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Time Constructs: The Origins of a Future Internet

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Time Constructs:
The Origins of a Future Internet

A dissertation submitted in partial satisfaction of the requirements

for the degree Doctor of Philosophy in Information Studies

by

Brittany Paris

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ABSTRACT OF THE DISSERTATION

Time Constructs:
The Origins of a Future Internet

by

Brittany Paris

Doctor of Philosophy in Information Studies

University of California, Los Angeles, 2018

Professor Leah A. Lievrouw, Chair

Technological time has been a topic of much theorization and dread, as both intellectuals and laypeople fear that human life is increasingly becoming secondary to the technological world. Feelings of despair and nihilism, perhaps attributable to social, political and economic upheavals brought by the synchronization of human life with technology, have been theorized by numerous scholars in a plethora of overlapping disciplines. What is left undertheorized is how technology develops in ways that might or might not actually foster these sensations of synchronicity, or speed. Technological development includes patterns of social coordination and consumption, as well as individual use and goals, that all relate to a sense of lived time. But what of the ways that technical design fosters these relations? What is the *discourse of time* in technological projects?

This dissertation investigates the aforementioned questions in the context of NSF-funded Future Internet Architecture (FIA) projects—Named Data Networking (NDN), eXpressive Internet Architecture (XIA), and Mobility First (MF)—which are currently underway. Architecture engineers and developers for these projects are building new global Internet networking protocols that are intended to challenge many of the features of, and indeed replace, the longstanding Internet Protocol (IP). To answer the question above, I gathered data from over 100 project documents, 30 hours of interviews with project principals, and application code from each of the protocol projects.

The analysis of this data focuses on three main categories of technical discourse surrounding real-time applications: temporal representation, technical time, and speculation on the future of the project itself, each with many subcategories. The ways that the project data fits into, exceeds, and overlaps with these categories and subcategories illuminate a “discourse of time” that reveals the processes by which concepts of “time” are built into these FIA projects.

The dissertation of Brittany Paris is approved.

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2018

This dissertation is dedicated to my grandmother, Walda Paris.

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Some materials in this dissertation have been or are scheduled to be presented in other publications. Parts of chapter 4 will appear in a chapter in a book entitled "Hardwired Temporalities" edited by Axel Vollmar and Kyle Stine, published by Duke University Press. A truncated and revised version of chapter 5 is under review at *Science, Technology & Human Values*. A case study of NDN's Flume was published in *First Monday* in August 2018.

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Chapter 1: The Importance of Technological Time

As human life becomes increasingly synchronized with the speed of technology, many wonder what would happen if that vector were altered. Articulations of fear and nihilism in the face of technology's speed have been theorized by numerous scholars in a plethora of overlapping disciplines. In recent years, headlines from the popular press seem to support these concerns, including "The Google Effect: How Smart Technology is Making Us Dumb" in *The Independent* (Roberts, 2015), "The End of Reflection" in *The New York Times* (Wayne, 2016), "Fast Playback and the Art of Speed Leisure" in *The Atlanti*c (Feldman, 2015), and "A Nation of Kids with Gadgets and ADHD" in *Time Magazine* (Rock, 2013), to name just a few. At the very least, these titles suggest a re-imagination of time, and a conception of life that potentially exceeds our grasp and signal a troubled future.

This topic of time as it manifests in communication technologies at once as a nebulous concept and an organizing principle in contemporary society has motivated my graduate-level research. The trope of technological speed affecting users, viewers, and society at large stems from my background in communication and film studies, which highlight this relation with regard to legacy media in the work of theorists from Harold Innis to Gilles Deleuze. In many of these works, politics and time are inherently related.

As this dissertation was taking shape in early 2017, the deregulatory stance of the Trump administration and federal agencies crystallized many once-nebulous intersections of technology and politics. Indeed, it has become clearer how Internet speed, which enables Silicon Valley to capitalize on user attention, is directly related not only to economics but also to politics. On December 14, 2017, the Federal Communications Commission (FCC) reversed net neutrality, instituting the ironically-named "Restoring Internet Freedom Order" (Federal Communications

Commission, 2018), which has led many to hypothesize about what this might mean for a society increasingly reliant on Internet speed (Falcon & Trendacosta, 2017; Cohen, 2017; Brandom, 2017; Finley, 2017). It may start with something akin to *zero rating* in which Internet service providers (ISPs) could partner with tech companies like Google to allow a user to access an app like Google Maps at no cost to the data available on their plan, but using Facebook would count against their data plan. It may mean ISPs would charge customers for a fast lane for streaming YouTube, Netflix, or Spotify. Or it might mean that ISPs can continue cost-based discrimination in which they can refuse to build the infrastructure necessary to provide affordable Internet access to remote and low-income areas already plagued by poor connectivity. While the loss of Internet speed for some users (or the persistence of slow service for other users), a few slower websites, or endlessly buffering videos may seem like easily acceptable and rather marginal changes to the quotidian user, they suggest a continued calcification of social and economic structures that further enrich the powerful at the expense of everyone else. While we know that technologies have politics (Winner, 1980), it makes sense to continually interrogate what these values are and how they came to be in an attempt to consider how we might develop technology that functions otherwise.

Intellectuals from several disciplines, including critical theorists from Scott Lash (2002) to Trebor Scholz (2016), software and protocol studies adherents such as Alex Galloway (2004; 2012), sociologists including Manuel Castells (1996), and science and technology studies (STS) researchers such as Judy Wajcman (2014) have pointed out that the mobility, speed, responsiveness, and increasingly real-time characteristics of computer and application interfaces have a great deal to do with the social, economic, and political structure of contemporary society.

These works show a deep and complex relationship between human sociocultural life and the speed of technology.

However, while the speed of technology carries implications for interactivity, knowledge production, and social relations is a topic of study in philosophy, cultural and media studies, speed is just one well-known facet.of how technology is built with regard to certain temporal concepts. STS and software studies examine interface speed and its implications but leave relatively undertheorized *how technology is developed in relation to concepts of time and temporality,* that is, *how* do engineers consider and work with time and temporally-based concepts and technologies and what can that knowledge enable us to learn?

The interrelated questions that this dissertation explicitly tackles are:

- How are these FIA protocols built with regard to time?
    - What are the practices of protocol development that are related to time?
- What is the discourse of time in these projects?
    - How are the assumptions about time articulated with relation to the project?

This dissertation outlines the aforementioned questions in the context of National Science Foundation (NSF)-funded Future Internet Architectures (FIA) projects—Named Data Networking (NDN), eXpressive Internet Architecture (XIA) and Mobility First (MF)—which are currently working to develop solutions to supplement or replace Internet Protocol (IP). To answer the questions above, I gathered just over 100 project documents and 30 hours of interviews with FIA project principals. In what follows, I describe the modes by which engineers working on the FIA projects—NDN, XIA, and MF—articulate the complex sociotechnical contexts that influence the way a design functions with relation to time.

This dissertation contributes to the broad and multidisciplinary field of information studies, specifically to the sub-discipline of critical informatics, and to the adjacent field of STS. This dissertation attends to an undertheorized component of information infrastructures, that of *time*, which often remains elusive in information studies, to foreground it so that we might better see how it is also a force that shapes how we know, what we know, and how we see ourselves in the world.

Readers might wonder why someone from the information studies discipline with a media studies and critical theory background, not a scientific or technical one, is writing about how time relates to the development of FIAs. However, I believe that interdisciplinarity in these realms is the only way that important tensions, problems, and solutions can be brought to the forefront.

This is a dissertation about network engineering by someone who is not, by training, a network engineer. I have some experience coding, structuring databases, and building both front and back ends of websites, but these skills were largely self-taught. I make no statements about being anything more than an amateur technologist. My expertise lies in using the lenses of theory in film and communication, feminism, postcolonialism, semiotics, and poststructuralism to uncover how political economy undergirds technologies that affect cultures of knowledge production over the long-term. It is from this vantage that I became interested in the topic at hand, and it is from this perspective that I share the insights I have gleaned.

As a result of this training, when I started this project, I thought that perhaps the designers whose work I consulted would articulate a clear conception of how they thought about time as a subjective matter, both within their own lives and how they considered the subjectivity or even the perceptual experience of others in mind as they work. But overall, the data did not lead in this direction. These shifts in the analysis are discussed in Chapters 2–5.

The literature on the nature and perception of time is vast and cannot be covered adequately in a single overview. A few key aspects are especially relevant to this study, for example, the classical distinction between time as “objective”, “scientific” and “technologically mediated,” as opposed to “subjective”, “human” and “experienced” (see Bergson, 1913/2001; Heidegger, 1953/2010; Whitehead, 1925/1967). These aspects are touched upon in the following literature review, which focuses mainly on work from several fields – software studies, science and technology studies, materialist media studies, critical informatics – directly related to the development of contemporary technologies. Most of this work highlights the social construction of technology to reveal that individual, social, and technical concepts of time feed into technology design, which then shapes social time in a co-constitutive process.

Time and Coordination

Time is necessary for social and technical coordination, though its necessity is articulated in different ways by different groups with different goals. Social theorist Barbara Adam (1990) noted, “Time has occupied sociologists ever since sociology became developed as a separate discipline” (p. 13). Adam noted that many studies focus on time as a “socially constituted symbol” (p. 43), that encompasses a multitude of phenomena, things, and concepts that are particular and specific to the groups, historical setting, or phenomena under investigation that reflect and generate these temporal stances. This notion that time is reflected and generated through social coordination forms a common thread found in the social sciences and which can be traced from *Elementary Forms of Religious Life* in which Émile Durkheim (1915) stated:

> To represent what the notion of time would be without the processes by which we divide it, measure it or express it with objective signs, a time which is not a succession of years, months, weeks, days and hours! This is something nearly unthinkable. (p. 11; see also Gell, 2001; Walford, 2013)

As Adam noted, there are many examples of sociologists who attend to the production of time in historically- and socially-situated contexts. Those ideas dealing with the development of time in a technological sense are of interest here. For example, sociologist of science Bruno Latour's (1997) rumination on Jean Piaget, a developmental psychologist who wrote on the ways children embody and understand time, focused on the ways that space and time are enmeshed in the history of modernity:

> There is an inordinate number of rigid bodies in the paraphernalia of laboratories. But this does not mean that scientists are themselves rigid bodies or have rigid geometrical minds! It means that, in the laboratory, to detect differences they use benchmarks. The circulation of those rigid bodies will locally generate a specific type of space-time like the circulation of any other body with different properties will generate other spaces-times-actants.[1] (Latour, 1997, p. 185)

Latour argued at once for the necessity of a nuanced understanding of the notion of an "objective," materialized time, which is so often derided in sociological and phenomenological accounts, or in this case, disregarded. He located a missed opportunity in Piaget's accounts of human developmental time, specifically in children's peer groups. Latour suggested that Piaget should have argued that children's social contexts are much like science disciplines in that they are "time producing collectives" (p. 189) because they embody and understand time in nuanced

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[1] Space is an important concept that relates to time and surfaces in Chapter 3.

ways. Latour maintains that Piaget instead erroneously sought to separate the developmental mind “from the history of life itself … and from time producing practices” (p. 189).

In this vein, Latour drew from evolutionary biologist Stephen Jay Gould to argue that “one cannot account for the history of life without the history of life sciences” (pp. 188–89) with their various modes of measuring the world (the passage of time included). Furthermore, Latour noted that to disregard instruments of science and the modes of production of time would extend an epistemology that would become lost in an “obsession with constancy, a mad search for structures which would remain elusive, and a fixation on conservation” (p. 185).

As Latour argued, time can be usefully instrumentalized to learn new things about specific and general contexts, and that this technically mediated and produced time can shed light onto important epistemological concepts. He argued in *Pandora’s Hope* (1999) that there are also serious implications that arise from allowing time’s instrumentality to exert a form of agency. In what follows, I describe the agency of time in the work of Latour and in that of philosophers of technology, Martin Heidegger and Bernard Stiegler, that serves as provocation for the work in this dissertation.

A well-known treatise on the ways that time is bound with space and imbued with agency, in some sense, to negative ends, is Heidegger’s (1954/1977) essay “The Question Concerning Technology,” in which he attempted to argue for breaking apart the co-constitution of time, technology, and instrumentality. In this text the famous philosopher of phenomenology becomes more narrowly a philosopher of technology. He proposed thinking of technology’s “essence”[2] as a process that frames the way we interact with, think about, and visualize the

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[2] “The essence of technology is by no means technological. When we are seeking the essence of ‘tree,’ we have to become aware that what pervades every tree, as tree, is not itself a tree that can be encountered among all the other trees” (Heidegger, 1954/1977, p. 4). Translator William Lovitt noted that in English *wesen*, translates as the noun *essence* but does not mean what something is, but rather what it means and how it endures.

world. In Heidegger's theorization technology's essence is an inherent characteristic that seeks to erase the boundaries between human subjectivity and technology's own necessity, and in the process of doing so, to make people completely dependent upon it.

Philosopher of technology Søren Riis (2008) pointed to Heidegger's famous example of a hydroelectric plant on the Rhine used to describe the self-reproductive process of "enframing,"[3] as it mobilizes more and more natural resources until the boundaries between the two entities, natural resources and technology, are erased (p. 291). Riis equated this with Latour's example of factory workers in *Pandora's Hope* (1999) who used different technologies to produce computer chips. According to Riis, and of interest here, is that Latour's and Heidegger's workers are just another resource and are caught in the process of enframing whose subjectivity becomes ontologically flattened in relationship with technology. Human actors and non-human technologies are both instrumentalized, foreclosing on the possibility for an ontological distinction between the two.

Latour (1999) called this flattened ontological relationship between humans and technologies "the collective" (pp.193–98). He asserted, much as Heidegger did in the late 1940s, that the contemporary technological landscape interprets all beings, both human and nonhuman, as resources that can be assembled, or summoned to serve the ends of technology. This assemblage process is implemented through what Latour describes as "delegation" (pp. 187–98), in which human discourse, social, and political expressions are translated into objects or technologies, and become part of the regulation of human activity. Moreover, it is important to

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[3] *Gestell* used in the original is translated into English as *enframing* to mean an active gathering together of both humans and things, assembling and ordering as it does so (Heidegger,1954/1977). The prefix *ge-* (gathering) is added to *stellen* (frame). Lovitt noted that "Gestell is also the name for a skeleton" (p. 20), a different type of goal-oriented biologically-animated, gathering of inanimate material that uses resources to sustain its function.

note that Latour's "collective," with its flattened ontologies, is reified over time, and, according to Latour is an integral part of the modernist project: "Instead of clarifying even further the relations between objectivity and subjectivity, *time enmeshes*, at an even greater level of intimacy and on an even greater scale, humans and nonhumans with each other" (p. 200, emphasis added).

Technological time for Latour (1999) is teleological, imbued with intentionality, and drives humans and non-humans into an ontologically flattened state. But, he noted, the concept of "the future" in the modernist sense promises hope to bring humans back into "proper" relation with technologies—that the distinction between subjective and objective worlds of humans and nonhumans might come into a more desirable, unconfused relationship as time continues forward along the vector of the myth of modernist progress (p. 200).

Latour's contemporary, philosopher of technology Bernard Stiegler, comes to many of the same conclusions over the course of his series on technology and time (Stiegler, 1994/1998; 2009/1996; 2010/2001). However, Stiegler sets himself more directly in relation to Heidegger, and dedicated an entire book to understanding Heidegger's technological determinism that Latour had critiqued more obliquely through *Pandora's Hope* (1999) and other works. Stiegler argued that *technics,* the practices, skills, and externalized tools of discerning temporality, are co-constitutive of human subjective temporality. But the ends of this process differ between Stiegler and Latour. Stiegler is more focused on the subjective apprehension of time and how it affects society. He drove home this point by drawing from anthropologist André Leroi-Gourhan (1964/1993) and Edmund Husserl's (1966/1991) modes of retention.[4] Following Leroi-Gourhan,

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[4] Husserl's lectures presented in the 1966 published collection date back to 1893. The retentional apparatus described by Husserl (1966/1991) in his lectures on time-consciousness is similar to what Latour might call the material-semiotic nature of knowledge. One must interact with the physical structures of the world through primary retention apparatuses of human senses, secondary retention happens as it is processed by the brain, and tertiary

Stiegler argued that humanity itself originates in its use of tools or technologies which subsume the non-human or the non-living material into human existence. Thus for Stiegler, Heidegger is incorrect because he places too much emphasis on the artificialness of technologically-mediated time and leaves human agency out of the equation in the development of these technologies. Like Latour and Heidegger (to some degree), Stiegler (2010/2001) argued that over the centuries, human technological intervention in the modalities of time have resulted in human time becoming more tightly enmeshed with machine time to a point where people lose important subjective skills and abilities, such as the notion of *care*. Stiegler's notion of care is progressive and suggests that the ability to conceptualize a more harmonious future world should govern human decision-making. In this vein, he (2001/2010) argued that human subjectivity in contemporary society is increasingly bound to technologies designed to generate a temporal orientation that directs human consciousness toward an ungraspable present, rendering us uninterested in the past and incapable of envisioning a future. Stiegler (2001/2010) echoed the teleology of Heidegger's enframing in the context of the technological milieu of the late 1990s characterized by real-time processing. Stiegler's update on Heidegger's "enframing" can be seen as compatible with Latour's notion above that time enmeshes humans and technologies into tighter relations over time, as a result of the modernist notion of the future and technological progress that is assumed as a given, and the modernist belief that future technological progress will address present sociotechnical maladies. From the intertwined but distinct perspectives of Heidegger, Latour, and Stiegler, we might similarly consider how time enmeshes in different ways through the process of technological development.

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retention comes with inscription of knowledge into material substrates (see also Stiegler, 1994/1998, p. 246-247). This might also be understood in conjunction with information theorist Michael Buckland's (1991) declarations about the materiality of information and how it is processed by people to become knowledge.

As noted above, this dissertation finds its direction in the productive tensions found in Heidegger's and Latour's work on time, technology, and individual and collective agency. In this case, it seeks to uncover *how* time enmeshes humans and nonhumans into tighter relations, by understanding how the discourse of time in the course of the development of these FIAs. It looks to reveal the multiple ways time is instrumentalized to structure the process of development in these projects. In the attempt to bring time and its ostensibly unquestionable direction to the surface, I locate categories of the discourse of time that can be employed to similar ends in other projects, as well as provocations about the ethics of technology with relation to concepts of time.

Moving on to other ways time has been understood with relation to technology, it is necessary to mention that time has long been regarded as a metric of labor, commodities, and exchange that perform in the broader political economy (Horkheimer & Adorno, 1944[5]; Marx, 1867/ 1993;[6] Innis, 1948;[7]). Not unlike Lash (2002), Stiegler (2001/2010), and other postmodern thinkers, in *The Postmodern Condition* Jean-François Lyotard (1984/1979) argued that the widespread introduction of computers in society in the late 70s and early 80s was accompanied by changes in the cultural, political, and economic landscape that emphasized the commodification of information. The reason for this, he claimed, is the drive toward truth and the erasure of social problems through technological and scientific progress that has taken root as postmodernity has lost faith in other teleological "metanarratives" (p. xxiiv). The metanarratives

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[5] The notion of the ways in which leisure time is developed as a concept with the advent of capitalism as a mode of pacifying workers runs throughout this work. Theodor Adorno spoke to how the burgeoning postwar "culture industry" served the dual role of commodifying leisure time and further pacifying workers.

[6] Marx wrote extensively about labor time and how it related to use value and wages in a capitalist system. This version of the first volume of *Capital* begins a discussion of this on p. 129.

[7] Innis discusses how the temporality of communications media had a profound effect on the way commerce and government structures spread through antiquity to the 19th century.

he points to are the ability for science to explain everything, the linear and forward trajectory of time and historical development, and the concept of progress that would lead to ultimate freedom (p. 34, 35, 37). In this sense Lyotard argued that new technologies have made information more economically valuable, efficient, and programmable. In the years since the publication of Lyotard's work, digitized information has become an incredibly valuable commodity. According to Lyotard, information technology follows the principle that time is considered a metric of labor, commodities, and exchange that form the political economic structure for contemporary society that is driven by the accumulation of wealth and power. As such, when relating concepts of time to technology, he notes that, "Technology is therefore a game pertaining not to the true, the just, or the beautiful, etc. but to efficiency: a technical 'move' is 'good' when it does better and/or expends less energy than another" (p. 44). In this sense technology's efficiency is paramount in contemporary society because it is a value that meshes well with the political and economic concerns that undergird a capitalist society. The question of technological time, manifest as efficiency, in Lyotard's reasoning, is key to understanding how contemporary society puts a premium on resources.

In the vein of technological transformations of culture though maximization of time, German media theorist Friedrich Kittler (1993/2017) wrote that the "processing" of human cognition increasingly happens through "new" media. In a translator's introduction to the republication of Kittler's essay "Real-Time Analysis, Time Axis Manipulation," Geoffrey Winthrop-Young (2017) noted that Kittler worried that the "ability of digital media to store, process and communicate the level of the real is inaccessible to human perception and comes at the costs of humans no longer being able to determine whether that which is processed by media is not in fact processed by them" (p. 2). According to Sybille Krämer (2006), Kittler's explanation of the real- time technology in the early 1990s situates data processing as the method by which the temporal order becomes “moveable and reversible in the very experience of space” (p. 8) and threatens to exceed not only human perceptual capacity but also to match and overcome the human ability to predict, determine, and decide. While Kittler has often been described as a technodeterminist, like Latour, he is interested in opening “black boxes” of abstract concepts, like time, linked with communication technologies as he does with real-time processing made possible by the digitized audiovisual technology of the 1990s. Unlike Latour, however, he resists or neglects the idea that humans have any part in the development of technologies.

At the level of the production of temporal experience through technology, stands software studies. This field is at the intersections of cultural studies, critical theory, and computer science, and draws from German media studies’ emphasis on the material and political function of technology, in order to understand software as a cultural practice. However, for the most part, software studies deals with computation at the plane of software sources and processing, with attention to broader sociocultural implications (Fuller, 2008). Yet, it often overlooks how the concept of time drives these practices forward. Wendy Chun’s (2011) *Programmed Visions* comes the closest to tackling the way temporality is imbued in computation systems and how these are related to power, but it does so only in a short chapter on the ways in which concepts of human memory and computational memory have driven the rhetoric of one another through history.

Alex Galloway (2004) attached the temporal concept of speed to protocols as he provided examples of his thesis that “protocol is how technological control exists after decentralization” (p. 8). He described at length how Transmission Control Protocol/Internet Protocol (TCP/IP), Hyper Text Transfer Protocol (HTTP), and other common Internet protocols structure networks and human relations to these networks. He points to the ways these protocols promote information speed, so that the information purveyed through computational devices become a “natural extension of the user’s own body” (p. 67), but does not explore this concept further. Galloway’s provocation, along with Chun’s observations about the rhetoric of memory in computation suggest that technological development, in conjunction with the speed of contemporary technology, is inextricably linked to power relations. Chun and Galloway each argue that the human experience of technology often occurs in the context of power relations, which are inherently connected to epistemology.

If technologically-mediated temporal experience has such an effect on humans, and if overall, in the practices of sciences and engineering of technologies, time asserts intention or agency, it makes sense to uncover the discourse of time in engineering projects—that is, how it is described and worked with as a *concept*, a *process*, and a reified *thing*.

This dissertation draws inspiration from Leigh Star and Karen Ruhleder’s (1994) characterization of technological infrastructure as a process, an ongoing negotiation between the social structures that give rise to institutions, and the individuals building technologies that in themselves define and are defined by their relationship to these institutions and social structures. The work at hand describes the processes by which information infrastructures develop over time, in relationship to concepts of time, and how designed products are intended to affect users’ temporal experience, each of which is not inherently neutral.

Concepts of time and the process of working with time as a technical object are relevant, since a single technology can both include and induce a variety of temporal conceptions and regimes. Within social theories of time, science and technology are often connected to the measurement and spatialization of time through clocks and other devices or the flattened or "synchronous" concept of time facilitated by new communication technologies such as mobile phones, or even hydroelectric dams in Heidegger's example from the 1940s. Remarkably enough, Internet infrastructure development, as it is investigated in this dissertation, employs scientific theory and is by default a technological practice. It also seems to incorporate elements of the above: the tendency toward linearity, causality, and control, and the emphasis on the here and now, as we will see in later chapters.

The work reviewed in this section clarifies that the notion of technological time contains a few dimensions of interest—that time is socially constructed, that time is often discretized in technical apparatuses, that the demands of contemporary capitalism shape the impetus for technical efficiency, that time is related to technical speed that users experience and that notions about time become enmeshed into technologies as they are developed. These dimensions of technical time were those I looked for as I designed and executed the research project. Each of the following chapters, save chapter 6, coalesces around broad categories (the projects' trajectory through time, modes of communicating temporality, technical time, and conceptions of a socio-technical future) that I found as I gathered and analyzed the data. Each of these chapters contains reviews of literature that were useful in further fleshing out these categories and contextualizing the findings in that particular chapter.

Methods

I conducted this study from spring 2016 to spring 2018. I developed a multi-method design that included gathering project code, documents, and interviews with principals for applications running on new networking protocols. I started this process with a focus on the development of NDN. To guide the examination and theorization of my data, I used discourse analysis. I first reviewed NDN documents and spoke with principals on the project, and found the concepts outlined in the literature above to be the most compelling categories of the emergent discourse of time in the NDN project. These conceptual categories formed the basic framework that guided, but did not determine, subsequent analysis of the application code, document text, and schematics relating to time in Internet networking for each application in question. I interviewed the NDN project principals, as well as the principals in the XIA and MF projects, to discover their perspectives on what I found in the code and project documents. While I was attending to general concepts derived from the first round of talks and outlined in the literature above, I let the data gleaned from the code, documents, and interviews inform new threads of inquiry not suggested in the literature to develop and refine categories and subcategories of the discourse of time in Internet protocol projects.

Site Description: Future Internet Architectures (FIAs)

Each of these FIA projects was envisioned by different research groups in relation to a 2010 National Science Foundation call for proposals to improve upon IP. Each project—NDN, XIA, and MF—is briefly described below, but will be outlined in more detail in Chapter 2. These projects are excellent sites to study with regard to the ways in which they consider time as they build, for two reasons. First, at face value, the NSF naming scheme for the grant they applied to and the way they are framed by the NSF intentionally positions these projects toward a notion of a “future.” Second, at the time of the study these projects were still under construction and had not yet become “black-boxed,” a term used in STS to refer to how technological processes become invisible and inscrutable once technologies become successful (Latour, 1999). Instead, FIAs are still relatively open, academic endeavors, which affords better access to the researcher. It is likely that this access would allow the researcher to compile an illustrative case that might be instructive in other, closed scenarios of technological development. Third, I started studying the FIAs by researching NDN, which is located on the UCLA campus. Doing so granted me easy access to the project and its principals and other researchers.

Last, and perhaps most importantly, it is interesting to note that even in many of the project documents, there is a notion that the new networking architectures will allow content to be distributed between stakeholders faster and more efficiently. These documents then go on to explain the technical aspects of *how* this new speed will come to pass, in varying degrees of abstruseness (Jacobson et al., 2009; Mobility First, 2018a; So et al., 2013; XIA, 2018c). These are the attributes of speed most commonly cited in the popular press, in which the affordances of these projects gets broken down into discussions of developing an architecture that is “faster” or “swifter,” or that “allows smoother content streaming” over today’s Internet (Bauman, 2017; Brown, 2015; Rutgers University, 2016; Talbot, 2013). As the speed of the new architectures is lauded, using various terms, as an advantage in the project documents, and as this is the public-facing rationale for the projects, it makes sense that these projects would be good sites to rigorously interrogate what these time-laden terms mean in practice to principals and how that might differ from, or be in tune with, the common perception of a faster Internet. I will now provide an overview of each project, to sketch out broad notions of their relationships and technical goals.

Named Data Networking (NDN)

NDN served as my primary research site. It is where I learned about the NSF-funded FIA program, from which NDN received most of its funding in 2010 for work that continued through 2016. As I learned about NDN’s FIA funding, I became interested in the other FIAs—XIA and MF as possible sites with which to contextualize and compare NDN’s work. Indeed, the FIA funding is the third round of funding NDN received from the NSF for this type of work developing future Internet protocols to replace IP, making it the longest running project among the other FIAs. This will be further detailed in Chapter 2.

Before moving on to discuss the technical aspects of NDN, it is useful to give an overview of the organization that supports the NDN protocol. NDN is a research-based instantiation of Information Centric Networking (ICN). ICNs generally include a networking protocol designed to allow Internet infrastructure to support location-independent communications by transmitting named data (Saucez et al., 2016). Named data is the feature of NDN and other ICNs; instead of routing packets based on IP addressing schema, data is given a unique name and routed according to requests for that named data, which NDN developers claim will allow more secure and efficient network communication (Zhang et al., 2010).[8] IP is the networking protocol that has been in place since the beginning of the Internet in the 1960s and is still used today. It is the juncture at which packets are transmitted according to the IP address tied to the packet's location in the network. Transmission Control Protocol (TCP) checks and controls the flow of packets to and from their destination as they are transmitted through Internet infrastructure. Content-Centric Networking (CCN) is also an ICN closely related to NDN, but instead of being built and developed at research institutions, it is being developed at Xerox PARC. Both NDN and CCN hope to either supplant or co-exist with TCP/IP.

NDN is the most well-known and outward-facing version of ICN as it is a major research endeavor. Indeed, there are eight Primary Investigation (PI) sites of NDN in the United States, and more than 21 sites primarily across North America, Europe and Asia working on NDN; it

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[8] This document is the first technical report for NDN and the executive summary is copied through many of the NDN reports published through the years. I will give bibliographic information for where quotes and ideas appear first in this document.

boasts a user-friendly website and a publicly-available codebase (NDN Project, 2018). The main research hub for NDN is located at UCLA. Its PIs are Lixia Zhang, a Professor in the Department of Computer Science, who heads networking research at the Internet Research Lab (IRL), and Jeff Burke, a Professor in Residence and Associate Dean in the School of Theater, Film, and Television, who leads the applications development for NDN at the Center for Research, Engineering, Media, and Performance (REMAP). According to Zhang and Burke, and the 40 published reports, webpages, and videos on the project, the technology has the potential to address many of the major challenges the Internet faces today, including distribution, mobility, security, and scalability of content across distributed networks (L. Zhang, personal communication, September 22, 2016; J. Burke, personal communication, September 12, 2016; Zhang, 2010). When I attended the NDN community meeting in Memphis, Tennessee, in March 2017, conversations and presentations highlighted the fact that NDN's prizes their security affordance, provided with their cryptographically signed name-space for each piece of data, over other possible values like privacy, or accessibility.

The networking research happens across all sites but is coordinated by Zhang's IRL via listserv emails. Nearly all technical questions and troubleshooting issues are handled by Junxiao Shi, a graduate of UCLA who previously worked under Zhang at the IRL, and who now teaches at the University of Arizona. The networking solutions are demonstrated and checked via the NDN testbed, which is run from Washington University in St. Louis under the direction of Dr. Patrick Crowley and managed by John DeHart. Most PIs, engineers, and researchers working on NDN also work on other projects, but in some cases, such as that of Lixia Zhang and Peter Gusev, their work is fully dedicated to NDN.

Beyond the general communication regarding research, much of the discussion about upcoming NDN meetings, calls for proposals, and requests for technical information happens through various semi-open listservs that anyone can petition to join. Little of the interaction that leads to work in NDN happens in person, unless those working at the same university happen to share physical lab space.

eXpressive Internet Architecture (XIA)

Similarly to NDN's trajectory through the NSF-FIA program, XIA has been developed at Carnegie Mellon University by PI Peter Steenkiste and his associates at Boston University and the University of Wisconsin, to develop a network to route data through the Internet's least-congested points intelligently. XIA includes 40 faculty, working primarily in the department of computer science and adjacent departments at CMU, so that XIA has been developed in a much more localized setting than NDN (XIA, 2018b). While their interface with the public is not as advanced as NDN's, the focus is clearer within the small group of participating researchers undertaking this enormous project, as will be seen in later chapters.

XIA hopes to address "the growing diversity of network use models, the need for trustworthy communication, and the growing set of stakeholders" and principals (human and non-human) that coordinate activities to provide Internet services, "including hosts, content, and services, while accommodating unknown future entities" (XIA, 2018a, p. 1). Their main goal is to build an Internet that is more scalable than the current TCP/IP Internet, which XIA principals characterize as very rigid. XIA is conceived as an entire architecture to replace IP, in which TCP would run over XIA's protocol. This has proven to be a huge research issue for XIA because networking protocols are a small part of the architecture. Steenkiste noted in a 2017 interview that "you have to build the whole architecture out, or it doesn't work. This entails that you spend time on low-level things and you constantly have to work with existing protocols” (P. Steenkiste, personal communication, October 30, 2017).

The architecture Steenkiste mentioned is that of the entire protocol stack built of increasingly complex and codependent layers, the most basic level of which are electrical impulses traveling through physical infrastructure, wires and cables, which are then packaged into data and packets and transmitted through networking protocols to the user-facing applications like browsers and platforms like Facebook. The networking protocols are crucial for a functional Internet, but they are just one small piece of the architecture that must work in concert with all other pieces of the architecture. This will be discussed further in subsequent chapters.

As with NDN, most of the work for XIA happens remotely, though the fact that most of the researchers are located at CMU allows closer intra-project communication. Most of the work that happens goes through Steenkiste, and indeed he seems to coordinate not only the work, but most of the communication regarding XIA. The semi-open listserv and GitHub are managed by Dan Barrett, through which, similar to NDN, most of the work is coordinated and made available to the XIA community.

Mobility First (MF)

MF PI Dipankar Raychaudhuri is a Professor of Computer Science, running the project out of the Wireless Internet Lab (WINLAB) at Rutgers University. Six other co-PIs work at the University of Massachusetts–Amherst, Massachusetts Institute of Technology, University of Michigan, Duke University, University of Wisconsin, and the University of Nebraska (Mobility First, 2018b). According to Raychaudhuri, he knows everything that is going on with the project at any given time, as they are a small set of researchers. Most of the research on policy and values happens at the University of Massachusetts–Amherst, and most of the technical research happens with Raychaudhuri's WINLAB at Rutgers University.

MF envisions that shift driven by the increased mobile and application-driven Internet will gradually demand a new "more flexible, but more secure Internet in which mobile devices and applications, along with updates in service and trust, drive the architecture" (Mobility First, 2018a, n.p.). As with XIA's focus on scalability as a motivating concern, MF is dedicated to enhancing network mobility—networks can support the easy physical movement of users, whether those are people or applications, and not experience a breakdown in network connectivity.

Data Gathering

As noted above, I first became involved with NDN in Spring 2016. I arranged meetings with an informant working on NDN at UCLA, Zhehao Wang. Wang introduced me to the NDN website, where at the time, there were over 75 published papers on NDN, so that I could begin researching on my own what NDN was, or more appropriately, what NDN thinks it is and wants to be. I first focused on a subset of four webpages within the website, 36 technical reports, and 10 videos that feature, often in the exact same language, explanations of how NDN works. I then met with Wang three times between February and June 2016 to ensure I understood the published works' description of the organization overall, as well as how the various components to the NDN protocol work. I interviewed five people from NDN between June and October 2016. Each conversation that took place in this time frame was recorded and transcribed. My basic interview instrument was a set of questions that I modified and adapted to fit each conversation (see Appendix). In many cases in which I was asking about specific projects or circling back for clarification, the interviews were more conversational and did not follow any strict set of questions.

In April 2017, I started researching applications built on NDN. By that time, I had reviewed a great deal of the technical aspects of time in the documents and general discussions I had with principals regarding the NDN project, but I still needed NDN application developers to tell me more about the codebase for the applications. I met with NDN's sole application developer and obtained quotes by essentially sitting with him and playing the "helpful idiot." I had him open up the codebases and explain his rationale behind doing what he did and where he solved the problem of packet-sequencing for real-time applications.

In 2017 and 2018, I contacted and investigated XIA and MF in a similar process. I first waded through primary project documents online, then interviewed PIs for background and context for each protocol project. I also followed up by looking at documents describing applications and then interviewed application developers for each project in much the same way I did with the NDN application developer.

To document conversations with principals, I used a QuickTime audio recorder on my computer, and took notes on the computer and by hand during our meetings. I recorded audio because our talks were often technical, and I wanted to ensure I did not get lost in acronyms or processes that I did not immediately understand. For the 2017–18 talks with the informants from all FIA projects, I took copious notes during the meetings, including useful quotes, then sat down immediately afterward and typed up a memo to document everything I could remember from our meeting, using my handwritten notes to capture quotes and concepts to remember. From these field notes I "coded" observations, quotes, and concepts by pasting them into the document with the broad categories. For this part of the study, I only transcribed those useful quotes.

