Advancing Applications from the Edge In with Information-Centric Networking

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ice-ar.named-data.net

Outline

- ICE-AR Project Concept
- Edge-in Approach to ICN Research & Rollout
- Augmented Reality (AR) as Driver for ICN-WEN Research
- Trends & Counter-Trends in Application Development
- ICE-AR Browser Design Concept
- Research Thrusts
  - Naming
  - Performance
  - Security / Privacy
- Key Challenges
- Collaboration Opportunities
- Conclusion

For UCLA and NMSU team members and more background, see: **ice-ar.named-data.net**

ICE-AR: ICN-Enabled Secure Edge Networking with Augmented Reality

Apply NDN to unify advances in wireless communication with domain-specific computing technologies to accelerate AR at the wireless edge and deliver robust performance for large groups of people interacting in real-time by exchanging context & content.

(i) Realize ICN in an operational demonstration system that integrates **low-level wireless performance improvements with domain-specific *acceleration as a service***.

(ii) Investigate the design of robust and resilient networking for an information system that comprehensively uses infrastructure resources while withstanding infrastructure failures.

(iii) Develop approaches that **transition content delivery** from monolithic, context-independent streams to highly granular and context-dependent.

(iv) Investigate the **management of identities and trust relations** in dense deployments in large campus networks of the future **where content can be generated by all edge devices**.

(v) Explore how to **infuse comprehensive end-to-end security and identity privacy protection** for users/applications–intrinsic security and privacy in all cyberspace elements at the edge.

Edge-in Approach

- Reap ICN benefits without requiring deployment in the core.
- Target greenfield applications where IP is challenged / heavyweight stacks are a poor fit.
- Pursue decentralized computing and communication models:
    - Built around NDN's "fundamentally new abstraction for general purpose networking";
    - Remove cloud dependency for content, processing, rendezvous and trust management;
    - Avoid silo'ed approaches to information exchange.

Examples from the NDN team

Vehicular Networking

- G. Grassi. "VANET via named data networking." 2014 IEEE INFOCOM Workshop on Name-Oriented Mobility

Internet of Things

- W. Shang et al. "Named Data Networking of Things (Invited Paper)." IEEE IoTDI 2016.
- W. Shang et al. "Named Data Networking of Things: A case of cloud-independent home entertainment design (Invited Paper)," IEEE IoTDI 2017.

Augmented Reality

- J. Burke, "Browsing an Augmented Reality with Named Data Networking (Invited Paper)," ICCCN 2017.

Augmented Reality as a Driver for ICN-WEN

- Drive architecture development for wireless edge networking, “UX beyond device capability” (Geng Wu’s talk).
- Prominent, *integrative* emerging area with reqs suited to >5G wireless, fog computing models; foregrounds inversion problem.
- >5G enables us to imagine edge-in-the-loop of interactive, multimedia applications; integrating compute and comm.

<u>Requirements</u>

- **Context-dependent** retrieval of media; context from location to content preference
- **High throughput** for scene video and content overlays
- **Low latency interactivity**, suggesting packet granularity requests, edge acceleration
- **Progressive retrieval** for responsive/scalable display, variable level-of-detail, predictive fetching.
- **Reverse CDN to scale consumers:** Content *and context* publishing from all parts of fog, incl. users’ mobile terminals
- **Code as data**: Just-in-time code delivery to edges and clients for content navigation/interaction
- **Real-world trust:** Diverse, non-binary trust models that need to be understood by developers and users.
- **IoT Integration**: Ability to integrate with data/devices that may not be Internet-accessible and have varied trust.
- **Heterogeneous wireless**: User terminals (and local IoT) using a variety of comm. technologies

ICE-AR Browser Concept

Have we seen this before, or not?

Yes & No

"It is widely accepted that creative design is not a matter of first fixing the problem and then searching for a satisfactory solution concept;

instead it seems more to be a matter **of developing and refining together both the formulation of the problem and ideas for its solution**."

Cross & Dorst (1999), quoted by Brooks (2010).

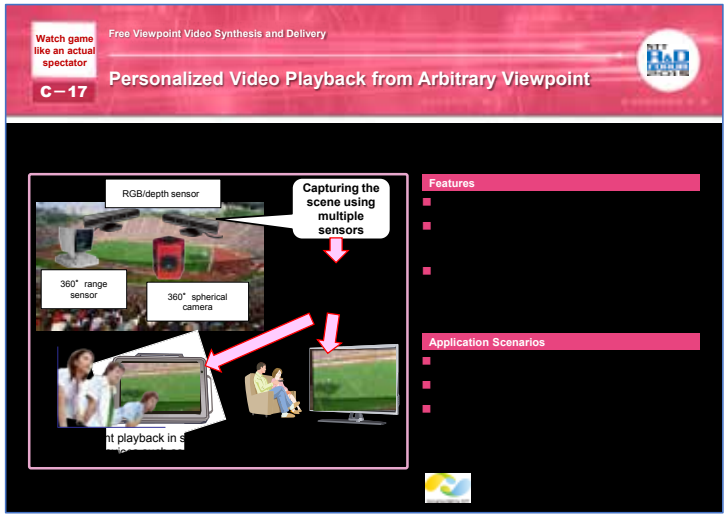
“Post-app” Design Strategy

- Reformulation of the problem suggested by ICN:
  AR built on “**multiparty context-content exchange**”
  with a mix of local / global sources, non-binary trust, context-dependent privacy.

