OAM Functions: Error Reporting, Configuration, Management (ICMP, DHCP, NAT, SNMP)

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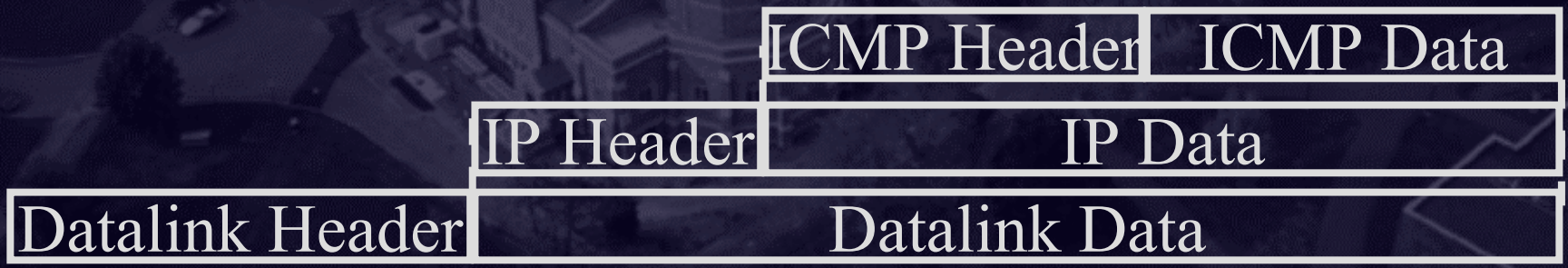
Based in part upon slides of Prof. Raj Jain (OSU), S.Deering (Cisco), C. Huitema (Microsoft)

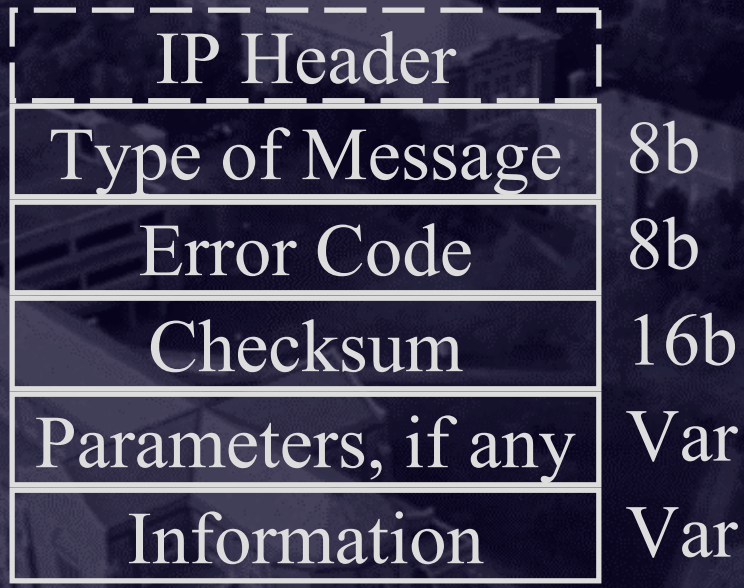
- Operations and Management (OAM)
- Error Reporting (ICMP); Tools: ping, traceroute
- Configuration: RARP, BOOTP, DHCP
- Address Management: DHCP, Private Addresses, NAT, RSIP
- Network Management: SNMP, RMON
- Ref: Chap 5,6,9,20,23,30: Doug Comer textbook, Interconnections by Perlman
- Reference Site: IETF NAT Working Group
- Reference: RFC 2663: IP Network Address Translator (NAT) Terminology and Considerations: In HTML
- **Reading:** RFC 3022: Traditional IP Network Address Translator (Traditional NAT):
- Reference: Borella et al, RFC 3102: Realm Specific IP: Framework, In HTML

ICMP Features

- Used by IP to send error and control messages
- Uses IP to send its messages
- Does not report errors on ICMP messages.
- ICMP message are not required on datagram checksum errors.
- ICMP reports error only on the first fragment



ICMP Message Format



- ICMP error messages normally include the IP header of the datagram that generated the error, plus at least 8 bytes following the IP header => Typical ICMP message sizes = 70 bytes

Sample ICMP Messages

- Echo Request/Reply: *Used in ping*
- Source Quench: Please slow down! I just dropped one of your datagrams.
  - Congestion control function: *deprecated*…
- Time Exceeded: Time to live field in one of your packets became zero." or "Reassembly timer expired at the destination.
- Fragmentation Required: Datagram was longer than MTU and "No Fragment bit" was set.
  - Used in *fragmentation/reassembly and path MTU detection*

Sample ICMP Messages (Continued)

- Address Mask Request/Reply: What is the subnet mask on this net? Replied by "Address mask agent"
- Redirect: Send to router X instead of me.
  - *Configuration functions… Redirect used. Mask config handled by BOOTP/DHCP.*
- Time Stamp Request/Reply: used to find current time or RTT.
  - Deprecated…

ICMP: Message Types Summary

Type	Message
0	Echo reply
3	Destination unreachable
4	Source quench
5	Redirect
8	Echo request
11	Time exceeded
12	Parameter unintelligible
13	Time-stamp request
14	Time-stamp reply
15	Information request
16	Information reply
17	Address mask request
18	Address mask reply

ICMP-based tools: *Ping*

- Ping: Used to test
  - destination reachability,
  - compute round trip time
  - count the # of hops to destination
  - may provide record route option.

- Ping failure does not guarantee unreachability. Firewalls may filter pings.

ICMP-based tools: *Traceroute*

- Traceroute: Exploit TTL and ICMP
  - Send the packet with time-to-live = 1 (hop)
  - The first router discards the packet and sends an ICMP "time-to-live exceeded message"
  - Send the packet with time-to-live = 2 (hops) etc…
  - Does not use optional features like record route

ICMP-based tools: *Path MTU Discovery*

- Send a large IP datagram with "Don't fragment" bit set.
  - Failure to fragment at a link will result in ICMP message.
  - Later version of ICMP specifies MTU size in such ICMP messages.
- Reduce MSS until success (No ICMP message received)

Configuration: Issues

- Configuration: give protocols the parameters they need to operate
- Several things to configure… Eg scenario:

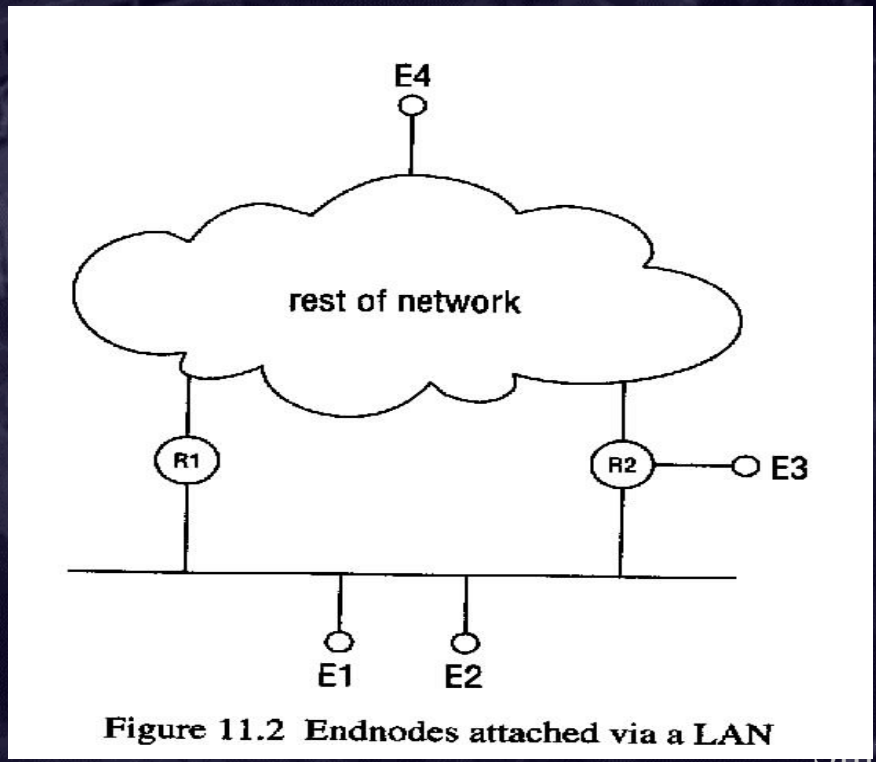


Figure 11.2 Endnodes attached via a LAN

7 Things to configure…

- 1. End systems need Layer 3 address, names, masks
- 2. Router finds Layer 3 addresses of end systems
- 3. Router finds Layer 2 addresses of end systems
- 4. End systems find a (default) router, name server
- 5. End nodes on the same LAN discover that they can send directly to each other
- 6. End systems find the best router for exit traffic
- 7. End systems communicate on a router-less LAN

- Typically end systems only know their hardware (IEEE 802) address…

Method 1: Reverse ARP (RARP)

- H/w (MAC) address -> IP address mapping
  - End system broadcasts RARP request…
  - RARP server responds.
  - Once IP address is obtained, use “tftp” to get a boot image. Extra transaction!
- RARP design complex:
  - RARP server is a user process and maintains table for multiple hosts (/etc/ethers). Contrast: no ARP server
  - RARP needs a unique Ethernet frame type (0x8035) & works through a special kernel-level filter
  - Multiple RARP servers needed for reliability
    - RARP servers cannot be consolidated since RARP requests are broadcast => router cannot forward
- After all this, you get only the L3 (IP) address

Method 2: BOOTP

- Runs over UDP/IP as a user process
  - IP software can broadcast (to 255.255.255.255) even if local IP address unknown => client broadcasts BOOTP request
  - Port number 67 for server and 68 for client (not an ephemeral port)
    - Delivers BOOTP reply to BOOTP client and not other UDP apps when reply is broadcast
    - Does not wake up other servers during broadcast reply

BOOTP (Continued)

- BOOTP requests/replies sent w/ DF bit set.
- Server can send reply via broadcast or unicast:
  - For unicast reply, BOOTP server knows the IP address, but the link layer address is not in the ARP cache
  - Note that the server cannot send an ARP message because client does not know its IP address
  - Server can use ioctl(8) {or arp -s } to set the value of the cache based upon BOOTP request => can do this only if it has permission

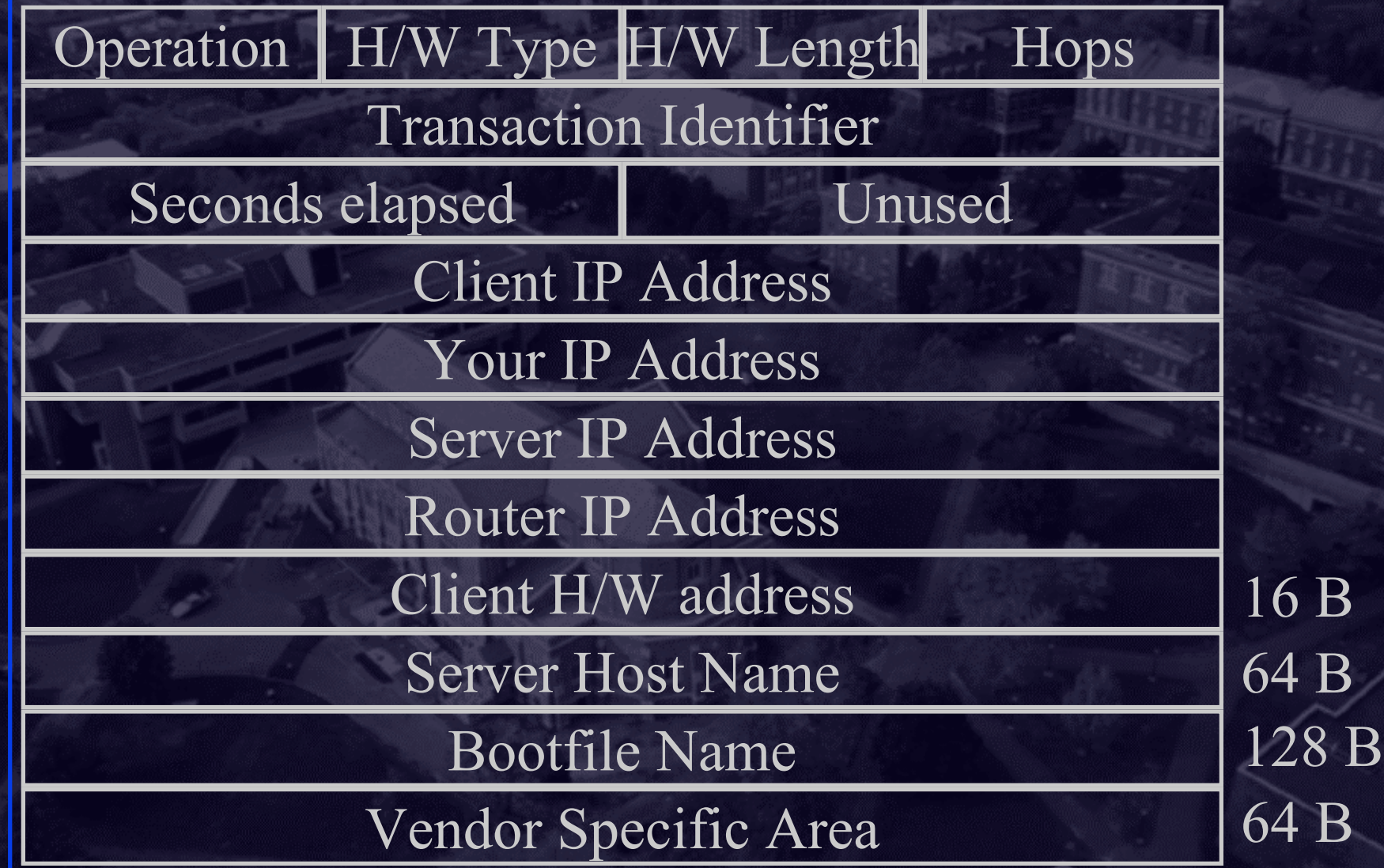
BOOTP Features (Continued)

- Else send broadcast reply
- Reply: IP Address, Boot Server IP address, Default Router, Boot file name, subnet mask
  - More information, but still only a single packet exchange
  - Client gets boot image using TFTP => booting still a 2-step process

BOOTP features (Continued)

