Security Issues in Active Networking

IWAN '01 Tutorial

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Tutorial Outline:

- Security Challenges
- Principles of Active Network Security
- Protection Methods
  - Language Based
  - Node Architecture Based
  - Network Based
- Applications
- Summary

1. Security Challenges

- What is *security* (versus, say *safety*)?
- Protection of Resources
- Computational Resources
- Objects/Memory Resources (namespace)
- Bandwidth Resources - QoS

Challenges: Safety & Security

- Safety: Accidents; Security: Malice
- Specification of goal (@30,000 feet!):
  Right Information to
  Right Place at
  Right Time
- Insecurity: Deviation from goal
  e.g., information to *wrong* place

Right information/Right place

- Requires identifying information units
- Requires identifying places

  e.g., locations, personnel, etc.
- Requires *security association*

  e.g., per-place *password* encrypts info.

  deny information to other places

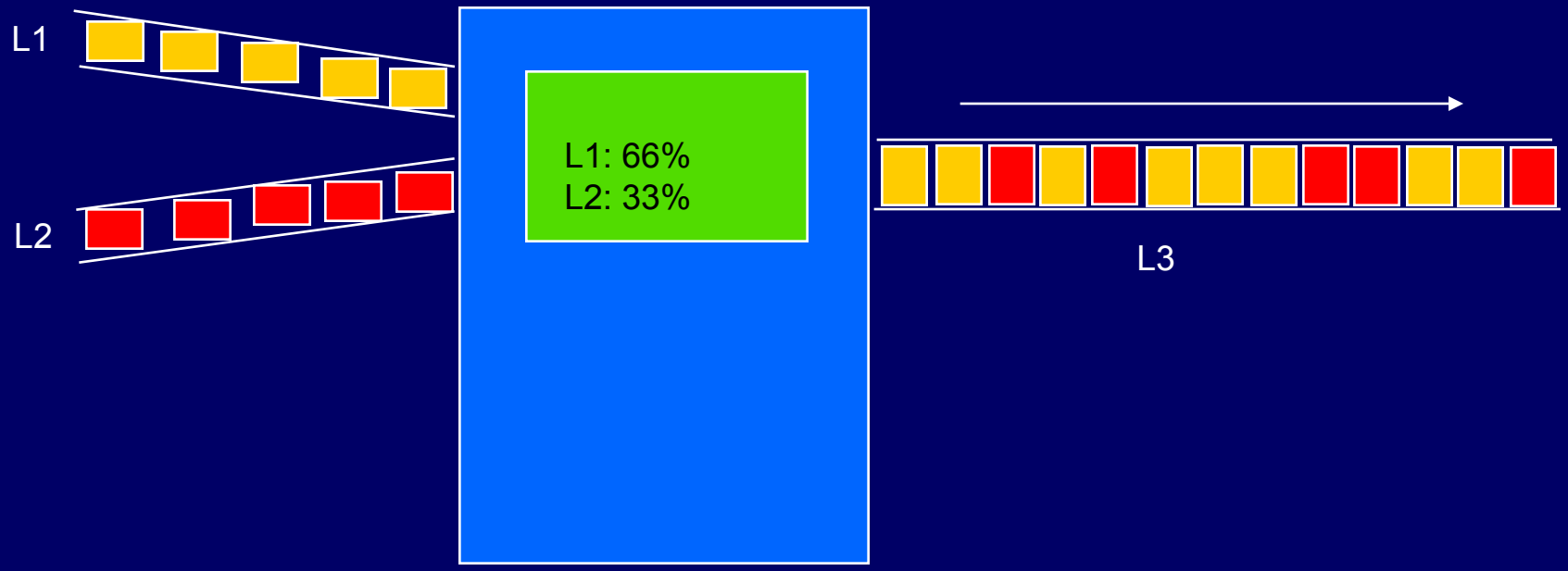
  cryptographic protocols: good progress

Right Time (the tricky one)

- Late information may be useless
- Basis of *denial of service* attacks
- Requires identifying *real* times
- Languages have no time semantics
  - gettimeofday() in C/Unix world
  - is ML better? (Dannenberg's *Arctic?)*

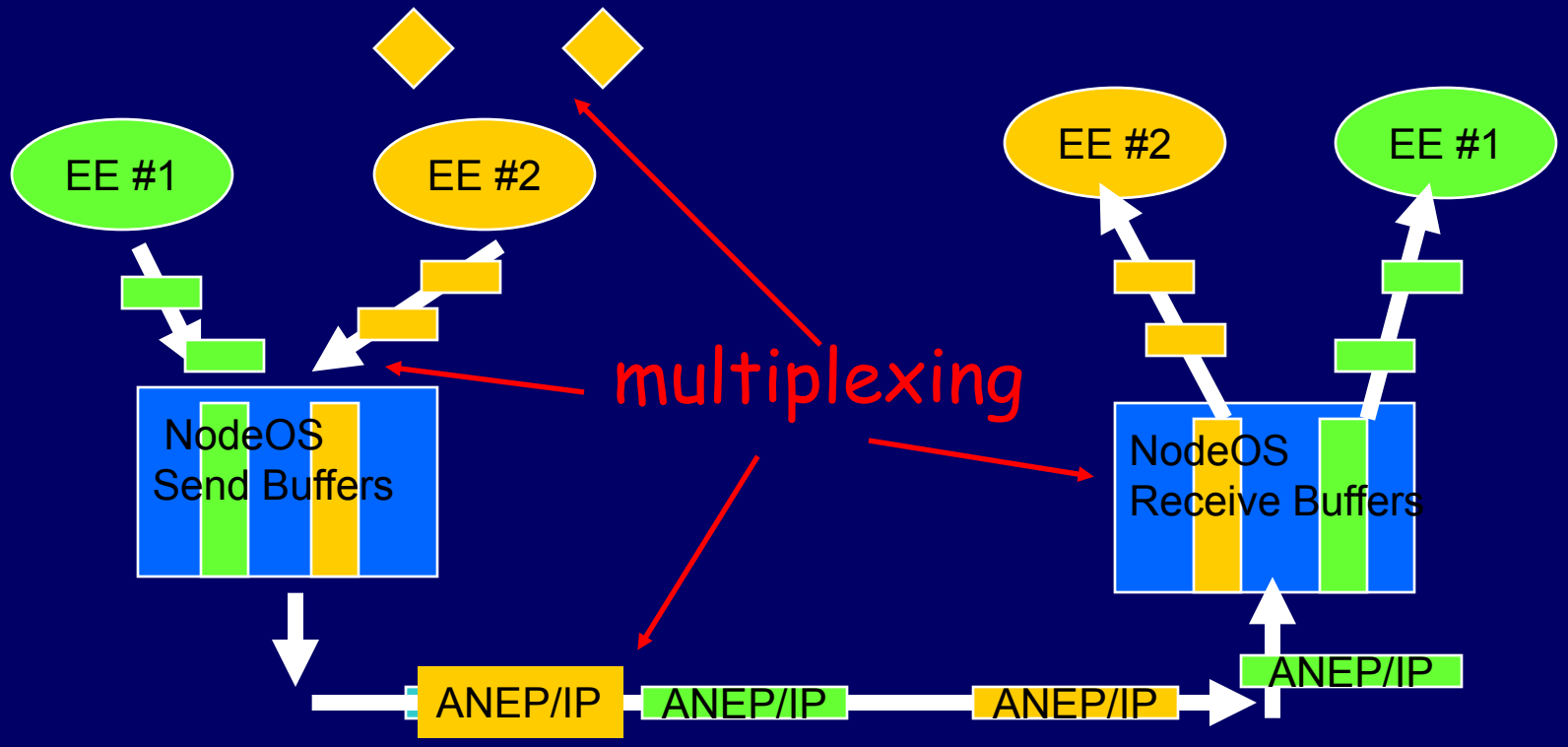
Need to control multiplexing

- E.g., assign L3 bandwidth 66%/33%



Resource Management, End-to-End

- Resource Management Challenges

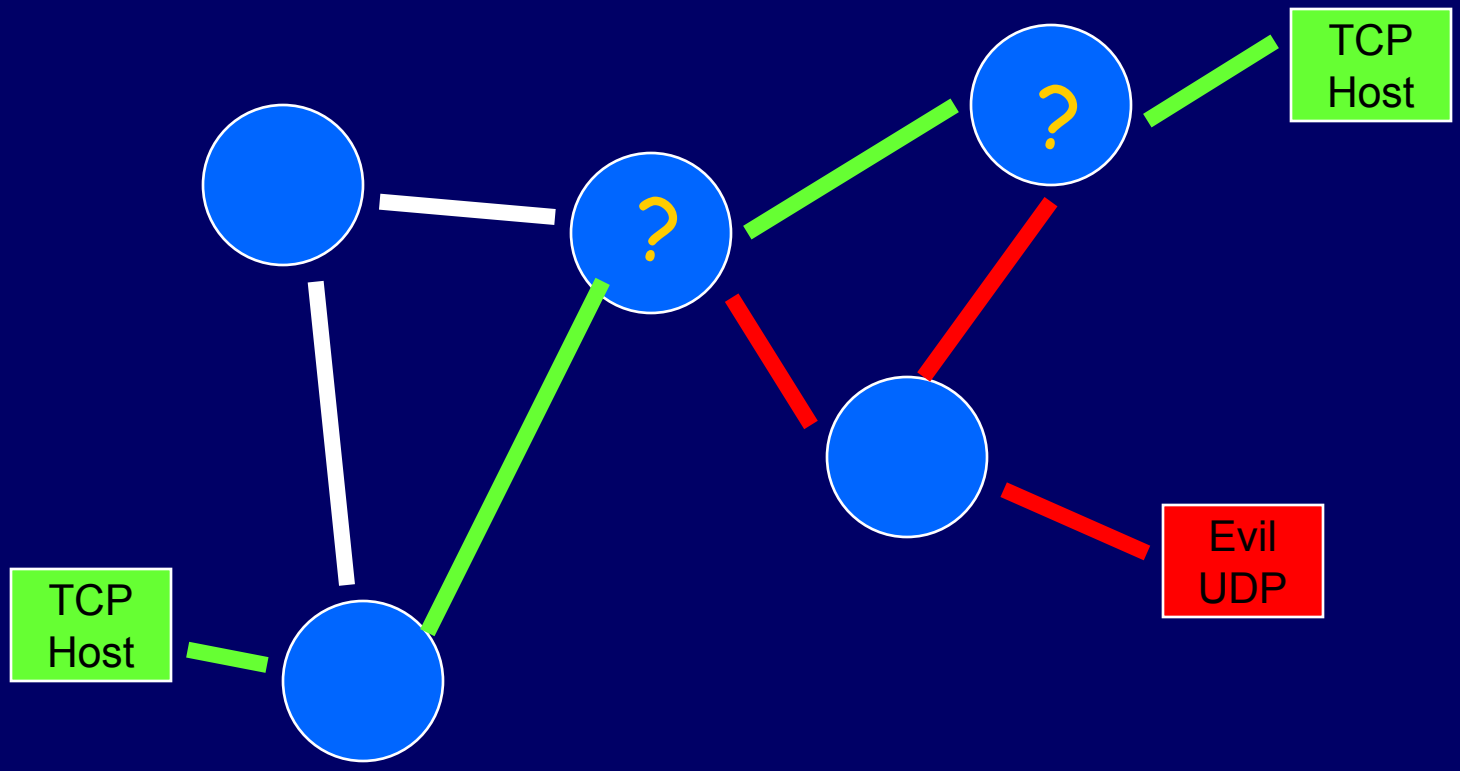


Denial of Service

- Easy to protect server hosts
  - Resource domains, interrupt masking, firewall shielding on host *itself*
- But service is unprotected between client and server site
- This problem *must* be solved with network-embedded functionality

