Engaging Values Despite Neutrality: Challenges and Approaches to Values Reflection During the Design of Internet Infrastructure

Internet protocol development is a social process, and resulting protocols are shaped by their developers' politics and values. This paper argues that the work of protocol development (and more broadly, infrastructure design) poses barriers to developers' reflection upon values and politics in protocol design. A participant-observation of a team developing internet protocols revealed that difficulties defining the stakeholders in an infrastructure, and tensions between local and global viewpoints, both complicated values reflection. Further, internet architects tended to equate a core value of *interoperability* with values *neutrality*. The paper describes how particular work practices within infrastructure development overcame these challenges by engaging developers in praxis: situated, lived experience of the social nature of technology.

1. Introduction

In his influential theorization of design worlds, Schön describes design as "a dialogue with a situation" (Schön, 1988, p. 183), in which defining and bounding a situation is a primary challenge of design. Researchers have long been interested in how designers define particular values or political beliefs as salient to design situations, impacting design decisions and the politics of artifacts (Flanagan, Nissenbaum, & Howe, 2008; JafariNaimi, Nathan, & Hargraves, 2015; Suchman, 1997; Winner, 1980). This article describes a case study in the design of internet infrastructure in which dialogues with bounded situations and conversations about values in design proved difficult. It explores the relationship between the practices of infrastructure development and developers' engagement in values-oriented reflection.

Internet protocol development, like all technology development, is shaped by biases and political choices with ethical consequences (Braman, 2013; DeNardis, 2009, 2012). This paper

draws on a three-year participant-observation study of the Named Data Networking (NDN) project, a research collaboration to redesign fundamental internet protocols. The NDN project sponsor, the U.S. National Science Foundation, recognized the potential political and ethical consequences of new internet protocols, and the NDN team was encouraged to engage in two explicit values-oriented interventions. I joined the team and conducted a lightweight intervention focused on discussing values issues with project leaders. A group of senior sociotechnical scholars also conducted a more formal external intervention using approaches drawn from the values in design tradition (Flanagan et al., 2008; Knobel & Bowker, 2011).

Both interventions faced difficulties engaging participants in sustained and impactful discussions of values or politics in design. Values conversations occurred infrequently, and rarely engaged participants in serious discussion of alternate design decisions or possibilities. This paper explores the relationship of these difficulties to the design of infrastructure. First, infrastructural design factors such as challenges defining stakeholders, tensions between local and global needs, and work path interdependencies made it difficult for developers to define design worlds. Problems scoping design worlds in turn challenged developers to define salient values. Next, NDN team members' assertions that their infrastructure was, or could be, values *neutral* frustrated the outsiders conducting values interventions. The paper uses field notes and interviews to trace expressions of neutrality to deeply held values of interoperability within the Internet architecture community. However, assertions of neutrality and challenges defining the design world coexisted with moments when architects engaged with the value-laden nature of their infrastructure. This paper examines this tension and concludes that work practices that enable designers to experience design worlds through *praxis*—situated, lived experience of the

social nature of technology, as theorized by Feenberg (2014)—help infrastructure developers engage in reflection on values within design.

2. Background

Investigating how values, ethics, and politics intertwine with technology development is an ongoing project in philosophy of technology (Feenberg, 2014; Vallor, 2016), information studies (Fleischmann, 2013; Kelty, 2014; Knobel & Bowker, 2011), human-computer interaction (Friedman, Kahn, & Borning, 2006; LeDantec, Poole, & Wyche, 2009), media studies (Coleman, 2012; Flanagan et al., 2008), and science and technology studies (Johnson, 2011; Latour, 2008; Sclove, 1995; Winner, 1989). In the values-oriented design literature, values have been defined as entities that appear in technologies, built consciously or unconsciously by developers and made material through a technology's features (Flanagan et al., 2008; Friedman & Nissenbaum, 1997). Values have also been described as properties of human actors; developers (Fleischmann & Wallace, 2010) or technology users (Alsheikh, Rode, & Lindley, 2011; Woelfer & Hendry, 2010) may prioritize certain values. Other scholars have criticized the idea that a static set of values can or should be considered in design (Borning & Muller, 2012), and sought to expand the definition of *values*. Increasingly, researchers interpret values as processes or practices (Houston et al., 2016; JafariNaimi et al., 2015; Snyder, Shilton, & Anderson, 2016). For example, Houston et al frame *valuation* "as the processes through which something is rendered important," and *values* as "moments where these broader processes become stabilized" (2016, p. 1404). JafariNaimi et al. propose values as *hypotheses* that illustrate "what the possible courses of action are, and how they might transform the situation" (JafariNaimi et al., 2015, p. 97).