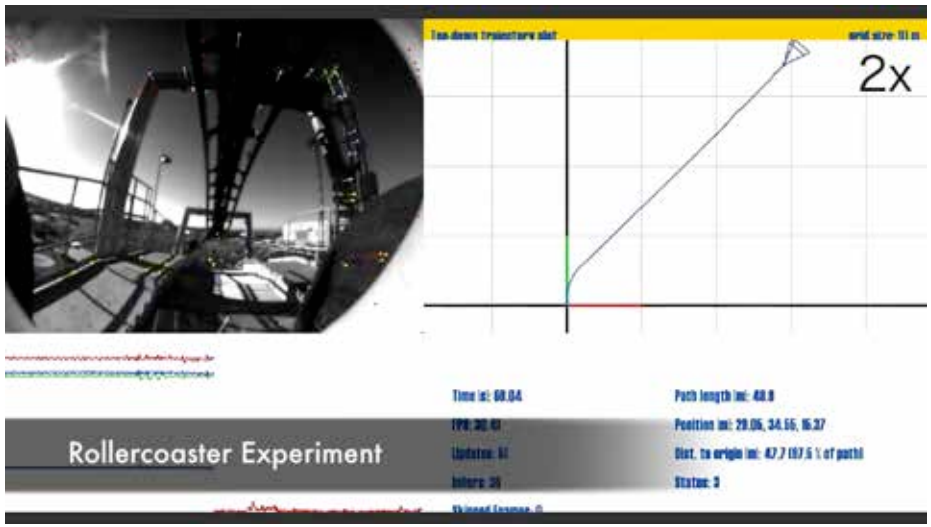
- Decentralized ecosystem of data and services, seen via various (branded) views and filters, rather than each author (brand) generating a vertically integrated stovepipe app.
- Cloud-assisted but not cloud-reliant. Approach should work in disrupted infrastructure scenarios (e.g., emergencies).

- *Names* to standardize exchange of data:
  media; metadata / media descriptions; sensor readings;
  code; keys; function or service pointers
- *Relationship between names* to standardize trust management and rendezvous.

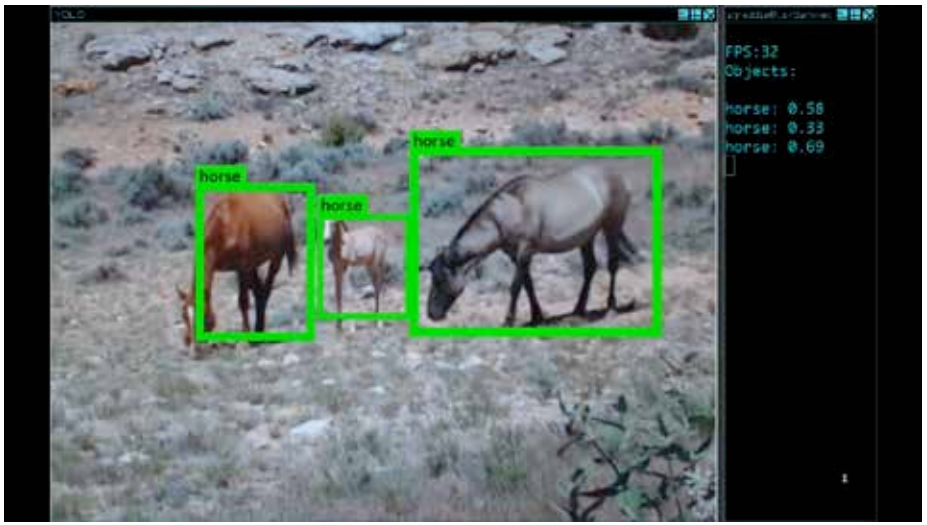
Context <=> **Content** Exchange



Context <=> Content Exchange



Google Tango @ GTC 2015



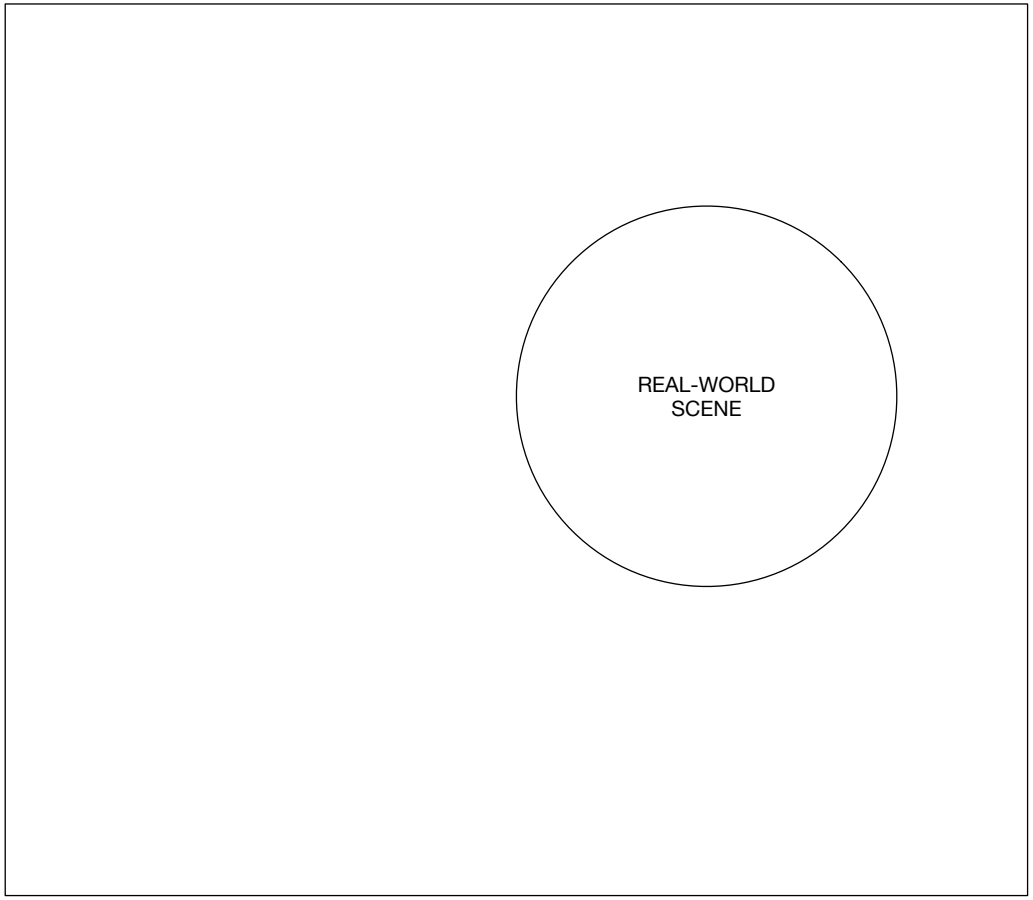
Darknet YOLO (You Only Look Once)