The handwritten notes were recorded in a series of research notebooks. The notes I took on a word processor, as well as my audio recordings, exist on my computer and on an external hard drive. I should mention here that since March 2017 I have relied less on transcribing the entirety of the recorded conversations as I am now more comfortable with the concepts central to each of the projects and because transcribing each of the recordings on my own takes far too much time; paying for transcription requires far too much money for a self-funded research budget. I did record the conversations, and transcribed the specific instances in which I was playing the “helpful idiot” to applications developers as they described the code base. In other circumstances, I listened to the recordings multiple times, made notes interesting or important quotes in the recordings and transcribed only those useful quotes.

Analysis

As I compiled the data, I found that the engineers articulated interesting concepts and processes that I had not expected. I asked them further questions to probe in these scenarios and began analyzing the data according to a discourse analytical framework. However, I found that comparing what the engineers actually said in my discussions with them, and what I saw in the documents, illuminated preliminary topics for further theorization. The following sections highlight my methods of analyzing the data and topic theorization.

Discourse Analysis

Discourse analysis is a data-driven method of analysis that is often used in sociology, media, and textual studies (Kittler, 1986/1999; van Dijk, 2005; Fairclough, 1995). It attempts to understand how and why concepts and related terms are developed, and is procedurally similar to content analysis, a common research method in the social sciences (Krippendorff & Bock, 2008; Timmermans & Tavory, 2012). Practitioners first gather their data and set it into a contextual frame, noting who wrote and published the documents, performances, or designs they use. At that point they note when each piece of data they consider was written or produced, and conjecture whether and how each piece might have influenced or been influenced by others. They then prepare materials they use as data for thorough analysis using a rough and informal coding schema. This might include making copies of data or schematics to be annotated, or in the digital age, it might simply be done by copying a document using word processing software. Once an analyst finishes looking at the corpus of documents using the coding schema to make notes about what words, images, or passages relate to the conceptual schema, they might color-code the documents with regard to concepts. The analyst might categorize these findings into a table or document with concept headings. At this point some discourse analysts dive deeper into the language, looking for things like modalities that express levels of certainty—expressed in word choice such as *could* versus *should*, or phrases like *obviously* or *everyone knows*—or their relationship to the process they describe, such as in statements like *we* versus *them*. While this sort of linguistic focus is common, it is not always used. Discourse analysis can be useful as it looks to understand a formalized language; this can be useful in analyses of film, design projects, or other visual media. Here, discourse analysis is interested in understanding a sort of canon of conventions for communicating simple concepts or ideological directives. Then comes interpretation or finding the "so what" of the analysis. This usually involves a new mode of categorization or overarching concepts based on the findings that produce a theory. This hermeneutic process is rarely linear and can nicely complement a grounded theoretical approach.

For this project, I adapted a mode of critical discourse analysis (CDA) made popular by Foucault (1982) and Fairclough (2010) to articulate how the ways in which people interpret, represent, and conceptualize social reality are reflexive, both contingent upon and generative of these realities. This has much in common with Latour's (1988; 1999) constructivist understanding of how practice and physical objects in the realms of science and technology shape and are shaped by social reality which can include data from discursive practices. In the project at hand, I focused on investigating how discourses of time and temporality in engineering form and are formed by technical functions. Each of the discursive concepts I found was linked to the representation of or practices of working with time or temporality in a given project, the technical conditions which contributed to its development within the project, and how the process of production of the concept affects practices. In this study, power is something I attended to as it arose, but my method departs from CDA because it was not looking specifically for power and ideology *prima facie*. That said, power and ideology were clearly evident, as I note in subsequent chapters.

I followed the process of discourse analysis described above. When I started in 2016, I first gathered the publicly available technical documents from NDN and determined how they laid out the rationale for my project overall, noting any temporal dimensions I could find. My 2016 study focused on how the project, as it was articulated in the documents, related to political discussions of possible monetization of the Internet coupled with the claims of increased security and efficiency of the project. I then interviewed NDN project agents at UCLA to determine if what I was understanding about monetization was indeed the goal, or if this was merely my own interpretation. I also probed the temporal concepts related to the technical issues I saw in the documents. This interview component of the study was invaluable in clarifying both the political and temporal concepts of NDN, as well as pointing to new ones to investigate further, which were the categories of representation of time, issues of technically managing computational resources, and how each project works with regard to a concept of *the future*. These main categories (representation, technical and future) I developed were derived organically from previous discussions and reviews of literature in 2016 and early 2017. These helped guide, but did not determine, my analysis.

In the 2018 analysis of all data, I found Reinhardt Koselleck's (1979/2004) categories of experience and expectation to be useful in conversations talking about the duration of the projects. Koselleck highlighted modes of addressing the past and future that consider Western teleologies of time and progress:

> *Experience* and *expectation* are two categories appropriate for the treatment of historical time because of the way they embody past and future. The categories are also suitable for detecting historical time in the domain of empirical research since, when substantially augmented, they provide guidance to concrete agencies in the course of social and political movement (p. 258, emphasis added).

For Koselleck, these two concepts form categories that are attuned to the temporality of humans and work to "disclose" historical processes and drive history forward (p. 258). Using these categories, one might ask actors what has happened and what they expect to happen, at a fundamental level. Koselleck's concepts of experience and expectation were useful in analyzing data found in Chapters 2 and 5.

Beyond using Koselleck's method to surface the past, present, and future, as I began this process I realized that looking at the data through these lenses afforded a type of immanent critique in the mode employed and developed by Adorno throughout this work (Horkheimer & Adorno, 1944; Adorno, 1966/1973).[9] Immanent critique is a type of critical analysis that seeks to understand the implications to any context of study from a position inside, rather than from an

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[9] There are other works from Adorno that fit, of course, these exemplify Adorno's most important works of immanent critique.

externalized, idealized perspective that assumes that one can maintain a neutral perspective on the political economic or another totalizing system. I found that this mode of critical analysis was useful in further fleshing out how statements of expectation relate to articulations of what happened to understand better where narratives might depart from the actual processes at play in these projects. Overall, the notion of immanent critique was useful in the analysis of data, as it interrogates the difference between what people say they are doing and what they actually do. With regard to overarching systems, it is useful in drilling down into engineers' normative statements that are given confidently and as if they are straightforward.

Topic development and theorization

Throughout the study, as I conducted interviews and reviewed project documents, I noted relevant data – quotes, diagrams, and other contextual information of interest – and wrote up subsequent memos detailing what I had found and how I understood those findings. I pasted these data into the concept headers and annotated how these quotes, ideas, or processes fit. Since the concept-header document was an electronic word-processing document, it was easy to move the data examples around and juxtapose them with others as I thought about them and as I gathered more data. Some concepts fit perfectly beneath the headers and some fit with a caveat. Eventually, the ones I thought fit with a caveat or two fell into groups that related in interesting and illuminating ways, providing subcategories or elements that speak more broadly to the interrelated themes of the "discourse of time" and the "working with time" within these projects. I used these elements of the discourse of time to develop a model for how I witnessed the relation of these discursive categories with relation to the way time is expressed and carries through the process of development in the FIA projects.

As mentioned in the last section, the categories I noticed in preliminary work with NDN in 2016 contributed to the framing of the chapters in this dissertation. The inevitable discussions of latency in different components of the NDN technical system in my preliminary work with NDN in 2016 led to the development of the “technical time” category. The “representation” category arose from looking at NDN documents’ description of packet routing and latency through words and through diagrams. Finally, I found the notion of “the future” of the project in articulations in the documents and videos, along with observations from the NDN community meeting. This idea of the future is one of the more important time-based concepts that the 2016–early 2017 study brought to the forefront. These notions of a technological future are significant because they place the work of NDN and the other FIAs in a broader sociocultural context. Once I had these basic categories set up, I then focused on Flume as a case study to see if these categories would hold, how the data would fit them, and what new questions, themes, categories, or subcategories the data posed.

As the data pointed to other FIA projects, in the summer of 2017 through early 2018, I began focusing on the other FIA projects. I went through the documents for NDN again, in addition to those for XIA and MF. I copied and pasted concepts, quotes, and images from the document into broad concept headers (Representation, Technical and Future) that formed the concepts found in the 2016–17 NDN study. My guiding principle in developing these categories was that they encompass aspects or elements of the interconnected themes of the discourse of time and temporality present in the data, and the technical practices of building time into these FIA projects. From these themes, I derived the *time constructs* framework described in Chapter 6.

Chapter Organization

The following chapters organize the study on FIA projects into the primary categories of time that I found while investigating these new networking projects. These primary categories were that of the representation of time in projects, the ways technical time is considered in engineering practices, and how principals articulate future trajectories for their projects. Each chapter includes the numerous subcategories and discusses overlaps and gaps in order to describe the nuances and fine distinctions these FIA projects contain in comparison to one another.

The conclusions of Chapters 2–5 highlight how the findings in each chapter illustrate a discourse of time in these projects that include articulations of time-based practices, processes, and concepts. Chapters 3–5 are organized to show how the investigation is vertically-integrated as it uncovers how assumptions about time are built into the most granular level of technological development (bits and code) to larger scales (hardware and protocols), then demonstrates broader conceptions of how we can consider the articulations of technological progress we can expect from any type of new technological infrastructure. It suggests that, similar to vertical integration in the economic realm, the more power a single concept of the future has over the process of technological development, the more it becomes reified in the ways of thinking about a better, more just, or even a different type of future relationship between technology and society.

Chapter 2 introduces many of the voices that will reverberate through the subsequent chapters. This chapter makes use of Koselleck's categories of experience and expectation to present the short history of the FIA projects. It uncovers the in-project and public-facing narratives surrounding the FIA projects in question and how these have progressed over time. This chapter further contextualizes the study, what the FIAs are and how they work, and the people and institutions involved. In order to familiarize the reader with the distinct flavors and characteristics of each project, I present the work of the Values in Design (VID) Council, a group of policy analysts, sociologists, and ethicists mobilized by the NSF in order to push the technical teams involved with the FIAs to consciously build positive social values into their designs. I then disclose principals' articulations of what has happened in each project with regard to "values in design," in the time since the FIA's engagement with the VID Council, as well as what the council wrote about their interactions to pinpoint some areas of disjunction that are picked up in Chapter 5. The documentation of the trajectory of how values directives have been carried out through time in the FIAs marks a contribution to the STS field of values in design.

Chapter 3 shows how issues of time and temporality are characterized spatially in the development of applications these three new networking protocols. These spatialized representations of time occurred primarily through schematics and user interfaces (UIs). This chapter finds that graphical representation of time in these projects, along with the ways that these are described indicate three main ways in which time is spatialized and represented: as qualities, as shapes, and as characteristics. These categories of the discourse of time reveal how engineers understand the temporal needs of the users of these applications, how they organize and order computational processes, and how and to whom these illustrations communicate.

Chapter 4 further describes the technics of time in these FIA projects. It demonstrates how time is understood and worked with at the level of practice to show how it is rendered into a technical object through bits, code, protocols, and hardware that all work to materialize time into discrete components that can be handled by the networked computational system. It interrogates the technical design value of efficiency articulated in Chapters 2–4 as a fundamental discursive concept of time in technological projects that shapes the ways in which the FIAs have been and will be developed. It finds that latency and speed are interrelated faces of this concept of efficiency that orient engineers to the technical and social values of their work.

Chapter 5 points to many conceptions of a “future” of these FIA projects. This chapter reveals how principals articulate the possibility of the future existence of these FIA projects. It uncovers concepts of the future of technology by interrogating notions of experience and expectation found in each project, with regard to each project’s stated goals and to what has actually happened, in order to discern how future-oriented discourse in these projects is bound to surprisingly rigid notions of utopia and possibility.

Chapter 6, the concluding chapter, reprises the elements of the theme of the discourse of time found in the previous chapters. It clarifies how these elements indicate concepts of time that are co-constitutive with the processes of working with time as an object in these projects. It also shows how these discursive elements manifest in the production of technical components that further influence concepts of time and processes of technological construction. The final chapter closes by pointing to the implications of this study and suggests future work.

Chapter 2: The History of the Future Internet Architectures

This chapter provides a historical narrative of the FIA projects and the NSF initiatives that launched them in order to contextualize the analyses presented in subsequent chapters. Here I center the narrative on an unusual component of the FIA effort: its directive that projects articulate not only their technical design features and rationales but also to attend closely to the social and ethical values that informed them. The NSF's Computer and Information Science, and Engineering (CISE) program enlisted a Values in Design (VID) Council to help shape the FIA call for proposals, then to work with awardees to identify and develop values frameworks for their projects. The outcomes and consequences of that effort are examined at length later in this chapter. First, however, it is useful to review the basic technical features of the Internet as it operates today, and then how the architectural designs of all three projects—NDN, XIA, and MF—depart from and improve upon that model.

The Internet, Past, Present, and Future

The Internet is a meta-network of interconnected networks, often described as a network of networks, that transmits packets using a standardized set of instructions for communication procedures, called *protocols*. Information (data) is discretized into small, transportable packets that then circulate through the Internet following the procedures of various protocols. The most common protocol suite, TCP/IP, defined the beginning of the Internet and is still in use today. It enables packets to be sent across networks. IP uses an addressing system to determine the origins and destinations of packets. IP has been called the "thin waist" of the hourglass shape of the Internet's structure and has been the arbiter of the "explosive growth, allowing lower- and upper-layer technologies to innovate without unnecessary constraints" (Zhang et al., 2010, p. 2). TCP determines the rules for sending and confirming receipt of packets as they are transported to and from their destinations. The TCP/IP layer connects the lower-level hardware and the user-facing applications layers and is often called the networking layer, or Layer 3, when regarding the International Organization for Standardization (ISO) framework (Zimmerman, 1980). Once two networks are interconnected, and end-to-end communication with TCP/IP is enabled, any node on the Internet can communicate with any other, regardless of their physical location or the network. This architecturally-determined openness feature has allowed the Internet to become a global communication system.

As the term suggests, the *end-to-end* principle has been a crucial factor in this growth. It maintains that the network should be designed to focus on communicating packets between applications anywhere in the network (Saltzer, Reed & Clark, 1984; Clark, Wroclawski, Sollins, & Braden, 2005). Proponents maintain that the end-to-end principle encourages the development of robust, reliable applications at the endpoints of a network that treats all traffic the same.[10] Internet policy experts (Lemley & Lessig, 2000) often contend that this principle is necessary to ensure Internet openness, freedom, and innovation.

In the mid-2000s, the advent of social media precipitated a paradigm shift in Internet traffic. While the original premise of the Web was moving documents, social media encouraged a notion of a read-write Web for which enormous amounts of data were generated. Researchers and funding agencies became concerned that the demand for increased connectivity and application-based communication would surpass the capacities of TCP/IP and would spell the of

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[10] Tarleton Gillepie (2005) notes that while networking engineers generally point to Saltzer, Reed & Clark's 1984 paper on end-to-end design to argue that it is an important principle, it is tied to a conceptualization of an Internet that is defined by the simple exchange of data and not real-time data or voice streaming. End-to-end is invoked as a rigid and important principle by technologists, but is far from a foregone conclusion in the current sociocultural context (as of 2005) surrounding internet use which is increasingly interested in real-time data flows. Moreover, he finds that the term "end-to-end" when invoked by engineers mean many different things, from the most common—the trajectory of a packet through TCP/IP "from start to finish," (p. 434), to the network's capacity to accommodate functionality at the endpoints, like applications or acknowledgement (ACK) verification of packet receipt (p. 435).

demise end-to-end communication (Clark, Wroclawski, Sollins, & Braden, 2005; Gillespie, 2005). To this end, NSF's CISE initiated the Future Internet Design (FIND) program, the first-generation future Internet projects funded by the NSF (Fisher, 2007; see also "NSF Future Internet Architecture Project," n.d.). In 2009, NSF hosted a Future Internet Summit to survey the results and formulate a call for the next round of projects under the banner of FIA Architectures. In 2010, CISE funded four projects at $8 million each for three years; in 2014, three of these (NDN, XIA, and MF) were awarded a further three years of Next Phase support through 2017 (National Science Foundation, 2010).

At the outset, the NSF "anticipated that the teams would explore new directions and a diverse range of research thrusts within their research agenda, but would also work together to enhance and possibly integrate architectural thinking, concepts, and components, paving the way to a comprehensive and trustworthy network architecture of the future" (National Science Foundation, 2011, n.p.). Darleen Fisher, program director of the NSF FIA project, stressed that the FIA program is just one step toward an improved Internet of the future that will have an influence on all other Internet projects that come after it.

> While to the ultimate goal is the design and deployment of a network that serves all the needs of society, we realize that these projects are just the beginning of what it would take to create a full-scale Future Internet. (National Science Foundation, 2011, n.p.)

However, as funding ended in 2017, each of the NSF Next Phase FIA projects found themselves seeking new funding sources and research partners. The consequences of this are discussed at length in the following chapters, but at present, each project faces an uncertain future. In this context, it is important to understand what NDN, XIA, and MF have proposed and accomplished to date, as well as how they have sought to address what they see as the problems of existing Internet architecture.

Figure 2.1 shows the flow of funding first from the NSF to the FIND projects in 2006, and second to the FIAs in 2010. The right-hand side of the figure shows the intricacies of NDN project partnering, funding, and acquisition. It partners with CCN, which was originally funded by Xerox PARC, but was acquired in 2017 by Cisco. Note the NDN is but one example of ICN, of which there are many.

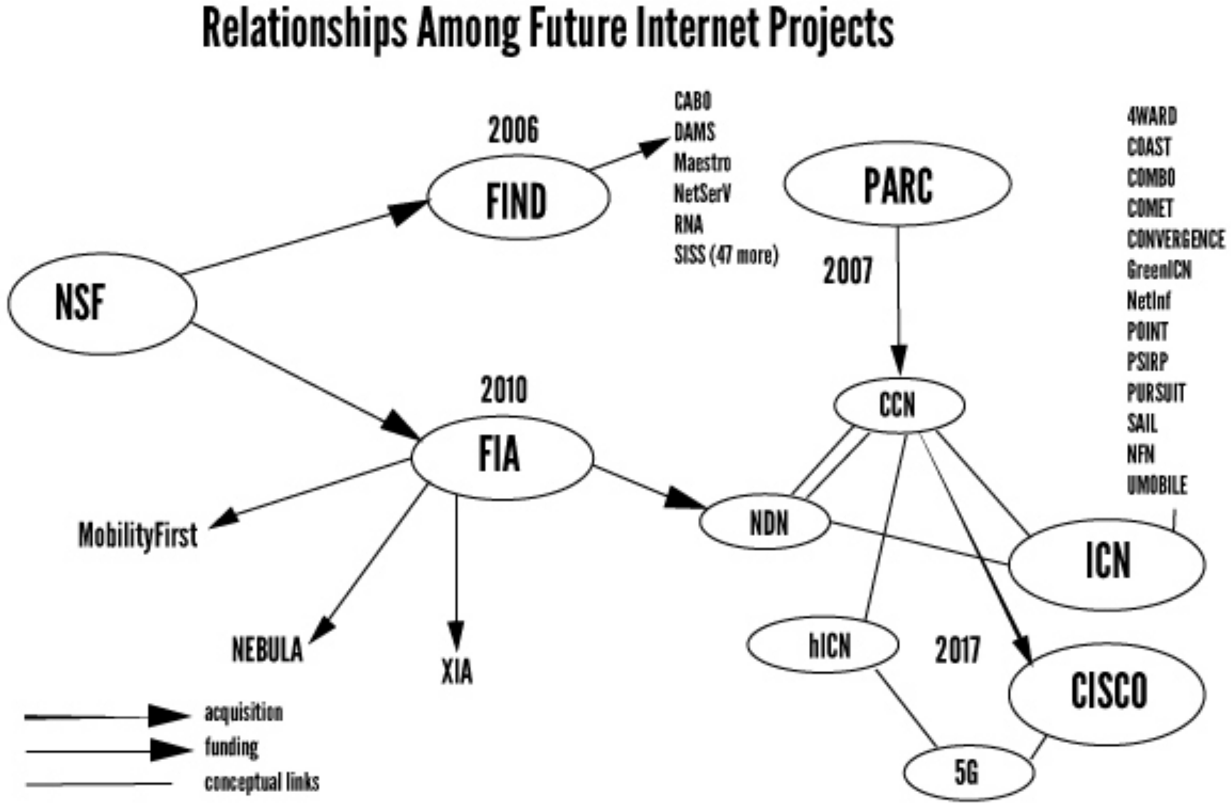


Figure 2.1. Relationships among future Internet projects. (Fisher, 2007; National Science Foundation, 2011; National Science Foundation, 2010; Nissenbaum et al., 2014; Burke, personal communication, September 12, 2016; Steenkiste, personal communication, October 30, 2017).

Named Data Networking (NDN)

Lixia Zhang is a professor of network engineering and head of UCLA's IRL. In the 1980s, she was Internet pioneer David Clark's student at MIT, and she began her career working on IPv4 and v6 and early Internet quality of service (QoS) agreements (L. Zhang, personal communication, December 8, 2017). Zhang is the primary PI involved in all networking issues with NDN. She frames the affordances of NDN for laypersons this way:

> So let's talk about Internet of Things (IoT) applications. Say you want to know the temperature in a room and you have three sensors in a room. First, you have to give every sensor an IP address. How do I know those addresses? I do not if I'm just a mobile temperature sensor. I walk into this to say, "What is the temperature?" You can never ask that question here. The very first thing you have to figure out is what is the address for those three sensors. Second, you have to pick one. Which one are you going to ask? You see how it is inefficient. IP increases complexity for Internet of Things. NDN seeks to simplify the process and increase efficiency.

In the midst of her explanation of how NDN and IP differ, she switches the context for NDN, but continues:

> With NDN, you can just throw out a question, "Who's near me?" Then whoever hears the question, the car answers you back. It doesn't have to tell you whose car I am, but at least I can tell you I'm a car like only three meters away from you. (L. Zhang, personal communication, September 22, 2016)

Zhang's quote shows how, at face value, NDN wants to simplify networking by transmitting data based on the name of the data, not its location, thus increasing efficiency. To begin to describe how a car can answer with data in NDN, an overview of the goals of the NDN project is necessary. Overall, the documents show six architectural principles that guide the NDN architecture (Zhang et al., 2010, p. 2). The first three, they say, are gleaned from the successes of IP routing, and the latter three build from the failures or challenges that IP routing has presented in recent years. Nearly every document concerned with what NDN is and how it works describes the hourglass architecture of the existing TCP/IP Internet that "makes the original IP design elegant and powerful" (p. 2) because it takes packaged data and delivers it to applications and users. A representation of the hourglass architecture with the narrow waist is shown in Figure 2.2. It centers on a "universal network layer (IP) implementing the *minimal* functionality necessary for global interconnectivity" (p. 2).

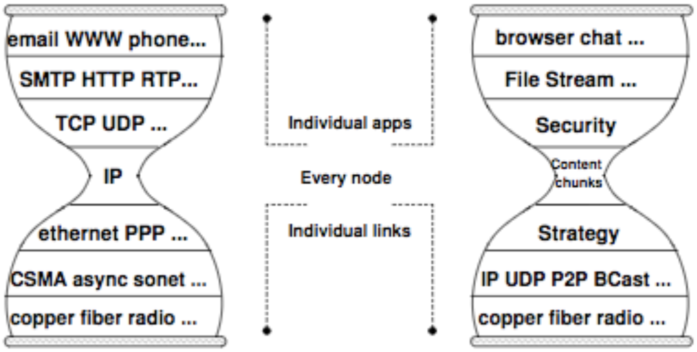


Figure 2.2. Comparing IP and NDN at the narrow waist (Zhang et al., 2014, p. 66)

So as the thin waist of named data is the focus of NDN design, it is opposed to IP addresses of IP architecture. This simple change at the thin waist results in significant differences between IP and NDN in their function (Zhang et al., 2010). The diagram below illustrates the ways that data is requested and sent via NDN. Communication is driven by the data consumer, who sends out an interest packet that carries the name of the desired data (Zhang et al., 2010, p. 3).

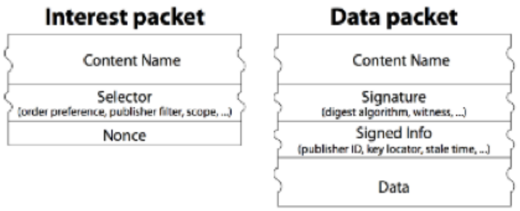


Figure 2.3 Packets in the NDN architecture (Zhang et al., 2010, p. 4).

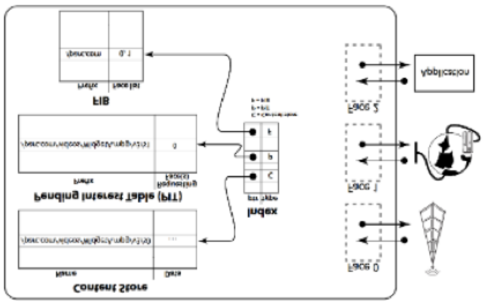


Figure 2.4 NDN forwarding process (Zhang et al., 2010, p. 4).

NDN PI Jeff Burke discusses NDN-specific concepts *consumer* and *interest* as they apply to packets:

> In IP you define a source and destination host, and the network delivers the packet from the source to the destination. In NDN, it's reversed. When you ask the network a question, "Here's the name of the data I'm interested in," then it's the job of the network to route that request somewhere that can answer it. So it's really more in terms of consumers or requesters of information and publishers of information than it is senders and receivers. Yes, you're sending a request, but you're also receiving a response. The terminology of consumer/publisher seems to fit better—or consumer/producer. (J. Burke, personal communication, September 12, 2016)

He goes on to explain how data transmission is described in NDN:

> The important thing is in the vast majority of applications nodes or apps will be both, the same way that on the Internet today you both act as a sender/receiver of packets, especially at the lowest level. Even if conceptually you're just downloading a webpage, there's all kinds of stuff happening. The same thing is true with NDN. At some conceptual level, a lot of times you'll talk about there's a publisher of data, and you consume it. This is how we talk about the data transmission. (J. Burke, personal communication, September 12, 2016).

Despite Burke's insistence that the idea of publishing interests and consuming interests is an unproblematic articulation of the way that data is forwarded, to non-experts, it might be difficult to understand exactly how this might be different than the ways that IP addresses are carried with packets in the existing Internet. To articulate what is happening in the complex NDN communication system, it is first important to note that NDN is predicated on the "data consumer," as Burke and the project documents call it, issuing pull requests called *interest packets* (see Figure 2.3). These interest packets contain the name for the data to be pulled from the network. The data consumer can only initiate a request for data; data producers cannot push data before it is requested. (This marks a unique feature of NDN compared to FIA and XIA, to be discussed in subsequent chapters.)

Moving on to how the processes of publishing and consuming interests work with NDN, a packet "arrives on a face, a longest-match look-up is done on its name, and then an action is performed based on the result of that lookup" (Jacobson et al., 2009, p. 2). Figure 2.4 is a schematic of the core NDN packet-forwarding engine. It has three main data structures: the Forwarding Information Base (FIB), content store (buffer memory), and Pending Interest Table (PIT) Once the interest packet arrives, it is checked against the FIB, which performs the longest match lookup, searching for the name of data indicated in the interest packet, and then sends back the requested data along the same path by which the interest packet came to ensure the requested data reaches the interest packet issued (Zhang et al., 2010).

In the case that the name of the data is not found in the FIB lookup, the PIT (Figure 2.4) stores the interest packets and the devices on which those interest packets were produced that have not yet been matched with data. When the requested data packet arrives at the PIT, it finds the matching interest packet and forwards that data to all devices in the PIT that have issued interests for that data. The PIT interests are removed, and the data is cached in the content store. This cached data can be called upon to satisfy future requests for that data. This in-network caching is a feature of NDN (Zhang et al., 2010) that has numerous benefits from increased efficiency to a possibly more democratic mode of content transfer. The other FIAs also cite in-network caching as a feature. In this way, NDN improves upon IP's first-in-first-out (FIFO) buffer model because nodes can provide in-network caching, subject only to their resource capacities (Jacobson et al., 2009, p. 3; Zhang et al., 2010, p. 5).

The documents show that the developers see an advantage in NDN's encryption, which allows location, where the bits are stored, to be secured and private by virtue of a cryptographic key (Zhang et al., 2010 p. 14). NDN looks to provide security by signing all named data with a cryptographic key, so the only thing one can know about is the data's provenance, and authenticity, not where it has been (Zhang et al., 2010, p. 4). Reliability checking, data signing, and trust decisions are made at the application layer (Zhang et al., 2010 p. 3, 6).

In IP networks, nodes and links may overload once content becomes popular and is requested often, such as a video going viral. In NDN, more requests also mean more nodes will have a copy of the popular content in the cache (Zhang et al., 2010, p. 7; Takemasa et al., 2016).

The probability that a node near the application or user on the path to the content generator has a cached copy of the content increases by its popularity. Via the caching mechanism, copies of content are automatically distributed toward the parts of the network where it is requested (Zhang et al., 2010). One will note, however, that push notifications from producers of interests are not something that NDN is built to accommodate. (This point will be revisited in subsequent chapters.)

eXpressive Internet Architecture (XIA)

Dan Barrett, senior research programmer at Carnegie Mellon University and primary network architect with XIA, declared that a more efficient transport layer protocol than TCP/IP is necessary: "TCP/IP is very old, and it's causing people to do tons of things inside of HTTP to work around deficiencies in that transport. XIA is an attempt to be a more modern transport protocol that's extensible" (D. Barrett, personal communication, February 28, 2018).

Barrett refers to people using HTTP to secure content in the form of HTTPS at the application layer of the Open Systems Interconnection (OSI) networking protocol stack. The problem presented by the IP-controlled Internet that XIA seeks to remedy is how to securely route content in a way that can easily scale up or down depending on the network topology at any given time.

The core of XIA, shown in Figure 2.5, is the eXpressive Internet Protocol (XIP), which allows networked communication among various types of principals—content, hosts, and services (XIA, 2018c). Each principal type has a narrow waist that allows communication using eXpressive Identifiers (XIDs), which are 160-bit identifiers that are cryptographic hashes that can variously "represent a host (HID), a piece of content (CID), or a service (SID)" (XIA, 2018c, n.p.). Content is defined by what it is—either a packet or piece of data. A host is defined by which device it is. A service is defined by what it does at the application layer. According to the public-facing website, “Knowing the XID of a communicating party makes it possible to verify certain security properties without needing to rely on external information (e.g., databases)” (XIA, 2018b, n.p.). Therefore, key security properties are intrinsic, or built-in (XIA, 2018c).

For example, in today’s Internet, packets are addressed to an IP address and a port number. Instead, XIA has SIDs, or service identifiers that are cryptographically unique. Barrett noted in a 2018 conversation that with XIA, every single web server in the world would have a different SID “unless they are doing something with them where they want the SIDs to be identical,” like load balancing (D. Barrett, personal communication, February 28, 2018).

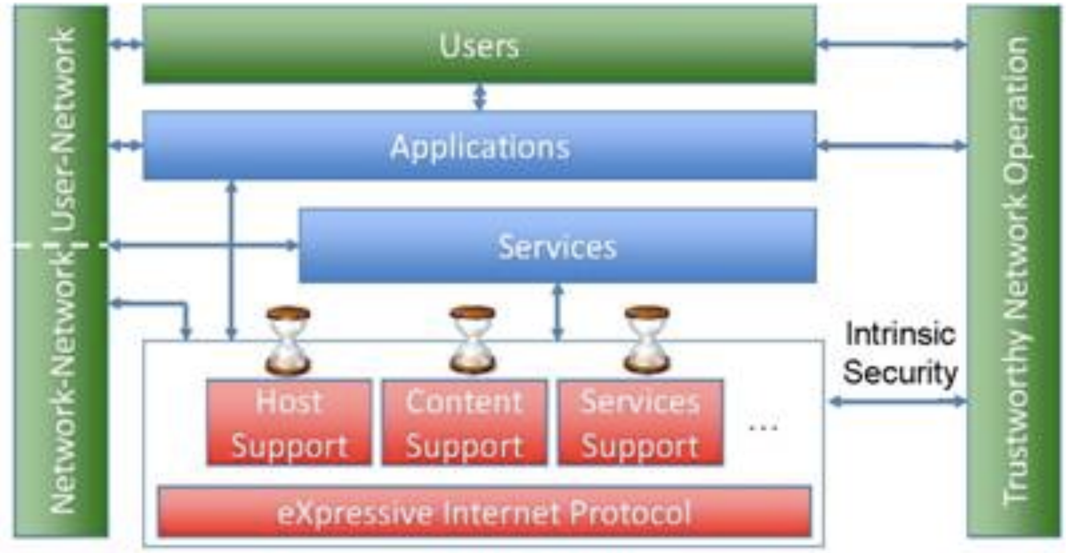


Figure 2.5. XIA protocol stack (XIA, 2018a, p. 3).

With regard to this system, Barrett noted:

> One of the issues with TCP/IP is if you want to change something, something like a packet header, everybody needs to know about it, or everything is going to break—which is not a good thing. XIA allows apps at both ends to understand one another, but the

> routers and things in the middle do not have to understand that packet header or anything new in there. It can just pass through them, and the data will move normally, as long as the endpoints know what they want to do. (D. Barrett, personal communication, February 28, 2018)

XIA allows for the network to be upgraded over time and for new functionality to be added. XIA addressing is predicated on determining a path to a principal—content, services, or a host, rather than just to an IP address and a port. Importantly, this allows for extensibility—the ability to efficiently scale up and scale down with regard to topology and principal types in the network, which will be discussed later in this chapter.

Mobility First (MF)

The MF architecture's main goal is "allowing the flexible development of mobility-centric services, while also improving security" (Mobility First, 2018c, n.p.). The MF protocol is based on the concept of "delivering information among any objects that communicate with the network, such as a smartphone, a person, a group of devices/people, content, or even context" (n.p.), much like XIA's focus on enabling communication among diverse entities. In addition, "each object is identified by a cryptographically signed Globally Unique Identifier (GUID)" (n.p.). In addition, "the 'narrow waist' of the MF stack is the GUID service layer supported by a logically centralized Global Name Service (GNS) and enables creation of flexible services such as mobility, multicast, multi-homing, and delay-tolerant delivery with in-network storage" (n.p.). MF's architecture is set apart by the rest because its architecture includes this centralized GNS which "can significantly enhance mobility, security, and network layer functionality" (n.p.).

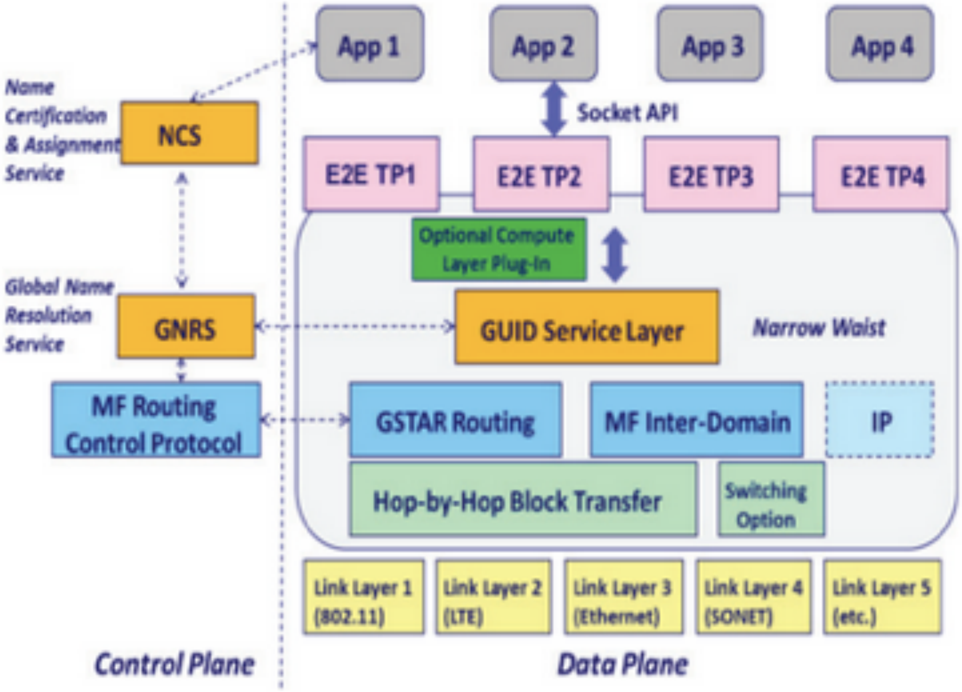


Figure 2.6. MF protocol stack (Mobility First, 2018c, n.p.).

