The eXpressive Internet Architecture: from Architecture to Network

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NSF Future Internet Architecture

- The Internet has been unbelievably successful
  - Has sustained tremendous growth
  - Supports very diverse set of applications and services
  - Integral part of our society and economy
- Lots of exciting research on how to improve Internet
  - Security, routing, wireless/mobile, management, …
  - But Internet architecture constrains what can be modified
- Future Internet Architecture frees researchers to go beyond today's IP architecture and infrastructure
  - Five teams funded by NSF, including XIA

Outline

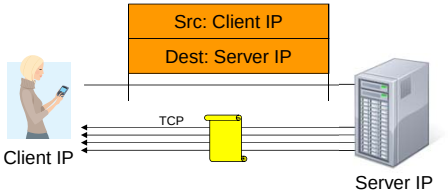
- XIA architecture concepts
  - Motivating example
- Building an XIA network
- Research directions

Predicting the Future is Hard!

- A lot of really smart people don't agree:
  - Named Data Networking: content centric networking - data is a first class entity
  - Mobility First: mobility as the norm rather than the exception – generalizes delay tolerant networking
  - Nebula: Internet centered around cloud computing data centers that are well connected

We love all of them!

Today's Internet



- Client retrieves document from a specific web server
  - But client mostly cares about correctness of content, timeliness
  - Specific server, file name, etc. are not of interest
- Transfer is between wrong principals
  - What if the server fails?
  - Optimizing transfer using local caches is hard
    - Need to use application-specific overlay or transparent proxy – bad!

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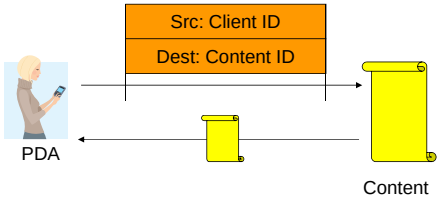
eXpressive Internet Architecture



- Client expresses communication intent for content explicitly
  - Network uses content identifier to retrieve content from appropriate location
- How does client know the content is correct?
  - Intrinsic security! Verify content using self-certifying id:
    hash(content) = content id
- How does source know it is talking to the right client?
  - Intrinsic security! Self-certifying host identifiers

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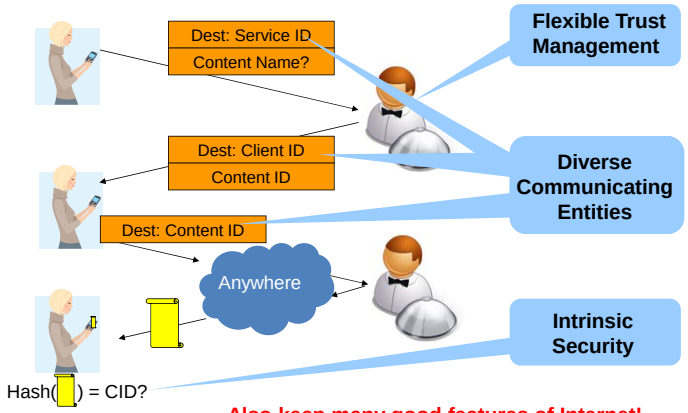
A Bit More Detail …



Also keep many good features of Internet!

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XIA: eXpressive Internet Architecture

- Each communication operation expresses the intent of the operation
  - Also: explicit trust management, APIs among actors
- XIA is a single inter-network in which all principals are connected
  - Not a collection of architectures implemented through, e.g., virtualization or overlays
  - Not based on a "preferred" principal (host or content), that has to support all communication

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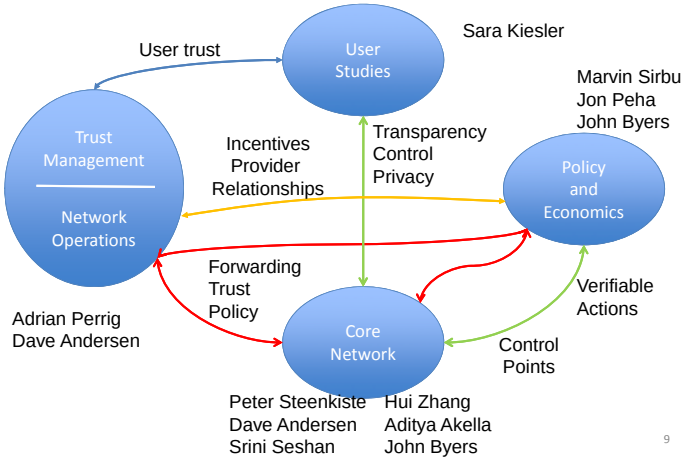
Interactions between Actors