Explicit attention to values – whether in discourse, affordances, processes, or practices – by developers during design unites all of these perspectives. Attention to values might be fostered through interventions using structured design activities and toolkits (e.g. Friedman &

Hendry, 2012), or through activities such as reflective design (Sengers, Boehner, David, & Kaye, 2005) or critical making (Ratto, 2011). Or purposeful attention to values during design might happen endogenously. Empirical work has demonstrated that technology development teams discuss a complex range of values (Fleischmann & Wallace, 2010). For example, Coleman (2012) described how shared values are learned among free software developers through processes of acculturation as well as moments of punctuated crisis. Braman's historical analyses of internet Requests For Comments, the memoranda that document the design of Internet standards, illuminate values debated by early network architects, including social values such as privacy, security, democracy, and citizenship (2013). In previous work, I have described the role of *values levers*: work practices (distinct from interventions) that encourage conversations about values during development (Shilton, 2013).

Encouraging developer consciousness of values *during* design is part of a larger project in philosophy of technology, which argues that the process of recognizing technology as values-laden and ethically charged is critical to fostering more democratic social orders (Feenberg, 2014). In *The Philosophy of Praxis*, Feenberg describes a history of philosophy that critiques morally-neutral views of technology, instead interpreting technological systems as social institutions that "more nearly resemble legislation than mathematics or science" (2014, p. viii). Praxis, defined as experience that reveals the social shaping of technology, enables collectives to resist immoral technological systems. This paper investigates conditions under which developers experience praxis, in the hopes that encouraging this consciousness during design can enable more just technological futures.

3. Method

In 2011 I joined the NDN project and began an ethnographic, participant-observation study of values reflection within infrastructure design. NDN is a major research effort within the

computer science field of information-centric networking. The team is a ten-campus collaboration that has received over $13.5M in funding from the U.S. National Science Foundation over seven years. I was funded to engage project PIs in analysis of the values and politics of their architecture. My participation consisted of lightweight interventions designed to surface values discussions, including giving talks about values in NDN at team meetings, conducting interviews in which I raised questions about values (described below), and collaborating on papers about NDN's social and policy implications.

Sponsored participation also afforded me the opportunity to observe the NDN team. I attended dozens of videoconferences and teleconferences, and traveled to twice-yearly all-hands meetings. I also conducted semi-structured interviews with nine project PIs, two graduate students, and two staff members (identified here by position and a pseudonymous initial). The data corpus from these observations (August 2011-August 2014) consists of approximately 50 hours of field notes and recording transcripts, and full transcriptions of all interviews. A graduate student and I iteratively coded field notes, meeting transcripts, and interview transcripts. In both field notes and subsequent coding, I focused on the relationship between work *practices*—routine activities that comprise the labor of developing, testing, and implementing internet protocols—and values *reflection*—discussions of, debates about, or claims to, particular values.

4. Challenges to values reflections

Engagement with the NDN project illustrated that NDN's protocols, like all infrastructures, embed explicit social and political values. These values have been discussed at length elsewhere (Shilton, 2015; Shilton, Burke, claffy, & Zhang, 2016; Shilton & Koepfler, 2013) and include technical values such as efficiency and innovation, as well as social values such as security, privacy, and resource democratization. Participant-observation of NDN also illustrated how the work of infrastructure design posed barriers to engineers' recognition of the politics of their

artifacts. This project was in many ways a contrast to my previous study of values reflection during the design of a user-facing technology (Shilton, 2013). Values discussions were more difficult to engage and less frequent on the NDN team than in my previous work. This was despite both my own presence as a values-oriented researcher on the team, as well as twice-yearly meetings at which a team of outside experts in computer ethics and values in design conducted reflection activities with the team ("Values-in-Design Council," n.d.). Both interventions struggled to make values conversations consistently relevant and engaging for NDN team members. A common intervention was for a Values in Design (VID) Council member or me to pose a scenario for discussion, for example, which affordances in NDN might enable government wiretapping. This often led to reactions like the following, from PI W:

> I think there's a legal issue here. I mean please correct me if I'm wrong, but I'm not sure how much of... When these values discussions get discussed, how much of the burden should be shouldered by the technology part? And how much should be shouldered by the legal part? I mean so the thing is, if we are burdened with considering all possible consequences, then we cannot... It's very difficult for doing... for us to do anything, right?

Reactions like PI W's, in which participants felt it was difficult to "do anything" about social issues, led me to question *why* values conversations were so challenging to spark and sustain. I turned to infrastructure studies for sensitizing concepts. Tracing infrastructure studies concepts through my interviews and field notes revealed that common challenges for the design of infrastructure *also* challenged values discussions in particular. For example, I paid close attention to the organizing work required of infrastructure development (Lee, Dourish, & Mark, 2006; Ribes & Finholt, 2009), revealing that path interdependencies in NDN development frustrated

values-oriented activities such as interacting with working prototypes. In addition, while scholars of information infrastructures have described ways that stakeholders can be engaged as co-designers (Pipek & Wulf, 2009), delineating users and stakeholders of internet-scale infrastructures proved to be quite complicated in NDN. Further, a need to scale up (grow in size or number of users) while also scaling down (making an infrastructure useful to local applications) is a common challenge for infrastructure design (Edwards, Bowker, Jackson, & Williams, 2009). In NDN, challenges of scope and scale frustrated developers attempting to talk about values in particular use contexts. Finally, my field notes revealed an infrastructural challenge to values discussions not yet explored in the literature: the tendency of a key infrastructural value—*interoperability*—to be conflated with values *neutrality*. I describe each challenge in detail below.

4.1 Path interdependencies

A challenge to values reflection within the project stemmed from the daily realities of infrastructure-building work. Path interdependencies within infrastructure development tended to stymie values reflection. NDN developers had to develop infrastructural tools (in this case, complex routing protocols and a robust code library) before they could develop applications to test. This required collaboration across multiple campuses, and meant it was sometimes years before prototypes were ready to be used. As PI J put it:

> I had a goal to make sure that everybody, that more people were using the NDN chatroom [at an all-hands meeting] …We succeeded barely by the skin of our teeth, and only because our local system guru guy was walking around making sure people were connected... So, [using our applications] is still perhaps our biggest challenge, partly because we do not have funding for people dedicated to

> software infrastructure support, including sysadmins, software engineers, and usability experts. We are trying but we are far from there yet.

As I discuss in section 5.2, experiencing self-testing of NDN technologies was important to developers' engagement with values issues. However, the slow path to working prototypes that PI J describes frustrated discussions of values, because most participants didn't experience using an NDN-enabled application until several years into the project. (Indeed, when I checked her quote with PI J six months after her interview, she noted that using the NDN chatroom continued to be a challenge for the team). Further, even working prototypes were often "toy" applications, without the complicated trust architectures and security mechanisms needed to operate in the real world. As PI H described it:

> We run all the toy applications that have been pushed out into the group. … But no, I can't say that I personally learned anything. It's a nice thing to see, but it's not been like an eye-opener.

Delays in prototype testing and the relative simplicity of toy applications meant less time spent experiencing self-testing, a work practice that can encourage values reflection (Shilton, 2013).

4.2 Imagining users and stakeholders

Values-oriented design methods often emphasize analysis of system users and stakeholders, and incorporation of stakeholder viewpoints (Friedman et al., 2006). An ongoing challenge to discussions of values and politics in NDN design was the difficult issue of who, exactly, should be considered users of, and stakeholders in, the infrastructure. When I asked staff member Y if he'd been able to get feedback from users, he replied:

> Users. It's hard because maybe you... Are you saying users or developers?

