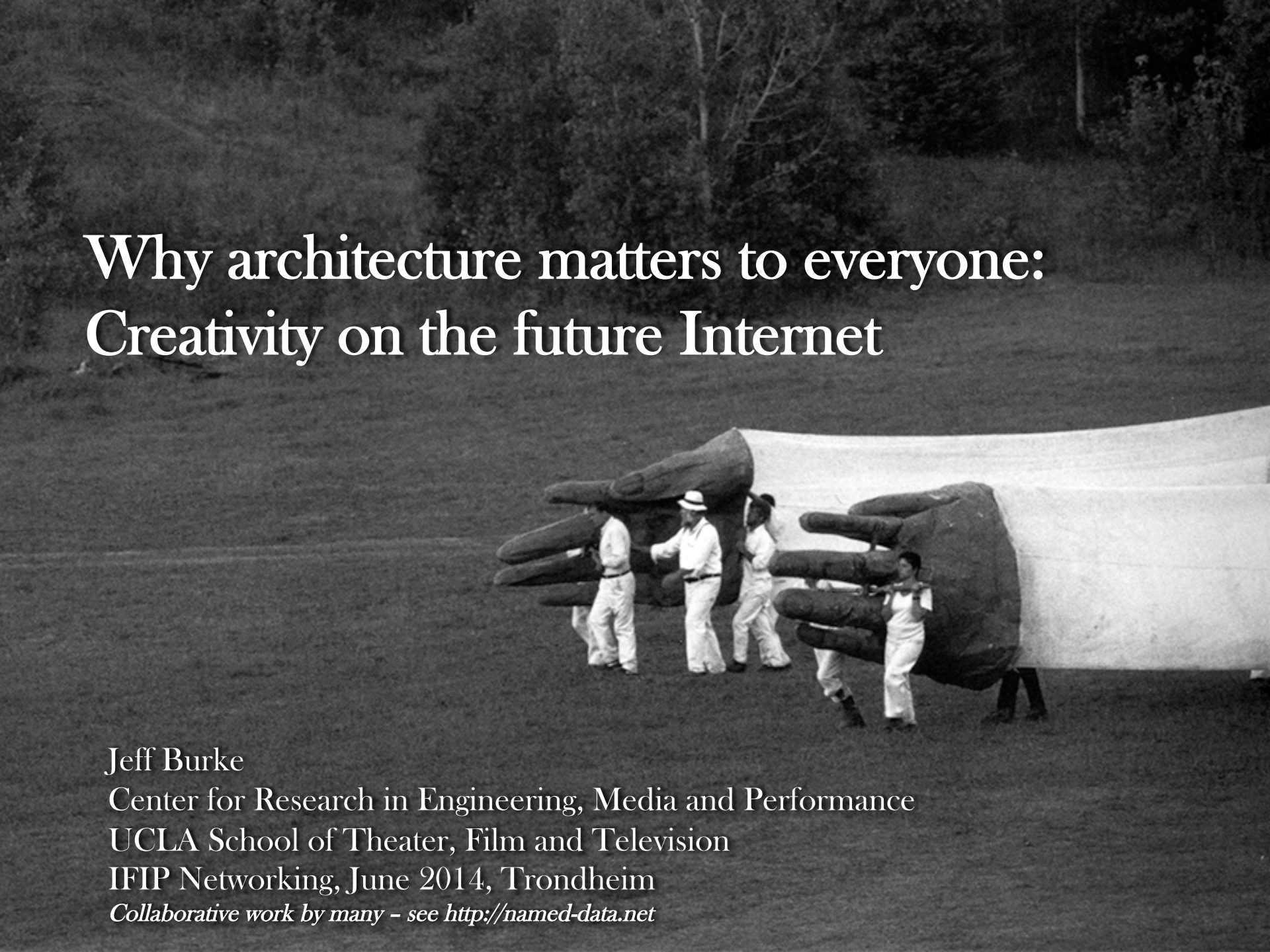
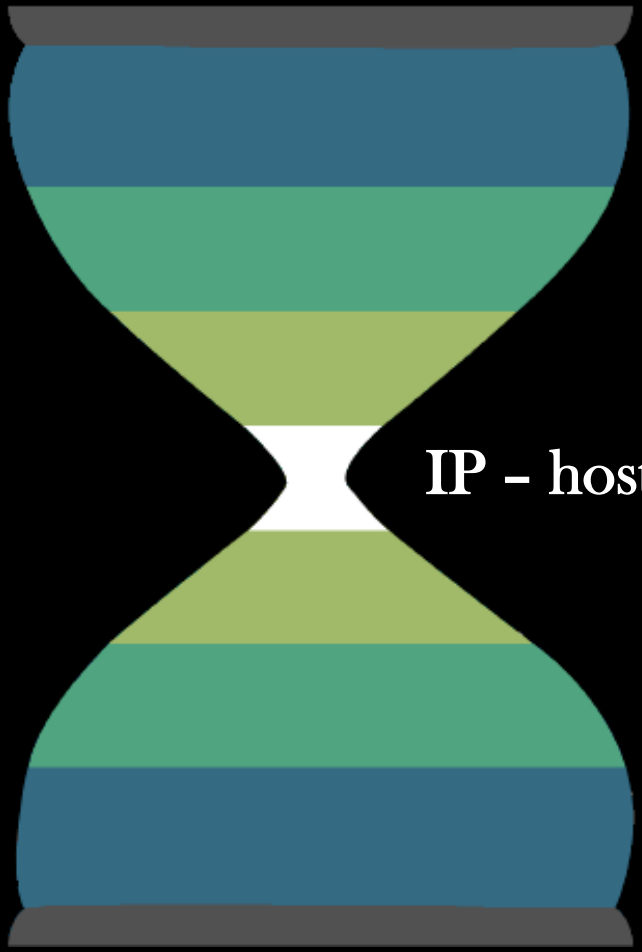
Why architecture matters to everyone: Creativity on the future Internet

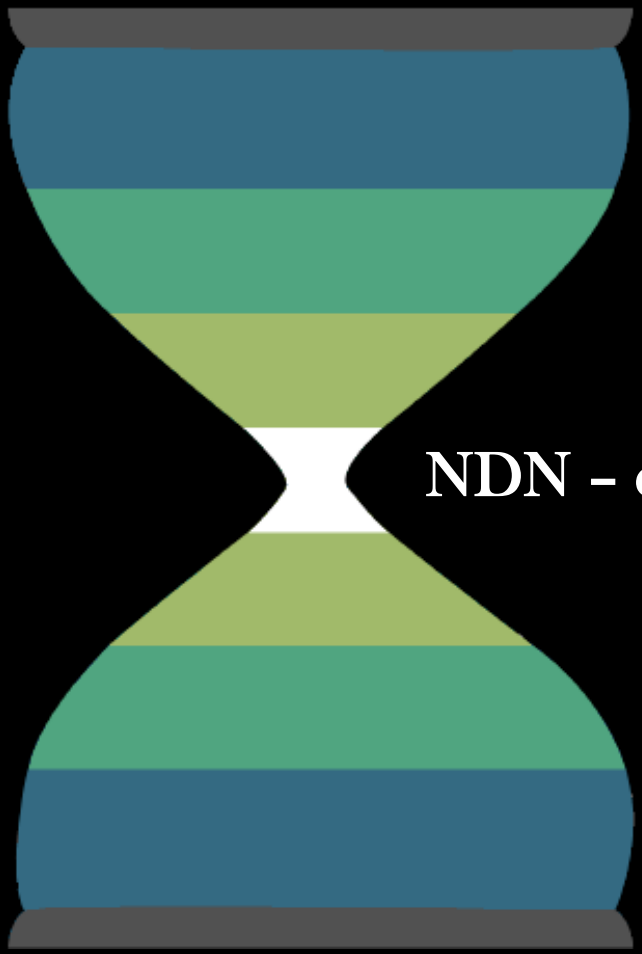


Jeff Burke
Center for Research in Engineering, Media and Performance
UCLA School of Theater, Film and Television
IFIP Networking, June 2014, Trondheim
Collaborative work by many – see http://named-data.net

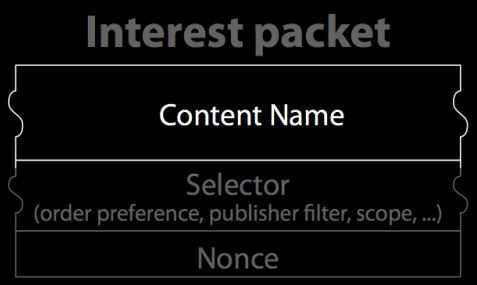
www.thefamilysavvy.com/wp-content/uploads/2012/02/annenberghole.jpg

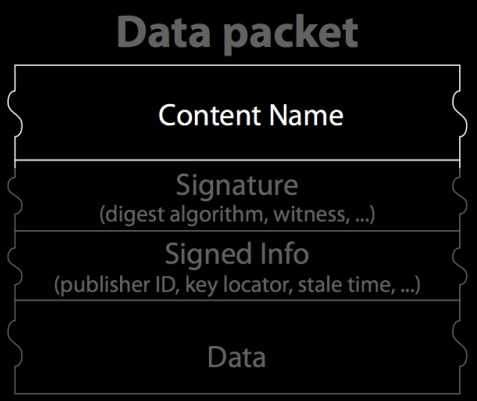


IP – host-centric addressing



NDN – data-centric addressing





Named Data Networking (NDN)

Lixia Zhang, Lead PI
Van Jacobson, Architect

http://named-data.net • NSF CNS-1345318

Why does network architecture matter to a School of Theater, Film and Television?

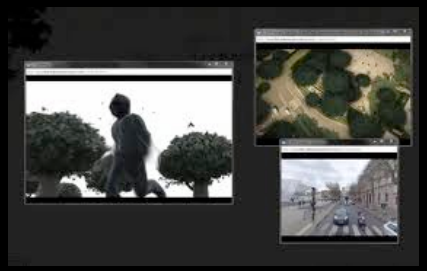
1. We are a school for professional storytellers.

