CHAPTER 5

THE INTERNET AS INFRASTRUCTURE

CHRISTIAN SANDVIG

In October 2010 the international web development community was thrown into disarray when it suddenly appeared that millions of common websites across the world would be required to satisfy the decency standards of Sharia, the religious law of Islam.[1] To understand how this unlikely situation came about requires that we know about the infrastructure of the Internet; it is a story about the collision of what is ultimately a variety of seemingly unrelated actors and actions, and this instance is comprehensible only after assembling all of them. Beginning with this example, this chapter will argue for the value of investigating the details of Internet infrastructure as a method of studying the Internet and society more generally. It will argue for the study of Internet Infrastructure and also for the value of considering the Internet infrastructurally, as a system foundational to other activities.

An infrastructure example: from the GET method to a woman's bare arms

The first factors in this particular story about Sharia and the Web are technical. Over fifteen years earlier, web server programmers on the www-talk mailing list anticipated that the Web would become more than just static web pages: they proposed a method for adding the information required for interactive web applications to the right side of a web page's address or URL (this was called the "GET" smethod; see Robinson and Coar 2004:33). By 2010, the increasing dynamism of the Web had confirmed their vision, causing the

[1] The original blog post that started this controversy is Ben Metcalfe's "The .ly domain space to be considered unsafe" (Metcalfe 2010).

URLs for web services to become lengthy with codes, id numbers, and ephemera that made them ungainly to remember, type, and share. Eventually, these ever-longer addresses in turn created a demand for what became known as "URL shortening services": applications that would produce a short synonym that could be used to represent the ever-longer and harder-to-share URL.

The next factors in this story are financial. The first such service, TinyURL.com, created in 2002 as a not-for-profit organization, was quickly joined by hundreds of commercial firms: bit.ly, is.gd, ow.ly, tiny.cc, go2.me, and so on. Governments joined in (go.usa.gov). Major web companies developed their own shorteners: goo.gl (Google), nyti.ms (The New York Times), fb.me (Facebook), and bbc.in (BBC). Nine years later, millions of dollars had been invested in a variety of URL shortening start-ups (Johnson et al. 2010) as it became clearer that shortening URLs was about more than convenience: every click on a shortened URL generated data that could be captured, and this data about who clicked on which links could have considerable commercial value. It could also be re-sold. The leading URL shortening company, bit.ly, served over 4.7 billion clicks every month (Siegler 2010).

The flash point where Sharia intersected web hosting came from a site hosted by the URL shortener vb.ly. It contained a picture of San Francisco Chronicle sex columnist Violet Blue in a sleeveless top, drinking a beer.[2] The service hosting the image (vb.ly) was ordered closed by Libyan Telecom & Technology (LTT), Tripoli. The LTT representative involved in the case commented that "a scantily clad lady with some bottle in her hand isn't exactly what most would consider decent" (Johnson 2010).

To know how Libya gained the power to take down this website and potentially billions of others requires some history. In the quest for shorter and shorter web addresses, URL shortening services had turned away from three-letter addresses ending in .com and .net and toward two-letter domain name suffixes (.ly, .gd, .cc., .me, .in, and so on)—after all, every character that could be saved would produce a faster-to-type URL. Two-letter Internet addresses are called "country codes," and they were added to the Internet's naming and addressing system in the 1980s in order to provide an alternative way of naming websites that would be linked to nationality (eg. the United Kingom's is .uk). Yet the original engineers of the Internet were wary of "the business of deciding what is and what is not a country" (Postel 1994: 5), so they decided that the system of names would be based on a recognized international standard dating from 1974 that establishes two-letter abbreviations for countries (arcanely known as ISO #3166 [see ISO 2011]).

The next part of the story depends on peculiarities of the English language and the process of standardization, with a dash of geopolitics. This ISO standard decrees that the nation of Libya shall be represented in English with the two-letter code "LY." An English-speaker will recognize the –ly suffix and its synonym –y as a way to transform nouns, adjectives, and verbs into adverbs (from "quick" to "quickly"). The suffixes can also have a cute sound as a diminutive ("kitty"). Adding –ly to "bit" to produce "bit-ly" could thus

[2] A discussion of the controversy and a screen shot of the original picture can be found in the blog post, "I, For One, Welcome our New TLD Overlords With Bare Arms" (Blue 2010).

mean "just like a bit" or "a little bit." Since the Internet is made of bits, this is a promising name for an Internet company. Other countries like Latvia (LV), Liechtenstein (LI), and Liberia (LR) didn't happen to have ISO standard abbreviations that are also cute English suffixes. Unlike ".ly" (for Libya), other handy English two-letter words were in the hands of pro-Western allies, but these were politically unstable—like the Kingdom of Tonga (TO). Safer suffixes existed, such as the British overseas territory of South Georgia and the South Sandwich Islands (GS), but quirky addresses like "blo.gs" didn't catch on (for more examples, see Steinberg and Mcdowell 2003).

