Architectures of Distributed Systems 2010/2011

Naming & references

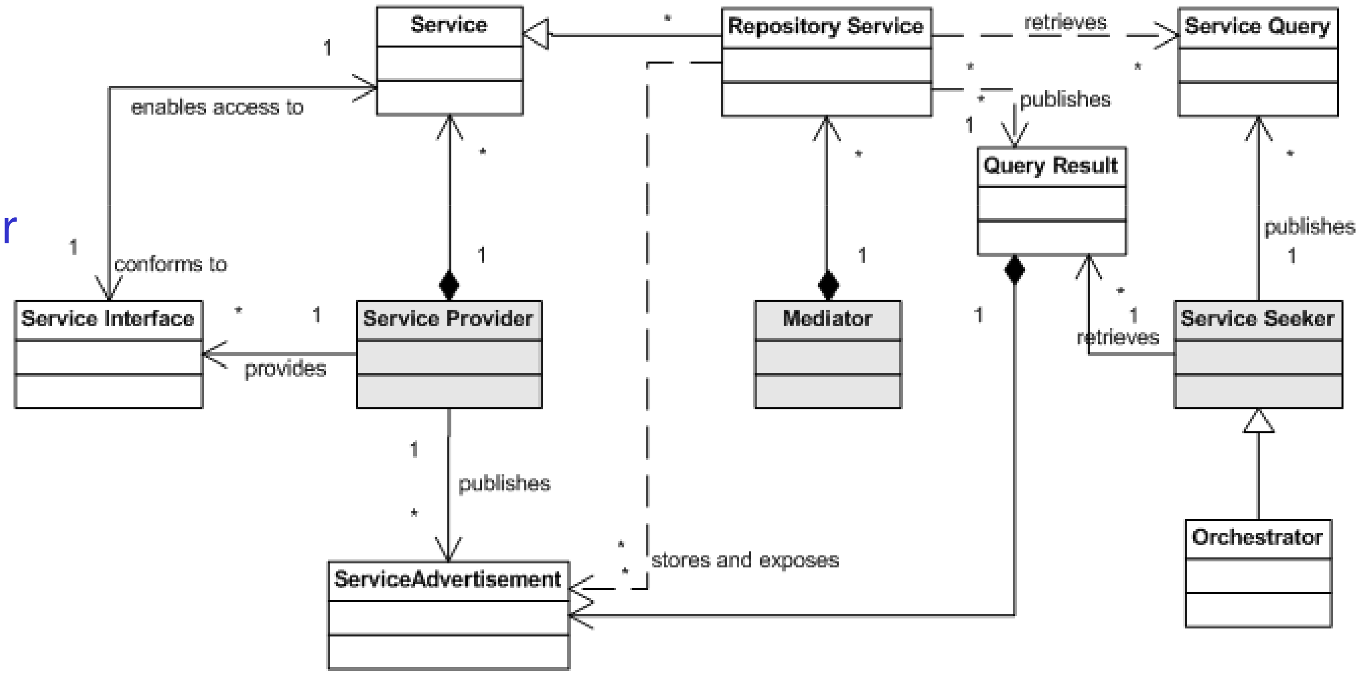
Johan Lukkien

Agenda

- Service discovery
- On naming
- Distributed flat resolution
  - DHT (distributed hashtable) of Chord
- Distributed structured resolution
  - DNS

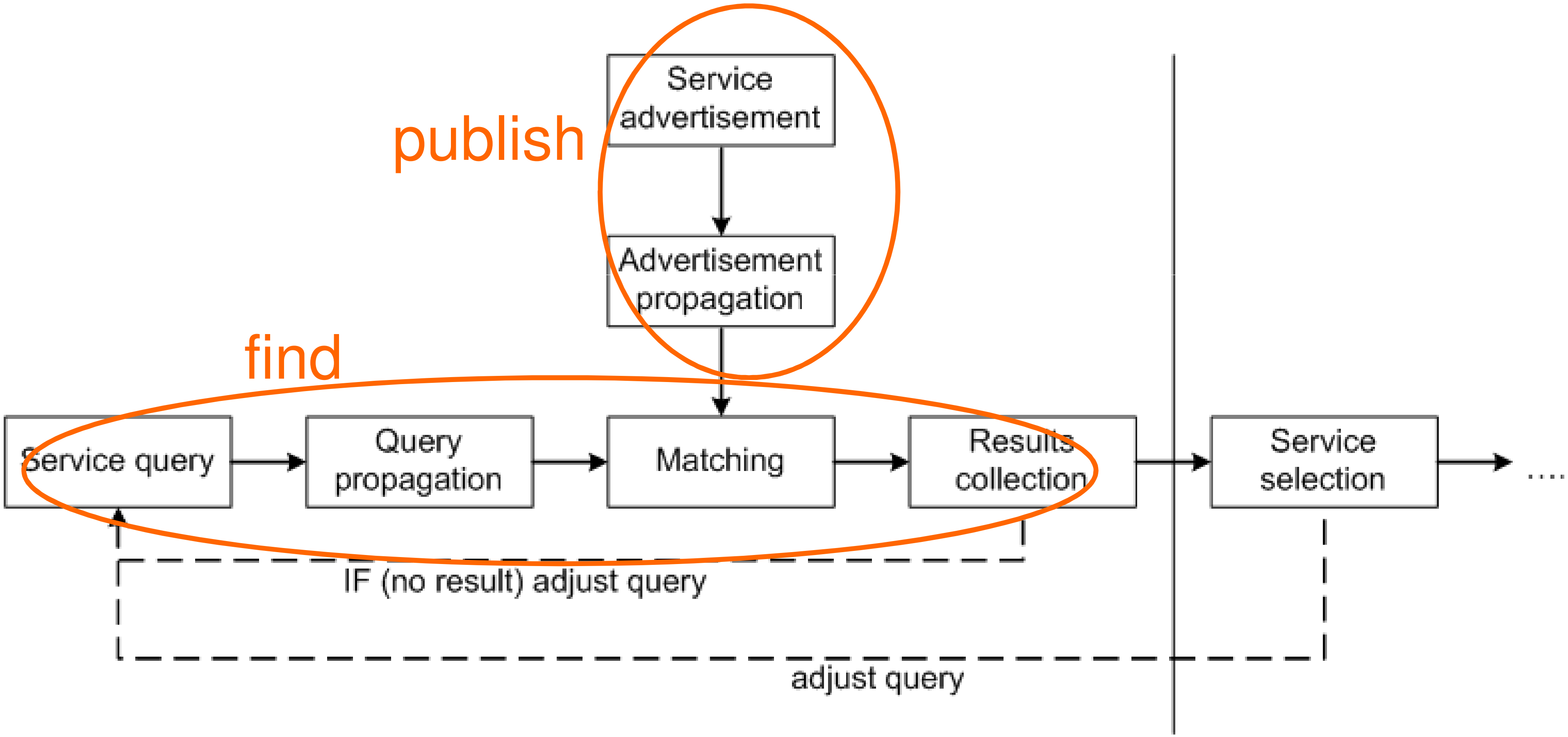
Service discovery model

- The basic problem: how do two parties, that don't know each other, meet?
- Three roles:
  - publisher, seeker, mediator (broker)
- Tasks:
  - service/query advertisement, (propagation), matching, evaluation