2. How much traffic on the global network is, or will be, part of a story?





3. How well does the current Internet architecture provide for visions of future storytelling?

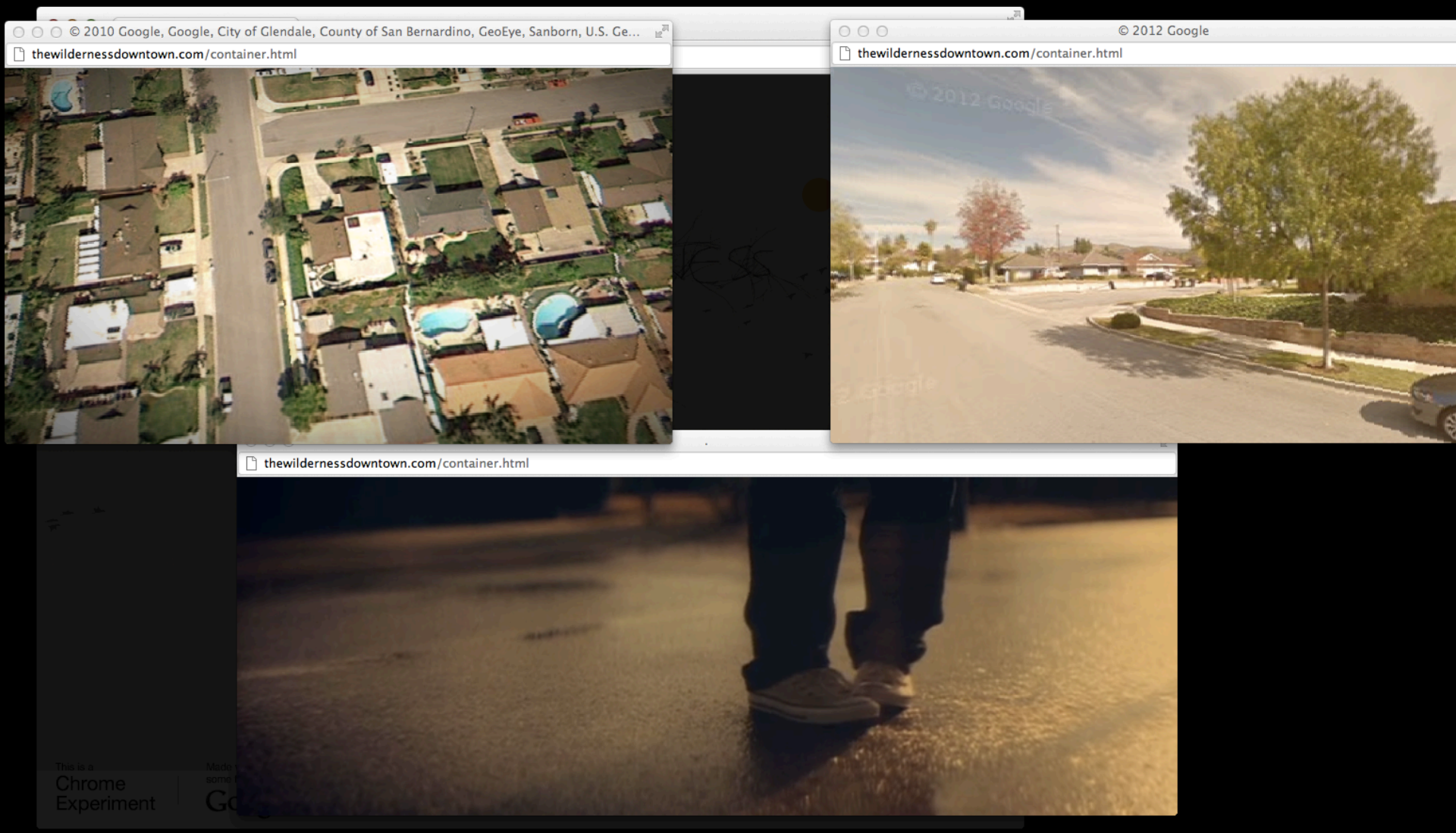

Wilderness Downtown


Moveable Type


Bear 71

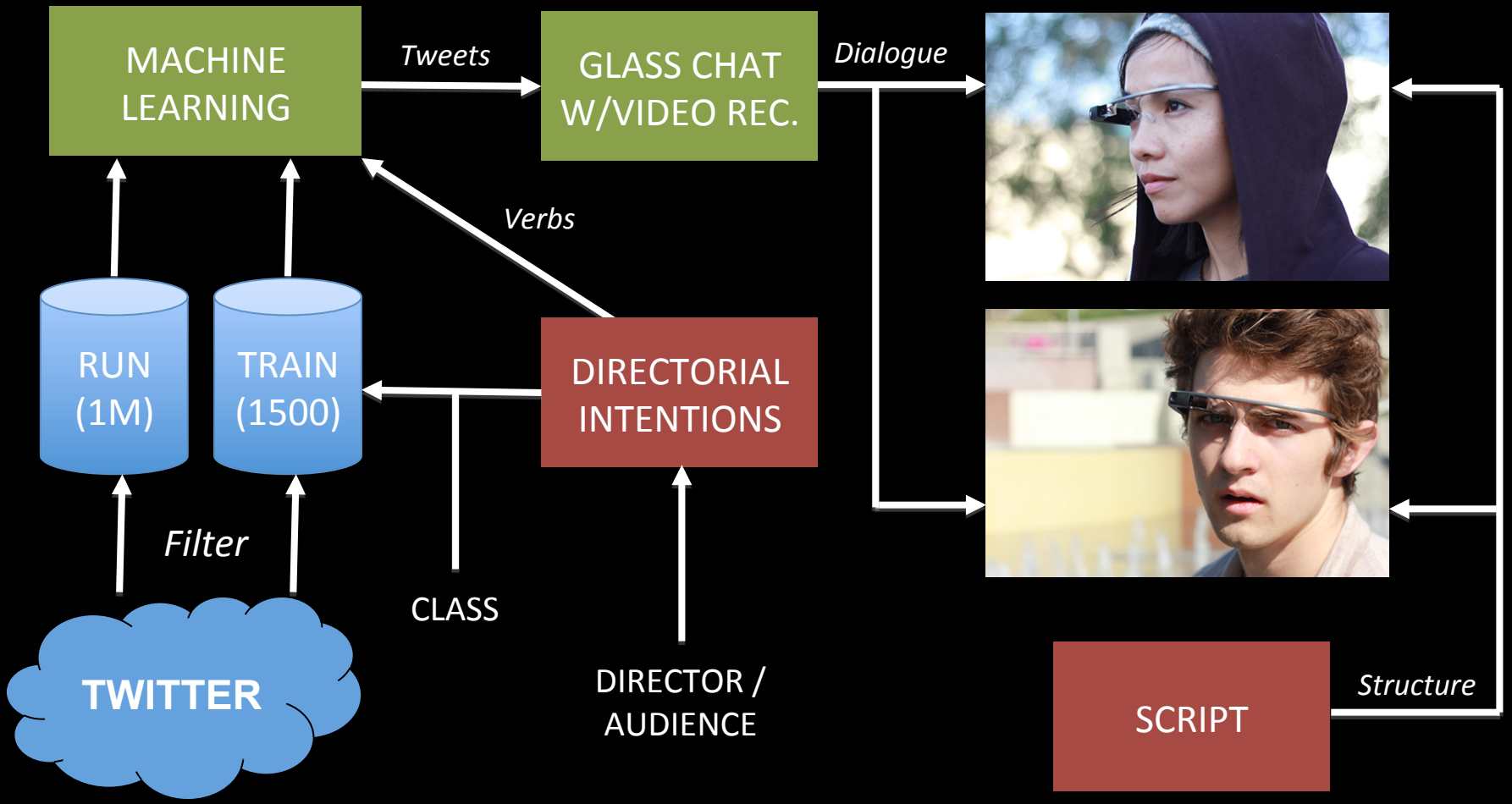
World of Warcraft

The Wilderness Downtown



[Web demonstration: http://thewildernessdowntown.com/]

Bodies for a Global Brain



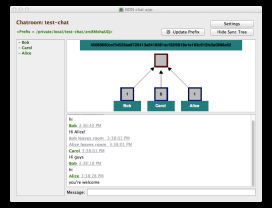
Eben Portnoy, Karan Chugh, Joon-Sub Chung, Alex Horn, Zoe Sandoval & the "Glass Class"

Evaluating Architecture[1]

- Formalizing why architecture matters.
- Clarify the domain – Prototype vs. System vs. Architecture
- Clarify the architecture's underlying principles and resulting structure
- Mixed mode evaluation for a still-empirical discipline
  - Evaluate through analysis
  - Evaluate through discourse
  - Evaluate through experiment

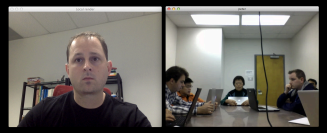
[1] "All hat, no answers: Some issues related to the evaluation of architecture." John Wroclawski, NSF FIA PI Meeting, March, 2013. http://www.nets-fia.net/Meetings/Spring13/FIA-Arch-Eval-JTW.pptx

Prototypes: Application-motivated Approach



<u>NSF FIA 2010-present</u>

Video streaming, live chat, file sharing, lighting control, sensing

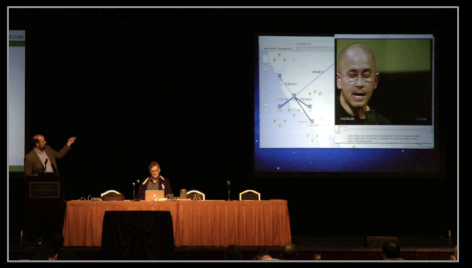


<u>NSF FIA "Next Phase" (2014-2016)</u>

Enterprise Building Automation & Management

Open Mobile Health

Mobile Multimedia Applications



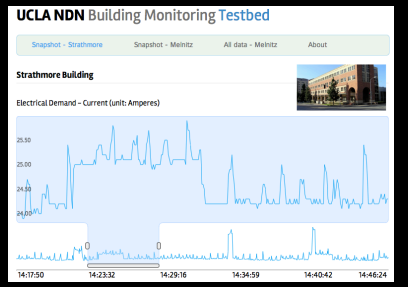
<u>Other ongoing work (2014-2016)</u>

Internet of Things, Raspberry PI support

Climate Modeling (Colorado State)

Information Maximizing Networks (UIUC)

Vehicular Networking (UPMC, UCLA)



Support from NSF, Cisco, Comcast, Toyota, Qualcomm, Verisign, and others.