Outline

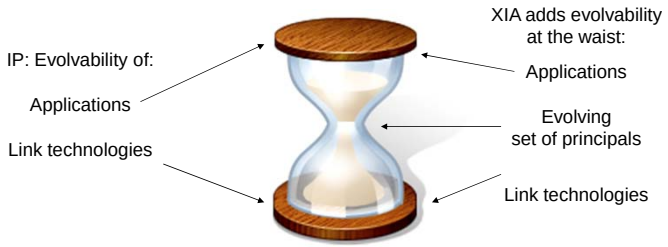
- XIA architecture concepts
- Building an XIA network
  - Making it work
- Research directions

Multiple Principal Types

- Hosts XIDs support host-based communication similar to IP – *who?*
- Service XIDs allow the network to route to possibly replicated services – *what does it do?*
  - LAN services access, WAN replication, …
- Content XIDs allow network to retrieve content from "anywhere" – *what is it?*
  - Opportunistic caches, CDNs, …
- Autonomous domains allow scoping, hierarchy
- Associated with different forwarding semantics
- Set of principal types can evolve over time

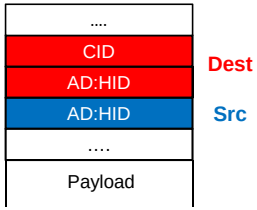
What Do We Mean by Evolvability?

- Narrow waist of the Internet has allowed the network to evolve significantly
- But need to evolve the waist as well!
  - Can make the waist smarter



Supporting Evolvability

- Introduction of a new principal type will be incremental – no "flag day"!
  - Not all routers and ISPs will provide support from day one
- Creates chicken and egg problem - what comes first: network support or use in applications
- Solution is to provide an *intent* and *fallback* address
  - Intent address informs network of user intent
  - Fallback address is guaranteed to be reachable



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Addressing Requirements

- Fallback: intent that may not be globally understood must include a backwards compatible address
  - Incremental introduction of new XID types
- Scoping: support reachability for non-globally routable XID types or XIDs
  - Needed for scalability
  - Generalize scoping based on network identifiers
  - But we do not want to give up leveraging intent
- Support for mobility, in-path services, …
- Want to combine the above requirements

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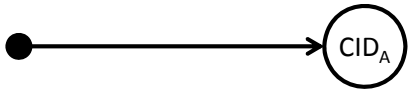
Our Solution: DAG-Based Addressing

- Uses direct acyclic graph (DAG)
  - Nodes: typed IDs (XID; expressive identifier)
  - Outgoing edges: possible routing choices
- Simple example: Sending a packet to CID_S



Dummy source: special node indicating packet sender

Intent: final destination of packet with no outgoing edges

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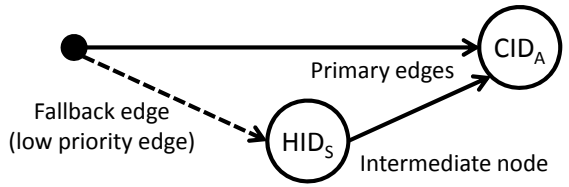
Support for Fallbacks with DAG

- A node can have multiple outgoing edges



- Outgoing edges have priority among them
  - Forwarding to HID_S is attempted if forwarding to CID_A is not possible – Realization of fallbacks
  - Helps routers deal with routing failures

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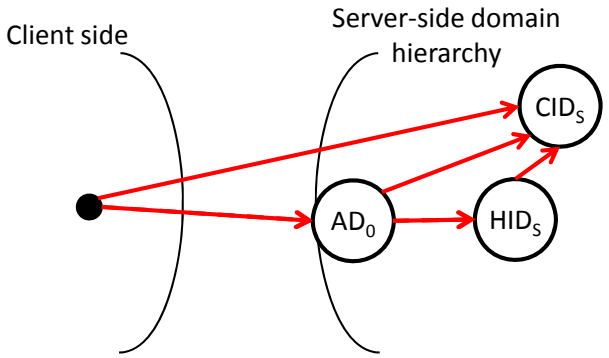
DAGs Support Scoping and Iterative Refinement



Raises many interesting questions!