Mobility First PI Dipankar Raycharudhuri stated in a 2017 conversation:

> The basic idea for Mobility First is to make a very lightweight model for the architecture, that doesn't involve a lot of signaling back and forth through the network's control plane. So Mobility First has a self-identifying practice that can be, that can be looked at by [the network] and forwarded very quickly. So it tends toward speed in that sense—there's very little holding back a packet that needs to be transmitted. (D. Raychaudhuri, personal communication, August 17, 2017)

As with NDN and XIA, the MF networking protocols are designed to do more compared to IP, but also to do more with less overhead. Under IP, an application has to send a message to the Domain Name System (DNS) to verify a URL; then the DNS has to send a message back so the packet can be sent out over IP.

In contrast, as described above, and shown in the orange boxes in Figure 2.6, in MF the packet name binds a GUID with a service, similar to the Domain Name System (DNS), a hierarchical naming system for all entities participating in a network currently used in the Internet, which is called the Global Name Resolution Service (GNRS). Functionality-wise, DNS is similar to GNRS. But GNRS is a decentralized function, allowing an application to send out a message for the URL and then let the network decide where the content is, or the best server to route to (D. Raychaudhuri, personal communication, March 1, 2018).

In order to complete this process, the GNRS would respond with multiple potential destinations, and then the network would route the traffic to one or several of those potential destinations. This is different from a DNS because in IP it is the application's responsibility to look up DNS, rather than the networks' job to look up the GNRS in MF. In IP, if the user is moving, the user must continue to query the DNS (D. Raychaudhuri, personal communication, March 1, 2018).

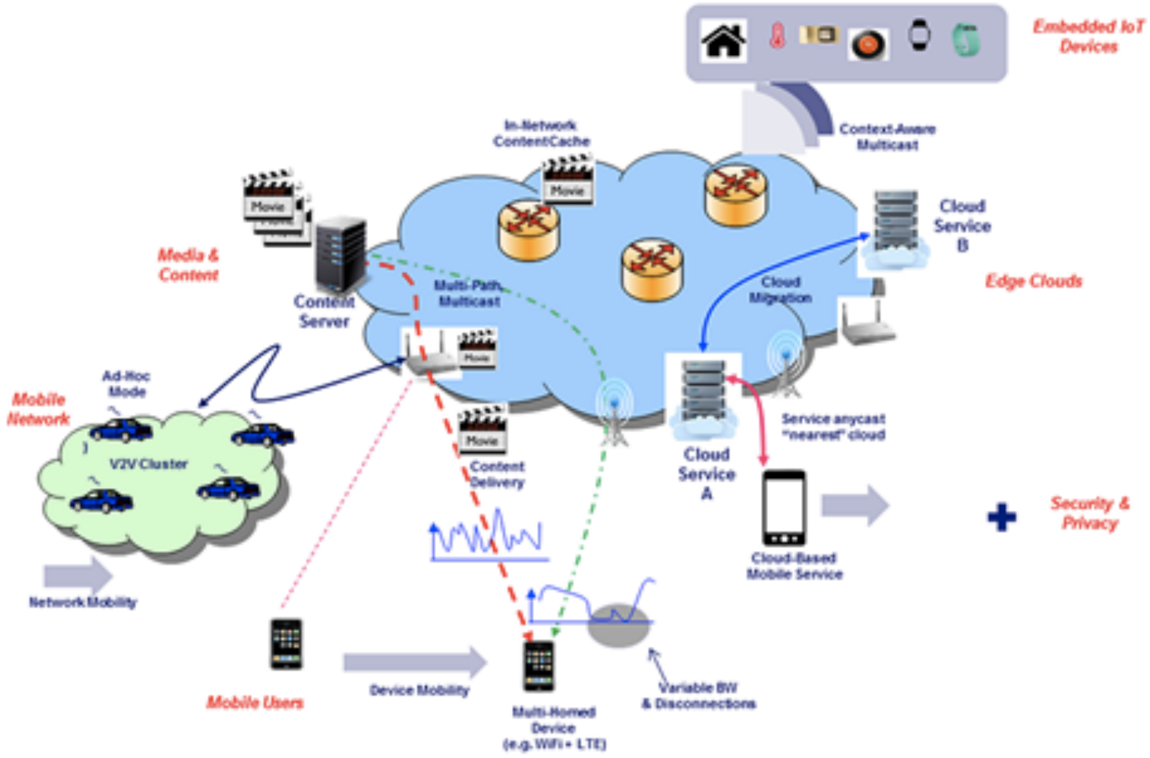


Figure 2.7. MF functionality (Mobility First, 2018c, n.p.).

Furthermore, MF, like NDN, has the capacity to store content forward. In relation to Figure 2.7, MF PI Jiachen Chen used the example of using some application requesting data from UCLA while in a car moving down the New Jersey Turnpike:

> In Mobility First, when the packet is sent to where I'm attached, maybe five seconds ago, but in the meanwhile, I have moved away, it is the last hub's job to look up the GNRS. The last hub is going to look up the GNRS and find where I am. Right? So all that you need to do is to transmit from my last hub to the new hub, which might be maybe two, three miles away, maximum. You don't have to initiate the traffic all the time.
>
> If the network cannot find where I am, the router would cache the content for me instead of telling you, oh, this guy's not there, so your transmission fails. Next time please try and good luck [as it would in IP]. The network can store the content for me, and the network can even predict where I will show up. (J. Chen, personal communication, March 9, 2018)

MF, unlike NDN, gives applications push capabilities, thus theoretically eliminating some of the issues in naming and sequencing with real-time application flows. MF is unique in its ability to initiate multi-casting with different groups receiving different messages, based on a graph-based structure:

> The overall philosophy of the design is thus back to the basics of packet switching, with hop-by-hop routing of entire data files with a minimum of in-network state—the packets themselves carry destination and service identifiers that can be dynamically bound to routable addresses during transit through the network.
>
> Mobility First attempts to eliminate most kinds of two-way handshakes and control signaling, which are currently used in the Internet. For example, in the wireless

> network, as one accesses the Internet for one mobile phone, there at least six messages that go back and forth before your data packet can be sent. (Mobility First, 2018a, n.p.)

Raychaudhuri noted in a 2017 conversation:

> In the current Internet, you take a photo and try to send it to your friend, and there's a process by which 26 messages must go back and forth before that photo itself can be sent. So that leads to a lot more latency, which we try to eliminate (D. Raychaudhuri, personal communication, August 17, 2017).

He reiterated much the same point in a subsequent conversation in March 2018.

This notion of speed of data delivery is key to the project at hand. In the description of MF, it is articulated explicitly with relation to the speed of hop-by-hop routing, which is faster because it relies on in-network caching. The data is already there, it must only be retrieved from a node, circumventing the "pipes of the Internet"—TCPs control signaling, which increases the latency of data transmission.

Values in Design Directives

In 2010, when the NSF was funding the FIA projects, a few problems loomed on the horizon. First, as social media surged in popularity, the public was kept oblivious to the fact that data generated from interaction with these platforms could be monetized and assigned value. Second, content streaming was just becoming a more widespread practice following the advent of platforms like Netflix, Amazon Video, and Hulu, among others. In addition, net neutrality, a topic that had been evoked and debated in preceding years, became more prominent as the FCC began leaning toward a policy position that the Internet could be considered a public utility.

In this unique context, the NSF suggested developing solutions for the future Internet that would not just solve these technical issues, but also attempt to address the looming problems of Internet privacy, security, and openness. This section focuses on the ways in which the NSF FIA projects were directed to incorporate ethics into their designs, and what actually happened. It tells the story of how these projects engaged with this directive over time, revealing temporal orientations both within each project and within the FIA program overall that are not necessarily technical and certainly not subjective. Instead, temporality here has to do with how project principals understand and envision past, present, and future relationships between society and technology.

The NSF has long supported research programs, such as Societal Dimensions of Engineering, Science and Technology Studies, and other initiatives to encourage the integration of social scientists, ethicists, or policy/legal analysts into scientific and technological projects (Nissenbaum, Stark, & Zeiwitz, 2013. p. 1). The end-of-project document for the VID Council stated its original purpose. As all too often "communities of technical personnel and ethical analysts are not sufficiently integrated into individual projects; the NSF FIA project incorporated a new model of interdisciplinary collaboration that aimed to enrich and augment interactions" (p. 1) between these two groups before and during the process of design. Accordingly, the VID Council, an interdisciplinary team of social scientists and policy analysts, was mobilized to guide the work of the FIA projects.

This VID/FIA collaboration incorporated tactics of "anticipatory ethics" in technology design, in which ethics advocates become involved in the technical projects early in the design process with the goal of guiding the development of a given technology (Shilton, 2015, p. 2). According to Shilton's overview of the NDN's participation in the VID/FIA collaboration, while the impetus for anticipatory design was clearly important both to technicians and to ethicists, she highlighted the cross-disciplinary difficulties inherent in meaningfully engaging with anticipatory ethics in the VID/FIA collaboration. From Shilton's engagement with NDN's involvement with the VID Council, she developed a typology of values as well as possible approaches to anticipatory and sustained ethics projects to be applied in both academic and commercial settings of technological development. I will return to this point in Chapters 4 and 5. Here it is important to note that there were some interesting nuances that came forward when talking with principals from the FIAs about their collaboration with the VID Council. In order to address these nuances, I first provide an overview of the work of the VID/FIA partnership.

The VID Council/FIA project held 10 meetings from 2010 to 2014. The topics ranged from FIA project overviews to specific meetings focusing on comparing FIAs, privacy, security, deployment scenarios, and evaluation. The VID team suggested a number of tactics to promote fruitful discussion. The VID Council members at the meeting would offer prompts or questions for the FIA teams coalescing around the meeting topic. The VID Council posed real-world scenarios as provocations to get the engineers to describe in simple terms how they were understanding and building values into their designs. For example, one provocation taken from the meeting records posed the question: "The protesters demonstrating in Tahrir Square, Cairo or the streets of Ankara or Rio de Janeiro wish to communicate anonymously. What could be done to make that happen and what would be the implications?" (Nissenbaum et al., 2013, p. 6).

These probes were meant to draw out discussion and find ethical issues that the engineers had not thought about and to communicate what would and would not be possible within these new frameworks for Internet architecture. The NSF's expectation with the VID/FIA partnership was stated as such: "While the ultimate goal is the design and deployment of a network that serves all the needs of society, we realize that these projects are just the beginning of what it would take to create a full-scale Future Internet" (National Science Foundation, 2010, n.p.), said

Darleen Fisher, program director for the FIA projects. “We expect that the knowledge obtained from this research will inform the development of future networks” (National Science Foundation, 2010, n.p.).

While that was the expectation, the experience of the partnership both converged with this stated goal and departed from it in significant ways. A report by members of the VID Council at the conclusion of their involvement with the FIA projects noted that there were ongoing issues with the FIA and VID partnership. Prominent themes were the “ongoing negotiation of a shared language” (Nissenbaum et al., 2013, p. 3), “diverging assumptions about the directions and capacities of the research” (p. 4), and the “barriers to and difficulties presented by a lack of prolonged engagement” (p. 6). However, in my conversations with the FIA principals, they disclosed some interesting solutions they developed that resulted from their experience with the VID Council. These conversations also highlighted the ways in which they experienced the project, as well as their projections for the ethical development of their projects into the future.

Language Problems and Translation Solutions

The VID Council paper suggested that the most the most challenging issue that arose in the VID/FIA partnership was the difficulty in finding commonalities – common languages and definitions that could be used by the technologists and ethicists to work together towards common goals. According to the VID Council paper, this problem stemmed from a nearly insurmountable disciplinary divide that pervaded the VID/FIA partnership. This cross-disciplinary struggle was reflected in the discussions with the FIA principals.

Jon Peha, a policy analyst on the XIA project, is a professor in the Department of Engineering and Public Policy and the Department of Electrical & Computer Engineering at

Carnegie Mellon University and holds a courtesy professor appointment in the department of electrical and computer engineering. Prior to working at CMU, he served as Chief Technologist with the FCC, was White House Assistant Director of the Office of Science & Technology Policy, and worked for the House Energy & Commerce Committee. At the U.S. Agency for International Development (USAID), he helped launch and lead a U.S. Government interagency program to assist developing countries with information infrastructure (Carnegie Mellon University, 2018).

Thus, Peha is no stranger to the idea that ethics, policy, and technology design are intertwined. Of his involvement with the FIA/VID partnership, he noted,

> *Values and design* as a concept was certainly discussed more at NSF meetings. NSF asking questions of PIs causes faculty to discuss these issues. I am not certain if it would have gone in a different way otherwise. Things like what are the privacy implications or what are the competition implications are things that I would have raised with or without that. As long as I was part of the team, those issues were going to come up. In this realm, I think privacy and security were much more on everybody's mind than these so-called values issues. (J. Peha, personal communication, December 4, 2017, emphasis added)

Lixia Zhang, of NDN, expressed a similar view of the problematic dialog between disciplinary worldviews:

> I think it's very important to understand the impact of new architecture on society. I think the challenge, however, is in the details, because the *value-added group* [are those] who study sociology, the policies. So, therefore I do not have an impression that they have a good understanding of the existing TCP/IP architecture. (L. Zhang, personal communication, December 8, 2017; emphasis added)

While the name of the group was always the VID Council, in our conversation she consistently, and mistakenly, referred to it as "the value-added group." Peha's comments, including his reference to "values and design," revealed a similar slip, which I will examine in more detail later in this chapter. Zhang later explained more precisely what she meant. She emphasized that she was not accusing the VID Council of being bad actors or of being unintelligent; rather, she thought that their field-specific concentrations do not allow them to see the important technical components of NDN:

> Everyone knows that the Internet—there's IP that carries the traffic; but beyond that, I would say, surface knowledge, they do not understand the intrinsic, how this technology works to understand its limitations. I think to understand a new design, the starting point is, you have a good understanding of the existing architecture. Without that in-depth understanding of that, it's really a challenge to understand how the new proposals differ from the existing Internet architecture. That is my overall impression. (L. Zhang, personal communication, December 8, 2017)

In terms of the technical community's ability to engage in meaningful cross-disciplinary issues of policy, she said, "I think we do have a good grasp on policies. I think you need to understand how network works to understand what's the right way to set up policies." At face value, this seems obvious and true. But the issue the FIA faces is how to make a new Internet that not only is more efficient and able to interact with existing hardware, standards, and protocols that are already in place, but also will hold certain values paramount. Of course, one must understand those technical constraints in order to build a new architecture. But what seems to be disregarded here is that in this project that has dual aims, one would also want the people who are experts at policy to be on equal footing with those who are technical experts. The ways in which this equal footing might be granted was a stumbling block for the FIA/VID initiative, as will be discussed later in this chapter.

Zhang reiterated that networking engineers do have a grasp on policy: “We have [our] positions, like the recent debate about network neutrality. There’s a proposal to overturn the early decisions; but the network community, I believe, has very strong opinions on those kinds of policy decisions” (Zhang, personal communication, December 8, 2017). Here she implies that despite what the FCC does with regard to net neutrality, the networking community not only has agency to overturn these decisions through design, but such technical experts are equally experts at determining the policies that are best for the Internet and society at large. It is possible that some technical experts might be equally gifted at understanding the long- and short-term social and political implications of a particular networking design; however, her statement implies that social scientists who are experts in these areas should not be at the table in these discussions. It betrays a sort of “business-as-usual” parochialism that pervades the engineering side of these projects, as we will see in later chapters. The idea Zhang extends here is that the technical experts know best, as they have through the history of the Internet, and strictly social or policy experts should be excluded simply because they have never really been included, except in specific ways, for example, in computer engineering departments with trained policy experts like Peha.

Despite these perhaps unsurprising problems with cross-disciplinary communication in the VID partnership, there were a few instances of how these experiences fostered more meaningful attempts to reconcile design visions among policy analysts and social scientists at the level of individual projects.

The XIA project collaborated with Laura Dabbish and Sara Kiesler, human-computer interaction researchers at Carnegie Mellon, in order to more fully address this issue of cross-disciplinary language difficulties as a part of their original work. Peter Steenkiste noted that this collaboration helped him and other network engineers on XIA better understand the whole notion of network privacy and trust. Engineers and developers have a general understanding of privacy issues in the Internet, but as Steenkiste said:

> After this, we became more aware of the challenges associated with informing users about the more subtle aspects of communicating privacy. We started to really appreciate that there was this balance between privacy and functionality … There was clearly an education process going on there where we educated each other. And I think they taught us that there are some users that don't care, for example. [But we were interested in the question], how do you make people not just aware of potential privacy issues but also convey what the implications are? (P. Steenkiste, personal communication, October 30, 2018)

Indeed, issues surrounding privacy are nebulous for the common user. Regarding certain applications or platforms, privacy issues change as often as terms of service are updated. It is difficult even for experts and professionals in this arena to stay on top of what data is being tracked, monitored, and sold by any given website or platform. To attempt to remedy this, Steenkiste and his team made a toolkit for high school students. As he explained, the rationale behind this is that there is no required computer science training in secondary education and little technical Internet literacy education in high schools, despite the fact that people of all age ranges, but especially students in high school, spend a huge amount of time on the Internet. As such, Steenkiste and his team offer an example of one way that more concentrated and robust computer science and Internet literacy programs might be implemented in high school curriculum (P. Steenkiste, personal communication, October 30, 2017).

He noted that the solution is not simply encouraging kids to be concerned with privacy or using tools to protect their privacy online, because these tools change and the ways in which corporations and regulators view privacy changes, as do any number of other factors that influence the notion of online privacy. Because of this, he suggested that Internet privacy education should be grounded in an understanding of how Internet architecture works (P. Steenkiste, personal communication, October 30, 2017).

He described a project he thoroughly enjoyed that enlisted the help of two high school teachers who helped students understand what messages are passed through the network in order to transfer a packet:

> The thing that I really, really loved was the first thing that they came up with all by themselves was this notion that they emulated the network … by having boxes that represented routers and the messages were printed around the classroom. If students wanted to pass something from one person to another, they would have pieces of paper that would be the messages or the packets or some other physical objects. (P. Steenkiste, personal communication, October 30, 2017)

Steenkiste noted that this project helped students see that in order to exchange information over the Internet, they need to have an address and then the network figures out which path to take. It helped the XIA team concretely explain to the students what some of the components of Internet infrastructure are and what they do.

While the VID Council found that language was a problem, XIA took it a step further. This in-project example of an anticipatory ethics undertaking addressing the translation between science, technology, and society was largely successful, according to Steenkiste. However, more interesting to the project at hand is what the emphasis on this project says about the ways in which XIA envisions the technological future in which it is designed to intervene. Conceived and implemented by XIA, the high school toolkit project was developed as an example to prove how useful it might be to include computer science and technical literacy in public education, under the assumption that not only will it continue to be important for these future citizens to know how to use the Internet, but also that—adding a notion of *technical* literacy to the function of other types of basic literacies taught in secondary education—students will need to continue to be able to adapt to changing Internet topologies and emergent ethical issues. On the other hand, perhaps the impetus behind this push is that academic engineering departments would prefer not to have to teach basic technical competencies to their own students. While this push by XIA to intervene in public secondary education seems to suggest that they may be unselfishly interested in producing a well-rounded populace, able to stay informed of technological advances and possible threats to privacy, it might also indicate that they envision a future where this knowledge is crucial to economic survival, as is the case with some types of knowledge imparted in secondary education.

Directing Research and Articulating Tradeoffs

While in the last section we saw that XIA found ways to effectively leverage meaningful cross-disciplinary discussions and even small-scale projects, the second issue addressed in the VID Council paper was the "discrepancies in pre-conceived assumptions regarding the direction, capacities, and intents of research on both sides of the VID/FIA team divide" (Nissenbaum et al., 2013, p. 5). The final VID Council report found that it was difficult to address these discrepancies in practice. While this seemed true in some projects, there were again ways that these experiences with the VID team led to productive outcomes.

One of the core tenets of the FIA program was that it would allow for a secure, decentralized networking structure that could be deployed in different scenarios. Lixia Zhang underscored discrepancies between what people who are interested in social consequences of technology think about these concepts of trust and decentralization and the reality of how these values are implemented in technical practice:

> I think the reason we changed the name from Content Centric Networking to Named Data Networking is exactly to move away from this kind of confusion as to what exactly a network should do: When you use the word content, for people in general, content translates into Netflix, not necessarily things like IoT. Data networking is really the essence of NDN. I think, again, people outside the NDN team tend to think, oh, because you can have caches in-network, that's decentralization; but no. You can have caches. It's a byproduct, not a goal, of NDN decentralization. Actually you have caches only because NDN names the data, and the data is secured. That's how you can just pick up anything from any cache.
>
> But [the essence] is that data is named and secured. The question is really about how you manage security. That requires this really decentralized trust management. Today, when we talk about Internet security, it is centralized in the sense that there is CAs, certificate authorities. Those are the companies that sell certificate … Essentially they need to really figure out whether you are who you said you are. Then they give you a certificate. So they become the authority, and not the individual organizations' authority

> for themselves. That's a decentralized version of the security. (L. Zhang, personal communication, December 8, 2017)

In the quote above, Zhang stated that in-network caching is a type of decentralization that is a welcome byproduct of NDN's naming and routing schema, but it is not the type of decentralization that is the goal of NDN. It is interesting that she actually highlighted the centralized certificate authority (CA) that assigns cryptographic signatures to the data; according to Zhang, this security feature is NDN's core ethical value and their primary technological affordance. So according to Zhang, this decentralized security comes from the centralized CA that grants these cryptographic signatures and not the individual organizations themselves. This seems to be negating that NDN has a notion of decentralization built in at all.

A related focus of the VID/FIA partnership was promoting networking solutions that would foster the social expectation of privacy or the expectation that while on the Internet, users should not be tracked and spied on. On the other hand, another core feature was security—that one can trust that the data streaming into and out of devices is verified and not vulnerable to outside tampering. This is especially relevant for IoT devices, which are notoriously not secure and easily hacked. Each of the FIAs claims that privacy and a notion of security will be built into each networking protocol.

Steenkiste summarized the dilemma of security and privacy between those pushing for social consideration and those working practically to build protocols:

> There are a lot of people who say, you know, everything needs to be private. Well, you know, that's a nice statement to make, and maybe there's probably nothing wrong with making everything private. But, at the end of the day there are penalties for that, in terms

> of, you know, things like middle boxes (Steenkiste, personal communication, October 30, 2017).

Most people do not know that there are algorithms that check what is being said, going online and being downloaded over any connection, through technologies called *middle boxes*. The reason middle boxes exist is because organizations that run networks do not want users on their networks to intentionally or unintentionally share company or organizational secrets, or download pirated content, for example by users logged into a router at an institution like UCLA. Middle boxes exist so that platforms can track and sell user-generated data, as happens when one is logged into Facebook, a service for which one pays for the platform's functionality with one's data – and privacy.

While some middle boxes perform a spying function, the vast majority of them enhance performance and customization. Middle boxes are used to optimize connection among wireless devices like cell phones as they cache and compress large objects, as well as to customize content, which can be desirable for some, but is not for others. But man-in-the-middle attacks can turn these middle boxes into malicious traffic hijackers, as with the Stingray devices used by various police departments across the country to monitor ingoing and outgoing traffic from individual phones at protests (Parks, 2016).

Furthermore, Steenkiste noted: "But your mobile operator ultimately is very much restricted by all kinds of legal constraints and regulation … Maybe more so in Europe than here. But, so the question then is, can you strike more of a balance?" (P. Steenkiste, personal communication, October 30, 2017).

This notion of balancing the security and technical function of middle boxes with the need for privacy is a difficult one; each of the FIAs attempts to address this problem, as it was one of the core values identified in the original VID Council documents (Nissenbaum et al., 2013). Indeed the current Internet architecture does not afford much agency for users apart from opting out of increasingly tracked and commodified Internet services (Rainie, 2018). Steenkiste addressed this balancing act in the current Internet, as it is one of the main issues he's working to overcome with the XIA project:

> In reality, there's just a lot of things people do for which it really doesn't matter. And so the question is there a way of doing things a little bit more balanced, because ultimately there are penalties associated with making things completely private, and especially making things anonymous (P. Steenkiste, personal communication, October 30, 2017).

According to Steenkiste, making the Internet more private and anonymous by removing middle boxes would render the Internet unworkable, or at least inefficient for wireless and wired connections, and customization would be more difficult. Importantly, it would also threaten the security of individual websites, organizations, and wired and wireless connections. From a non-technical perspective, one cannot guess whether this claim is true or false; however, it does point to future designs being determined by constructions of the past and especially by prior beliefs about what people want and do not want in Internet service. For example, MF started in 2010, when people were largely unaware and unconcerned about data tracking and online privacy; many of the recent large hacks of private information had not yet happened. However, a 2018 Pew Research Center survey found that the majority of Americans polled believe that online privacy is important, and that nearly half were willing to trade functionality to this end (Rainie, 2018). Perhaps making the Internet more private and less customized would actually now be in tune with what people want.

Jon Peha picked up on this thread of the delicate balancing act between privacy, security, and technical design from Steenkiste and from Zhang's responses on how networking experts have a better hold of net neutrality than others:

> Sometimes I want to have continuity. Sometimes I want to have anonymity. Those two things are actually in conflict. Right now, it is more likely to be the network who decides how that conflict is resolved. [With XIA] we have created mechanisms whereby the end-user rather than the network could make the decisions. The trade-off still exists, but the power shifts. (J. Peha, personal communication, December 4, 2017)

This notion of shifting power to the user is in tune with Peha's and Steenkiste's earlier discussions of advancing computer science and Internet literacy as necessary components of postsecondary education. If the future Internet incorporates the idea that the user could make decisions about these tradeoffs in privacy and security suggested by XIA, users would necessarily have to know *how* to make these decisions—what parameters to look at, how the network architecture functions, what the privacy and security liabilities might be, et cetera, in order to make decisions to adequately protect their online traffic and identity. These mechanisms represent a second or corroborating piece of evidence of how XIA views the future, one in which users are in charge of safeguarding themselves and selecting the values that are individually important to them as they make decisions about Internet services, in whatever form they may take. Continuing on this idea of where power lies—in network, or with the user—Peha offered a discussion of net neutrality under the FIAs:

> I have done extensive work on net neutrality but not a part of XIA. Net neutrality is lots of things … We [XIA] do have content-based routing methods, which as do several of the other [FIAs], NDN most completely. All of them make reversing net neutrality more

> complicated. It's harder to block content when you don't know where it's sitting. (J. Peha, personal communication, December 4, 2017)

With this quote, Peha drove home what Zhang alluded to above when she noted that networking experts had actually attended closely to the notion of net neutrality, and indeed regardless of what Zhang said about decentralization above, it is reasonable to assume that each of these FIA projects have designed their protocols with democratic openness of the Internet in mind, which primarily comes as a result of in-network caching. As the NSF FIA funding cycle began in 2010, it also marked the year of the first set of FCC rulings of the upholding net neutrality (Genachowski, 2010).

Expecting issues with net neutrality, monopolies, and the democratization of the Internet, Peha noted:

> Among the issues that we've paid a lot of attention to are whether you are concentrating some functions into what might be monopoly hands and to wherever possible we can maintain a competitive infrastructure at all layers and functions. That isn't always possible, but that is desirable where we can do it.
>
> We also want to try to keep in areas where we expect laws to differ significantly by country, for example. We at least need to be careful about baking things into the protocols that we expect—that it would be actually illegal to adopt in some countries. (J. Peha, personal communication, December 4, 2017)

The preceding discussion highlighted how XIA articulates the affordances of providing extensible networks with regard to the relationships of power between users, technology companies, and regulators. On one hand, Peha and Steenkiste suggested that if some technical functions of XIA become the future of the Internet, the user might have more control over their privacy. Though it was not articulated as such, this seems to be another plausible reason that XIA has developed a high school curriculum to inculcate future users and practitioners about Internet architecture, and attendant privacy, and security issues; so that, if they were given the opportunity to choose among privacy and security options afforded by future Internet architectures, they might be able to do so more judiciously.

Anticipating and Sustaining Engagement with VID

The third notable issue raised in the 2013 VID Council report was that, as a result of these divergent disciplinary perspectives in the VID/FIA partnership, a significant investment of time would be required to reconcile. The interlocking facts that the VID Council was short-lived, that it was comprised of a number of busy PIs and VID researchers who could only attend a couple of meetings, and that these groups presented meaningful differences in design emphasis—required non-trivial amounts of work. Shilton (2015) showed how some of the anticipatory ethics tactics altered the course of NDN and recommended that this important work should begin *before* the technology is developed, and it be sustained in a robust way through the duration of the project. This is largely in tune with what the 2013 VID Council report suggested. While principals of FIA projects seemed to agree that engaging with ethics projects before and throughout the process of technical development is desirable, they also indicated that there was an almost an insurmountable disciplinary divide between themselves and the VID Council. They suggested a related but altogether different orientation toward the trajectory of engaging with values in technology design. As Zhang noted above, there *are* policy analysts who come from technical backgrounds. In the opinion of computer scientists and network engineers, this seems the more desirable way to go. Peha noted how this notion rang true with him as he termed the collaboration with the VID Council “values and design:”

> I wouldn't always use the phrase *values and design* [emphasis added]. That is as far as … that particular phrase, I associate with this FIA project. Thinking about economic policy societal implications of designs in general and network designs in particular has been part of my work for about twenty-five years. That's not a new thing for me.
>
> I was one of the people who was developing the technical aspects of it. I think the idea that you have a bunch of people who think about technology and a bunch of people who think about societal issues is inherently broken. That is the way that NSF often forces things to happen. It doesn't work very well.
>
> I think the way you make progress is if you have people who in a single brain can include both the technical issues and the policy issues. If you separate them fully, you say there must be technical people on the team. There must be policy, values, economics, societal, whatever you call them, people on the team. Then you are almost forcing a separation that makes it harder, not easier, to address the problem. (L. Zhang, personal communication, December 8, 2017)

Both Peha and Steenkiste pointed out that this confluence in design and technical expertise is not altogether common, and that their work with XIA benefits from a formal departmental relationship between engineering and public policy that is unique to Carnegie Mellon. Through their statements, they suggest that this harmonious marriage among social science, policy and technology development expertise is the best and only desirable solution. Thus they privilege the hybrid knowledge that people in their program, or discipline, have over other types of knowledge held by, say, people who are strictly social scientists who are experts in technology or even ordinary laypeople who use the Internet and think that it should function ethically and equitably.

Regardless of how these technologists envision the correct way to balance values and technological design, in the current sociotechnical context, the stakes are high. With current news about powerful platforms' desire to increase user engagement unintentionally causing racist and misogynistic disinformation to proliferate to serious human and civil rights consequences, intentionally tracking and selling data to analytics organizations to influence elections, algorithmic bias constraining the types of information we are able to know, and the use of data and technologies to solve social and institutional problems, at present there is real need for the types of solutions discussed in the VID/FIA partnership. There is also a need for the types of affordances each of these architectures seeks to foster as the Internet and social relations are likely to become even more tightly bound as time progresses. The evidence presented here about how these technologists envision the future possibility of a more ethical and equitable Internet, in conjunction with the present fever-pitch public discourse on technology ethics, demonstrates that these types of cross-disciplinary knowledge-sharing collaborations are absolutely necessary in order to remedy the contemporary situation of tech-centric and tech-critical siloing, the decimation of the public sphere, and the tech industry's seemingly insatiable desire to monetize every last bit of human life.

Discourse of Past, Present and Future Values in Design

This chapter explains not only what the FIA projects are, who is involved, and how they envision themselves and their goals; it has also traced their shared roots in an early project directive to design ethical values into the FIA protocol projects. It shows how, over time, the projects have changed and adapted not only to the ethical project directives, but also to the technical construction of their respective protocols. I have uncovered a notion of the in-program and in-project temporality for each group participating in the FIA program. While the temporality revealed in this chapter is not necessarily a strictly “subjective temporality”—participants are not talking about how they consider time in a personal, cosmic, social, or any other sense—this chapter gives examples of how each project has constructed itself both technically and discursively *over time* as each has progressed through the FIA funding cycle. By triangulating among what principals explicitly articulate, what those policy and ethics experts have to say about the values in the project at the beginning and the end, and principals’ informal discussions of what has happened in the project, we are able to get a clearer picture of the stakes for these projects in the technical, social, political and economic realms and how they have changed or have remained unchanged over the duration of the NSF FIA funding cycle. Moreover, we get a sense of how principals articulate whose values should be attended to in the process of development, and how these engineers extrapolate on a sociotechnical future by intervening in the technological present.

The data presented clearly indicates how engineers’ assumptions about whose knowledge and priorities should be privileged in technology design, and suggests how these types of political assumptions might be built into the technology itself. Participants from XIA and NDN suggest that engineers, rather than sociologists or policy and ethics scholars from other fields should be the arbiters of these decisions. The discussion of developing designs that might allow users to decide how they balance privacy and security appears to be a way to rework the terms of service agreements so that they give the user the semblance of agency, while their ability to make decisions is constrained by the design, with little ability to readdress these.

Peha and Steenkiste suggested that an answer to the disciplinary divide is to train and educate technical people to be adept at thinking about values and policy, this being the strength of the Computer Science Program at Carnegie Mellon. Taken together, Peha and Steenkiste’s language of “all-in-one training,” “earlier training,” and “designing balancing mechanisms into XIA” suggest a disciplinary conservatism underlying these projects that is not particularly surprising, given the age of the principals, their relationship to prestigious institutions, and their probable interest in maintaining status quo in the relationship between society and technology.

For example, Peha noted XIA wants to “maintain a competitive infrastructure,” which, at face value, aligns it with the market-based thinking that pervades Silicon Valley and which sees every commons as a site for economic “disruption.” In addition, Peha would not articulate, one way or another, whose side XIA is on (tech companies’ or users’) when it comes to net neutrality—just that they want to keep the infrastructure “competitive.”

The ways in which the project principals articulated their values-related projects also suggest that they are attempting to extrapolate future use contexts and create values projects for them. Steenkiste articulated idea that the process of inculcating broader technical literacy needs to start with students in elementary or secondary schools is a relatively common idea in contemporary society, which offloads responsibility for all manners of problems onto education or blames illiteracy, whether it be in the realm of reading comprehension, media, or technical knowledge—the ability to access and process information to make appropriate decisions of any sort—for the inequalities that exist in today’s society. To change school curricula across the country, in schools that already struggle to teach students basic skills and competencies, let alone to include even higher-level concepts that have little meaning to young students, seems a rather misguided or self-serving directive. Steenkiste’s suggestion that technical literacy begin at a younger age seems to suggest that it should not be the work of the professional sciences in academia to teach students the basics of networking.

It is important to mention that simply letting the individual users make decisions, or even teaching the users to make decisions, does not make this vision of the future Internet more democratic or reduce inequalities that exist between users and the tech industry in any meaningful way. Instead, it positions a more ethical and equitable Internet as an individualized option for those with the right type of education, which is opposed to seeing it as a right granted to all.

This exploration of values in design within the FIAs, in relation to issues of experience and expectation, illuminates more clearly how the FIAs relate to one another and clarifies how technology is a process, an active engagement among the constraints of the technologies themselves, which are built by people who live in said society and whose technologies shape that society. Regarding the main categories found by Nissenbaum based on the initial VID collaboration, certain unforeseen practices and ways of articulating these ethical imperatives have emerged since the publication of that paper. Balancing technical designs and social values is a difficult task that each technological infrastructure project must contend with. However, the various discursive techniques they adopt amongst themselves reflect this difficulty and suggest an overall discourse of the way future trajectories for technology are constructed within engineering projects.

This chapter perhaps shows most clearly how these projects attempt to articulate the problems of the present Internet and intervene with solutions. The current problems with the current IP-based Internet and the Silicon Valley giants that have mobilized it to their enormous economic gains were on the horizon when these projects were conceptualized, but these problems have become more palpable and widely recognized in recent years.

The interesting thing about these FIA projects is that while they are not yet black-boxed, they are becoming that way. With this chapter, we begin to uncover the political dimensions of infrastructure development overall in the case of the FIAs. At the same time, we also gain a vantage on the processes by which FIAs are built with regard to political dimensions. Even the notion of who gets to make decisions about what values are incorporated into these FIA designs is a political one. Understanding more fully the process of infrastructure, by examining infrastructure projects as they are underway, proves that technological infrastructures are built through messy and overlapping processes. This also allows us insight into how ideologies fit into these processes and how values are actively adjudicated as technologies are built. This is nothing new in the realm of infrastructure studies and STS, which recognize the values present in technology design. In keeping with this tradition, this chapter has provided an example of how values can be traced from their origins through the process of building technologies. In the next chapter, I continue to unravel the technical and social processes of building these Internet architecture projects. I begin to show how the project is a messy process of overlapping layers of practices and concepts of time that feed into one another and hope to give shape to a sociotechnical future.