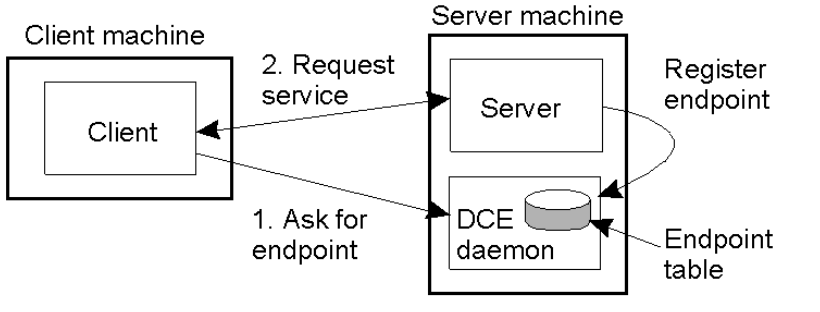
Slides based on work by Melissa Tjiong, SAN, TU/e

Service discovery process

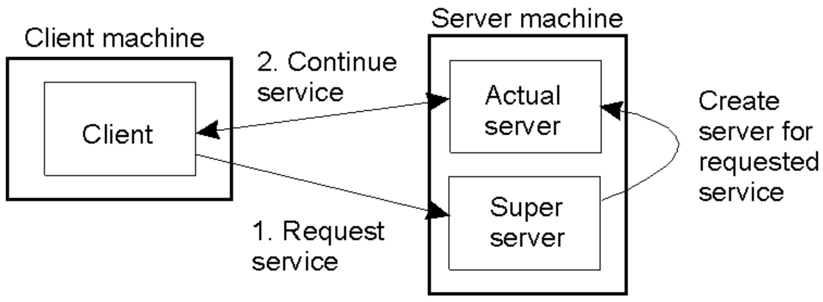


Discovery techniques

- Discover and contact, alternatives
  - Server registers at repository (a)
    - can be on different machine
  - client contacts repository for access point
    - e.g. DCE, DNS, SLP
  - client contacts *known access point* for server access
    - needs some accepted list of services
    - example: services coupled to fixed transport port
      - e.g., ftp: 21, telnet: 23 etc.
  - Server:
    - 'Superserver', listens to many access points (b)
      - Superserver instantiates particular server on request
      - example: *inetd* (internet daemon)
    - just start the server beforehand on the known access point
- **Note**:
  - the repository (a) or superserver (b) is again a server itself



(a)



(b)

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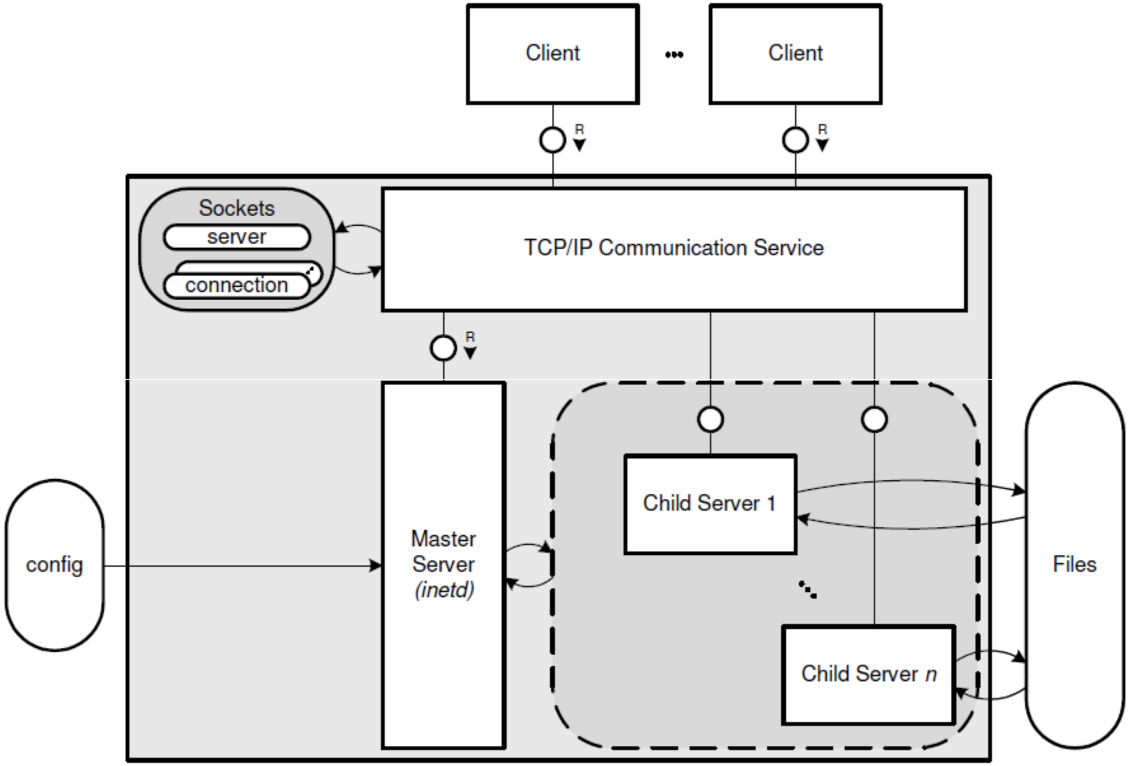
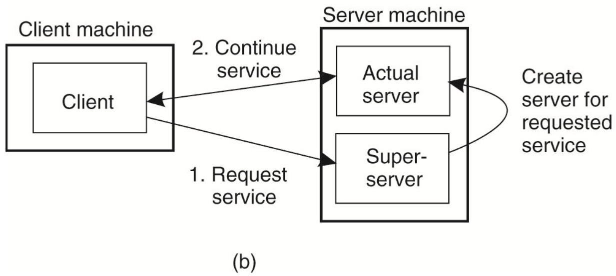
Inetd (create server upon request)





Picture from 'The Apache Modeling Project',
Grone, Knopfel, Kugel, Schmidt, Potsdam University

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Further alternatives: immediate