Augmented Reality* as…

Not surprising…
NDN semantics mirror web semantics

"App"	**"Service"**	**"Web"** (Our Focus)
• *Walled garden; branding-driven perspective*. Silos… • Vertical experiences of the augmented world. • AR functionality in libraries, services. • Cloud-based hosting of content ecosystem, typically app-specific. • Edge services (ala CDNs) tightly integrated and out-of-view. • In-app apps, to enable plugging in of other features. • UI/UX consistency enforced by platform. • *How to run multiple overlapping AR views of the world simultaneously?* • *How to handle proliferation of entry points?* One app is simple, 100s of context-specific apps are not. • Example: Apple ARKit.	• *Interoperability- and resale-driven perspective.* • Focus on AR as addition to existing ecosystems and applications. • Largely independent of content distribution. • Cloud-based support for critical compute functions, such as machine learning. • UI/UX consistency up to application or enforced by user-facing services. • Local (and proprietary) libraries for service interface. • *How much to tie applications to one service provider?* Incumbents favored. • Example: *Wikitude Cloud Recognition*; *Facebook AR Studio*.	• *Exploration- and connection-oriented perspective.* • **Vision of a (decentralized) data web integrated with physical world**. • Sessions replaced by **multi-party context-content exchange**. • Many entry points into content navigation – brand, location, etc.. • Common services expressed as data-centric protocols. • Self-publication simplified. • Security and consistent user experience challenging. • UI/UX consistency enforced by evolving convention. • Can provide for app- and service-driven models. • *How to manage proliferation of entry points, trust models, etc. ?*

ICE-AR Browser Design Concept



Augmented Reality as:

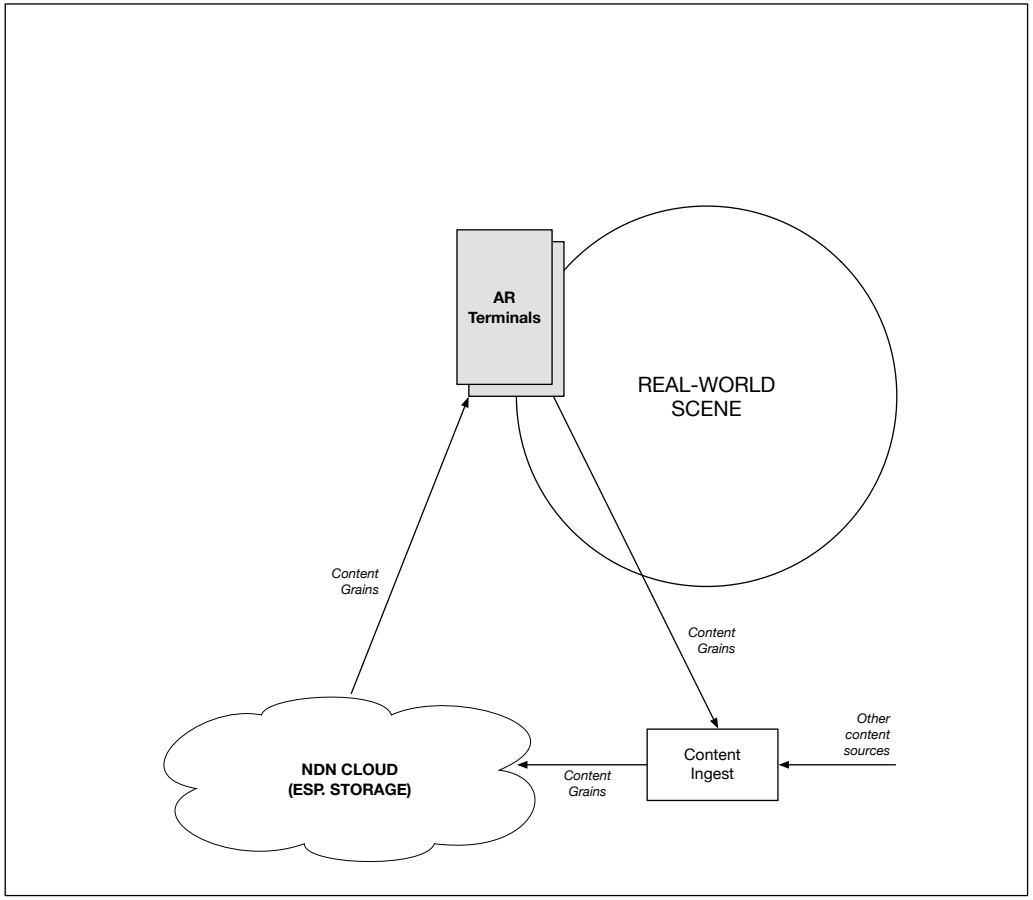
Multi-party exchange of context and content

Context = Generalization of user POV.