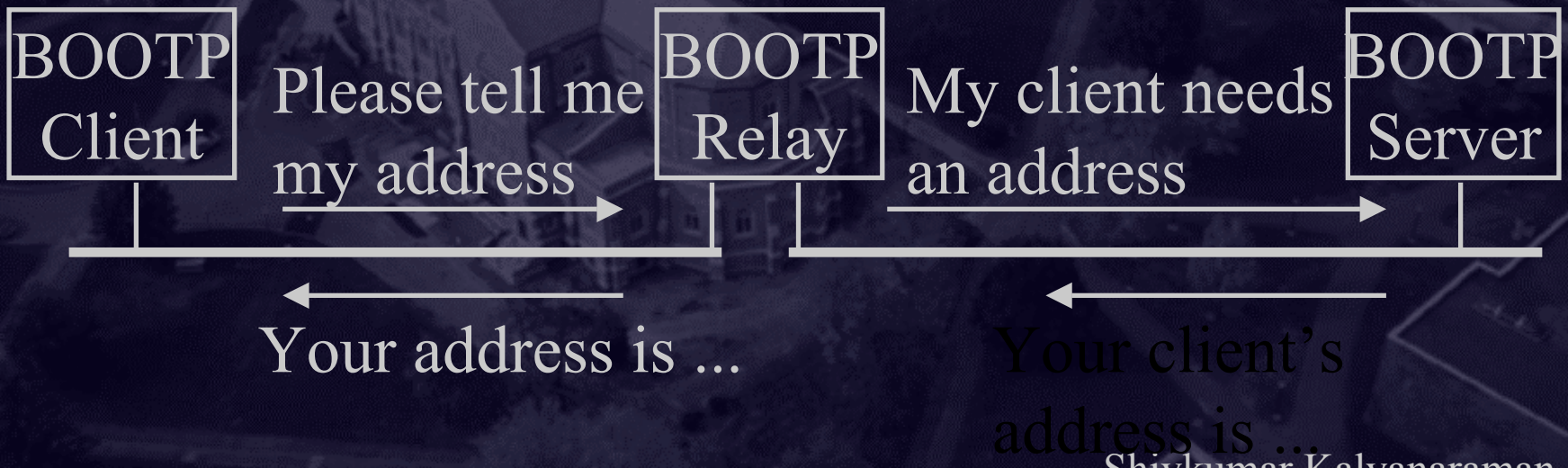
- Advantages of using UDP/IP:
  - Bootstrapping can occur across a router via a relaying mechanism
  - BOOTP uses checksum provided by UDP
- Multiple requests/replies
  - Process the first one
  - Client uses a transaction ID field to sort out replies
- Clients responsible for reliability
  - Uses timeout, retransmission & exponential backoff
  - Random initial timeout (betn 0 & 4s): simultaneous reboot after power restoration.

BOOTP Message Format



BOOTP Message (Continued)

- Operation: 1 = Request, 2 = Reply
- H/w type: 1 = Ethernet
- H/w Address Length
- Hops: Initialized to zero. Incremented by BOOTP relays (routers)



BOOTP Message

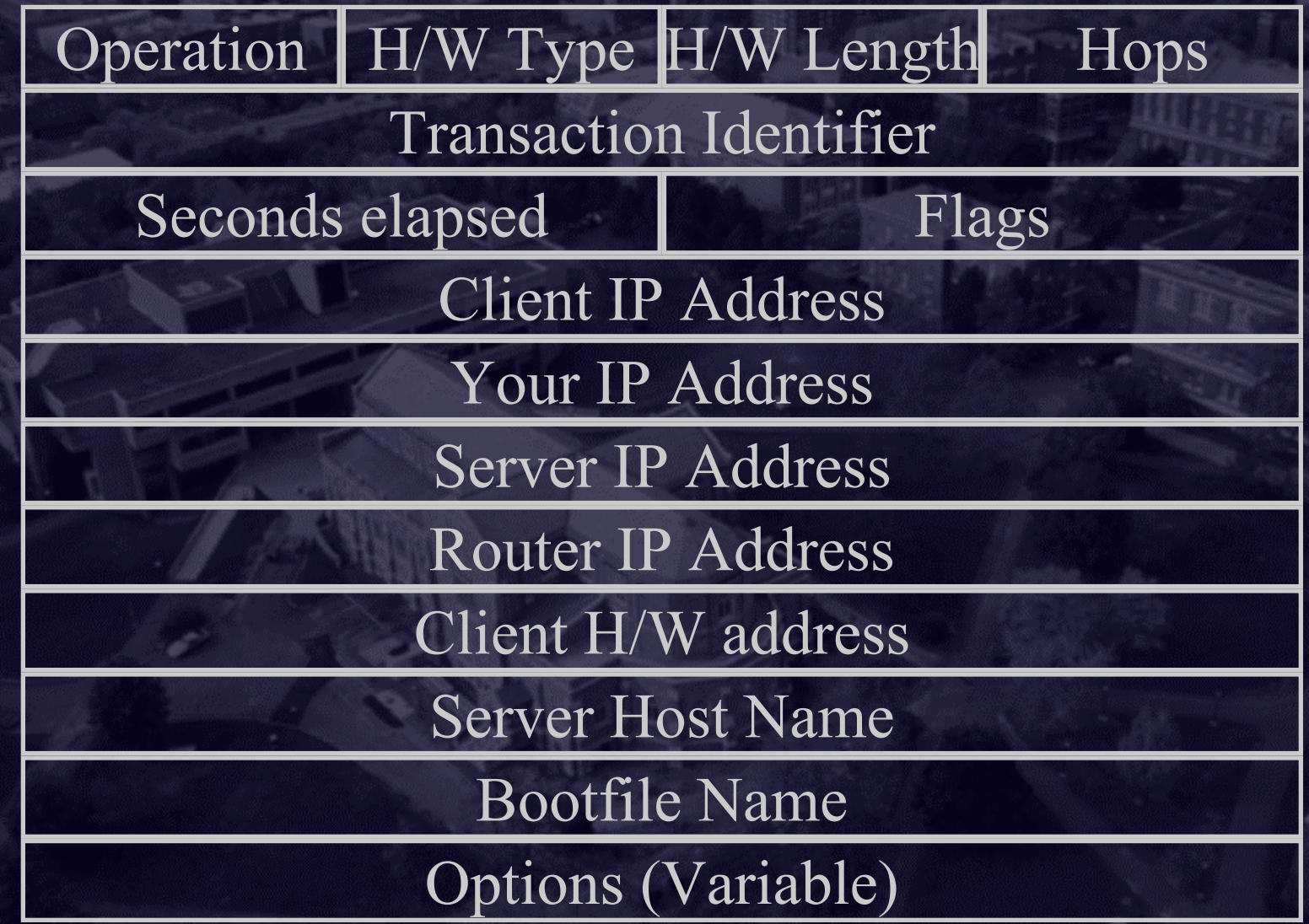
- Boot File name: Generic name like "unix" in the request. Full name in response.
- Vendor specific area: Misnomer. Also used for general purpose info.
  - Magic cookie: First 4 octets = 99.130.83.99
  - Type-length-value: describes the option