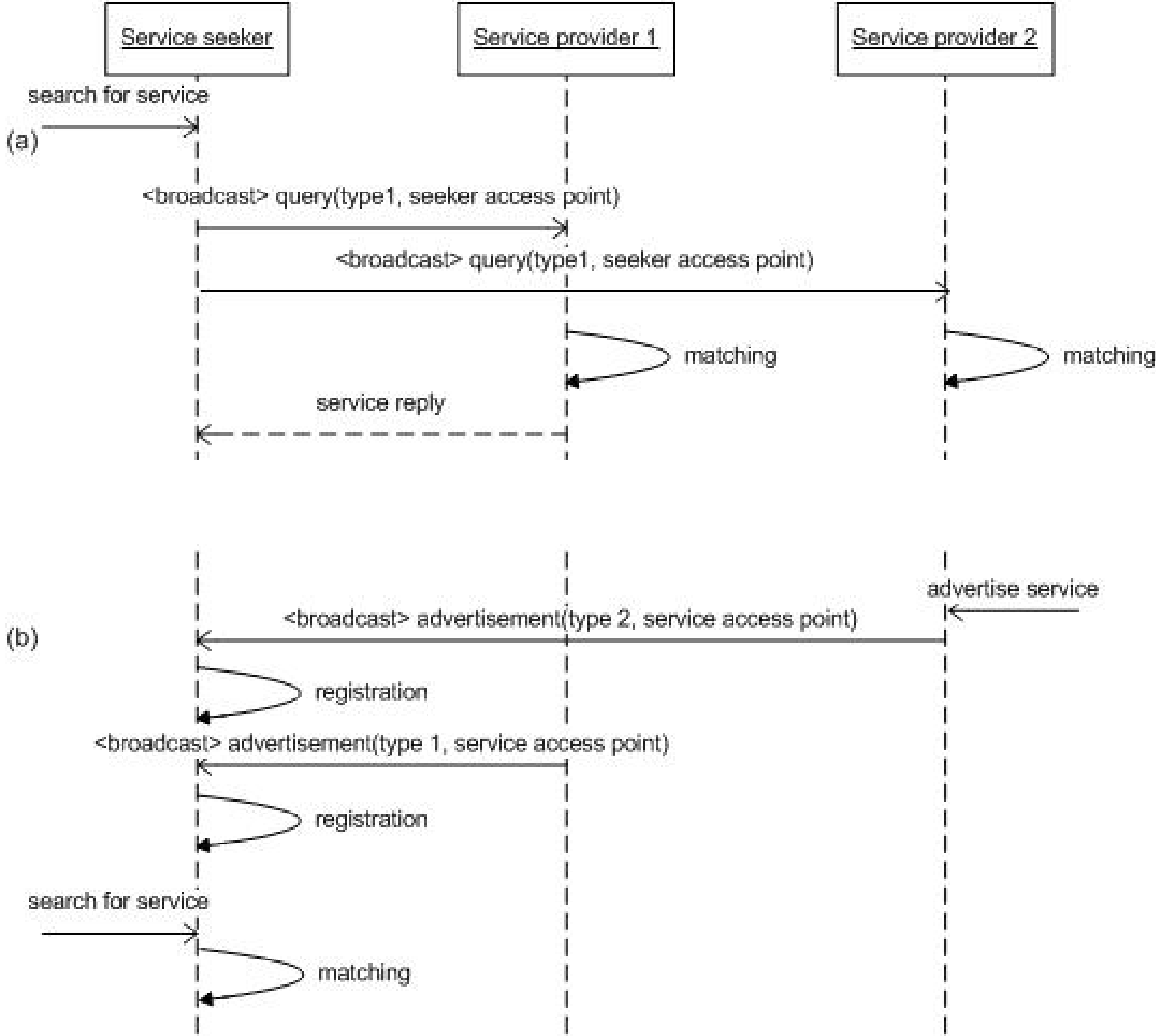
- Interested parties find each other through *multicasting (broadcasting)*
  - server or client, or both,
    - multicast presence periodically or
    - single multicast of each party upon joining a community (network, other group) or
    - multicast as query
  - examples: unmanaged SLP, DHCP, SSDP (UPnP), Apple Bonjour (rendez-vous)

- Important for *bootstrapping*

- Advantage:
  - fully distributed
  - no central state maintained
  - ‘zero configuration’

- Disadvantage
  - each contender implements the entire protocol, including storage
    - no shared services
  - scalability
    - performance [what are performance measures of interest here?]
  - limited to multicast (broadcast) scope

Immediate architecture



DHCP

- Immediate, bootstrapping protocol, provides
  – IP address, with a lease
  – addresses of *caching DNS servers*
- Client side broadcast on local net
- Client side selection of server (not shown in previous diagram)

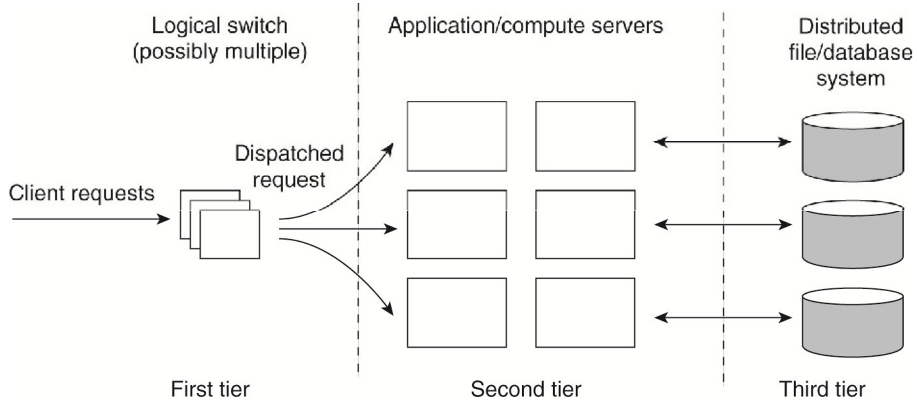
```
                Server          Client          Server
            (not selected)                    (selected)

                  v               v               v
                  |               |               |
                  |     Begins initialization     |
                  |               |               |
                  | _____________/|\____________  |
                  |/DHCPDISCOVER | DHCPDISCOVER  \|
                  |               |               |
              Determines          |          Determines
             configuration        |         configuration
                  |               |               |
                  |\              |  ____________/|
                  | \________     | /DHCPOFFER    |
                  | DHCPOFFER\    |/              |
                  |           \   |               |
                  |       Collects replies        |
                  |             \ |               |
                  |     Selects configuration     |
                  |               |               |
                  | _____________/|\____________  |
                  |/ DHCPREQUEST  |  DHCPREQUEST\ |
                  |               |               |
                  |               |     Commits configuration
                  |               |               |
                  |               | _____________/|
                  |               |/ DHCPACK      |
                  |               |               |
                  |    Initialization complete    |
                  |               |               |
                  .               .               .
                  .               .               .
                  |               |               |
                  |      Graceful shutdown        |
                  |               |               |
                  |               |\ ____________ |
                  |               | DHCPRELEASE  \|
                  |               |               |
                  |               |        Discards lease
                  |               |               |
                  v               v               v
```

from RPF2131: DHCP

After discovery: server cluster

- Goals
  - improve performance
    - scalability: increase number of requests served
    - decrease delay
  - improve reliability
  - improve availability

