NDN Tutorial

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Outline

- How NDN works
  - Data, Interests, Security, Network
- Open research problems
  - Applications, Security, Network
- What have been been doing
  - Applications and protocols, Codebase, Community

An example scenario: smart homes

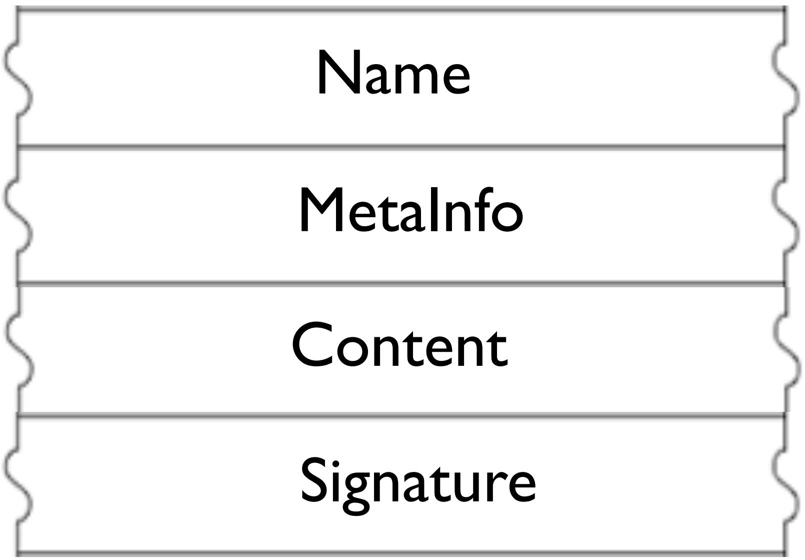
- Read temperature, get camera feed, turn on a light, etc.

- IP solution
  - Figure out where (address) to get the information
    - thermostat, camera, home controller
  - Send request to that particular address.

- NDN solution
  - Send request explicitly asking for the data without specifying destination.

Data Packet

- The most essential component of NDN architecture



Uniquely identifies the content, e.g., */UCLA/BH234/temperature/timestamp*

Info to help common data consumption e.g., *FreshnessPeriod*.

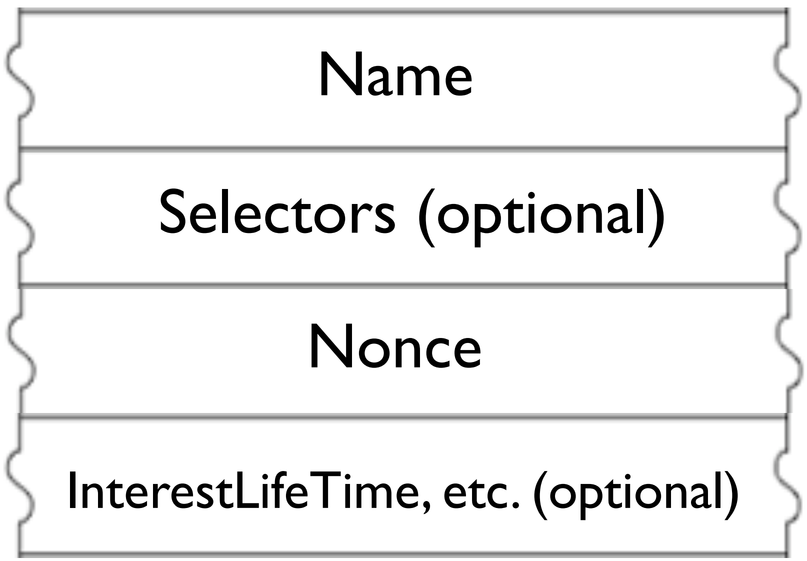
Can be anything

Signed by the data producer

- Data is an immutable object.
  - When content changes, name as well as signature should change too.

Interest Packets

- Interests are sent to retrieve Data



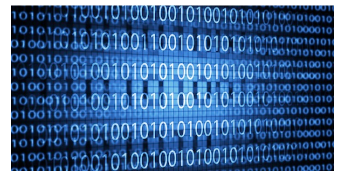
What data are of interest, e.g., */UCLA/BH234/temperature*

Help narrow down data selection

A random number to differentiate interests that have the same name.

Basic communication

Consumer



Data

Producer

- Consumer ***pulls*** Data
  - one interest for one data packet.
  - Interest and data names must match
  - Rate control, data verification, loss detection and recovery, explore different network interfaces, etc.

- Data production
  - Naming
  - Signing
  - Segmentation if needed.

It's all about names

- **Data and Interests carry names, no address or port.**
  - That's what makes all the differences: benefits and challenges.