Item	Code	Length
Padding	0	-
Subnet mask	1	4
Time of Day	2	4
End	255	-

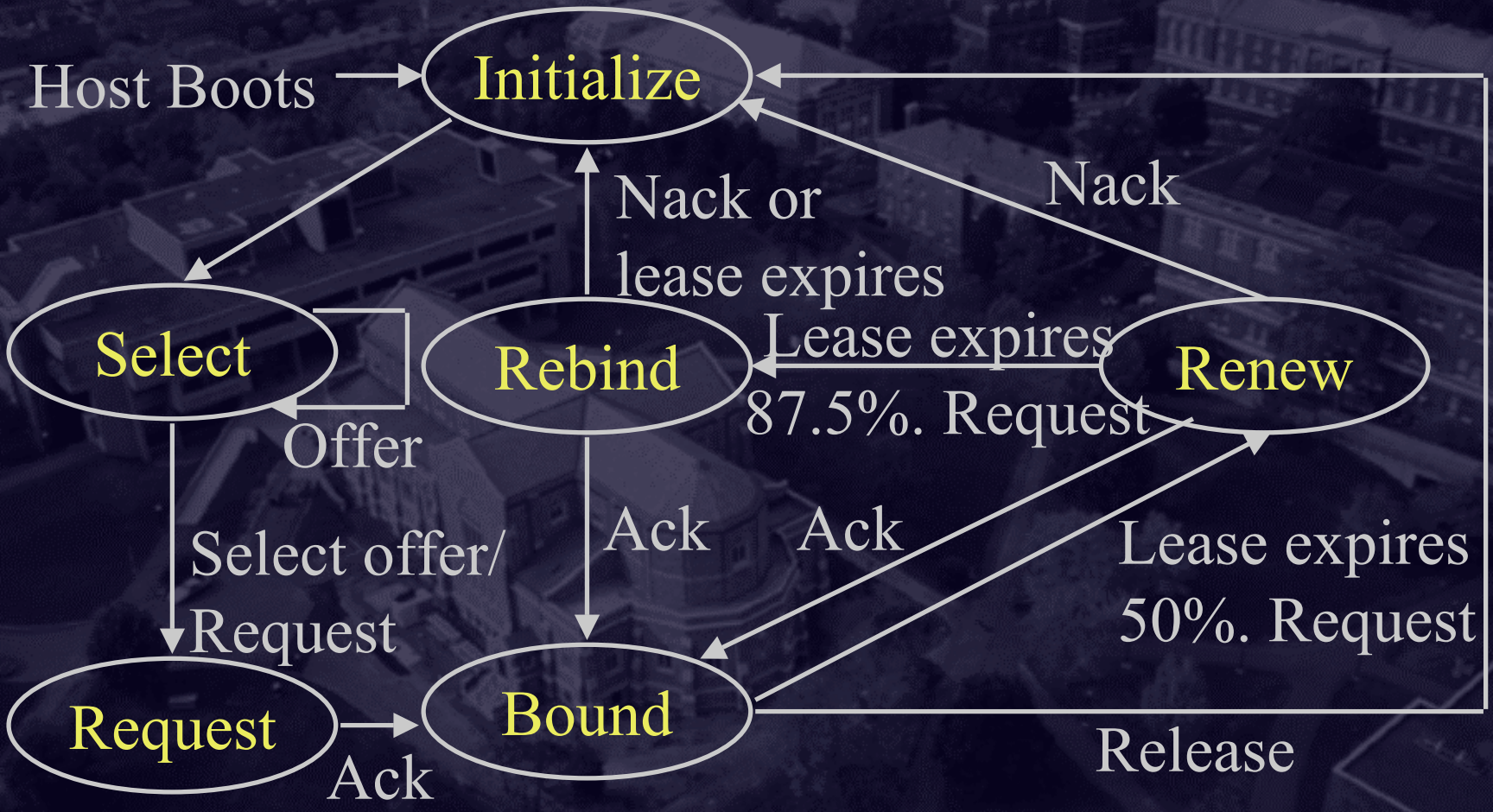
Method 2a: DHCP

- BOOTP limitation: *cannot dynamically assign IP address*
- Dynamic Host Configuration Protocol (DHCP)
  - BOOTP + Dynamic allocation of IP addresses => compatible with BOOTP.
  - No new fields in header.
  - Addresses can be leased for a period. Reallocated to the same or other nodes after lease expiry.

DHCP Message Format



DHCP State Diagram



DHCP States

- Boots => INITIALIZE state
- DHCPDISCOVER: broadcast request to servers => SELECT state
- DHCPOFFER (from server) => remain in SELECT
- DHCPREQUEST => select one of the offers and notify server (goto REQUEST state) about the lease

DHCP States (Continued)

- DHCPACK => server Oks request to lease => go to the BOUND state
- Renewal: after 50% of lease go to RENEW state
- Rebind: after 87.5% of time, if server has not responded, try again and go to REBIND.
- If server NACKs or lease expires, or client sends DCHPRELEASE, go to INITIALIZE, else come back to BOUND state

Answer to 7 config problems…

- 1. End systems: Layer 3 address, names, masks: DHCP
- 2. Router finds Layer 3 addresses of end systems: Same network ID (I.e. IP prefix)
- 3. Router finds Layer 2 addresses of end systems: ARP
- 4. End systems find a default router, name server: DHCP
- 5. End nodes on the same LAN discover that they can send directly to each other: Same network ID + ARP
- 6. End systems find the best router for exit traffic: ICMP Router Redirect
- 7. End systems communicate on a router-less LAN: need a DHCP server at least. Same prefix => same LAN; ARP

- Zeroconf IETF WG: networking without server-based configuration in certain scenarios…
- http://www.ietf.org/html.charters/zeroconf-charter.html