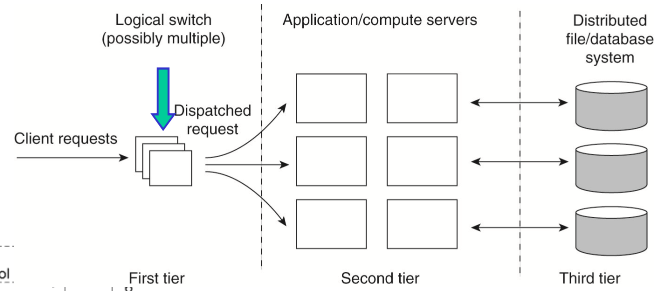


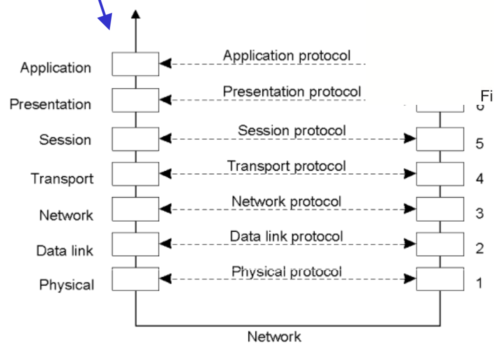
Server cluster general architecture

- Problems to be solved:
  - transparent (for client) distribution of request
    - particularly: dealing with the single access-point
  - security
  - management
    - see Planetlab case study in the book

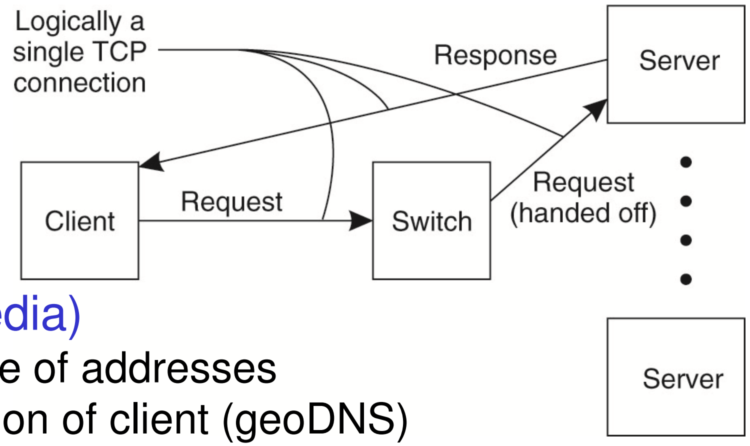
Cluster access

- Handoff based on application request
  - supports dedicated servers
  - requires request interpretation
    - potential performance probler





- TCP handoff
  - incoming transport-layer request passed to the server
  - needs protocol adaptation
    - ‘spoofing’ of the destination ID
    - switch routes all request traffic
    - OS support (both sides)



- Multiple access points
  - DNS load balancing (e.g. Google, Wikipedia)
    - DNS resolution cycles through a sequence of addresses
    - DNS resolution uses geographic information of client (geoDNS)

Agenda

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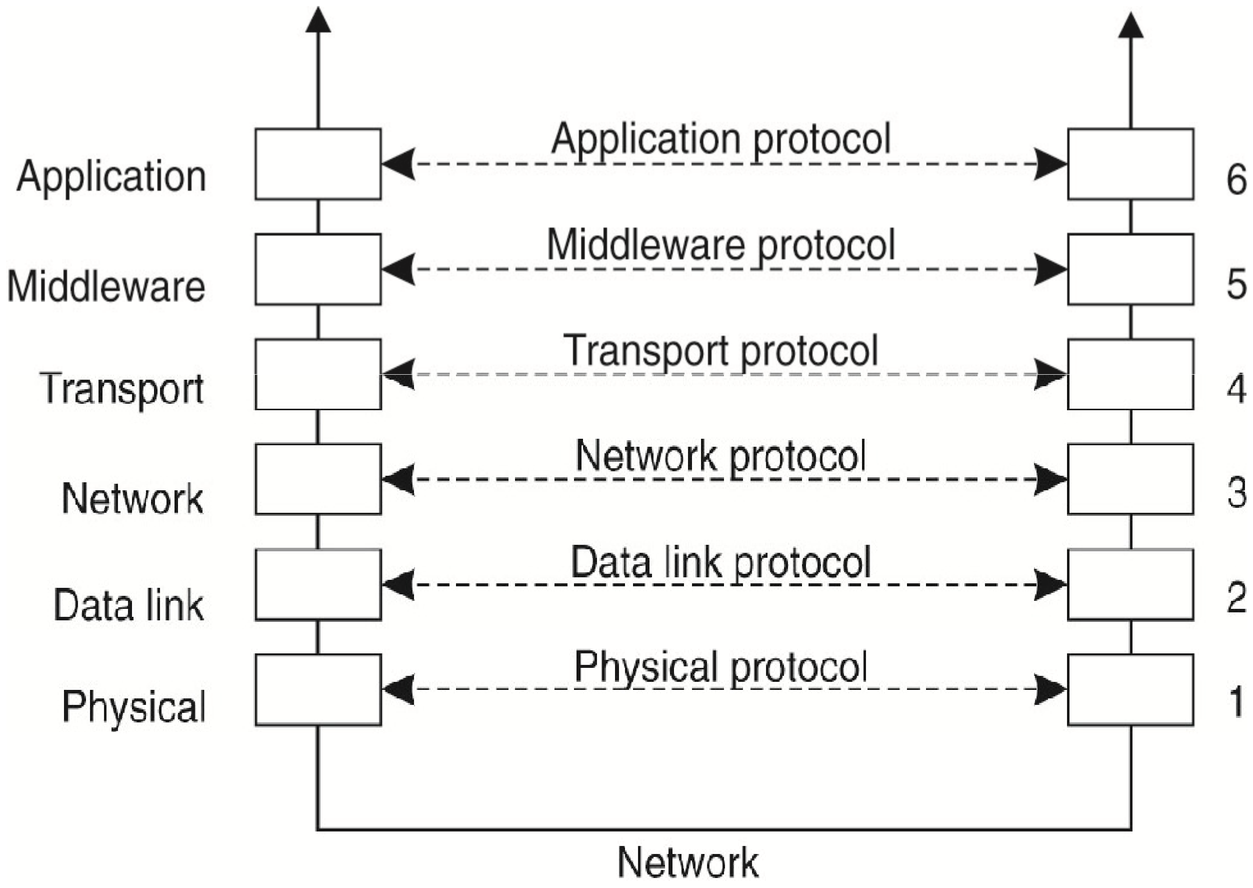
Naming

- A *name* serves as *reference* to an *entity*
  - entity: i.e., anything that can be operated upon

- Motivation:
  - Delay binding
    - *mobility transparency*: name remains constant under mobility
    - *replication transparency*: map name to several different entities
    - *location transparency*
  - Lookup
    - name serves as a means to locate an entity
  - Human-friendliness

Naming in the Internet stack

Structured/flat	Name
structured, both	DNS, URL
(structured, flat)	(IP, port)
structured	IP address
flat	MAC address