Content = Overlays on the world, based on the user context/POV.

J. Burke, “Browsing an Augmented Reality with Named Data Networking (Invited Paper),” ICCCN 2017.

ICE-AR Browser Design Concept



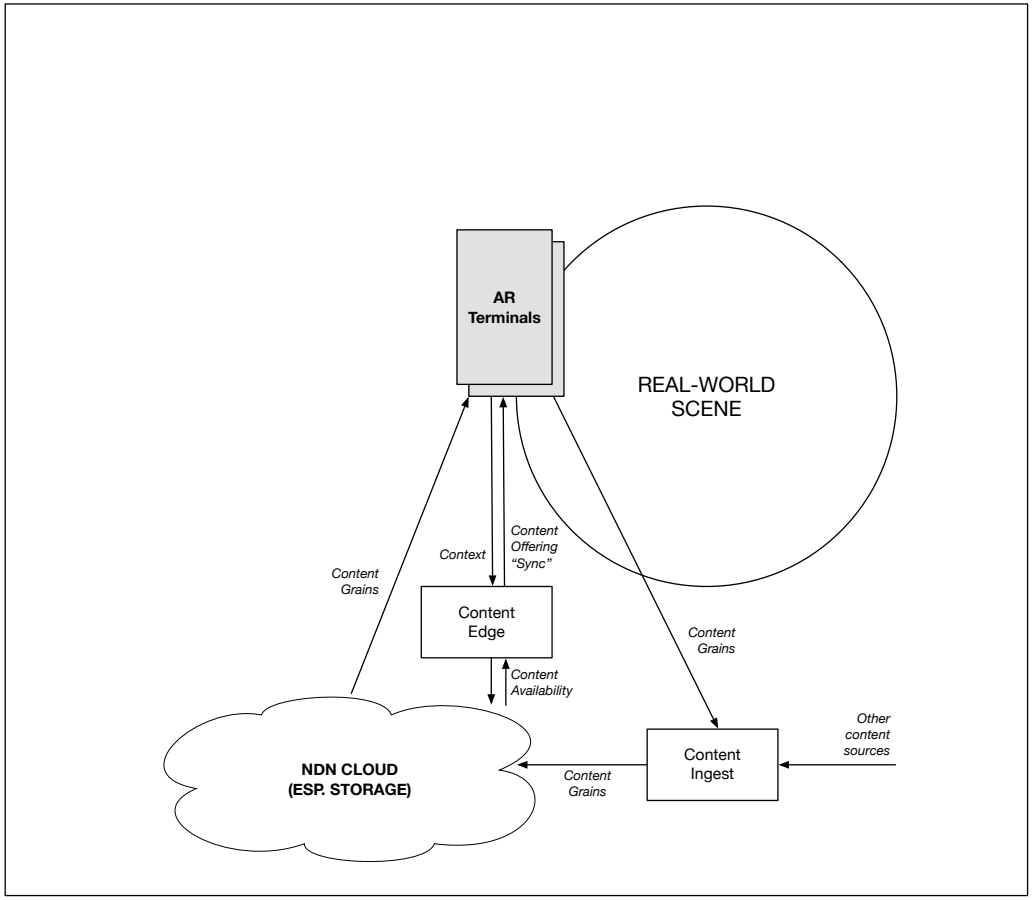
Augmented Reality as:

Multi-party exchange of context and content

Context = Generalization of viewer perspective on the world.

Content = Overlays on the world, based on the user perspective.

ICE-AR Browser Design Concept



Content edge

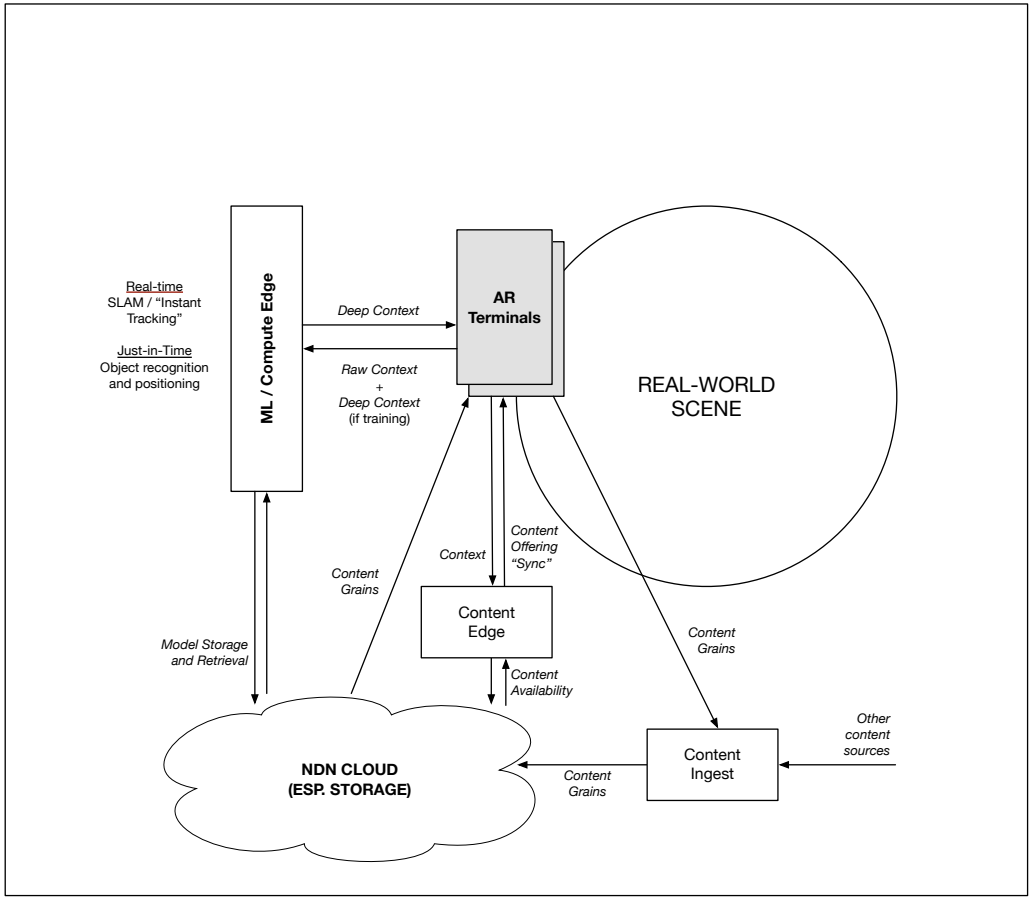
Offer (potential) content based on context. (Terminal chooses what to fetch.)

