures, see Friedlander (1995a; 1995b; 1996).

some way of carrying out the function in question). In the terms I am using here, system builders imagine an infrastructure.

Following a diffusion stage, when variations on the original concept emerge, networks begin to acquire “technological momentum,” characterized by “mass, velocity, and direction” (Hughes 1987). In this phase, some particular version of the system acquires a critical mass of users. The latter’s collective financial and cognitive investment gradually acts to inhibit radical change in fundamental system properties.

At this point, standards emerge which limit the possible configurations. This is a critical stage, at which chaotic competition becomes organized around a relatively stable system concept. Eventually, competing networks must convert to these standards, find ad hoc ways to connect non-standard equipment with them, or else die out. Standards reduce the risk to manufacturers as well as the cost to consumers, thus increasing the dominant system’s overall momentum. In a consolidation phase, any remaining independents convert to the established standard. This creates a unified infrastructure, sometimes in the form of a public or quasi-public monopoly (“public utility”). More recently, some major infrastructures in the United States and Europe (especially Great Britain) have entered another phase: deregulation, in which government reduces or removes monopoly protection, re-creating a (limited) free market for infrastructural services such as telephone and electric power.

Hughes also demonstrated that national infrastructures developed according to different “technological styles.” Comparing the history of electric power systems in the United States, Germany, and England, he explained technical variations among systems through the influence of particular histories and political economies, and sometimes through more intangible factors, such as the desire to assert national identity through a unique technological style (Hecht 1998).

The large technical systems group convincingly showed that these and similar patterns can be found in the history of many major infrastructures. The lessons of these studies are twofold. First, individual infrastructures follow a life cycle, a developmental pattern visible only on historical time scales. Second, infrastructures consist not only of hardware, but of legal, corporate, and political-economic elements. For example, the developmental pattern of the US national railroad system had as much to do with Federal land grants, the regulatory activities of the Interstate Commerce Commission, certain Supreme Court decisions, and corporate defenses against stock market speculation as with innovations in steam engines, railbed technology, and signaling systems. “Technology” is not only socially shaped; it is social through and through. Understanding how it is shaped demands appropriate choices of temporal and social scale of analysis. While individual system-builders like Edison, Thomas Watson Sr., or Bill Gates can matter greatly in the history of infrastructure, the real lesson of Hughes-inspired histories has been the crucial role of large social institutions.

Most of the patterns discerned by the large technical systems group apply directly to infrastructure development. But the two concepts are not quite identical. The idea of "large technical systems" focuses attention on growth around a technological core. By contrast, infrastructures are not merely large systems, but sociotechnical institutions. Some infrastructures (such as school systems and constitutional legal systems) rely very little on technology, though I will not discuss this form of infrastructure here. Furthermore, some kinds of infrastructures — particularly digital information infrastructures — can be extended, interconnected, and "re-purposed" almost infinitely, creating meta-level webworks that no longer fit the mold of a technology-centered system. A good example is contemporary "digital convergence," in which radio, television, recorded music, cellular telephony, and other media come together in new systems based on the Internet and World Wide Web (Edwards 1998a; Edwards 1998b; Hanseth & Monteiro 1998). Clearly these emerging, interconnected systems do not fit the mold of electric power grids or telephone networks. As I use it, the notion of infrastructure invokes possibilities of extension in time, space, and technological linking that go beyond individual systems.

This description of infrastructure development clearly situates it as a modern phenomenon. Building regional- to world-scale infrastructures requires large institutions with long lifespans, enormous political, economic, and social power, and (on the private-sector side) great wealth. Individuals and small social groups do affect their course, but chiefly in earlier phases, before institutions have taken control. This understanding is generally compatible with the widespread view of modernity as the submergence of individuals and local communities beneath the imperatives of state and corporate power (Borgmann 1984; Borgmann 1992; Foucault 1977; Vig 1988; Winner 1986). In this case, such imperatives operate by means of generalized, and pragmatically unavoidable, enrollment in the forms of life dictated by infrastructures.

Micro scales: the user heuristic

Yet views of infrastructure at other social scales offer different lessons. Under the rubric of the social construction of technology (SCOT), much recent scholarship in science and technology studies has concentrated on the micro scale of individuals and small social groups (Bijker & Law 1992; Bijker et al 1987). Here I will focus on Claude Fischer's social history of the telephone (Fischer 1992), among the most successful examples of this perspective.

Fischer studied telephone users in the years when the telephone was still acquiring its infrastructural status. Fischer argued that user innovation shaped the social role of the telephone — more so than telephone company marketing. While early telephone companies thought of the phone by analogy to the telegraph, which was chiefly a business instrument, women (and others) rapidly adopted it for their own, non-business-related purposes, such as sociability. This was initially seen by the telephone companies as "idle chatter" that wasted the system's value; only after decades of spontaneous, user-driven telephone sociability did telephone companies perceive the vast marketing opportunity this represented.

Working-class telephone users also innovated, creating sociotechnical networks within their communities that allowed them full use of telephone technology without subscribing to the system individually. For example, in working-class neighborhoods, young boys would monitor banks of public pay telephones, answering calls and then running off (literally) to find whomever the caller requested. This kind of system persisted for decades, even after the cost of telephone service made it possible for even the very poor to afford a home telephone. By using their own bodies and their existing community structures (neighborhoods, gathering places) as components, these users created an important variation on the infrastructure offered them by corporations and governments.[7]

Rather than assume that users are powerless pawns of dominating corporations or technological systems, Fischer argued, technology studies should adopt a "user heuristic." In other words, analysts should always determine empirically whether users are active agents of technological change. Fischer acknowledged important "system effects" on the micro scale (for example, the large disadvantages of not having a telephone once most people do). Nevertheless, he maintained, the empirical history of the telephone does not fit an a priori view of modernity as a condition of technological subjection and alienation. Instead, users appropriated telephone technology to their own ends, and they employed it for a decidedly pre-"modern" purpose: sociability.