Namespace

- Set (of names)
  - Specification/algorithm as how to generate names

- Methods
  - flat naming
    - simply an unstructured set of names
  - structured naming
    - hierarchical, mostly, e.g., /user/johanl/....
      - *relative* name: relative with respect to a given prefix
      - *absolute* name: complete
    - prefixing
      - embedding a set of names uniquely into a larger set
        - » e.g. <gm:weerbericht xmlns:gm="http://GlobalMeteo.com">

Entities and identifiers

- *E:* Entities
  - the collection of 'things' that need to be referred
    - resources, devices, network ports, ...
- *I:* Identifiers
  - the namespace for entities

- An identifier for an entity is unique; identifiers are not re-used
  - e.g., MAC address as identifier for a network card

- $Id: E \rightarrow I$
  - *Id* is injective and static

Access points and addresses

- *X:* Access points
  - a access point represents a place where an entity can be accessed
  - an entity can have several access points
    - loosens the tight relation: entity-identifier
    - an entity is associated with a subset of *X*

- *A:* Addresses
  - a namespace for access points
  - an address of an access point is unique
    - Though not always! This leads to ambiguity in the resolution procedure.
    - Examples?
  - addresses of access points may change over time

- Example
  - A PC has several access points (network cards). Each network card receives dynamically an IP address. Resolution of the IP address yields the identifier of the network card.
  - The access point of the network card is found directly through this identifier.

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Binding, Resolution

- **Binding: (**the establishment of) the relationship between a reference (a name) and a referred object (another name or an access point)
  – *symbolic*: referred object is again a similar reference
  – *aliasing*: several names for the same object

- **Resolution:** given a name, determine referred object
  – ‘structured’ resolution: follow structure and levels in naming hierarchy, e.g
    - given a DNS name, find Transport address, then find MAC address
  – ‘flat’ resolution: flat naming, no hierarchy support, e.g.,
    - reverse DNS: what is the DNS name of this IP address?
      – not entirely flat though as still information is remaining in the IP address
    - reverse ARP: what is the IP address of this MAC address?
    - given identifier, determine access point

- **Closure:** starting point in resolution

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Flat naming and resolution

- Problem: given identifier, find access point
  - possibly, via an intermediate structured address

- Search (see: service discovery)
  - broadcast: ‘ask everyone’
    - limited physical scope
    - example: ARP
  - multicast
    - e.g. overlay networks
    - limited logical scope
    - example: searching in P2P overlay
    - may combine with *repositories* storing *associations* (identifier, address)
  - table lookup – hashing, tree-search
    - hashing inside repositories
    - distributed hash tables
    - distributed, tree-like repositories

Example: distributed storage and lookup

- Flat name space of *m*-bit identifiers
- Set of nodes, *N,* set of other entities (files, objects, processes, ...)

- Each node or entity *e* has an identifier *id(e)*
  - typically a random assignment
  - we refer to nodes by their identifier; hence, 'node *p*' means 'the node with identifier *p*'
  - the set from which we take nodes is therefore *id(N)*

- Identifier *k* has an associated <u>node</u>, the one with the next largest or equal *id,* modulo 2^m
  - $succ(k) = \begin{cases} (\mathbf{min}\ n \in id(N),\ n \geq k:\ n) & \textbf{if } k \leq \mathbf{max}(id(N)) \\ \mathbf{min}\ n \in id(N) & \textbf{otherwise} \end{cases}$

- Using this function *succ* we define successor and predecessor of a node *p*
  - successor of *p* is $succ(p+1)$
  - predecessor of *p*, $pred(p)$ is defined as follows: $pred(p) = y \equiv succ(y+1) = p$

- An entity with identifier *k* is managed by (stored by) node $succ(k)$

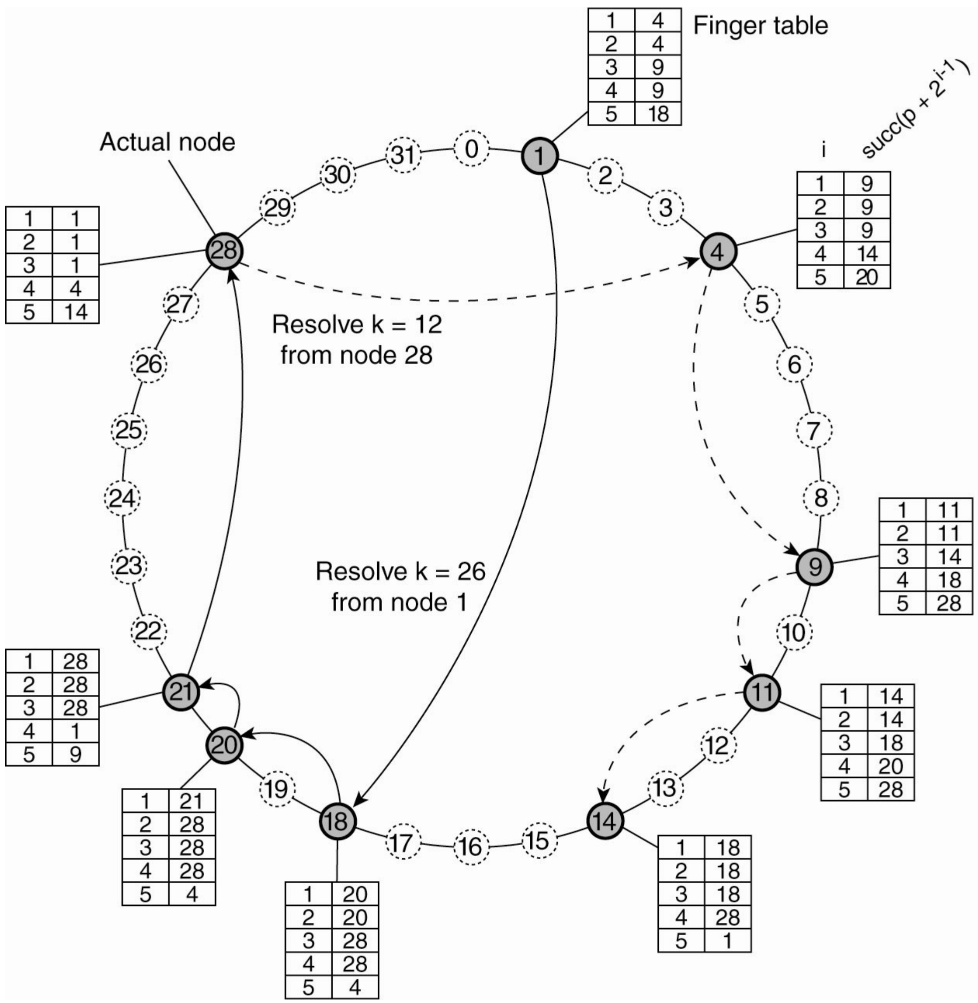
- Hence, the problem is: given *k,* find (the address of) $succ(k)$