System: NDN Platform and Testbed

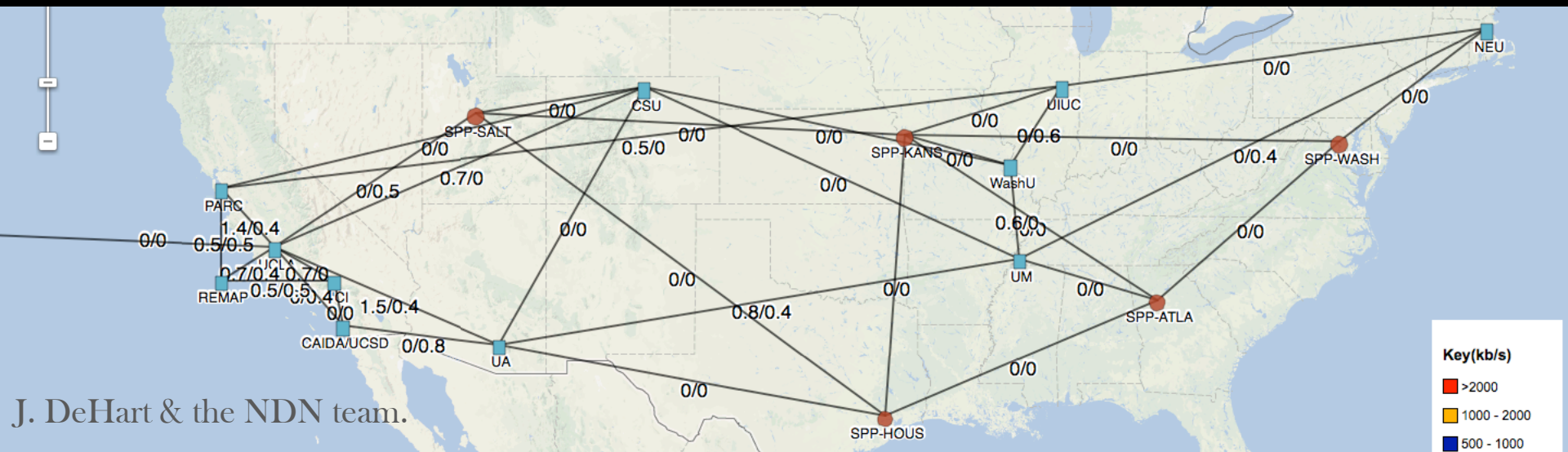
NDN deployable now as an overlay on IP for edge-in use, and on Layer 2 for greenfields (like V2V).

NFD – Second generation forwarder. New TLV packet format.

Library support in C++, Python, Javascript, C, and Java.

Testbed of ~15 routers, incl. 5 on GENI, some physical world integration.

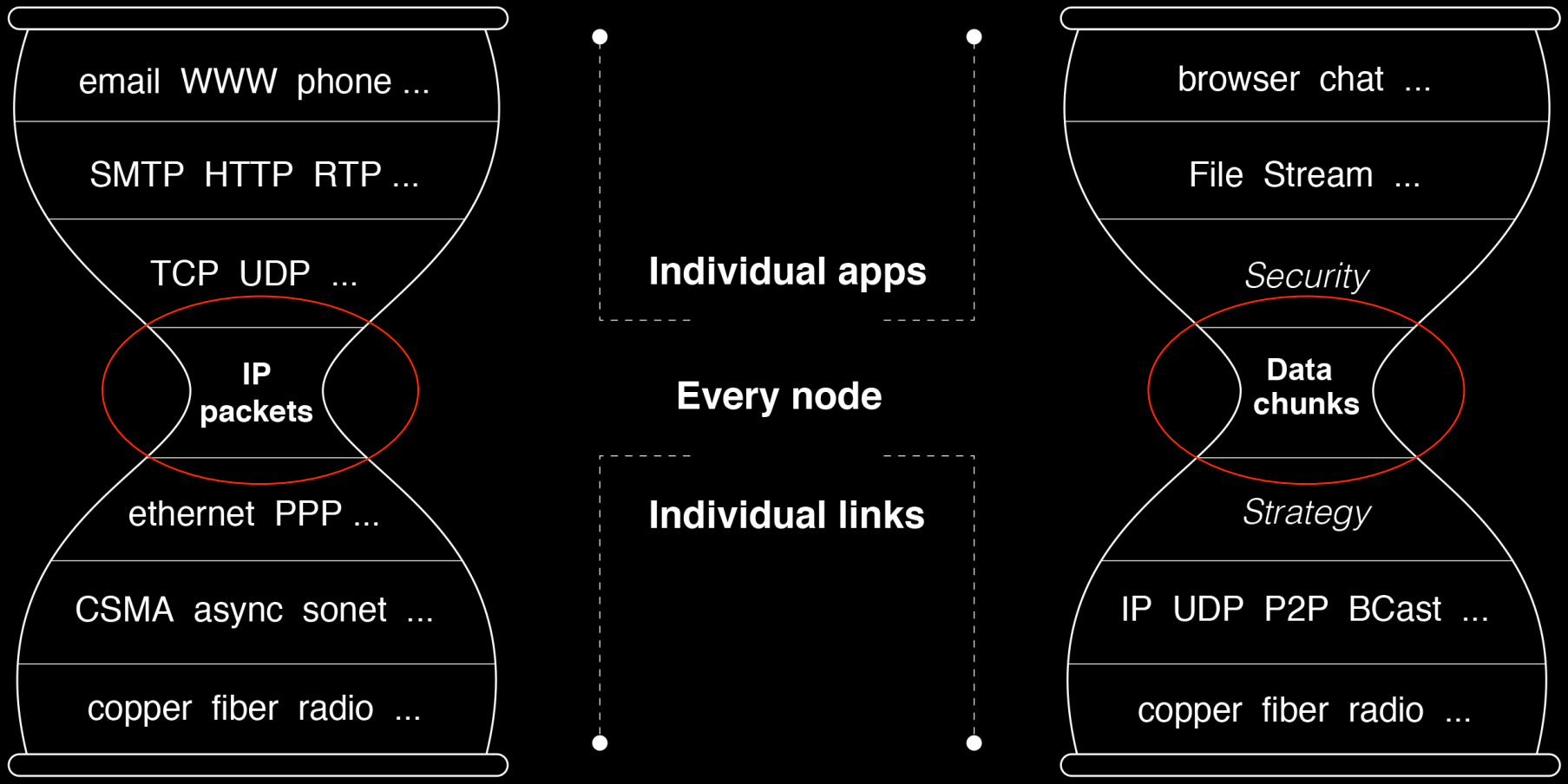
Research paving the way for global roll-out:
Scalability results of Yuan & Crowley, IEEE INFOCOM 2014.



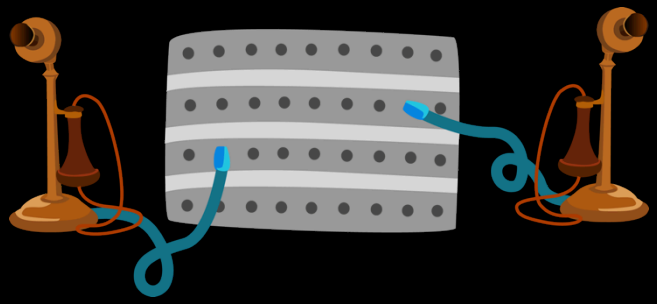
J. DeHart & the NDN team.

Architecture: Underlying Principle

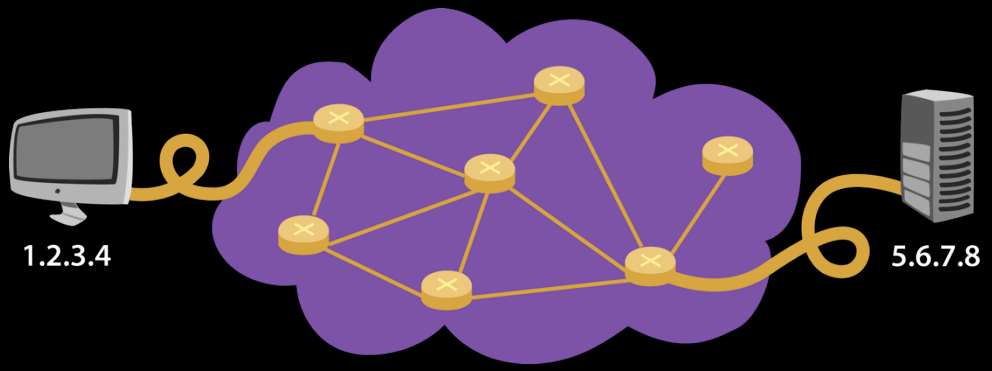
Shift the universal component in the Internet protocol stack to *named data*.



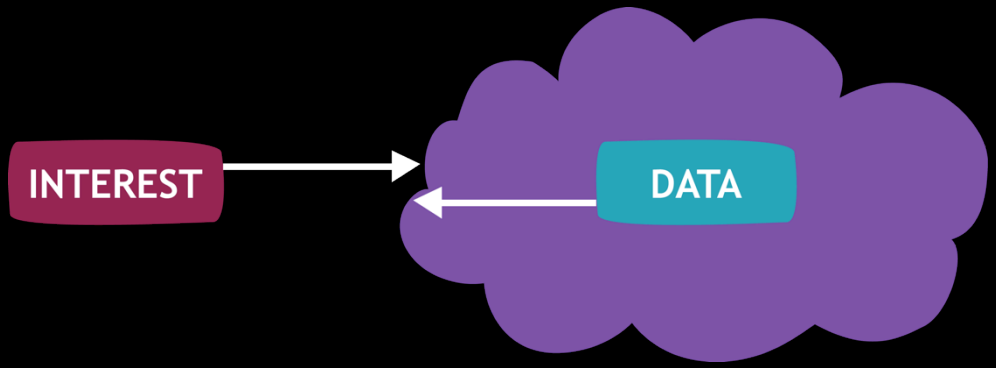
Evolution of the communication abstraction



Telephone Network:
Focused on building the *wires*



Internet Protocol (RFC791): Focused on delivering packets to destination *node*



NDN: Focusing on retrieving *data*

Abstracting away the notion of "node"

Superset of node-to-node communication model

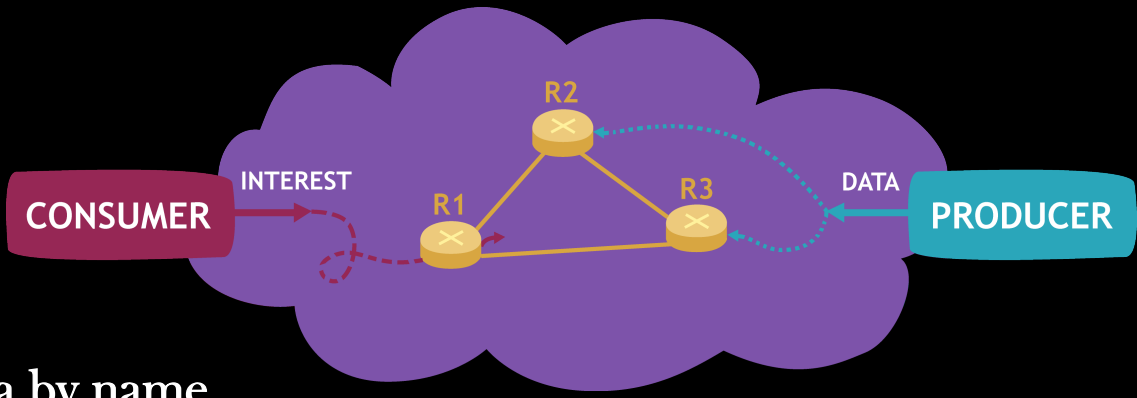
App-Supplied Names, Packet Granularity, Web-inspired Semantics

PRODUCER

Announce name prefix(es).