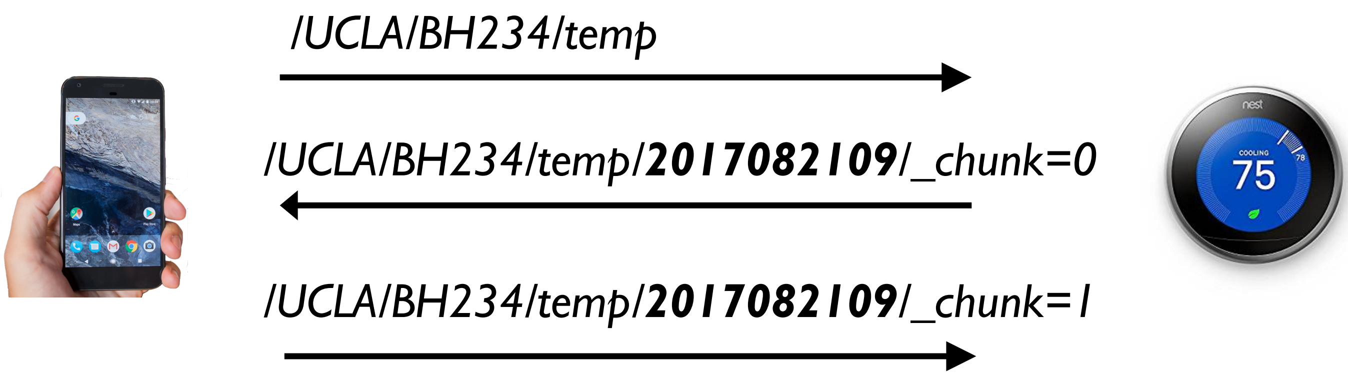
- Names are assigned to each packet by applications, e.g.,
  - */UCLA/RoyceHall/ARFeed/FrontView/mp4/_frame=12/_chunk=20*
- Names are hierarchical
  - Facilitate name aggregation
  - Preserve application context for data consumption, e.g., security.
- Naming conventions to avoid conflicts and facilitate communication.

The role of names

- Names are used as the de-multiplexer across layers.
  - No need for each layer to have its own identifier (e.g., address, port), the management of them, and translation between them.
  - In cases of multiple interfaces and mobility, not bound to a particular address or port.
- Auto-configuration and auto-discovery
  - /_ThisRoom/Projector/command/TurnOn/…
- Naming is the major part of an application protocol design.
  - Once the naming convention is known, any application can use it to access the projector.

Name Discovery

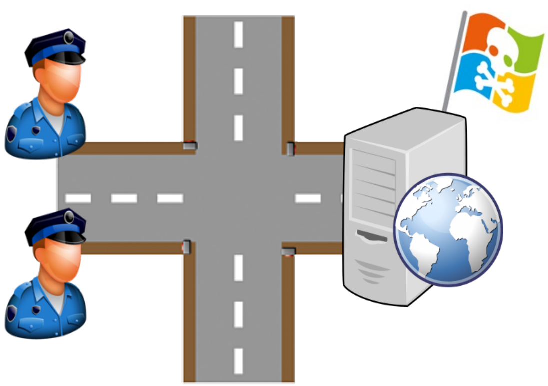
- How do consumer apps learn about data names?
  - Usually know the name prefix, but not the complete name.
- In-network name discovery
  - May also use selectors to narrow the selection.



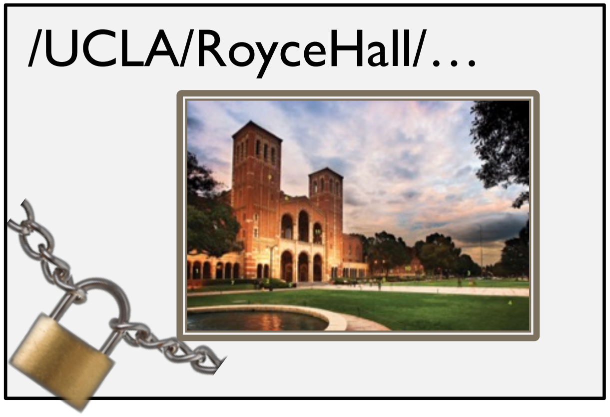
- Other discovery mechanisms for specific scenarios.
  - E.g., a Manifest that lists known names of relevant data.