As Y pointed out, the first users (and direct stakeholders) of an NDN infrastructure are application developers: designers building Internet application to comport to NDN. Application

developers were not only primary stakeholders, they were a critical link to end users. PI J described a trickle-down relationship between end user needs, application needs, and infrastructure design:

> I mean no architecture is user-facing; if it is, you've done something wrong, right? IP wasn't user-facing, so how did we get IP deployed? … It was, to some extent, user-driven. And it wasn't IP they were deploying, it was, "I want email, so some system and geek has to deploy IP so I can get email." The users don't drive the architecture, the users drive the applications. The demand for the applications drives the architecture.

Here, PI J describes users as a stakeholder category, but also stipulates the layers between end user needs and infrastructural responses that complicate imagining end users as direct stakeholders.

PI I was sometimes frustrated that the layers of indirection between infrastructure and users meant that end users were not considered direct stakeholders. He described trying to emphasize a more user-centered approach to design when he joined the project:

> A lot of the [early] presentations about architecture were cheerfully derogatory towards users of the architecture as not really knowing what they wanted from the network, from the features of the architecture … well not everybody said this but there was sort of a feel, a sense that, you know, we need to make the best thing and then people will figure out how to use it. …I gave a short response, it started with the user like a big picture of Darth Vader, the user as Darth Vader, and talked a little bit about conversation with users would be worthwhile.

Even when the team tried to imagine or incorporate end users, they faced an additional challenge. NDN developers were aware that *everyone*, theoretically, was an end user of NDN. But designing an infrastructure for "everybody" is a difficult values challenge (Oudshoorn, Rommes, & Stienstra, 2004). As PI F put it when asked who the users of NDN would be:

> I'd imagine they would be just as broad in terms of user base as today's internet. I mean, there will be all kinds of creatures, good and bad.

In NDN, imagining stakeholders and their values – from the too-narrow category of application developers to the too-broad "all kinds of creatures" – was a task subject to enormous complexity.

4.3 Interpretive flexibility

Challenges imaging stakeholders and their values extended to imagining the broader social worlds into which NDN would be inserted. New internet protocols must interact not only with future imagined users and unpredictable user needs, but also with changing business models and regulations. NDN's architects grappled with interpretive flexibility: the different ways that varying social groups define the functionality or working of an artifact (Pinch & Bijker, 1984). Knowing that their protocols would be flexibly interpreted challenged NDN architects' ability to ground values discussions in specific use contexts. As project PI K expressed in a discussion about an NDN-enabled future social networking site that could protect user content:

> I mean what's hypothetical there though, I think, that makes it problematic is not *technically* how you could do it, but what the business model [would be]. Like what sort of combination of technical solution and business model that we believe [could work]. ... I think maybe there are too many ambiguities.

The interpretive flexibility of NDN infrastructure—in which not only technical solutions, but future business models, policy decisions, and user adaptations mattered to ethical and social outcomes—created frustrating ambiguities for developers.

This frustration was expressed to me when I co-authored a paper with several NDN PIs on potential policy implications of the infrastructure. I began the drafting effort by speculating about what I considered to be important social affordances of NDN, while avoiding fully deterministic statements about what sorts of "impacts" NDN might "cause." In a comment to me, PI J wrote:

> I have a real problem with the many sentences in the paper that say "NDN will change/impact/have-implications/affect [value] X, Y, or Z" when you don't say what the change/impact/implication will be. … I'd rather have a paper that the technical community will also read and buy into, and this kind of hand-wavy claim is not going to fly with them.

Outlining values issues in NDN required some "hand-wavy" claims, because the interaction between architecture, future applications, and an ecosystem of policy and law enforcement decisions meant that the social impacts of NDN could not be fully determined. As PI J said in an interview:

> I think a lot of privacy comes down to how things are implemented and how things are regulated rather than the architecture. I'm not convinced that architecture can make such a big difference.

Embracing this ambiguity was difficult for developers and strengthened the feeling on the team that the *architecture* was not the site of values decisions. Values issues were seen as someone else's challenge. As PI K put it in an all-hands meeting: "…this is not an NDN problem; it's an applications problem."