Name and sign Data packets.

Answer Interests in prefix(es).



CONSUMER

Express Interest packets for data by name.

Receive Data, verify signature, decrypt if necessary.

ROUTER

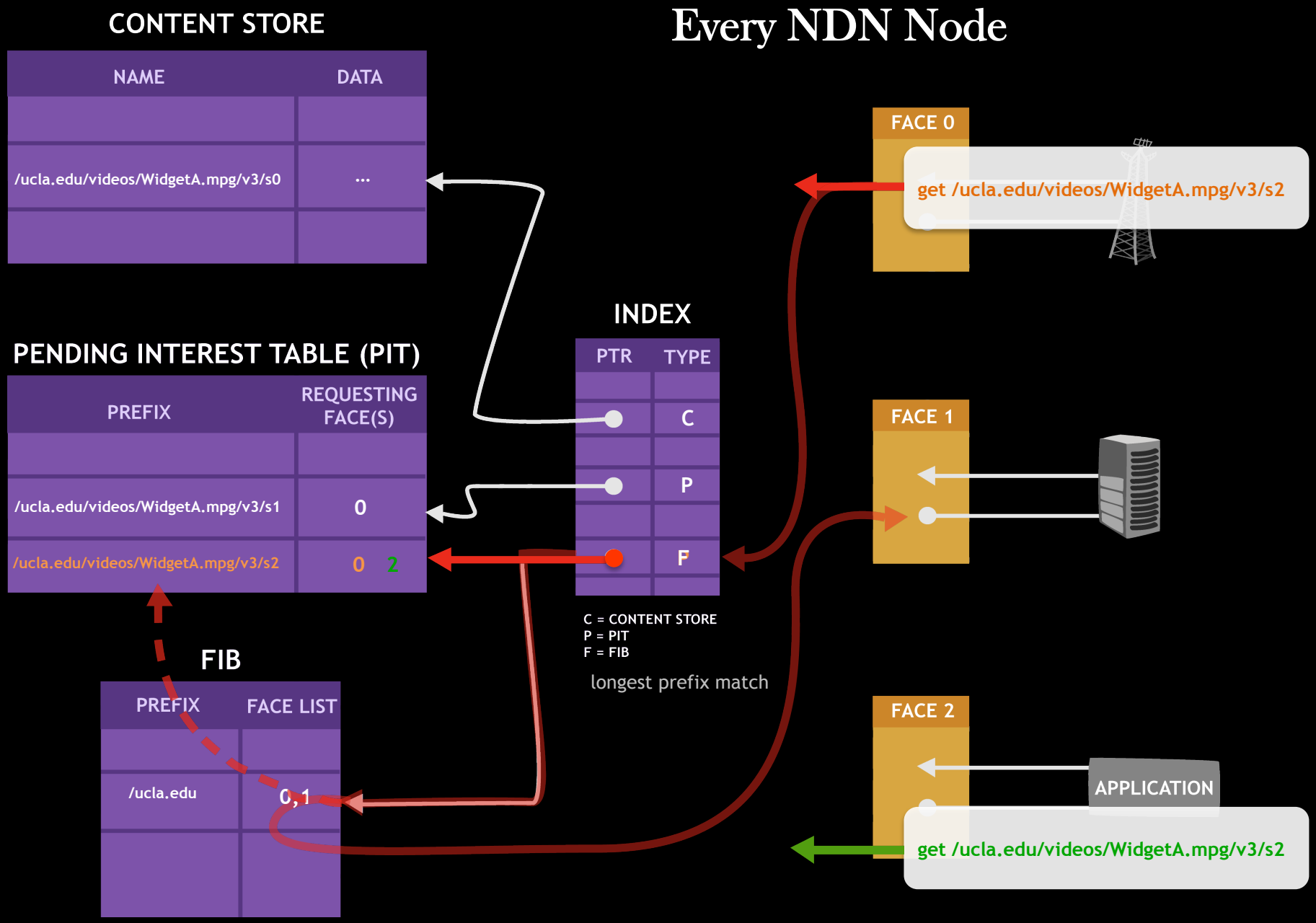
Forward Interests directly on app-specified prefixes. (Inherently multicast.)

Collapse duplicate Interests into a single pending Interest.

Return Data along the path Interests came on. (Stateful.)

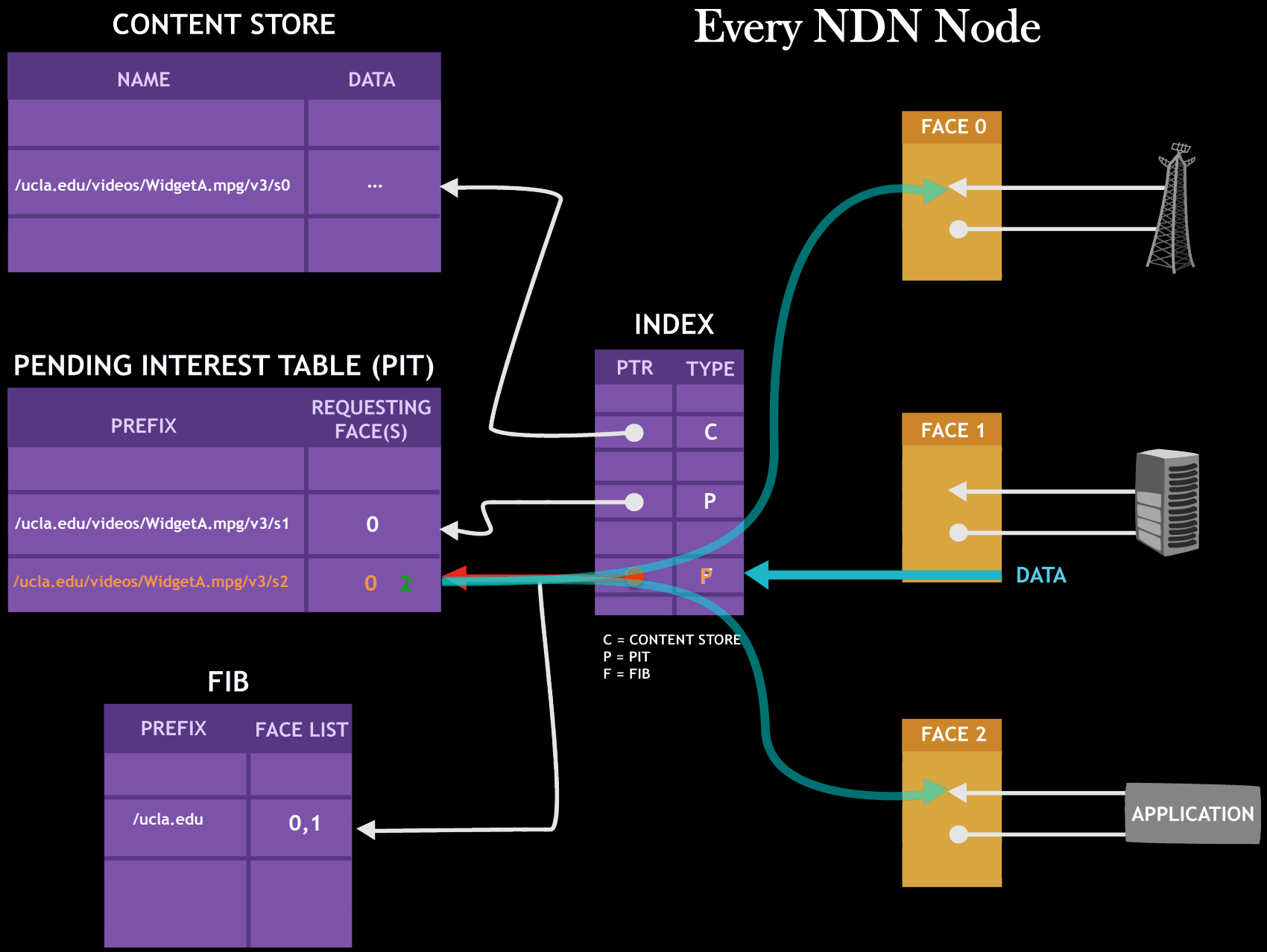
Answer from cache if Data available locally.