Data-centric security

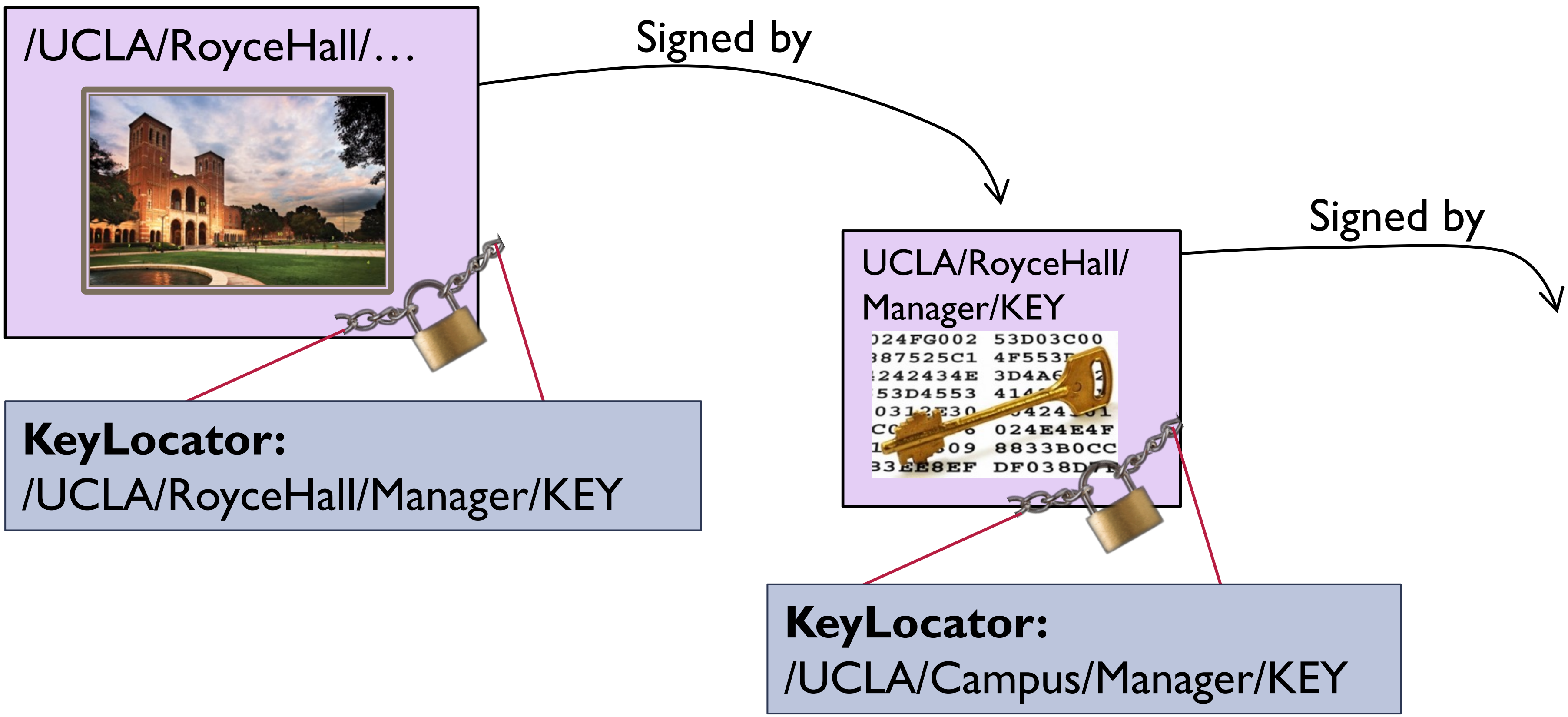
- In the Internet you secure the connection…
- …but the server may still be hacked!



- In NDN the producer signs the data …
- … so that consumers know when they get bad data!
- even when the producer is offline.

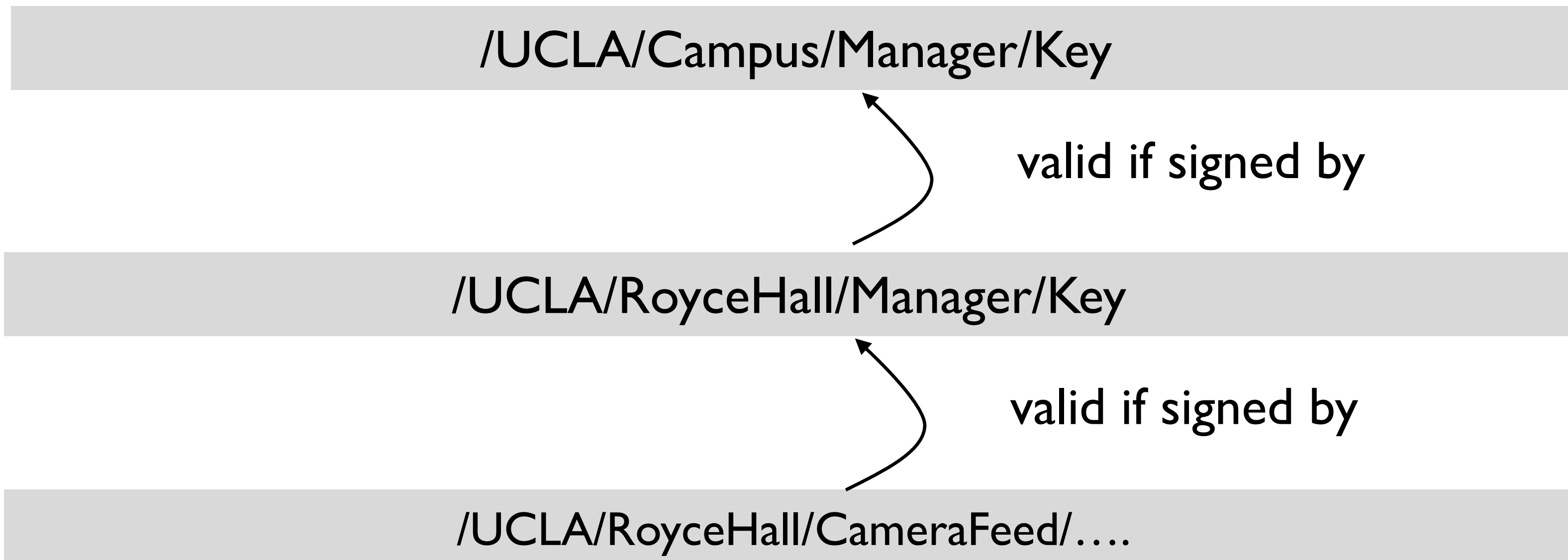


Authentication of NDN Data



- Keys are named data, retrieved and secured as any other Data.