Applying the user heuristic to ARPANET/Internet history

Empirical studies of the ARPANET/Internet and the World Wide Web have brought to light stories quite similar to Fischer's account of the telephone network. In 1968-69, the ARPANET's designers imagined it as an official communication channel for ARPA-sponsored research groups across the United States (but see below for another aspect of the ARPANET's design). The purpose was to allow ARPA computer science researchers to share programs and data quickly, cutting down on delays and inefficiencies in the existing channels such as ordinary mail and telephone.

By 1972, however, ARPANET users had composed simple electronic mail programs that allowed them to use the system as an unofficial, general-purpose communications medium. Just three years after the ARPANET's creation, 75 percent of network traffic was email (Hafner 1996, 194). This spontaneous user takeover of an official medium for unofficial purposes has many parallels in the history of information technology. For example, corporations using email for groupwork have sometimes felt it necessary to impose random surveillance to prevent employees from using the medium to "socialize." While their (modernist) power to do this has been upheld by US courts (in-house email counts, legally, as official communication), the dampening effects of this strategy have often led corporations to remove surveillance later (Zuboff 1988).

[7] In modern India and Bangladesh, microcredit programs are deliberately promoting a similar, community-centered telecommunications strategy. Village women receive cellular telephones from Grameen Bank and other sponsors. They then selling call time to local customers. They earn money, but in the process they also become central to village life in a new and significant way.

Similarly, Usenet newsgroups were an unforeseen, entirely user-developed application of the ARPANET (Hauben 1996). Though initially many newsgroups were computer-related, they too rapidly became a medium for general-purpose communication on a vast variety of topics. Today Usenet comprises tens of thousands of newsgroups, spanning subjects from scuba diving to Star Trek. This and similar phenomena have been widely discussed under the rubric of “virtual communities” (Rheingold 1993). Where telephone-supported sociability occurred primarily between people who already knew each other, and who continued to meet in person, these forms of Internet-supported sociability frequently involve strangers who never meet face-to-face.

The World Wide Web originated at the European high-energy physics laboratory, CERN, in the late 1980s. Once again, its original purpose was narrow and official. The title of the document proposing what became the Web was simply “Information Management: A Proposal”; its author, Tim Berners-Lee, sought a way to cut down on the vast volume of CERN documents and data mailed around the world in support of the many physicists who collaborate on CERN experiments. Instead, he proposed a system by which such documents and data could be accessed easily, through a hypertext interface, via the Internet using a simple protocol (hypertext transfer protocol, or HTTP). Berners-Lee named this system the “World Wide Web” (WWW) in 1990.

Yet what this really meant, at the time, was the “World Wide <u>High-Energy Physics</u> Web.” Berners-Lee and Robert Cailliau wrote in their 1990 project proposal that

> …a universal hypertext system, once in place, will cover many areas such as document registration, on-line help, project documentation, news schemes and so on. It would be inappropriate for us (rather than those responsible) to suggest specific areas, but experiment online help, accelerator online help, assistance for computer center operators, and the dissemination of information by central services… are obvious candidates. WorldWideWeb (or W3) <u>intends to cater for these services across the high-energy physics community</u> (Berners-Lee & Cailliau 1990, emphasis added).

Similar language characterized most of the early CERN project. Indeed, until mid-1993, virtually all the computer servers running HTTP were located at CERN and other high-energy physics laboratories around the world.

Here too, however, users very quickly began to add features and to use the system for general-purpose communication. Unlike the ARPANET’s designers, however, Berners-Lee and his colleagues had intentionally built the system to allow users to add new material and expand the transfer protocol. With the 1993 release of a graphical browser (Mosaic) by the US National Center for Supercomputing Applications (largely a support system for US physics laboratories), the WWW began its explosive growth into the emerging infrastructure we know today.

These examples illustrate an important lesson of empirical studies for theories of modernity. Selective attention to the specifically “modern” aspects of infrastructures can produce blindness to other aspects that may in fact be “anti-modern” (as Fischer called the sociability aspects of telephone systems). For example, modernity studies continually note the anonymity and geographically dislocated character of Internet virtual communities (Stratton 1997), but they tend to ignore, or to dismiss as utopian illusion, their well-documented qualities of spontaneity, self-organization, and sociability (Rheingold 1993; Rheingold 1996; Sproull & Kiesler 1991). They point to the panoptic power of corporate surveillance in networked offices, but they fail to notice when employees find ways to work around surveillance systems (Zuboff 1988).

The key point here is that infrastructures (like all socio-technical systems) have many, and sometimes contradictory aspects. At the micro scale of social organization, “modernity” — as subjection, control, dominance of systems, panopticism — becomes slippery and difficult to locate.

Macro scales: functional approaches to infrastructural change

Empirical studies at the macro scale — entire societies and economic systems — reveal yet another set of patterns, especially when they also employ a historical time scale. As Misa has noted, explanations on these scales tend to be functional and systemic, rather than constructivist, in character.

On society-wide, historical time scales, infrastructures die. Gas lighting, the telegraph, the passenger railroad, and inner-city streetcars are all examples of once-major infrastructures that are dead or radically diminished in the United States. Any complete explanation of why they vanished requires a functional view of the reasons they came to exist in the first place. If we look at function rather than at the particular technology or infrastructure that fulfills it, we see not disappearance but growth. Gas lighting may be dead, but artificial light illuminates the world; the telegraph is gone, but far more intricate and capable long-distance communication systems have replaced it .