Denial of Service attack

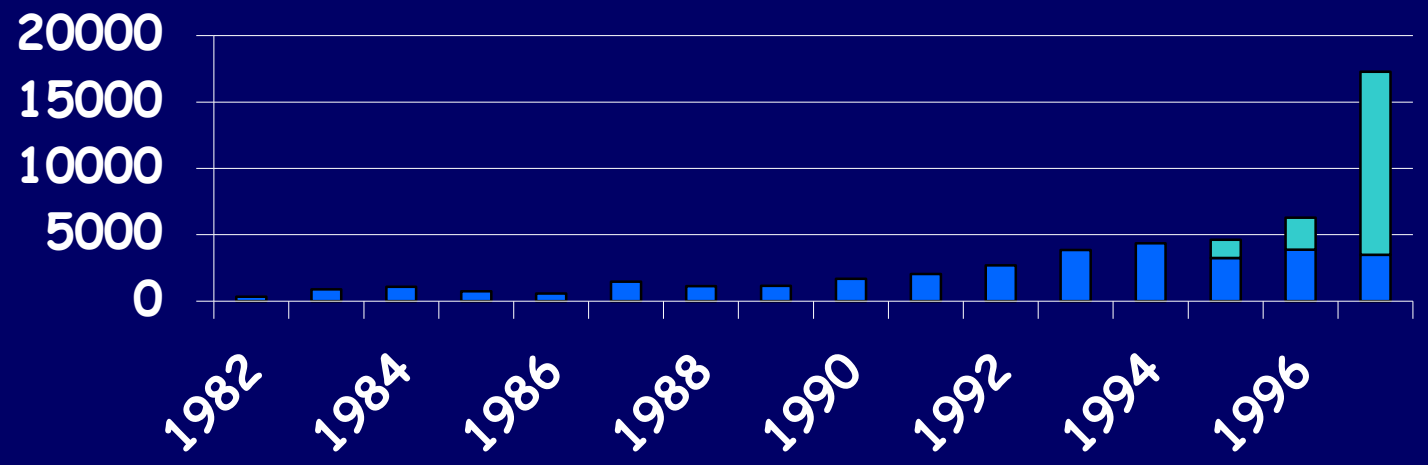
- Cross traffic in an Internet



2. Principles of Active Network Security

- Existing Internet is ad-hoc (& complex)
- AN complex in a different way, but leverages new design principles
  - Modern programming languages for safety
  - Extensive use of cryptography
  - Conscious of resource control & QoS
  - Safe, rapid adaptation to change

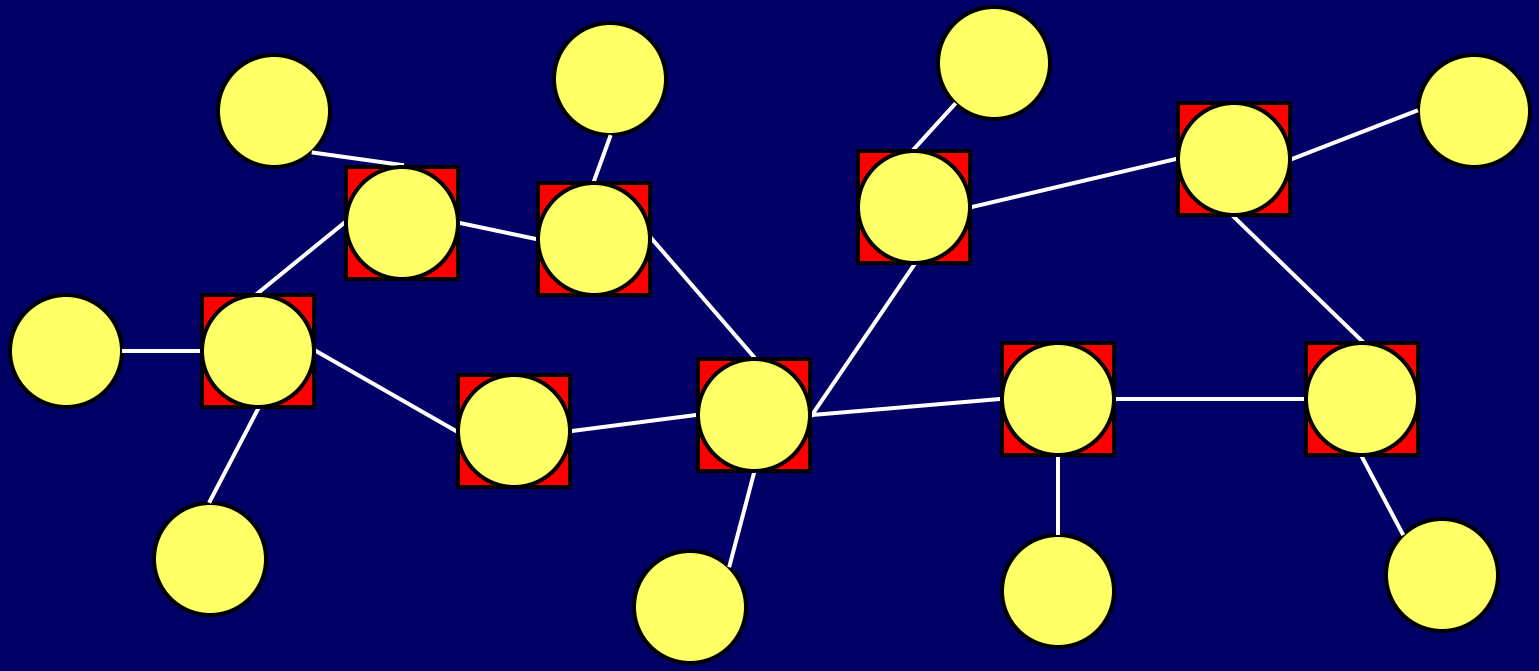
Complexity: RFC Pages '82-'97



- Draft pages overlaid since 1995
- log(f(pages,year))>log(f(users,year))?

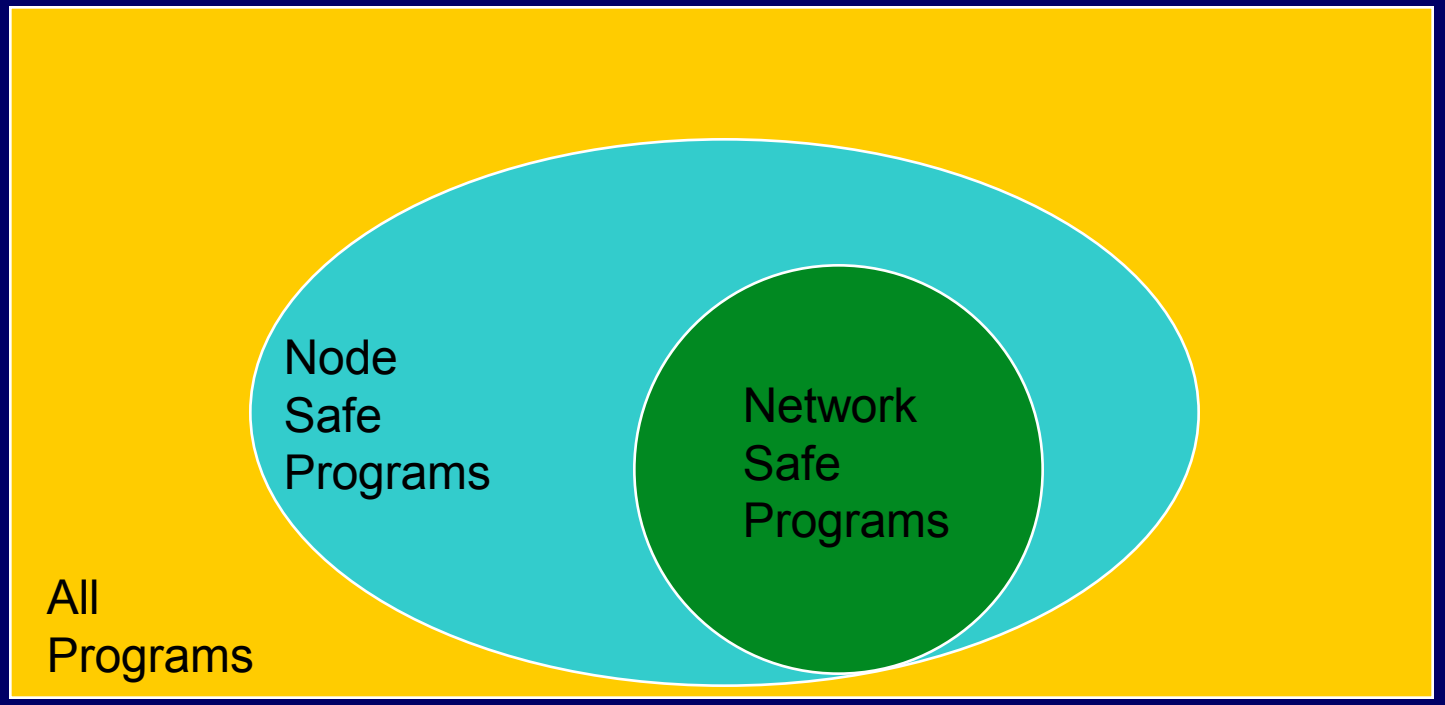
Active Network Model

- Packets can change the behavior of the switches "on-the-fly"
  - In-band active packets
  - Out-of-band active extensions



Restricting Programs

- Node safe versus network safe



Observations

- Code is either untrusted or trusted
- If untrusted, mechanisms must defend against misuse
- Alternative is to make trusted, e.g., by trusted compilation with restrictions
- Untrusted requires heavywight mech.

  Example – OS, *e.g.,* Cambridge Xenoserver

Principles

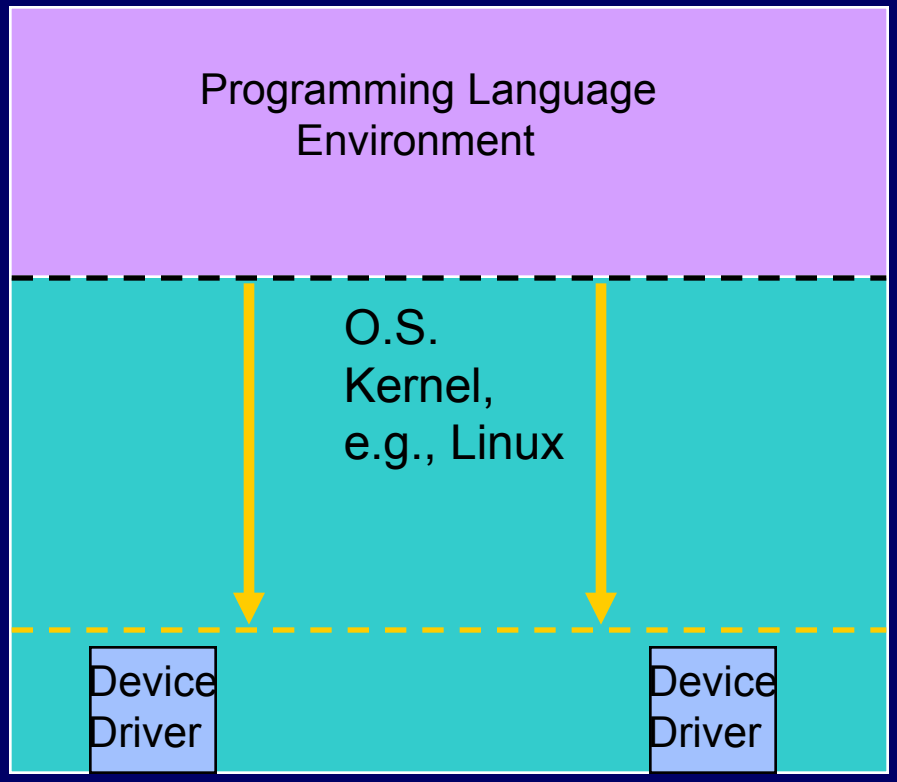
- Network safety without node safety hard
- Node guarantees can extend to net
- Distributed state hard to model, particularly at compilation time
- Cryptography is *not* security
- Resource management limited to layers under control (e.g., bridge for layer 2)

3. Protection

- What must be protected in a network?
- Bandwidth resources
- Memory resources
- CPU / computational resources
- Static versus dynamic protection
- Location of protection in architecture

How do we control programs?