Chapter 3: Spatializing Time

The first major conceptual theme that arose from my analysis of the data was *representation*, or how time and temporality are articulated and demonstrated as a set of spatial concerns. In the FIA projects, developers and engineers created and deployed a variety of spatialized visualizations to depict their designs, schematics, interfaces, and system processes, as well as detailed explanations of those images in project documents, interviews, and presentations for colleagues. In what follows, I outline concepts that can help describe and analyze the verbal, written, and visual descriptions of applications built on the FIA architectures.

Translated literally from German, *zeitgeben* means time givers. Through history, zeitgeben have been any number of natural phenomena, from the position of the sun to barometric pressure, that evoke a human phenomenological response or experience (Aschoff, 1965). Zeitgeben, from sundials and mechanical clocks to digital processors, have transformed the flow of experience in the natural world into instrumentalized, technological events with enormous consequences for the human experience of time and the development of the modern world.

The development of clocks, first to chart the heavens and then to organize labor, commerce, and shipping, is often cited as an example of how social, political, and economic assumptions and concerns have been instantiated not only in the human perception of time but also in its mechanized measurement and reporting (Bowker 1995; De Solla Price, 1959; Landes, 2000; Mumford, 1934). For the purposes of the present study, we can consider how concepts of time are socially shaped and rendered visually and technologically in the contemporary era, and how such tools, in turn, might shape the ways that people perceive time. In this chapter, I first discuss different perspectives on conventions that are commonly used to depict time visually, and in computing systems, and then turn to an analysis of how time is understood, represented, and designed into the key applications developed by NDN, XIA, and MF.

Modes of Revealing Time

Several scholars and designers have examined or proposed different ways of representing time that are relevant to the present discussion. Isabel Meirelles's (2013) *Design for Information* reviews the graphical conventions for representing time devised by the 18th-century thinker and educator Joseph Priestley. According to Meirelles, Priestley's graphical system comprises six main graphical elements, two of which are most relevant for the FIA cases. **Timescale** is represented as unidirectional, uniform, and linear, and thus lends itself to mathematical measurement. **Time indicators** are markers for events, often notated with dates or dots; time intervals may be represented by lines that denote their duration (Meirelles, 2013, p. 95).

Johanna Drucker (2009) noted that diagrammatic representation of time in computational systems is often limited to the representation of time-marked information in which time and its passing is generally regarded as linear, uniform, and taken as a constant or as a given (p. 49). Drucker found two fundamental elements of such schematics, the "**reference frame** through which time is structured and the **notional vocabulary** with which temporal relations are expressed" (p. 49). The reference frame can either be internal to the system being represented or external with regard to an objective time framework. The vocabularies for noting these temporal relations are generally "points, intervals, and events" (p. 49). Diagrammatic representations of temporal relations are generally linear, as can be seen in timelines, the most prevalent forms of temporal representation. Then there are planar charts of temporal relations; these are generally depicted as linear but mapped along two axes. Less common are forms of temporal representation that mark spatial dimensions, which "maps data onto multiple axes" (p. 50). Spatial representation can include many different types of notions to render multi-dimensional models of temporal representation (Drucker, 2009, p. 49-52).

Fabio Schreiber (1994) offered a somewhat different frame, dividing computer time into two main categories**.** The *representation of time in computer systems* includes **clock monitoring**, which uses a square wave to indicate the yes-no or 0-1 voltage levels that mark clock ticks (p. 7), and **synchronization in systems**, by which networked computers with different clocks can be coordinated to conform to the same time reading (p. 9). In complex computing environments, synchronization guarantees that operations proceed in the desired order, and so logical relations can be established between precedents and antecedents.

The second category, *time representation in computational processes,* includes several concepts. **Time primitives** are events that can be considered with respect to absolute or relative time. **Time topologies** are similar to Drucker's reference frame in that they determine how time primitives are shown in relation to one another. For example, relations can be linear, circular, periodic, or branching (p. 13). **Time bounds** are also relations between entities, events, or primitives, but which may not be discrete. Bounds can be strict divisions or fuzzy and indeterminate (p. 14). **Time structure** is the kind of shape or form used to represent time. Structures may be dense or loose, continuous or disjointed, for example (p. 15). Finally, **time metrics** must be defined with regard to some codified system with levels of granularity, such as days, hours, minutes, seconds, et cetera. Schreiber noted time metrics means "we can express a temporal proposition in terms of a chronologically stable time specification, i.e., a date such as April 7th, or in terms of a pseudo-date such as 'the day after tomorrow'" (p. 16).

A key aspect of design/engineering practice in the FIA projects was their use of visual and linguistic representations to describe and explain their projects both with colleagues and with non-specialist stakeholders. As the following discussion suggests, they tended to rely on some of the formal conventions noted above. More broadly, however, their visualizations and accounts can be seen as representations of their understanding and assumptions about time, as well as the perceptions of time among users.

The Relationship between Applications and Time

Applications in FIAs are where users and developers interact with the network's functionality. Applications can be platforms like Facebook or Skype, or they can be something like a browser. Overall, the FIA project principals articulated areas in which their projects could highlight the networks' functionality by allowing applications to control the flow of content and data in networked computing. Here, an entirely new palette of possibilities arises with regard to application design, user experience, efficiency in information dissemination and, of course, monetization. In the last chapter, we saw that maintaining the end-to-end principle is important to NDN; its documents overall argue for a dual focus on application development to demonstrate the affordances of the networking protocol to the lay public.

In an address to the 2015 NDN community meeting, CCN and NDN "spiritual leader" Van Jacobson gave a recorded address in which he stated, in the midst of an hour-long talk:

> When you're telling stories you need a vocabulary, you need idioms, you need ways to express those stories, and we're telling stories as computer scientists, particularly networking researchers, with our protocols, with APIs, with packet formats. And the thing that kicked off all the [FIA's] efforts was this frustration in the community that telling our stories with IP is getting really hard. (UCLA REMAP, 2015, 1:06:20)

To clarify, Jacobson offered a simple simile: "In vocabulary terms, IP is like a good middle school education … the Web kind of brought us up to high school … the real goal of NDN was to get us into college" (UCLA REMAP, 2015, 1:07:50; see also Brown, 2015, n.p.). At a superficial level, Jacobson's simile has been picked up in the industry press and exemplifies NDN's slick presentation and management of the public-facing rhetoric surrounding the project compared to that of XIA and MF.

Jacobson's positioning of the networking schema (IP, the web, NDN) relative to different levels of education and correspondingly increasing communicative ability is an interesting one. Networking is often referred to as communication of data between networking layers, and sending messages between addresses in IP. Jacobson's simile highlights that the NDN networking protocol sets forth new rules for communication, which he claimed would facilitate applications to communicate more and differently than the rules for communication set forth by IP currently allow. This notion of rules for more efficient communication can also be connected to time, as Harold Innis did in *Empire and Communications* (1948), where he argued that modes of communication are made more efficient over space and time for the purpose of governance over millennia. For example, he discusses the introduction of paper into bureaucratic practices, which made it possible for Egyptian and later Roman empires to expand across larger territories. The lightness and ephemerality of paper compared to the heavier and more permanent form of decreeing laws and governance procedures via heavy, localized, immobile obelisks reduced friction, allowing governance to be spread more quickly over a wider area, and to change as needs arose. Innis's work highlights that reducing friction or increasing efficiency in communication often happens because someone stands to benefit. Thus, it makes sense to ask whom efficiency of communication ultimately benefits.

To begin to unravel how time, efficiency, and markets come into play with NDN and the other FIAs, it is useful to first uncover how these projects sit at the level of the current Internet's political economy. NDN most clearly intervenes at the level of applications—the site at which, in the current Internet, user data is transmitted, tracked, and commodified. NDN PI Jeff Burke, who also heads UCLA’s Center for Research in Engineering, Media, and Performance (REMAP), detailed the story of how the NDN project came to focus on applications. The call for participation invited inquiries from non-computer scientists and the project intrigued him, so he put together a proposal. Ultimately, he was asked to organize the applications component of NDN, in a project that was funded in 2010. He noted:

> In the meeting, as I listened to people talk about networking, a consistent theme was that the people who write applications for networks don’t know what they’re doing, don’t understand the network, or aren’t writing the application in a way the network architects intended, or something like that. (J. Burke, personal communication, September 12, 2016)

He presented a rebuttal to this notion expressed by network architects at the meeting. He talked about how REMAP used TCP/IP networks in experiments in IoT-style environments for which his team had written middleware or invisible applications that feed data to other applications “to present hierarchically named data access to things like sensors or controllers to augment installations or performances” (J. Burke, personal communication, September 12, 2016), which was remarkably similar to the goal of NDN.

This demonstration of how to work with hierarchically named data in IoT contexts was appealing to NDN PIs Jacobson and Zhang. At a 2015 NDN community meeting, Jacobson remarked that this focus on user engagement became a core tenet of the NDN project after Burke’s REMAP project joined NDN in 2010. Jacobson declared, “Named-based data could be a godsend for exploiting Big Data, including information served up by a sensor-based IoT, and for supporting emerging applications, such as video streaming like we have never seen before" (UCLA REMAP, 2015; see also Brown, 2015 n.p.). Jacobson's comment suggests a keen awareness of the potential social and market interest in big data and the IoT, and positions NDN as part of that trend. A 2016 interview with Burke showed how polished this marketing message had become, especially with respect to its claims about the future. "[NDN can] take us far beyond the connection-oriented model that a lot of our applications started in," Burke said, adding that people should be excited about "the opportunities to be designing for applications that are coming" (J. Burke, personal communication, September 12, 2016).

Burke (2010) noted that in the current Internet, applications are conceived with respect to "where" information is located; several layers of middleware are necessary to complete data communication between IP and the application layer.[11] With NDN, the "where" of information in applications running on IP is replaced by a data-based "what'" model, which can be "implemented directly, removing all the middleware and its associated configuration and communication inefficiencies" (n.p.).

Interestingly, the NDN principals' emphasis on applications does not explicitly address time, though it is certainly implicit in the project's promises of more efficient communication. The directness of the applications seeks to make communication more efficient. However, Jacobson's discussion of NDN's directness as capable of changing conversational vocabulary, he performs a neat elision that suggests that the *communicative* capacity of the NDN protocol, a quality largely invisible to application users, will enable *humans* to more easily express themselves as a result of the new architecture as friction is reduced. In a sense, he is overselling

---

[11] This notion of "what" and "where" is also echoed in technical documents, such as Zhang et al.'s 2010 report and on the website, and Jacobson stated this in a video stream from a 2015 NDN community meeting (UCLA REMAP, 2015).

the notion of reduced friction of communication at the network level, which may not necessarily offer a new user-facing set of opportunities for user expression.

Burke and his REMAP colleagues have led and will continue to lead the effort to develop and deploy prototype applications to exercise and test the new NDN architecture:

> REMAP has been exploring the use of named data at the application networking level since 2002. We realized it would help us organize and develop distributed applications that incorporated sensors, media, and automation of the physical environment. The NDN project is very exciting, as it makes a more sophisticated and comprehensive version of this idea fundamental to the network itself. (J. Burke, personal communication, September 12, 2016)

MF and XIA, meanwhile, engage in a more agonistic relationship to developing applications. In an interview, Peter Steenkiste mentioned that XIA builds applications simply to prove that their new networking protocol stack works, but that "a lot more money [is] invested in applications than in Internet infrastructure. So that's something to consider. The good news is a lot of application functionality can be hidden in libraries" (P. Steenkiste, personal communication, October 30, 2017). So, while XIA sees applications as a necessary component of proving the usefulness of the extensibility of their protocol suite, they also recognize that applications are where there is money to be made. For its part, MF is barely interested in developing applications and is more interested in developing standards. The lone application they have developed, discussed below, is mainly there to prove the feasibility of a naming standard.

Steenkiste's observation about the market potential of the application layer, and NDN's stated focus on applications, suggest an interesting tension in the discursive elements of time, which are explored below. NDN positions itself as focused on applications as a result of the project's relationship with Jeff Burke and REMAP. Jacobson frames NDN's capacity to reduce friction at the networking level in terms of "expressivity" at the application layer despite the lack of evidence for this in the project results to date. Indeed, such user expressivity or fluency is not even stated as one of the project's goals. His rhetoric seems mainly useful as a way to position NDN as hospitable to applications where, as Steenkiste noted in the same interview, there is "a lot more money invested."

Time Representation at the Level of Applications

The ways in which time was represented in these projects seemed to be most observable at the level of developing programs, applications, and demonstrations of how applications function to solve real-world problems. Each of the applications reviewed in this section was either suggested by individuals from each FIA project as being exemplars of how their particular FIA project would benefit society, or in the case of NDN's Flume, as the newest example of the types of applications that are possible running atop the NDN networking protocol.

NDN Flume

Burke's REMAP employs Peter Gusev, the NDN project's only paid application developer. In our first conversations, Gusev described Flume as an application built for the NDN architecture that uses the codebase from a real-time video conferencing application (RTVC) he built for NDN in 2015. Gusev intended Flume to be a conversational group of channels, like the collaboration application Slack, but with video-conferencing capacities, playback features, and access to historical data that temporally connects text chat and RTVC. With Flume, one would be able to access any note made at any point during a live conference and see when the text messages coincide with a particular video stream. In a preliminary interview with Gusev, I mentioned that my dissertation was shaping up to be an attempt to think through the nuances of temporality in applications built on new networking protocols. In response, Gusev noted that Flume is time-sensitive and that “all I do these days is think about time” because of his work on Flume (P. Gusev, personal communication, March 9, 2017). The following discussion is based on documents gathered from the publicly available NDN documents, Flume project documents, including code, as well as recorded and annotated conversations with Burke, Gusev, and other individuals involved in the NDN project.

Schematics

Gusev shared Flume schematics for explaining how packets move with regard to the application code and protocol. Each of the nodes in Figure 3.1 is a file in the application code directory; the map illustrates how they interact.

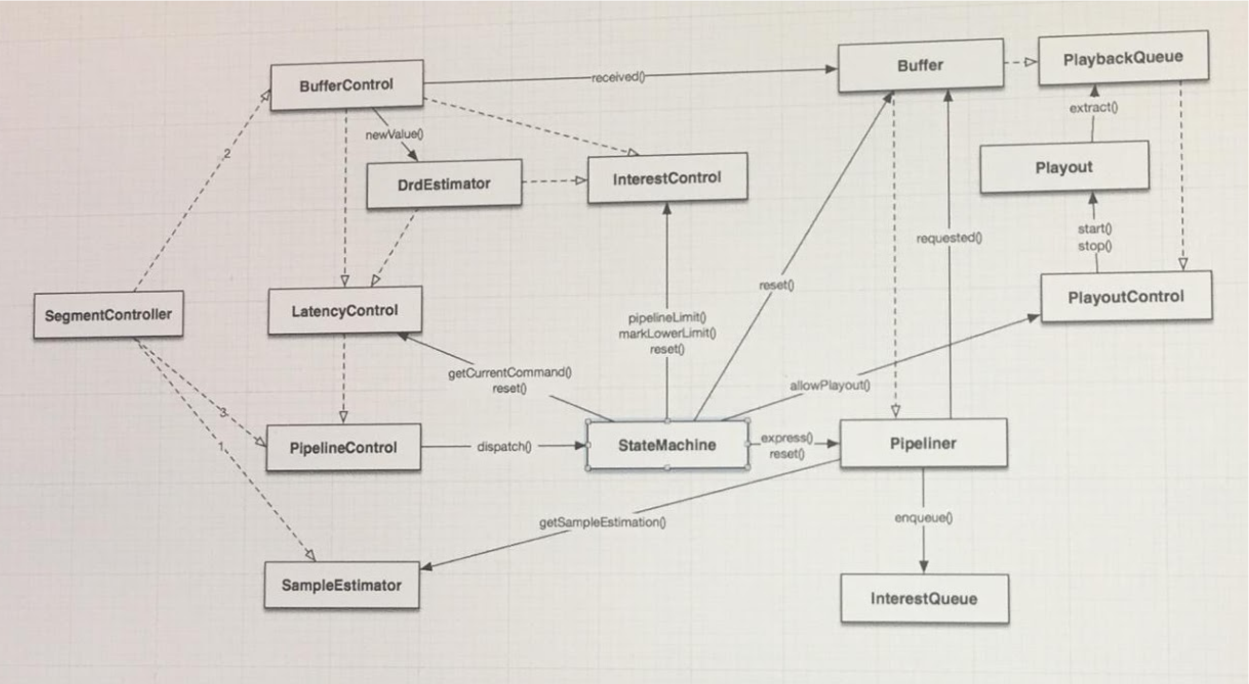


Figure 3.1. Flume application flow chart (P. Gusev, personal communication, July 26, 2017).

The decision to switch through states is driven by information gathered from different components, or nodes, shown in boxes here. For example, in the left-hand side of the figure, the *latency control node* tells the producer whether the process has reached minimal latency. The *interest control node* essentially indicates the size of the interest pipeline, or how many interests a consumer can issue at a certain point in time (P. Gusev, personal communication, July 26, 2017).

This process cycles through each node of the map at the same time. Gusev noted that each box in Figure 3.1 represents a class of instructions. Each class receives notifications, represented by dashed arrows, from other classes "once something is happening," such as a when a video stream is established. For example, he pointed to the *segment controller*, which is the interface that defines the instructions that the segment controller will give to its observer classes, or the classes it issues instructions to. The solid lines with arrows represent that any one class directly sends instructions to other classes (P. Gusev, personal communication, July 26, 2017).

Audiovisual latency for Flume is managed in the *buffer node*. During our interview, Gusev pointed to the code where this happens and traced it on the diagram (Figure 3.1). The buffer passes data to the slot, and the slot figures out the segment to which that data belongs. This assembles an audiovisual frame. There is a pointer to the data, and then there's a pointer to the frame of data to which it should be passed to be further decoded. Gusev highlighted that this method of pointing to the data and the frame where it belongs avoids having multiple copies, which would slow the CPU and increase latency between the packaging of the stream on the producer end and the display of the stream on the consumer end. Using the method he described, when a piece of data arrives, it is already allocated memory, as he put it:

For creating frames and being decoded. When data is received, it is copied right away

> into the correct place in the memory that represents a frame that is not copied anymore; it is sent to the decoder. You can't avoid this one copy. (P. Gusev, personal communication, July 26, 2017)

He emphasized that one copy is much more preferable than the copies that would proliferate if, when they arrived, they had to be placed in order with no frame to guide their placement. This practice of incrementalizing the stream keeps the stream running in real time or close to real time. While this description may seem rather technical, it indicates how application source code organizes the time-sensitive functions of the application to produce the user-facing interface with a real-time text chat application.

Interface

A great deal of time and thought went into building Flume's UI. Gusev mentioned that he talked with REMAP's UI consultant, who wasn't really convinced that this type of timeline was the way to go. But, Gusev noted, "When I met with [REMAP PI] Jeff [Burke] and the UI guy, Jeff was like 'absolutely this is the way to go,' so that was fun and it felt good that he saw what I was seeing" (P. Gusev, personal communication, August 3, 2017).

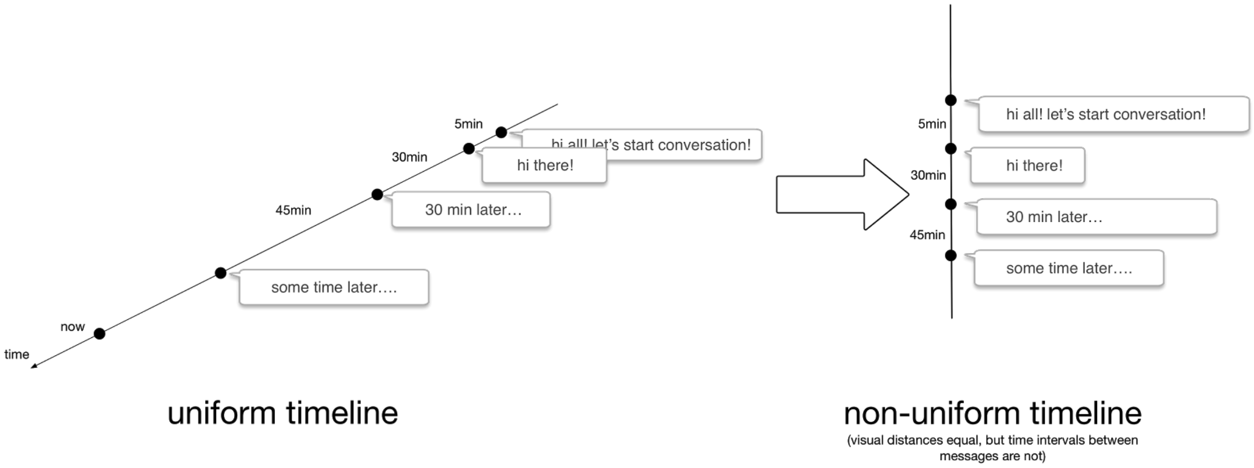
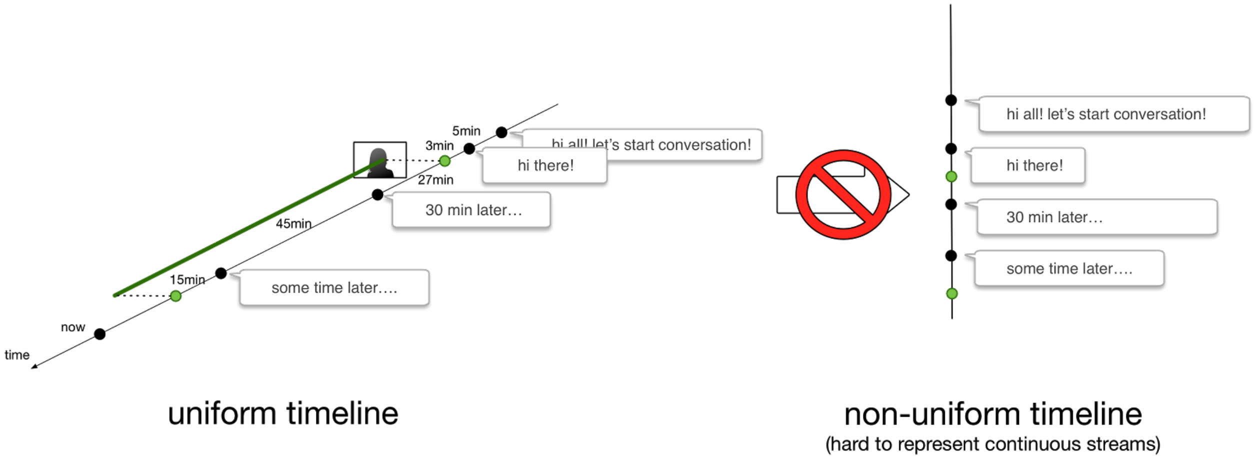


Figure 3.2. Flume conceptualization of a uniform v. non-uniform timeline (Gusev, 2017, p. 2).



uniform timeline

non-uniform timeline
(hard to represent continuous streams)

Figure 3.3. Incompatibility of uniform and non-uniform timelines (Gusev, 2017, p. 3).

Gusev explained that he used a non-uniform timeline for Flume because it can be found in conventional text-based chat applications and would thus be easier for users to understand and use:

> The timeline is just something that people are used to, I think. They see their news feeds in Facebook or they see their text chats in Slack. It's always, basically, a timeline, a chronological timeline, right? You can always scroll back or forward to view previously received information. (P. Gusev, personal communication, March 9, 2017)

Recalling Mierelle's (2013) notion of the graphical elements of timelines, and the manifestation of the linear time topology described by Schreiber (1994), it is worth noting that visual distances between messages are not proportional to the time durations between these messages. For example, in Figure 3.3, the text messages on the left are presented on a uniform timeline, where one can see that messages which are five minutes apart are closer than those that are 15 minutes apart. This uniform timeline directly represents units of time passed with units of visual distance in a standardized way.

However, in user interfaces (UIs) for messages that can have a great deal of time pass between them, and then be followed by short bursts of many messages, as in Slack or Google Chat, using a uniform timeline uses up much more screen space and might actually be more confusing to users because there is no distinction between types of information, such as short events like a text chat or a video of a meeting with duration. Flume manages these scenarios by time-stamping messages and bundling them together. In an unpublished *Flume Specifications* paper, Gusev notes that in these scenarios this content is “presented in a non-uniform, event-based timeline” (Gusev, 2017, p. 2). As opposed to a uniform timeline, the non-uniform timeline does not indicate the temporal duration between messages but instead shows ordering of messages spaced uniformly.

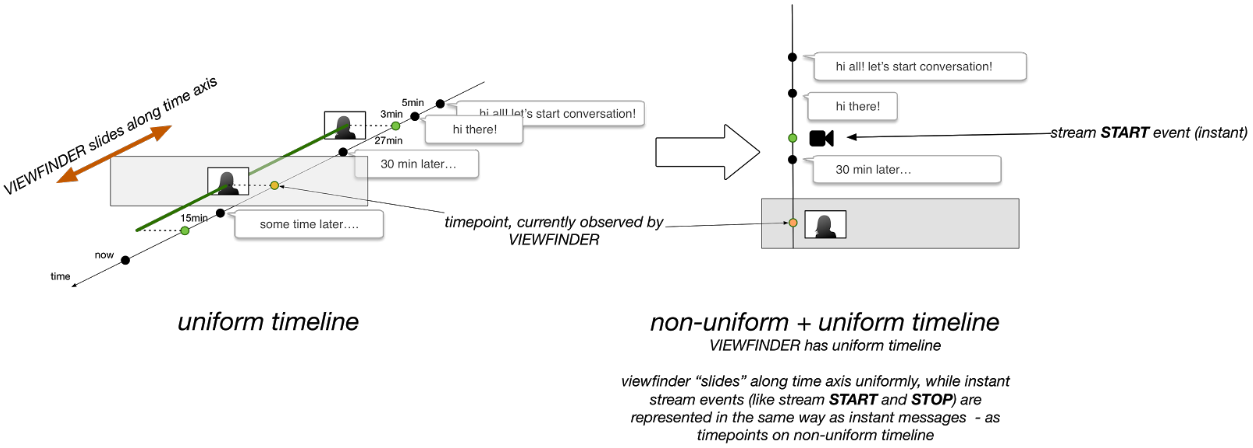
It is important to note that the elision between uniform timelines in this project shows the duration of time between messages or streams with different spatial distance, while the non-uniform timeline shows the duration of time as a uniform distance between events, messages, or streams. This seems counterintuitive, but the uniformity in both descriptors stands for the uniform mapping of spatial distance and duration of time passed. Gusev observed:

> Non-uniform timelines work great for textual data because the actual time interval, it will always be different because of the difference in the time zone. In the user interface, say a text chat, you see a message from today, a message from yesterday. They are adjacent. The gap between messages that came five minutes before or one hour before. It’s represented the same because makes more sense to see it all upfront. (P. Gusev, personal communication, March 9, 2017)

In Flume, the orientation of the linear trajectory of time is displayed as older messages appear on top and newer messages appear from the bottom. Gusev noted that when he was thinking about how to display the data, he thought not about how people experience time but about the data he was trying to represent through the interface. With regard to the way the data was named, Gusev said that, if it was just one set of discrete points to be shared—say, through a document—or if the data was part of a real-time stream, it would be named differently. He said,

> This idea really got me—that you can issue interest for data and map the data received to some dimensions, to some coordinate system, and then retrieve whatever data is there in this coordinate system, right? So on one side, there is interest, on the other side data, and both sides will map them through names to some third abstract coordinate system. In the case of the Flume application, this would be the coordinate system of a timeline.
>
> For Flume, the idea was just to map data that has some continuity, right, that has some duration. So the step was to map this information under the same timeline.
>
> Then when we have interests that are mapped to coordinate system of this timeline, we just issue interest in this name space in these coordinates, and we get whatever data was published there and has the same coordinates we're asking for, right? In our case, in the Flume case, it will be either text messages or samples of video or audio. (P. Gusev personal communication, July 26, 2017).

Non-uniform timelines pose difficulties for presenting continuous data, like audiovisual streams, as seen in Figures 3.2 and 3.3. As these continuous data streams are intervals, they are difficult to integrate into a point-based timeline. Of course, these non-discrete streams have start points and endpoints that are marked as discrete events, it becomes difficult to map neatly into the timeline, especially if there are multiple streams that overlap. Gusev asserts that "despite their non-discrete nature, continuous streams can be viewed only using uniform timelines" (Gusev, 2017, p. 2). His statement that the only way that these streams can be viewed along with more discrete data is through a uniform timeline seems wholly incorrect, especially considering Drucker's and Schreiber's different modes of thinking about the representation of time. Time does not have to be linear or uniform; one can also combine notional vocabularies to include discrete events and continuous intervals. However, he is working with other technical constraints and had already been approved to develop a timeline interface for Flume.



*viewfinder "slides" along time axis uniformly, while instant stream events (like stream **START** and **STOP**) are represented in the same way as instant messages - as timepoints on non-uniform timeline*

Figure 3.4. Merging continuous streams with instant events **(**Gusev, 2017, p.7).

Gusev's (2017) principles are based on the idea of combining the two types of timelines (non-uniform and uniform) in one viewer. To achieve this, he introduces a viewfinder that "always has the exact timestamp and operates in the uniform timeline. One can imagine the viewfinder moving along the uniform timeline axis" (p. 7). It retrieves discretized bits of the audiovisual streams that correspond to the point in time as one scrolls through the viewfinder. One can also note that there is non-uniformity in the distances between the events delineated by different colored dots for different types of data available at that corresponding point.

An important addition in this iteration is that the window is split, and the bottom viewfinder that can be activated by scrolling through the timeline to focus on certain messages or certain points in time. Gusev stated in the unpublished Flume document, “[the viewfinder] is present in the UI *only* if the lower boundary of the time interval observed in the text chat view ‘encounters’ continuous data [of a real-time stream] from any viewer” (Gusev, 2017, p. 3, emphasis added). As soon as the user encounters this real-time stream, the viewfinder pops up in the lower portion of the window with a preview of the stream at that particular timestamp. The user can click on this and “replay the meeting or scroll within the viewfinder for fine-grained (frame-level) control” (Gusev, 2017, p. 3). Gusev noted, “With live streams, the viewfinder is perennially active and represents the *point of now***,** showing currently streamed content” (Gusev, 2017, p. 3, emphasis added).

That Gusev highlighted the “point of now” as the place for users to orient themselves toward the application, on one hand, seems interesting, but at the same time is not that groundbreaking in terms of how he thinks about interfaces in widely-accepted ways. With the interface, he said he wanted to develop something that users will know how to interact with based on a cannon of convention for interaction in comparable video conferencing applications (P. Gusev, personal communication, March 9, 2018). But it seems to be a sticking point for Gusev that he has not yet figured out how to navigate or design for an interface that gives users something new while keeping it easily navigable.

Gusev seemingly understands that there are multiple ways of designing a human-user interface, but he seeks to represent time in ways that he thinks most users would intuitively understand. However, if expressivity and showing users something different are important to NDN and to Gusev as he develops human user-facing applications, such as Flume, then the notion of the topology of time, highlighted by Schreiber, would be something to press further. One might think of different ways to represent time-based streams of content to users through applications. But this type of user-facing design betrays the ways in which software engineers must interact with the networking stacks to get streams in real-time order at the UI, as with each of the applications in question—but shown explicitly here with Flume and Vehicle Video demo below.

The XIA Vehicular Video demo, technical diagrams, interface, and description were bound into one instance found in a YouTube demo video that was used at the Global Environment for Network Innovations (GENI) Conference in 2015 (N. Gupta, personal communication, February 28, 2018) to show what the demo could do. Here both the schematics and interface are introduced together because it makes the most sense to show how they interact. The demo first steps through the schematics.

XIA Vehicular Video demo

In the current Internet, joining a network is an involved process. XIA senior developer Dan Barrett noted that if, for example, you go to Starbucks and want to join their network on your computer or phone, you see its network name on your device, and click on "join" (D. Barrett, personal communication February 28, 2018). Those who have ever logged onto the Internet in an airport, hotel, or restaurant will know that it may take a long time for a signup page to appear; some locations may have an agreement with another provider that gives access. This works for basic personal Internet use, but the process is certainly too slow and complex to provide access for devices in moving vehicles, for example. XIA developer Nitin Gupta emphasized that XIA is trying to fill this need for quick mobile access with its focus on extensibility; the demo was developed to highlight this capability. Gupta continued:

> Say you're going 65 miles per hour on a highway and you want to talk to these access points that are on basically poles along the highway. If you want to do that, you want to

> be able to join these networks fairly quickly. So we developed basically a network-joining protocol that allows us to do that by exchanging two round-trip messages. That's four messages total. That sets us up with the entire stack, going down from the hardware up to the application level. It's extensible, so we can add more things to it. (N. Gupta, Interview February 28, 2018)

The notion of network ***extensibility*** is crucial to XIA. As he used the word here, it means the XIA network's ability to scale up or allow applications to join without losing functionality. In software engineering texts, the term extensibility refers to the capacity of a program or a software system to change without having to rework any components of the overall program or system (Kelley, 2002). This is interesting in the context of XIA because software engineering generally happens at the application layer, not the networking layer of the OSI protocol stack. However, again, as with NDN, Gupta and Barrett use language common to the application layer to frame the complex technical processes happening between the network and the application layer. This could be simply because they are first and foremost applications developers and may not necessarily indicate the overall application-oriented focus implied by its official name, which includes "expressive" as a primary descriptor. However, their framing of XIA's extensibility feature might be in line with the economic reasons for framing discourse in terms of user-facing speed of applications highlighted above with Jacobson's articulation of NDN's expressiveness.

Moreover, the notion of extensibility in this context generally means the technical design's ability to support and maintain functionality while scaling up through a duration of time. This process is currently a huge problem that the contemporary Internet running on IP is ill-equipped to address. The problems with IP's extensibility at the application layer comes directly into focus with user-facing streaming content applications like Netflix, which has been trying to solve their extensibility problem in a number of ways so that content can stream smoothly regardless of how many people are using the service in an area (Netflix Technology, 2015). It is also a known problem in the mobilization of self-driving cars using IP for all the reasons mentioned by Gupta above.

This Vehicular Video demo (Gupta, 2016) showed how mobile devices streaming content in moving vehicles could work in XIA more efficiently than in IP:

> We're driving along. We're streaming a video, and the video is obviously content in terms of XIA. This is chunks of content that you're streaming. While you're streaming, you just happen to disconnect from one and go to another content. You can go away from the range of one network and join another one, and the streaming continues. Of course, there's buffering on the client side, but the idea is to basically join the other network quickly enough, so that even if you're in range for a couple of seconds, you can still stream a significant amount of data during that time. (N. Gupta, personal communication February 28, 2018)

The demo shows XIA's affordances for mobility. The video could be streaming on any mobile device. It could happen on an airplane. It could be another vehicle. It could be vehicles talking to vehicles. It could be vehicles talking to infrastructure—anywhere where there is a mobile computer coming in and out of ranges off of various networks. Herein lies another feature of *extensibility* discussed in engineering literature on vehicle-to-vehicle communication, the notion of infrastructure being extensive or pervasive enough in the built environment. This definition of extensibility of infrastructure, considered in conjunction with the concept of extensibility as a mode of interoperability that could support communication with and between different vehicles in a way that is scalable as traffic waxes and wanes, makes it a useful term to use when describing these engineering projects. The term extensibility can mean a number of things but is generally understood as useful and user-friendly because it implies notions of pervasiveness and communication speed to the lay public and the same to corporate or government partners who might be interested in exploiting these capacities for profit.

Gupta pointed out:

> If you're on a bus with your iPad, the bus has its own local network. That network has to be joining two other networks as you're driving down the highway, potentially. I mean, it could be used for inter-vehicle things and so on. I think our use case is more—is driven by the NSF. Mobility and video were a couple of the use cases that they wanted to see out of our project (N. Gupta, February 28, 2018).

Taken at face value, the fact that he framed the Vehicular Video work as a proof of meeting goals that the NSF had set for XIA would suggest that XIA is not primarily interested in mobility and video but worked on it only because the NSF directed them to, or because they are funded by the NSF. In any case, Gupta did a lot of work for mobility, allowing a client to move and ensure a person on the other end would be able to find the client after they have moved. Barrett added, "A lot of this is just using XIA's specific features to allow you to be mobile and not lose what you're doing" (D. Barrett, personal communication, February 28, 2018).

Extensibility can further be understood as a time-laden concept in the specific case of the Vehicular Video demo because this notion is paired with the ability to maintain connectivity in situations where it is difficult to do so under TCP/IP. In TCP/IP real-time streaming is predicated on the continuous network connectivity. Low and intermittent connectivity causes network delays and high latency packet transfer which causes real-time streams to time out.