On this scale, we see that new infrastructures at first supplement, then sometimes replace, existing ones. For example, the (expensive) telegraph supplemented (inexpensive) postal services. Telephone at first supplemented telegraph, then replaced it.[8] At present, email supplements the telephone, and is rapidly replacing postal services for personal, letter-length messages. The infrastructures delivering these services changed — but the fundamental functions they performed did not.[9] This perspective draws attention away from particular technologies, and it is scale-

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[8] Business users at first resisted general use of the telephone because it left no written record. Fax machines, piggybacking on the telephone system, serve this record-making function today.

[9] Micro studies would certainly reveal systematic, though subtle, changes in the content and form of messages sent through each infrastructure, e.g. McLuhan’s “hot” and “cold” media, or recent studies of differences between email and other communication forms in business organizations (Sproull & Kiesler 1991). Part of my overall argument is that these differences, too, could be seen as a matter of scale.

dependent. On macro scales of time and social organization, function matters more than form.

Beniger, for example, developed a theory of industrial capitalism centered around the problem of control, a functional issue linking technological, social, institutional, and informational dimensions. He argued that a generalized "crisis of control" resulted from the Industrial Revolution. Mass production techniques created control problems at the micro level of individual machines; such technologies as the steam engine governor and the Jacquard loom represented solutions at this level. But mass production also created a control crisis at the macro level of the entire production-distribution-consumption system. It rapidly produced more goods than local markets could possibly absorb. Therefore, finding new markets for this dramatically increased output soon became an urgent imperative. Faster, higher-capacity transportation systems could increase the flow rate of mass-produced goods to new, more distant markets (recalling the PCCIP definition of infrastructure, above). Therefore, transportation became a Hughesian "reverse salient" in the distribution system, overcome by technological innovations such as railroads, trucking, and air freight.

But in order to handle the new, higher flow rates, manufacturers and distributors required better, faster control mechanisms of a different type. Information needs — about inventories, orders, accounts, commissions, orders, clients, and so on — grew enormously with the production and distribution system's increasing scale. Solutions to information processing and communication were both technological and social. Beniger argues that the rise of bureaucracies in the 19^{th} century was a direct response to information-handling demands. Like Chandler, Yates, and others (Chandler 1977; Yates 1989), Beniger noted that railroads — the 19^{th} century's largest and most complex infrastructures — deployed innovations in both human organizations and information technology to administer and coordinate their far-flung networks. Problems of scheduling, optimizing loads, transferring shipments from one railroad to another, technological standardization, and accounting in what rapidly became national and even continental networks were severe. Railroads resolved these control problems through both social innovation (complex administrative organizations, with multi-layered managerial hierarchies and a high degree of functional specialization) and technological change (vertical files, standard reporting and accounting forms, etc.). These socio-technical systems later became models for the administration (control) of other emerging infrastructures, such as the telephone network, which adopted and adapted them (Friedlander 1995a).

Control through information and communication was driven by two additional imperatives deriving from the production-distribution problem described above. First, efficient distribution across expanding, widely distributed sales networks required feedback; as flow rates increased, speed became more critical. Communications innovations such as the telegraph and telephone provided the possibility of near-instantaneous feedback, vastly increasing the control capacity of the overall production-distribution system. Second, Beniger argued, the problem eventually became one of creating new markets, as even distant markets were saturated with mass-produced goods. Advertising — a way of generating demand, often by creating "needs" from thin air — and market research, another form of feedback that acts to increase the efficiency of sales and distribution, constituted responses to this new reverse salient.

The macro scale of this functional view offers several unique advantages. First, it focuses attention not on “technology” but on socio-technical solutions to large problems. Paradoxically, while many read Beniger as a technological or economic determinist, his functional view could also be seen as the ultimate in social constructivism, since it is fundamentally indifferent to whether solutions come in the form of hardware, organizations, micro-scale user innovation, or some combination thereof.

Beniger’s work is deeply problematic in many respects. In particular, some scholars have challenged the idea that an inherent functional logic drives industrial capitalism regardless of location or past history. The existence of widely different production techniques and structures across industrial sectors, nations, and time periods has been used to argue that the macro view fails to account for (or even correctly to describe) the historical realities (Sabel & Zeitlin 1985; Sabel & Zeitlin 1997).

This debate is far from closed, and I will not presume to resolve it here. Yet something like Beniger’s macro-scale, evolutionary perspective on industrial capitalism has been widely shared, most notably by Marxist scholars and world systems theorists. Whether or not it is generally correct, and radically underappreciated. The “control revolution” concept allows us to understand not only the genesis and growth of the many large infrastructures that characterize modernity (see the list at the beginning of this chapter), but also the process of linking these infrastructures to each other, beginning (perhaps) with the 19th century co-development of the telegraph and railway systems.

Explaining information infrastructure: a macro perspective

The macro-scale perspective has important implications for understanding the origins, evolution, and importance of modern information infrastructures, with relevance for modernity studies as well. Among these implications is that notions of a “computer revolution” or (more recently) an “information revolution” miss, crucially, the continuity of information infrastructures over time. Seen as infrastructure, information systems are ways to handle the functional problems of information storage, transfer, access, and retrieval; books and libraries remain our most important information infrastructures even today.

Ever since the vertical files, typewriters, and punch card tabulating equipment of the late 19th century, information processing techniques and technologies have received enormous attention from innovators (Campbell-Kelly & Aspray 1996; Cortada 1993; Cortada 1996). Beniger’s analysis explains why this should be so. The increasingly global markets of the post-WWII world presented renewed control challenges, as the speed and efficiency of transportation rose with air travel, intermodal freight, and other infrastructural innovations. Control requires information; increasing speeds and/or sizes of the systems to be controlled require, in turn, faster and more powerful information processing technologies. Better information processing is not a mere convenience but a sine qua non of the increasing speeds and scales at which the global material economy operates.