NAT: translate addresses, *without changing the application*

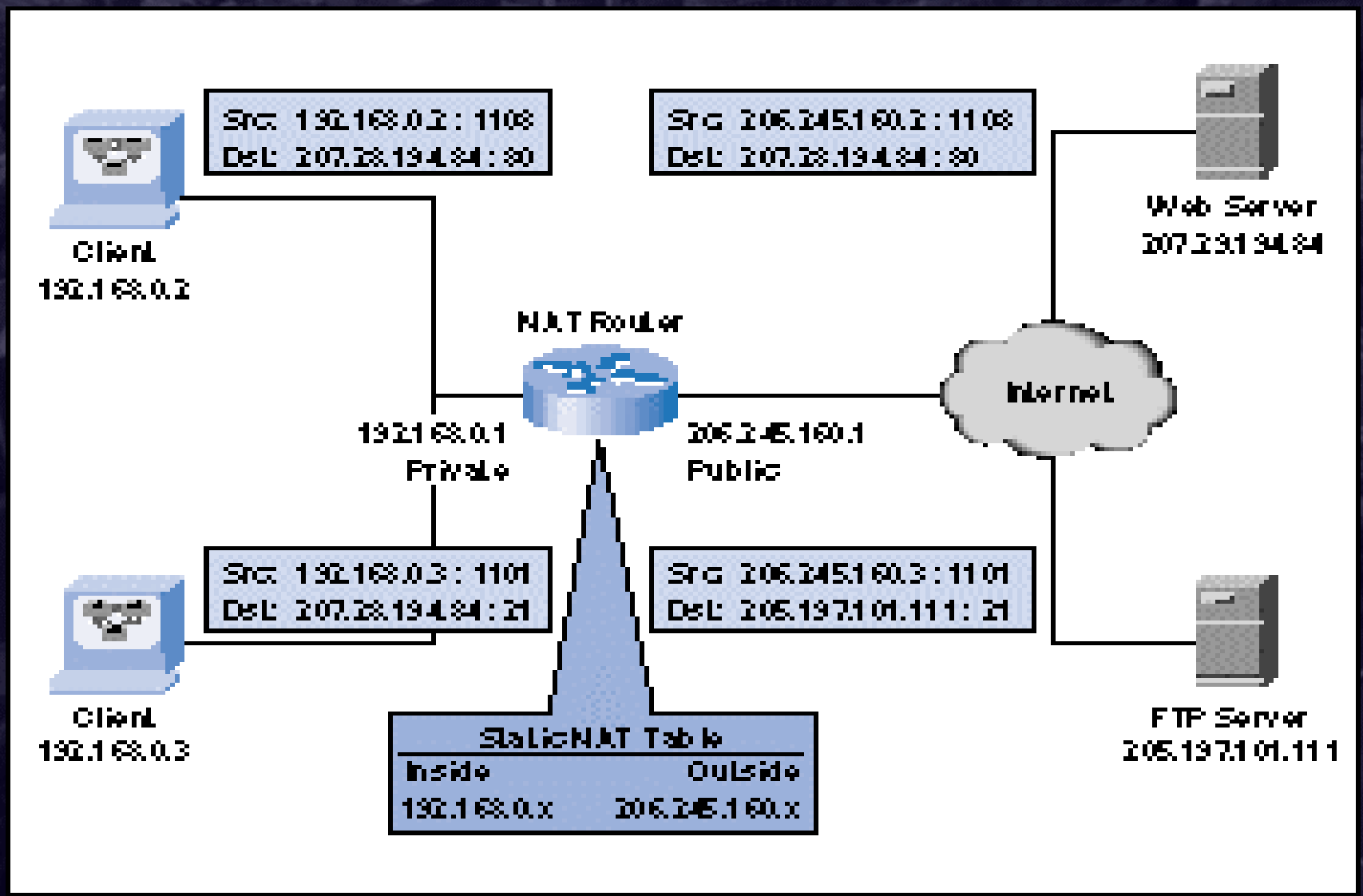
Address Management: Private Addresses

- Since IPv4 addresses are scarce, enterprises may use private addresses within their "realms"

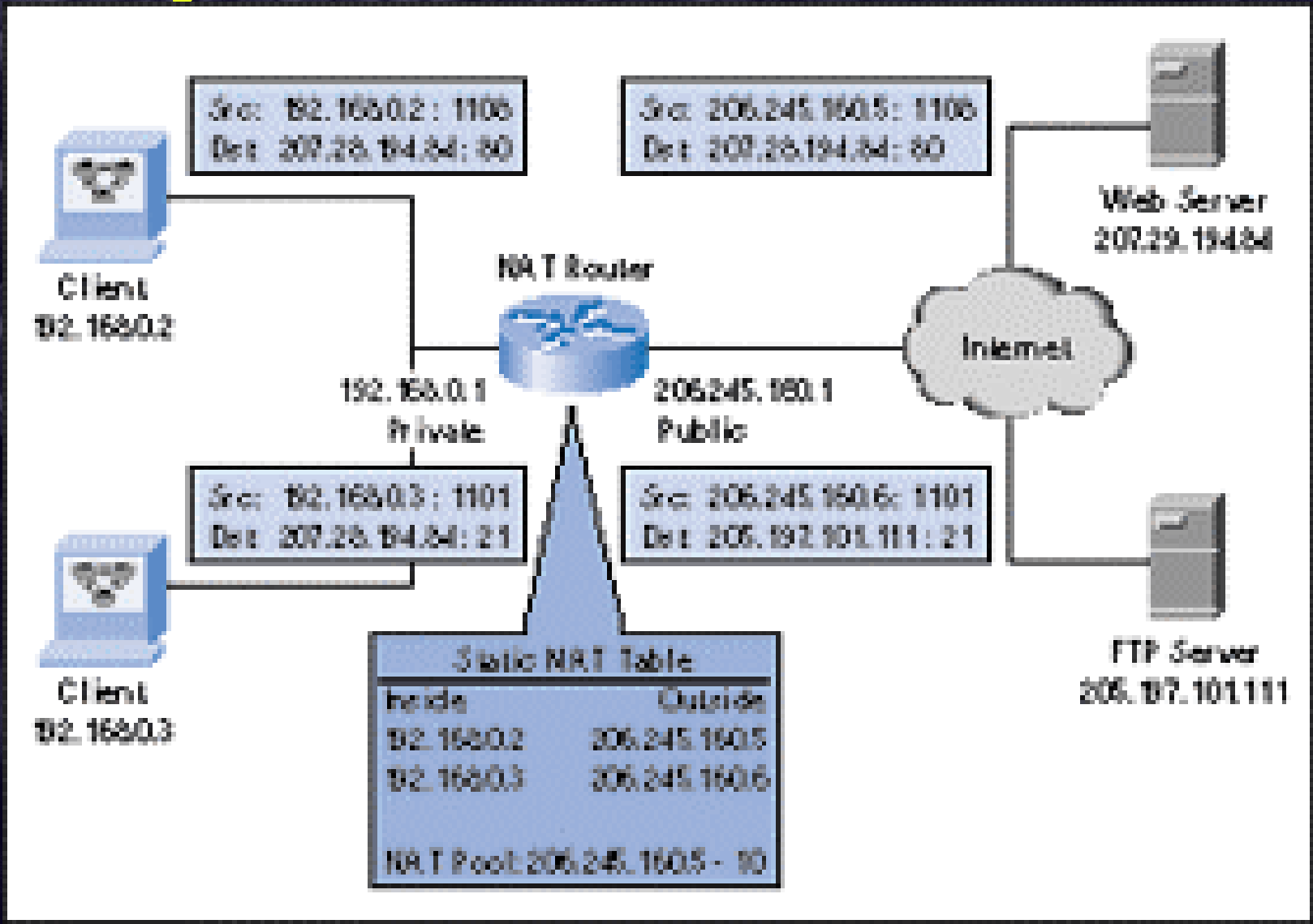
Class	Private Address Range
A	10.0.0.0 … 10.255.255.255
B	172.16.0.0 … 172.16.255.255
C	192.168.0.0 … 192.168.255.255

- Need to get "globally unique" public addresses for external use.
- Mapping between public & private addresses done by NAT (Network Address Translator)