- Safety & Security: P.L., O.S. or hybrid?



3.1 Languages / Programming

- ANTS
- ALIEN
- PLAN
- SNAP
- Language Independent Approaches

ANTS

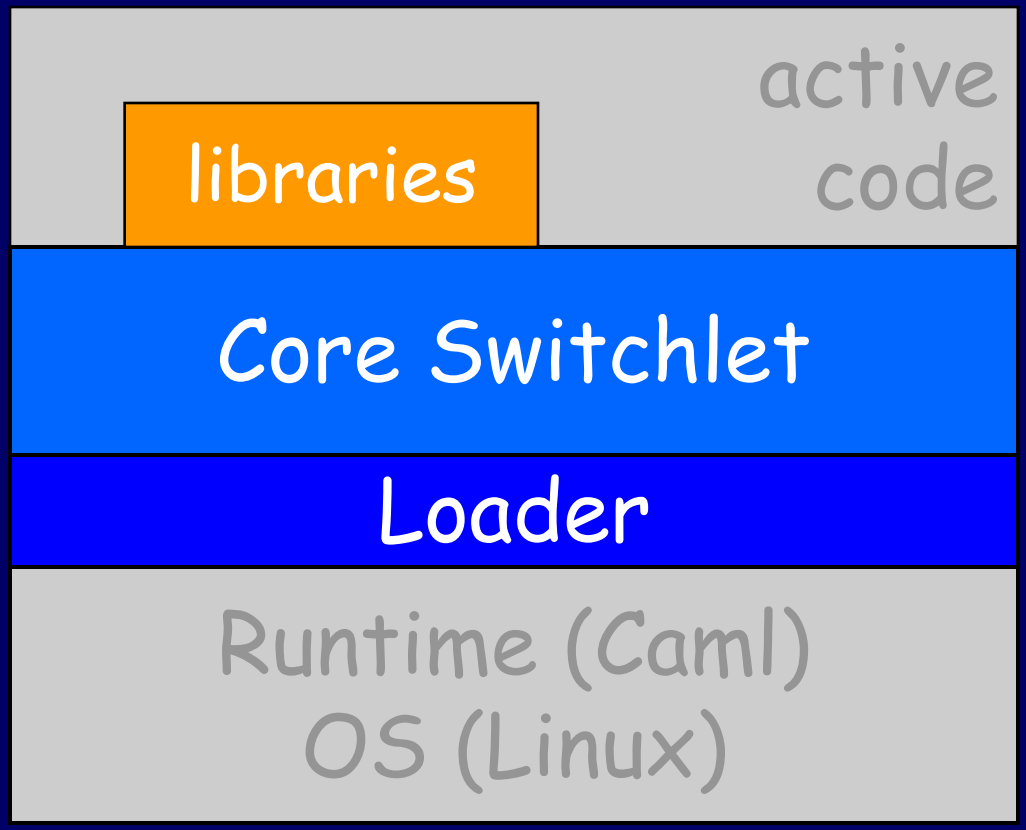
- Active Network Transport System
- See Weatherall paper in SOSP 99
- ANTS based on a Java platform
- Used for several applications such as Active Reliable Multicast (ARM)
- Security Model of Namespace Isolation
- Achieved with MD5 hash of module

The ALIEN Active Loader

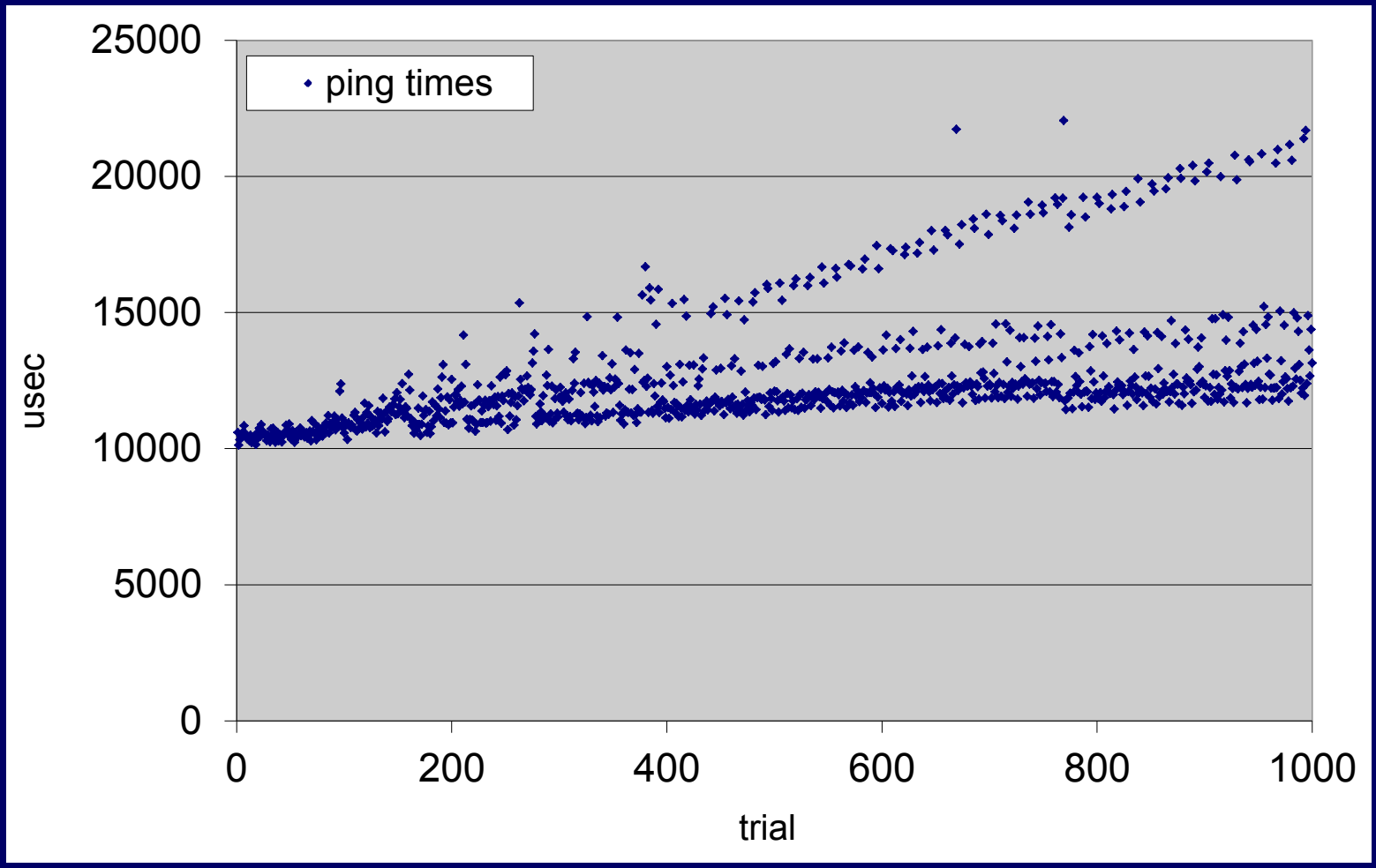
- See Alexander IWAN 99
- Active extensions and packets in CAML
- Namespace isolation via module thinning
- Only privileged portions of the system can directly access shared resources
- Digital signatures for remote accesses
  - Resembles a capability model

ALIEN in an Active Element

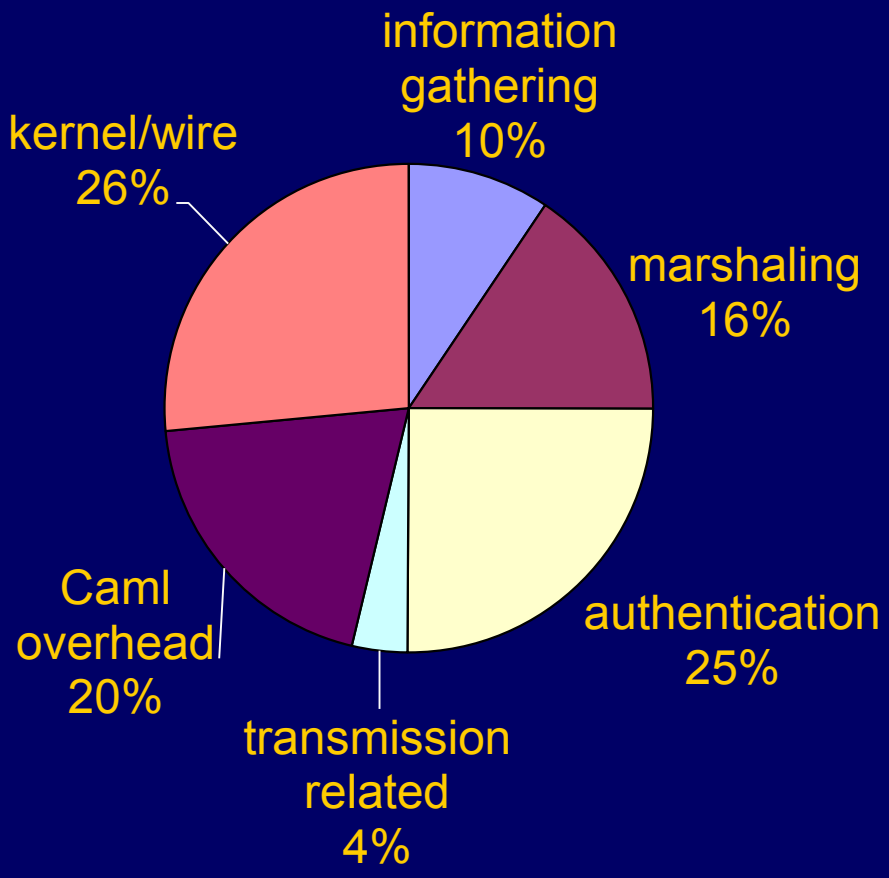
- Three layer architecture



saneping Performance



Overall Breakdown of Costs



Major Costs

- Kernel/Wire (26%, 3078 μs)
  - Kernel time + transmission time
  - To avoid
    - Reduce size of packet
    - Reduce or avoid kernel boundary crossing cost
- Authentication (25%, 2910 μs)
  - Mostly cost of performing SHA-1 (4 times)