Similarly, Manuel Castells' monumental three-volume study The Information Age: Economy, Society and Culture explored the functional role of computers and telecommunications in a new "informational mode of development," i.e. "the technological arrangements through which labor acts upon matter to generate a product" (Castells 1989, 10). In the informational mode of development, information itself is both a raw material and a product. This feature generates an ever-faster development cycle; since each new process or product consists largely of information, it can instantly become input to a new round of innovation (Castells 1996, 32-65). Information infrastructure thus plays a double, and doubly important, role as the fundamental basis not only of information products and processes, but of the global organization of material production and distribution as well. The informational mode of development takes different forms in different world regions, with material production concentrated in some areas and information production focused elsewhere. But information technology, he argues, creates everywhere a "networking logic" that integrates specific technologies into larger systems. I will return to this point below.

The point here is not to make IT the centerpiece in some kind of progress ideology. Instead, I simply want to acknowledge that whether for better or for worse, on macro scales of time and social organization the co-evolution of industrial capitalism and its infrastructures displays a powerful, if never entirely determining, functional logic. As Hughes observed, this logic accounts for such historical phenomena as simultaneous invention; to those who understand a system's overall characteristics and potentials, reverse salients can become quite obvious, and can command extraordinary theoretical, practical (engineering), and economic interest. The solutions adopted are not necessarily the "best" ones, if such a term is even coherent; they are simply those which endure in the market. The principles of technological change are frequently not "survival of the fittest," but rather "survival of the surviving." Neither Beniger nor Castells can explain why particular innovations occur, or why one is ultimately successful while another is not; for this one needs micro- and meso-scale views. Yet the macro perspective points to the centrality of technologies of information and control, and to the ways in which overall system problems of industrial and post-industrial capitalism both generate technological solutions and are, in turn, driven by the special powers they create.

At the largest levels principles of increasing speed, volume, and efficiency drive the entire economy, with each increase in one area (e.g. production capacity) creating a reverse salient in another (e.g. market "development"). The overall system can be fruitfully described as posing a linked series of sociotechnical problems; the informational dimensions of many of these fall under Beniger's rubric of control. Just as Hughes used reverse salients to explain the phenomenon of simultaneous invention in electric power and lighting, Beniger's concept of the macro-scale control problems of industrial capitalism helps account for the massive investments in information infrastructure, and information technology research and development, throughout the 19^{th} and 20^{th} centuries.

Issues of scale in the history of information technology

At this point I want to illustrate the implications of attention to scale in some of my own work on the history of computers.

Electronic digital computers were developed for entirely modern purposes: code-breaking and ballistics calculations for military forces, calculation and data processing for giant corporations and governments, and numerical analysis for "big science." One of the most important episodes in early computer history was the construction of the largest and most grandiose single-purpose, centralized control system ever designed: the nuclear command-control system of the Cold War era. Few infrastructures could serve better as icons of modernity.

Ironically, within a few decades these same machines had evolved into desktop devices and embedded computers which distributed and dispersed control to a completely unprecedented degree. The present era, well characterized by Castells' phrase "the network society," looks very little like the subjection to large, panoptic systems characteristic of some concepts of modernity. It is thoroughly postmodern, yet it is also, as I mentioned above, in many ways antimodern. Indeed, the tensions between centralized, hierarchical forms of power, on the one hand, and decentralized, distributed, networked forms of power, on the other, are fundamental characteristics of the present moment. A great deal of evidence documents the relatively recent rise of networks as a major mode of sociotechnical organization, strongly facilitated (though not determined) by the availability of new information technologies (Arquilla & Ronfeldt 1997; Castells 1996; Held et al 1999).

SAGE: the first computerized control system

The first important use of digital computers for control — as distinct from calculation, the chief purpose for which they were invented — arrived as a direct result of the Cold War. When the Soviet Union exploded its first nuclear weapon in 1949, well ahead of the schedule predicted by US intelligence analysts, a nervous Air Force suddenly began to seek solutions to a problem it had, until then, been able to ignore: air defense of the continental United States.

Several different solutions were pursued simultaneously. All of them faced an extremely difficult communication and control problem: to recognize and then to track an incoming Soviet bomber attack, and mount a coordinated response that might involve hundreds or even thousands of aircraft. "Response," in that era, primarily meant interception by manned fighter aircraft. Limitations on radar systems, and the speed of then-nascent jet bombers, meant that the response would have to be mounted with only a few hours' warning at most. One, the Ground Observer Corps, was human-intensive; some 305,000 volunteers staffed observing towers along the entire Canadian border, reporting what they saw by radio and telephone. A second, the Air Defense Integrated System, proposed to automate some of the calculation and communication functions of the existing air defense structure using analog aids.

The third solution, proposed by engineers at MIT, was radical. It involved using electronic digital computers to process radar signals, track incoming aircraft, calculate interception vectors for defensive fighters, and coordinate the entire response across the continent. The system concept included the abilities for the computer to send guidance instructions directly to the interceptors' autopilots, and even to control directly the release of air-to-air missiles. (The latter capability was never implemented.) All of these were real-time control functions; the computer, in other words, had to work at least as fast as the weapon systems (jet aircraft and others) it would guide. When the proposal was made in 1950, no digital computer could perform the required calculations at the necessary speed. Worse, electronic digital computers were extremely expensive, poorly understood, and highly unreliable. Containing thousands of burnout-prone vacuum tubes, their failure rates were enormous. In my book The Closed World (Edwards 1996), I argued that these issues made the choice of a computerized command-control system highly problematic, to say the least. Why did SAGE eventually win out?

