Authoring Place-based Experiences with an Internet of Things: Tussles of Expressive, Operational, and Participatory Goals

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Introduction

"[S]hared visions of the possible and acceptable dreams of the innovative…" – Susan Leigh Star quotes this definition of infrastructure in her 1999 paper, "The Ethnography of Infrastructure." [Star99] The Internet of Things concept envisions the internet as a new kind of infrastructure for the built environment: by interconnecting the embedded and mobile devices surrounding us, it will become a fundamental part of how we create *places* and *experiences*. Future internet applications will expand the vision of the Internet of Things into the mainstream media world of high definition content and interactive environments, integrating capture, processing and dissemination of high-bitrate digital media, sensing and control, distributed processing, and user interfaces in increasingly sophisticated and complex combinations, with scales and diversity far beyond today's applications. Practical, public deployment of such *heterogeneous, experiential cyberphysical systems* has been limited by current approaches, including the semantic disconnect between the host-based addressing of the Internet and the communication and data distribution need of these systems. We suggest a fundamental challenge for those creating an *Internet of Things* is how to make it more *authorable*—a substrate for creating systems that are not just "functional" or "efficient" but have a wide-range of expressive, operational and participatory goals.

Tussles: Authoring for Expressive, Operational, and Participatory Goals

This can be considered a tussle between three types of goals: *Operational* objectives deal with familiar requirements for performance and robustness (among others). *Expressive* or communicative goals emerge from applications' important, non-functional considerations: lighting color quality or cross-fade smoothness; use of multiple modalities of media; the size and thickness of a display; the openness of a platform to user configuration—these are connected not by basic function but by the needs of experience or expression. They place high demands on integration across heterogeneous systems and suggest that high-bitrate content and sensing/control will not be so separate in the future. Finally, *participatory* goals emphasize the demands of user-facing components, just-in-time configuration and content selection, ad-hoc networking, as well as consideration of intermittent interaction and other human factors.

Technical Lens: Named Data Networking

Our current exploration of *authoring cyberphysical systems* exists within a specific network architecture research project. It offers examples of how architecture can support developers in tackling these challenges. Named Data Networking (NDN) is a new network architecture being developed under the NSF's *Future Internet Architecture* program by PARC, UCLA, and eight other institutions.[1] It is based on Content Centric Networking, developed by Van Jacobson, which is being implemented in a freely available software package called CCNx.[2] NDN replaces the internet's current host-based model of addressing, which is based on *where* data is located—as identified by an IP address, to a model based on *what* data is desired—referred to by a name. In effect, the approach shifts the "thin waist" of the internet upwards from IP, which becomes one of many possible transports, to data names. Names are application-specified, and enable data semantics that make sense to authors to be embodied at the network level. The NDN approach is detailed in [Jacobson09, Zhang10] and briefly summarized here.

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[1] http://named-data.net/
[2] http://ccnx.org/

Applications issue *Interest* packets that specify data by name (e.g., `/ucla/boelter_hall/occupancy`). Names are opaque to the network protocol, but conventions are defined for hierarchical names that facilitate scalable routing. Other applications register as providers for a given name prefix and answer these *Interests*. Each *Interest* is answered by a single *Data* packet, which can be cryptographically signed. The protocol allows for name enumeration, content freshness parameters, signing key specification, and other features. Protocol details as well as research in routing rules and security techniques are available in the references given above.

In collaboration with the NSF Center for Embedded Networked Sensing (CENS) and the University of Illinois Urbana-Champaign, UCLA REMAP is leading the application research thrust of the NDN project. We aim to ground NDN architecture research through experimental deployments in two emerging application areas that embody the potential of the future internet and incorporate the Internet of Things: (1) Media-rich instrumented environments, which aim to realize the vision of heterogeneous, experiential cyberphysical systems for culture, education, and simulation that began with ubiquitous computing; [Burke06a] (2) Participatory sensing, which leverages the billions of deployed mobile phones and secure cloud-based storage and processing to enable globally-scaled but personally-regulated sensing for science, health, planning, and expression. [Burke06b, Abdelzaher07] For brevity, here we focus on the first application, but look forward to the opportunity to discuss both at the workshop.