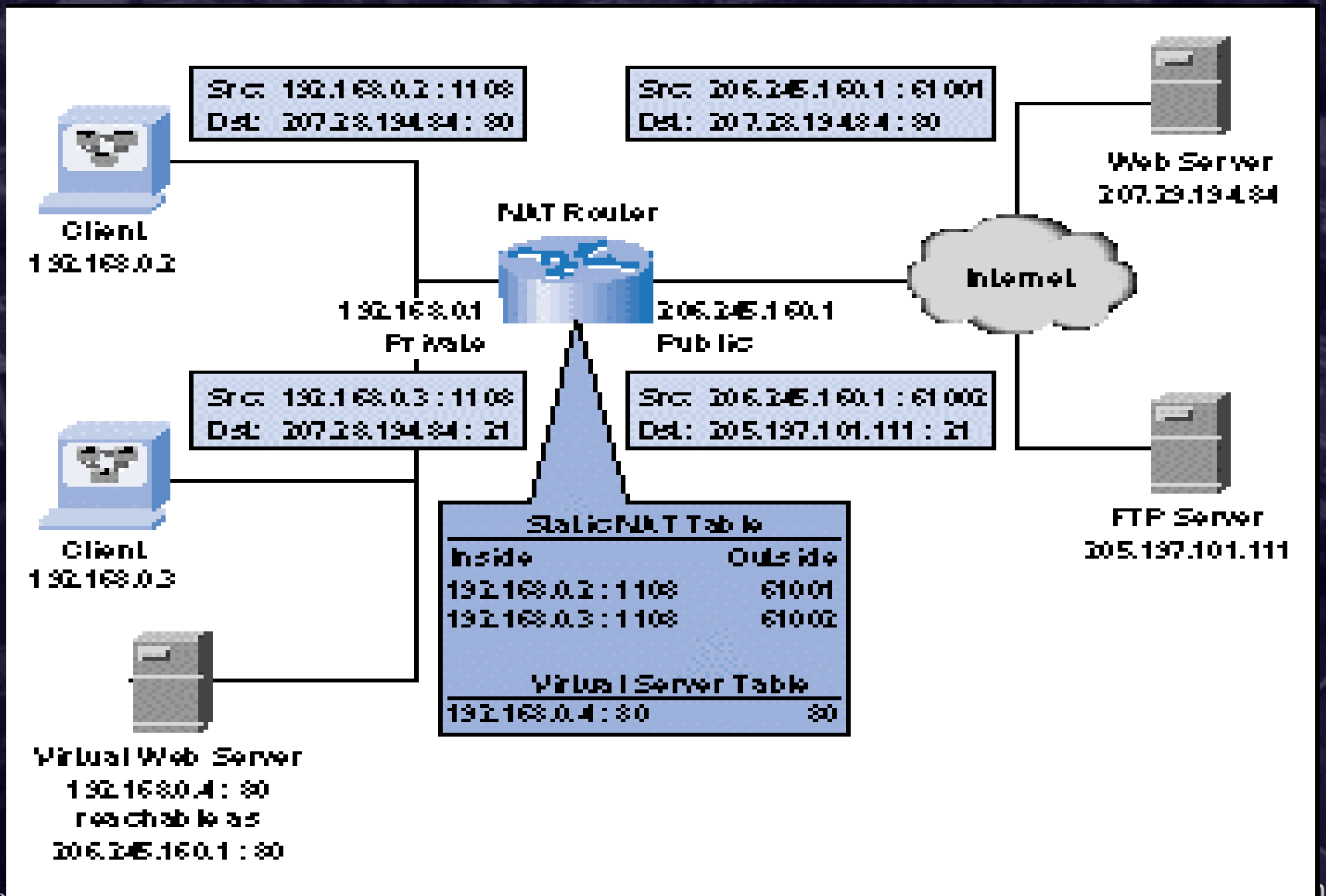
Simple NAT operation



Dynamic NAT = NAT + DHCP



Network Address Port Translation (NAPT)



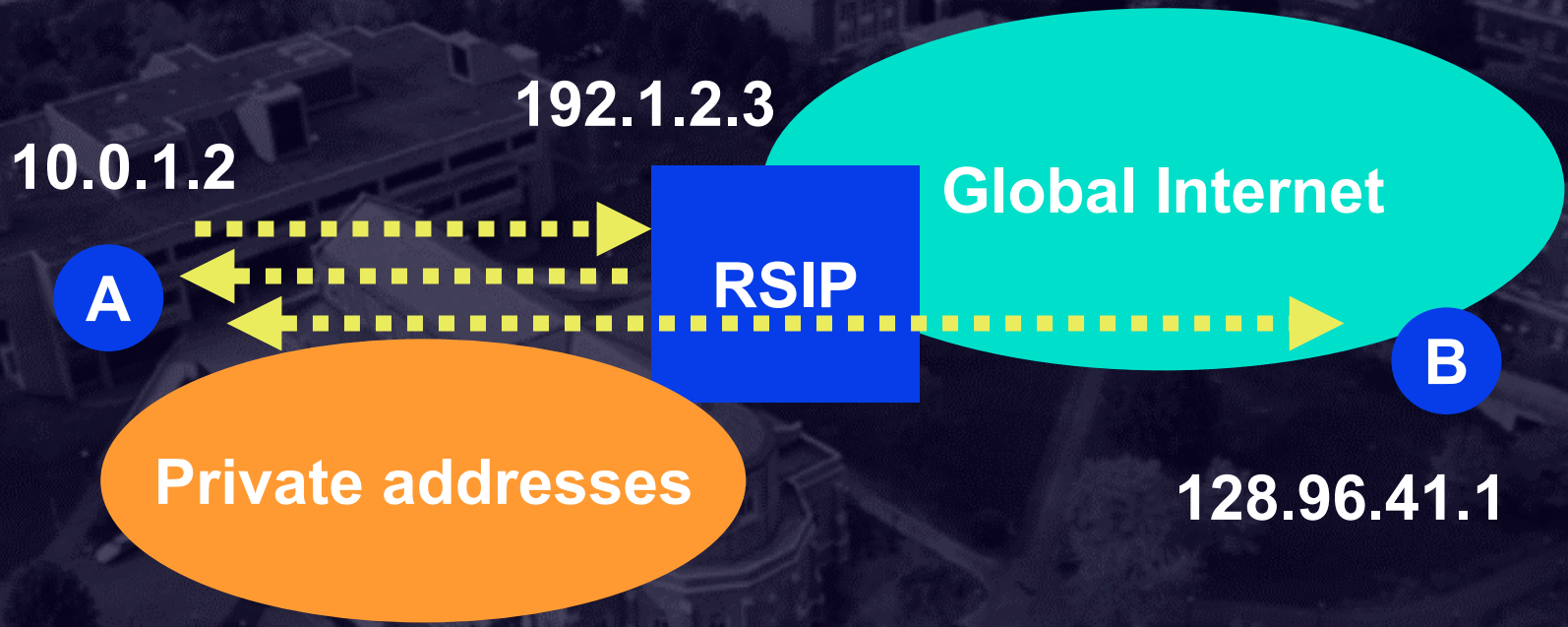
NAPT (contd)

- Also known as IP masquerading. Allows many hosts to share a single IP address differentiated by port numbers.
- Eg: Suppose private hosts 192.168.0.2 and 192.168.0.3 send packets from source port 1108.
- NAPT translates these to a single public IP address 206.245.160.1 and two different source ports, say 61001 and 61002.
  - Response traffic received for port 61001 is routed back to 192.168.0.2:1108,
  - Traffic for port 61002 traffic is routed back to 192.168.0.3:1108.

Realm-Specific IP (RSIP)

- NAT (and NAPT) have to mess with several transport/application level fields.
- NAT breaks IPSec…. Solution: RSIP
- RSIP leases public IP addresses and ports to RSIP hosts => not transparent like NAT.
  - RSIP does not operate in stealth mode and does not translate addresses on the fly.
  - RSIP allows hosts to directly participate concurrently in several addressing realms.
  - Avoids violating the end- to-end nature of the Internet => allows IPSec