4.4 Interoperability and neutrality

A final hurdle to reflection on values in NDN was a frequently expressed assumption among NDN participants of infrastructural neutrality. As PI K stated in a paper-drafting discussion:

> NDN can bring great benefits to society, but can be abused by bad guys to do bad things. … I feel it is worth saying loud and clear…

She also requested the paper cite Feynman's "The Value of Science," which stipulates: "Scientific knowledge is an enabling power to do either good or bad—but it does not carry instructions on how to use it" (1955, p. 13). PI K was not alone: many team members asserted a belief that the NDN infrastructure was free from instructions on how to use it. However, the same people would also engage in heated discussions of, for example, NDN's resistance to government surveillance. While a belief in technological neutrality is common in technical work (Feenberg, 2014), as my participant-observation progressed, I became interested in the dissonance between assertions of neutrality and willingness to engage in discussions of ethics and politics. I came to believe that asserted belief in the neutrality of architecture was at least partially an expression of a core value: the interoperability of infrastructure. Where a desire for interpretive flexibility emphasized the creativity and imagination of users and use worlds, a desire for interoperability emphasized the interworking of systems. Infrastructure increasingly succeeds by enabling existing and future technological systems to work together (Palfrey & Gasser, 2012).

For internet architects, interoperability is ensured through adherence to a key guiding norm: the end-to-end principle (Gillespie, 2006). Theories of network design based on the end-to-end principle specify that functionality is best implemented on the ends of the network (in applications), rather than within the network itself (Clark, 2013; Solum, 2009). As Gillespie (2006) describes, "end-to-end" was a technical descriptor adopted as a principle and goal to foreclose controversies in early network design. Over time, the interoperability enabled by end-to-end design has become associated with other values important to network architects, such as

increased innovation, as well as broader sociopolitical goals such as information freedom (Gillespie, 2006). Importantly, the word "neutral" is often used to describe the way end-to-end networks interact with data. For example, in a court decision quoted by Gillespie (2006, p. 429): "control lies at the ends of the network where the users are, leaving a simple network that is neutral with respect to the data it transmits."

The aspirational nature of "end-to-end" was reflected in the way NDN architects talked about network design. As PI K put it:

> What we learned from TCP/IP is that the narrow waist, the hourglass shape is the right shape for internet architecture, so TCP/IP succeeded.

The "narrow waist" refers to a bare minimum set of requirements for networked communication; more complex protocols may be layered on top, but the narrow waist should be as simple (and "neutral") as possible. PI K credits the simplicity of the narrow waist for the success of TCP/IP. NDN was frequently spoken of (and visually referenced in slides and papers) as replacing the "narrow waist" of TCP/IP.

An ideally simple, interoperable architecture should work with any higher-layer system that wants to take advantage of its data-sharing mechanisms. While NDN will (like all architectures) afford some interactions more efficiently, more cheaply, or more elegantly than others, an *ideal* infrastructure would not have these limitations. Attempts to move features laden with other values (security, for example, or control) into the "narrow" architecture challenge a fundamental and long-held principle of internet design.

I came to read team members' assertions of values neutrality—the ability of the infrastructure to do both good and bad things in equal measure—not as a denial of values, but instead as expressions of the value of interoperability and the tensions interoperability poses to

other values like privacy and security. However, the tendency to equate universal interoperability with neutrality made it difficult to discuss other values issues (such as security or control), as it led to similar "not our problem" pushback as challenges of scope and scale. As PI J concluded during an interview:

> I mean, I think this just comes down to the way we think about networks in general. I don't think that NDN or any of these architectures are special in the values that we associate with them…. We've talked about privacy. …I don't think [privacy] is specific to the future internet architectures. …We embed privacy, some aspects of privacy into the architecture but we embed a heck of a lot more aspects of privacy into regulations (or the lack thereof), and into business models.

5. Work that encourages praxis

Despite assertions of the neutrality of NDN, or assertions that NDN was not the place for values decisions, coding and analyzing the field notes and interview transcripts also revealed many moments when team members discussed their own values, debated the values they hoped to instantiate in NDN, or used values as hypotheses to better interrogate courses of action. Vertesi (2014) has discussed the ways that actors reliant on multiple infrastructures artfully align those infrastructures in ways that work for them, calling this *seamfulness*. NDN architects displayed values seamfulness, engaging with discussions about ethics and politics even though doing so meant dealing with complexity regarding stakeholders, interpretive flexibility, and interoperability.