With a colossal infusion of government cash, the technical problems were more or less resolved. The social problems — including resistance from some elements of the Air Force to a system that wrested control from individual pilots and placed computers in charge of command functions — were more difficult, but eventually they too were overcome. In 1958-61, after ten years of research and development, the Air Force deployed the SAGE system (Semi-Automatic Ground Environment) across the United States. It was by far the single most expensive computer project to date. IBM, which built the system's 56 duplexed vacuum-tube computers, grossed $500 million from SAGE, its largest single contract of the 1950s. This was arguably among the chief reasons why IBM came to dominate the world computer market by the early 1960s, since although not highly profitable, the project gave IBM access to a great deal of advanced research at MIT and elsewhere, much of which it introduced into its commercial products even before the SAGE computers were built.

SAGE consisted of 23 regional sectors. The computers at each sector's Direction Center communicated with neighboring sectors, in order to be able to follow aircraft as them moved from one to another. Modems allowed radar data to be sent to the Direction Centers from remote locations, and computer data to be shared. In a rudimentary sense, then, SAGE represented not only the first major computerized control system, but also the first computer network. Yet it was designed to enable hierarchically-organized, central control of the nuclear defense system.

In a pattern entirely characteristic of infrastructure development (Bowker & Star 1999), SAGE piggybacked on other, existing infrastructures, relying on leased commercial telephone lines for inter-sector communications. Upon implementation, SAGE immediately spawned a host of follow-on projects with similar features. In the early 1960s, computers had already achieved a nearly irresistible appeal, far beyond what their actual capabilities then warranted. For example, intercontinental ballistic missiles made the SAGE system obsolete almost before it was completed; the easily-jammed system would probably never have worked anyway, and the co-location of SAGE Direction Centers with Strategic Air Command bases made them bonus targets. Despite these glaringly obvious problems, literally dozens of computerized command-control systems, including the Ballistic Missile Early Warning System, the Strategic Air Command Control System, and the NATO Air Defense Ground Environment (NADGE), were constructed in the following decade. Among the most ambitious of these was the World Wide Military Command Control System (WWMCCS,), developed to automate planning for large-scale military operations across the globe.[10]

In short, computer-based command-control systems rapidly became a kind of holy grail for the American military. In 1969, General William Westmoreland, former Commander in Chief of US forces in Vietnam, labeled this the “automated battlefield.” The automated systems deployed during the Persian Gulf War and the recent Kosovo/Serbia conflict, though not nearly so perfect or so accurate as claimed, mark the near-realization of Westmoreland’s vision.

Cold War-era nuclear command-control systems, all of them constructed on the model of SAGE, reflected the attempt to deal simultaneously with imperatives from strategy, policy, technology, and culture. As the warning window shrank from hours to minutes with the deployment of ICBMs, constraints on command structures became extremely severe. The traditional hierarchical chain of command yielded to a “flattened,” highly automated (but still hierarchical) version which reduced choices to a set of pre-programmed war plans for various “contingencies.” Military planners, attempting to reduce time delays inherent in the human command system, increasingly integrated computerized warning systems with weapons-release systems. Although the ultimate decision to launch nuclear weapons always remained in human hands, fears of nuclear war initiated by machine were far from groundless (Borning 1987). Soviet and American warning systems reacted to each other in an extremely sensitive way, producing a ratchet effect in which even sober analysts saw the possibility of “nuclear Sarajevos” (Bracken 1983).

Traversing scales: “mutual orientation”

In The Closed World, I attempted an explanation of these developments that crossed frequently between the macro- and meso-level constraints and enabling forces of strategy, policy, history, and culture, on the one hand, and the micro- and meso-level worlds of individual inventors, work groups, and institutions, on the other.

A process I call mutual orientation described the relationship between small groups of civilian engineers and scientists and their military sponsors, large institutions whose goals derived from the kinds of macro- and meso-scale imperatives discussed above.[11]

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[10] First operational in 1972, WWMCCS was replaced in 1996 by an updated version, the Global Command Control System.

[11] This concept resembles, of course, other sociological ideas for relating actors and contexts of widely varying sizes and capacities, such as Giddens’s dialectic of agency and structure (Giddens 1979; Giddens 1981) and actor-network theory (Bijker & Law 1992; Callon & Latour 1981; Callon et al 1986;

In the early Cold War, most funding for research and development came directly or indirectly from military agencies. Very often, these agencies did not know exactly what they were looking for. They could define general goals, but not a new means of reaching them. Generally speaking, military institutions of that era were inherently conservative, suspicious of innovation, and worried about “egghead” scientists taking over their traditional responsibilities. At the same time, WWII was widely perceived as “the scientists’ war” (Baxter 1948). In the wake of radar, the atomic bomb, missiles, jet aircraft, and computers — all WWII products — American society credited scientists and engineers with almost superhuman powers. So, after the 1949 Soviet atomic test, the Air Force turned to them for help.

Here, as in very many other situations during the Cold War, the Air Force offered a general problem — continental air defense — and a set of existing weapons, such as airplanes. At the time, it was still integrating radar-based ground control into the cowboy pilot culture it had inherited from the days of dogfighting during WWI. It had no real concept of how to conduct air defense on such a scale, nor did many believe such a goal was even feasible (see Edwards 1996, Chapter 3). In fact, the primary strategic policy of the period was “prompt use,” or pre-emptive strike — one which left no role for a defensive force, since Soviet bombers would in principle be destroyed before they left their runways (Herken 1983).