Media-Rich Instrumented Environments

A modern building is likely to be equipped at construction with digitally controlled and often IP-addressable lighting and environmental systems (heating, ventilation, air conditioning), motivated at a minimum by energy management concerns. The same building may have security systems for intrusion detection and access control that employ a variety of presence, contact, flow, and identity sensing. They often expose monitoring and configuration over an IP interface, as do fire-life-safety systems. Additionally, most facilities have broadband wired and wireless access to the public internet as well as private IP networks. With the increasing importance of digital media, it is common for facilities to have locally and remotely fed displays and projection, paging or sound systems, video recording or web broadcasting capabilities, and even large displays with touch or movement-based interfaces. These media subsystems often support IP-based control and configuration as well as media streaming over IP using common codecs (e.g., H264) or LAN-focused approaches such as the CobraNet digital audio protocol.

While IP has provided consistent and cost-effective connectivity to building systems, traditional hosts, and mobile devices, this is not enough to enable the vision of ubiquitous interactivity and heterogeneous cyberphysical systems. The typical segmentation and/or address translation in these networks makes their configuration difficult to *author* with and brittle to application change. In practice, for reasons of security/stability, QoS, and simplicity of administration, these many IP networks are often implemented in isolated VLANs, with firewalls between systems, or are not interconnected at all. They use different protocols to share even basic data and control mechanisms, and are surprisingly hard to integrate in practice, especially at the scale of an enterprise or in specialized facilities. Differing protocols and IP gateway mechanisms, addressing schemes, content distribution and security requirements across various subsystems pose further *authoring* challenges to software developers.

We are exploring the advantages that NDN provides for such systems: Its intrinsic support for named data suggests that we can reduce or simplify middleware previously used to implement publish-subscribe mechanisms, service registration and discovery, and to control various hardware subsystems. The broadcast model and infrastructure-free local communication (no address is needed to issue an *Interest* packet) support systems of many embedded devices, often wireless. Signed data enables more straightforward security approaches that mix a variety of control and data traffic on the same network rather than relying on IP-based firewalls or physical network segregation to separate traffic.

We have argued since 2002 that interconnection of sensors and actuators based on names named data networking (considered then at the middleware level) is extremely valuable to authors of hybrid physical and digital environments, especially in cultural applications. [Burke06a, Mendelowitz05] NDN addresses fundamental limitations unearthed in that project by providing: (1) internet-scale and wirespeed routing based on names; (2) IP-independent addressing; (3) no distinction between media and control data; (4) integrated support for security and trust. Other challenges still exist and can be informed by past experience, notably namespace query and propagation and service discovery.

Authoring an Internet of Places and Experiences from the Internet of Things

To this workshop, we can contribute a perspective on networked systems authorship with expressive, operational, and participatory goals. We are interested in building *Places* and *Experiences* using internet-connected *Things.* To connect lighting, sound, sensing, and industrial control components, REMAP has used IP- and ethernet-based control systems, RS485 and other legacy mechanisms, and is now contributing to new network protocol research.

We believe there are systematic ways to evaluate ease of authorship. For example, to evaluate NDN in applications from the perspective of *usability of the network by application developers*, one could apply the cognitive dimensions framework of Green[3]. Three of dimensions that directly apply to comparing data-driven vs. host-driven architectures are: **Closeness of mapping** between "problem world" (mental models) and system design; **Secondary notation**: Expressiveness beyond the official semantics. **Hard mental operations**: How much must be expressed / manipulated outside of the notation. Three other dimensions underline the value of NDN in iterative deployment or real-world systems with intermittent updates: **Premature commitment**: constraints on the order of doing things; **Progressive evaluation**: ability to work with incomplete systems; **Viscosity**: resistance to (local) change.

We look forward to developing these ideas further and contributing to the workshop!

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[3] Introduced in [Green96] to evaluate programming languages and extended for usability considerations [Green00].