Application-specific interactivity, transcoding, etc.

Edge can leverage predictability of user requests if media choices are published as

Edge (or cloud) provides code just-in-time to terminal to manage fetching.

ICE-AR Browser Design Concept

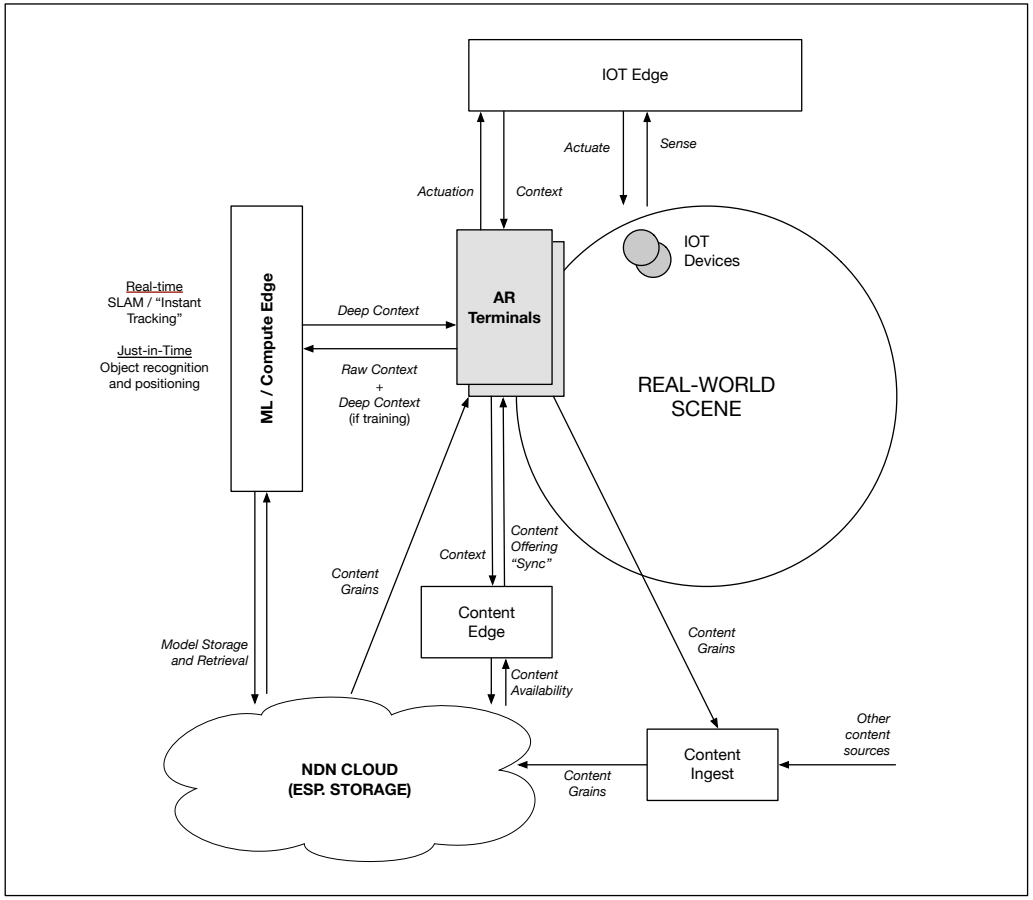


ML / Compute Edge

Machine Learning (ML) used to transform raw, or shallow context, such as sensor data, into deep context.

Note that some subsystems could be run locally – would we use an NDN model there, within the end client code?