The assignment of these two-letter address codes to national administrators that would parcel them out was yet another step, and it was fraught with politics. The engineers weren't at all successful in avoiding controversy and they found they couldn't simply implement the ISO standard. They were forced to tackle knotty problems like: "Does a sovereign aboriginal nation receive a 'national' two-letter country code?" (No, according to the standard.) "Should Catalonia have an independent country code, or is it part of Spain?" (No, it is part of Spain, according to the standard.) "Should Hong Kong have an independent country code, or is it part of China?" (Yes, it should have a code [.hk], according to the standard.) "Is Antarctica a country?" (No, but it gets a code anyway [.aq], according to the standard.) "What happens to nations that disappear, like the USSR?" (Their domain names remain anyway [.su], even though that violates the standard). "Everyone already calls Great Britain 'the UK' and not 'GB,' what should we do?" (Give it the address [.uk] even though that violates the standard.) "Who should control the country code for Iraq [.iq] while it is at war in 2003?" (Instead of a country, give it to the InfoCom Corporation of Richardson, Texas, USA, even though that violates the standard.[3]) Libya, the sovereign nation, at that time governed by Moammar Gadhafi, was delegated control of .ly.

The remaining elements of this story are legal, cultural, familial, and religious. Gadhafi gave the job of running .ly to LTT, a company owned and nominally run by his eldest son, Muhammad. LTT sold the rights to use some .ly domains to American URL shortening services, such as bit.ly and ow.ly. LTT's contracts included clause 3.5, requiring that "the domain name is not being registered for any activities/purpose not permitted under Libyan law." Libya is one of a handful of countries whose legal system is based on Sharia (Islamic Law). The Qur'ran asks women to "guard their modesty," (24:31) and Violet Blue's bare arms were taken to be a violation.

The Libyan decision caused significant consternation in the Internet industry. The suffix .ly had become the most popular suffix for URL-shortening, and a significant fraction of the English-speaking world's URLs were therefore reliant on a symbolic resource that was controlled by the dictator of an Arabic-speaking country who was traditionally hostile to the English-speaking world. Indeed, it now appeared that he might invoke religious law to redirect traffic away from popular websites. An almost immediate, major substantive reaction was an investor panic around URL shortening companies—surely encouraged by Islamophobia. Details emerged later that LTT had formed a plan to

[3] This is an Internet Service Provider dedicated to hosting websites for Muslim organizations in the United States.

re-issue the extremely valuable .ly domains it seized from the West to Libyan nationals, presenting an economic motive instead of a religious one (Horn 2010).

LTT backed down from these threats after an international controversy in the technical community, but this still resulted in a significant reorganization of capital and Internet addressing. For example, if you tried to reach the popular URL shortener bit.ly in 2011 you would have been redirected to the ungainly URL "bitly.com." By February 2011 a revolution was in progress in Libya, and LTT cut off Internet links with the outside world (Google 2011).[4] By October, the Libyan government had fallen and was replaced by a transitional council of revolutionaries. LTT finally declared itself through with the confusing situation, and it ordered that no future .ly domain names, three characters or less, would be registered without a local presence in Libya.[5]

For the purposes of this chapter, Violet's bare arms are useful because they represent a baffling network of relationships producing significant outcomes that no single actor seems particularly able to foresee (and, in this case, that no actor is really that happy about). The case of Violet Blue implicates technical decisions about the design of interactive software (via URLs and the GET method), usability, culture, religion, history, politics, and economics.

Approaching the case from only one perspective is doomed to fail: if we considered this is simply an instance of Libyan censorship, for example, this would beg the question of how on earth a legendarily capricious dictator came to acquire veto power over an important part of the Internet's functionality. As it unfolded, the situation put the sex columnist for the San Francisco Chronicle in a public conversation with the eldest son of the ruler of Libya—a bizarre pairing.

This episode led to the financial ruin of some investors in URL shortening firms, the loss of millions of dollars, and at the time it appeared that LTT's actions could have affected millions of English-speaking Internet users. Despite all this, the story is an obscure one, receiving only minor press coverage. The full arc of the story is available only for those technical insiders involved in Internet addressing who follow specialized fora, dedicated mailing lists, and blogs.

Messy, holistic investigations that cross social and technical boundaries like this brief example have lately come to be called "infrastructure studies."[6] As both a label and, increasingly, a research method, infrastructure studies has a growing scholarly currency and relevance to the study of the Internet. This chapter will trace the evolution of this field of work and outline two major constituent intellectual components. It argues that "infrastructure" is the new "network." That is, although infrastructure is at times inchoate as a concept and it holds many, sometimes inconsistent meanings for different researchers, nevertheless the term is now galvanizing a newly vibrant pool of Internet-related scholarship in the same way that equally diffuse and inconsistently applied concepts like "network" have in the past (Watts 2004).

[4] *.ly domain names mostly continued to work, however.

[5] See <www.nic.ly/lyregistrars.php> (accessed July 7, 2011).

[6] This phrasing of the approach owes a debt to Actor-Network Theory (Latour 2007).

Linking structure and symbol: defining infrastructure

The word infrastructure doesn't usually sound exciting, and infrastructure studies is "a call to study boring things" and to vitalize them—to make them exciting (Star 1999: 337). Studying the Internet as infrastructure involves turning away from the topics that motivate a great deal of writing about the Internet. For example, Silver boldly asserted that "the twin pillars of cyberculture studies are virtual communities and online identities" (Silver 2006: 3). Studying the infrastructure, as described below, implies turning away from the symbolic and investigating the structural—this is the Internet not as "what people say with it" but as "how it works."