Example

- Assume *m* = 4, *N* = { 2, 5, 8, 12 }
- *succ(4), succ(5), succ(6), succ(13)?*
  - *succ(4) = 5, succ(5) = 5, succ(6) = 8, succ(13) = 2*
- *Successor of 2, 5, 8, 12?*
  - *5, 8, 12, 2*
- *Predecessors of 2, 5, 8, 12?*
  - *12, 2, 5, 8*
- *2 stores*
  - *0, 1, 2, 13, 14, 15*
- *5 stores*
  - *3, 4, 5*
- *8 stores*
  - *6, 7, 8*
- *12 stores*
  - *9, 10, 11, 12*

Distributed location lookup

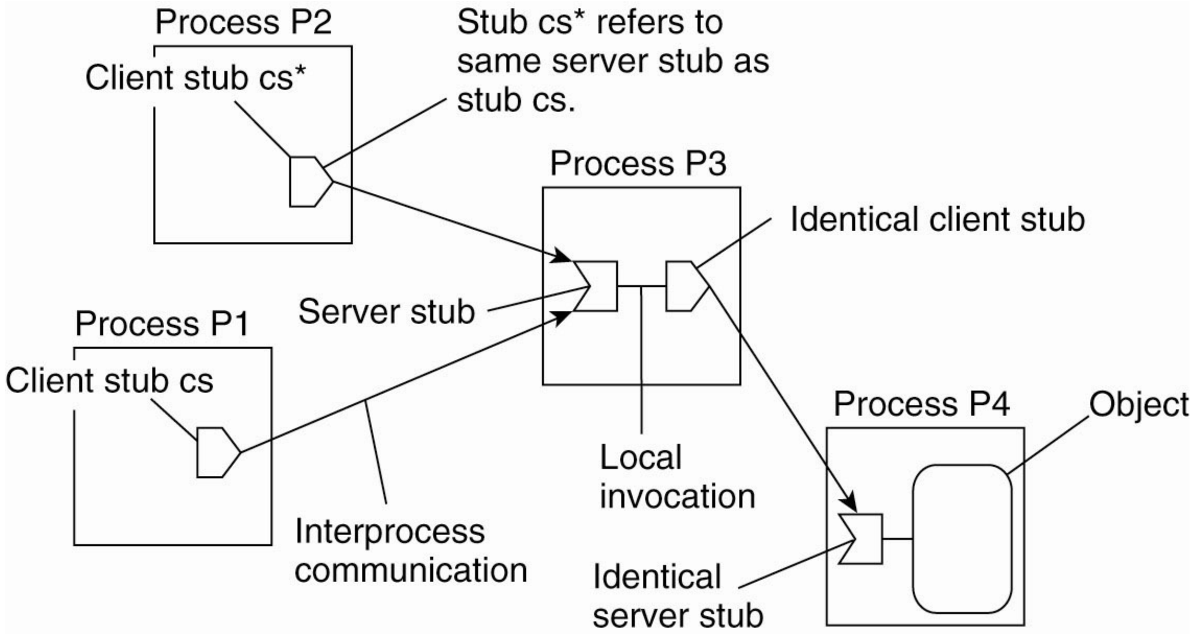
- Logically the nodes are organized in a pipelined or cyclic fashion
- Linear search
  - node *p* stores addresses of *succ(p+1)* and *pred(p)*
- ‘Binary’ search (distributed hash table, DHT)
  - node *p* stores addresses of nodes that take large steps (chords) along the circle
  - routing table with entries for $succ(p+2^{i-1}), 1<i\leq m$
    - Chord system: ‘finger tables’
- Issues in:
  - entity insert: simple
  - node insert:
    - table updates in DHT
    - relocate entities
  - routing efficiency - use the underlying network efficiently

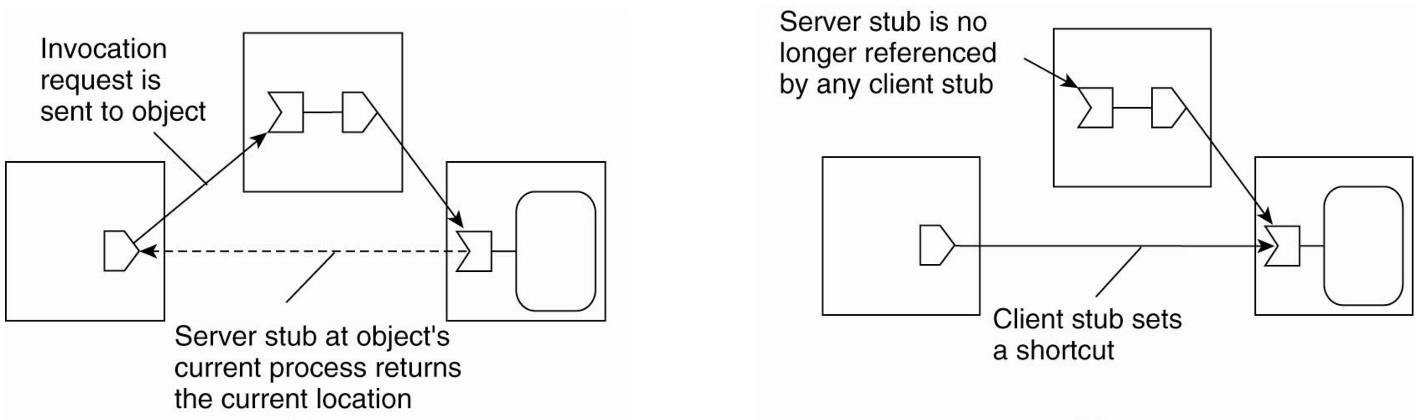


Flat naming and mobility

- Leave 'follow me' to new location
  - typically as part of middleware to establish *location transparency* as well as *mobility transparency*
  - sensitive to
    - broken links (dependability)
      - all intermediates must be online
    - long chains (efficiency, scalability)
      - all intermediates must maintain state
  - solutions:
    - pointer fusion
      - distributed object based systems
    - keep first indirection up-to-date
      - mobile IP: maintain a reference to current location at home location
      - (Question: how transparent can this be?)

- Mobile object replaced by stub that forwards invocations
- Pointer fusion: final stub responds with new reference (below)
  - not transparent