ICE-AR Browser Design Concept

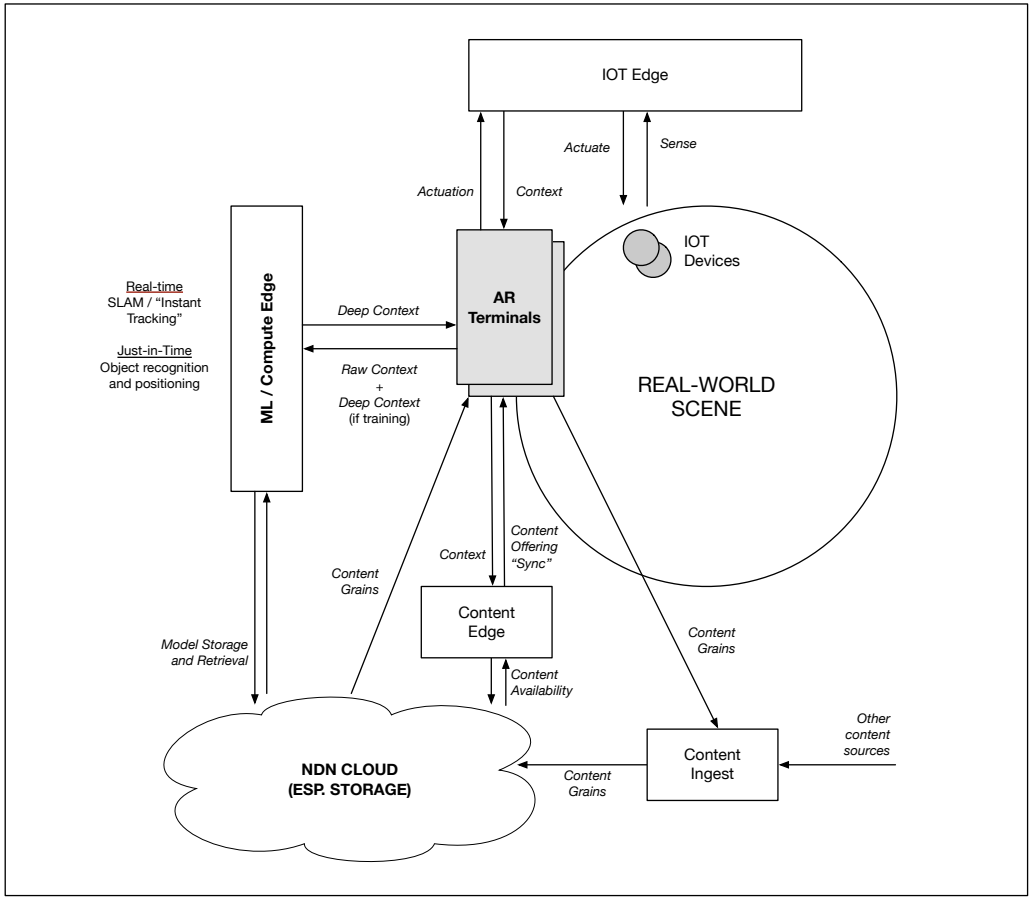


IoT Edge

IoT integration is a significant part of our AR vision, though addressed on partially in this project.

AR provides an *interface* to interface-less IoT devices, an opportunity for data visualization and summarization using local computer, and can coordinate IoT actuation to *orchestrate MR* (and RR) experiences.

ICE-AR Browser Design Concept



Multi-party exchange of context and content

Notably absent from this drawing is how to integrate trust management and privacy.

Left for the afternoon deep dive; app concept builds on FIA-NP work such as H. Zhang et al. "Sharing mHealth Data via Named Data Networking." *ACM ICN 2016*.

Driving ICN-WEN Research Thrusts

Naming

Performance

Security / Privacy

Naming

Designing the namespace(s):

- Context (and Meta-Context)
- Content (and Meta-Content)
- Keys (Certs)

Considerations

Supporting discovery of desired data

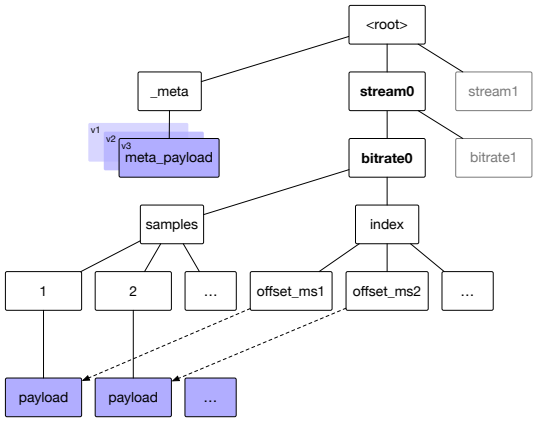
Forwarding Interests along the best paths

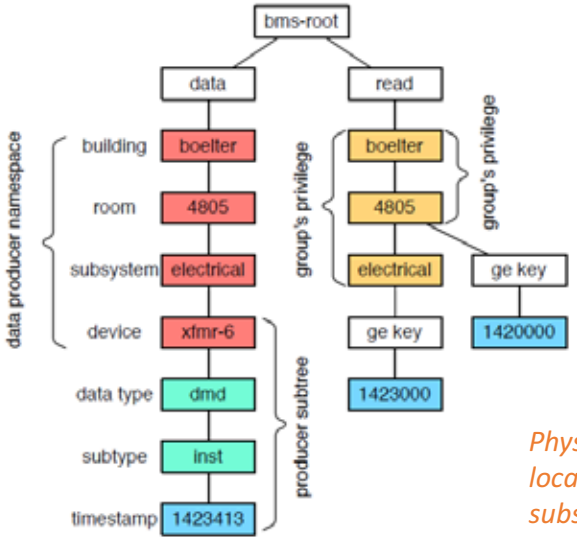
Seamlessly embedding edge acceleration

Leverage benefits of >5G wireless

Content Namespace(s)