The following excerpt from Vanderbilt's journalistic account of his online life demonstrates how one might describe Internet use infrastructurally:

> I have photos on Flickr (which is owned by Yahoo, so they reside in a Yahoo data center, probably the one in Wenatchee, Wash.); the Wikipedia entry about me dwells on a database in Tampa, Fla.; the video on YouTube of a talk I delivered . . . might dwell in any one of Google's data centers, from The Dalles in Oregon to Lenoir, N.C.; my LinkedIn profile most likely sits in an Equinix-run data center in Elk Grove Village, Ill.; and my blog lives at Modwest's headquarters in Missoula, Mont. If one of these sites happened to be down, I might have Twittered a complaint, my tweet paying a virtual visit to (most likely) NTT America's data center in Sterling, Va. (Vanderbilt 2009)

In this story about the Internet, otherwise obscure features like ownership and network topology (here, the geography of data centers) are pushed to the forefront. This chapter will describe which researchers are doing this inversion, how it is done, and why it is useful and important.

Infrastructure refers to "the subordinate parts of an undertaking" or its "foundation," and it is a modern coinage, dating to 1927 (Oxford English Dictionary), but really finding traction in the 1970s. In common usage it is often used in a similar sense to "utility," or "public utility," meaning "a service regarded as essential." We commonly think of utilities as involving a public purpose and as including electricity, gas, and water, and sometimes roads and telecommunications, although there is no exact legal definition of the set, and no ironclad rule across political systems as to whether these should be public or private undertakings.

It is obvious, after a moment's thought, that these examples of infrastructures and utilities must be quite context-specific. Both piped, clean water and the wired telephone were once considered a luxury fit only for the rich and not at all an essential (de Sola Pool 1983). This view is still held in some places. As Edwards writes, "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" (2003: 187).

Germane to this chapter's purpose, the Internet is in the process of becoming foundational. In the last twenty years it has become an emergent essential—a new infrastructure—across the globe and in a wide range of human activity. Certain components of the Internet have also been notably singled out for "meta-infrastructural" status as essential components of the Internet without which the Internet itself would not function: most notably search engines (Bracha and Pasquale 2008) and the Internet's addressing and naming system introduced in the example at the beginning of this chapter (Mueller 2002).

Infrastructure studies, for the purposes of this handbook, refers to the multi-disciplinary body of scholarship that is increasingly directed toward understanding the co-evolution of the Internet and society, and it does so by considering the Internet as infrastructure. Definitionally, in this phrasing it is helpful to distinguish the study of infrastructure and "infrastructure studies." Many disciplines and scholars from electrical engineers to specialists in human development (see Ch. 25, this volume) follow the dictionary definitions just given above and are concerned about infrastructures. Yet there is a more distinct group that considers infrastructure not as a member of some definable group of objects, networks, or companies like "the providers of water, communication, heat, light …" but rather as an analytic and even a research method in itself. This chapter will emphasize the latter—those who employ the idea of infrastructure as an analytic and a research method.

The chapter will thus review infrastructure studies of the Internet as two complementary approaches: it will call the first grouping "the relationists," a group of scholars exemplified by Bowker, Star, and Edwards (see below), closely aligned intellectually with the science and technology studies movement, and sometimes found in information science programs or called "information infrastructure studies."[7] The second, smaller grouping will be termed "the new materialists," a group exemplified by Sterne and Parks (see below) that often identifies itself as media studies, cultural studies, or cultural history. These groupings are artificially imposed and non-exclusive, and are proposed merely as an aid to traversing the research in this area.

The relationists, the Internet, and their turtles

An origin story of one strain of the relationist approach begins with a series of disasters. In its first decades, computing appeared to be a new kind of engineering drastically unlike other kinds of engineering, like building bridges or buildings. In the hybrid social and technical area of research then called "systems analysis" (and later "computer-supported

[7] This use of the word "relationism" is meant to imply that these thinkers see infrastructure as relational. It is not meant to evoke Mannheim's philosophical relationism or any other use of the term (Tsekeris 2010).

cooperative work," CSCW), social researchers who turned to computing and socially minded computer scientists both continually faced the problem that when new large-scale computing projects were planned, designed, or introduced, things almost never happened as expected (Kling 1992).

It is true that most complicated projects of any kind have unforeseen consequences, yet computing projects seemed especially likely to be doomed. Initiatives involving new computers and (later) computer networking were often costly fiascoes that failed totally, with multi-million dollar systems abandoned before completion, never able to perform the tasks written in their specifications, and abandoned (or at least hated) by the users they were intended to serve (Brooks 1995). For example, as strange as it may seem, large-scale computing projects were portrayed in the normally staid technical computing literature of the 1980s with the image of a monstrous, unkillable werewolf (Brooks 1995: ch. 16, also cf. Law 1991) certainly beyond the control of mere human programmers and analysts. These computing werewolves continue to haunt the industry (Wright 2011).

In the late 1980s and early 1990s, influenced by the newly vibrant science and technology studies movement (Bijker, Hughes, and Pinch 1987), CSCW researchers began to argue that understanding this situation required systematic reconsideration of "the scope of the boundaries that [we] draw around the computer system" (Kling 1992: 5). At the time it was normal to consider computer systems to be a kind of infrastructure, but this word referred only to the computer boxes themselves and maybe to the wires connecting them.