Cryptography is Expensive

- Implemented in C because too slow in Caml
- Times to hash 4MB of data

	bytecode	native
Caml Int32	86.45s	61.99s
Caml int	36.03s	2.48s
C		0.33s

The take-home lesson:

- Must reduce per-packet crypto costs:
  - Active extension amortizes costs
  - ANTS caching amortizes costs
  - Smaller packets (Dense CISC, a la BBN)
- Or, find another way to avoid crypto in the common case…

Packet Language for Active Networks (PLAN)

- Hicks, Kakkar, Moore, Gunter, Nettles
- Capsule-based approach
- CAML runtime
- Highly-restricted domain specific language (a safe "glue" language, like the UNIX shell), extensible via ALIEN
- Active extensions do restricted things

Safe and Nimble Active Packets

http://www.cis.upenn.edu/~switchware/SNAP

- Build on first-generation successes
  - Notably, PLAN/PLANet
- Address open issues of
  - Resource safety
  - Performance
- SNAP adds flexibility over IP without sacrificing safety or efficiency

SNAP Language Design

- Stack-based bytecode VM
- SNAP instructions
  - Simple computation, environment query, control flow, packet sends
- Resource safety via language design
  - Execute in constant time and space
  - All branches go forward

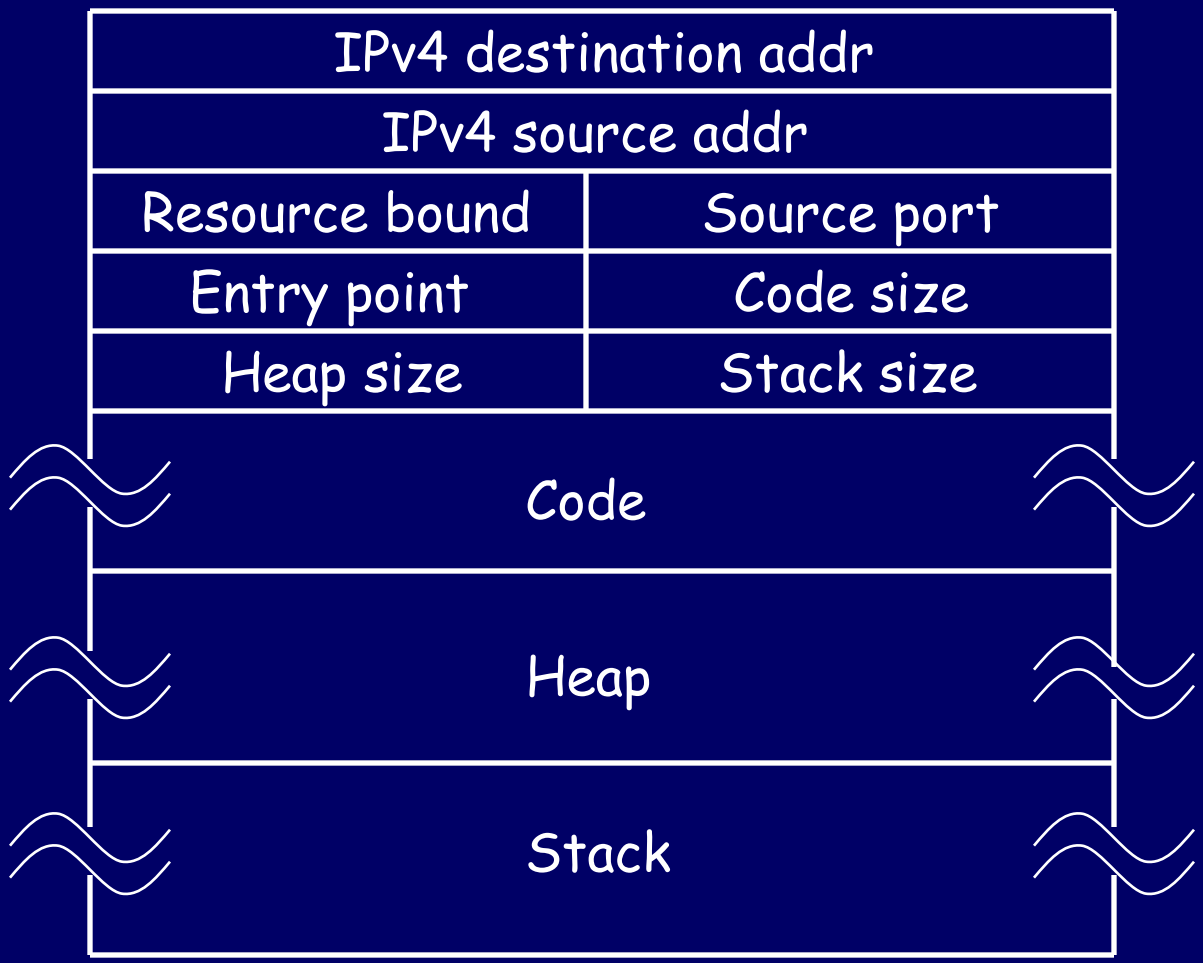
Safety and Security

- Node integrity
- Isolation
- Resource safety
  - TTL-like resource bound
  - Linear CPU and memory usage
  - *A priori* guarantees

Compilation techniques

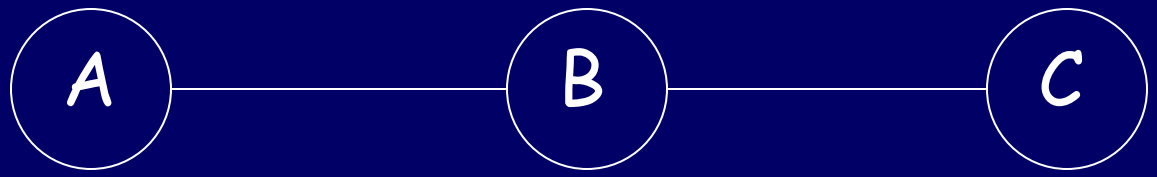
- SNAP: no backward branches!
- Function inlining
- Loop unrolling
  - User provides upper bound
  - Generally few iterations anyway
- Code size issues
  - Most PLAN programs very simple
  - Resource use tied to access bandwidth

Packet format



Example: SNAP ping

```
forw        ; move on if not at dest
bne  5      ; jump 5 instrs if nonzero on top
push 1      ; 1 means "on return trip"
getsrc      ; get source field
forwto      ; send return packet
pop         ; pop the 1 for local ping
demux       ; deliver payload
```



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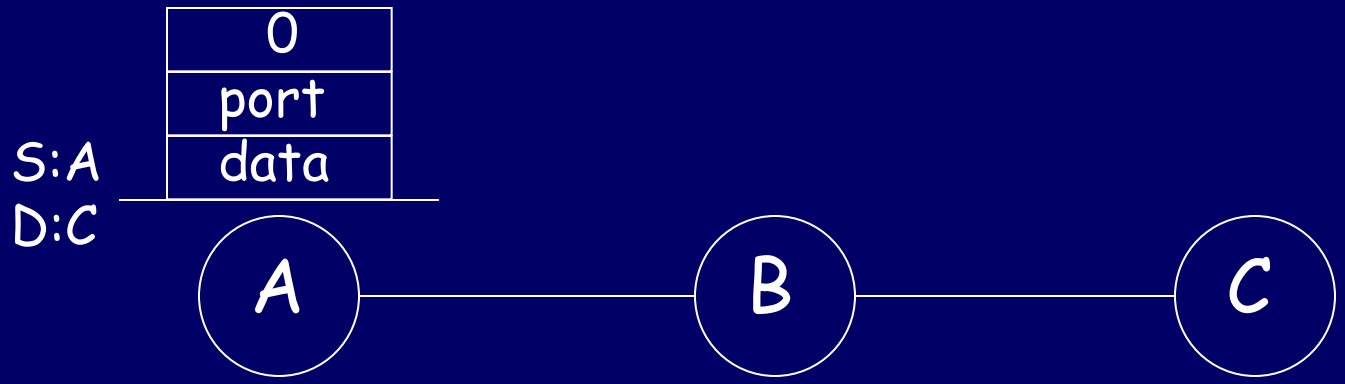

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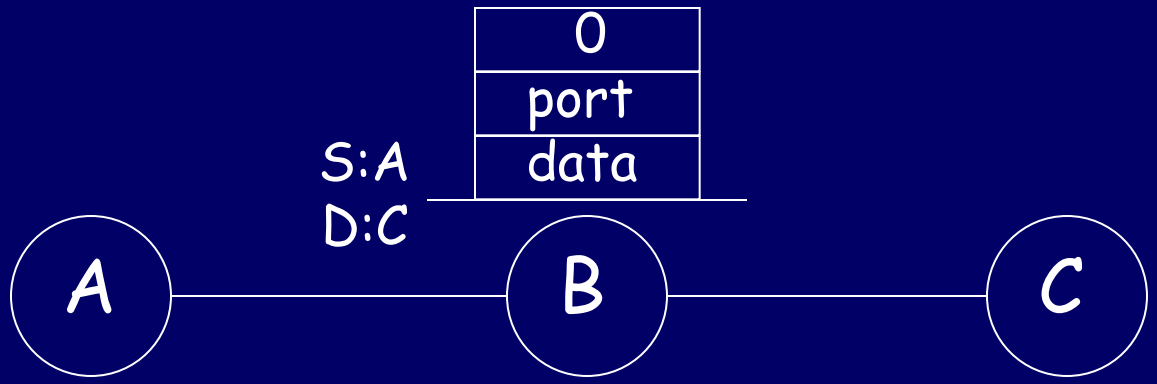

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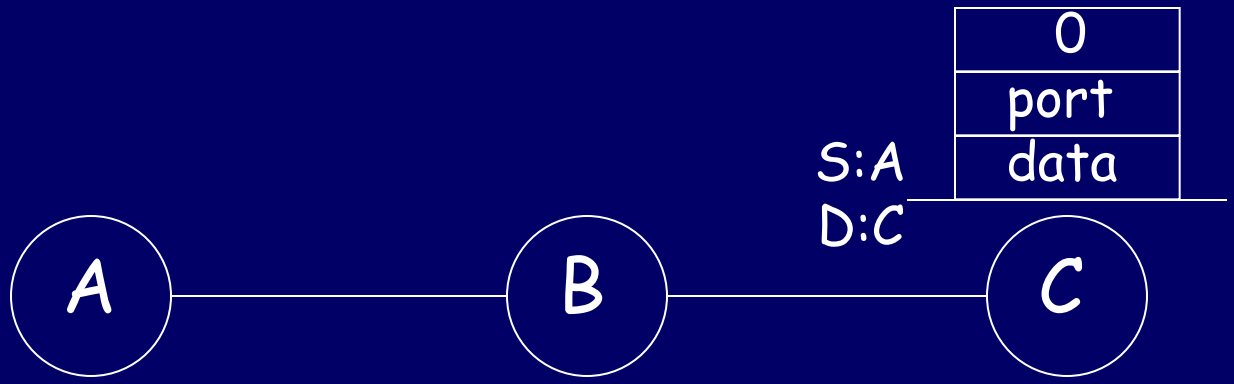