Gupta detailed how real-time, mobility-based use contexts do not work in conditions where there is little or no network extensibility that allows many users to join and exit the network with less friction:

> If you want mobility and you want real time, you will need better connectivity. You cannot have basically blind areas where you don't have connectivity because otherwise real-time applications will not work. If we are on this call and I'm moving between networks, as long as I can connect to the other network fairly quickly before leaving the existing network, you will probably not even see a glitch, but if there is a five-second delay in joining a network, that's technically infeasible to bypass. You will see the five-second delay in terms of data transfer. You will drop that five seconds of conversation, or buffer it and be delayed. (N. Gupta, personal communication, February 28, 2018)

The real-time streaming depends on the requirement of the application and expectation of users at the other end and what kind of connectivity is available. Gupta noted how these notions of user-based experience influence the design of the Vehicular Video demo:

> In the Vehicular Video example, we have intentionally created a blank space between the two access points. The example on the website is different from other examples we've tried, even inside buildings when you're moving around the laptop, where you might be in the range of multiple networks at the same time. Depending on the network strength—the signal strength—you will join the other network. (N. Gupta, personal communication, February 28, 2018)

This means streaming is not the same process of packet numbering and transfer as it is with NDN. XIA streams each chunk, enabling a TCP-like connection, where the ordering of chunks is not an issue because the underlying transport takes care of it (N. Gupta, personal interview, February 28, 2018). In XIA the endpoints are services, so they can assign the changes for themselves. A service can basically communicate that it has moved to a new address and to send all future packets to that address. That type of addressing scheme is not possible with TCP/IP.

While the Vehicular Video demo running on XIA supports mobility and content streaming using a nebulous and time-laden concept of *extensibility*, MF's most-developed application supports mobility because it theoretically reduces the resource overhead that inhibits mobility in IP contexts. This demo also was meant to highlight the benefits of the network in its ability to foster user-facing mobility.

Schematics/Interface

The demo was hard to separate into instances of distinct interface and schematics, so here they are presented together, as they originally appeared. The experimental set up diagram shows roughly how the networking and computational processes are ordered. The screenshots of the video show what the interface looks like as well as the buffer monitors that indicate what processes are happening within the application.

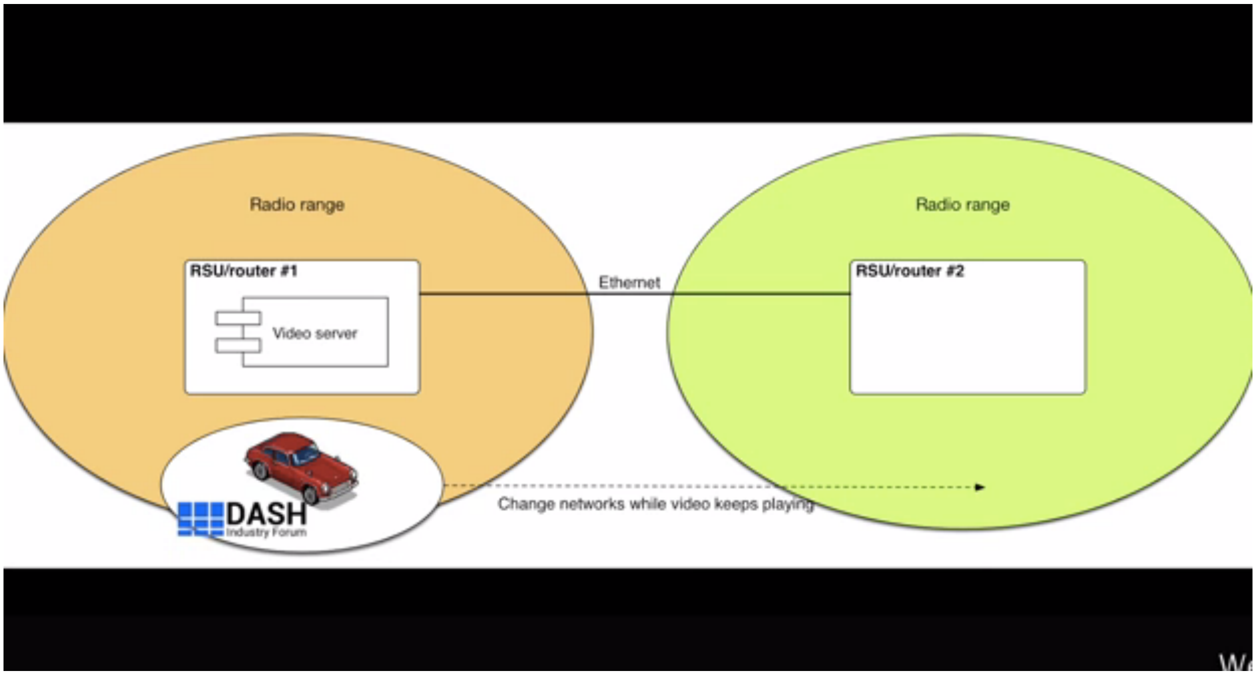
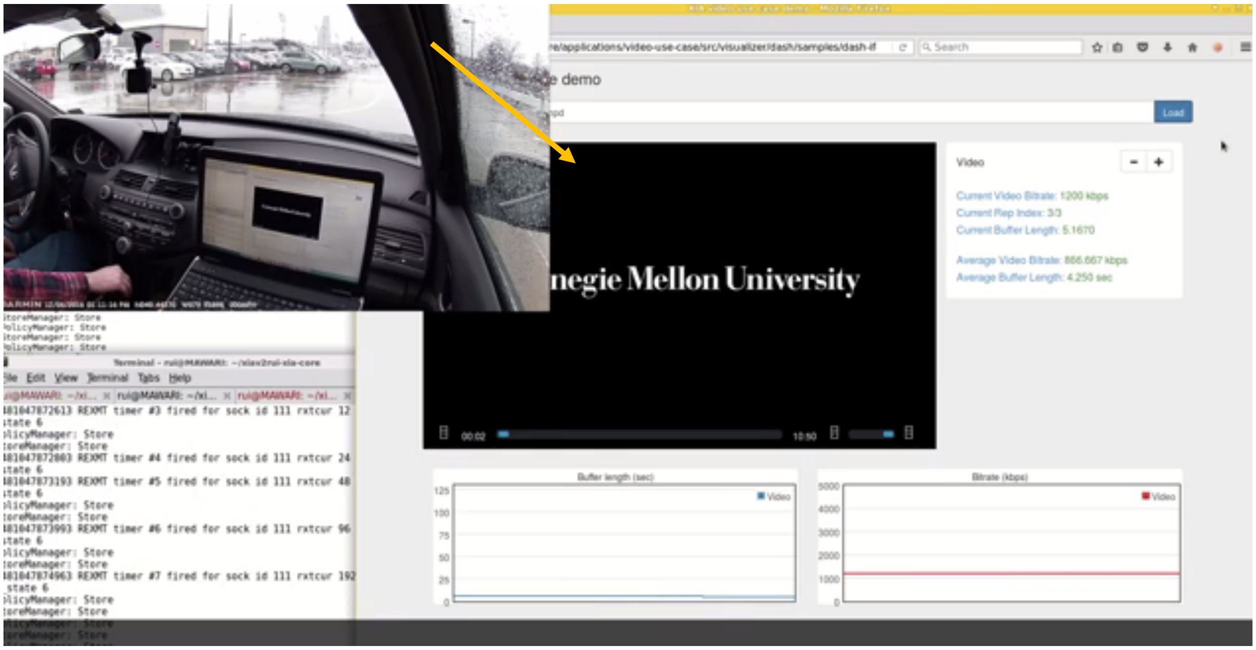


Figure 3.5. Vehicular Video demo: The experimental setup (Gupta, 2016, 0:23–1:09).

Here the two XIA networks each have their own router and connect through Ethernet and accepting clients through dedicated short-range communication (DSRC). One router is a video server. A client onboard unit (OBU) connects to the video server and starts to stream the video. As the unit moves away in the car, and loses connectivity, it migrates to the right hand network. "While all this is happening, the video continues playing without interruption" (Gupta, 2016, 1:03).



re/applications/video-use-case/src/visualizer/dash/samples/dash-if

Current Video Bitrate: 1200 kbps
Current Rep Index: 3/3
Current Buffer Length: 5.1670

Average Video Bitrate: 866.667 kbps
Average Buffer Length: 4.250 sec

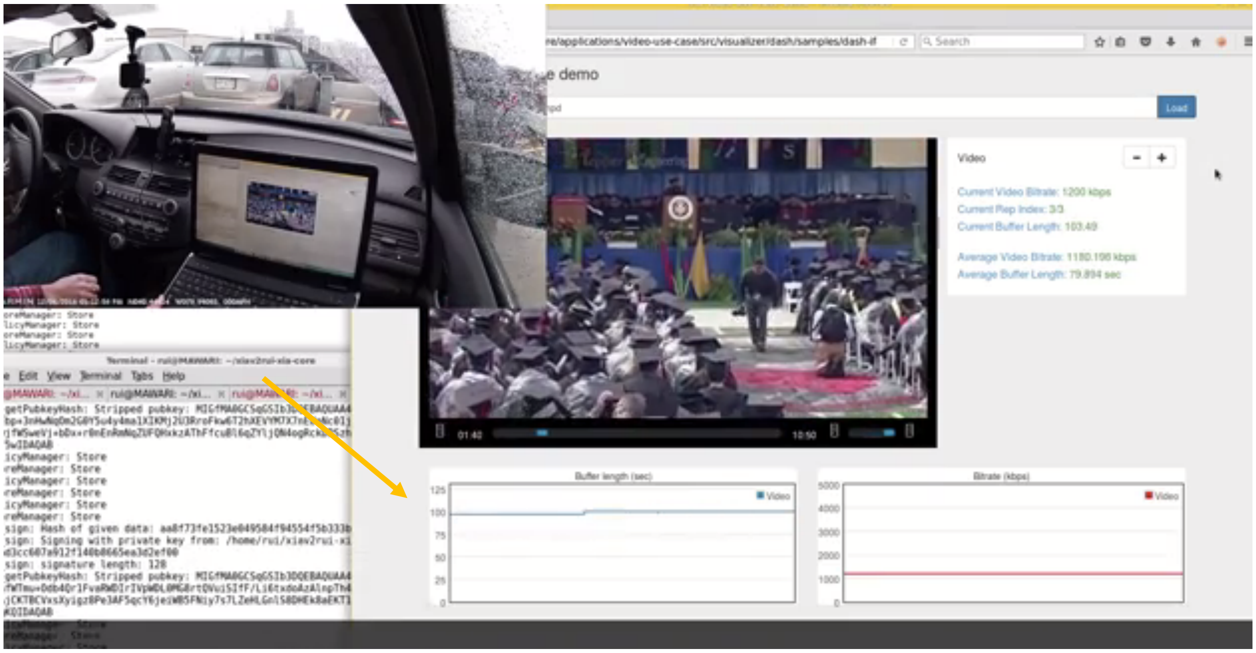
```
toreManager: Store
olicyManager: Store
toreManager: Store
olicyManager: Store
```

Terminal - rui@MAWARI: ~/xiav2rui-xia-core

```
481047872613 REXMT timer #3 fired for sock id 111 rxtcur 12
state 6
olicyManager: Store
toreManager: Store
481047872803 REXMT timer #4 fired for sock id 111 rxtcur 24
state 6
481047873193 REXMT timer #5 fired for sock id 111 rxtcur 48
state 6
olicyManager: Store
toreManager: Store
481047873993 REXMT timer #6 fired for sock id 111 rxtcur 96
state 6
olicyManager: Store
toreManager: Store
481047874963 REXMT timer #7 fired for sock id 111 rxtcur 192
_state 6
olicyManager: Store
toreManager: Store
olicyManager: Store
toreManager: Store
```

Figure 3.6. Initiating the Vehicular Video demo **(**Gupta, 2016, 2:24).

Once the first network is established, it launches, and the video and the server begins publishing the video. When the video is published, the second router can be launched to create the second network. The second network initiates the client that allows a modified browser to communicate with an XIA network. The video is then loaded in the Dash MPEG video player (Gupta, 2016, 2:10–2:30).



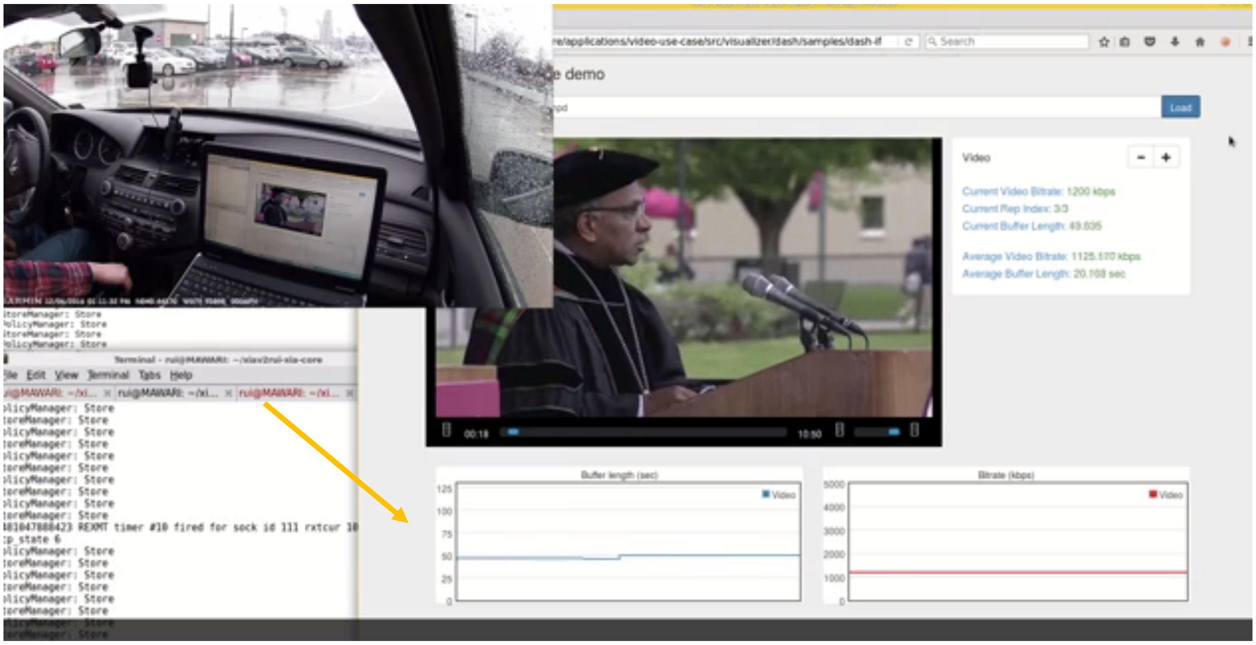
Current Video Bitrate: 1200 kbps
Current Rep Index: 3/3
Current Buffer Length: 103.49

Average Video Bitrate: 1180.196 kbps
Average Buffer Length: 79.894 sec

```
oreManager: Store
licyManager: Store
oreManager: Store
licyManager: Store
getPubkeyHash: Stripped pubkey:
icyManager: Store
reManager: Store
icyManager: Store
reManager: Store
icyManager: Store
reManager: Store
sign: Hash of given data:
sign: Signing with private key from: /home/rui/xiav2rui-xi
sign: signature length: 128
getPubkeyHash: Stripped pubkey:
```

Figure 3.7. Vehicular video buffer (Gupta, 2016, 2:30).

Here we note that as the vehicle with the OBU is near to the first roadside unit, the buffer length plot below the video window increases to the maximum of 120 seconds.



Current Video Bitrate: 1200 kbps
Current Rep Index: 3/3
Current Buffer Length: 49.836

Average Video Bitrate: 1125.170 kbps
Average Buffer Length: 20.108 sec

```
StoreManager: Store
PolicyManager: Store
StoreManager: Store
PolicyManager: Store
olicyManager: Store
toreManager: Store
olicyManager: Store
toreManager: Store
olicyManager: Store
toreManager: Store
olicyManager: Store
toreManager: Store
olicyManager: Store
toreManager: Store
481047888423 REXMT timer #10 fired for sock id 111 rxtcur 10
cp_state 6
olicyManager: Store
toreManager: Store
olicyManager: Store
toreManager: Store
olicyManager: Store
toreManager: Store
```

Figure 3.8. Vehicular video streaming (Gupta, 2016, 2:42).

> Connectivity diminishes as the vehicle moves away from the first roadside unit until it is finally lost. As the vehicle moves away from the roadside unit and continues playing video from the buffer, the buffer length decreases. As the connectivity is lost, the OBU client joins the second network to which it is now physically closer. As the video streaming session is initiated on the second network, the buffer length again increases, stabilizing at a maximum of 120 seconds (Gupta, 2016, 2:30–3:20).

In these diagrams, interfaces, and attendant descriptions, again we see that the time topology is linear in that the video is represented in a linear progression. But, interestingly, in conjunction with the linear unfurling of the video, the process of the network being configured is visible as the car moves through space, and this does not affect the video. Again, the notion of time is conceived of and depicted as linear. However, the ways in which the images of the network configuration, the graphs of the buffer output, and the video playing in real time illustrate the slight disjunction between the linear trajectories of time and how even in this "frictionless" scenario, real-time streaming is a myth. Time intervals and points are not exactly in keeping with Meirelles' conception of those components of timelines because we are seeing the linear progression of time played out through the duration of the video as it changes with code and the buffer graphs, each of which, when shown together on the same interface plane, highlight a more complex and disjointed, illusory, real-time scenario that is playing out in the demo.

The network user in the demo can be a person straightforwardly streaming content from a car, as demonstrated, but the implication is that this type of network set-up can also be used for vehicle-to-vehicle (V2V) communication. Indeed, Gupta acknowledges this (N. Gupta, personal communication, February 28, 2018). While we can understand what sorts of temporal flows of information are necessary for mobile video streaming, those flows in a V2V scenario are dependent on a number of technical factors that are still being adjudicated in the field of transportation informatics and continually negotiated as these technologies are deployed to the wider public. An interesting thread for future discussion might be to consider a discourse of temporality in automated vehicle safety, as it is an interesting example of the construction of a discourse that touches a social issue, a technical issue, and a temporal issue.[12]

MF Content-Oriented Naming Service (CNS) for Managing Disasters

MF's most recent application area is emergency response services, for which they have developed the Content-Oriented Notification Service (CNS) for Managing Disasters. MF PI Chen et al. (2016) detailed the need for emergency networking in disaster scenarios like the 2005 London bombing, in which some network areas were cut off but there remained a need to deliver messages to the right people at the right time. In an interview for the present project, Chen stated that one of the primary applications for the CNS might be to dispatch emergency responders in particular areas. "There are a lot of discussions about how people are working great, but the communication infrastructure is failing them" (J. Chen, personal communication, March 9, 2018). MF has storage features and the ability to hold packets inside the network until they can be delivered, using a technique called Delay Tolerant Networking (DTN).

DTN is a networking topology that evolved from a schema for networking architecture that was originally designed for the "Interplanetary Internet, a communication system envisioned to provide Internet-like services across interplanetary distances to assist deep space exploration" where "conventional IP-based networking approaches are unworkable or impractical" (Cerf et al., 2007, p. 1). Indeed, existing Internet protocols do not work well in environments where

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[12] Sprenger's (2015) *Politics of Microdecisions* highlights how the speed of algorithmically driven surveillance technologies are programmed to make many different kinds of "microdecisions" that result in larger scale social and cultural phenomenon. These microdecisions are similar to the types of "microdecisions" that automated vehicles make.

direct and immediate end-to-end paths between sender and receiver are not possible. This is because TCP/IP requires end-to-end paths between senders and receivers exist for the duration of a communication session. In TCP/IP simple packet delivery is given utmost importance. Optimization of communication performance is not (Cerf et al., 2007, p. 4).

The DTN architecture is conceived to circumvent these brittle components of existing Internet architecture. Delay- and/or disruption-tolerant networks (DTNs) are those without continuous connectivity limitations. In these contexts, routing protocols like TCP/IP and others fail to establish routes. Data cannot be transferred because routes cannot be established, which is required for data forwarding. In this scenario, routing protocols like MF use a *store and forward* approach where data is stored in-network until the moment at which end-to-end connection can be established (Cerf et al., 2007).

The use of DTN in this MF application relates to issues of time. The notion that this schema was originally created for speculative space travel suggests that not only social and technical time considerations but also interplanetary time scales of light years and incomprehensible magnitudes of time and space, were original design considerations. But interestingly, the context that the CNS is developed in relation to is the breakdown of network connectivity in mobile applications, in large-scale terrestrial emergency situations when seconds count.

However, in Chen’s description of the application, the notion of user-facing communication re-emerges, as he articulated that human aid workers “are doing great” in these situations, but that the “communication infrastructure fails them.” In a sense, he is attempting to argue that while humans on their own do adapt in these scenarios, their productivity or ability to save lives in these situations would be improved by being able to direct their efforts more efficiently.

Indeed, the notion of how CNS works in "emergency" situations frames the MF CNS as a technology that can be used to ameliorate the human inability to predict and react to large-scale disasters that might arise for any unforeseeable reason. Here Chen related the work in response to the 2005 London bombing, a human-induced event, the likes of which at present are more unpredictable than natural disasters, or even man-made ecological disasters. This represents a difference in the orientation of the project from those articulated or even implied by XIA and NDN. With CNS, MF attempts to augment the speed and efficiency of communication through technology to manage people, but redress, to some degree, the human inability to prognosticate, even with the powers of artificial intelligence powered by big data, many types of human-induced and ecological events that endanger many people.

Diagrams

Jiachen Chen detailed how his CNS project fits into MF as an architectural template for naming data. He reasoned that a functioning system where the named space holders present in the template can be assigned with names and functions that are appropriate to different events, circumstances, and locations (J. Chen, personal interview, March 9, 2018).

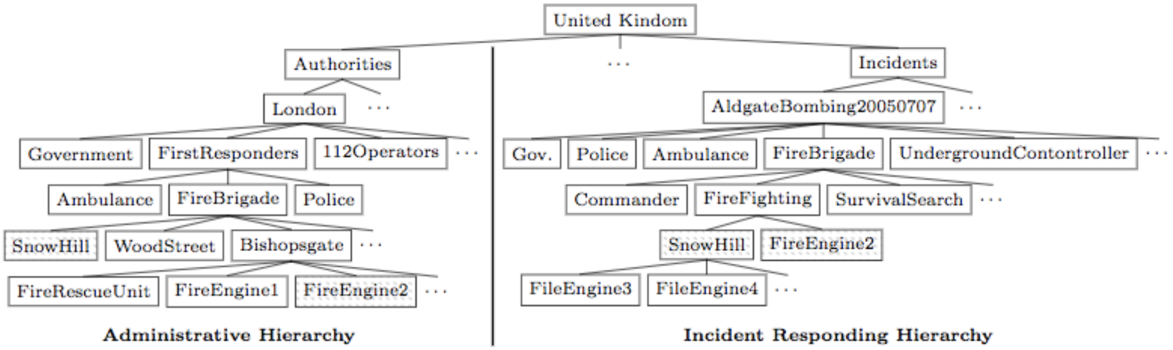


Figure 3.9. Name hierarchy in content networking stack (Chen et al., 2016, p. 126).

Regarding a figure in the paper, shown as Figure 3.9 here, he continued to describe how first responders may belong to one hierarchy, labeled as the administrative hierarchy, but need to be copied into a different incident hierarchy in order to deal with a particular incident. In Figure 3.9, copying Fire Engine 2 from the administrative hierarchy expresses the intent to add Fire Engine 2 into a category of entities sending and receiving messages. Once this happens, Fire Engine 2 now belongs to two different hierarchies, the original administrative hierarchy, and the incident management hierarchy. In each one, Fire Engine 2 has one in-degree and multiple out-degrees forming the tree hierarchy. But now, Fire Engine 2 is part of two hierarchies, so there are two incoming links, which form a graph. When this name copying happened previously, it caused a lot of overhead because it would require the Fire Engine to re-subscribe to both hierarchies. In this graph-based structure, all that needs done is to create a link (J. Chen, personal communication, March 9, 2018).

In his explanation of Figure 3.9, Chen stated first that the goal is to send a set of messages to the right set of people (J. Chen, personal communication, March 9, 2018). Theoretically, IP allows multicasting, or sending one message to many different users at once, but the way it does this is not efficient and does not allow, say, a message to be sent with regard to different scopes of users or devices. Chen explained that in the paper, they used the example of the 2005 London bombing, which involved four different sites where bombs went off. In that scenario, it would be desirable to send different messages to different emergency teams. For example, a message might be sent to every responder in the area; or, a message might be sent to all people who have already been dispatched to just one of the sites. Or, as Chen described it, "Let's say I want to dispatch some people who are only dealing with firefighting, from [the]

Outgate site to the King's Cross site because there is a fire emergency" (J. Chen, personal communication, March 9, 2018).

There are many different scenarios where it would be necessary to communicate with people based on their roles or proximity to certain sites. The goal with this naming schema is to decrease the technical overhead necessary to communicate specific messages to particular groups of people. Chen clarified that that the way this type of messaging currently works under IP is that first responders subscribe to multiple multicasting groups so that when a message goes out, it unicasts to each and every responder who satisfies the requirement. This results in a shotgun approach to messaging that burdens many of the emergency workers with numerous and irrelevant notifications. According to Chen, the idea of sending role-specific messages to the right people is a form of content-oriented messaging. He noted, "Here, the role is another kind of content. So you might need to have hierarchical roles also" (J. Chen, personal communication, March 9, 2018). In the scenario above, it would be more desirable to issue messages to individuals based on some hierarchical structure.

IP cannot provide this capacity. In designing the CNS, Chen and his team are designing a general model that can satisfy all types of ICNs. The special thing about MF, Chen argues, is that it can perform reliable transmission, store content forward, and push messages once content types become available (J. Chen, personal communication, March 9, 2018).

The ability to quickly and efficiently communicate this type of time-sensitive information in critical scenarios is driving a collaborative research project with the National Institute of Standards in Technology (NIST). Most interesting in this case is that the applications are not necessarily user-facing, but Chen, Raychaudhuri, and the others on the MF team are attempting to lay the groundwork so that the infrastructure can be used for these types of efficient and secure message transmission in time-critical scenarios where decisive action is required to save lives.

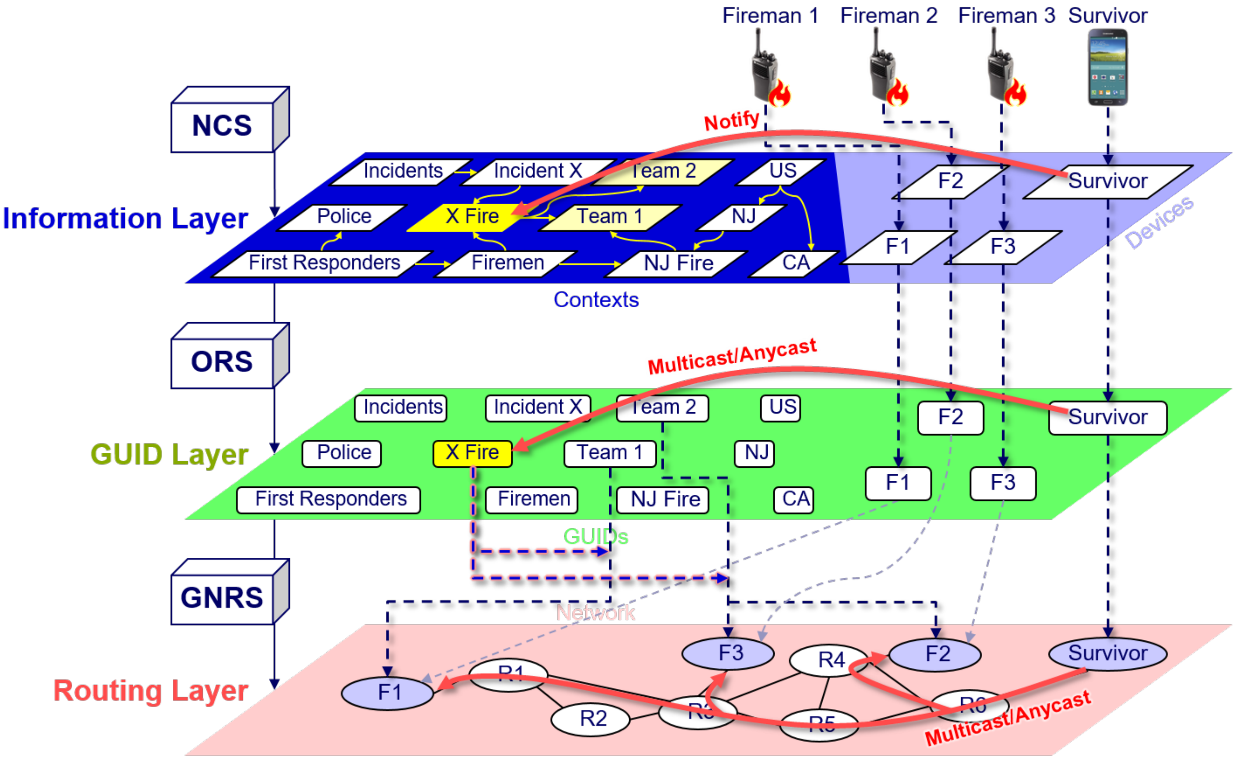


Figure 3.10. CNS in natural disasters (Mobility First, 2018c, n.p.).

Figure 3.9 shows a neat map Chen developed, in which the time topology is linear, and the flow of organizing functions is shown in a type of mapped flowchart. The graph in Figure 3.10 similarly shows the linear flow organizing functions but through dimensions of space, or the proximity of different actors within the network, to show how messages are mapped in ways that address location in these time-critical situations.

Spatialized Time in the Future Internet

From these three descriptions of applications built on top of NDN, XIA, and MF, respectively, it is clear that they have different aims. On their face, all three want to show the affordances of each protocol, but the ways they conceptualize and present problems differ markedly with regard to what they understand as the primary affordances of their respective protocols and how they position them *vis a vis* industry. However, what lies under the surface of the projects' rhetoric is that the affordances also deal with time-based difficulties encountered by the various industries toward which the projects are position themselves. The discussion of key schematics and graphic figures shows how the FIA applications teams all attempted to articulate of the **qualities**, **shape,** and **characteristics** of time that shed light onto the ways in which time is spatialized and used as an ordering principle on a practical level, along with the types of user-facing temporality the developers are considering as they build these applications. While these applications seem to be built to consider different modes of user-facing temporality, at present they only serve as proofs of concept to other engineers or non-specialist stakeholders.

The qualities featured in the application images—expressivity, extensibility, and emergence—all have to do with different types of efficiency, which is itself a time-based design value. NDN, according to Burke and Jacobson, is focused on the **expressivity** of applications (or at least they say it is), despite that the project has just one paid developer, who—as will be detailed further in Chapter 5—was not given sufficient information about what was going on in the project or what the principals wanted. The XIA team sees their advantage to be **extensibility** and mobility, and thus they have built a demo that shows how XIA can support real-time streaming content in a moving vehicle. MF's goal seems to be broader in scope, as they seek to show how mobile multicasting can be wielded to address unforeseeable **emergent** situations in which seconds count. It is important to mention that all three networking protocols could theoretically support the functions inherent in one another's applications described in this chapter.

Each project seeks to remedy time-based issues at the application level, as illustrated by schematics and interfaces used to demonstrate the applications, which show the particular ways engineers conceptualize the spatial dimensions of ordering the process of data transmission to the application function. In Gusev's code map and the Flume interface timeline, we see that time is presented as a spatialized thing with a shape. The code map dictates how data is placed into buffers for real-time streams that then could be represented using a non-uniform timeline that would theoretically be experienced by a user. The ordering of time is less explicit in Chen's description of the grid and the graph-based diagrams of the function of the CNS for managing disasters.

Engineers in the FIA projects build applications using time as an objectified concept that is communicated in both the function of the application and the schematics that describe how the application is supposed to function. The schematics represent how time is supposed to be managed within the FIA applications invoke well-worn, standardized concepts and representations of time that are often presented to users at the interface. The schematics that explain how this happens in the application are more interesting and a bit more chaotic. They indicate a discourse in which the organization of time-sensitive functions are balanced with the many technical requirements and imagined use contexts that applications developers and network architects use to troubleshoot and navigate their work. This notion will be further explored in the next chapter.

Flume and the Vehicular Video demo attempt to give the illusion of a real-time flow of content. However, even in these designs for the transmission of "real-time" content flows, there is still a buffer; there is still some friction that cannot be designed away. In the next chapters, we will see just how difficult it has proven for Gusev, Gupta, and Barrett to handle the friction that arises from all sorts of actors, from routers to the bit size of packets. It seems that, while theoretically there are many possible ways of thinking about the new affordances of the protocol (such as data and content) that exist at the network edges, this could be something exciting to try to reconceptualize. Instead, it seems as though they are either limited by their training in imagining possible user-facing temporalities in new ways, or bound by their conceptions of what users expect real-time flows to be and what they can comprehend. Perhaps it is a combination of all of the above in varying degrees. Similarly, the Mobility First CNS for Managing Disasters is a way of pushing technical efficiency to mobilize much-needed resources in crucial moments with a significant impact on individual and collective lives. Time pressure here means something different than it does in other projects. This is not only a type of pressure felt by humans related to their use of technology though it could be for first responders. More broadly, it is framed as a way in which technology can be demonstrably driven by human needs to positive material ends.

Time is not only assigned a shape that indicates a process, or the ordering of functions, it is also assigned characteristics as it passes in these schemas. Gusev’s discussion of uniform and non-uniform timelines draws this into clearer focus. It shows how engineers are taught to think of time and the temporal experience of those for whom they are designing. The way that time’s passage is characterized also suggests what might be possible within this design frame.

Despite their differing composition and aims, each application-level product in question renders time and technical processes in a relatively un-nuanced way, largely conceptualizing time as linear and unidirectional, and suggesting a particular globalized view of time. However, the ways in which these projects were described suggests project principals consider time to be more than a mere organizing principle for processing information. Though they might not have articulated it in this way, they sense that there are material and informational needs that are neither just technical nor just human. In this vein, there are some interesting overlaps in the ways that human time figures into the ways these different applications, demos, and grid structures are built and discussed.

Perhaps most interesting here is how the Flume code that actually drives functions links up with schematics, and thus suggests a discourse of time. Gusev thought about time in terms of organization of data into streams first, efficiency second, and user experience of time at the interface last. The FIA diagrams all show the juncture at which engineers balance the function of applications in relation to the structure of the data and the function of the network. For Flume and NDN, the schematics (particularly the one that shows the flow of data queueing and chasing through the application) show how flows of information are managed technically, focusing on code. It also shows how packets for streaming content are made discrete and organized temporally, then arranged into a real-time stream in NDN.

In XIA keeping latency low is important, but time is less of an organizing principle in the vehicular video streaming application than in NDN's Flume. In the latter case, the representations show how a user-facing application must be built differently to give the illusion of a real-time stream.

Finally, the ways that projects position themselves in relation to other industries and uses is reflected in their choices of applications that warrant their effort. REMAP's influence on NDN and Gusev working at REMAP under Burke aligns NDN with the audiovisual content industry: games, video, film, and televisual experiences. In contrast, XIA is located at Carnegie Mellon University in Pittsburgh, a university leader in robotics that is constantly being "raided" for tech talent. As just one example, Uber recently hired away prominent members of the CMU Robotics Department in their push to develop self-driving cars. Indeed, the city of Pittsburgh was the first city to become a testbed for the technology in Uber-owned vehicles (Kang, 2017). Thus XIA's focus on extensibility and mobility is in line with the development of these types of attempts to further automate transportation infrastructure. Finally, MF is positioning itself as a socially-responsible community member in its focus on social needs in disaster situations.

It is important to point out that these applications are in varying degrees of working order. With the exception of the Vehicular Video demo, they are still at the concept stage. Flume has been built out, but no demo exists yet. MF's CNS has been built out and tested, but it has not been deployed in any wider sense. Thus, while NDN expected to develop applications that would be integrated with NDN's own development, the project-development experience has not played out as planned. The possible reasons for this will be detailed in Chapter 5, but it suffices to say here that the stated goals and the internal goals have not always been the same. Projects often grow organically in response to specific calls for proposals or funding streams but are often rather rigid in the ways that they actually incorporate novel working arrangements.

Initially, representational images tied with each of these projects might not seem particularly relevant to the discourse of time or how time is built into these technologies. However, isolating these images from documents and triangulating them with the developers' own words about their conceptions of time yields richer results, and illustrates how engineers' concepts of time influence the construction of technologies. This investigation has revealed how these technologies become hardened examples of the engineers' conceptualizations of time, which would then influence a user's temporal experience.

The descriptions of each future networking architecture and the applications built over them show a set of underlying assumptions to be investigated in more depth regarding the relationship between speed, latency, and efficiency as terms used in the projects to describe how time is being operationalized in different material components of the network and application design.