Kling and others found that when trying to understand what was happening in a particular computing project, they needed to ignore the material objects and foreground the previously hidden or background activities that made the system possible—they needed to examine the infrastructure for the computing infrastructure (Jewett and Kling 1991). They initially framed this distinction as "hard" vs "soft" infrastructure, where soft infrastructure denoted things like the everyday habits of the human operators.

Infrastructure as relational

Star, Bowker, and collaborators took this inspiration to develop a theoretical and methodological apparatus for the study of infrastructure (eg. Star and Ruhleder 1994). For them, infrastructure is a relation and not a set of things. The study of infrastructure is a change in perception like the figure-ground shift explored by Gestalt psychology—when we change the way that we look at something, the background becomes the foreground and vice–versa (Bowker 1994, cited in Star and Ruhleder 1994: 253). Infrastructure is then not a thing but a question: what does this activity depend on?

Crucially, this means that since different actors are differentially positioned as to what goals they want to achieve, one person's background is already another person's foreground, and one person's infrastructure is another's obstacle (Star 1991). Thinking about infrastructure as a relation sensitizes the scholar to these multiple perspectives by asking

to whom an infrastructure is addressed and, therefore, who is left out. To the person in a wheelchair, stairs to the second floor are not "seamless subtenders of use, but barriers" (Star 1999: 380). In Internet terms, to the network engineer the Internet's everyday traffic in bits is not a substrate or a foundation to other work but instead the major topic of their working life. An Internet blocking and filtering system is one person's infrastructure to maintain important public values, while this same system is another person's threat to the freedom of expression, while it is yet a third person's irritating check on their ability to easily obtain pornography (see Nash,, this volume).

Finally, a key implication of this relational framing of infrastructure is that it represents "an infinite regress of relationships" (Bateson 1978: 279). This means that there is no particular point in the sequence of infrastructure where things stop being social and become purely technical (or vice–versa), or where infrastructure itself stops—any thing that one points to has "subordinate parts" (therefore, it has an infrastructure), and this infrastructure must also have an infrastructure, and so on. In philosophy and cosmology, untangling this recursion is known as the problem of first cause (from Aristotle's *primum movens*). Stephen Hawking popularized the anecdote that one cosmology holds that the earth is supported on the back of a tortoise. In this cosmology, when asked, what supports the tortoise? the answer given is, "it's turtles all the way down" (Hawking 1988: 1).[8] Infrastructure theorists hold that "it's infrastructure all the way down" (e.g. Star 2000).

Selecting a topic: infrastructure studies as an applied art

Since every infrastructure (turtle) has an infrastructure (turtle) that supports it, the task of the infrastructure scholar is to find a useful point of entry into this infinite series: to choose an infrastructure that raises to consciousness some unstudied background detail, but not just for the sake of its curation and preservation. Instead, infrastructure studies is practiced as an applied art—it diverges from the mainstream fields of history and anthropology because in each study its practitioners usually try to find a lens that reflects insight onto a present-day problem. The methods used may still be historical, but the goal is unlikely to be preservation. Pioneers like Star demanded that in choosing a topic the focus should be on those who are left out (Star 1999): who is harmed, who is forgotten, who is unserved, and how research might rectify the situation. For instance, a book-length history of computing could fall within this framing, but only one that argues that the military origins of computing and the precursor technologies for the Internet still constrain the shape of these technologies today and the way that we think about them (eg. Edwards 1996). In contrast, a purely descriptive or curatorial history of computing might discuss infrastructure (and focus on the technical—"how it works") but it would still have little in common with the group of scholars identified here as belonging to "infrastructure studies."

[8] In the anecdote the speaker does not appear to realize that turtles and tortoises are different animals. This anecdote is sometimes linked to Native American or Hindu mythology (as an elephant).

To drive this point home, recall that some early work in the then-emerging domain of "technology studies" had been castigated as bloodless and overly theoretical. It was charged and found guilty of "disdain for anything resembling an evaluative stance or any particular moral or political principles" (Winner 1993: 371). In contrast to these critics, the researchers aligning themselves with the study of infrastructure refused to participate in scholarship that showed such a separation from human experience. It is this repeated orientation toward societal problems, social justice, and applied knowledge, when combined with a comparative urge and a present-focus that distinguishes the relationists from other infrastructure researchers or from other fields. They argue: "Understanding the nature of infrastructural work involves unfolding the political, ethical, and social choices that have been made throughout its development" (Bowker et al. 2010: 99). The CSCW literature seems an unlikely location for these developments. CSCW can otherwise be quite restrained—according to its acronym it was devoted, after all, to the suspiciously Taylorist task of "supporting" people's "work." Yet affiliating with infrastructure studies by following the voice of writers like Star (1999) can feel like manning the barricades.[9]

Infrastructure, urbanism and history

Major intellectual allies in this endeavor have come from urban planning and the history of technology—these thinkers are so closely allied as to be at times indistinguishable as an intellectual tradition. In the historical work sometimes known as "large technical systems" (LTS) research (a term of art), Thomas Parke Hughes provided groundbreaking, detailed and compelling treatments of infrastructure where a major theoretical drive was to explain difference and possibility in technological systems (see Hughes 1983 and 1998). Rather than "straight" history, Hughes's comparative approach outlined the political and social choices in arenas that had previously seemed only technical and mundane—such as the early electrical power systems of the world. Hughes also advocated for theorizing system development across time and space rather than studying devices or people in isolation, and he promoted the value of research across specific instances of infrastructure (most notably, transport, computing, power, and communications). He proposed that all infrastructures, the Internet included (Hughes 1998: ch. 6), passed through loose and overlapping but recognizable phases of development. These can be roughly summarized as (1) invention and early development, (2) transfer across space and context, (3) growth in scale, and (4) momentum or inertia (Hughes 1983).