Every NDN Node



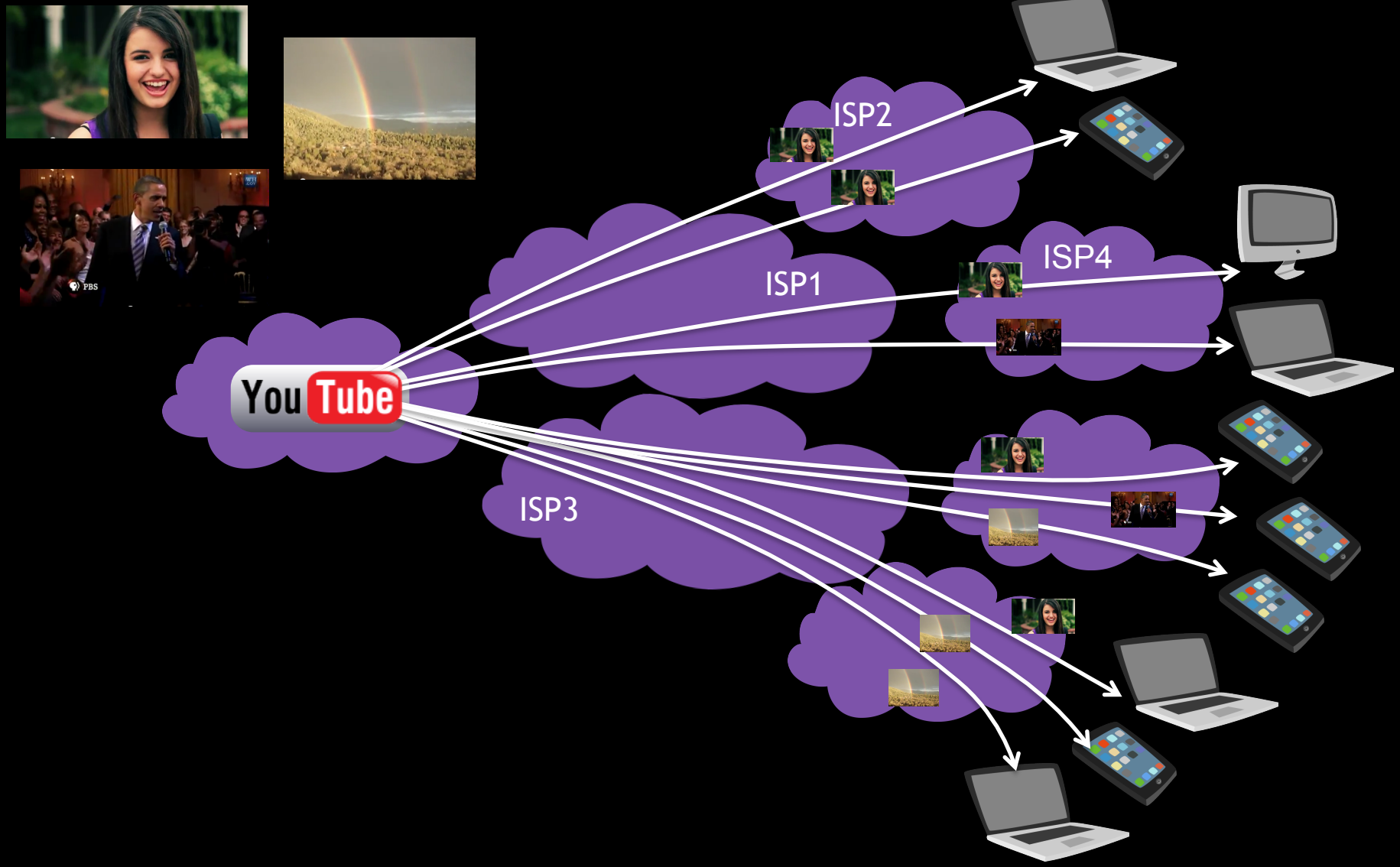
Jacobson, et al.

Every NDN Node



Jacobson, et al.

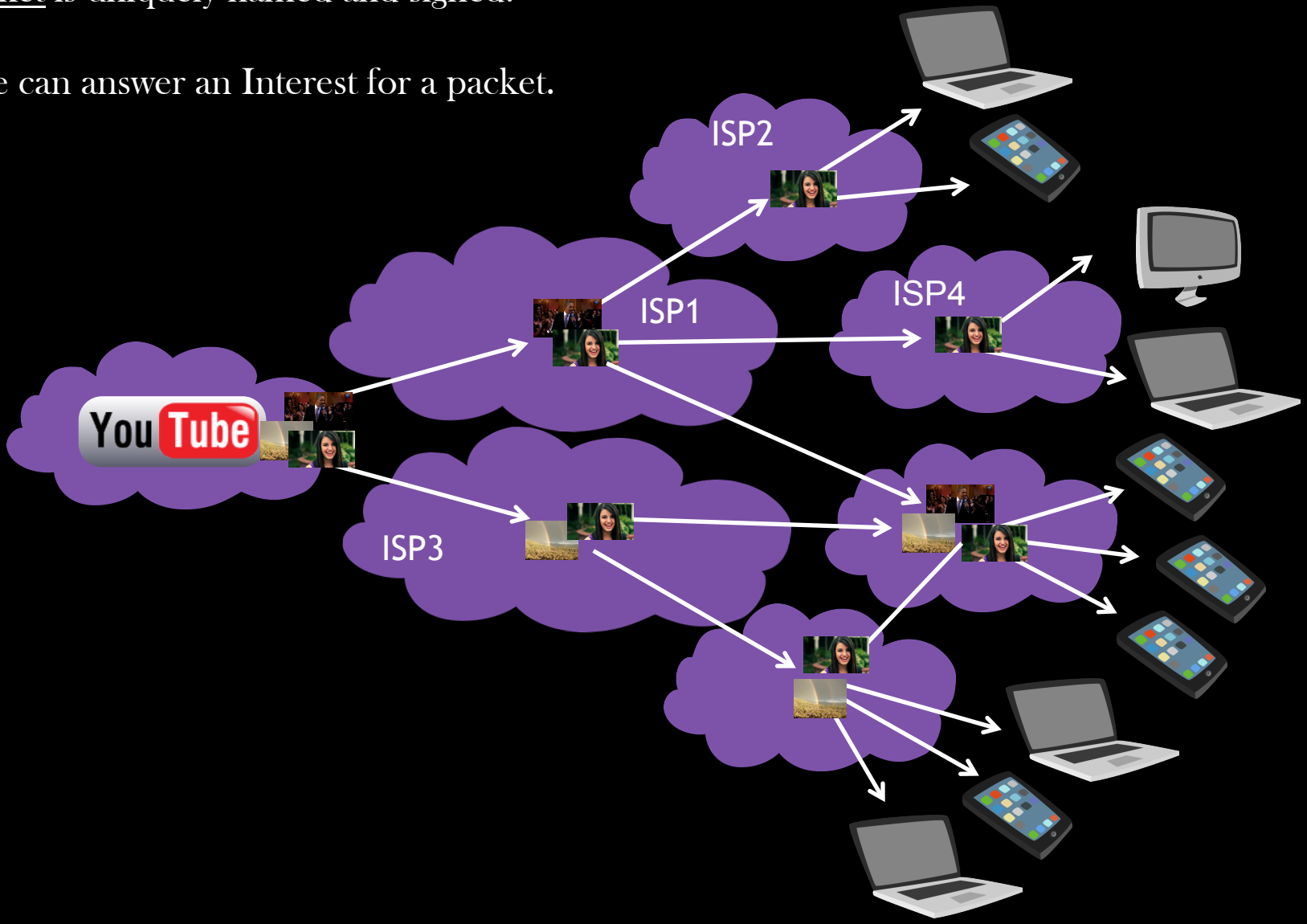
Canonical Content Distribution Example



Canonical Content Distribution Example

Each packet is uniquely named and signed.

Any node can answer an Interest for a packet.



Can’t this be done with IP?

Can’t this be done with HTTP+TLS+TCP+IP+DNS?

We know from the study of design that

Can do something ≠ *will do it*
≠ *will do it well*
≠ *will do it easily*
≠ *will try it at all*

Cognitive Dimensions Framework

Deepen discussion of how architecture matters.

CDs are "descriptions of the artifact-user relationship, intended to raise the level of discourse."

- T.R. Green, 1989

Several CDs address cognitive fit between mental and external representations, critical to NDN's named-based approach.

- Abstraction gradient
- Closeness of mapping
- Consistency
- Diffuseness
- Error-proneness
- Hidden dependencies
- Premature commitment
- Progressive evaluation
- Role expressivenesss
- Secondary notation
- Viscosity
- Visibility

Green & Petre, 1996

ABSTRACTION GRADIENT

What is the range of abstraction available?

Abstraction Support at the Network Layer

IP

Primary support not until upper layers, unless host-related

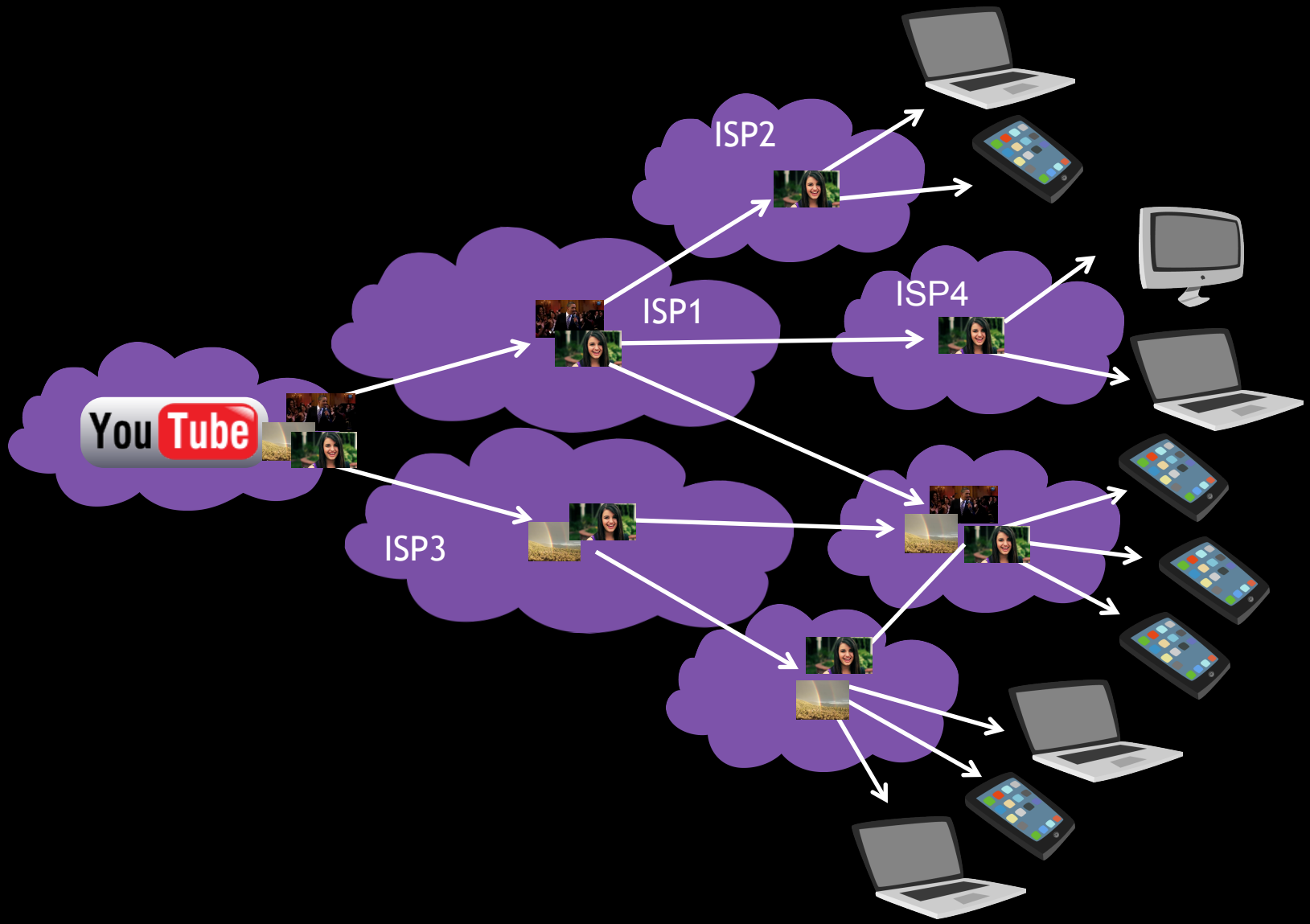
Network forwards based on host addresses (abstraction-*indifferent*)