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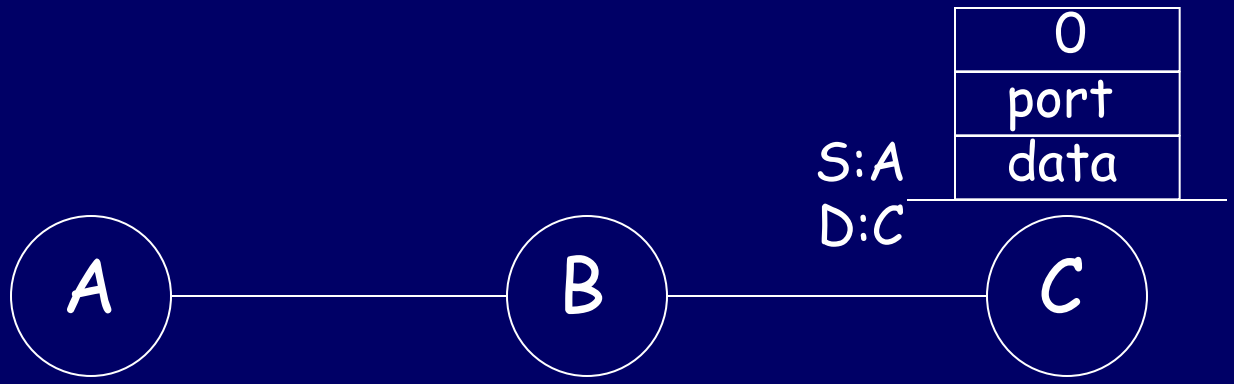

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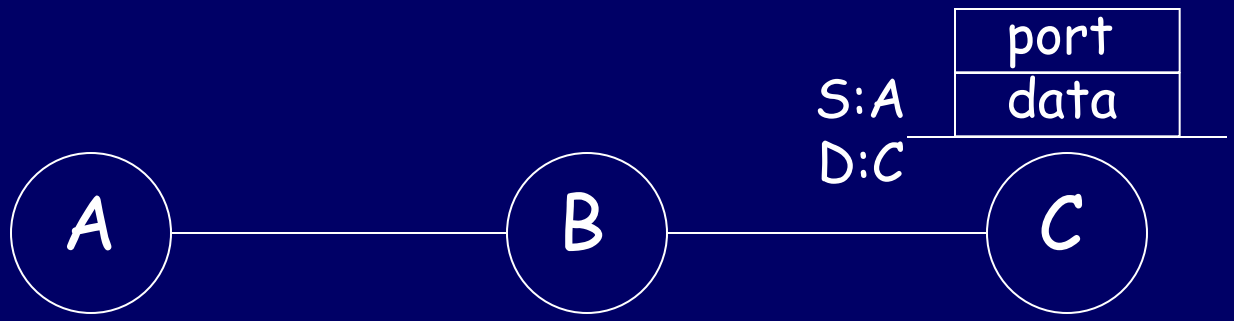

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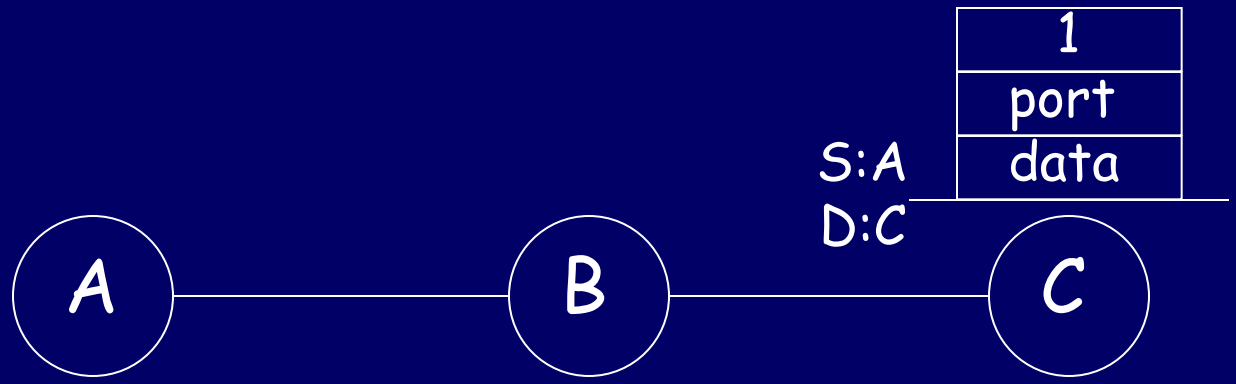

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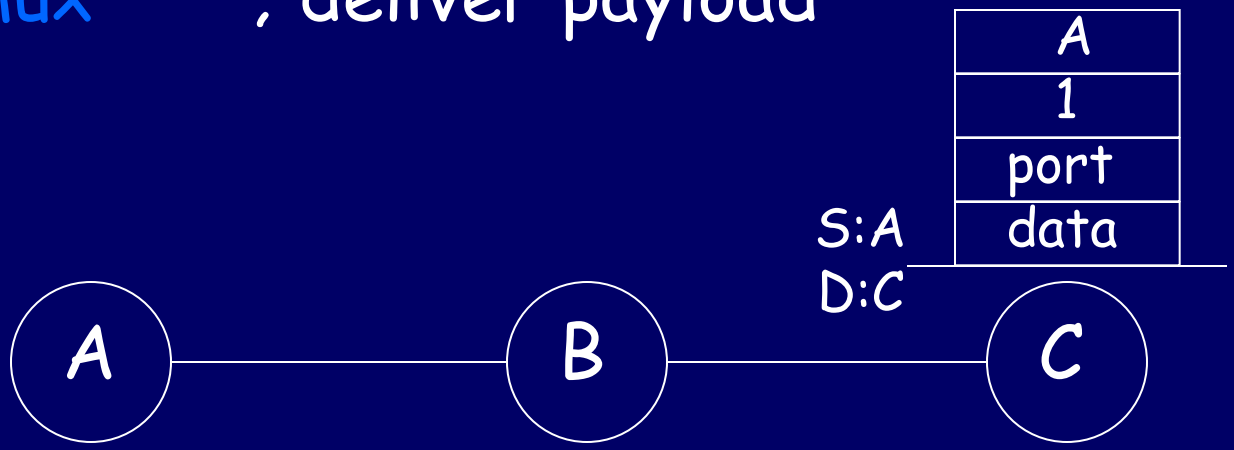

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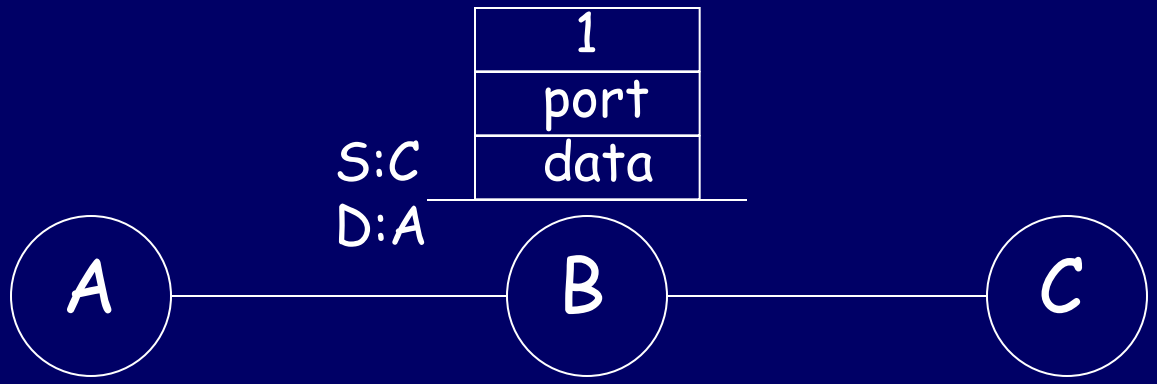

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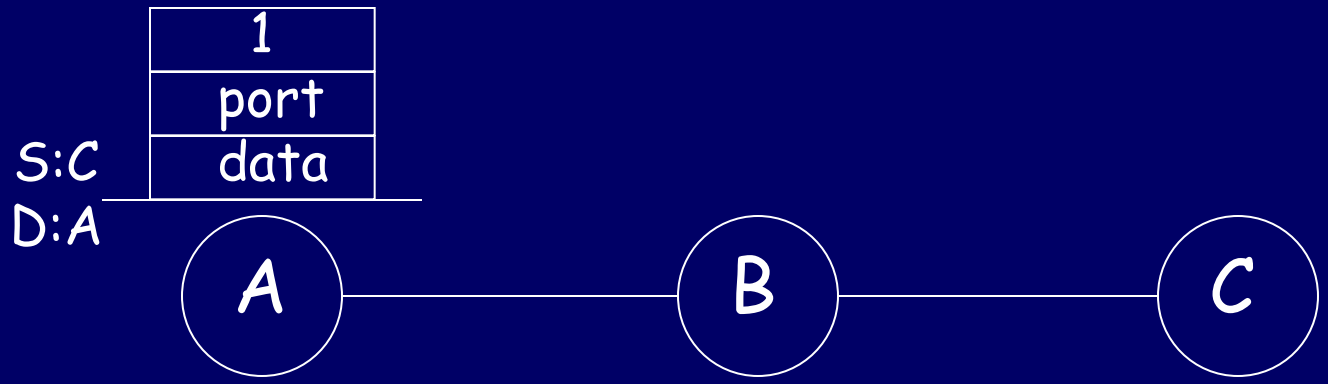

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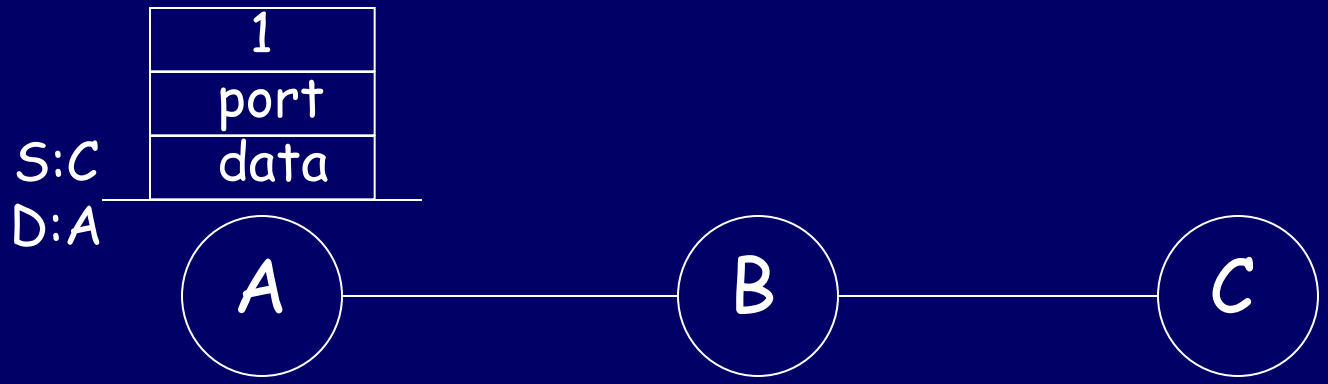