[9] For example, see Star (2010: 614–15), or consider that Star writes "there are millions of tiny bridges built into large-scale information infrastructures and millions of (literal and metaphoric) public buses that cannot pass through them" (1989:389). For more on this controversial bus example, see Winner (1986) and Woolgar and Cooper (1999).

As another example, at nearly the same moment but proceeding independently, Sawhney, writing as a historian of the telephone system, advocated that the evolution of transport and communications networks were often parallel, and proposed an eight-stage model of infrastructure development that explained the gradual replacement of one technological network by a complement (Sawhney 1992 and 1993). He later demonstrated the value of this framework for understanding the evolution of the Internet (2003). Today, the relationists agree that historical knowledge like this is a requirement for any study of infrastructure—even if it is not meant to be a historical study. As infrastructures are always complex networks that change relatively slowly they can only be appreciated with a historian's sense of time (Edwards et al. 2007: 8). As they often follow parallel trajectories they must be understood via comparisons to other infrastructures across history.

Theorists of the built environment represent a separate group of close allies, as they often choose their object of study to be "the city," they have in parallel developed infrastructurally-comparative historical approaches and theories. Most notably, writers like Castells (1989) and Graham and Marvin (1996) demonstrated forcefully that telecommunications' infrastructures like the Internet had been left out of urban planning, and argued for the integration of telecommunications and the Internet into thinking about urbanism, space, and place (for an overview of this work, see Graham 2003). Later, they developed an important periodization of infrastructure itself, writing in *Splintering Urbanism* (2001) that infrastructures generally had been conceptualized in the early twentieth century and earlier as a "modernist infrastructural ideal" of homogenization, utopian integration, and master planning under one provider. For example, consider Haussmann's famous boulevards for nineteenth century Paris: a master plan for transportation that was also meant to regularize and distribute gas lighting, water mains, sewers, drainage, and even security (54). Graham and Marvin argued that by 1975 this ideal had broken down. Coincident with the rise of the Internet, infrastructures of all kinds became "splintered" and unbundled, relying on competition, market mechanisms, and segmentation of users into the privileged and the less privileged who were offered different services (or no service at all). While from 1975 to the present the Internet itself was splintering (Bar et al. 1995; Kesan and Shah 2001), in Graham and Marvin's view, the Internet (and telecommunications) was the single most important infrastructure "leading [the] shift towards the splintering of mass markets under forces of global capitalism and privatization" (233–4) by providing a model of a privately managed, transnationally funded distributed system apparently free from the old-fashioned meddling of government planning. Under the regime of splintering urbanism, the organization of the Internet has now become the mental model used to think about the future of other systems like transport (e.g. smart roads, dynamic road pricing, the driverless car) or electrical power (e.g. the smart grid). The Internet, the newest infrastructure, has become an infrastructural primitive or template for its parents: a model privately organized system of distributed computation–the *ur*-infrastructure.

Methods: The Heuristics of Infrastructure

For method, the relationists draw broadly from the humanities and interpretive social sciences, with a special affinity for both history and ethnography. They explicitly hope to address scholars in the fields of sociology, history, systems engineering, science and technology studies (STS), communication, urban planning, and cultural geography (for example: see the list of fields in Graham and Marvin 2001: 33). Atop these more general methods and disciplines sits a common toolbox of analytics. As seen above, a prerequisite for the relationist's work is to stipulate that infrastructure is relative and context-specific, but that all infrastructures share features such that its proper study must be comparative and historically-informed. These starting points lead inevitably to infrastructure as the proper object of theory. That is, a relationist may give you an article about the telephone system, a book about the infrastructure for climate science, or a book about the classification of diseases. Yet in each of these cases the ultimate goal will be to theorize "systems" and never just the instance of one. Infrastructure studies are about "a growing body of evidence pointing to patterns or dynamics common to the development of many infrastructures over many times and places" (Jackson et al. 2007). Studies of computing and information technology are best undertaken in a broadly comparative fashion, linking (for instance) seemingly separate areas like bioinformatics and architecture (Lenoir and Alt 2003). This means that the pinnacle of infrastructural thinking consists of precepts like: "Infrastructure creates systemic vulnerabilities to nature" (Edwards 2003: 221). This very high level of abstraction has opponents, who argue that such broad comparisons across contexts and technologies should be considered invalid prima facie (Fischer 1985).

Nonetheless, defining a set of overarching "dynamics," "tensions," or "heuristics" (see Jackson et al. 2007) common to all infrastructure is a major contribution of this strain of work, and the ability to use these as analytics to relate disparate technologies to each other gives the relationists their name in this chapter. Five attributes of infrastructure have been found by many authors and will be explained below by way of example. They are: invisibility, dependence on human practices, modularity, standardization, and momentum. Other common attributes exist, but these five provide an introduction (for a review, see Jackson et al. 2007). These attributes are meant as features that all infrastructures are claimed to possess, but also as guides that researchers should use to target their investigations.