I was explicitly interested in work practices that encouraged participants to abandon a neutral stance. Many of the interventions we outsiders engaged were hypothetical, asking developers to imagine their technologies in real-world situations. Tools such as scenarios and card sets for imagining users and use contexts are common within values-oriented design

traditions (Flanagan, Howe, & Nissenbaum, 2005; Friedman & Hendry, 2012; Nathan, Klasnja, & Friedman, 2007). However, a commonality in work practices that sparked successful values reflection within NDN was that these practices went beyond the *imagining* required by scenarios to encouraging *praxis*: lived experience of the social nature of technology (Feenberg, 2014). Successful values-oriented work practices encouraged developers to *experience* values issues. If values are verbs as well as nouns (JafariNaimi et al., 2015), to engage in sustained values reflection, developers must engage in action. Work that encouraged praxis in NDN included long-term engagement with contexts of use, experiencing self-testing, and encountering sociotechnical constraints.

5.1 Long-term engagement with contexts of use

Though the scope and scale of NDN posed theoretically infinite future use cases, NDN team members nevertheless made concerted efforts to engage with a set of use cases for their network. This engagement went well beyond scenarios to long-term exploration of design contexts. They termed these explorations *applications*. As PI I put it:

> [The applications sub-team] develops things that are both demonstrating the strengths of NDN, maybe challenging things that we don't understand about the architecture, and then also just trying to think about what would be interesting applications, and how will they be supported or not supported by the architecture.

When the NDN team engaged with applications, they also engaged the broader social context(s) of technology use, and reflected on values particularly salient to those contexts. For example, designing NDN applications for media consumption prompted discussions of provenance and trust in content. As PI E put it:

> The idea is that you can get data from anyone, anywhere, anytime. And it doesn't matter where this data came from … I get it from you or I get from my graduate

> student or I get it from the *New York Times*. And in that sort of model, if you don't have security, the whole thing is meaningless. Because I need to authenticate that this came from the right person.

Designing media applications underscored team efforts to ensure that NDN supported data authentication.

In a different example, PI S worked on NDN support for vehicular networks. As he described:

> I'm driving in a big city and I really want to know how to get to my destination, the quickest [route] today … So if cars could talk to each other and relay the real time traffic information, it would help me a lot as I commute.

He went on to describe how this scenario helped him think about NDN data in a new way:

> … those cars probably aren't all connected together at all times. …Any type of bottleneck that prevents you from sharing all the data that you want to share, you have to now prioritize. You have to figure out which data to send first and which data to send next. And it struck me that NDN namespace design can inform a very general type of prioritization policy that would essentially maximize information transfer across bottlenecks. … And so, we work on this class of prioritization policy in the context of that type of car application.

Engaging with vehicular networks grounded PI S's work in a context that highlighted constrained data sharing resources. Fairness became a value salient to this context, because researchers had to decide which data was most important to send through the bottlenecks. Considering this context highlighted the importance of fairness, influencing later conversations about policies for data congestion management.

5.2. Experiencing self-testing

While some work practices encouraged praxis by contextualizing NDN development, others encouraged developers to experience their technologies as a user would. This lived experience helped developers realize tensions between their designs and complex human uses. Participant-observation of the NDN team revealed that constructing and testing material prototypes particularly encouraged praxis. To engage in a form of thinking that incorporated real-world complexities and values concerns, it helped to have something material to play with, bounce ideas off of, and iterate on.

PI I was very familiar with the creative potential of prototypes. He described his campaign to encourage development of a prototype file sharing service. NDN is particularly suited for peer-to-peer data sharing, and a file sharing application could highlight this strength of the architecture. As he described it:

> The reason we're doing the file sharing thing at all is because I took a student project that was in one of [PI K]'s classes and really encouraged them to build something. And then that prompted others in the group to think: "Oh, file sharing is a really important application" and focus on it.