NDN

Primary support in namespace design, trust model

Network forwards based on application names (abstraction-*hungry*)

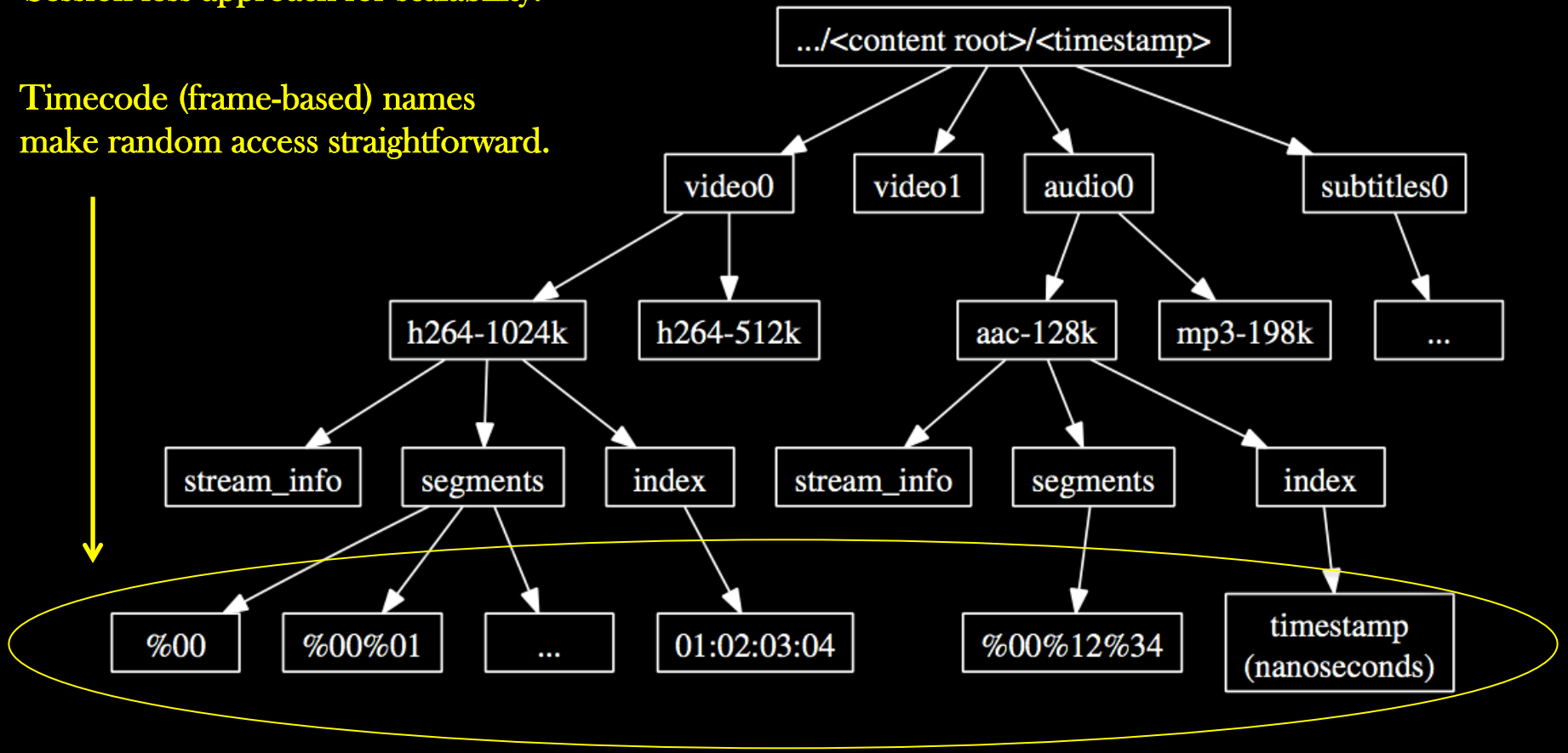
Return to the Canonical Content Distribution Example



Design App Namespace to Leverage Architecture

Session-less approach for scalability.

Timecode (frame-based) names
make random access straightforward.



D. Kulinski and J. Burke. NDNVideo: Live and Prerecorded Streaming over NDN.
Technical Report NDN-0007, September, 2012.

Sessionless, Scalable Live, Pre-recorded Streaming

Interest for
00:01:40.20
or
Segment 2981

EDGE ROUTER
W/CONTENT STORE

VIDEO
AUDIO
CLOCK
SENSORS
CLOCK

ACQUIRE
A/V

ENCODE
(Future: SVC)

STORE
TO REPO

STORE
TO REPO

"REPO"

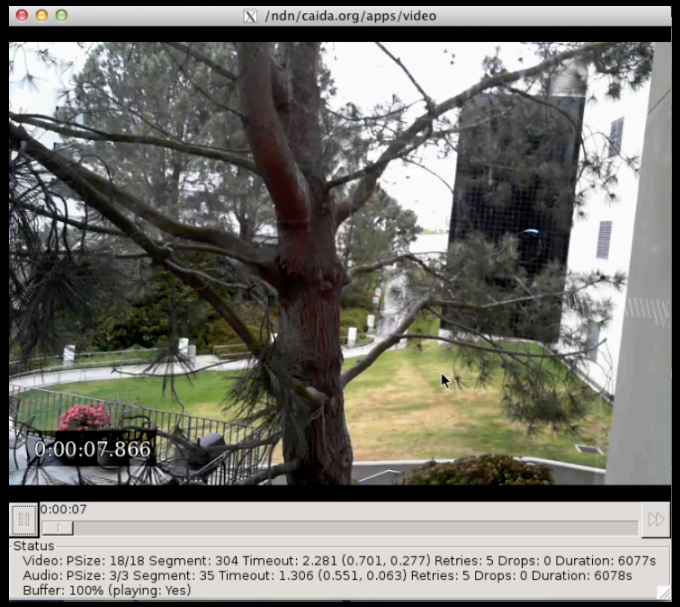
"REPO"

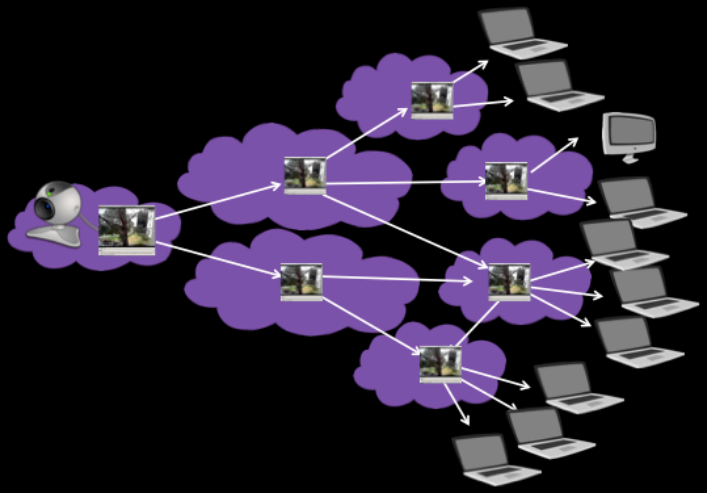
D. Kulinski and J. Burke. NDNVideo: Live and Prerecorded Streaming over NDN. Technical Report NDN-0007, September, 2012.

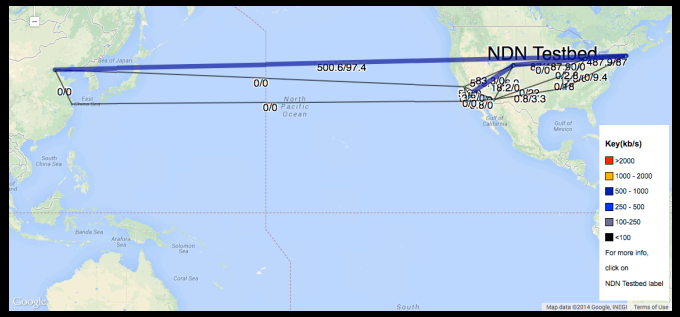
Experimentally tested

Scaling Test @ NAE Beijing 2013

- 1000 headless consumers over 15 gateways
- Single publisher at CAIDA/UCSD
- “Plain vanilla” NDN forwarder
- Only one copy of data on any link
- Automatic multi-path route switching







Why don't we just implement DASH?

Other people are doing this.[1]

We are interested to see if NDN provokes problem reformulation.

Because the app domain itself is in the midst of reformulation(s).

[1] e.g., Liu, Yaning, et al. "Dynamic adaptive streaming over CCN: a caching and overhead analysis." 2013 IEEE ICC and Detti, A, et al. "Peer-to-peer live adaptive video streaming for Information Centric cellular networks." 2013 IEEE PIMRC.

[Web demonstration: http://www.thejohnnycashproject.com/]

Architecture Matters Because it Drives Problem (Re)Formulation

"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)

Iterate:

Architecture's generalization of needs and possibilities

Specific new possibilities arising from the architecture itself

How particular existing needs are solved by the architecture

PREMATURE COMMITMENT

When do we force early decisions?

Example of Architectural Detail

Interest Selectors tune NDN's longest-prefix match.

- Count of child name components.
- Child name range, based on a well-known sort ordering.
- Scoping criteria – host, hop, world.