Chapter 4: Technics of Time

Early clocks and timekeeping devices encouraged people to think of time as discrete and measurable seconds, minutes, hours, and days. Similarly, computers have further divided time to ever-smaller increments, transforming microseconds and nanoseconds into useful instructions for manipulating data. Time has become information as it has been transformed into billions of countless impulses of electrical energy which manifests in all varieties of computing technologies from geo-positioning clocks to the push and pull of the real-time web.

This chapter explores such transformations in the technics of time in the context of the three FIA projects, particularly the complex sociotechnical contexts that may shape network engineers' and designers' understandings of time as a computational resource and as information and how those understandings may shape design decisions across the three projects. *Technics* is used here in the classical sociotechnical sense elaborated by Mumford (1934), who used the word to define technologies as material devices and as the cultural knowledge, practices, skills, methods, and forms of social organization associated with technologies. Stiegler's (1994/1998) notion of technics falls in line with Mumford's but emphasizes how time and temporality shape, and are shaped by, sociotechnical systems. The aim here is to further tease out how engineers make decisions and construct technologies – that is, how they assert agency in the design process – with regard to the way time is measured and distributed through systems in ways that users cannot directly perceive.

As discussed in Chapter 2, the founding documents for the FIA projects all shared the goal of enabling faster and more efficient distribution of content between users though their methods for achieving this common goal differed (Mobility First, 2018c; Zhang et al., 2010; XIA, 2018a). However, another key temporal concept for all three projects was latency, the time it takes for a computational function to process. Engineers generally agree that latency should be low to achieve maximum performance. In this chapter, the analysis focuses on how these concepts might interrelate, in order to interrogate the projects' promises of new, user-facing temporal experiences; to examine how engineers reconcile social concepts of time with computational constraints in system design; and thus to illuminate how concepts of time may be integrated into Internet infrastructure.

The chapter begins with a brief historical overview of computational technology and time, and then it turns to an empirical analysis of code, hardware, and protocols as three sites of technical problem-solving in FIA projects where notions of time are brought into play. I discuss *efficiency* as the central or governing concept of time in the discourse among FIA engineers and designers, and its articulation with concepts of *speed* and *latency*. The chapter closes with some observations regarding the FIA projects' unfinished goals including those of increased efficiency as they face uncertain futures.

Computational Time and Technology

The concept of rendering time into an object in computational systems is not new. Charles Babbage's *Difference Engine* is often recognized as the first large-scale mechanized intervention into the bureaucratic documentation and counting of individuals as well as for astronomical calculation (Lindgren, 1990; Gleick, 2012). The importance of time as one of the first and most fundamental computational resources was highlighted by Ada Lovelace in 1843:

> In almost every computation a great variety of arrangements for the succession of the processes is possible, and various considerations must influence the selections amongst them for the purposes of a calculating engine. One essential object is to choose that

> arrangement which shall tend to reduce to a minimum the time necessary for completing the calculation. (p. 710)

The time it takes for a particular computational activity to function is now called *latency*. The analysis presented in this chapter suggests that speed and latency are encompassed in the concept of efficiency. These conceptual connections are briefly addressed in the conclusion of this chapter.

In this discussion, it is first useful to briefly describe how time became materialized into information in the history of computing. Prior to and during World War II, Claude Shannon and his research team at Bell Labs developed transistors that would permanently change the nature of communication across time and space (Waldrop, 2002). Transistors' capacity to sense and sort through electrical impulses to convey messages were rife with possibilities for investigation. Shannon (1948) is most well-known for developing a scientific theory of communication (information theory) that distinguished between *signal* and *noise.* His theory was intended to find a way to sort through the profusion of impulses generated and transmitted through a channel at any given point. Shannon referred to this concept of a message (as many at Bell Labs did at the time), or the voltage differentials in electronically conveyed messages, as *information* (Shannon, 1948; Waldrop, 2002, p. 32-36). This term signified something technical, bridging mathematics and engineering and eventually leading to computing as we know it today. The voltage differentials, or bits, carried in signals and sensed by Shannon's transistors were the stuff of information—signified as the binary 0-1 or yes-no. They remain the foundational material manifestation of information, generated through electricity and carried through transistors, each bit with its corollary in the real world.

As bits are material, they must be processed to have some meaningful result for human interpretation. Indeed, Blanchette's "A Material History of Bits" (2011) helpfully described how data, computation, and networking are all material processes with physical components that affect latencies in networked computation systems. Data in these systems are comprised of bits, with "magnetic polarities" and "electric voltage" differentials, then "circulated as physical products through resource stacks and layered chains of modules that work between applications and resources" (p. 1,042). This is how programmers and engineers understand computational infrastructure, and this material understanding of computation and networked computing resources is fundamentally linked to concepts of speed and time.

Just after World War II, John von Neumann built on Shannon's information theory to develop a model of serial computation (Waldrop, 2002, p. 32-65), which reduces all computational functions to sequences of atomistic instructions that move the data. This was convenient in its simplicity but created what systems architects call the *von Neumann bottleneck*, in which the processor can function as quickly as it can call data through a slower memory subsystem from storage (Blanchette, 2011, p. 1,049). Increases in processing speed over the last half-century relied on increasing the clocking speed at which instructions are processed and transistor densities that allowed larger troves of storage (p. 1,049).

At present, computer hardware, software, and networking protocols work in concert so that the central processing unit (CPU) of a computer, and each program it executes, consumes time. Time, then, is the resource used to manage these material bits in these computational settings. Electronic clocks measure the electricity that is the ultimate source of all functions; they serve such varied purposes as data sequencing, calculation, storage, and retrieval. The computer processes the voltage differentials of data coded into binary and stores these in the electronic medium. The clock measures its progress.

In what follows, I describe the modes by which engineers working on the FIA projects—NDN, XIA, and MF—articulate the complex sociotechnical contexts that influence the way a design functions with relation to time.

Solving Technical Problems

Although efficiency is a complex and multifaceted phenomenon, with numerous technical expressions, in the present analysis it emerged most clearly in three particular system components: code, hardware, and protocols. At these specific technical sites of solving technical problems, the engineers and developers interviewed for this study spoke most plainly about how they worked with time and understood it not only as a technical value, but also how they articulated time in relation to existing technical, social, physical, and political infrastructures.

Code

A program in *machine language* is "that representation of programs that resides in memory and is interpreted (executed) directly by the hardware" (Blaauw & Brooks, 1997, p. 16; in Blanchette, 2011, p. 1,048). *Programming code*, on the other hand, is understandable by humans, who write code in languages such as Java or C++, which is then translated to machine language by *compilers*. While all programs translate and execute programming languages and could be considered to be compilers, programming language compilers affect the run time of programming languages, that is, how fast the program executes on the machine (Blanchette, 2011, p. 1,048).

For example, Bjarne Stroustrup (1994), the creator of C++, noted that his intention was to develop a language based on objects and procedures) (p. 22). These procedures are also called *functions*, and they structure the program. C++ was developed first as C to more efficiently manage the issues resulting from the slow run-time of an earlier language, Simula. C++

improved upon C by keeping the efficiency intact while allowing programmers more flexibility and capacity for improvisation (Stroustrup, 1994).

Today programmers use higher-level languages like C++ or the like, but whenever languages with compilers are used, the compilers essentially analyze the human-written code so that it can be synthesized by the CPU or virtual machines (Blanchette, 2011; Mogensen, 2011). Languages use letters or symbols to stand for variables or functions called *tokens*. The compiler separates these strings of letters and symbols into meaningful *token streams*, that is, tokens are parsed into data structures that make sense to a machine and are optimized, so that meaningless code falls away (Mogensen, 2011). Compilers work to ensure that a program executes, but in doing so, they utilize CPU capacity and cause the program to run more slowly than it would otherwise.

Peter Gusev of NDN pointed out an issue that was solved relatively well in the Real-Time Video Conferencing (NDN-RTVC) app, which was a sequential numbering system for the data packets, and a forwarding strategy that allowed packets to remain available until they were used, that he developed in 2015. In an attempt to improve upon the RTVC app and add new, user-facing features, Gusev built a new video conferencing app, Flume, in C++ because this language operates with the least overhead in terms of computational resources and thus keeps latency low. It also allows NDN to operate locally without being connected to a more powerful computer testbed.

Thus, Gusev uses C++ for Flume and indeed for all applications he builds for NDN because he prefers it for real-time applications. It works at the level of hardware with no computational overhead, in contrast to a higher-level language like C#, which Gusev noted, “takes up hard drive space and causes latency problems. With real-time, you want something that has no extra baggage to slow it down" (P. Gusev, personal communication, July 20, 2017).

At Carnegie Mellon, XIA senior engineer Dan Barret stated that XIA user applications are generally written in C++ or C, depending on how developers want to write them. The team's rationale the XIA team employs is that it must be easy for someone who knows the specifics of XIA networking to write applications. The crucial issue is that writing applications should not be contingent on whether someone can learn new APIs, but whether they can understand how XIA addressing works to effectively highlight the functionality of the architecture. Barrett remarked, "Our daemons [processes like logging into the XIA network or caching data that are set to be triggered by other actions and run unobtrusively] are written in C++. Also, some are written in Python, which makes life easier for some things. Obviously, Python is a lot faster to develop in" (D. Barrett, personal communication, February 28, 2018).

In the interest of saving engineers time writing code, Barrett added that writing code is secondary to the operation of conceptualizing applications and how they might work more efficiently; that is where the excitement is. Engineers, he observed, were able to make stock applications work using XIA functionality and were able to get some applications and demos out quickly using a Python API library (D. Barrett, personal communication, February 28, 2018).

Gusev's explanation of the way code works in NDN, and Barrett's explanation of code in XIA reveal two related assumptions emerge regarding code and time in technical projects. First, each of the developers prefers programming languages that have the least technical overhead (i.e., use the least computational resources) and can function most quickly. Second, using C++ (in this case) saves individual team members time. It allows them to bring in collaborators in a more straightforward way so that the new participants do not see learning a new programming language as a barrier to entry.

However, Mobility First's Jiachen Chen stated that when evaluating his Content-based Emergency Response Application with MF, he did not worry as much about the performance (i.e., speed or responsiveness) of the application because he was simply attempting to prove that the naming system worked. In cases where he is interested in merely proving that an application functions over MF, he uses C# and Java. In these scenarios, he is less concerned that the application performs optimally. C# and Java differ from C++ in that they contain compilers to check the code as it is translated into machine code. This tradeoff increases latency but ensures that the application code will effectively function. He explained:

> The reason that I choose C# and Java is they have memory management. You don't have to worry about how to, you know, to allocate memory and their free memory. That is kind of distracting, I would say. While simulating, I can sacrifice a little bit of performance. You know, if C++ can run it in one hour, I'm fine with Java running it in two hours or a simulation. But I can shorten the programming and the debugging time by a lot. I only need to focus on logic. That's why I choose those managed languages. (J. Chen, personal communication, February 28, 2018)

The engineers all articulated how their technical goals are influenced by the coding languages they choose to use. This is not surprising. The engineers' articulations of *how* to build given the temporal constraints or advantages of coding languages illustrate that they choose languages to reduce application latency in certain situations. Or, they may choose a particular language to save work time. Where performance is not an issue, bulkier languages such as C# and Java are chosen because they are able to carry and organize information internally over time in the form of internal memory management, which eliminates the need to design for memory allocation.

Chen's framing of the trade-off between memory (understood as information management over time), and performance (understood as low latency), shows how time is a resource in these decisions but rarely articulated as such. In addition, time is made into information by assigning data and content timestamps, which determine how the packets, or the data attached to them, are organized and transmitted through the network.

Hardware

Blanchette (2011) describes how processors and CPUs contain circuit logic that is designed to execute programs; in turn, these programs "provide instructions, each directly operating on the processor's hardware by performing the necessary sequences of logical operations (opening and closing gates, moving data to and from memory, etc.) to produce the appropriate result" (p. 1,048). At the level of individual computers, and indeed, in terms of configuring a network to work appropriately, there are a number of low-level processes that must happen with regard to real-time applications. First, the data must be time-stamped.

Gusev explained that every time one starts an application running on NDN, it starts an internal clock that operates at the millisecond level:

> For this project and for all the projects I work on here, my clock runs in milliseconds. I am not interested in the [shorter/more minute] microsecond level. It's really overkill; not necessary. People theoretically using the application don't notice milliseconds and definitely not microseconds. Every time a packet is received, that packet queries the computer's internal clock and stamps it with the time. This allows packets to be time-stamped or sequence stamped so as to arrange the packets into a real-time stream. (P. Gusev, personal communication, July 20, 2017)

Here, Gusev makes two important points: (a) that it is common for software developers to assume that users tend not to notice short time delays on the order of fractions of sections and (b) that the internal clocking mechanism is one of the most important hardware components in the orchestration of the Flume app. The ordering of the packets into a flow that appears to be real time depends on the clock's allocation of timestamps.

Regarding application testing, Gusev said, "We absolutely measure the demand on CPU process time, but it's not hardware-accelerated like with Skype," meaning that the Skype application uses some of the hardware to perform some functions more efficiently than is possible in software running on a more general-purpose CPU like that of a personal computer, for example. "We are just trying to run a simple video on NDN, and that already places enormous demands on CPU in terms of the bandwidth of the computer" (P. Gusev, personal communication, July 20, 2017). Thus, process time is generally slower for Flume than it would be with a video conferencing application like Skype.

Although process time may not be Flume's primary concern, Gusev's remarks do suggest that NDN engineers may feel at a disadvantage in comparison to, or pressured to compete with, IP-based computation. It also shows that the engineers' designs are bounded in any case by what they believe users will tolerate in terms of responsiveness and time delays.

XIA's Vehicular Video demo encountered an entirely different set of problems. The senior XIA developer responsible for the demo, Nitin Gupta, reported that XIA developers work with Click, a commonly used router toolkit developed by Eddie Kohler at UCLA, on which Gupta builds applications. While using custom hardware can be useful in some scenarios, he said, it is often very challenging to work with this hardware for a number of reasons:

> Of course, the vendors are one thing. You have this piece of hardware. It's locked down because they don't want anybody meddling with it. In practice, this hardware is supposed

> to be tamper-proof. They don't want people running random stuff on it, so bypassing that, with or without vendor support, is not easy.
>
> Then, dealing even with parking services ... This [Vehicular Video demo] was actually done in a parking lot, so we had to do a lot of explaining because we were driving around slowly with strange equipment. (N. Gupta, personal communication, February 28, 2018)

These remarks indicate that in many cases the temporality of the application depends on the prerogatives and constraints imposed by outside hardware vendors whose concerns are more focused on control of their products than on innovative research. Second, the Vehicular Video demo is dependent on wider physical infrastructure and how (and by whom) it is controlled and regulated, as Gupta's quote about having to explain the team's activities to the Carnegie Mellon parking services suggests.

MF architect Chen also noted issues with Click routers, but they were different than those Gupta mentioned:

> There is always a tradeoff between flexibility and performance. If you want to design a general-purpose thing that everyone can just write some piece of code and make it run, it won't be that high performance. By high-performance, I mean, you know, tens of gigabits per second. If you're thinking about like one gigabit per second, that is fine. That is fine with Click, but if you want the backbone router kind, like 40 gigabits per second, yeah, I don't think Click is going to do that.
>
> That is the problem that, well, that is not the problem yet, because currently, we don't have the resources to do that 10 gigabit per second, you know, links, or 40 gigabit per second links. That is not there. Our main purpose is to test our protocol and make it

> work. That means whenever it works at like 100 megabits per second. Sometimes, we even need to lower the speed, make it one megabit per second or even increase the latency, which means we may also deal with satellite links. That is like a 300-millisecond round trip, right?
>
> So, this is what we are doing. Currently, we are not really dealing with like ultra-high performance, but at this point, Click is doing well, I would say. (J. Chen, personal communication, February 1, 2018)

These discussions speak to three primary challenges involved in dealing with hardware. First, as in the case of NDN's Flume, making the application work with the hardware is not a trivial issue and must be approached carefully. Similarly, the MF team is still developing a protocol for working with hardware. Regarding XIA, while the project takes a more coordinated approach to network design and applications, project time is saved by building on top of others' proprietary hardware, which causes problems of its own. Vendors do not want researchers modifying their hardware, and they insist on supplying their own support for their machines. When companies are bought or merged, or drop product lines, hardware support is often abandoned. As Gupta observed, research projects like his exist in a world bound by all sorts of social, cultural, economic, and political considerations.

Protocols

Protocols have long been understood generally as rules or guidelines, but in the era of networked computation, they also have become "standards governing the implementation of specific technologies" (Galloway, 2004, p. 7). In networking, protocols determine specific procedures for transmitting data across networks, which require messages to be sent requesting what data is needed, where it goes, or confirming its receipt of this data, in concert with the careful navigation of the alphabet soup of networking protocols.

Thus, before turning to the FIA cases, it is useful to review the features and operations of what is called the *network stack*. As stated in previous chapters, networking ensures the transmission or communication of structured data from one computer to another. It is assumed that the transmission will be error-free, with the highest throughput and lowest latency possible.

In 1978, the ISO adopted the OSI model that standardized how networking protocols should function together in a networking stack, which guides the production of bits from physical voltage differentials to applications (Zimmerman, 1980). The model is based on layers of functionality built on top of one another. The *physical* layer is the most basic physical conduit to carry voltage differentials. The *link* layer manages the communication links that send the 0s and 1s. The *networking* layer is responsible for the transmission of packets to and from users. The *transport* layer checks packets as they are sent and arrive. Ultimately, the *application* layer provides services, such as network access, to software and other applications like Microsoft Word or Skype. The Domain Name Service (DNS) mentioned in Chapter 2 is an example of such an application layer protocol that translates a human-readable name into an IP address to access network services. Each layer builds on the services provided by the layers below it. OSI stack layers can have multiple standards for service. For example, for layer 3 there are currently three standards: IP, IPv4, and IPv6.

But despite the fact that the layers are standardized, *assuring* that services operate is anything but simple and straightforward:

> There are significant material constraints: (a) signals must travel over physical media, whether air, copper wire, or fiber optic, each with different characteristics with regard to susceptibility to interference, dissipation, capacity, and cost; (b) the physical

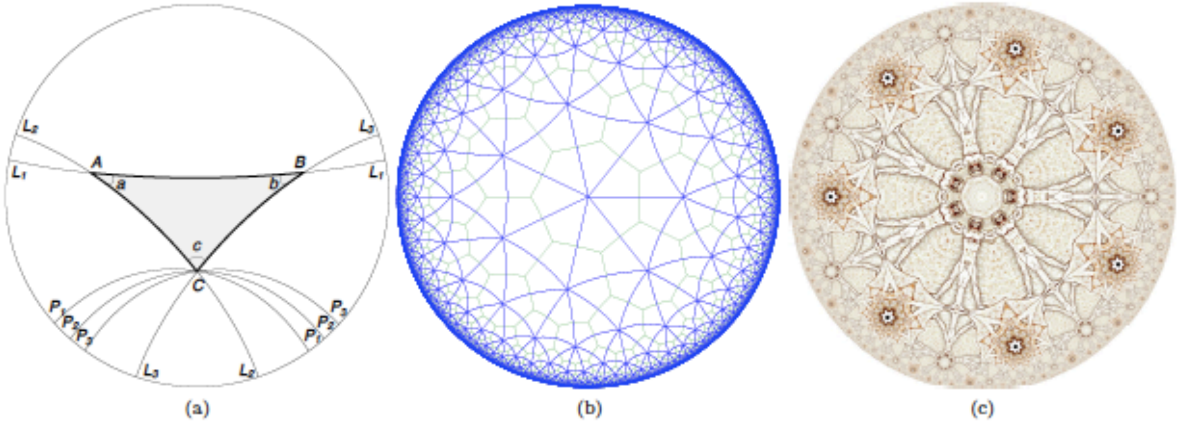
> infrastructure necessary to provide point-to-point communication is enormously costly, and consequently driven by particular economic dynamics, including network effects, and economies of scale and density; (c) these costs require that communication links be shared among multiple users with the corresponding need for fair policies to manage traffic and its attendant inefficiencies. (Blanchette, 2011p. 1,051)

Packet switching is an important concept in the network layers. The idea for packet switching was developed by Paul Baran (1964), and put into practice by Leonard Kleinrock's (2007/1964) packet queueing strategy. Vint Cerf and Bob Kahn's (1974) concept of Transmission Control Protocol (TCP) checks packets and controls the flow of limited communication links, bandwidth, and changes in traffic (Blanchette, 2011, p. 1,052). However, there are some problems with packet switching using TCP/IP protocols. There is no guarantee of minimum latency in TCP/IP networks. This causes problems for real-time or streaming applications (p. 1,052). As network latency increases, it causes time-sensitive applications to time out or fail (p. 1,052). Increasingly there are many different types of applications with different network requirements which, as the work of the FIAs demonstrates, is a complex problem for which traditional packet switching over TCP/IP does not ensure optimal performance, throughput, or speed.

Within the networked system, there are networking protocols that allow the systems' component hardware to interact with the networking stack. Network Time Protocol (NTP) is a step more complex than system time. One of the oldest protocols still in use today, NTP synchronizes computers within a network to the same Coordinated Universal Time (UTC) (Mills, 1992, p. 2). Its specialized algorithm employs UTC to select accurate time servers to "maintain accuracy and robustness" of packet transfer across networks, "even when used over typical Internet paths involving multiple gateways, highly dispersive delays and unreliable" networks (Mills, 1992, pp. 1, see also 37–39). NTP can be used in any network in which computers send and receive time-stamped data issued from IP (see Mills, 1992, pp. 1-3).

Routing strategies are protocols for transmitting data that are bound with a specific discourse of time in FIA projects, and especially in NDN. In talking with Gusev, I found that the concept of hyperbolic routing is one aspect of NDN that is most concerned with the speed and efficiency of data transmission. A hyperbolic routing strategy is distinct from a surest-route strategy (the most commonly used routing strategy in today's Internet), which ensures delivery of a packet, regardless of its speed or efficient transfer. Instead, hyperbolic routing functions on the basis of geo-coordinates and timestamps, which it uses to make a new calculation, assigning costs to different routes and taking the "cheapest" route. In speaking about a new augmented reality project he is working on that runs with the RTVC codebase, Gusev said, "This [cheapest route] is a number that takes into account the distance between geo-coordinates and speed, and routes data accordingly" (P. Gusev, personal communication, July 26, 2017). In trying to test the project, testbed operator John DeHart found a problem with the hyperbolic routing strategy misinterpreting timestamps given to packets using Flume. Colleagues at Zhang's IRL fixed the issue, and now the entire project runs more efficiently. This is an example of debugging that can only occur when applications are built on top of protocols. It also shows how the poor performance of an application, meaning that it stalls out or runs slowly, can help diagnose problems in the network.

Thinking of "hyperbolic routing" implies an interesting coupling of space and time in the form of a complex geometric shape – the hyperbola. This routing schema is often represented using the Poincairé disc model, shown in Figure 4.1**,** as a two-dimensional circle with nodes distributed primarily, though not exclusively, toward the perimeter, and arcs of connection between these nodes to indicate the fastest path between any two coordinates.



(a) (b) (c)

FIG. 1: (Color online) Poincaré disk model. In **(a)**, $L_{1,2,3}$ and $P_{1,2,3}$ are examples of hyperbolic lines. Lines $L_{1,2,3}$ intersect to form triangle ABC. The sum of its angles $a+b+c<\pi$. As opposed to Euclidean geometry, there are infinitely many lines (examples are $P_{1,2,3}$) that are parallel to line L_1 and go through a point C that does not belong to L_1. In **(b)**, a $\{7,3\}$-tessellation of the hyperbolic plane by equilateral triangles, and the dual $\{3,7\}$-tessellation by regular heptagons are shown. All triangles and heptagons are of the same hyperbolic size but the size of their Euclidean representations exponentially decreases as a function of the distance from the center, while their number exponentially increases. In **(c)**, the exponentially increasing number of men illustrates the exponential expansion of hyperbolic space. The `Poincaré` tool [1] is used to construct a $\{7,7\}$-tessellation of the hyperbolic plane, rendering a fragment of *The Vitruvian Man* by Leonardo da Vinci.

Figure 4.1. Hyperbolic routing tessellation (Krioukov, et al., 2010, p. 2).

In any case, hyperbolic routing associates a geometric shape to real geographical coordinates, places, using computer-allocated timestamps to determine the speediest path for packets (Krioukov et al., 2010), or in the case of NDN, the data. This mode of routing, also called “greedy forwarding,” is specific to NDN, and distinct from and touted as faster than the current Internet, which prioritizes the “surest route” for packets to travel, rather than speed.

This simplified discussion of hyperbolic routing shows that when more efficient communication is the technical goal, the conceptual models for achieving this must be put into practice by project designers, Gusev in this instance. Time is made discrete and assigned to packets in the form of timestamps. This is a concrete instance in which time is made into an object and manipulated to achieve faster communication speed, albeit still theoretically, using NDN.

With regard to Quality of Service (QoS) issues, Gusev commented, “We aren’t really thinking that much about QoS issues like bandwidth, because the overhead for the packet header for the data alone is like 30% of its size, which is really inefficient” (P. Gusev, personal communication, August 2, 2017). The applications are built to work with intermittent connectivity, so if the network connectivity is irregular or unstable, any application can still work. Gusev reported that when developing applications:

> We work on algorithms first and make sure they are configured properly. Once that is sorted, we are very concerned with how well the algorithms work in a particular scenario. Generally, we aren’t as interested in optimization as we are in just getting the applications to work (P. Gusev, personal communication, August 2, 2017).

The RTVC application is the most optimized, Gusev said, because he actually had time and funding to work on it.

Networking architects and testbed managers did not skip a beat regarding this notion of the temporality of protocols. John DeHart, the primary NDN testbed manager at Washington University even noted that time was one of the main problems he grappled with. “Time is such a problem for me,” he said. “Getting all the equipment synched to run so that we can even see how things are running is incredibly difficult. You know where we have most problems—NTP” (J. DeHart, personal communication, November 14, 2017). He noted that synching NTP, much as I had discussed with Zhehao Wang at our very first meeting, remains a difficult issue for network engineers and applications developers attempting to obtain metrics on how well their designs perform.

Regarding how NTP functions in the Flume app, Gusev said, “With Flume and with RTC, we never used NTP to run the application because it’s not really a thing in the wild.” In real life, computers are always out of sync. NDN projects use NTP to run tests and to get metrics on network function. For example, Gusev said, “We may use it if we want to run a test to know whether the actual latency between producers and consumers is okay or needs to be optimized” (P. Gusev, personal communication, July 26, 2017).

With MF, NTP is also an issue in testing to gauge application performance. However, Chen stated that NTP was not as much of an issue when developing the MF protocol because they rely on the Open-Access Research Testbed for Next-Generation Wireless Networks (ORBIT) laboratory, which is comprised of several test domains in which experimenters can use the hardware provided by Rutgers’ WINLAB for use in wireless experimentation (WINLAB, 2018). Unlike NTP, which synchronizes participating computers to the same UTC using timestamps, the ORBIT laboratory allows synchronization on the basis of GPS.

> We use NTP sometimes in the evaluation. We have to synchronize all the machines because [we wanted] the timestamps on those machines [to be as] accurate as possible. Then, we can know, okay, how much time is spent where, but when designing the protocol, we don’t rely on timestamps. You know, if you rely on timestamps, that protocol really isn’t working well, right? So, yeah, we would prefer those machines to be synchronized, which is doable in our ORBIT, which perfectly synchronizes each machine and each node via GPS messages (J. Chen, personal communication, February 28, 2018).

XIA seeks to reinvent the entire protocol stack, and so is not as interested in conventional metrics. As each network entity is identified, they do not all have to be synched, so NTP is not an issue. The Vehicular Video demo shows XIA’s ability to communicate with these DSRC access points. DSRC is a protocol accepted by the Federal Communications Commission in 1999 that "allows short-range, wireless links to transfer information between vehicles and roadside systems" (Federal Communications Commission, 1999 p. 1), such as automatic toll billing and the like. DSRC radio has limited range, so as indicated in the Vehicular Video demo described in the last chapter, there would need to be a number of DSRC-emitting terminals along the roads for the Vehicular Video demo to become something that would work on a larger scale. Indeed, the power of Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications is the network effect, which only occurs when there is a critical mass of vehicles with this capability.

At present, performance seems to be less of a conscious issue with XIA and MF than with NDN since XIA and MF seem less interested in proving anything in relation to current protocols and more interested in showing their capabilities in other ways. Though NDN has big plans for hyperbolic routing, application and network performance in NDN is severely limited. This is something that Gusev is working on. In any case, NTP is critical in assembling the NDN testbed, but MF has its own ORBIT testbed that tests across a number of synchronization scenarios in addition to NTP. The DSRC protocol is important in the XIA Vehicular Video demo, which is interesting because the protocol is overseen by the government agencies, the FCC, now in partnership with the Department of Transportation (Department of Transportation, 2018). Nearly all of the other standards mentioned through this paper are overseen by private sector or non-profit organizations. In each of these cases, the FIA protocols must consider and effectively design in accordance to long-standing, external standards and protocols, if any of these FIA networking protocols are to support higher-level applications with adequate performance and thus encourage buy-in.

Thus, QoS issues also crop up in MF in various ways, while NDN and XIA are not yet concerned with QoS. Chen stated that there are two levels of granularity in MF with basic service IDs, one that provides reliability and another that does not. At the level of MF's virtual networks, the MF team uses SDN-like solutions built on top of MF to specify QoS issues such as virtual topology, bandwidth, and latency.

With regard to QoS, it is interesting that although MF claims it is not interested in scaling up to build applications or do anything more than develop standards, their solutions allowing QoS to be built into MF are more advanced than those used in NDN and XIA. This fact highlights the ways in which each of these projects has different goals and approaches to the concept of performance speed. In this vein, it is useful to consider how temporal concepts of speed, latency, and efficiency were articulated in all three projects. Overall efficiency is the primary technical value articulated by the FIA project principals and documents, and it is the only value that relates directly to time, but its importance in the design process is considerable. Managing latency, or keeping latency low, is an expression of efficiency articulated at more granular levels of technical work. Speed, on the other hand, is mentioned as a subset of efficiency that faces users at the level of applications or interfaces, and would so seem to be linked to a social value of time.

Efficiency

A primary goal of networking research is building faster networks. This was reflected in a focus on efficiency in the many of the NDN, XIA, and MF documents. Shilton (2015) found that with NDN, efficiency was often articulated as *dynamism* and in comparative statements like, "Content transfer via [NDN] is always secure, yet the results show that it matches the performance of unsecured HTTP and substantially outperforms secure HTTPS" (Jacobson et al., 2009, p. 10, quoted in Shilton, 2015, p. 9).

From Lixia Zhang's, point of view, efficiency drives Internet technology:

> Very often people talk about efficiencies. I remind them that the most efficient transmission technology is still the old telephony circuit switch. How come we no longer have that old telephony, most efficient circuit switch? That is because technology has moved forward so that we can afford some less efficiency to achieve other functionalities. So what drives technology forward is really the user demand, the applications. What enabled the design moving forward is the technology.
>
> One should also understand: What NDN does is also the result of technology advances. Back twenty years, the NDN proposal would not help anyone because the processing, the memory, the storage, and even the transmission capabilities back then, were way limited than what we have today; and also what we believe will come in near future. So as you probably know, the technology always moves forward. That actually pulls or enables the design. (L. Zhang, personal communication, September 22, 2016)

These remarks encapsulate the model by which NDN network engineers think about values in design as discussed in Chapter 2. User demand is understood superficially in terms of the technological functionality at the application layer, instead of any complex reckoning of what social values, hierarchies, and other ethical considerations might actually affect user activities, broadly defined. The most frequently expressed values in the NDN founding documents were those responding to technical pressures. This is not surprising in a research setting where technical innovation is the primary motivator and marker of success. And indeed, many of the values emphasized by the NSF request for proposals were technical values such as scalability and reliability (National Science Foundation, 2010).

Barrett said in-network caching is one of the primary ways that XIA promotes efficiency:

> If we're dealing with chunks and a client makes a request, and say we're trying to get it from you [in California], but there's a router in Kansas or something that has the data. As the request is passing through that router, it'll say, "Oh, I know about this thing. I can give it to you. You don't have to go all the way over there and get it." We can move content closer to people, sort of like what NDN does, but you have to tell it which content delivery method to use. XIA does it opportunistically … So we can short-circuit the network, so to speak, to improve efficiency. (D. Barrett, personal communication, February 28, 2018)

MF project documents boast a "fast global name resolution service combines network efficiencies" (Mobility First, 2018c). Raychaudhuri clarified in a 2017 conversation:

> The name resolution service can have different designs. There's one which we have which is much faster than the basic one. So fast means that we can look up a name in a book in ten milliseconds, and that part of the design is something that we worked on. We have a couple of nice papers on that topic. (D. Raychaudhuri, personal communication, August 17, 2017)

Thus, MF is looking to eliminate most kinds of two-way handshakes and control signaling that are used currently in the Internet. Raychaudhuri gave an example in a 2017 conversation: as one mobile phone accesses the Internet through one wireless network, at least six messages that go back and forth before a data packet can be sent. As he said (see Chapter 1), "If you take a photo and try to send it to your friend, there's a process by which there are 26 messages going back and forth before that photo itself can be sent. So that leads to a lot more latency, which we try to eliminate" (Raychaudhuri, personal communication, August 17, 2017). While efficiency is an easily articulated design value for engineers, it is also imbued with issues of time. Although efficiency balances computational resources like bandwidth and storage, the simplest computational resources are those of computation time (the number of steps necessary to solve a problem) and memory space (the amount of storage needed *while* solving the problem).

Thinking about efficiency shows clearly how time is considered a thing. Again, as seen in the last chapter, time is considered as a reified linear trajectory, a computational resource that can be broken into many subsets, assigned timestamps and organized accordingly—not only in these complex protocol projects, but also in the larger context of network and application engineering. Three resource subsets are particularly relevant here: (a) memory as information with duration, carried with data and packets in all three projects, (b) the organization of functions in relation to time through code and how the choice of code handles the packets of different sizes, and (c) the ways in which efficiency is constrained by protocols such as NTP or DSRC.

In the FIA cases, efficiency refers to the use of computational resources through the entire process from protocol to the application, and latency management happens both at the level of the protocols and the level of applications though the concept of latency at those different layers means something very different. High performance can be seen as an intermediary between low latency and the concept of efficiency. In any case, the leaders of each protocol project do not envision that their specific protocols will have much to do with changing the user-facing speed of applications, but that their protocols will each offer a new palette of possibilities at the application layer because of how protocol decreases network latency or enables higher performance at the network edges.

Latency and Speed

The discussion to this point demonstrates that latency is a powerful concept that is used to describe how the technical system components feed into a particular design's function, and thus increase latency or hamper performance. To reiterate, latency is the time a particular computational activity takes to function. In the context of the FIA projects, as we have seen, code, hardware, and protocols all introduce or decrease latency that affects the engineers' ability to develop efficient designs.

Generally, the principals alluded to, but never clearly articulated idea that the concept of speed relates to user-facing temporal experience. Moreover, the ways the principals articulated speed is particularly evocative of how they view the advantages of their respective projects. However, engineers have a hard time effectively building for protocol and interface speed in their work, for all of the reasons addressed in this and the last chapter.

Jeff Burke noted that, while NDN is just a networking solution that seeks to improve efficiency in the transmission of data over the Internet, it is possible that some notion of faster user experience features might be possible:

> NDN is not going to change the speed of light. It's not going to change the typical behavior of networks. Is it going to be the same for the end user? I'm not sure. For example, maybe the idea of scrubbing video that's streaming, because of the way that it happens on NDN versus how it typically happens on IP—something like random access into video may actually perform better. While you're not talking about fundamentally the network, I'd say the application-level behavior might be different.