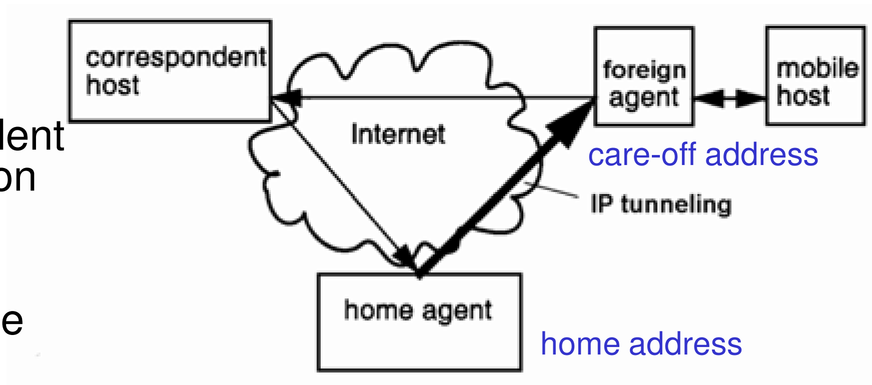


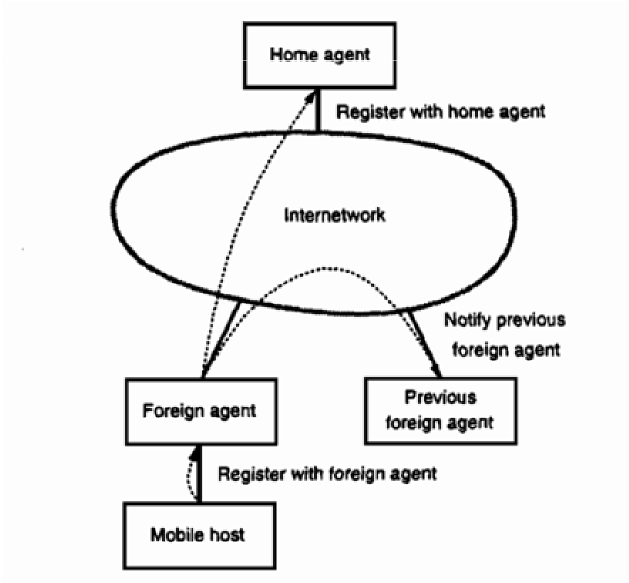


(a) (b)

Mobile IP

- *Home agent* (HA) maintains binding between a fixed *home address* and the current *care-off* address of a mobile node.
- HA receives packets from a client (‘correspondent host’) on the home address and passes them on to current care-off address, via an IP tunnel.
- The *foreign agent* maintains the binding (mobile node, care-off address) at the current location. Typically, it is addressed via the care-off address and forwards the traffic via the local link.
- Mobile node uses home address as source in its datagrams.
- This establishes *triangular routing.*
- Agent discovery: immediate, advertisement of both query and agent
- Agent handoff: upon registering with a new foreign agent (2nd figure)





Pictures taken form Helsinki University of Technology, Seminar on MM

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Hierarchical naming systems

- Graph: labeled, directed, acyclic
  - edge labels: partial names
  - paths: names

- Leaf nodes
  - access point
  - name in new naming system
  - name in same naming system (‘symbolic’)

- Directory nodes
  - access point to directory structure
    - references to child nodes
  - often represented by a special symbol
    - “/”, “.”

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Name space examples

- File systems
  - usually, hierarchy
  - resolution: through file-tables
  - closure: e.g. superblock
- Internet addresses
  - basic hierarchy
  - binding: e.g. DHCP
  - resolution & closure: ARP

- Internet names
  - hierarchy
  - binding and resolution: DNS (yields Internet-address)
  - closure: local DNS server
- URL
  - combines several naming systems
  - Question: what is the resolution procedure here? and the closure?

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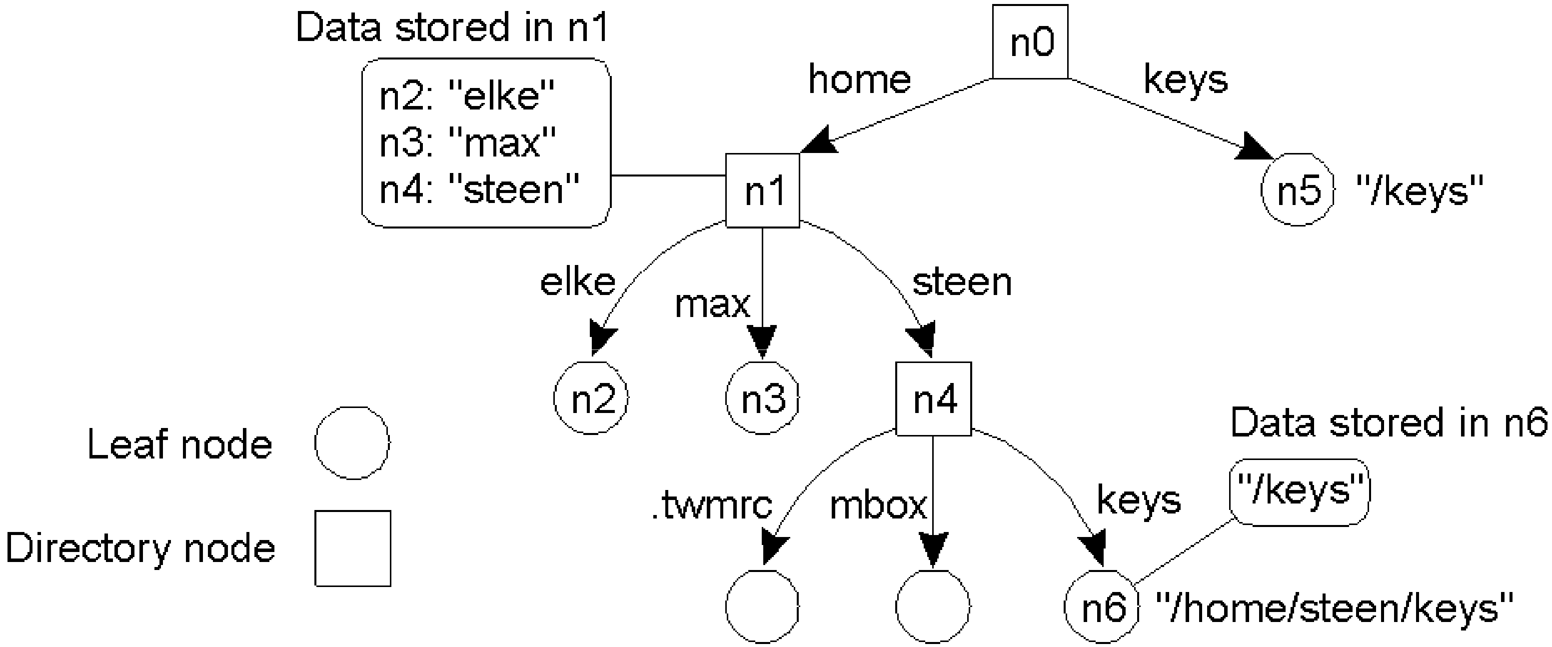
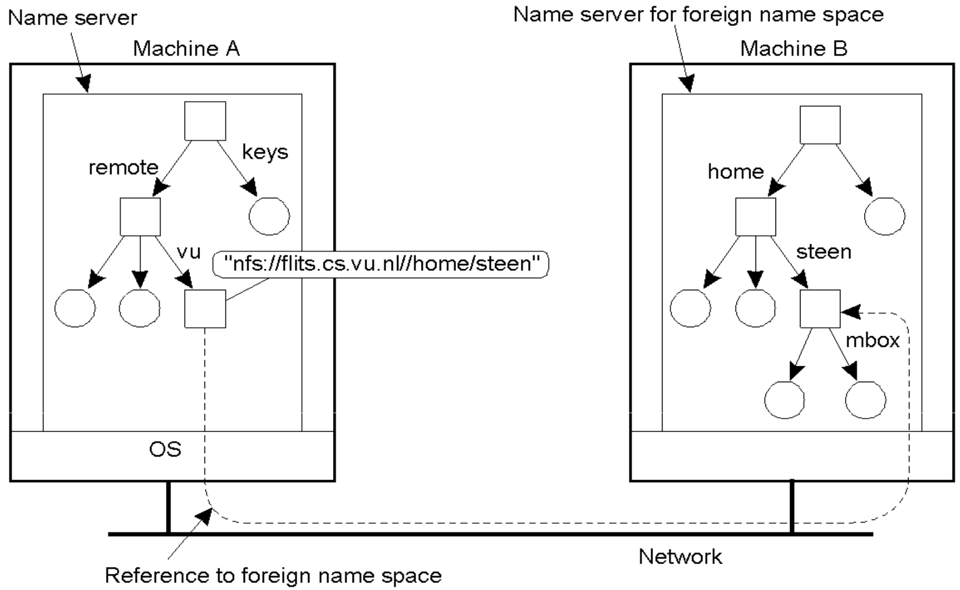
Filesystem