The first such attribute of infrastructure states that it is normally invisible, becoming apparent only when it breaks (Star 1999: 382). Breakdowns have become a key investigative tool for the infrastructure analyst because they illustrate dependencies (Nye 2010). Visibility can itself be a site of struggle around infrastructure: for instance, cities exist politically in order to provide shared services, therefore cities often actively work toward infrastructural visibility to try to prove their value. As Mitchell puts it, cities celebrate their infrastructure (Mitchell 2005)—but with a few exceptions like this or that brightly-lit, iconic bridge, cities are mostly not successful in making these systems stand out. Infrastructure is taken for granted. Nowhere is this rule of invisibility more true than the

Internet, whose major physical parts are often literally invisible: they include wireless signals, buried wires (e.g. fiber optic lines) or machines hidden in nondescript, locked office buildings (e.g. data centers and Internet traffic exchange points). Yet beyond its material components, the idea of the Internet is also invisible, with web pages arriving as if by magic, relying on processes that are totally unknown and unquestioned by most Internet users.

The second common attribute of infrastructure is perhaps derived from Kling's original distinction between "hard" and "soft" (discussed above). Recent work on infrastructure always emphasizes the importance of the "soft" (non-technical) practices and routines to the system. The successful infrastructure investigator must, in this view, guard against being distracted by the shiny material parts and uncover the tacit labor that must always be present. Infrastructures are arrangements of practices. Star (2010) gives the example of the QWERTY computer keyboard, which was originally one arrangement of keys on a typewriter among many competing arrangements. Over time, most typists learned the QWERTY layout, and it has endured to the present day from its origin in 1873 (David 1985). It eventually appeared on the keyboard for devices of all kinds, and the widespread practice of typing this way was re-integrated into the physical and material parts of infrastructure: even the designers of office furniture meant for working with computers now take the orientation of the QWERTY layout into account (Becker, cited in Star 2010: 611). Yet it has been argued that the QWERTY layout is a very inefficient way to type (David 1985). In this example a human practice, such as learning to type one way vs another, can be powerful and important, even though it is also intangible.

One specific focus within the study of routines and practices of infrastructure has lately emerged surrounding maintenance and upkeep (Graham and Thrift 2007). When our stories about technologies like the Internet do focus on human practices, these are usually practices of development and invention. This ignores the fact that the bulk of a system's work and expense is actually maintenance (see also Ribes and Finholt 2009). Graham and Thrift go so far as to urge a focus on "decay" and "entropy" to understand the true scope and life cycle of infrastructure and infrastructural work (2007: 5).

When analyzing Internet infrastructure, uncovering important practices and routines is particularly difficult because the world of computing presents itself with a mythology that insists, ideally, that computers do not need to be learned at all: they are "intuitive" or "user friendly" (for a critique, see Bardini 2000: 226). We are also told that simple exposure to the Internet at an early age produces impressive skills without a need for formal education about the Internet—these "digital natives" already know it all (Palfrey and Gasser 2008). On the producer side, the Internet industry promotes back-end products with sales jargon like "turn-key." Calling a product like an Internet router "turn-key" means that the device requires no labor; as with starting a car, you only need to "turn the key" and the engine will run. This is clearly a romanticized vision of both routers and automobiles. The Internet is likewise composed of "user friendly" systems that require a great deal of skill to learn, while "turn-key" computing devices are actually maintained by an army of shadowy laborers. For instance, in 2009, a video surreptitiously taken at a Google engineering talk revealed how failed computers are replaced inside Google's top secret Internet data centers.

A technician—a young man with a ponytail and headphones—was shown riding his official Google-provided two-wheeled scooter back and forth between shipping containers that are filled wall-to-wall with servers (DataCenterVideos 2009). He keeps the spare computers in a messenger bag.

As the third attribute of infrastructure, Star (1999) also emphasized that infrastructure is modular and incremental. Even when a billion-dollar apparently top-down effort is made to rationalize and standardize an infrastructure, this proceeds in a process that takes years (Hughes 1998) and is more akin to negotiation between many disparate parts and actors (Latour 2007). Infrastructure itself could be described as an achievement of negotiation, as its interconnectedness means that modifying one part requires adjustments in another—and these adjustments are both social and technical. This precept of infrastructure is a strike back at older theories of technological systems like Ogburn's "culture lag" (1957) that presuppose a technology can be a monolith or exogenous, understood as separate from culture. The Internet is an excellent example of this precept because it is officially leaderless and decentralized: it is no longer a project of any particular country or person (Mueller 2002). Infrastructure studies would hold that this is also true of infrastructures that *seem* to be projects of a particular institution, place, or person (such as Google or the Great Firewall of China). In that case, observers simply overlook the full complexity of the system, and falsely ascribe a single human will to a network of decentralized actors. The task of the analyst, in this view, is to find and make comprehensible the invisible negotiations that are producing the infrastructure.