Name-based trust relationship and policy

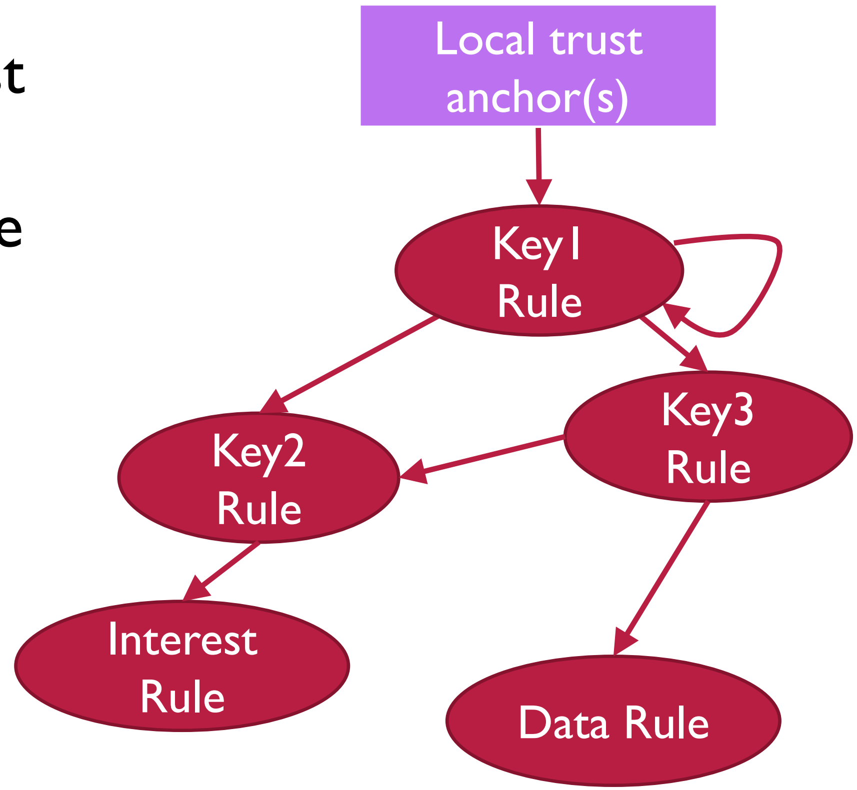


- For Data to be valid, they must be signed by certain keys.
- The chain goes all the way to the trust anchor of the application.

Trust Schema: Name-Based Definition of Trust Model

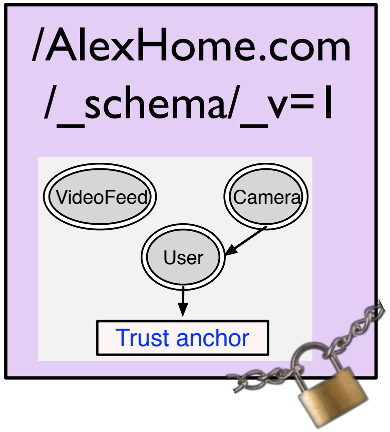
- Formal description of the trust model by schematizing the relationship between the name of the data and the name of signing key.

```
<>    <CONST>
token*  token?
[func]
(:group:token)
```



Trust Schema as a Bag of Bits

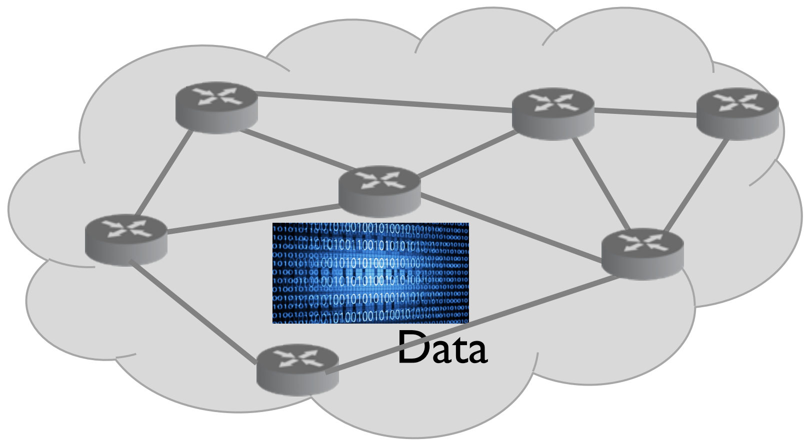
- Can be distributed using basic NDN mechanisms
- Secured as any other data packet



- Power of trust schema data
  - My phone can reliably validate the received video feed data
  - Camera can properly sign video feed data
  - Camera can validate commands from my phone
  - Routers can validate data and authorize requests