> I think there will be benefits when we leave linear video behind. If we're interested in applications that do more real-time selections of—everything from the perspective on a scene from an immersive camera or light-field camera—anything that involves making quick decisions about what's being delivered over the network. There may be benefits to performance that would be perceived by the end user, but I am not sure how.
>
> You could always make it work in IP, but in ways that are simultaneously very proprietary or very brittle underneath. The architecture has probably better affordance to random access to content—efficient random access to content because each request has a name that expresses what you want. So to direct what you want at packet granularity—you could probably do that better on NDN. That probably would have an impact on what the perceived real-time behavior is of the network. It's not a fundamental difference; it's just it has better affordance for building those kinds of applications.
>
> We're just not doing that exactly yet, though. When we first built video streaming—not conferencing, but video playout—one of the things we did was we named all the data based on a frame number so that you can, with the very first request that goes to the network, more or less, start getting back the frame that you want. It doesn't quite happen that quickly in the HTTP world. So I do think there are those kinds of [possibilities]. (J. Burke, personal communication, September 12, 2016)

Similarly, Gupta reiterated that they are just building out a networking architecture, the way XIA conceives of extensibility will be faster or will beat other ways of joining networks:

> What we have built is an architecture, or a prototype of an architecture. We were not specifically focused on making it faster or do things faster than what the current Internet

> does, but yes, there are cases … The network joining stuff is going to beat pretty much any current way of joining networks. (N. Gupta, personal communication, February 28, 2018)

Barrett went on to claim that, while the speed of joining networks in XIA might be better than it is currently under IP, the size and process of assigning cryptographic identifiers on packets that will inject a small amount of latency into the system, a term he uses here to mean the opposite of speed or high performance:

> Since we are running on top of Click, which is a slower application—a slower framework—we cannot really talk about efficiency or lowered latency. Another example people think of are XIA's crypto-based addresses. So, what comes to mind is, "Oh, now that you're doing these more complicated addresses for—and doing cryptography to sign messages, won't that have an impact?" The answer is yes, but the impact is very minimal because most of these operations can be done in hardware. So increasing latency is kind of not an issue. (Barrett, personal communication, February 28, 2018)

He suggested that writing secure addressing in the kernel would make applications a lot faster:

> Our message headers are a lot bigger than a TCP packet, which is maybe what, 20 bytes or whatever. We're probably close to 200 on an average packet that we're sending. Our headers take up a lot more space, but they give us a lot of options for routing. (Barrett, personal communication, February 28, 2018)

These remarks suggest that while efficiency is the most frequently cited technical value in projects like NDN and the other FIAs, latency management and speed can be understood as subcategories of efficiency. Reducing latency and increasing performance are persistent topics in engineers' articulations of time or temporality in these projects. Speed, on the other hand, is more of a countervailing concept that forces technologists to think about the social value of their work, particularly with respect to user attention.

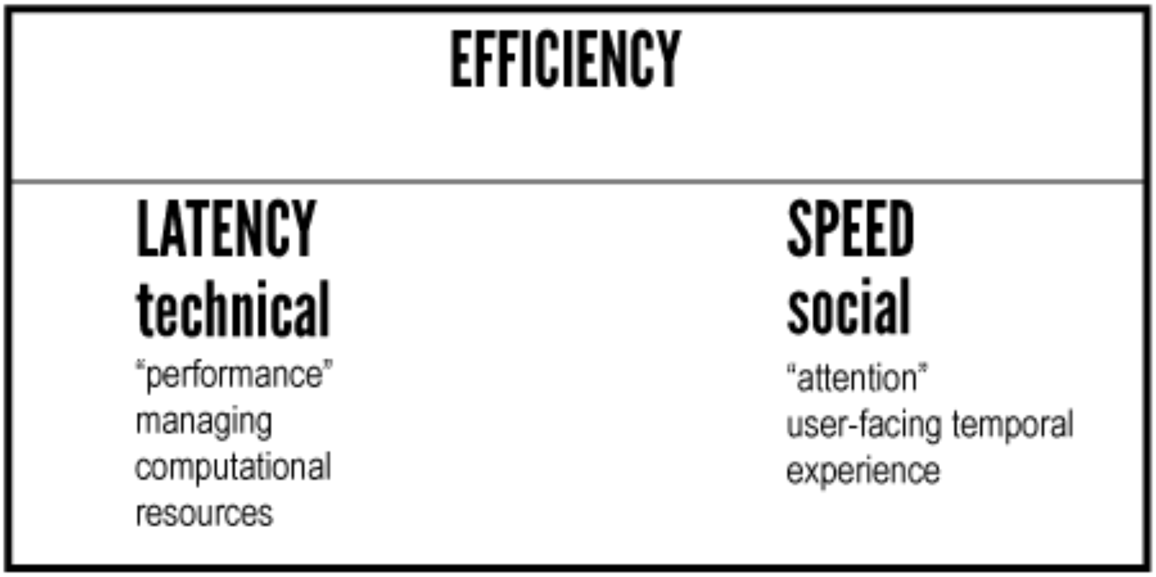


Figure 4.2. The relationships among efficiency, speed, and latency in FIAs (Paris, 2018).

Figure 4.2. shows how I conceptualize speed and latency as dimensions of efficiency that are respectively the social and technical faces of this crucial concept in FIA engineering. In technical practice, smaller-scale latency management in system components makes user-facing performance or speed possible. Furthermore, locating speed and latency management as subcategories of efficiency highlights how dogged adherence to the technical design value of efficiency seeks to make the design appear frictionless, and as a byproduct, makes technical underpinnings of the system invisible.

Materiality and Cultural Coordination of Technical Time

With the discussion presented in this chapter, we see how articulations follow Mumford's (1934) sociotechnical definition of technics, which includes a consideration of the materiality of technology as well as a culturally-based understanding that influences practices of technological development and use. Stiegler's notion of the materiality of the technics (1994/1998) that shape and are shaped by human temporality and the time of social coordination are also relevant here. In the remainder of this chapter, I show how materiality is bound up in the technical concerns articulated in the FIA projects, and how it is a determining factor in the ways time is conceived and expressed in each of these projects. Materiality also influences sociocultural considerations of coordination in and around technical projects.

The discussions presented in this and the last chapter support the idea that networking protocols are technologies of time that materialize time into information in a way that is beyond the perceptual capacities of humans, while still invoking the human temporal perception/experience as a partial justification for their work. Time is materialized into information as packets and data are named, time-stamped, and transported in order as they move through the new FIA networks, as, for example, in Gusev's discussion of the way timestamps are allocated and used in the hyperbolic routing schema. Here time is made into a thing with the timestamps and is used in conjunction with geo-coordinates to determine a most efficient path for the data to take. This most efficient path entails not just the lowest resource cost to the network, but as a result of this low overhead, it would also theoretically cause the network to function faster.

The concept of time as a material resource in the work of these protocol projects is one that the engineers readily acknowledge. In-project standards, such as the use of C++ code, that are used to develop applications due to their low overhead, thus lowered use of resources in the network and in any user's CPU. In some cases, like the one Chen mentioned, when testing a certain naming scheme or application, it may not matter that the design runs fast. In Chen's case, he only hoped to understand if and how the CNS works over the MF network, and so he used C#

because he was more interested in checking the code and ensuring the application worked than having it perform efficiently. Preexisting protocols like NTP also impart material requirements (the need for time-stamped data) in the process of design and as such represent a fundamental obstacle or technical concern that must be attended to in the design processes of ordering functions in technical systems.

The discussion here also suggests another facet of Mumford's and Stiegler's emphasis on the materiality of technics in the contemporary technological era. The technologies they wrote about were and still are material – physical objects that mediated time in Stiegler's case or performed some other social or cultural mediation, in Mumford's case. Similarly, these new networking protocols are not only based in but also concerned with materiality. The engineers' technical goals – primarily, but not exclusively, efficiency – structured every choice they made. The analysis presented here indicates that the technical design value of efficiency is primarily a material concern, that is, one of maximizing use of material computational resources and keeping latency low, so that the system can perform faster.

Gupta discussed how the Vehicular Video demo made use of the material infrastructure at the CMU campus. If the application (or anything similar) were to run at a wider scale, it would entail the coordination of physical infrastructure along highways across the country. This would require not only technical precision in communicating with stuff of infrastructure such as parking garages, routers, cars, et cetera that are necessary to fulfill the goals set forth by these subsets of the larger FIA projects, but also the participation of the people that govern these physical infrastructures, from standards bodies and the Department of Transportation to car manufacturers, not to mention car owners and users.

This chapter also revealed the technical decisions meant to facilitate the sociocultural coordination of work. Barrett mentioned that XIA uses C++ code for all application development that language because has low barriers to entry and allows new collaborators to focus on the important issues of technical design instead of learning a new language. In this case using C++ saves everyone time and assumes that the optimization of the work will happen at some later date.

Similarly, protocols by their very common definition entail sociocultural coordination. Gupta mentioned that the DSRC protocols were crucial in the success of the Vehicular Video demo. DeHart maintained that NTP is instrumental in running the testbed. These protocols are enduring standards that have been established by standards governance bodies for use in communication over the Internet. They entail easier coordination between different groups in building out Internet-based technical systems,

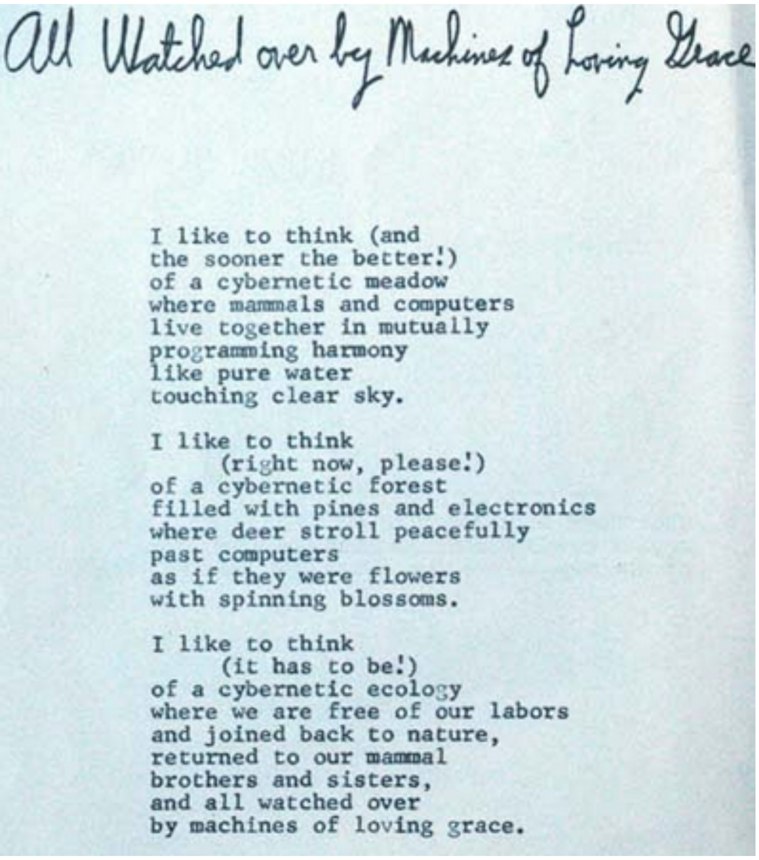
This chapter also points to ways in which the coordination of these networking protocol projects entails the participation of institutions and private companies that own or administer hardware. Recall Gupta's harrowing discussion of choosing to use Click routers, then having problems with them and encountering difficulty with troubleshooting because Click had been bought out and no longer offered customer service. At its core, this is an issue of social coordination and collaborative problem solving; Gupta got in touch with someone who used to work for Click to work out the problems in that particular instance. This amasses cultural capital not just for the attendant who helped him but also for Gupta himself who now has this knowledge and a contact who can help him with problems with Click that will undoubtedly arise in the future.

Finally, in the FIAs, we see that technical materiality has directly caused problems with the social coordination of these protocol projects. While efficiency and a faster Internet were a partial stated goal of each of the FIAs, particularly NDN, building out the network and troubleshooting has taken more time than they had originally imagined. Principals from each FIA articulated how the namespace load carried with each piece of data or content project is still quite bulky, as it literally takes up more physical space and resources to process, and thus contributes to the material load of these technologies. Thus the social and economic good of the speed touted by these FIA projects that would come from optimization has not yet come to pass.

Much work still must be done to get the FIAs' functional efficiency to be on par with the conceptual efficiency touted by project principals of each of the FIA projects. Each of the FIAs hopes that once they have partnered with the Department of Defense or other entities, these issues of efficiency will work themselves out. It remains to be seen whether this imagined efficiency, or any combination of the related concepts discussed in this chapter, will come to fruition for any of the FIAs.

Chapter 5: The History of a High-Performance Future

This chapter examines different conceptions of *the future* in FIA projects, especially how perceptions of personal experience and speculation about the future were articulated in participants' expectations about the respective futures of these technology projects. To begin the discussion, I present some visions of the future that seem to align with, and perhaps portend, the FIA developers' and engineers' assumptions about a future world in which their designs will exist.



All Watched over by Machines of Loving Grace

I like to think (and
the sooner the better!)
of a cybernetic meadow
where mammals and computers
live together in mutually
programming harmony
like pure water
touching clear sky.

I like to think
    (right now, please!)
of a cybernetic forest
filled with pines and electronics
where deer stroll peacefully
past computers
as if they were flowers
with spinning blossoms.

I like to think
    (it has to be!)
of a cybernetic ecology
where we are free of our labors
and joined back to nature,
returned to our mammal
brothers and sisters,
and all watched over
by machines of loving grace.

Figure 5.1. "All Watched Over by Machines of Loving Grace" (Brautigan, 2007/1969).

A cybernetic meadow, where humans and computers would harmoniously coexist connected in ways that would seem both natural and impossible, became a common trope in the popular imagination in the 1960s. Brautigan's poem, reproduced in Figure 5.1, was written in

1969, the same year the first message was sent via the Advanced Research Projects Agency Network (ARPANET); the same year in which the original TCP/IP protocols, packet switching, and concepts and structures that undergird the contemporary Internet began to coalesce (Abbate, 2000).

That year also saw the publication of Phillip K. Dick's *Ubik*, which envisioned a future in which everything including common "dumb" objects like doors, showerheads, and the like would be intelligent and interconnected, with the ability to monitor users, request payment for use, and/or withhold access to the basic functions and necessary services of life. The plot is mind-bending, but generally deals with the ability to meld time and human desires to all sorts of unpleasant ends, the worst of which are the descriptions of people disintegrating. Oddly, the "Ubik" in the novel, the invisible forces bound in time that have the ability to counter the ill effects of time regression, can only be accessed through a comparatively utilitarian item: a spray can, a commodity advertised in many different ways throughout the book.

Almost 30 years later, Mark Weiser (1991; 1994), a researcher at Xerox PARC, drew from Dick's visions of invisible and pervasive technology to illustrate what computing might look like when technology extends beyond the desktop, becoming invisible and ingrained everywhere and in everything. Weiser's notion of "ubiquitous computing" has been further explored by Dourish and Bell (2012; 2014), who suggested that speculative fiction can be a useful tool to interrogate technological development because these narratives are examples of technological imaginaries bound with epistemological and ethical assumptions. They suggested that in technological development endeavors, in-project narratives about the future expose political agendas that manifest in articulations of certain functionalities, failures, and technological solutions, while at the same time, obscuring others. Taken together, these authors and many others sketch a world in which the span of life itself becomes the space of networked computation.

Throughout the present study, respondents consistently articulated notions of the future that can be organized into five distinct themes about past experience and speculation: understanding the will of the public and whether that will determine project goals; the intra-project communication of these goals to create a cohesive design vision; learning from the field, particularly other FIA projects; negotiating resources; and carrying project values forward. I conclude that, while the concept of the future is by no means coherent in the FIA projects, their designs demonstrate a desire to reduce the friction and political tension between computing and everyday life, with varying levels of recognition among participants that the external partners they seek in these projects may not share these same visions or values.

Facing the Future

There are a number of ways to understand the trajectory of technological development in which the concept of *the future* is an important part. Analysts from a number of fields have taken different approaches to how technologists imagine, describe, and design for future needs, social contexts, and political-economic landscapes.

Several bodies of literature are relevant to the question of how technology development projects frame their own progress and frame the future for users and stakeholders. Michel Callon's (1980) sociotechnical characterization of scientific innovations gives nuance to the political and social interactions through which actors within scientific or technical projects struggle toward existence. As they begin with variety and struggles to meet market demand, technical projects, in Callon's account, compete for market and political dominance from the moment they are developed. However, only a few win out, and these then set terms for all others in the field. As this project is interested in the ways in which technological projects come to exist over time, dealing with competition, striving for primacy in the field and the ways in which they determine new standards, it's useful to mark key parts of this process. Chapter 2, and to some extent Chapters 3 and 4, detailed the FIA projects' emergence. This chapter seeks to explain how they have dealt with competition, sought market and political dominance, and the ways in which they have attempted to set new standards, guided by the experiences of their engineers and project leaders that have shaped their expectations about the future.

Star and Ruhleder's (1994) incisive work draws from Callon to problematize linear models such as the "waterfall" or "life-cycle" heuristics that show phases in neat alignment in the social development of technologies. The authors noted that "traditional methodologies for systems development and deployment assume that tasks to be automated are well-structured, the domain well-understood, and that system requirements can be determined by formal, a priori needs-assessment" (p. 253). In the computer science literature, infrastructure is a passive physical artifact to be acted upon, for example, a network for linking computers. These models, Star and Ruhleder argued, "form complex mythologies of systems development and use in 'real-world' domains" (p. 253). When they do not lead to acceptance, users are blamed for resisting, while organizations are held responsible for resource inefficiencies.

The authors also claimed that these models are inadequate in part because technological infrastructure is a process, not a thing, and that such processes are messy and unique to each endeavor. This sentiment is echoed by information theorist Rob Kling et al.'s (2000) refutation of the layer cake model of information infrastructures, which treats them as collections of scientific instruments and information technologies that exist only for use and to support interaction. As Star frequently pointed out (Star & Bowker, 1999; Star & Griesemer, 1989; Star

& Lampland, 2008), certain choices determine how such tools can be used for interaction; thus, treating technology as a mere substrate misses a great deal of the messiness encapsulated in the social aspects of technology. Moreover, the idea that technology is political has become more widely understood than ever before (Eubanks, 2018; Noble, 2018). These two premises – that technologies and infrastructures are not only politically-motivated and determine political constellations, but also *processes* that can be studied as such – illuminate part of the broader project for this dissertation and guide this chapter in particular.

Before describing how the data presented here reveal the processes of technical systems development in light of market and political dominance, it is important to say something more about the impetus to *periodize* or assign stages in historical, social, or cultural cycles as warned against by Star and Ruhleder. Critical theorist Frederic Jameson (1991) claimed that "all isolated or discrete cultural analysis always involves a buried or repressed theory of historical periodization; in any case, the conception of the 'genealogy' largely lays to rest traditional theoretical worries about so-called linear history, theories of 'stages;' and teleological historiography" (p. 3). It is in this spirit that the investigation at hand seeks to problematize the notion of linear trajectories of technological progress. While neat models are not necessarily sought here, Koselleck's concepts of *experience* and *expectation* (Chapters 1 and 2) are two categories appropriate for the treatment of historical time because they allow a type of navigation between what the FIA project principals expected or intended and what actually happened, that allows us to pick apart the messiness of the present, future, and past, if imperfectly or incompletely (Koselleck, 1979/2004, p. 256).

With respect to market dominance, fields concerned with marketing strategies and business decisions consider the future in relation to consumer expectation management, an effort to define the product and position it positively with consumers, so that in many cases consumers' expectations of a product or field of products are defined before the consumer has a chance to interact with them. Wroe Alderson and Miles Martin (1965) discussed expectations as one "primitive" that defined behavior and transactions in market systems (p. 121). They suggested that expectation*s* are dependent on information and values, and that managing expectations might be most easily done by managing information (p. 125).

According to Jukka Ojasalo (2001, p. 200), expectations can be implicit or explicit, precise or fuzzy. Managing expectations, then, requires imparting different types of expectations to different groups. Those with fuzzy expectations may not have been led to believe in any particular outcome, while those with precise expectations have been given information or have a certain understanding of a situation that encourages them to believe it will produce a specific type of outcome. Implicit expectations are assumed, but they are often not thought about until they have been met. Those with explicit expectations are on the customer's mind. This can be done by carefully managing information around a product, service, project, or a subject of interest (Ojasalo, 2001, p. 202-204).

Similarly, outside of traditional marketing and communications concerns surrounding technology development, as a literary genre science fiction often defines, shapes, and predicts technological development by introducing a vision of what types of technological futures are possible in the first place. Eugene Thacker (2001) noted that science fiction "is a contemporary mode in which the techniques of extrapolation and speculation are utilized in a narrative form, to construct near-future, far-future, or fantastic worlds in which science, technology, and society intersect" (p. 156). His description of science fiction is useful to the discussion because it also “situates the production of science fiction as a translational project between science, technology, and society” (Dourish & Bell, 2012, p. 778).

Science and technology studies, historical studies, and literary studies all give some insight into articulations of the future as translations of how the participants view the trajectories of science, technology, and society based on their own experience. The next section surveys how data relating to instances of in-project and external narrative construction fit into five major themes of experience and speculation that can be seen as examples of a type of translation between technology and society.

Speculation and Past Experience

As I spoke with the FIA teams about their project structures, overarching project and sub-project goals, their day-to-day work, and the ways in which they solved technical problems, the theme of the future emerged persistently, although it was not always articulated explicitly. But given the fact that the FIA projects literally have the word *future* embedded in their brief from the NSF, and that they are all still at prototype stage and thus have not met their original goals or timelines, it makes sense that a concept of the future surfaced again and again in what the respondents said about the future based on their FIA experiences thus far. Their remarks revealed how project designers and engineers view the future and how these views get built into their work. A common thread through all of their responses is that technological development is engaged in a kind of translational work, in which project narratives privilege technical considerations over social and cultural ones.

Engaging with the Will of the Public

The principal theme that emerged from the analysis of the applications running on NDN, XIA, and MF was the differing ways in which the designers and engineers situated their work socially. On the one hand, they claimed to have clear concepts about what the public cares about with relation to their projects; on the other hand, they felt compelled to make conjectures about the best ways to make the public care about the technologies and affordances they were designing. Yet none of the projects actually included public consultation or testing to confirm these conjectures.

At NDN's community meeting, most of those working on NDN seemed flattered, and perhaps a little flabbergasted, to find that an outsider/layperson like myself was interested in their work. At dinner on the last day of the meeting, one network engineer at UCLA said that determining how to make things run together temporally was a huge issue and one that he thought about all the time. He noted that it would be amazing if people outside of the networking world cared about or understood the issues of temporality in networking. From across the table, a lead network architect at NDN countered that only thing people care about is that stuff works.[13] This exchange highlights engineers' ambivalence about the public's understanding of technology projects like NDN, their responsibility for public outreach, and the tensions about the technological and social goals of the project.

At the same meeting, Peter Gusev's Flume presentation brought a storm of questions and debates, unlike many other talks. Lixia Zhang asked Gusev whether creating something like Flume is the right direction to go: Is imagining a novel application that runs on NDN the best way to showcase the affordances of NDN? Why, for example, was he not working on something that seeks to show off NDN's security features?

Gusev's answer was that NDN should give the market something new, something that works better and more efficiently than Slack, a collaborative work platform (P. Gusev, personal

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[13] These two NDN engineers preferred not to be identified but the exchange happened at the NDN Community Meeting on March 27, 2017.

communication, March 9, 2017). With no compelling or easily demonstrable affordances and no interesting story that the wider public can understand, he argued, NDN needs to develop an engaging, outward-facing application that encourages user buy-in. He made the comparison with email, which people did not know was possible or something they wanted until somebody developed it. In a follow-up interview, Gusev noted, "I think it's important to make a killer app—something people have never seen before." In the unpublished *Flume Specifications* document, he elaborated the same point:

> Existing video conferencing tools lack the ability to record both textual and audio/video data in a seamless, easy-to-search and review way. Users are usually presented with the recording of a meeting, which is represented as a video file and does not incorporate any other type of data that was shared during the call (i.e., messages, files, links, etc.). In the best cases, users are also given historical access to the meeting's group text chat; however, messages are not referenced back to the timestamps in the audio/video streams, published during the call. (Gusev, 2017, p. 1)

Overall Gusev is tasked with developing applications that do two things: (a) demonstrate NDN's security affordances and (b) show how applications running on top of NDN can innovate, not only with respect to data use and presentation, but also for user-facing audiovisual capacities. Jeff Burke agreed that NDN might be a unique solution, but that it will also likely require industry funding to realize. "[D]eveloping an application with both live and historical playback is incredibly hard," Burke said, "but once Gusev cracks it, he will have something unique that highlights aspects of NDN security in the wild." Burke also suggested that they might, in fact, seek industry funding for further application development (J. Burke, personal communication, May 12, 2017).

For his part, Gusev has hope for the future:

> The research will continue. It’s interesting work, and people will continue to get funding for the research, in the same way probably that all experimental engineering research happens. But if it’s ever going to be something that scales up, application development needs some corporate funding. I don’t think the Cisco merger of CCN will really help with that in the near future, but who knows, maybe I am wrong. (P. Gusev, personal communication, May 1, 2017)

In a subsequent interview, he reiterated some of the same points, but also speculated how Flume might fit into new types of priorities:

> I think we are still about five years away even from applications for early adopters. What we really need is a killer app. The best way forward would be an app that has NDN bundled into it. One app that you can download that would run on NDN, and that would be bundled into the application. Ideally, it would be one that really highlights the features of NDN, something secure (P. Gusev, personal communication, July 20, 2017).

In the same interview, one thing that Gusev did find useful about Flume that he noted about the market, in general, is that:

> Edge computing is very attractive to consumers. Maybe a secure messaging app, maybe something else focused on data at the edge … could be something that the military or DARPA uses on the battlefield. It could be something that does something with big data sets of physics (P. Gusev, personal communication, July 20, 2017).

Edge computing, which Gusev described as a possible future application opportunity, locates data processing near the source of the data. As of 2017, this was a technological buzzword, much as *the cloud* was in 2014 or *big data* in 2012. Research firm International Data

Corporation (IDC) defined edge computing as a "mesh network of micro data centers that process or store critical data locally and push all received data to a central data center or cloud storage repository, in a footprint of less than 100 square feet" (Quinn, 2017, n.p.).

Edge computing solutions can take many forms. They can be mobile (in a vehicle or smartphone), or they can be static (part of a building heating and cooling system, a manufacturing plant, or in an extractive mining rig). Judging from these examples, it perhaps comes as no surprise that edge computing is most commonly evoked with regard to the way data is managed through and for IoT devices. At present, edge devices collect the data and send it to a data center or cloud to be processed (Butler, 2017). The edge processes some of the data locally, reducing the traffic to the data processing center and thus improves efficiency. NDN is uniquely situated to provide data at the edge, as Gusev termed it. Recall Lixia Zhang's vivid description (Chapter 2) of how IoT sensors work by "calling out" to one another based on their locations and how NDN streamlines the "calling out" by keeping data at the edge from an early conversation cited in the beginning of Chapter 2.

Other NDN principals recognized the need for projects like theirs to respond to user demand, although some, like Zhang, tended to blur the line between society and the market: "A thousand feet above the ground, people need to see that overall picture where the society, or the market, is moving to." To do this, she proposed borrowing a concept from evolutionary biologists, *punctuated equilibrium*[14] as a possible model that also fit her experience of technology development: "Punctuated equilibrium is a phrase created by biologists to describe

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[14] The concept of *punctuated equilibrium* was developed by evolutionary biologists Eldredge & Gould (1972) to describe how fossil records indicate that a species undergoes incremental changes punctuated by short bursts of vast change. This term was subsequently adopted in technological management literature (Tushman & Anderson, 1986; Mokyr, 1990) and in literature on technology markets and industry (Abernathy & Utterback, 1978; Utterback & Suárez, 1993).

how biology advances … I think technology advances along the same pattern," said Zhang. She then continued:

> For so many years of IP, people were making incremental changes to it. The incremental changes have their limitations because they are based on the existing architecture. They try to optimize it, but eventually, the structural limitation of the existing architecture will become the bottleneck, and the incremental changes cannot overcome it.

However, at this point in the interview, Zhang shifted metaphors abruptly, comparing such incremental changes to the medical treatment of pain: "They can reduce the pain, but you cannot eliminate it. Just like you take medicine—every time you reduce the pain, there's a side effect" (L. Zhang, personal communication, December 8, 2017).

Zhang was confident about her view of the future based on her 40 years of experience as a networking engineer. She has seen this pattern of punctuated equilibrium (and its attendant "pain") before, and she is sure it will recur in the future. She suggested that only a clean break, a definitive, surgical-like intervention like the introduction of a new networking protocol, could cure the patient, not the incremental half-measures of medication (i.e., adapting existing architectures).

Across the future Internet projects, perspectives vary on affordances and public engagement. Within NDN, they focus on applications to demonstrate the protocol's advantages to the public, but debates continue about what types of applications should be developed to this end. As mentioned previously, XIA has different goals than NDN—primarily a focus on meticulous refinement of the XIA addressing schema, rather than application development. However, XIA's Peter Steenkiste had a clear eye on the project's relation to the public, and how it enables XIA's success, broadly defined. He pointed out that optimization was a specific *non-*

goal for the Vehicular Video demo. As XIA has large XIDs that make addressing complicated, the goal with applications is simply to provide an example of simple uses of XIA architecture for novel scenarios, or scenarios that exist but have few, if any, good and efficient solutions. To highlight the latter and contextualize why they built the Vehicular Video demo, Steenkiste continued, “Then, there’s the whole mobility thing. Increasingly people are interested in mobile networks, not just in mobile devices. A car is a mobile network.” In regard to showing just how differently XIA envisions its place in the future, Steenkiste noted:

> I mean, I think it would be nice if eventually somewhere people picked up [XIA] or some of the concepts. That for me would really be the nicest thing, right. But that obviously will take time. It was designed as a long-term research project, so I think you need to accept that that’s the way it will work. But I think showing that it, you know, can demonstrate some of the benefits in a specific context I think is important. (Steenkiste, personal communication, October 30, 2017)

While mobility is a key design factor that comes from XIA and NDN, developer Jiachen Chen highlighted how demonstrating improved mobility using MF is not as straightforward as it may seem. He stated, “How do we do expect those Mobility First or even NDN networks to be deployed? Only when they are deployed can we see how people are using it. Only after that can we see problems and decide how we're going to improve it.” Chen continued:

> Everyone is thinking about, you know, everyone is content-centric now. Nobody is really talking about, okay, this is the IP address that I’m going to talk to. Nobody cares, right? And someone even thinks, oh, I don’t even need to remember any URL. Well, nobody remembers URLs now. Either they go to Google or they scan the QR code, right? All normal people do is worry about is content—if the network can support it, okay. You

> know, really you need to convince people that this is a network that can do you good and *not eliminating existing functionalities that people like* [emphasis added]. For me, this is not easy. How could you make [using a new protocol] a common thing? You cannot ask people to replace all their routers. Or, if you do, they won't like it.

Furthermore, he stated,

> I don't expect Mobility First to be deployed outside the lab, for at least 10 years, to be very honest. But what I can tell you is, the design of Mobility First, some design concepts of Mobility First has been adopted by a lot of standards [bodies], you know, those either companies or organizations. For example, the GNRS [Global Name Resolution Service, MF's unique content authentication service] is being used to some degree. Now there is one new group in [Internet Engineering Task Force] IETF. We heard this from Huawei which is collaborating with us. (J. Chen, personal communication, February 28, 2018)

Dipankar Raychaudhuri pointed out that MF has been working on the standardization of this GNS, which can help IP. But he emphasized the idea that a protocol is not a standalone thing you can deploy into the network:

> You have to gradually evolve from the existing network if you want real changes. We are expecting our design concepts can help either IP or some totally new protocols like SDN-based stuff, to improve the current situation with the Internet. (D. Raychaudhuri, personal communication, March 1, 2018)

Each of these protocol projects has a different image of the future. NDN's Zhang articulated a future in which the model of punctuated equilibrium is fulfilled in fits and starts, but also where a clean, decisive, and possibly painful break with the past will be necessary. Chen and Steenkiste, with MF and XIA respectively, see smaller changes ahead that will almost imperceptibly shift the present into the future. MF, XIA, and NDN have different goals with regard to applications, the most public-facing part of their respective projects. However, the FIA principals seem to agree that the most important thing is that the protocol must work appropriately to allow applications to operate in more interesting ways. This seems obvious, but it is not a trivial issue when considering the work and time that has been dedicated to fleshing out their respective protocols. What may be more interesting, however, is that there is no clear agreement on what the larger, public-facing goals of each protocol should be both across the projects and within each project itself.

Understanding the Competition

At the community meeting, I found many things regarding the NDN project as a whole that I had not expected. First, there was relatively little overlap with other FIAs, or even much interest or understanding as to what their counterparts, or competitors as I saw them, were up to. People like Lan Wang, an NDN networking specialist, and the NDN engineers at dinner at the March 27, 2017 NDN Community Meeting, claimed not to have heard of the other projects, or if they had, only barely recognized their names. Each project's principals knew details of the other projects, but had different concepts of how their work fit together.

Lixia Zhang stressed NDN's superior knowledge about the other projects:

> You have to take into account that my view is rather biased. But I believe that our team has a much better understanding of the other projects compared to the other way around; that is, how much they actually understand our projects, exactly what they think NDN is and how it works. This is not just any specific project per se, but rather I think it's a

> human habit, if not shortcomings [sic]. You tend to use the model. You understand and use that to interpret the new things that you are yet to understand.

She continued and attributed this to the NDN's teams more inclusive experience:

> I believe a reason that we could see the overall picture clearer than the other teams is because in this team there are few old folks, like Van Jacobson and myself. We started working on this Internet back in its early days. So we believe that we actually understand today's Internet architecture in a deeper sense, compared to people who came into the Internet after the Internet already took off. If you come to the Internet after its takeoff, you tend to take how it works as a given and compare it to people who actually saw how the TCP/IP came from nothing to existence. So you have a much different view on what TCP/IP really is and why it works the way it works. I think it's not [anyone's] fault, but rather I think the historical background, I believe, does have an impact on people's understanding, generally speaking. (L. Zhang, personal communication, December 8, 2017)

Steenkiste distinguished XIA and MF by adding that MF is focused more on standards than XIA or NDN. He did see a tighter link between MF and XIA than with NDN. For example, MF has multiple versions of GNS, and one developed at UMass–Amherst is complementary to XIA:

> For me, the really, I think of the concrete outcome of Mobility First as being the GNS system—the global naming system. I actually viewed it as being very compatible with XIA, in the sense that, you know, it's something that we can very easily use with XIA. MF has multiple versions of GNS, and the one developed at UMass–Amherst is

complementary to XIA. MF is focused more on standards than XIA or NDN (P. Steenkiste, personal communication, October 30, 2017).

NDN, XIA, and MF all have overlay-based solutions that can help people deploy the networks over the communication layer directly, over IP, or that work within the functionality of TCP. These overlays work with the functionality of the OSI stack, or the existing networking infrastructure to transmit data or content in different ways than is possible with IP. Chen stated that with the MF overlay “we can develop demos where we have traffic crossing IP, NDN, and Mobility First, that means wherever you deploy, we can try to get the content from your network” (J. Chen, personal communication, March 9, 2018). Steenkiste later added:

> We actually ended up using the extensibility of XIA to implement content naming that’s effectively similar to what NDN uses. You can basically take a name, turn it into an address. Okay, it’s not—you don’t actually store the name in the packet, but you basically have an address version of it. And then you can basically retrieve content in a way that is somewhat similar to how NDN does that. (P. Steenkiste, personal communication, October 30, 2017).

On the topic of overlays and other FIAs Steenkiste explained that in his eyes, just because a project is considered a FIAs, it does not mean that all are equally focused on building architecture.

> I’m actually quite familiar with [the others]. So I’m not going to say that the other architectures can never run in a standalone fashion. But my impression is that in practice they are always running as overlays. NDN is interesting. I actually think that NDN is a fascinating project. [But] I’m not sure it’s an Internet architecture. But that is a philosophical question. But as an overlay, it actually, it makes a lot of sense.

One reason that Zhang and Steenkiste, NDN and XIA PIs respectively, were so well-acquainted with the characteristics and features of the other FIAs is that the NSF brought the different project principals together in a series of meetings where all the projects, their goals, and their plans for achieving them were introduced and discussed. Both Zhang and Steenkiste recalled those early meetings and agreed that it was a good thing that the NSF promoted cross-project discussions. Zhang recollected, “I remember in the first couple of years, we had multiple [PI] meetings. The NSF made each team to present their design under different scenarios to show how your design would address the problem” (L. Zhang, personal communication, December 8, 2017).

Another factor that may have influenced the PIs’ understandings of the other FIAs is that the projects might view one another as competition. While they acknowledge that each project has different goals, ultimately each takes a different approach to the same problem. The solution to that problem, a replacement for IP, has inherent winner-take-all, network-effects qualities since only one solution is likely to finally emerge as the network standard (as we may recall from Callon). Nonetheless, it remains that none of the projects are close to fulfilling the original goals proposed to the NSF, and since they offer similar (but not identical) functionalities, they are likely to compete for any future funding, as well as partnerships with industry.

Scrambling for Funding

At the March 2017 NDN community meeting, Lixia Zhang delivered the opening keynote and spoke of “exciting new developments” afoot at NDN. Notable among these was Department of Defense funding which had been “attained,” as she put it. She also highlighted Cisco’s acquisition of CCN, a related project developed in tandem with NDN at Xerox PARC;

the acquisition, she said, would improve upon the work they were doing and bring it to new audiences.