Fourth, standardization is a critical point of inquiry to learn more about infrastructure. "[H]owever much standards appear to be neutral, benign, merely technical, obscure, and removed from daily life . . . they are largely an unrecognized but extremely important and growing source of social, political, and economic relations of power" (Busch 2011: 28). Standardization allows seamless interconnection with other systems and processes, and it also promotes the normalcy and invisibility of the system itself (Star 1999). But standardization is both a technical and business tactic—it is an aid to consolidation in a diverse system. Standardization proceeds via "strategic intermediaries" (Jackson et al. 2007) that many scholars have labeled gateways (Egyedi 2001). Like the Internet's gateways, these are intermediaries that provide a translation from one system (or network) to another. But in the parlance of Egyedi and others, the gateway can be a device or it can be a written agreement—or even an organizational practice. The significance of the gateway is that by focusing our attention on the boundaries of an infrastructure we can better comprehend its form and its limits. The advice that follows from this precept is: to understand a system, study its boundaries and the gateways that allow it to work with other systems.

Fifth, as large-scale systems of great complexity, infrastructures all suffer or benefit from what Hughes called "momentum" (1983). "[O]nce established, systems tend to continue in particular directions, making reversals or wholesale leaps to alternative approaches costly, difficult, and in some cases impossible" (Jackson et al. 2007). In this, the relationists embrace the economics of path dependence, a form of network externality (e.g. David 1985) and they often refer to a technological system's "interia" or "trajectory." In terms of research method, the existence of system momentum argues for an attention to the early

days of any infrastructure, as "early technical choices (including some relatively casual or arbitrary ones) have a tendency to get reinforced as subsequent system elements are built around or on top of them" (Jackson et al. 2007). For example, almost all of the URLs on the Internet begin with "http://www" although most of this prefix is no longer necessary—it was originally meant to differentiate web traffic from other protocols that are now defunct (eg. nntp:, gopher:), and the prefix refers to an era where individual computers were named by their services (www, news, mail). Sir Tim Berners-Lee, inventor of the World Wide Web, recently admitted that some of the characters in URLs never served a useful purpose, and "were a mistake." These characters now simply make URLs longer and harder to type—Berners-Lee once publicly apologized for wasting everyone's ink and effort with them (Firth 2009). While these redundancies are now slowly disappearing from URLs, despite efforts to stamp them out after twenty-three years most URLs still have the "http://www" prefix. This is an example of infrastructural inertia.

Returning to Libya for the lessons of relationism

It should be clear by now that our introductory example for this chapter can easily be adapted to fit the relationist mold. The threatened censorship of the .ly domain name suffix under the Libyan interpretation of Sharia law demonstrates all of the heuristics mentioned above. The apparatus behind the operation of Internet domain names is obscure and was invisible until it threatened breakdown. Libya acquired power over a large number of foreign websites because of human practices (the preference for some "cute" suffixes like "ly" over others like "gs"), amplified by inertia as more and more users gravitated to the most popular domain name shortening services (which ended in .ly). Libya's claim on the .ly suffix also came from a formal standardization process that was both organizational (at the ISO) and technical (in the domain name software of the Internet). Throughout the whole story there was no central fulcrum that controlled the infrastructure or the narrative. Instead, a wide variety of actors were in a constant tug-of-war or negotiation for the future of the system. However, to make this truly a relationist account we would need to add a cross-system understanding of addressing as a persistent feature of infrastructure, and theorize the act of addressing in a way that would allow it to shed light on other infrastructures (e.g. Sandvig 2008).

The new materialists: technology, artifacts, and place

Unlike the relationists, this chapter will spend only a small amount of space discussing the new materialists. As there is a great deal of overlap between the two groups, it may be that in some circumstances it is not productive to distinguish them from each other.

However, a major difference worthy of note is that for relationists like Star, the use of the word "infrastructure" is usually a semantic move intended to take a social process and make it seem more material, concrete, or foundational. These relationist writers often started their careers with the history of technology or with computer science, which can both be quite material and quite technical to begin with. The relationists wanted to break away and brand intangible social practices so that they appeared just as important and solid as technical practices and objects. Following in the traditions of STS, they tended to start with a technology and gently or roughly lead their readers to exclaim, "Oh, look: it's actually cultural!" (or political, or social, or economic). Much of the writing in the relationist tradition of infrastructure studies doesn't use the word "infrastructure" in the way a common English speaker might—the average person would expect roads, power systems, and communications networks, but the relationists use infrastructure analytically as a way to materialize the ephemera of norms and organizations. They claim to do this in the service of understanding material systems, to be sure, but the material parts of these objects are de-emphasized. Turner, for instance, asks if the Burning Man festival is an "infrastructure" that provides cultural forms, ideas, and labor practices to the Internet industry in Silicon Valley (Turner 2009).

The new materialists, in contrast, are a group of scholars who are making the opposite transit. Starting in media studies and communication, they have long been concerned with the airy expanse of culture, but they want to lead the reader through an analysis of a communicative experience to eventually exclaim, "Oh, look: It's actually material!" (or technical, or spatial). The turn toward infrastructure is, for them, an attempt to ground their earlier cultural passions, focusing new attention on what the everyday dictionary-reading person would think about the word "infrastructure:" that is, roads, power systems, and communication networks; wires, signals, and dirt. Even though the backlash against the high theory of the 1980s is now decades old, it still may be the cause that impelled some postmodernists to decamp for the earthier environs of materialism. This turn is then comprehensible as their move away from earlier writing about production, reception, and texts.