RSIP "external address server", *eliminating side effects of NATs*

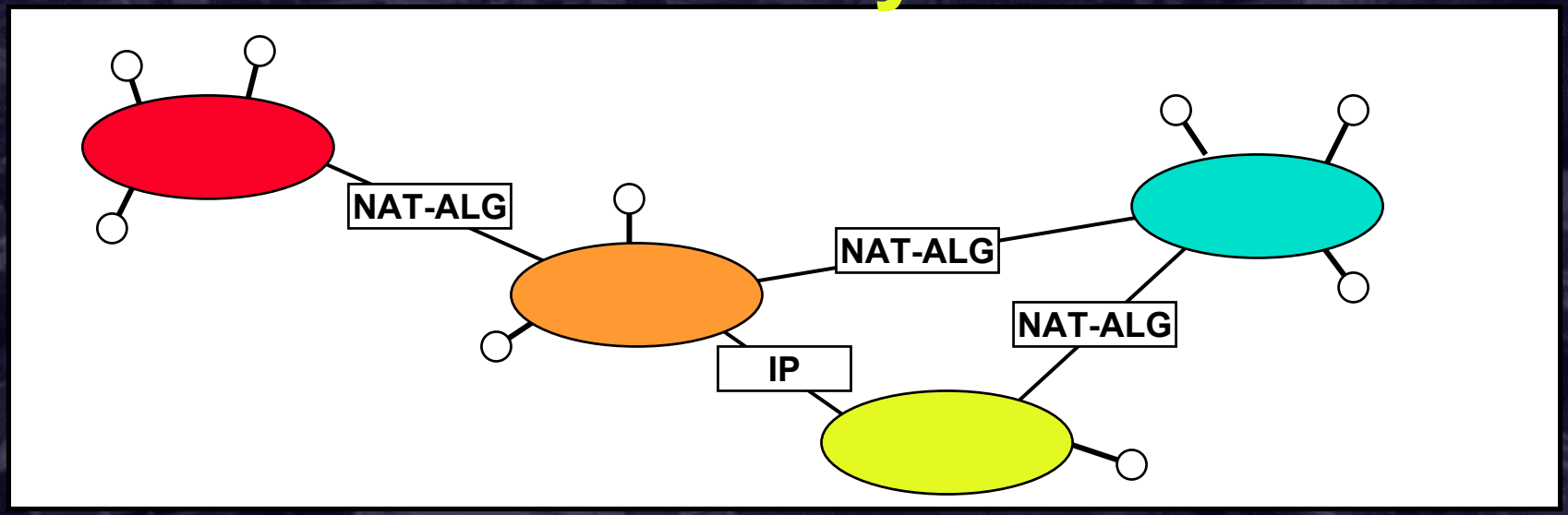


But the applications must be upgraded...

RSIP with "net 10" is a limited solution

- Not as easy to deploy as NAT
  - need to agree on a standard RSIP protocol,
  - need to upgrade the applications.
- Not as future-proof as IPv6
  - extensions by sharing address + ports between stations
  - one station may well use 256 ports,
  - hence RSIP = IPv4 + 8 bits = 40 bit addresses,
  - at most 4 billion networks.
- Limited interest in RSIP at this point…

The Internet Today: with NATs



- network address translators and app-layer gateways
  - inevitable loss of some semantics
  - hard to diagnose and remedy end-to-end problems
  - stateful gateways inhibit dynamic routing around failures
  - no global addressability => brokered with NATs
  - new Internet devices more numerous, and may not be adequately handled by NATs (e.g., mobile nodes)

Argument against NATs

- End-to-end vs Optimizations
- Short term problem
  - Connect many computers,
  - IP address are expensive
- Short term optimization
  - Use a NAT box,
  - Hide many computers behind one address
  - Works well for web clients…
- Addresses are the key…
  - Scarcity: the user is a "client"
  - Plethora: the user is a "peer"
- Qn: Today's optimizations, tomorrow's roadblocks?

Argument against NATs…

- they won't work for large numbers of "peers", i.e., devices that are "called" by others (e.g., IP phones)
- they break most current IP multicast, IP mobility, IP Security protocols
- they break many existing and emerging applications
- they limit the market for new applications and services
- they compromise the performance, robustness, security, and manageability of the Internet

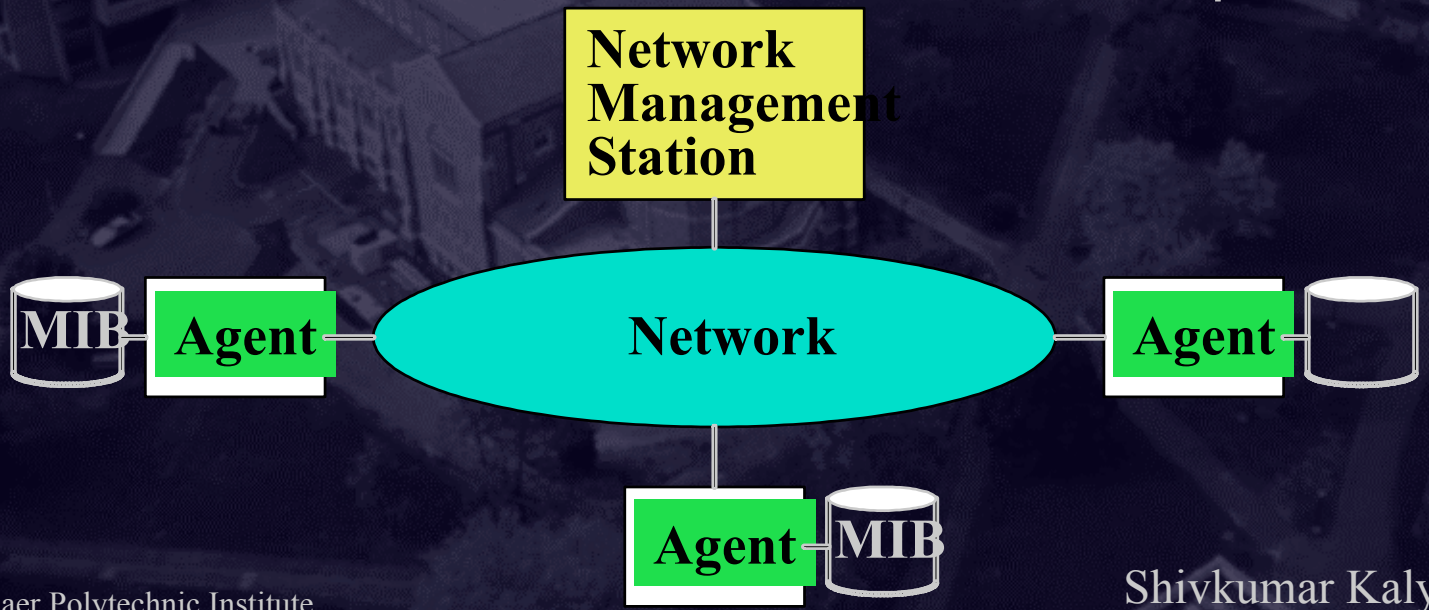
Can't We Make NATs Better?

- we could keep adding more protocols and features to try to alleviate some of their shortcomings
  - might improve their functionality, but will increase their complexity, fragility, obscurity, un-manageability,...
  - new problems will arise when we start needing inter-ISP NAT

- Anti-NAT suggestion: moving to IPv6 will avoid the need to continue doing many other things to keep the Internet working and growing
  - IPv6 is not the only possible solution, but the most mature, feasible, and widely agreed-upon one

Network Management

- Management = Initialization, Monitoring, Control
  - Today: automated, reliable diagnosis, and automatic control are still in a primitive stage
- Architecture: Manager, Agents & Management Information Base (MIB)
- Observe that management-plane has a new interface to the network distinct from data-, and control-plane



SNMP History

- Early: based upon ICMP messages (eg: ping, source routing, record routing)
- A lot of *informal* network debugging is done using tcpdump, netstat, ifconfig etc
- When the internet grew, Simple Gateway Management Protocol (SGMP) was developed (1987)
- Build single protocol to manage OSI and IP
  - CMIP (an OSI protocol) over TCP/IP {called CMOT}
  - Goal: Keep object level same for both OSI and IP
  - CMOT progressed very sluggishly
  - SNMP: parallel effort. Very simple => grabbed the market.