He described the initial file-sharing applications as extremely basic. But the prototypes were enough to inspire other PIs to rebuild the tool. The material fact of code they could play with, critique, and improve highlighted social challenges that ran alongside technical ones. For example, file sharing made verifying identity–in particular, who has the "rights" to use a particular identity–a particularly important problem to solve. As PI I described:

> Part of what applications can do is pick things to try where [the applications are] a foil for ideas that are important.

Members of the file-sharing program team went on to brainstorm ideas for identity management, including drawing identity and trust relationships from existing social networks. PI I credited the effort to build file sharing systems with encouraging the team to tackle hard social problems in identity management.

Staff member Z discussed a different set of social concerns realized through testing an NDN video application. NDN participants were requested to set up webcams in their offices to allow for testing of the video prototype. As Z described setting up his own webcam:

> I used to point [the webcam] in the office. And I'm like, well, we have a bunch of [high school] interns now. It's not quite fair to publish them. So do I put a sign up saying, "Enter this room, waive your [image] rights off to the [entire] future internet?"

The video prototype helped staff member Z to experience the broadcast nature of NDN, where data are not only recorded, but also replicated across servers indiscriminately (what Z describes as the "future internet"). Z realized that project interns, particularly young ones, might not want their images broadcast in this uncontrolled manner. Experiencing the data transfer realities of NDN provided Z with insight into concerns previously outside his focus, and helped him identify the salience of values such as privacy and informed consent.

5.3 Encountering sociotechnical constraints

The NDN team also encountered social or technical constraints that challenged their ability to protect or enforce particular values. In infrastructure studies, problems that block technical advances are known as *reverse salients*: critical features (sometimes technical, but often legal or social) out of sync with the rest of system development that hold back an advancing front (Edwards et al., 2009; Hughes, 2012). In NDN, a thorny reverse salient was organizing *trust models*: ways of distributing and revoking cryptographic keys to support content authentication,

privacy, and security. NDN's protocols rely on digital signatures to authenticate data provenance, and encryption to protect private information. But managing a global network of public and private keys to support both signatures and encryption is an incredibly difficult sociotechnical task. As PI F described:

> …Security is a real headache because signatures introduce overhead and bandwidth and storage [costs], and god knows what. Trust management introduces this, and also privacy concerns [introduce this]. … Entities could be routers, hosts, or we call them producers, consumers, whatever. But these entities need to interact securely and they need to be able to verify, maybe not encrypt, but at least verify stuff: content, packets, whatever. So, in order to do that, if you're going to verify stuff, you need some kind of a trust management architecture. And that's... That's the holy grail here. It's how do you design one? .... So, this has been a long running issue, and somewhat contentious issue in NDN: the design of this trust management.

As staff member Y put it:

> Key revocation is an unsolved problem… I mean, there are these unsolved problems of key distribution and revocation. For the trust model for the testbed, I mean just getting that to go up, it's taken like two months. … It took me like took two months to finally get it to work, it is hard! Yeah, so until it's easier…

Y expressed that even a basic trust model for the relatively small NDN testbed (where keys could easily be passed among participants interpersonally or "out of band") posed significant technical challenges. Designing global trust models was an order of magnitude more difficult. In meetings with external evaluators, NDN team members often struggled to explain how they would support

widespread encryption. As a senior NSF advisor responded in a discussion of NDN's plans for content verification:

> I'm going to have to get you guys a sign that says "magic happens here."

Though building workable trust models was a challenge for the NDN team, this challenge encouraged engagement with the politics of content security and privacy. As PI K described:

> Security has to be built into this new architecture. It's just the requirement. As required by today's environment. … You know crypto is a very useful tool to execute security. But crypto all depends on getting the right keys. And how do you get right keys?

As PI C told me:

> Our security [research] is related to what would you realistically do as somebody running a router in the middle of the network. Are you going to spend resources to authenticate the content? Whose job is it to get the right content? … We have some results there, I wish we had more, but I think it's still a hard problem. But we're still looking at that.

The team continues to work on, and around, the reverse salient of workable trust models, while grappling quite openly and consciously with the values concerns the topic raises.