The MIT engineers who designed the SAGE system, on the other hand, saw air defense as just one system control problem among others, solvable with the right equipment. Most of them had wartime experience with military problems (and sometimes with combat), but they were not military officers and they took a fresh view of the situation. The pieces of the puzzle as they imagined it were all in place — with the sole exception of the unfinished Whirlwind computer, which they were already building for other reasons, and whose completion was their own primary, overriding goal. Making the computer fast and reliable enough to solve the Air Force’s problem would also solve their own. The large implications of their concept were not lost on them.

In 1948, Jay Forrester and Robert Everett, the chief engineers behind SAGE, had produced a comprehensive, compelling vision of computers applied to virtually every arena of military activity, from weapons research and logistics to fire control, air traffic control, antiballistic missile defense, shipboard combat information centers, and broad-based central command-control systems. They had written a plan for a crash 15-year, $2 billion program leading to computerized, real-time command-control systems throughout the armed forces, projecting development timetables and probable costs for each application (Redmond & Smith 1980).

The question here is: why would civilian engineers spend their time working out a general systems concept for the military, which it had never requested and to which it was hardly (at that time) even amenable? The answer requires understanding multiple levels: Forrester and Everett’s own backgrounds and interests, their personal

Latour 1987). I like to think that “mutual orientation” is a more directly descriptive, and hence more useful term.

relationship with foresighted specialists at the Navy Special Devices Center, other Navy elements which had red-lined the Whirlwind computer as (to them) an expensive white elephant, and MIT's institutional response to this funding crisis.

This multi-scalar, many-dimensional history shows why a cowboy culture of pilots came to adopt a computer-based ground control infrastructure which it saw (initially) as a useless nuisance and anathema to the military ethos of battlefield responsibility. The civilian engineers oriented the Air Force toward a systems concept involving computerized control, while the Air Force oriented the engineers toward problems of very large scale, real-time, high-reliability command. The SAGE engineers were system-builders in the Hughesian sense: they perceived the control problem as the reverse salient, and devised a general-purpose solution that could be applied ad infinitum to other control problems. That particular reverse salient emerged simultaneously from technical, political, and cultural sources. Ultimately, US geostrategic policies dictated the speed, reliability, and scale of SAGE, while a few engineers fascinated by then-nascent digital computers convinced the Air Force that the latter could be forged into a possible solution. The consequences of this interplay were profound indeed: a global command-control infrastructure based centrally on digital computers.

The concept of mutual orientation, I argue, characterizes quite broadly the general relationship between Cold War scientists and engineers and their military sponsors. In that era of swollen military budgets, sponsors did not need to direct research and development in detail. It was enough to orient scientists and engineers toward a general problem area. If even a fraction of the results proved useful for military purposes, that was enough, since cost was not the dominant concern. Even the most indirect value, such as pushing forward the high-tech economy (aka the "defense industrial base"), could be counted among the useful results of military R&D spending, within the totalizing vision of Cold War military planners. Yet this was no conspiracy. Military sponsors relied, in turn, on scientists and engineers to generate applications concepts for new technologies. Grant writing — frequently viewed by scientists and engineers as a kind of make-believe, in which they pretended to care about military problems, while their sponsors pretended to believe in the military value of their work — looked quite different to military sponsors, who often took it quite seriously. This led to the weird (and often willful) nearsightedness of the legions of American scientists and engineers who consumed a steady diet of military money, yet claimed their research had nothing to do with practical military goals. They could be right, on the micro level, while being totally wrong about the meso-scale process in which they were caught up.

ARPANET history as mutual orientation

Another example of this process at work can be seen in the history of the ARPANET, which has developed a strange dual origin story. The version I described earlier holds that ARPA simply wanted to make links between its research centers more efficient and test some technically interesting concepts. A compelling part of this legend concerns the remarkable role of an anarchically organized group, consisting largely of graduate students, that developed the protocols for ARPANET message transmission. The non-hierarchical, contributory “request for comments” (RFC) process by which these protocols developed looks nothing like the hierarchical, spec-driven procedure held to characterize military operations; indeed, the supposedly meritocratic, otherwise egalitarian culture of the ARPANET protocol builders has become part of the defining libertarian mythology of Internet culture.[12] Computer scientists themselves frequently recount this version of ARPANET history (Hafner 1996; Norberg & O'Neill 1996). Note that this is a micro-scale story, both in time and in social organization: ARPA’s tiny staff promoted the ARPANET, of course, but they did so as fellow travelers (most being computer scientists themselves, rather than military bureaucrats). For their part, the scientists involved pursued packet switching strictly for their own ends, and created their own, unofficial processes, such as the RFCs, to do so. There is an unmistakably gleeful tone in some of these recollections, a feeling that ARPA actually stood between computer scientists and the military, allowing the former to do exactly what they wanted while casting a smokescreen of military utility before larger levels of the Pentagon.

An entirely different ARPANET origin story takes the meso-scale approach. On this view US military institutions, seeking a survivable command-control system for nuclear war, were the driving force (see, for one of many examples, the widely distributed Sterling 1993). This version begins in 1964, with a suite of RAND Corporation studies of military communications problems (Paul Baran et al. 1964). One RAND proposal involved a “packet-switched” network. Digital messages would be carved up into small pieces, individually addressed, and sent through a network of highly interconnnected nodes (routers). Based on network load, every node would determine routing independently for each packet; in an extreme case, each packet might take a different route through the network, passing through many nodes on the way. Upon arrival, the message would be reassembled.

Packet-switching meant that during a war, destruction of a few (or even of many) individual network nodes would not prevent the message from reaching its final destination. This contrasted with the existing circuit-switched telephone network, in which two correspondents occupied a single circuit, whose communication would be interrupted immediately upon destruction of any node in the circuit link. This was an express response to nuclear strategy, with its very high expected levels of expected destruction. In this second ARPANET origin story, the RAND studies fed directly into the ARPANET project. ARPA sought to build a packet-switched network for digital military communications. Whatever the research scientists believed, it was, all along, a deliberate strategy to build military applications.