SNMP

- Based on SGMP
- Simple: only five commands

Command	Meaning
get-request	Fetch a value
get-next-request	Fetch the next value
get-response	Reply to a fetch operation
set-request	Set (store) a value
trap	Agent notifies manager

- Simple: handles only scalars. “get-next-request” used successively to get array values etc
- SNMP is bare-bones protocol to support monitoring & management

SNMP (Continued)

- Stateless => one management station can handle hundreds of agents
- Simple: Works as an application protocol running over UDP
- Agent and manager apps work on top of SNMP
- Proxy-SNMP can be used to manage a variety of devices (serial lines, bridges, modems etc).
  - Proxy (similar to bridge) is needed because these devices may not run UDP/IP
  - For *each new device define a new MIB.*

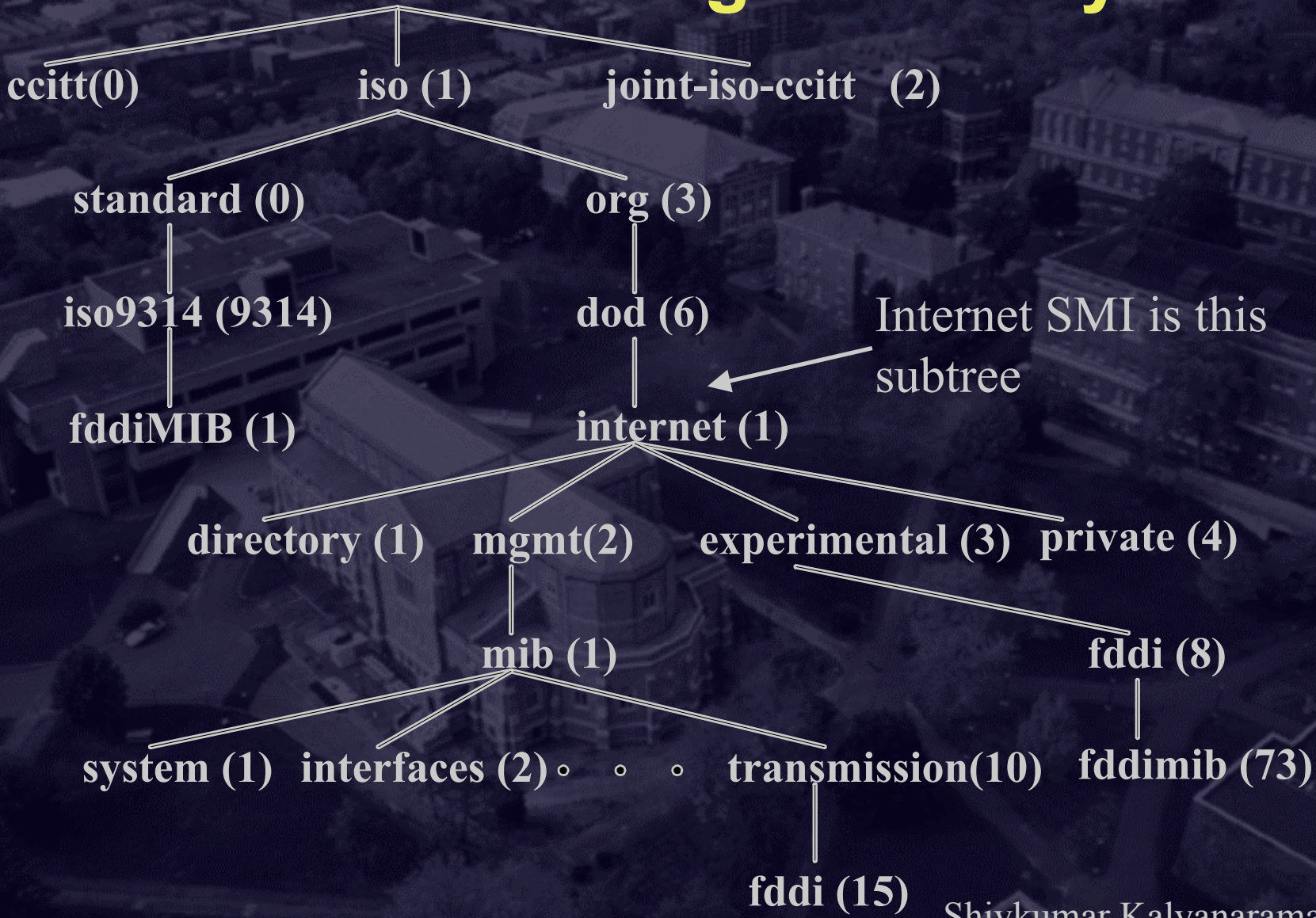
Management Information Base (MIB)

- Specifies *what variables the agents maintain*
- Only a limited number of data types are used to define these variables
- MIBs follow a fixed naming and structuring convention called "Structure of Management Information" (SMI). See next slide.

Management Information Base (MIB) (Continued)

- Variables are identified by "object identifiers"
  - Hierarchical naming scheme (a long string of numbers like 1.3.6.1.2.1.4.3 which is assigned by a standards authority)
  - Eg: iso.org.dod.internet.mgmt.mib.ip.ipInReceives 1.3.6.1.2.1.4.3

Global Naming Hierarchy



MIB (Continued)

- All names are specified using a subset of Abstract Syntax Notation (ASN.1)
- ***Types***: INTEGER, OCTET STRING, OBJECT IDENTIFIER, NULL
- ***Constructors***: SEQUENCE (like struct in C), SEQUENCE OF (table i.e. vector of structs), CHOICE (one of many choices)
- ASN.1 provides more types and constructors, but they are not used to define MIBs.

Standard MIBs

- Foe every new device, write MIB for it and include it as a branch of MIB-II
- MIB-II (RFC 1213) a superset of MIB-I (RFC 1156).
- Only "weak" objects. Tampering => limited damage
- No limit on number of objects (unlike MIB-I)
- Contains only essential objects. Avoid redundant objects, and implementation-specific objects.

Variable	Category	Meaning
sysUpTime	system	Time since last reboot
ifNumber	interfaces	# of Interfaces
ifMTU	interfaces	MTU
ipDefaultTTL	ip	Default TTL
ipInReceives	ip	# of datagrams received
ipForwDatagrams	ip	# of datagrams forwarded
icmpInEchos	icmp	# of Echo requests received
tcpRtoMin	tcp	Min retrans time
tcpMaxConn	tcp	Max connections allowed

Instance Identification

- How does the manager refer to a variable ?
  - ***Simple variables***: append ".0" to variable's object identifier
    - Eg: udpInDatagrams.0 = 1.3.6.1.2.1.7.1.0
    - Only leaf nodes can be referred (since SNMP can only transfer scalars)

Instance Identification (Continued)

- ***Table elements***:
  - Each element in a table needs to be fetched separately.
  - Traverse MIB based upon lexicographic ordering of object identifiers using get-next
  - Column-by-column: Elements of each column first.

RMON

- Remote Network Monitoring
- Defines remote monitoring MIB that supplements MIB-II and is a step towards internetwork management
- It extends SNMP functionality though it is simply a specification of a MIB
- Problem w/ MIB-II
  - Can obtain info that is purely local to individual devices
  - Cannot easily learn about LAN traffic as a whole (eg like LANanalyzers or “remote monitors”)

RMON (Continued)

- Functionality added: Promiscuously count, filter and store packets
- System that implements RMON MIB is called an RMON probe (or less frequently, an RMON agent).
  - No changes to SNMP protocol.
  - Enhance the manager and agents only.
- RMON MIB organization:
  - Control table: read-write. Configures what parameters should be logged and how often.
  - Data table: read-only (statistics etc logged)
- Other issues: shared probes, ownership of tables, concurrent table access ...

Summary

- Error reporting is a separate protocol in IP: ICMP
  - Features help build neat tools: ping, traceroute etc
- Configuration:
  - 7 basic configuration problems
  - Internet solution: ARP, DHCP (server-based)
  - Earlier attempts: RARP, BOOTP
- Address Mgmt: Private addresses, NAT, NAPT, RSIP
- Management = Initialization, Monitoring, and Control
  - SNMP = Only 5 commands (simple polled transfer of management information)
  - MIB: labeling of mgmt info using ASN.1 encoding
  - Standard MIBs defined for each object
  - RMON extends management functionality through definition of a new MIB (no protocol changes)