6. Discussion

Reflecting on values in technical affordances and processes can be a hard sell in technical communities. Values reflection was particularly challenging during the design of NDN, in which important shared values such as interoperability and the end-to-end principle were frequently conflated with values neutrality. Yet NDN architects were also willing to engage in discussions about values and politics even though doing so meant dealing with uncomfortable complexity.

In previous work, I have suggested that values discussions and debates can be spurred by "values levers": work practices that open new discussions about social values within technical work. Values reflection in infrastructure development, however, is not well-described by the "levers" metaphor, with its emphasis on values discovery and unpacking. Instead, infrastructure developers facing challenges of scope and interoperability must stitch together complex and multiple stakeholders and contexts (Vertesi, 2014). This stitching together is better suggested by Feenberg's (2014) theoretical development of *praxis:* an expereinced, *process-oriented* understanding of the complex social nature of technology. NDN developers' values reflections were enabled by seamful (Vertesi, 2014) praxis: ways of aligning complex ideas through consciousness of the social nature of technology. Design practices that encouraged praxis countered the practical (and often necessary) abstraction within infrastructure design by grounding development in social contexts. And these design practices challenged assumptions about the neutrality of infrastructure by encouraging experience with political concerns and values.

While effective at encouraging contextualization and embodiment, techniques that encourage praxis have clear limitations for design ethics. As Dourish (2004) points out, "contexts" are not a stable set of categories, and developers cannot rely on contexts to provide a reliable set of rules—or values—for development. While long-term engagement with use contexts encouraged values discussions, it also constrained the values discussed. NDN's use cases tended to focus on internet uses familiar to American network architects (reading the *New York Times*, fighting rush-hour traffic). Self-testing faces similar limitations, because the values experienced by developers are most likely to be those already prominent within their familiar contexts and world-views (Oudshoorn et al., 2004). By their nature, techniques that encourage

praxis focus on familiarity rather than diversity: a serious challenge for values in the design of global infrastructures.

This study also suggests approaches for researchers intervening in values-oriented infrastructure design. Interventions should encourage engagement over imagination when at all possible. Researchers should consider design teams' engagement with contexts of use, prototyping practices, and the impact of technical constraints. Exercises designed to expand the range of social contexts developers experience, and the diversity of the prototypes they develop, are important next step for encouraging values dialogues within infrastructure development work. Further, values-oriented researchers might lead the identification of sociotechnical constraints to encourage reflection on values during design.

Most importantly, intervening researchers must recognize that developers hold many values simultaneously in complex arrangements. This resonates with JafariNaimi et al.'s assertion that "Practicing designers … make sense of values not at remove, as in scholarship, but in the often-confused design situations…" (2015, p. 94). Declarations of values neutrality may themselves be signals of values, and researchers should take care to unpack these claims, and disentangle them from values such as interoperability. Interoperability is a primary value for many infrastructure developers (Ribes, 2017), and this work suggests that this value may, in some situations, be confusingly conflated with *neutrality*. Recognizing values seams – the places where multiple values are held in tension – is a critical technique to encourage values reflection beyond claims of neutrality.

7. Conclusion

Making values an explicit part of infrastructure design requires bringing values and politics into the design world for infrastructure architects. Schön writes:

> As a designer brings understandings, strategies, and images to a particular design situation, conducts a dialogue with that situation, and constructs in it a version of a more or less familiar design world, he instantiates a particular set of things to think with (1988, p. 183).

This paper suggests that bringing values explicitly into the realm of "things to think with" requires not only spurring developers' imagination, but also praxis: encouraging lived experience of the social nature of technology. As Schön's work on design worlds asserts, things to "think" with are more than simply cognitive: in his words, they require "a form of seeing- and doing-as" (Schön, 1988, p. 183). Praxis and "doing-as" are particularly necessary to encourage explicit values reflection in the design of infrastructure, because infrastructure's users and stakeholders are remote and diverse, scope and scale push back on meaningful contextualization, path interdependencies stymie embodiment, and interoperability is a primary value that may obscure discussion of secondary values. Experience of NDN's political nature helped NDN developers explore diverse ethical and political possibilities for their infrastructure, even while acknowledging tensions with primary values of interoperability. Methods of praxis point to an effective way forward for values-oriented design.

8. Author Biography

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