Media stream structure

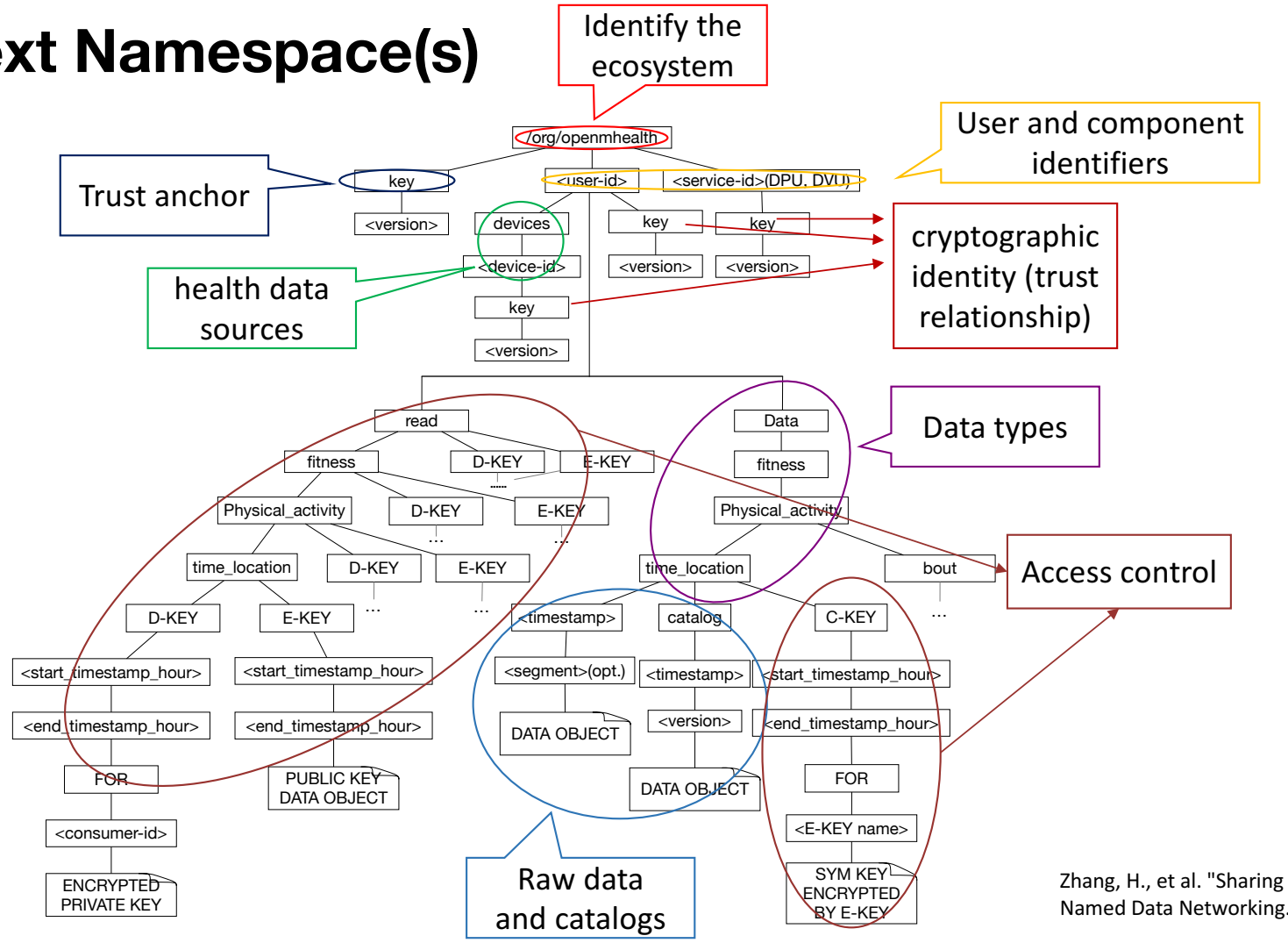




Physical location, subsystem

Virtual location

Context Namespace(s)


Identify the ecosystem
/org/openmhealth
User and component identifiers
Trust anchor
key
<user-id>
<service-id>(DPU, DVU)
<version>
devices
key
key
cryptographic identity (trust relationship)
health data sources
<device-id>
<version>
<version>
key
<version>
Data types
read
Data
fitness
D-KEY
E-KEY
fitness
Physical_activity
D-KEY
E-KEY
Physical_activity
time_location
D-KEY
E-KEY
time_location
bout
Access control
D-KEY
E-KEY
<timestamp>
catalog
C-KEY
<start_timestamp_hour>
<start_timestamp_hour>
(opt.)
<timestamp>
<start_timestamp_hour>
<end_timestamp_hour>
<end_timestamp_hour>
DATA OBJECT
<version>
<end_timestamp_hour>
FOR
PUBLIC KEY DATA OBJECT
DATA OBJECT
FOR
<consumer-id>
<E-KEY name>
Raw data and catalogs
ENCRYPTED PRIVATE KEY
SYM KEY ENCRYPTED BY E-KEY

Zhang, H., et al. "Sharing mHealth Data via Named Data Networking." ACM *ICN*. 2016.

Performance

Idea

1) Run NDN directly over wireless to leverage the media and lower latency.