Critical for bootstrapping content access and decoupling consumers and producers. *Relax the need for premature commitment by an app.*

Example

NDNVideo Interest packet for the first keyframe before 00:00:05:00

- Name `/edu/ucla/video1/h264-1024k/`
- ChildSelector `RIGHTMOST`
- Exclude `[00:05:01, ANY]`

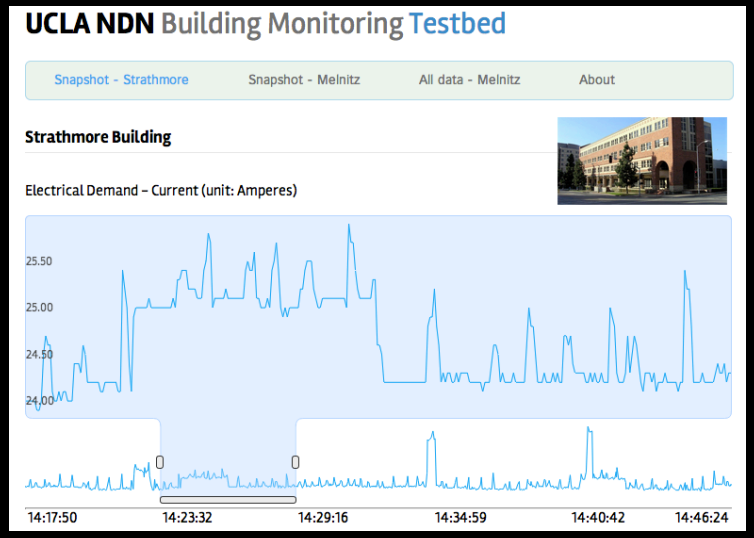
CLOSENESS OF MAPPING

What ‘games’ are needed to map from app to net?

ROLE EXPRESSIVENESS

Can one see how each part relates to the whole?

Sensing in Enterprise Building Management & Automation

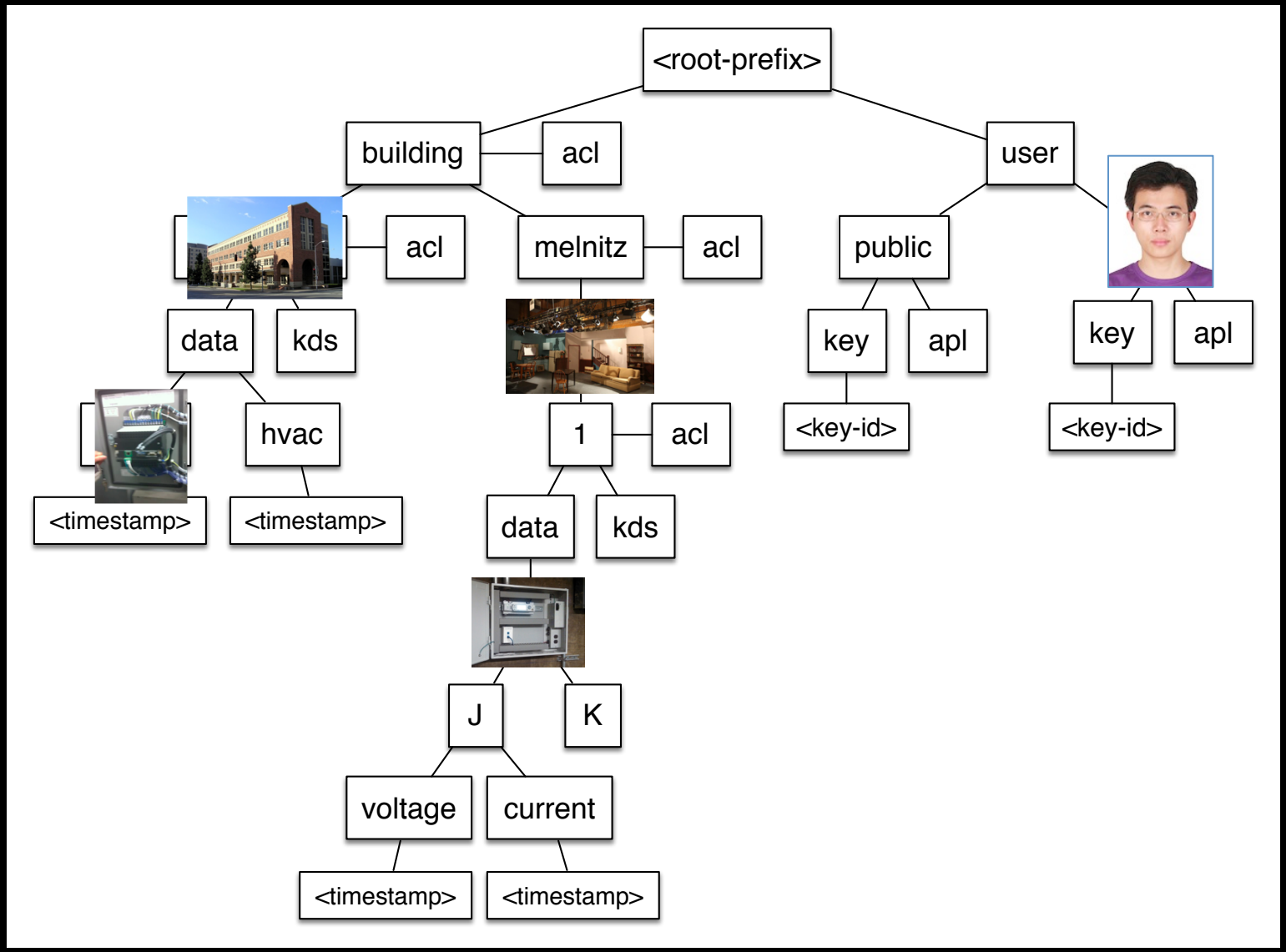


MLNTZ.PNL.J.SAT	LAO	SAT TOTAL	Value	0.0.0	No	No
MLNTZ.PNL.J.SEP	LAO	SEP TOTAL	Value	0.0.0	No	No
MLNTZ.PNL.J.SUN	LAO	SUN TOTAL	Value	0.0.0	No	No
MLNTZ.PNL.J.THU	LAO	THU TOTAL	Value	0.0.0	No	No
MLNTZ.PNL.J.TUE	LAO	TUE TOTAL	Value	0.0.0	No	No
MLNTZ.PNL.J.WED	LAO	WED TOTAL	Value	0.0.0	No	No
MLNTZ.PNL.J.WEK	LAO	WEEK TOTAL	Value	0.0.0	No	No
MLNTZ.PNL.J.CNSMTN.LO	LAI	ACTUAL LO CNSMTN	Value	1.1.8	No	No
MLNTZ.PNL.J.CNSMTN.HI	LAI	ACTUAL HI CNSMTN	Value	1.1.9	No	No
MLNTZ.PNL.J.DEMAND	LAI	ACTUAL VOLTS	Value	1.1.10	No	No
MLNTZ.PNL.J.AMPS	LAI	ACTUAL AMPS	Value	1.1.12	No	No
MLNTZ.PNL.J.VOLTS	LAI	ACTUAL VOLTS	Value	1.1.13	No	No
MLNTZ.PNL.J.DEM:DAY.NGT	LDO	300 AMP	On/Off	1.1.29	No	No

Already using hierarchical namespace at the application level!

Shang, W, et al. "Securing Building Management Systems Using [NDN]." IEEE Network 2014.

Forward based on names closely mapped to physical world



Shang, W, et al. "Securing Building Management Systems Using [NDN]." IEEE Network 2014.

HARD MENTAL OPERATIONS

Where must we resort to finger-counting or external annotation to keep track of what's happening?

Cross-layer addressing generates hard-mental operations

Addressing currently spread across many layers in the network:

```
VLAN 4
IP 128.97.152.23
Port 4722
Universe 2
Channel 1
Descriptive name, properties, URI
```

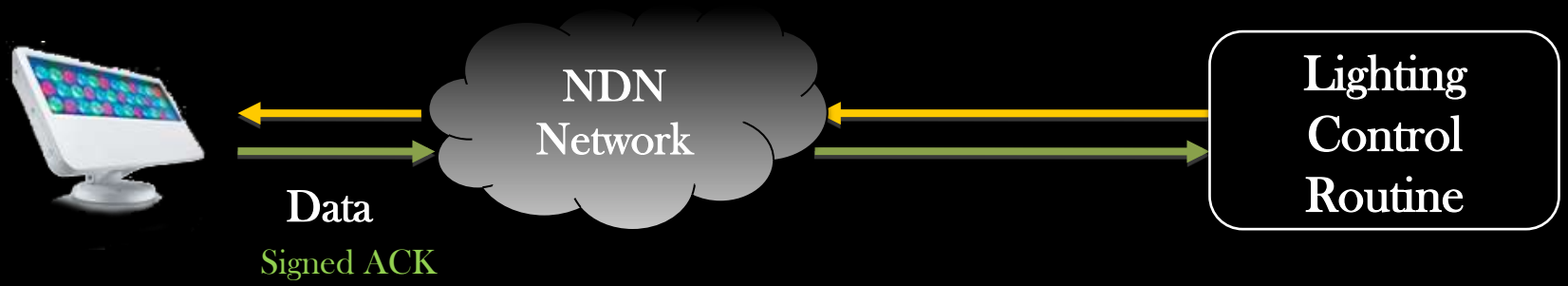
Many possible NDN names

- **Manufacturer-assigned:** `/lighting/etc/0041F31C493EF01A`
- **Controller-assigned:** `/controller_root/<port#>/<chan#>`
- **Physical location:** `/enterprise_root/<controller_id>/<fixture_id>`
- **Region of responsibility:** `/room_root/region/downlight/center`
- **Designer-assigned:** `/app_root/chandelier`