Multiscalar analysis of ARPANET history

It is tempting to try to choose between micro-, meso- and macro-scale analysis, to ask the question: which version of this story is correct? A social constructivist view might opt

[12] The term “mythology” here is intended in its full culture-defining sense, not as a contrast to a “true” history.

for the micro-level view, holding that the actor perspective debunks the macro perspective. A modernity-studies approach might do the reverse, taking the meso-scale story as "true" and the micro as irrelevant or illusory. On this view, ARPANET history would be a typically modern episode in which huge forces and systems dominated individuals and spontaneous social organization. Computer scientists and popular journalism frequently take the macro-level, functional view of the ARPANET, seeing it as one step in the continuous evolution of better, faster information infrastructures.

The concept of mutual orientation allows us to cross among these scales, instead, that all three stories were true. At the micro scale, scientists rarely if ever thought about the military communications problem; they had their own, private motivations for the work they did. Yet at meso scales of time and social organization, a packet-switched military communications network was a deliberate goal of military agencies (Abbate 1999). At a recent conference, a former high ARPA official told me: "We knew exactly what we were doing. We were building a survivable command system for nuclear war."[13] And indeed, within a few years (and with heavy ARPA backing) packet-switched networks had made their way into everyday military use (Norberg & O'Neill 1996). A macro-scale view might place the ARPANET against a larger background of the many other computer networking experiments already underway, some (such as Donald Davies' 1967 network at the UK National Physical Laboratory) having quite different social goals (Abbate 1999), or situate it in the long-term history of information and communication infrastructures (Rowland 1997; Standage 1998). At this scale, the ARPANET's military backing explains not so much its particular structure as why it grew faster than other prototypes.

The subsequent history of the Internet also bears out all three stories.

On the micro level, as I pointed out above, by the early 1980s users had turned the Internet into a general-purpose communication tool. Hackers, largely working without pay and without a practical purpose other than invention for its own sake, played major roles in the Internet's development. The legend of Internet culture as a libertarian meritocracy — "on the Internet, no one knows you're a dog"[14] — is partly legend, but also part truth. The astonishing growth of the World Wide Web after 1993 was also strongly driven by the private purposes of individuals and small groups. The technical tools for Website construction and Web browsing (HTTP, Mosaic, Netscape, etc.) were, by design, free and open; the development model for HTTP was the Network Working Group that designed and managed Internet protocols.

On the meso scale, digital packet-switched command-control systems rapidly became the military norm, partly as a result of ARPA proselytizing (Norberg & O'Neill 1996;

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[13] Because this comment came during a casual conversation, I omit this official's name. Suffice it to say that no one could have been in a better position to make this statement.

[14] This was the punch line of a popular New Yorker cartoon, which shows two dogs working at a home computer.

Reed et al 1990; Van Atta et al 1991). Pursuit of Westmoreland's (totally modern and modernist) centralized, electronic "automated battlefield" continues into the present. At a conference of the President's Commission on Critical Infrastructure Protection at Stanford University in 1997, an Air Force general claimed that "we are two years away from 24-hour, real-time surveillance and weapons delivery of any place on the planet." On a different meso-scale plane, corporate adoption of the Internet and the advent of e-commerce — especially pornography — were the decisive factors in turning the Web from a curiosity into a genuine global infrastructure.[15]

On the macro level, networking can be seen as a control problem along the lines posed by Beniger. The Internet explosion of the late 1980s would not have happened without a development entirely unrelated to the ARPANET, namely the spread of personal computers through the business world. As Gene Rochlin and James Cortada have argued, desktop PCs were initially adopted piecemeal by individuals and departments rather than by central corporate decisions. The effect of this pattern was to decentralize data (and therefore power) within corporations. Networking these many machines represented an attempt to re-establish central control, or at least coordination (Cortada 1996; Rochlin 1997). Until the later 1980s, most corporate networks were built without a thought of Internet connectivity. Yet they could be easily connected (because they generally used the same protocols), so that once the Internet began to become popular many thousands of computers could be rapidly connected to it. This version of the story sees connectivity and control as functional directions of the economic system as a whole.

But the macro scale also allows us to observe a fundamental transition, one frequently connected with the end of modernity and the arrival of postmodernity. The distributed architecture of the ARPANET, Internet and World Wide Web, and the open design processes that became their hallmark, made possible distributed networks of power and control — nearly opposite to the central-control purposes for which the ARPANET was built. Elsewhere, I have argued that the Internet and other computer technologies have made possible "virtual infrastructures," created and dismantled at will by constructing or destroying channels for information and control (Edwards 1998a). These virtual infrastructures are the foundation of what Castells (Castells 1996) calls the "network society": a postmodern world not of "systems," but of constantly shifting constellations of heterogeneous actors of widely varying scale and form.

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[15] As of 1998, 84 percent of registered Internet domain names were in the .com category, according to The Internet Index, vol. 24 (http://new-website.openmarket.com/intindex/99-05.htm). This figure probably presents a radically inflated view of the actual number of commercial websites, since many .com domain names are registered by speculators hoping to sell them later (or corporations trying to occupy a "name space"), and are not yet (and may never be) actually in use. Still, commercial/economic activity clearly became the dominant use of the Web in the late 1990s.

Conclusion

In this chapter I have argued that studying infrastructures on different scales of force, time, and social organization produces different pictures of how they develop, as well as of their constraining and enabling effects on social and individual life. Different scalar views also lead to different pictures of the solidity of the "modernist settlement" that separates nature, society, and technology.