How Packet Forwarding Works

Consumer

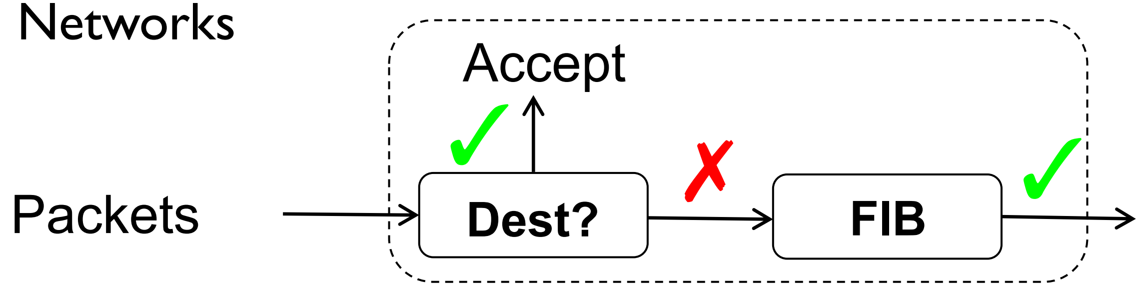


Network

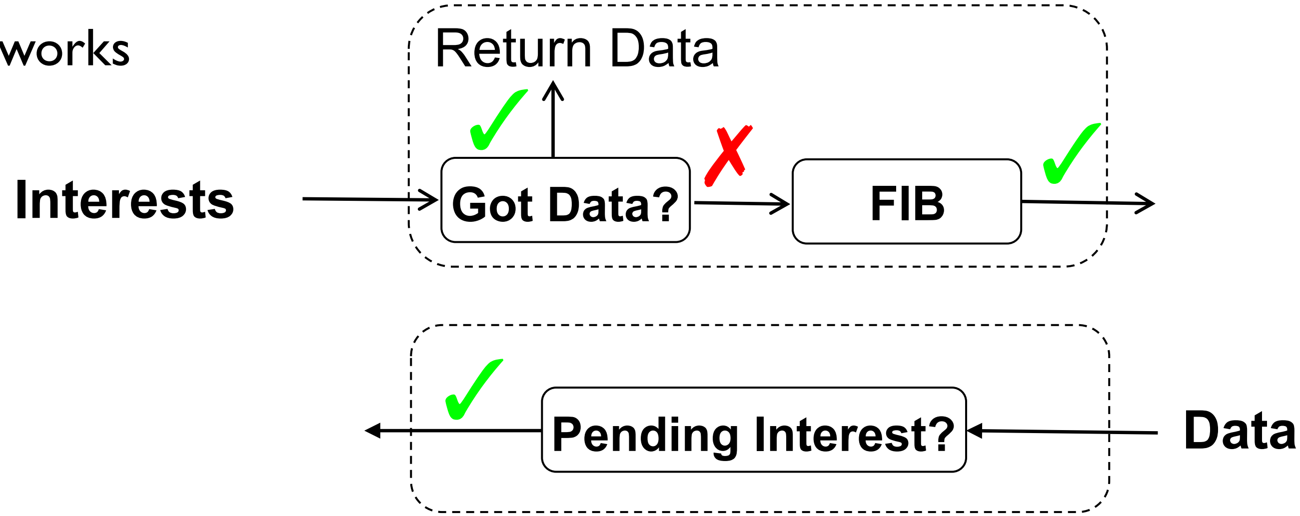
Producer

From a single node's point of view

Traditional Networks



NDN Networks



Forwarding Table (FIB)

- It stores name-prefixes and corresponding next-hops.
  - E.g., /UCLA
- Perform longest prefix match with incoming Interest's name.
  - E.g., /UCLA/RoyceHall/…
- Multiple next-hops, which may lead to different data sources
  - since we're forwarding towards data, not a particular destination.
  - NDN enjoys more forwarding choices since it doesn't need to worry about loops.