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Intrinsic Security in XIA

- XIA uses self-certifying identifiers that guarantee security properties for communication operation
  - Host ID is a hash of its public key – accountability (AIP)
  - Content ID is a hash of the content – correctness
  - Does not rely on external configurations
- Intrinsic security is specific to the principal type
- Example: retrieve content using …
  - Content XID: content is correct
  - Service XID: the right service provided content
  - Host XID: content was delivered from right host

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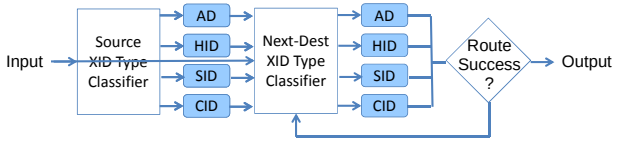
Packet Processing Pipeline



- Principle-independent processing defines how to interpret the DAG - core XIA architecture
- Principle-dependent processing realizes forwarding semantics for each XID type
- Implemented in Click – see NSDI 2012
- Optimizations possible: fast path processing, packet level and intra-packet parallelism

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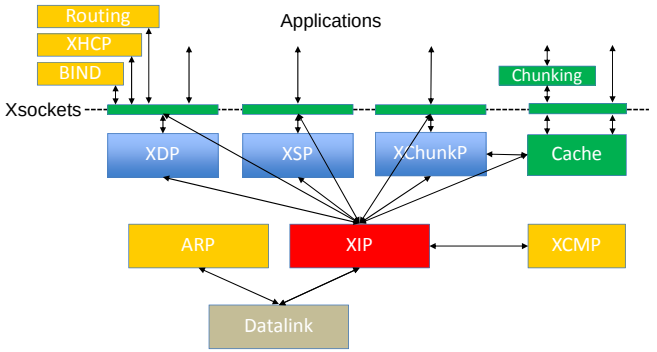
Full XIA Prototype



- Open source release: http://www.cs.cmu.edu/~xia
- Support for GENI and VM-based experiments

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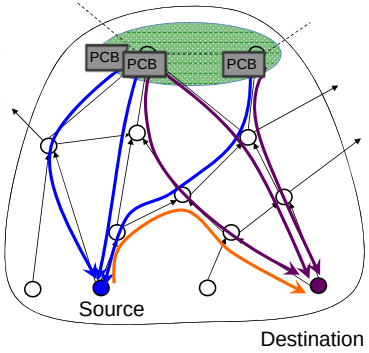
Path Selection in SCION Architecture Overview

- Source/destination can choose among up/down hill paths
  - Path control shared between ISPs, receivers, senders
- Desirable security properties:
  - High availability, even in presence of malicious parties
  - Explicit trust for operations
  - Minimal TCB: limit number of entities that must be trusted
  - No single root of trust
  - Simplicity, efficiency, flexibility, and scalability
- Porting to XIA DP this summer



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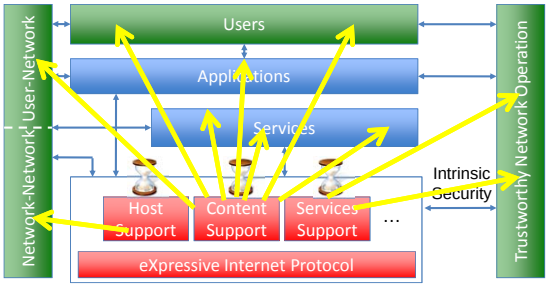
XIA Components and Interactions



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Outline

- XIA architecture concepts
- Building an XIA network
- Research directions
  - What is different?