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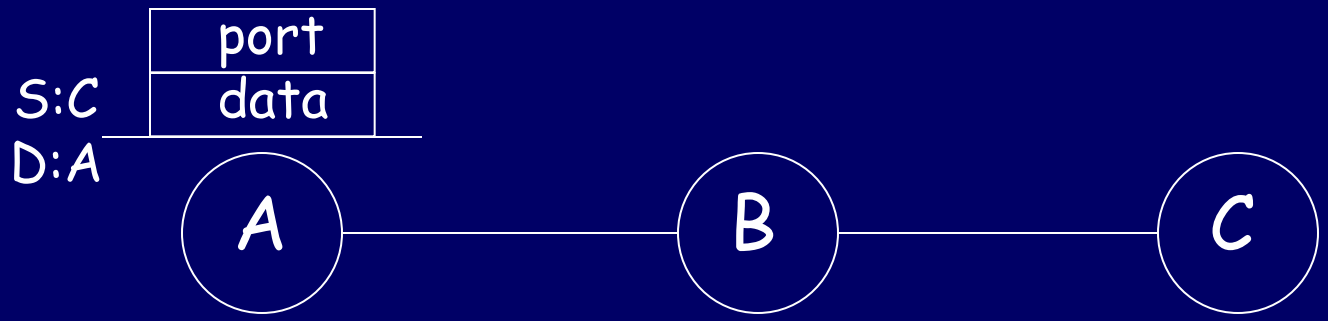

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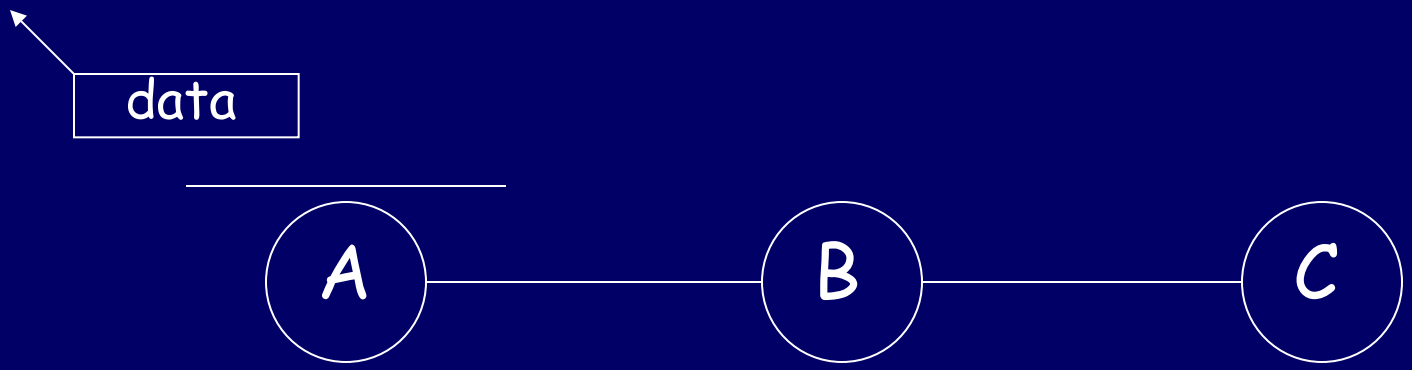


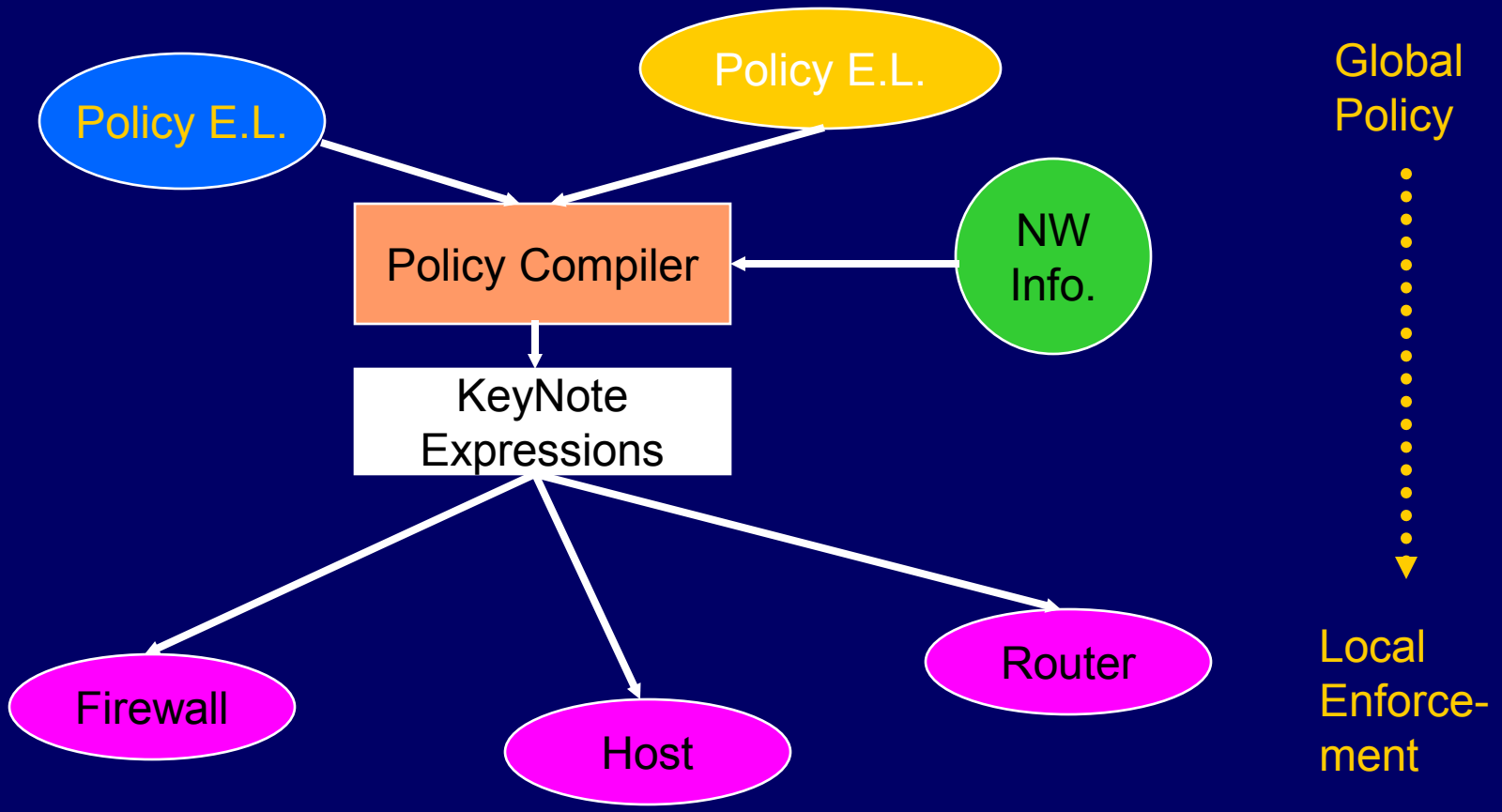
SNAP Contributions

- Provable resource safety
  - Linear resource usage
  - Guaranteed via language restrictions
- Retains flexibility of previous systems
- Performance comparable to an IP software router

Language Independent Approaches

- Proof-carrying code – a major idea
  - Program (mobile code) carries with it a proof of correctness
  - Much easier to verify proof than to perform proof
- Code-signing
  - Challenge with code signing is trust management

STRONGMAN Architecture



STRONGMAN

- Penn / AT&T Research
- Logical "meta-KeyNote"
- High-level *policy* compiles to KeyNote
- Policy-based configuration of *groups* of security endpoints (firewalls, hosts, routers, …)
- Multiple *policy expression languages* compile to common KeyNote policy model

Describing Actions in KeyNote

- <Attribute,Value> **Action Environment**

  $filename "/home/stan/foo"
  $owner "stan"
  $hostname "lake.sp.co.us"

- Attribute semantics application-specific
- An Action always associated w/Requestor

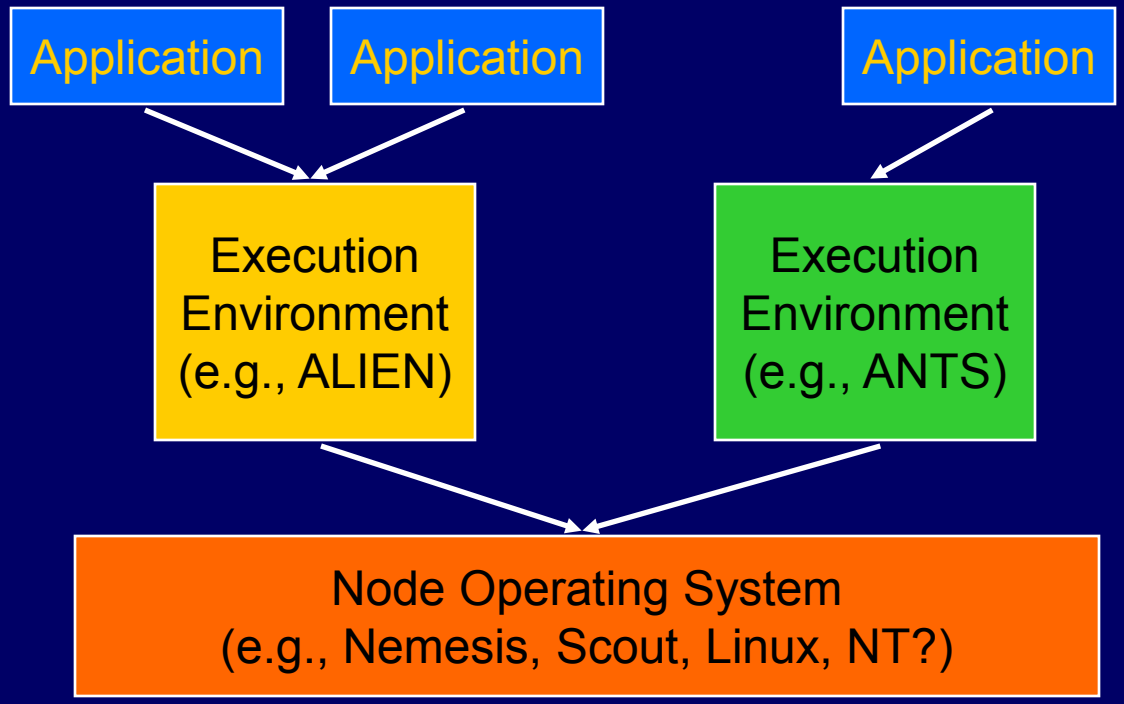
KeyNote Example

- Authorizer: *stan's public key*
- Licensees: *wendy's public key*
- Conditions: $file_owner == "stan"
  && $filename ~= "/home/stan/[^/]*"
  -> "true";
- Signature: stan's signature