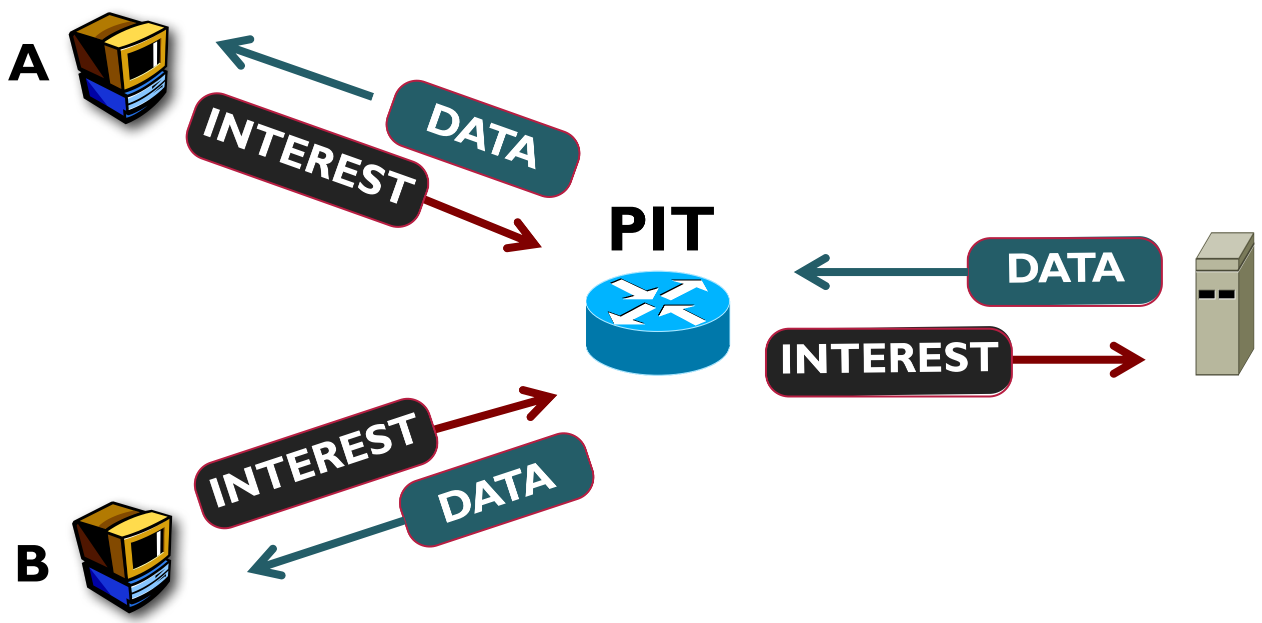
Building FIB

- Applications register their data's nameprefix with local node.
- Conventional Routing Algorithms
  - Announcing nameprefixes to the network
  - E.g., link state
- "unconventional" routing algorithms
  - Take advantage of underlying NDN networks
  - E.g., Hyperbolic Routing
- Flooding-based learning
  - Flood initial interest, observe where data comes from and add a FIB entry for it.
  - Suitable to local, ad-hoc environments

Content Store (CS)

- The data cache enabled by NDN at every node.
  - Transparent
  - In-network
  - On-path
- Many benefits
  - Reduce redundant traffic for ISPs
  - Reduce server load for producers, especially during attacks.
  - Reduce response time for consumers.
  - Even at time scale of RTT, it helps loss recovery and mobility.
- Decouples data production and data consumption
  - Naturally support DTN type of communication.

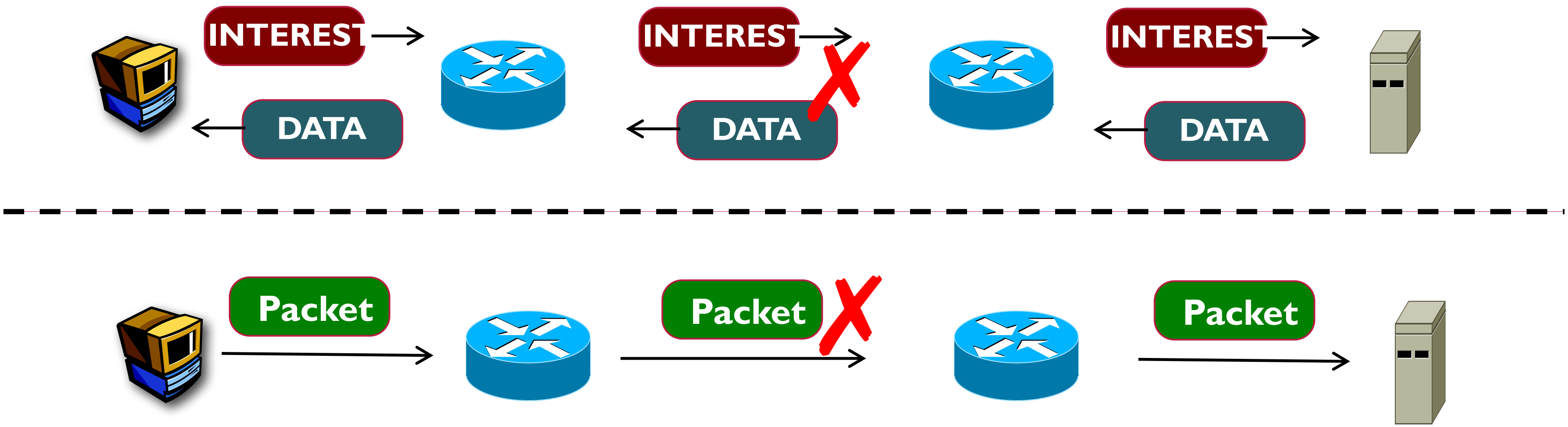
Pending Interest Table (PIT)



- New states introduced by NDN to get Data back to the consumer.
  - Each entry records (name, nonce, incoming faces)
  - Created when a new Interest is forwarded
  - Updated when more interests carrying the same name arrive
  - Deleted when a matching Data returns.