2) Named-based architecture for enabling edge acceleration of:

- **Context creation / processing** (e.g., location services, SLAM, viewing path, collaborative viewing)
- **Content generation** / **processing** (e.g., transcoding, chunking, rendering)
- **Security primitives** (e.g., signing, verification, encryption, group mgmt)
- *Note: NDN enables many consumers/services to use raw outputs from terminals, w/minimal addtl load.*

Objectives

- Exploit hardware to speed up AR and NDN security
- Reduce effective latency from network and compute
- Harness heterogeneous wireless link technologies seamlessly
- Support diverse communication patterns

Security

App Desires

1) Decentralize security and avoid cloud dependence;
2) Consistent and expressive new primitives to developers;
3) Real-world notions of trust;
4) Spectrum of support for powerful devices to IoT devices

Idea

1) NDN provides signing/verification of each packet as a building block.
2) Security relationships can be expressed in data names (schematized trust; name-based access control).
3) Named data provides a consistent way to share keys, certs, and context.

Objectives

- Provide scalable trust management in a coherent framework
- Provide data-centric security and access control
- Localize the impact of security compromises
- In NDN, requires good naming design

Privacy

Briefly:

- Range of solutions in NDN: name-based access control; encrypted/non-plaintext names; attribute-based encryption; user-selectable identities; no honeypot of name/identifier mappings; options for trust established by evidence/content rather than strong identity. Research challenge is how to apply them.

- Nissenbaum (2004) argues for **conceptualizing privacy as about contextual integrity**: There is a context for the flow of information, and violations to this context are what cause privacy concerns.
  - Car-on-fire example: Local vs. shared, proximate context vs. global.

- Opportunity to consider privacy directly in our driver application's explicit treatment of context exchange.

Nissenbaum, Helen. "Privacy as contextual integrity." *Wash. L. Rev. 79* (2004): 119.

ICE-AR Key Challenges from App Perspective

1) Formulate AR as a new web, new view of the world, rather than an app

2) Articulate app requirements for trust management, contextual privacy

3) Solve naming tussles: forwarding, security, data access, latency, metadata/content – all pull on namespace design

4) Utilize heterogeneous wireless media simultaneously

5) Design higher-level protocols for multi-party exchange and higher-level library abstractions:
    - How do developers and deployers encounter new network capabilities?
    - How are they guided in the creating applications and systems following new paradigms?

Collaboration Opportunities

Intel

- MEC / fog design strategies and interests; compute/comm integration
- Integration with IoT; local rendezvous and trust
- Edge acceleration / compute resources; leverage ultra low latency comm in AR display loop

Other teams

- Exchange new design approaches for ICN-based systems
- Security / privacy approaches for ICN
- Other team working on AR – architectural strategies & approaches

Other

- Lots of interest in our driver application; any way to leverage this?

Conclusion

Role of AR applications in our ICN-WEN project

- Drive NDN architecture development for wireless edge networking
- Provide integration opportunities with other research

Model of AR

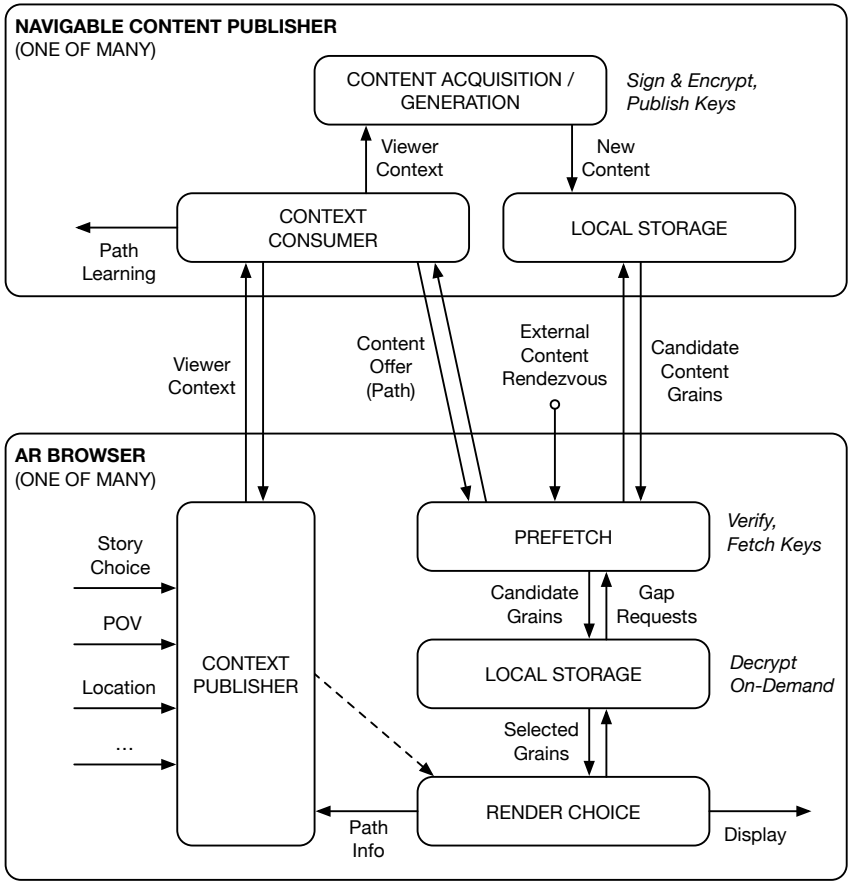
- Web of named data to be browsed, rather than an app or a service
- Multiparty context-content exchange (that is also low-latency, decentralized)
- Security built in. Exploring, for example, non-binary trust and privacy as contextual integrity.

Deeper Dives in Afternoon Talks

- Symbiotic Apps – Wireless Architecture Via Named Data
- Secure Edge Networking Via Named Data
- Edge Acceleration As A Service

Additional Slides

Concept without Acceleration (Extra Slide)



Components (Extra Slide)