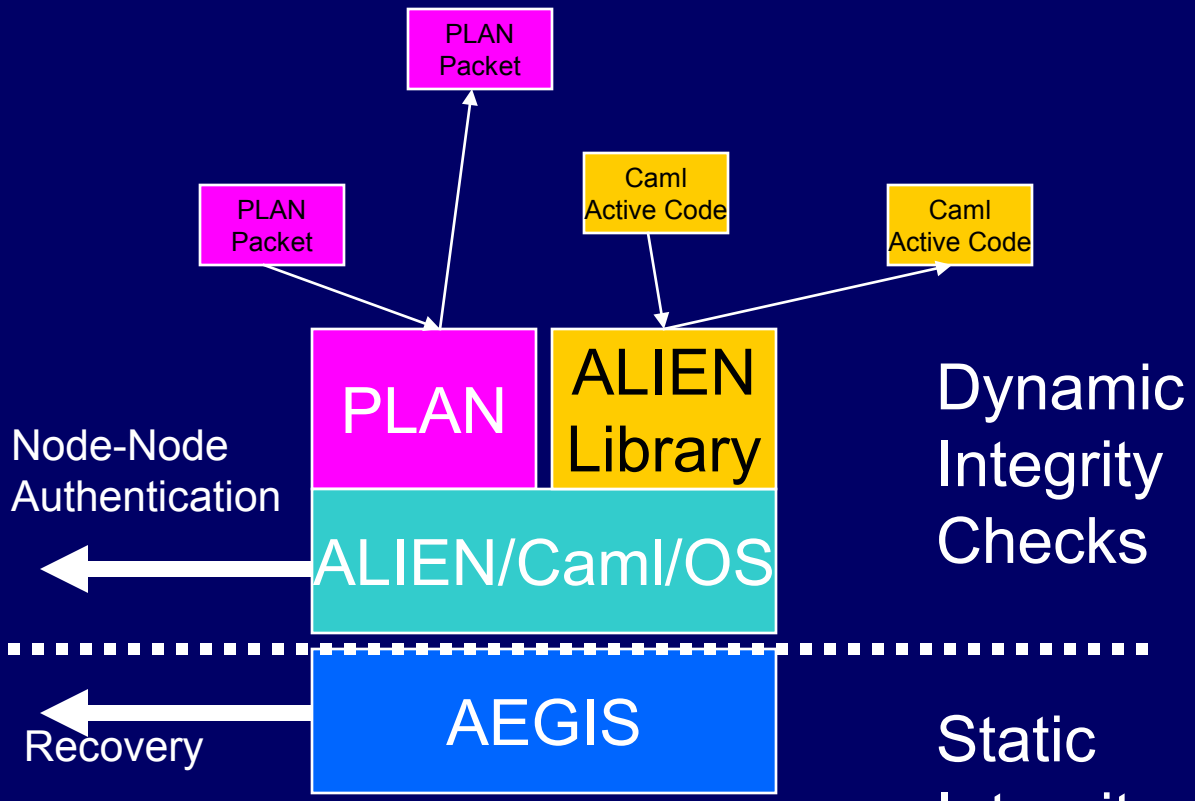
3.2 Node Architecture

- A Standard Architecture has been defined by DARPA
- There are various places where security principles must be applied
- When consider entire node, must take NodeOS & hardware into account
- Several NodeOS: Scout, Janos, AMP (see Peterson, *et al.*, IEEE JSAC)

"Active Network Architecture"



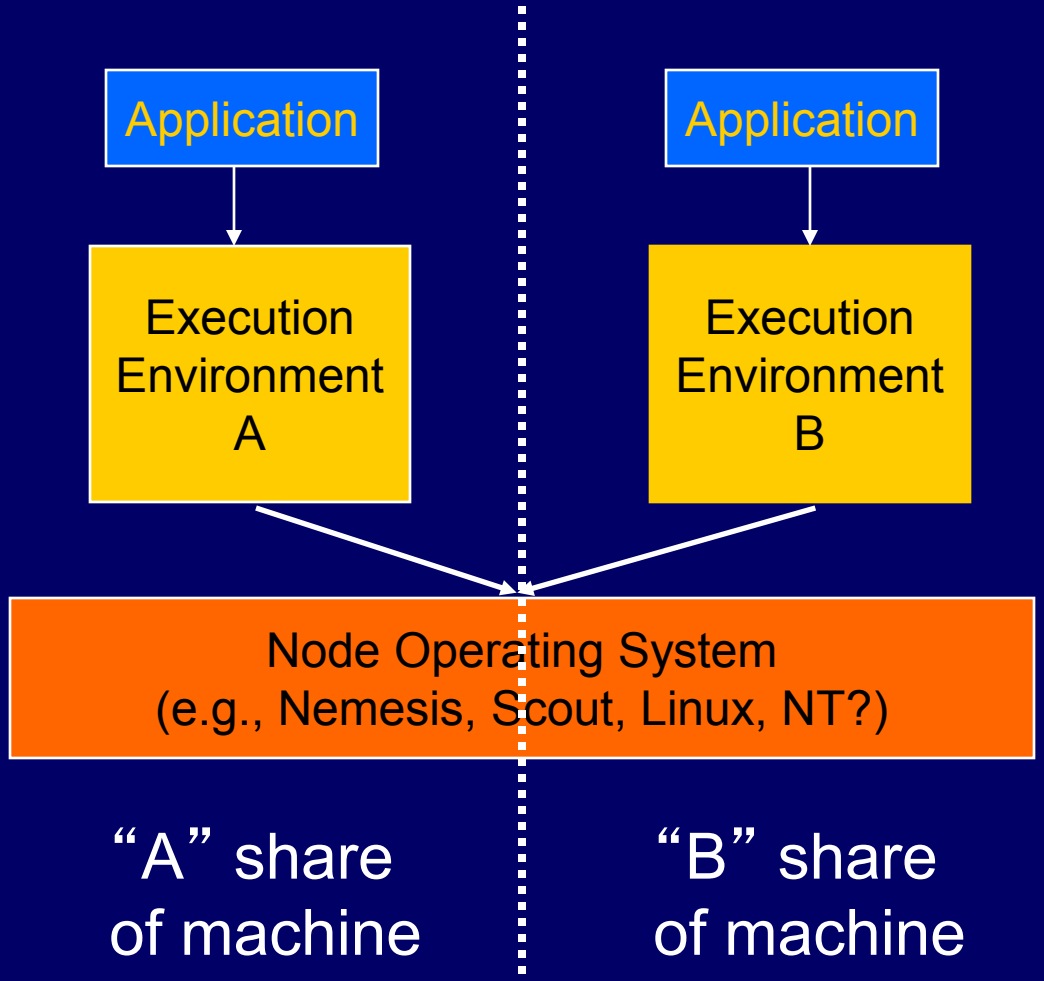
Example: SwitchWare Architecture



Resource Controlled Active Network Environment (RCANE)

- Manage CPU, Memory and Bandwidth
  - Challenge: Modern PL heaps (GC)
  - Challenge: Interrupts
  - Challenge: CPU/Mem/BW tradeoffs
- Approach
  - Nemesis for NodeOS + SwitchWare EE
  - See Menage, IWAN 99, Alexander, *et al.*, JCN, March 2001.

RCANE Vertical Architecture:

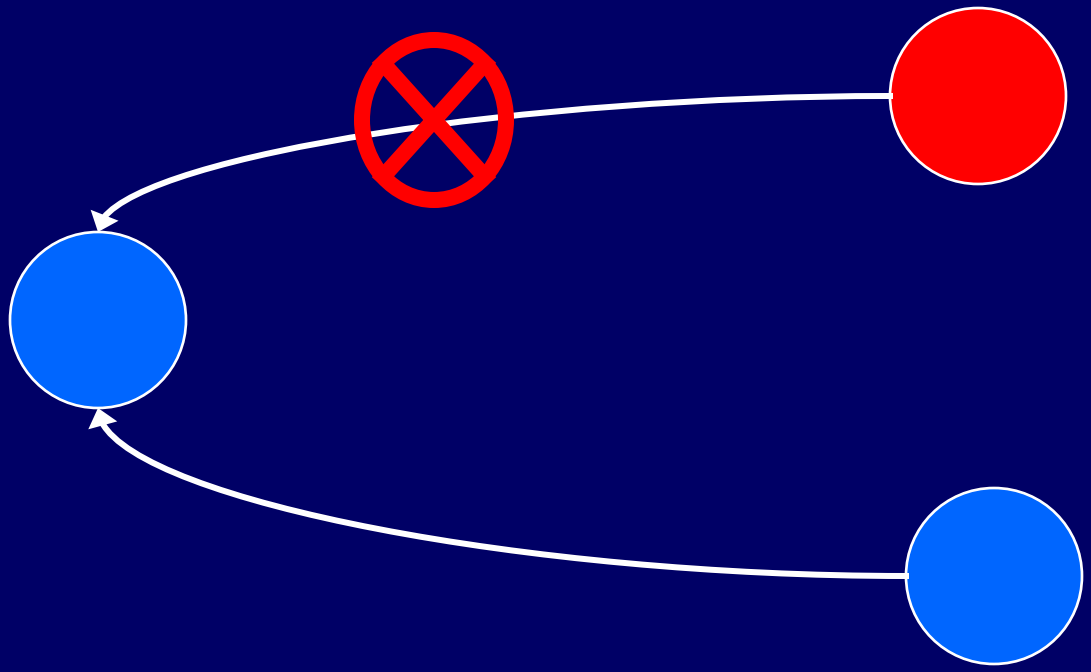


3.3 Network Based

- Nodes are interconnected to form the network
- Likely to interoperate nodes with conventional IP network devices, either as overlays or in management roles
- Distributed Resource Control rather than purely local, as in programming environment or in node