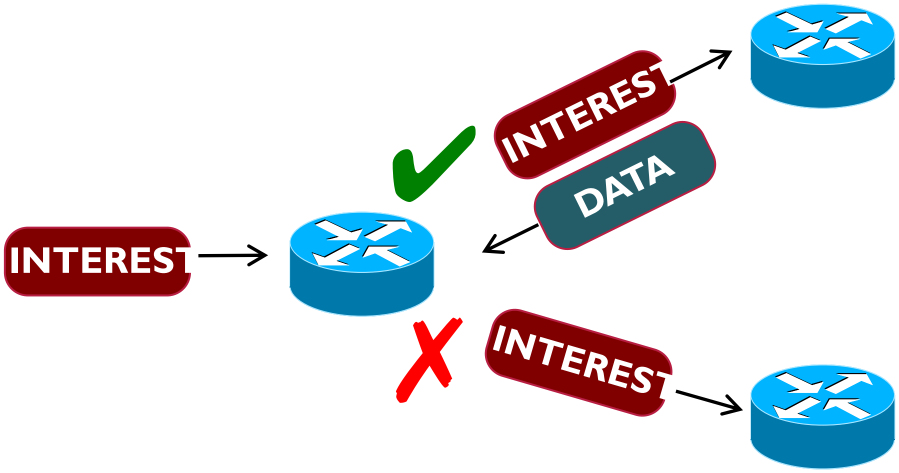
Benefits of PIT

- Native multicast
  - No difference between multicast and unicast operations
- Suppress duplicate packets (e.g., caused by forwarding loops)
  - Important to mobile, ad hoc communication
- Provide closed-loop feedback for the success/performance of data retrieval, at every hop.



Forwarding Strategy

- FIB provides multiple forwarding options.
- PIT enables fault detection and performance feedback.
- Based on the above, Forwarding Strategies make the best forwarding decisions for data retrieval.
  - E.g., a strategy may minimize path changes, or look for the shortest delay, or look for higher throughput, or always multicast/broadcast, etc.



Summary of how NDN works

- Data are identified by names, and signed by producer.
- Interests carry names to retrieve matching Data.
- Data-centric security and name-based trust schema.
- Stateful data-plane that supports in-network caching, native multicast, and versatile forwarding strategies.

Open Research Problems

NDN Research

- NDN is a new network architecture
  - from traditional ***point-to-point conversation*** to ***distributed data production, retrieval, and consumption***.
- It requires rethinking of applications and networks together with built-in security.
  - How does NDN work in a particular network environment?
  - How to fully take advantage of NDN's features?
  - How to optimize NDN's performance?
- Selected research problems in applications, security, and networks.

Applications

- NDN brings network semantics closer to application semantics.
- Data-centric app designs take the most advantage of NDN.
- We drive network architecture research by building applications. (And, vice versa.)
- Notably, enables *cloud-assisted* alternatives to the current *cloud-centric* paradigms for distributed computing, which fail to support highly dynamic, low-latency, mobile apps.

Namespace Design

- Data namespace design becomes a key part of app design.
  - Tussle between data access, forwarding, security, and other requirements placed on names.

- *Home IoT Example*
  - Name data, actuation points, devices, keys / certificates, access control policies.
  - Often, four-part name: /A/B/C/D
    - A: How to reach the data. (e.g., localhop, home-<guid>, /edu/ucla, etc.)
    - B: High-level identifiers. (e.g., living_room/temperature)
    - C: Derived or related data identifiers. (e.g., KEY, _mimetype)
    - D: Type-specific suffixes (e.g., segment or sequence number, version, etc.)
  - Keylocator in the data packet: another name related to trust.

Application APIs

- APIs and app conceptualization changes:
  - Consumer-driven: pulling rather than pushing data
  - Asynchronous multi-node data dissemination rather than client/server
  - Local and global communication can use same mechanisms

- *Home IoT Example*
  - Retrieval and actuation possible with basic primitives.
  - Discovery & bootstrapping can also be implemented with basic primitives + name conventions (afternoon demonstration).
  - Hierarchical names common in other layers.
  - Less obvious are how to achieve rare but critical notifications.
  - Important to remember NDN at Layer 3.

Usable Security

- App data security can be built in from the ground-up, but the approaches and tools are new and need work to be easy-to-use.

- *Home IoT Example*
  - Schematized trust: we've found easy to use, just need conventions and more examples.
  - Name-based access control: many options, harder to conceptualize just in terms of names.
  - Basic demonstrations this afternoon.

Research problems & approaches

- Open questions of what network provides to app
  - Network storage (e.g., repo)
  - Indirection (e.g., NDNS)
  - Handling mobile publishers

- *IoT Example*
  - ”Memory content cache” easily extended to persistent tuple store.
  - Certificate storage, name redirection, could come in infrastructure
  - From home networking to vehicular networking.
    - Multihomed, mobile.
    - Local, neighborhood, global data.

Data Access Control

- Separate data retrieval from data access control
  - Encrypt the data, which can be retrieved by anyone.
  - Control the access to decryption keys.
- The exact mechanism design has many options, also depending on the network environments, e.g., resource constrained devices.