The focus on "how it works" is still very much in play: A good example is the recent turn toward environmental ethics in media studies. These new materialists ask: Where do the components in media infrastructures come from? Where do server farms and media devices get their power? While a decade ago the cultural text of a TV-sitcom would be considered in cultural terms, today it is also queried as to its carbon footprint. The Internet is introduced with statistics like: approximately 1.5 percent of the electricity supply of the US is consumed by centralized server farms (Maxwell and Miller 2008); or with shocking slogans like: your old laptop is killing people in China (Slade 2007). This turn toward the environment is overdue in media studies, as communication systems are responsible for consequences like massive deposits of toxic lead (from cathode ray tubes). The communication industry holds the dubious honor of producing the consumer product with the single shortest product life cycle of any product—the mobile phone. It is almost instantly obsolete and toxic, and is typically not recycled.

Admittedly, these connections to the substrate of power grids and waste dumps are topics that other authors have explored before. However, the new materialists are of note as an intellectual movement in part because of their origin point: they are moving from the theoretical to the empirical. Phillips, writing in *Social Text* (2005), uses the work of Judith Butler and queer theory to theorize privacy as visibility in the context of ubiquitous computing environments. A few years later, Phillips and Clement (2008) are focused on discovering the likely routes taken by network traffic and the locations of "carrier hotels" (points where data are exchanged between two carriers) traversed along the way. Indeed, the spatialization of formerly placeless media-related practices is a hallmark of the emerging tradition. Neff interrogates the production processes in new media organizations and argues that their physical location in space is one of the most important ways to understand their development (Neff 2005). Starosielski (2010) argues that to understand film culture in Fiji it is important to know that most people obtain their movies by picking up pirated DVDs from the car wash. Still, the new materialists do not intend to wholly release their past focus on culture or content. New materialists ask questions like: how do specific undersea cable routes "contort and deform" digital film culture (Starosielski 2011). For them, to do infrastructure studies is to try to heal the dialectic between structure and form. It is to consider "the mechanics of transduction, storage, [and] transmission alongside creation, distribution, and reception" (Sterne 2003: 8).

This tradition has a longer history in the study of the media. Materialism itself usually refers to the Marxist conception of history, which informed cultural materialists like Raymond Williams (1974), but it is also possible to find a genealogy of materialism in the "Toronto School" of communication theory (Katz et al. 2003), specifically in the work of Harold Innis (eg. 1951). Just as Williams (1974) wanted to explain cultural formats like TV variety shows but he devoted pages and pages of prose to the technical minutae of the television apparatus, Innis (1950) sought to link the loftiest themes of history—such as the rise of Empire in ancient Rome—to the prevalence and characteristics of ancient papyrus and to particular techniques for rolling it up. Although these early accounts could be very technologically determined (Innis argued that the shift from papyrus to parchment led to the decentralization of religion), they still pushed their readers to a fresh consideration of the objects and technologies that underpin communications.

The urge for comparison between systems that is the hallmark of the relationists takes a different form among the new materialists, where communication systems are almost always central and are therefore the object of the theory that results. A book-length history of sound is a history of sound, not an attempt to theorize transportation or electricity as well (Sterne 2003). Nonetheless, these scholars build on a tradition of cross-infrastructure comparison of their own, quite often involving transport. In a classic essay that remains a touchstone in the field of communications, Carey argued that the technology of the telegraph marked a crucial break in the way that scholars should reason about communication technologies because it separated communication and transport for the first time (Carey 1989: esp. ch. 8). Indeed communication in its original meaning was transportation, a box of goods was said to be "communicated" when it was delivered (Peters 1999).

The new materialists are a less coherent grouping than the relationists. So far, although they call for the study of format (Sterne 2012) and a "populist" approach (Parks 2011), they lack an overarching manifesto or a checklists of heuristics. Methodologically, they are much more varied. They endorse experimental partnerships between artists, historians, and geographers, and advocate research methods like art exhibitions, media archaeology, photo essays (Parks 2009a) and interactive visualization (Sandvig 2007). There are probably more similarities than differences between the two groups, including a new focus on decay (Acland 2006) and alliances with urban theory. Yet each grouping has a different inflection, as Star's (1999) directive to emphasize hidden social practices aligns imprecisely with Parks's (2011) call for a "populist approach to infrastructure."

Conclusion: get into the guts

To sum up, the emerging area of "infrastructure studies" can be thought of as two largely compatible research streams: the relationists and the new materialists. A rough alliance of multidisciplinary work spanning media studies, art, geography, history, sociology, and more, both streams provide advice for the scholar of the Internet, and they are both engaged in an intellectual struggle that seeks to overcome the "mind-body dichotomy" that in the past separated content from infrastructure (Star and Ruhleder 1994: 256). The relationists start with the material parts of systems then run toward the social, while the new materialists pass them heading in the opposite direction. From either perspective, the Internet demands our attention as a foundation for modern life. The flowering of this research under the heading of "infrastructure studies" is poised to contribute new ways to unpack the Internet's complexity and to enroll the guts of its operation in future scholarly arguments about the Internet and society.

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