Modernity studies typically approach technology as fundamental to a generalized modern (or postmodern) "condition," i.e. on the meso scale (Borgmann 1984; Borgmann 1992; Harvey 1989). Meso-scale analysis typically takes historical time scales (decades to centuries) as the relevant frame. It describes large institutions — a typically modern form — as the dominant actors in infrastructure development. As large, force-amplifying systems that connect people and institutions across large scales of space and time, infrastructures seem like paragons of modernity understood as a condition of subjection to systems, bureaucracies, hardware, and panoptic power. The empirically observed meso-scale phenomenon of "technological momentum" explains the sense that infrastructures are beyond the control of individuals, small groups, or even perhaps of any form of social action, and that they exert power of their own. Infrastructures constitute artificial environments, walling off modern lives from nature and constructing the latter as commodity, resource, and object of romantic utopianism and reinforcing the modernist settlement.

Yet both micro- and macro-scale analyses challenge these constructions of technology and modernity.

Macro-scale perspectives on force see infrastructures as imbricated within, rather than separate from, nature. The view from this scale emphasizes the role of infrastructure in creating systemic vulnerabilities to rather than separation from nature, and the metabolic connections between technology and nature through fuel and waste — even to the point of anthropogenic global environmental change. Macro-scale perspectives on time and social organization show infrastructures as solutions to systemic problems of flow in industrial capitalism: how to produce, transport, and sell increasing volumes of goods, and how to control the overall production-distribution-sale system (what Hughes might call the maximization of "load factor"). At this scale, their structure and form shift constantly. Particular technologies and systems are less important than the functions they fulfill. Thus infrastructures become not a rigid background of overpowering technologies, but a constantly changing social response to problems of material production, communication, information, and control.

Micro-scale, social-constructivist analyses, especially those that study user activity, illustrate how individuals and small, spontaneously organized social groups shape and alter them, creating their own version of modernity. They make active use of, and design new forms for, emerging infrastructures. Here too, the form and function of infrastructures shifts and changes over time, albeit for much different reasons than at the macro scale.

Thus, if to be modern is to live within multiple, linked infrastructures, then it is also to inhabit and traverse multiple scales of force, time, and social organization. My concept of “mutual orientation” describes one process by which micro-scale actors interact with meso-scale institutions; doubtless many other such processes await discovery. As for interaction between meso and macro scales, I have advocated describing infrastructures in terms of function rather than technology.

This multiscalar, empirical approach suggests problems with most conceptions of “modernity” itself, stemming from modernity theory’s typically meso-scale perspective. Is there really a single condition describable as “modern”? Or is this a contemporary form of idealism, an abstraction to which reality corresponds only when viewed on a single scale? Micro-level, user-oriented approaches suggest that subjection and domination only partially describe actors’ complex (and active) relationship to technology and institutions. Meanwhile, macro-scale approaches suggest a general trend toward infrastructural integration, facilitated by new information technology. But this integration seems to be leading not only toward a shoring up of modernist state/corporate power and panopticism, but also toward a decentralized, rapidly reconfigurable “network society” whose postmodern dimensions are only beginning to be visible.

Perhaps, then, “modernity” is partly an artifact of meso-scale analysis, to which the multiscalar approach recommended here might be an antidote.

I will close, sotto voce, with two important asides.

First, the social constructivist approach currently popular in science and technology studies cannot generally, in practice, be distinguished from a micro-scale view (Misa 1988; Misa 1994). Social constructivist approaches almost always explore the early phases of technological change, when technologies are new, salient, and controversial. This is also the point at which individual and small group activity is most important. For example, user intervention in network design becomes decreasingly important and effective as standards are established and infrastructures become national or global in scope. The typical social constructivist argument is that if a technology was once controversial, it could become so again, and/or that ongoing social investment is required to maintain any given technical system. Constructivists tend to be skeptical of macro-scale explanations in any form, though they sometimes give attention to meso-scale actors.

My point here is that constructivist arguments not only depend upon, but actually function by, reduction to micro scales of time and social organization; it is a contemporary form of reductionism analogous to the physicist’s claim that all higher-order phenomena must ultimately be explained at the micro level of atoms and molecules. It is not that constructivist explanations are false; they have added enormously to our understanding of science and technology, and they offer a useful counterpoint to modernity theory’s meso-scale view. But taken alone, without attention to meso- and macro-scale analysis, constructivism creates a myopic view of relations among technology, society, and nature.

Second, my multiscalar approach suggests a complementary reflexive conclusion. The present popularity of constructivism and other micro- and meso-scale approaches among academics may stem (in part) from meso- and macro-scale forces we too often ignore. As the academy's ranks swelled after WWII, institutions and disciplines responded by increasing scholarly specialization, thus allowing the creation of new niches (e.g. jobs and academic journals). This specialization (a modern condition?) drives scholars to focus on ever-smaller chunks of time and space . The discipline of history, for example, demands topics (and archival sources) that a historian can hope to master within a few years. Working typically alone or in small groups, historians are ill-equipped to explore patterns at this scale. Similar points could be made about sociology, anthropology, and other empirical approaches to modernity. Today's scholars tend to sneer at genuinely macro-scale empirical studies, likely as they are to contain mistakes at the level of detail that occupies the forefront of specialists' attention.

Multi-scalar analysis requires an enormous depth of knowledge — more than can be expected of most individuals. Social and historical scholarship has few precedents for genuine team-based approaches, which require a complex process of coordination, agreement on methods, and division of intellectual labor. It may be too much to hope that our disciplines will evolve in this direction, particularly given the present reward structures of most academic institutions. But if I am right that multi-scalar analysis holds the key to an understanding of technology and modernity, we must at least make the attempt.

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