Authenticated, Closed-Loop Control in NDN

Interest signed by app

`boelter/3551/lights/fixture/41/rgb-8bit-hex/FAF87F/<state>/<authenticator>`



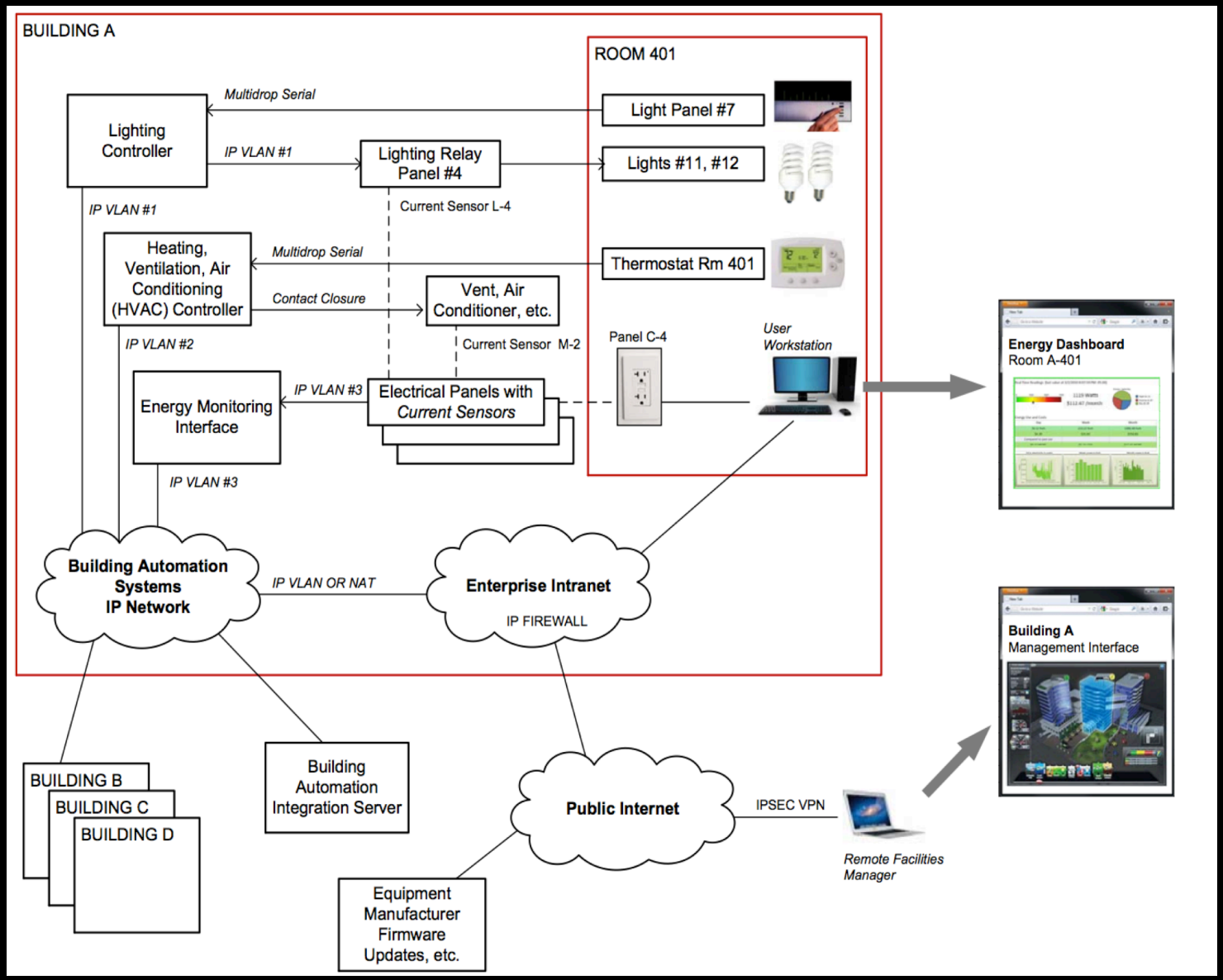
- Asymmetric keys to work directly with PK-based identities
- Symmetric keys and HMACs for faster 'signatures'
- Leverage NDN to distribute keys and establish key relationships
- Command privacy by encrypting non-routable portion of name

Burke, J., et al. "Securing Instrumented Environments over Content-Centric Networking: the Case of Lighting Control." IEEE NOMEN 2013.

ERROR-PRONENESS

Does the design induce ‘careless mistakes’?

Practical Deployments are Complicated & Hard to Secure



(Re)Formulation of IoT / ICS Security Problems

Until very recently, securing these protocols directly has not happened. Where it does, still perimeter-focused.

NDN Secures data (and control) directly.

- Application names data and keys
- Each Data packet is signed at creation (can be extended to Interests)
- Optionally encrypted using those keys (or derived keys)
- Data integrity and provenance can be verified by anyone, independently from how the packet was obtained
- Keys are data – use NDN to distribute

Stories will be told with IoT, too

SENSING

```
prop/witchstaff/1/acceleration
prop/witchstaff/1/position
prop/witchstaff/1/batterylevel
```

MEDIA

```
microphone/gertrude/audio/
```

Burke, J. "Dynamic performance spaces for theatre production." Theatre Design and Technology 38.1 (2002): 26-33.

VISCOSITY

How much effort is required to perform a change?

Grace Plains

Live role-playing experience on Google Glass - YouTube Space LA, April 2014.

C. D. Baker, P. Finn, P. Powers & the "Glass Class". Glassware by UCLA REMAP. Support: Google FRA, YouTube Space LA.

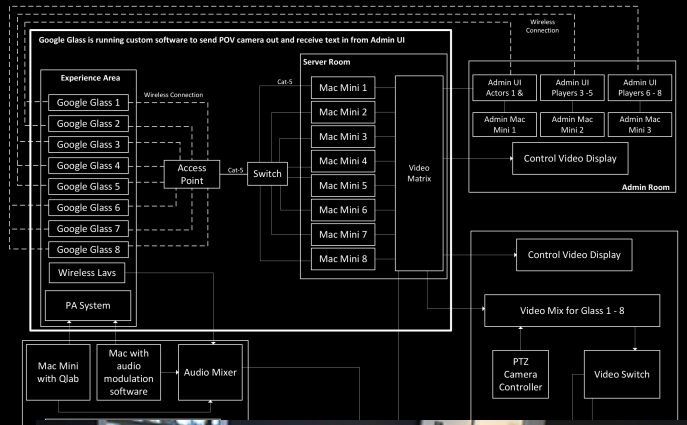
Grace Plains

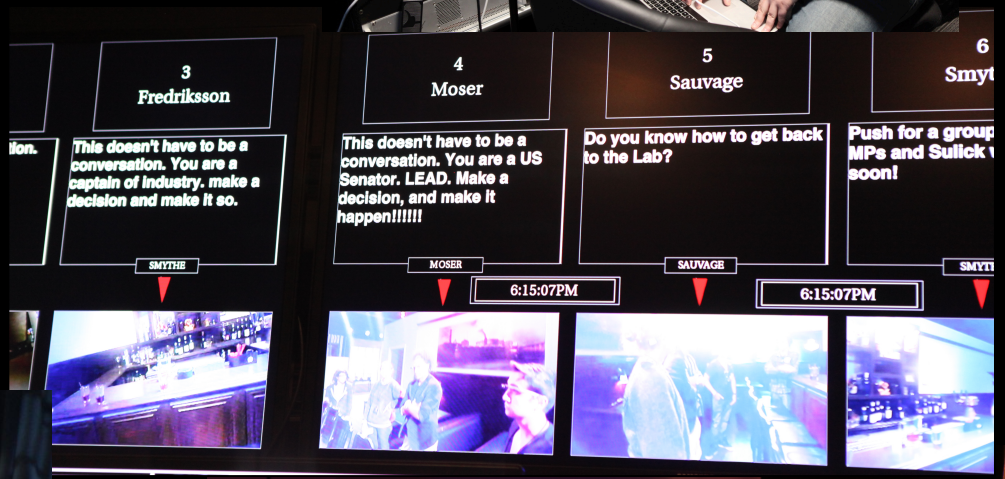
You are thrown headlong into a science fiction thriller where you must confront the emergence of artificial consciousness and make a critical decision its future.

Two actors and six live participants wear Glass, on which they receive real-time text prompts from human administrators to steer action within the story.

Each person's Glass streams their POV live via WebRTC over WiFi to a set of control rooms, these and other feeds are switched live to YouTube.

No time to cover the whole application ...





Sources of Pain, Viscosity, and Cruft

	"Grace Plains"
Collaboratively Developed	Glassware, experience admin, video streaming, and broadcast developed largely independently
Iteratively Deployed	Days for some critical components (rtc!), weeks for others, and months for a few
Dynamically Assembled	Sessions made the experience disruption-intolerant in a messy wireless environment
Physically Integrated	Mappings from device – host – character – stream – host made it hard to change devices
Asynchronously Experienced	Experienced by multiple people, in multiple spaces, on the web. But only one WiFi channel.
Globally Accessed	Perimeter and peer security made it hard bring the app into a new network environment quickly.

Distance from App Vision to Deployed Reality

	IP
Collaboratively Developed	Limited application semantics represented in network architecture
Iteratively Deployed	IP net configuration can be brittle to change or require NAT, etc. to scale
Dynamically Assembled	Connection- / session-oriented models, as well as address assignment requirement
Physically Integrated	IPv6 provides “room” but doesn’t aid application development
Asynchronously Experienced	Mobility and multicast not well-supported
Globally Accessed	Perimeter- and channel-based security model hard on integration, easy on internal vulnerabilities.

Apply Cognitive Dimensions to Discuss Improvements

	NDN
Collaboratively Developed	Express app semantics in names, at packet level (expand abstraction gradient)
Iteratively Deployed	Improved resilience to device config change (fewer hard mental operations)
Dynamically Assembled	Connection-less, session-less, leveraging storage (reduce premature commitment)
Physically Integrated	Consistent naming for physical, virtual elements (increase closeness of mapping)
Asynchronously Experienced	Disruption tolerant and multipath-friendly (reduce viscosity)
Globally Accessed	Data-centric vs. perimeter-centric security (decrease error-proneness)

Indeed, we built Grace Plains anyway. (Yes, we "can do" it.)

Cognitive dimensions provide a framework to discuss why architectural differences matter: "can do" ≠ "will do it well or easily".

- Abstraction gradient
- Closeness of mapping
- Error-proneness
- Hard mental operations
- Premature commitment
- Role expressiveness
- Viscosity

Not a definitive list – e.g., consider Brooks (2010):

- Orthogonality: Do not link what is independent
- Propriety: Do not introduce what is immaterial
- Generality: Do not restrict what is inherent

What does Internet as Infrastructure mean?

Infrastructure is our “Shared visions of the possible and acceptable dreams of the innovative.”

- L.L. Bucciarelli in Star, 1999

Conclusion

Open challenges (some of many):

- New design patterns: More work using NDN to both achieve well-known solutions and to explore problem reformulations.
- New "problems": What NDN suggests at the application and network level, especially in trust / security.
- Specific cognitive dimensions for discourse on network architecture, especially simplicity / capability trade-offs.
- Usability comparison of IP and NDN via these methods.

Architecture matters to everyone:

- Like all infrastructure, it embodies our imagination.
- Architecture impacts problem formulation.
- *What kind of innovations do we really believe are possible?*

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