DDoS and Content Poisoning

- NDN architecture is more resilient to DDoS attacks than IP.
  - Cannot flood victim with Data.
  - Not effective if flood victim with Interests for existent Data.
  - Only way to attack is to flood with Interests for routable but non-existent Data, but this can be detected from PIT behavior.
  - Design the mechanism to detect and mitigate this DDoS with minimal collateral damage.

- Content Poisoning
  - Routers by default don't verify data for performance reason.
  - What if consumers received forged data and want the routers to retrieve a different one.

Infrastructure-less environments

- Network environments that have no reliable fixed infrastructure
  - Mobile, ad hoc, wireless device-to-device, delay-tolerant network, disaster recovery, etc.
- NDN thrives in these environments
  - Fetching data vs. chasing a mobile node, or establishing a connection between two nodes not online at the same time, or going through cloud for local communication, etc.
- Research issues
  - Auto-configuration, auto-discovery, device-to-device communication
  - Security models and mechanisms
  - Routing and forwarding strategies under mobility, and use multiple interfaces at the same time.

Forwarding Strategy

- A powerful mechanism that makes data-plane smart
- Can employ different strategies for different types of data and in different networks.

- For examples:
  - Strategies for large scientific data movement, VR/AR data, IoT data.
  - Strategies for vehicular networks, smart homes, sensor networks, delay-tolerant networks, data center networks, etc.
  - Supporting flexible strategy composition

Sync

- Multi-party synchronization of a shared dataset.
  - Each party may start with a different subset
  - The dataset may change over time.
  - The abstraction for NDN transport.
  - TCP-like reliable transfer is a special case.
    - Two parties, sender has the full set, and receiver has none.
- Basic approach
  - Efficient representation and exchange of the subsets, utilize multicast/broadcast to share data and remove redundancy.
- A number of solutions have been proposed.
  - They different in data naming, state representation, change notification, and update retrieval.

Congestion Control

- It is a different story for NDN
  - No longer a point-to-point session with a single base RTT.
  - Now multipath, multi-source data transfer.
  - Need to regulate Interest rate in order to control congestion

- Need hop-by-hop solutions where
  - Every node on the path participates
  - Be able to use multiple paths and multiple sources
  - Impacts on overall network behavior

Routing, Forwarding, and Caching

- In NDN, these are all related.
  - For example, forwarding decision affects cache availability, which in turns affects future forwarding decisions.
- Joint optimization of them in different network environments
  - Data centers, ISP networks, mobile edge networks, etc.
- Explore new routing protocols
  - With smart data plane, the requirements on control plane have been relaxed.
- Routing Scalability
  - Table size
  - Routing churns

Scalable forwarding engine

- Table lookup and update (FIB, PIT, CS)
  - Names are of variable-length
  - Table size can be large, content can be dynamic.
  - Matching rules are also different for each table.

- A large body of work has explored different data structures
  - Hash tables, tries, bloom filter.
  - Mostly focused on FIB.
  - Need better designs for CS and PIT.

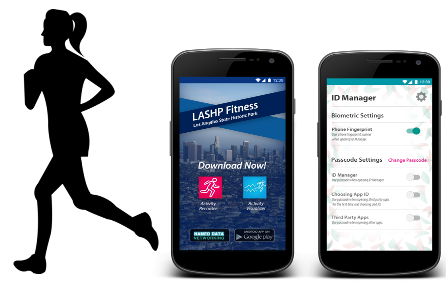
What we have been doing

Application-driven architecture development

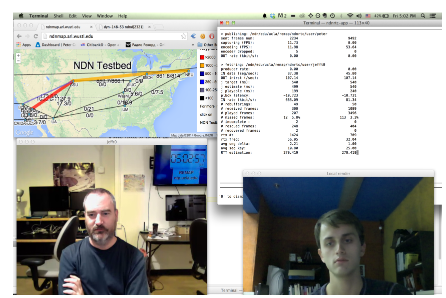
- Current focus areas:
  - Mobile edge computing
  - Internet of Things
  - Navigable media

- Other applications
  - Open mHealth (mobile health)
  - Building automation and management
  - Scientific "big data" (e.g., climate change)
  - Real-time conferencing
  - Neighborhood solar
  - File sharing, chat, etc.

AR Campus Browser



Mobile Health & Fitness



Video/Audio Conferencing

Protocol and Mechanism Design

- Articulated the design principles, developd the packet format and protocol specs.
- Routing protocols
- Forwarding Strategies
- Table structures and algorithms
- Name-based authentication, trust, and access control
- Sync protocols
- Congestion control
- ….

Running Code and Evaluation Platforms

- Network forwarder, libraries, tools.
- On conventional platforms and IoT devices
- Simulator, emulator, and global testbed
- All code is open sourced.

Research Community

- NDNComm
  - 2017 at Memphis, 73 people from 36 institutions
  - 2015 at UCLA, 116 people from 49 institutions
  - 2014 at UCLA, 87 people from 31 institutions

- ACM ICN conference and ICN-related workshops
- IRTF ICN RG
- Both academia and industry.

For more information

http://www.named-data.net

Don’t miss the demos and codebase overview in the afternoon!