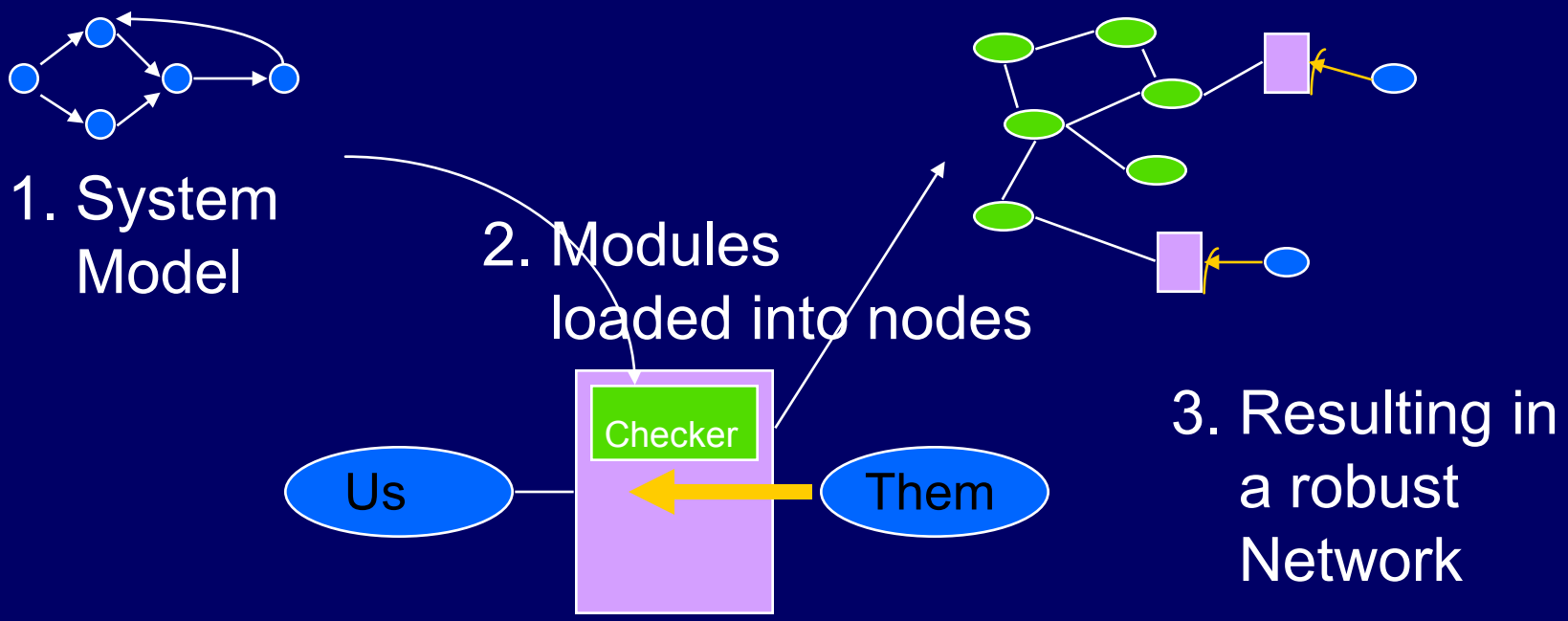
SANE Security Model

- Only process packets from trusted hosts

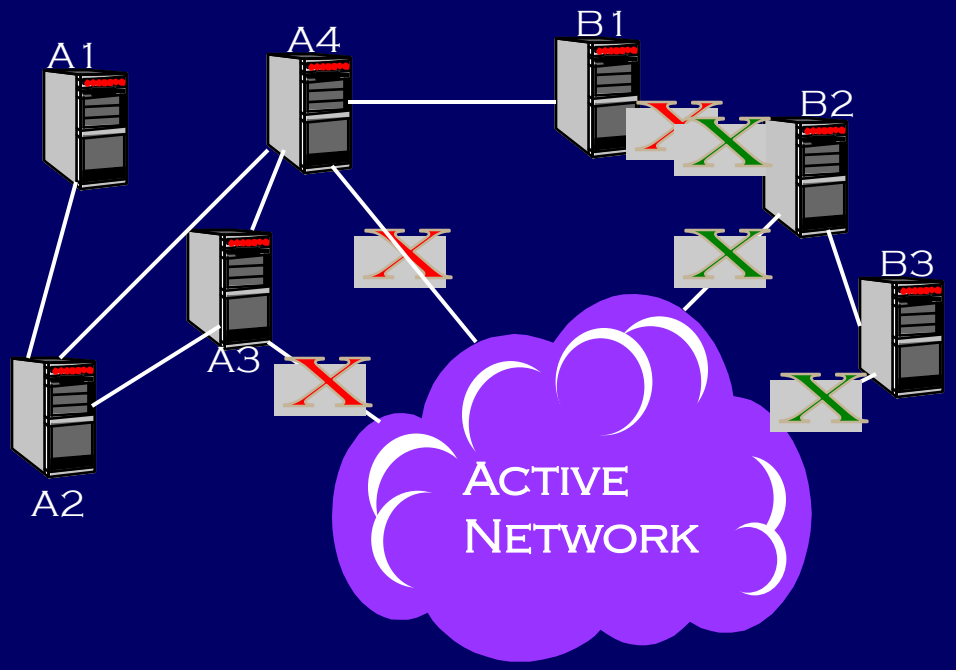


Model->Modules->Actions

- Syntax, Semantics, Node vs. Network
- Example: Securing a Network



Mutually Suspicious Nodes



- Nodes Authenticate their Neighbors
- Establish Trust Relations with Peers (PolicyMaker)
- Use Trust Relations to Solve Existing Problems (eg. Routing)
- Optimize Authentication

Node to Node Authentication

- Once at Boot Time, Periodically Thereafter (Crypto "heartbeat")
- Modified Station-to-Station Protocol (Well Known and Understood)
- Key Can be Used to Authenticate on a Hop-by-Hop Basis, Encrypt Sensitive Information
- Make Traffic Analysis Hard

4. Applications

- Firewalls
- Active Queue Management (AQM)
- FIRE
- Packet Marking
- Hash-Based IP Traceback

4.1 Firewalls

- Preceded organized A.N. effort
- Response to flaw in Internet scheme
- End-to-end argument results in network security dependent on hosts
- Hosts are insecure, ergo, net insecure
- Example: DDoS sources

Why a firewall is an A.N.

- Consists of filtering rules – see, e.g., the Berkeley Packet Filter (BPF) of McCanne and Jacobson
- These rules are composed of pattern/action pairs – e.g., IP source + destination address and port numbers, with actions such as drop, pass and log
- The programming is *event-driven*, in the style of PLs such as awk. Safe because limited.

Advanced Firewalls and A.N.

- Firewall technology widely used
- Would like "learning" for rule DB, action set
- Example: Intrusion Detection Systems (IDS) are string-matchers and event loggers
- Connect IDS to firewall policy for greater dynamics

Firewall Management

- Common policies needed at multiple firewalls
- One approach is careful manual configuration
  - Not scalable

4.2 Active Queue Management

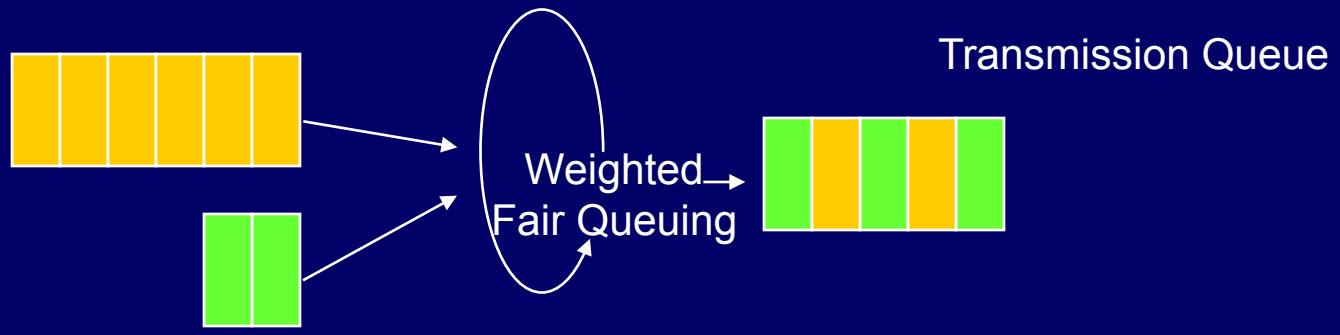
- Challenge of edge-provided congestion control – all edges must "play nice"
- Evil TCPs, or UDP lead to a problem
- Thus, network-embedded solutions have appeared as an attempt to solve these problems – called AQM in IP world
- Floyd and Jacobson RED, BLUE
- Stoica Core-Stateless Fair Queuing

Basic idea of AQM

- Packets assigned to queues in node
- When queue lengths hit "high water" mark, packets begin to be dropped
- Dropped at random location in queue
- Fairness, as "hogs" will be over-represented in queue
- Jeffay, *et al.* suggest tuning tough in SIGCOMM 2000 paper

Piecewise A.N. Node Solution: Loadable "Queue Management"

- Discriminates between "flows"
- Separate queue for each current flow
- Queues are serviced WFQ
- Control via RSVP, QoS Broker, etc.



4.3 FIRE

- Flexible Intra-AS Routing Environment
- Partridge, *at al.*, SIGCOMM 2000
- Link-State Intra-Domain Protocol
- Run-time reprogrammability
  - Information advertised
  - Routing Algorithms (by traffic class!)
  - All done in Java
- Can think of as an Active BGP

4.4 Packet Marking

- Savage, *et al.* paper in SIGCOMM 2000
- Approach to dealing with Denial of Service Attacks
- Basic idea is to (statistically) mark packets that go by

Probabilistic Packet Marking

- Routers periodically mark packets with their ID
- Only mark if packet not already marked
- Infrequent, since "slow path"
- Prob(mark)*#packets large with DOS
- Can be used to locate DOS source
- Improved by Song, Perrig in Infocom 01

4.5 Hash-Based IP Traceback

- Snoeren, *et al.*, SIGCOMM 2001
- Identifies originator of IP packet
- Generates audit trails within the network
- Routers enhanced with Source Path Isolation Engine – SPIE
- SPIEs contain packet digests

5. Summary

- Security of Active Networks themselves
- Use of AN techniques to secure IP nets
- Use of AN techniques to build more secure networks of all types

Security of Active Networks

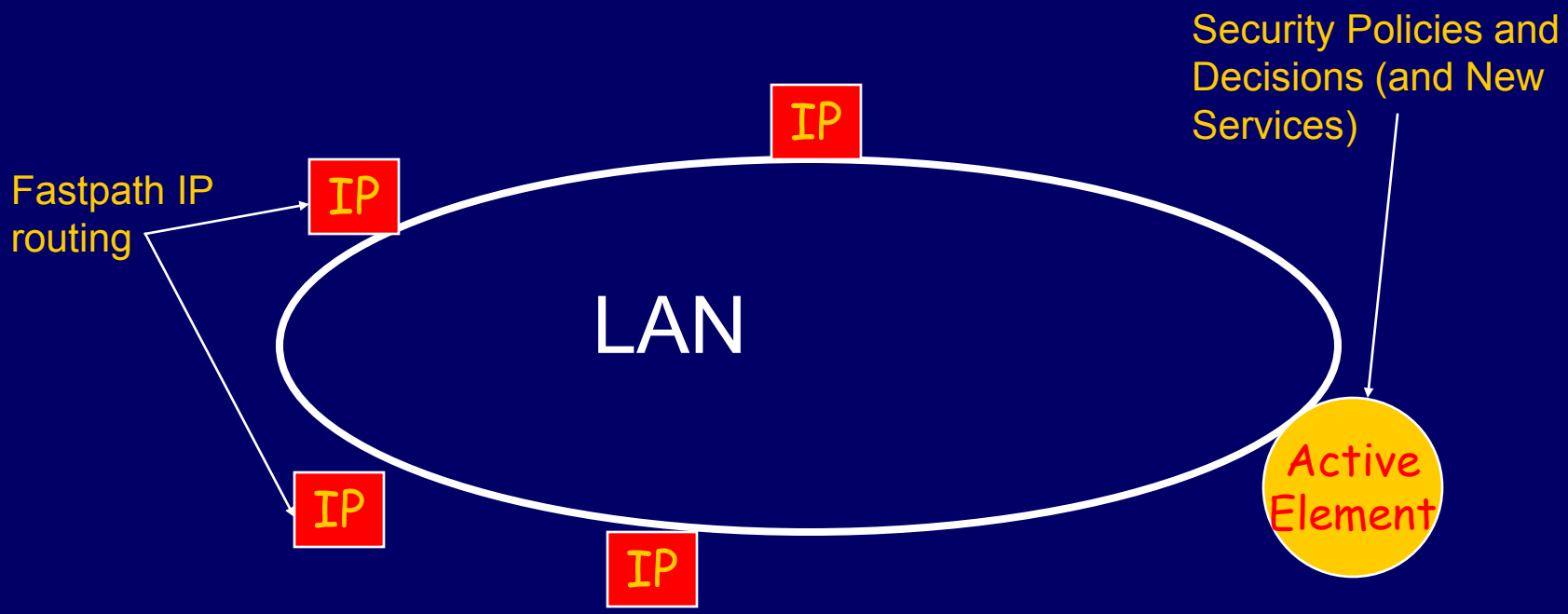
- Languages and Node Architectures show secure nodes can be built, for both active extensions and active packets (Alien, PLAN, SNAP, ANTS)
- Cryptography extends many node protections to networked uses
- Resources can be managed at both node and network levels – RCANE, NodeOS

Use of AN techniques to Secure IP networks

- Firewalls, NATs, more active follow-ons
- Programmable AQM (as with programmable BGP in FIRE)
- Packet Marking and IP-traceback techniques to locate attackers and attacks
- Active Router Control models

Active Router Control (e.g. FAIN)

- Routers co-located with Active Nodes



AN techniques for more secure networks of all types

- Begin to construct Internet overlays with provable properties such as SNAP resource bounds
- Many functions of "non A.N." devices are done in software (often see hacks of Cisco IOS in bugtraq)
- Migrate A.N. techniques into devices

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