Although these developments may have been particularly exciting for project PIs, the Master's and PhD researchers expressed a different take on the situation and what they considered to be the other side of the story: NDN was nearing the end of its funding cycle, and little money remained for them to continue working on their projects, outside of a few institutional grants and stipends. They expressed anxiety that the acquisition of CCN spelled the end of their work. They reported infighting over the remaining funding proposals, primarily that of DARPA's SHARE, and disagreement among PIs over how to keep the project going.

Jeff Burke also saw funding as a huge issue for application development and thus for Gusev's future with the project, since the NSF funding for the whole NDN project has run out. Burke said, "We are at an inflection point between basic research and development of viable projects because the funding is low with relation to the ambitious goals of the project overall" (J. Burke, personal communication, June 8, 2017). Moreover, Flume, an experimental application running atop an experimental networking protocol, is particularly difficult to justify in context of a project so seriously underfunded because the technical challenges in a new network architecture are always quite high, especially within an academically structured networking research project. "Flume," Burke emphasized, "is not working on the current Internet. Users, even users within the NDN community, have high expectations," which is problematic "because this is the group of people who would be ideally the most forgiving with the limitations of the applications" (J. Burke, personal communication, June 8, 2017).

In addition to the DARPA SHARE funding, Burke said NDN is seeking future support from other, non-FIA, NSF grants and partnerships with Huawei and Cisco. Regardless of what the funding situation is for NDN, he said that REMAP would continue to identify research goals that highlight the benefits of NDN and tasks that are hard to do with standard IP. REMAP would continue to work on secure content streaming and real-time audiovisual applications—for which NDN theoretically holds promise.

As discussed previously, Steenkiste recognized the market value of focusing on applications but also emphasized how XIA's application portfolio is diverse. Mobility, for example, as demonstrated in the Vehicular Video demo, is an area where he saw a distinct advantage. Another was that, like NDN with caching, XIA could store secured content in the network. This functionality was a key factor in winning XIA's collaboration with the DARPA SHARE program:

> It turns out that in certain environments [in-network content storing] is really very important, including the web but also more in a military context and so on. It was something that we could accommodate, even though that wasn't our goal specifically. In some sense, we knew there's a whole bunch of things we'd like to support, but none of them is really [our target] except for mobility and security. (P. Steenkiste, personal communication, October 30, 2017)

Given his informal NDA with DARPA, Steenkiste could not say much more than that, including whether, as he implied, a specific SHARE application is being built using concepts from XIA. However, this quote shows their in-network storage of information secured by the XID makes XIA a good collaborator with DARPA's SHARE program, which aims to "demonstrate secure exchange of information at multiple levels of classification over unsecured military and commercial networks (e.g., Wi-Fi and cellular) using a heterogeneous mix of devices from tactical radios, to laptops, to handheld devices" (Defense Advanced Research Projects Agency, n.d., n.p.). This indicates what types of applications might be in the works, if indeed there are any. Use in a military capacity is one way that standards evolve and gain public and institutional buy-in. This has been the trajectory for nearly all technical standards and devices in use today, from packet switching to Global Positioning Systems (GPS) (Abbate, 2000).

While NDN sees itself as the leader compared to the other FIA projects, the others do have some promising paths toward to the future. A variety of technological options are available in the field of future Internet projects, but the sense within the projects is that only one is likely to emerge and set the standard for the others to follow. This dynamic seems to be driving the growing sense of competition among the FIA projects, and their corresponding anxieties about obtaining continued funding, as well as the technical and values compromises that new funders may require. While the three projects are all technically similar options, their activities, goals, and organizational structures are different. It is not clear whether there will be a single "winner," or if they will differentiate themselves enough so that components of the projects might find homes in other areas from standards organizations to the tech industry.

Carrying Values Forward

As observed previously, all three FIA projects and protocols prioritize the values of privacy and efficiency. For XIA, privacy is the primary value, while NDN prioritizes its counterpart, security. Efficiency is MF's main value, though it is cited in all three projects. However, other values that might seem obviously relevant, such as net neutrality (a possible proxy for fairness or equity of access, for example), are not articulated by any of the project participants. Indeed, when asked explicitly about network neutrality, even the project PIs had a hard time connecting it to their efforts.

The ways in which these projects articulate values may have a great deal to do with how the NSF-enforced engagement with the VID Council brought some of these issues to light, as with XIA and the workshops with Dabbish and Kiesler, or that the engineers did not regard the work of the VID Council as particularly important or useful. We might recall, for example, the sentiment that engineers know better than policymakers and sociologists how to incorporate important values into their work, as voiced by Zhang and, to some degree, by XIA's Peha.

Efficiency is a guiding value in each project, but it manifests in different ways, which suggests that the projects may also have different visions of the sociotechnical future. With MF, Chen linked the CNS application's efficiency to wider social benefits of rapid response and community resources allocation in emergencies, rather than market priorities. This may account for their interest in developing standards with NIST and the IETF, rather than developing tech industry or military allies. In the other projects, efficiency in the form of interface speed and low latency is more strongly emphasized and aligns with their ambitions for establishing industry ties. We see this for example, in the way that NDN seems to be framing its applications for content streaming, or how XIA is orienting its solutions toward the driverless car market.

Participants at the NDN community meeting seemed to believe that the introduction of a deregulated, market-based version of IP might cause NDN's non-market version to be more attractive to potential consumers because it protects privacy by design. At the same time, NDN is also looking to partner with corporate entities like Huawei and Cisco to further develop their protocol. This is an interesting contradiction that poses questions as to what NDN envisions for the future.

The case for values in design in the FIAs seems to have fallen by the wayside, most strikingly in NDN. XIA's engagement with values has been more robust and longstanding. MF's engagement with values is apparent in the ways they are orienting themselves toward their work and standards development. Each project has taken its original directive from the NSF to incorporate values into their designs and practices, to promote protocols to underlie the "Future Internet" in different ways. However, it seems that despite claims that they want to see a different future for the Internet, generally the FIA projects are each attempting to follow the same paths as Internet projects have traveled in the past.

Manifesting the Future

The issue at the heart of this chapter is the how experience influences the extrapolation of or speculation about the future in the FIA design process. In this concluding discussion, we revisit the original values directive these projects received, how they have or have not followed through with it, and ultimately what the future means and how it has been manifested in their work.

One persistent issue throughout the study has been the projects' efforts to reduce the "friction" associated with the contemporary Internet to produce more "friction free" technology tools and experiences, not unlike the futures envisioned by Brautigan or Phillip K. Dick back in 1969. The FIA projects also embody two of Weiser's visions for ubiquitous computing in the form of IoT and mobile connections. However, if infrastructure is a process, as Star and Ruhleder (1994) argue, this study suggests that it can only be a slow one. The networking architecture these projects are working toward represents a huge investment of time and resources, and specifies, determines or constrains the requirements for every bit of technology to be built on top of it. In terms of technology design and implementation feasibility, changing the architecture every two or three years is unthinkable. While infrastructure undergirds everything online, unlike the spray can in *Ubik*, there is no simple fix to its delays, gaps, regressions, and decay.

In their effort to update Internet architecture for future needs, the NSF has pumped substantial funding into the FIA projects, coupled with a requirement that projects explicitly articulate and incorporate the values they bring to the design process. Based on these values, the projects have had to develop negotiated articulations of what the future means from several perspectives, for example, what the public will put up with; how the design and conception of each larger project reflects an existing in-project power structure; awareness of alternative ethical and design frameworks; and how funding (balancing time, money, and expertise) depends on each of these processes in each project. While the NSF envisioned that the FIA funding cycle would yield protocols that would realize a previously unfulfilled utopian vision of the technological future, the FIA projects examined in this dissertation now find that they must turn to other funding sources with different values and priorities, which may have different consequences for Internet architecture than what the NSF hoped to achieve.

Zhang's allusion to the evolutionary biological model of "punctuated equilibrium" is ultimately a lifecycle model that is tacitly accepted among all the FIA projects, if in different forms. However, building and conceptualizing a future technological architecture is messier. Each overlapping part of the process has been an experience from which the FIA developers and engineers have extrapolated designs that they believe will meet the public's yet-unknown demands, trends, desires, and requirements. The costs of the process are expected to be offset by the potential market value of the new systems and services with the rewards going to the few powerful interests that control them.

The project participants have tended to frame the failures of the current IP-based Internet as a key part of *gauging the public*—a process in which it makes sense to interrogate what costs are borne by whom, and which of those costs drive change. Some interviewees suggested that one drawback of the current Internet might be that the public will eventually reject tech companies' control and attempts to manage the public sphere, and thus might begin to search more actively for alternatives to IP that might promise more security. Yet, at least to date, IP-based Internet use remains at an all-time high. The shortcomings of the current Internet cited by FIA researchers and engineers—that people want to use it for things that it was not originally designed for, such as streaming content and mobile device use—continue to be a great source of opportunity and justification for the FIA projects.

Public interest in problems that pervade the current Internet in the form of hacking, surveillance, and challenges to democracy, has compelled the NSF to fund projects that might remedy both the efficiency problems and the ethical problems in one fell swoop. One might consider Callon's (1980) suggestion that the promise of technological innovation might lead to the "emergence of new political actors who, by fighting to impose their technical choices, are inevitably led to define the needs to be satisfied, the forms of social organization to promote, and the action to be undertaken" (p. 358).

From Callon's perspective, it might be the FIA projects themselves that become the policy actors, or it might be the organizations they have approached for funding, such as corporate entities like Samsung or Huawei, or government defense agencies. If these kinds of actors are enlisted in the projects to help flesh out the rest of the architecture, their first priority might not be the public good. However, to the extent that the FIA projects themselves can maintain control over the design and direction of the new architecture, there is some hope that the values they have worked to articulate still might shape it.

Though the odds are long, given how power tends to become intertwined with technological development—that technologists' engagement with and adherence to values could drive the projects forward and determine the types of things that can be built on top of them. The fact that they participated in anticipatory ethics discussions may encourage FIA developers, and thus the rights holders, to uphold public accountability, at least for the time being. In this context, recall Zhang's argument in Chapter 2 that developers *do* have a good idea of what positive policies are possible.

Finally, it is clear that the engineers' and developers' experiences with these various values and criteria have motivated a shift in the FIA projects' understanding of their own goals going forward. Their experiences have encouraged them to distinguished themselves from one another, creating a field, not necessarily of *competition*, but of alternatives for thinking about technology infrastructure development as a type of speculation on the future needs of society and how to meet these requirements in a practical way.

Moreover, by examining the relations among experience, expectation, and technological design extrapolation, it is evident that *the future* is by no means coherent in these projects. The design engineers hope to reduce the friction and tensions between computing, human life, and economics. The projects all engage to some degree in expectations management, articulating fuzzy visions of what they are doing and how they are doing it for the public in order to keep the possibilities open for them to partner with funding agencies. Their neglect of net neutrality, for example, may reflect the potential necessity of entering into partnerships with corporate firms that do not see the principle as serving their interests. In addition, the notion of keeping all data at the edges would also allow content to be more easily tracked and monetized, which might be in the interests of some possible partners for some of the FIA projects.

Projects seeking user buy-in must engage in expectation management and reframe their projects as long-term investments, as they find that it takes much longer than they had anticipated to complete their proposed goals. Even applications developers think it will be many years before they are able to develop applications over these protocols that will attract even the earliest adopters. In projects like NDN, within-project expectations management is not always effective when internal communication is poor. Even at the highest levels of a project, its goals and direction may be clearly articulated and incessantly repeated in documents and presentations, these pat articulations are often questioned, and the conversation devolves into squabbles over different explanations of how networking works.

In any case, deployment of this technology requires buy-in from governmental and industry actors. Project principals generally discount the influence or danger that these actors might pose to the projects' utopian goals for the future. The final chapter will consider how these contending concepts of the technological future, and the projects' own understanding and uses of time, play out in their designs.

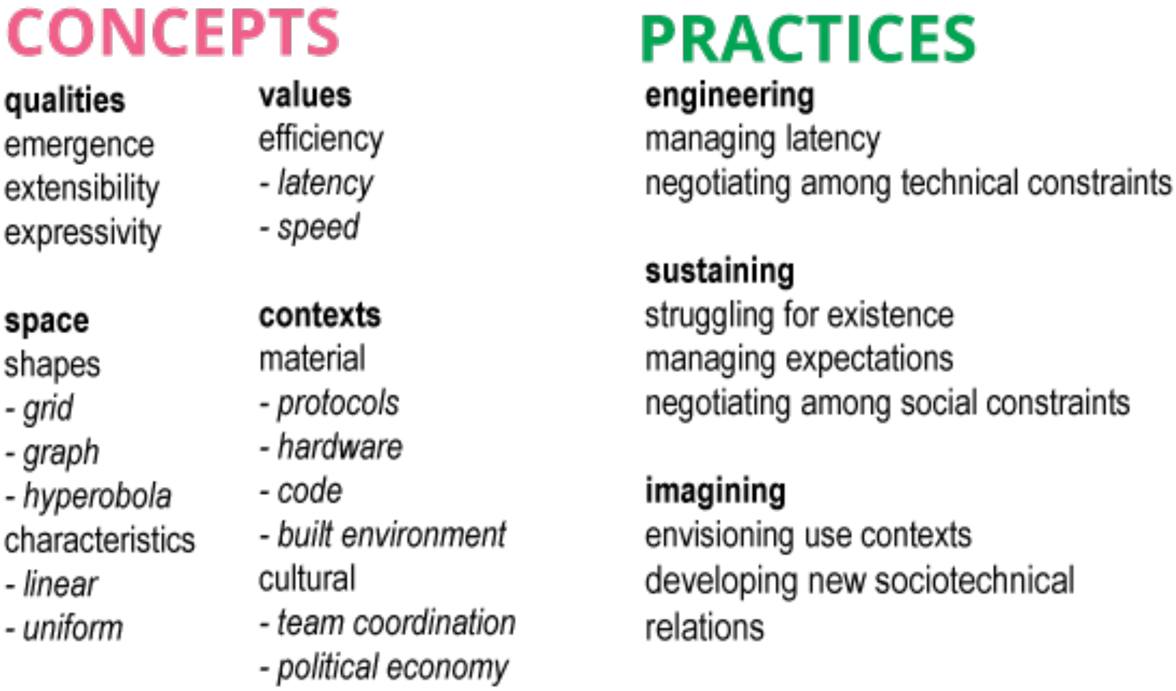
In many ways, the NSF FIA projects have extended the original model of government-funded Internet development that began with ARPANET and continued with the World Wide Web between the 1960s and the 1990s. As the FIA projects partner with organizations like the Department of Defense and standards bodies, they follow a model that has, in their eyes, worked relatively well. Just as ARPANET development included partnerships with private contractors like Bolt, Beranek, and Newman (BBN Technologies, which provided the funding for the first Interface Message Processor (IMP) and the development of TCP), the FIA projects now seek partnerships with Huawei, Cisco, and Samsung. Ultimately, the FIA projects' aspirations to fundamentally change the Internet by attempting to design and build new infrastructure without radically altering the organizational or economic structures of technological development may simply reproduce or calcify the problems of the past.

Chapter 6: Time Constructs

Recalling from Chapter 1 the different issues with instrumentality and time raised by Stiegler, Latour, and Heidegger, I begin my concluding remarks by reviewing the main findings, and then relating them to a conceptual framework, *time constructs*, that represents how the discourse of time and temporality manifest in the FIA projects.

Through this dissertation, I have identified several key concepts articulated in these projects that together comprise a discourse of time. In my view time exerts a nearly imperceptible, but powerful, agency in technological development, as suggested in different ways by Latour and Heidegger. The discourse and agency of time are seen in and mutually constituted by (a) the concepts of time, (b) the process of technology development, and (c) the built technologies produced by the FIA projects. This chapter explains how these elements of the discourse of time in technical projects have become bound together and points to some of the implications of this relationship.

Through Chapters 3–5, I have shown junctures at which time is a powerful concept that undergirds the processes of FIA development. Latency is managed at the level of interaction among hardware, software, code, and other protocols; in turn, this affects the efficiency of the overall design and the speed of the UI in application development. The diagrams that designers employ to explain and communicate the information transmission ordering process, both within their respective protocol teams and with the technical community at large, suggest how these protocols work and how they might have interesting and beneficial future-use contexts. Concepts of the future also determine how the FIA projects orient themselves internally, relative to the other FIAs, toward government agencies and industry, and to the public. Each of these junctures is influenced by the technical, material concerns of the existing sociotechnical world, as well as sociocultural concerns—how design teams should work together, whose expertise should be valued, and how these developers and engineers view the world in which their projects will be introduced and used.



CONCEPTS

qualities
emergence
extensibility
expressivity

space
shapes
- *grid*
- *graph*
- *hyperobola*

characteristics
- *linear*
- *uniform*

values
efficiency
- *latency*
- *speed*

contexts
material
- *protocols*
- *hardware*
- *code*
- *built environment*

cultural
- *team coordination*
- *political economy*

PRACTICES

engineering
managing latency
negotiating among technical constraints

sustaining
struggling for existence
managing expectations
negotiating among social constraints

imagining
envisioning use contexts
developing new sociotechnical relations

Figure 6.1. The categories of the discourse of time (Paris, 2018).

Figure 6.1 shows the range of elements in the discourse of time identified in this study, organized into several main categories. The elements are multiple and varied. For example, the spatialized representations of time and engineers' discussions are used to indicate how processes are ordered within applications; although intended to show that the protocols can change how people experience the Internet, they still represent time as linear and uniform, especially in user-facing applications. In the case of the Flume application, the user-facing experience is depicted as linear, and thus aligns with current video conferencing applications, despite the possibility for other, perhaps more exciting temporal interface features. Similarly, in the case of XIA's Vehicular Video demo, the developers thought only in terms of maintaining a linear real-time video stream as a car moves through space. In the case of MF, the CNS considers the duration of time as it is perhaps felt differently by, and carries different consequences for some individuals and not others. Such characteristics of time highlight how FIA engineers have learned think of time, in their training experiences and through working with technical constraints. They also suggest that an engineers' vision of time determines what types of user-facing temporal experiences they think might be possible.

In each project, time is conceived of not only as a straight linear vector continuing forever toward the future, but also as a resource, in the form of ideas familiar to engineers: efficiency, latency, and speed. Engineers structure and evaluate their work in these terms. The cases presented here how that efficiency (and its relation to time) is a design value at the core of the development and order of the processes and function of the FIA protocols. Latency is the technical face of efficiency, while user-facing speed is its social face. Time, in the form of efficiency, not only directs the process of technology development, but it is also used as an idealized *thing* in the design process that is balanced with resources, like processing power and user-attention.

The work of building the projects is further influenced by concepts of speed, insofar as it affords increased security or more robust privacy for public-facing documents or services. However, within these projects, the technical considerations of packet size and hardware problems impose their own complications onto the theoretical designs; otherwise, named data and named content would already have completely revolutionized Internet traffic. Standing in the way of these theoretical notions of speed are other, more brittle systems with their own hegemonies of time. As discussed in Chapters 3 and 4, the entirety of the built world of routers, standards, institutions, and other protocols, and perhaps even the perceptual capacities of the users, is in itself resistant to improvements in interface speed with their own hegemonies of time built in and harder to break than many network engineers had thought.

In Chapter 5, we see the ways that FIA projects have or have not come to fruition over the last ten years, influencing the projects' future goals and project-specific timelines. Many of the practices required to sustain large-scale technical projects, at least in the case of the FIAs, are ignored or taken for granted; possibly, project leaders may be more interested in theoretical proofs-of-concept than in polishing and perfecting their technical designs to market them or solicit buy-in.

The discourse of the technological development process is seen in the principals' expectations of future-use contexts for their protocols. Their comments reveal their beliefs about how their designs will fare in these future contexts and suggest that the participants are operating under dated assumptions of a revolutionary, utopian future. These are the same types of future imaginaries that the Internet founders and their milieu articulated over half a century ago—the cybernetic meadow will be a way of interacting with information in the future, just as in 1969. The limited vision is evident in the engineers' inability to conceptualize alternative use-cases, social, and ethical constellations of power and inequality, or user options or needs that depart from what exists at present. Their lack of imagination may be one reason the FIA projects have largely stalled out, as they have focused instead on technical concepts of efficiency and managing latency, rather than novel future-use cases.

At the same time, those working on the day-to-day development of the projects do acknowledge that the projects are not as fleshed out as they need to be to achieve their goals. Even the most modest of these goals will take many more years and a great deal more investment to achieve than the project principals anticipated or are ready to admit. Expectations are managed, both within projects and in the wider development community, remaining idealized and fuzzy to attract funders and partners without making concrete promises, much as private-sector tech firms might do.

The relations among the discursive concepts and processes presented in the previous chapters suggest a larger, more overarching way to think about how the discourse of time exerts agency in these infrastructure projects, which I call the time constructs model. I use this term in two senses. First, time is a construct—an ideal or belief held by engineers and institutions involved that influences the practice of technology design and use. At the same time, engineers and designers also construct technology in the material sense. As time is translated into bits and moved through the technological system through machine and software code, then routed through hardware and materials, and distributed in buildings and environments, we see how time is instantiated both as an idea and as built objects and devices.

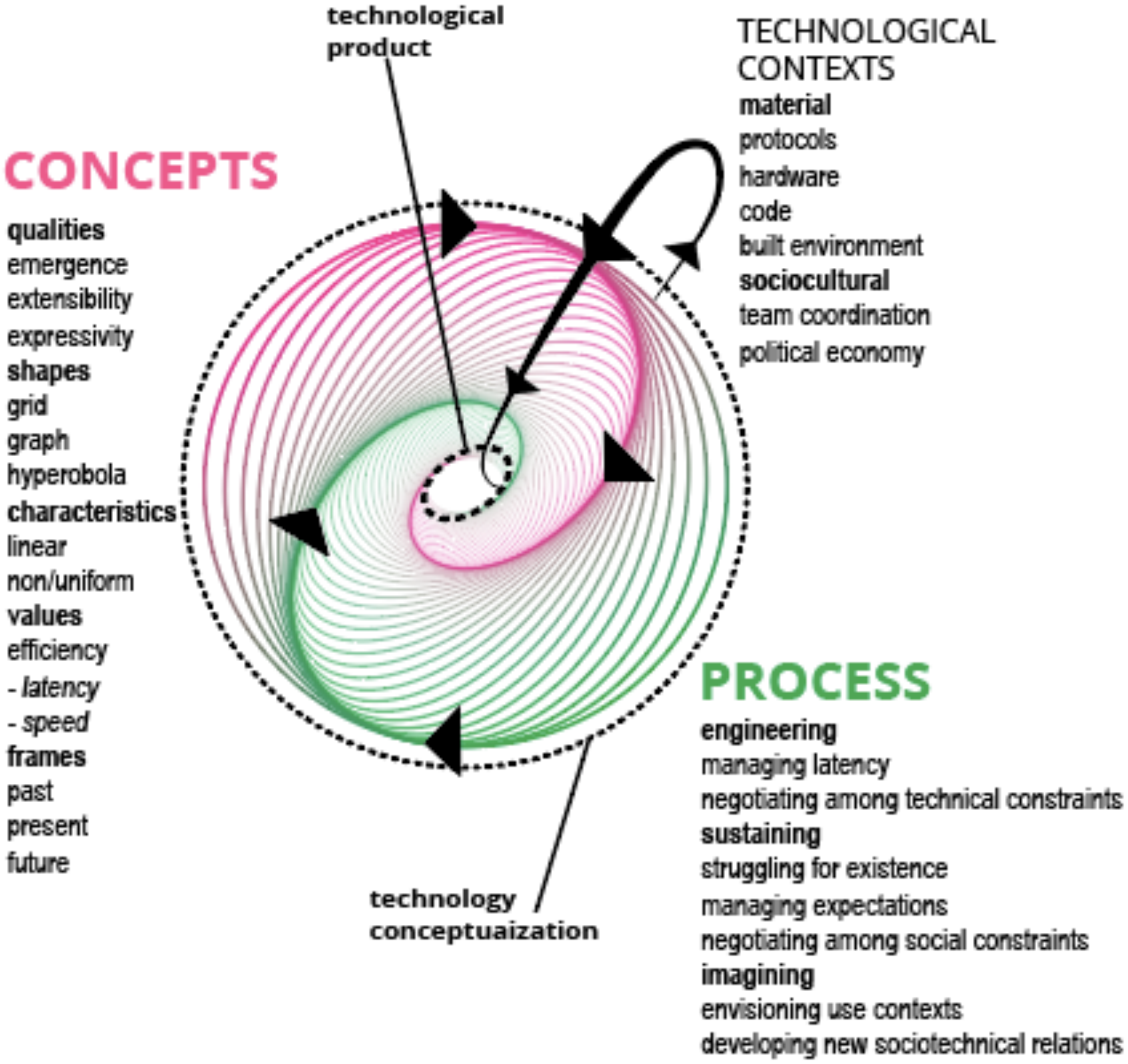


Figure 6.2. The time constructs model (Paris, 2018).

Figure 6.2 depicts this mutually constitutive duality of concepts and material processes as a torus (donut) shape. Engineering projects can be conceptualized anywhere on the perimeter of the spiraling torus as they pass by each face. As the projects spiral through several turns of the co-constitutive torus, which is powered by existing contexts of technologies and cultural ideas, processes, and concepts of time become bound into technological products. These products then become part of the forces of technological contexts that power new technological conceptualization, and the whole process begins anew (or continues to happen).

This dissertation has shown that the concept of time is both important to, and barely articulated in, the design contexts examined herein. One could see this silence on time as a further example of Latour's notion of a collective of actants working in conjunction with the ideologies of time and progress that is largely invisible and unknowable by virtue of the actants' intimate situation within the collective. However, findings from the FIA investigation reveal a discourse of time within the projects that intertwines ideas and processes of time in the technical development of these projects. These co-constitutive forces of the ideas and processes of time are *time constructs*, with *constructs* wielded both as a noun and as a verb. Describing the discourse of time found in these projects as components of time constructs renders visible these co-constitutive ideas and processes of time. From this, we can learn not only how these projects are built with regard to time, but hopefully we can also glean something about how the ideology of time fits with other hegemonic ideas, and how we might better interrogate these ideologies as they are built into technologies, in an effort to keep technology from becoming black-boxed in ways that completely foreclose on the future.

I argue that much like Latour's "collective" making computer chips in a factory or Heidegger's "enframing" in the hydroelectric plant on the Rhine, each of these processes of building technology is co-constitutive of the engineers' concepts of time, though this is not explicitly supported by the data. This dissertation shows how the processes of technological construction and the discursive concepts of time that engineers actually use intertwine with one another in these projects, though they are rarely articulated as time or "temporality," *per se*. The discourse of time can be accessed by interrogating the work of construction at granular levels of code and hardware, as well as the higher levels—as they articulate goals regarding concepts of efficiency, and a "faster Internet" in the future.

Contributions to Information and Science and Technology Studies

The goal of this project has not been to look mournfully to the traditions of the past to retrieve “being” from technology, as did Heidegger, nor is it to nihilistically report the state of technoscience as Latour does in much of his work. Instead, this project has sought to provide a perspective, or a partial stance, from which it might be possible to better critique and more justly build technology in the future. The time constructs framework may be tested as a mode of analysis in other technological development projects. It provides analytical elements of the discourse of time that might be identified in other technological investigations to reveal the material and cultural aspects of technological time. This project suggests that time can be further investigated as a design value, and perhaps most interestingly to the field of STS, it gives an account of how technological projects that start out with value-centered goals may or may not adhere to them throughout their development.

In a sense, interrogating how time is built into technologies in the FIA projects elevates this dissertation beyond a modernist project of describing the differences between affordances of scientific time and the temporality of social coordination. I have found instances of *how* these concepts have been co-constitutive in the construction of the Future Internet at a moment in which the projects are not yet completely black-boxed. This study not only points to values in design but traces them through the project’s trajectory. I have also shown that the technical value of efficiency can be unpacked as a design value with component elements – latency and speed – that can be interrogated in other technical projects.

This project also contributes to the field of critical informatics, a sub-discipline of information studies concerned with the ways power imbalances are reified in information infrastructures. projects has allowed a vantage from which I was able to access engineers’ articulations of what they hope to achieve in developing new and groundbreaking technology, who they think should be included in the process of developing Internet architecture, and how the technological future they hope to bring about is constrained by past and existing technologies.

As we have seen time and time again with Facebook, Google, and other tech giants, there is a tremendous disconnect between how Silicon Valley develops technology that serves capitalist interests and their claim that they build technology to serve the public (Washington Post, 2018). Numerous critical studies have been conducted (Eubanks, 2018; McChesney, 2001; Noble, 2018; Pariser, 2012; Smythe, 1981; Terranova, 2004) of communication technologies that seek on capitalize on our attention, our desires, and our consumptive patterns. While the FIA projects are not to be confused with Silicon Valley technologies, the present findings of how values formed the basis of these projects suggest that we should look deeper to attempt to correct the ills of corporately-owned and -managed technologies. We often think the political problems of the current Internet come from the applications built on it; and while that is true in many cases, the project at hand suggests we might better understand how to address the system's injustices by taking a more comprehensive, infrastructural approach to analysis.

But to do this, we need more than the kind of anticipatory ethical projects that were imposed upon the NSF FIA projects, though this effort was a good start. We need to develop better modes of technical training, as suggested by Peha and Steenkiste in Chapter 2, that recognize that in the contemporary context, regulation will not come from the government. We must rely on what remains of public education institutions to inculcate a concept of the public interest into its young developers. But perhaps we should conceptualize it in ways that are different than those suggested by Peha and Steenkiste.

Interrogating the process of development of these nascent protocol projects allows us to think about how certain undesirable practices might be corrected while there is still time. In Chapter 2, Zhang and Peha maintained that there are individuals who can anticipate and address ethical issues as easily as they can anticipate and address technical issues and that this dual ability can be learned. As such, a new educational model might promote better policy and ethics training in computer science and engineering programs. This, in turn, might allow technologists to be better stewards of their power and to truly understand how ethics should be a design directive; while also realizing that these ethics must come from the bottom up.

Indeed, if Zhang and Peha's comments are taken in conjunction with Nissenbaum's paper on the issues of the VID Council, engineers need to be trained to communicate meaningfully with colleagues in the humanities, social sciences, and policy realms—and vice versa. Part of this education must recognize that internal power structures in technological projects, even research-based ones, are as ineffective and undemocratic as those that exist in government, private industry, and society at large. If society wants ethical technological change, the investigation above suggests that this must start in part at the level of technical instruction at post-secondary institutions, in ways that are more meaningful and rigorous than currently take place in most institutions.

At present, technology seems to provide the answer to feeling constantly behind. The neoliberal impulse to look to technology to provide answers to contemporary hopelessness and individual responsibility is built into these designs. The data presented in this study show that networked computation is *designed by people* to sort, quantify, and organize information at speeds much faster than the current of human time; for computers, time structures information transfer. Overall, FIA engineers do not seem particularly concerned with human time as they develop their designs, this dissertation suggests that they might pay more attention to the construction of efficient systems with user-facing affordances like speed that can be mobilized for both aesthetic, economic, and political leverage.

This dissertation has shown that time exerts agency in technological development as it binds material, social, political and economic forces in ways that make it nearly impossible to imagine ways to reverse or reinvent the present state of technology. For example, at present it difficult to envision a way of developing the current Internet that encourages deliberate commons-based knowledge production rather than “user engagement.” Economic drivers underlie Internet technology, which is itself situated comfortably within constellations of power. For example, in the case of the current debates over net neutrality, ISPs benefit economically from the Internet’s protocological structure and deploys resources – money, marketing, public support, lobbyists, and government agencies – to keep it that way. In a capitalist system, power – especially economic power – is mobilized to reinforce itself. These powerful forces, are not just present in the form of ISPs and other nameable tech industry or government agency entities; our use of and reliance on technology, our often limited view of technological history, and our human need to believe in the possibility of the future encourage us to think that technology, by virtue of existing, will make the future better. This notion of technology as a panacea the ultimate myth that is driven by the technology’s existence over time. This dissertation has shown that, along with the fact that time is materialized in the process of FIA development, these new protocol projects are saddled with a notion of a utopian future that makes it difficult for them to imagine and build for new use contexts that promote positive ethics such as supporting the Internet as a public good. While the FIA projects may be seen as failures or as slow-moving projects that have no real sense of what their goals should be nor how to achieve them, they offer us a vantage onto processes of Internet infrastructure development under late-stage capitalism. I hope this work has also pointed to useful categories to look for in other information infrastructure projects, categories that will signal how these projects exist in political-economic constellations and help us begin to conceptualize how we might better structure them to serve the public interest.

Appendix

Preliminary Interview Question Guide

What is your involvement with [FIA project]?
    Who brought you in?
    Describe he sorts of problems you solve.
    Describe how you view efficiency in terms of the work that you do.
    Describe a [FIA project] problem that is interesting to you.

Why are you involved with [FIA project]?
    What makes your work interesting to you?
    Why is this work important?

What are the benefits of [FIA project]?

Temporal Dimensions of [project] Design
How is latency managed with [project]?
    What sorts of problems does that create?
How does [project] increase efficiency?
    How does this happen technically?

Epistemic Dimensions of the [project]
    What sorts of ways is data used and presented in [project]?
    How is information presented in [project]?
    What sorts of information is hidden or not able to be shown using [project]?
        How is that different from the current IP Internet?

Political Dimensions of Design of [project]
    Describe the values behind your involvement in the development of [project].
Describe the values of the organization overall in relation to their development of [project].

Describe ethical conflicts you notice either in your interaction with the various facets of [project] development, or that you have heard about.
Who stands to benefit from [project] as it is envisioned?

Consent Form 2016-18

University of California, Los Angeles
CONSENT TO PARTICIPATE IN RESEARCH

Time Constructs: The Origins of the Future Internet

Britt S. Paris, a PhD Student from the *department of Information Studies* at the University of California, Los Angeles (UCLA) is conducting a research study. She is working with her faculty advisor, Dr. Leah Lievrouw on this project.

You were selected as a possible participant in this study because *of your work with eXpressive Internet Architecture*. Your participation in this research study is voluntary.

Why is this study being done?
As XIA provides a new way to consider networked information infrastructure, I am interested in your role in developing XIA and how you balance implementation of values of privacy, openness and efficiency into your work.

What will happen if I take part in this research study?

If you volunteer to participate in this study, the researcher will ask you to do the following:

- Your involvement in the study will take place in Spring 2018 at a time of your preference.
- I will meet you at a place of your choosing.
- I will give you more information about the study and the and introduce the consent form and give you a chance to fill it out.
- We will the spend an hour or so talking about your work and the particular issues you face as you work to develop XIA while balancing certain values and efficiency.
- I will audio record our conversation for my records and to consult as data for my study.
- You can decide if you want to participate anonymously or be identified.

How long will I be in the research study?

Participation will take a total of about *1 hour.* It is likely that I will contact you again via email for further clarification.

There are no potential risks or discomforts that you can expect from participation in the study.

Are there any potential benefits if I participate?

You may benefit from the study by reflecting on values you consider important to your projects and how you implement them.

Will information about me and my participation be kept confidential?

Any information that is obtained in connection with this study and that can identify you will remain confidential. It will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of storing all data on a secure server.

What are my rights if I take part in this study?

- You can choose whether or not you want to be in this study, and you may withdraw your consent and discontinue participation at any time.
- Whatever decision you make, there will be no penalty to you, and no loss of benefits to which you were otherwise entitled.
- You may refuse to answer any questions that you do not want to answer and still remain in the study.

Who can I contact if I have questions about this study?

- **The researcher:**

If you have any questions, comments or concerns about the research, you can talk to the one of the researchers. Please contact: Britt S. Paris parisb@ucla.edu or Leah A. Lievrouw llievrou@ucla.edu

- **UCLA Office of the Human Research Protection Program (OHRPP):**

If you have questions about your rights as a research subject, or you have concerns or suggestions and you want to talk to someone other than the researchers, you may contact the UCLA OHRPP by phone: (310) 206-2040; by email: participants@research.ucla.edu or by mail: Box 951406, Los Angeles, CA 90095-1406.

You may keep a copy of this information to keep for your records.

You will receive a copy of the published paper when it is completed.

Mark an X with regard to anonymity:

__ I don’t mind being identified.
__ I would rather remain anonymous.

SIGNATURE OF STUDY PARTICIPANT

____
Name of Participant

____________________________________ ______________________
Signature of Participant Date

SIGNATURE OF PERSON OBTAINING CONSENT

Name of Person Obtaining Consent	Contact Number
Signature of Person Obtaining Consent	Date

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