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Balance of Control between Network Core and Edge

- Internet places most control in the network
- XIA provides more control to the edge
  - Choice of principal, DAGs, Scion path selection
  - Also offers flexibility to service providers: control path properties, new services, …
- Many research opportunities
  - Other mechanisms + other functions/layers
  - Customizing roles depending on context
  - How to manage the tradeoff at runtime

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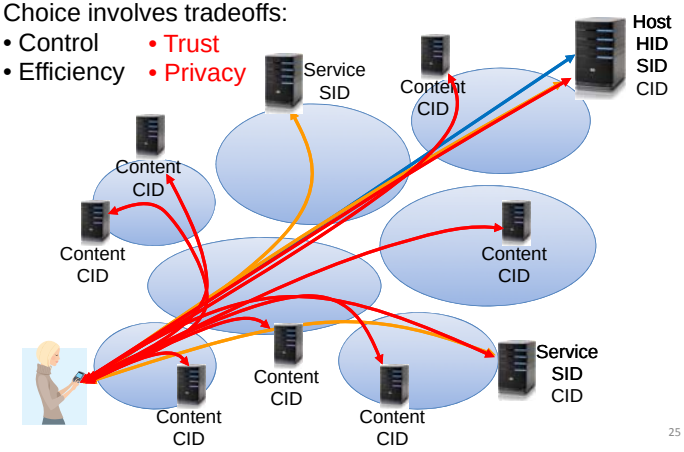
Multiple Principal Types

Choice involves tradeoffs:
- Control
- Efficiency
- Trust
- Privacy



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Using DAGs

- DAG is "locator" that helps network reach "destination"
  - Provided by destination through a name service
  - Has the right incentive!
- DAG is created jointly by all parties involved
  - Source can modify destination DAG, pick from options, ..
  - DAG can be modified during session
  - Networks can limit what DAGs they accept
- Many other options exist
  - Path based options, locator services, different headers, ..

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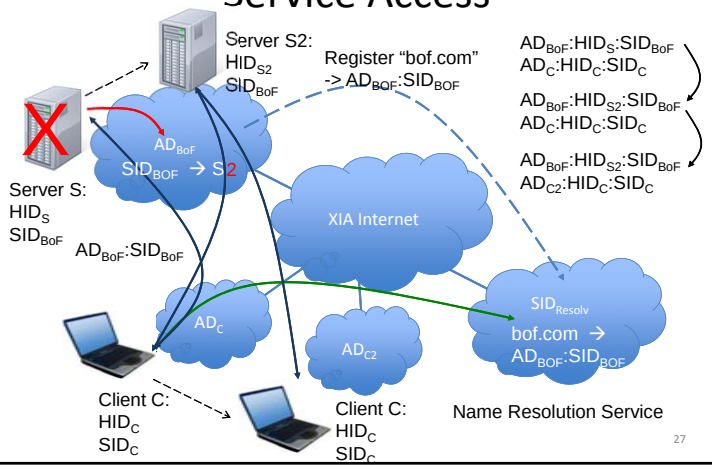
Example: Secure Mobile Service Access



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Functionality in Network versus Edge

- Internet had notion that higher level functions were implemented at the edge
  - Currently lots of functionality in the network
- XIA addressing flexibility simplifies adding functions to the network
  - Services, new principal types
  - Does not require universal agreement (DAGs)
  - Example: supporting diversity at edge (Tapa)
- Many alternative solutions
  - Service-oriented architectures, active nets, …

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How Much and What Security in the Network

- XIA uses "intrinsic security" to guarantee some properties of communication operation
  - XIA: cryptographic identifiers, Scion paths
  - Several other projects are using cryptographic ids.
- Many alternatives to explore
  - Different types of cryptographic identifiers
  - Alternative approaches, evolving the mechanisms
  - Verifiability of network functions

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What About the Users?

- Who are the users?
  - Human end-users, applications, or edge networks
- Trust management, naming
  - Hosts – DNS – nice and hierarchical
  - Services and content – different
    - Important: want to skip hosts
- User trust in network
  - Visibility + control
  - "Privacy button"

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Conclusion

- XIA supports evolution, expressiveness, and trustworthy operation.
  - Multiple principal types, flexible addressing, and intrinsic security
  - More information (including on release)

    http://www.cs.cmu.edu/~xia
- Broad research agenda on key tradeoffs in network
  - Edge versus core, security in network, evolvability, …
  - Affects all aspects of the network: transport protocols, trust management, applications, services, …

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