Data stored in n1
n2: "elke"
n3: "max"
n4: "steen"
n0
home
keys
n1
n5
"/keys"
elke
max
steen
n2
n3
n4
Leaf node
Directory node
Data stored in n6
"/keys"
.twmrc
mbox
keys
n6
"/home/steen/keys"

Joining namespaces

- Direct catenation, as in URLs
  - ftp://ftp.win.tue.nl/johanl
- Use name of system as a prefix
  - systemA:/home/...,
    systemB:/home/....
  - resolve in new root
- Symbolic linking
  - store reference in second name system as referred object
    - e.g. contents of /home/johanl/aap is oracle1://johanl
    - similar in effect to mounting, but less dynamic: stored within the file itself



- Mounting
  - (tell the resolution procedure that) from a certain prefix *p* on, a new resolution is used
    - mainly modification of resolution procedure
    - closure from *p* onward stored with *p* in a table of the *resolver*
    - transparent resolution

A distributed naming service

- A naming services provides
  - operation for adding, removing, and lookup of names
  - a *closure mechanism*: where does the search start?
    - Example closures: local, known fileserver, local, known DNS server, known gateway etc., just a context, ...
    - **notice**: at the place where two namespaces join, a closure mechanism must be included

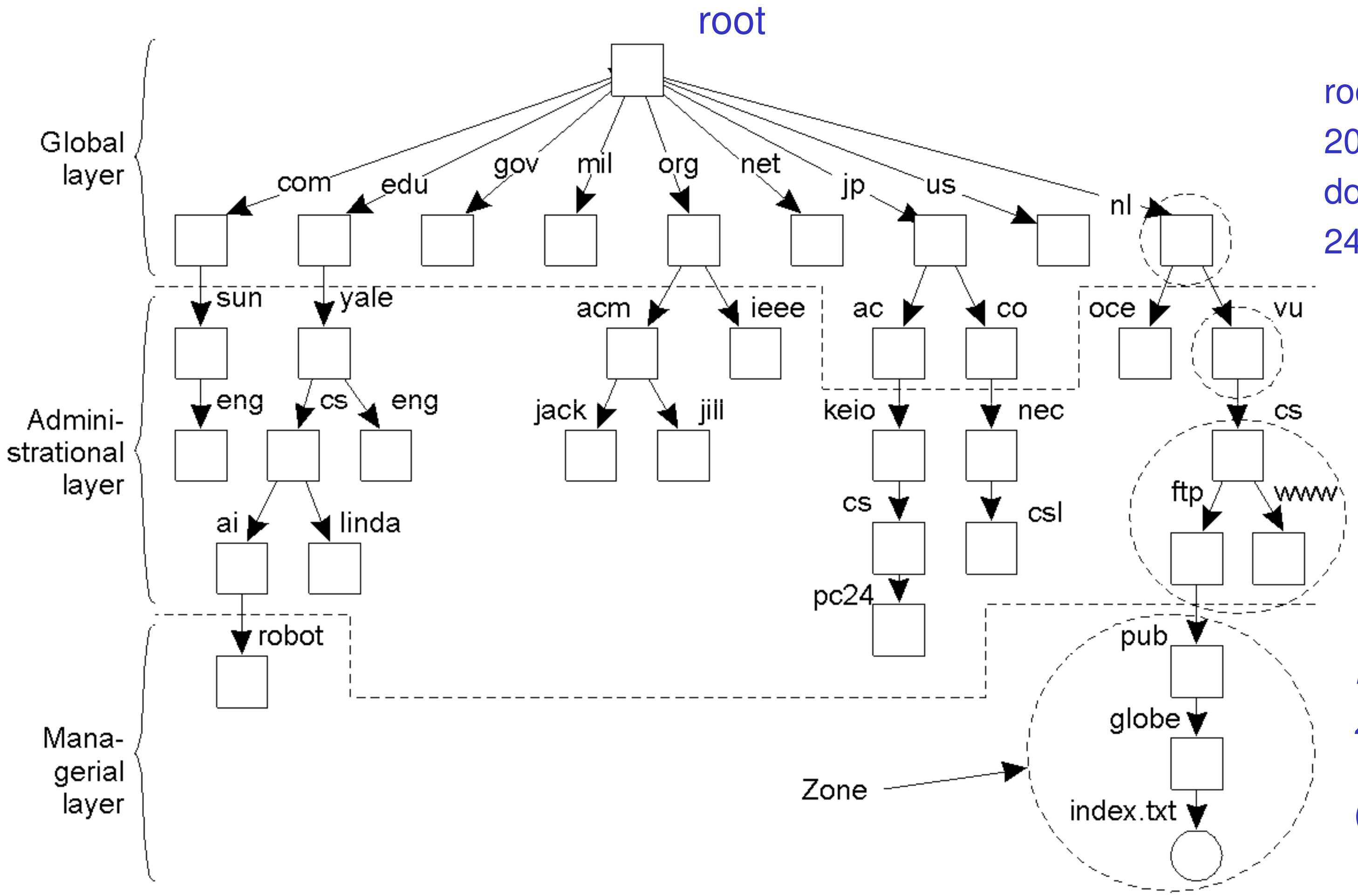
- For performance, scalability and dependability: distribute...
  - ...the data (i.e., directory nodes and subgraphs)
  - ...the process of name resolution

- Levels in the graph
  - Global
    - jointly managed by several administrations
    - changes are rare
  - Administrational
    - nodes managed by a single administration
  - Managerial
    - nodes within single administration mapped onto local nameservers
    - frequent changes

Comparison of layers

Item	Global	Administrational	Managerial
Geographical scale of network	Worldwide	Organization	Department
Total number of nodes	Few	Many	Vast numbers
Responsiveness to lookups	Seconds	Milliseconds	Immediate
Update propagation	Lazy	Immediate	Immediate
Number of replicas	Many	None or few	None
Is client-side caching applied?	Yes	Yes	Sometimes

Example: DNS namespace



root zone:
20 generic top-level domains
248 country-code TLDs

Domain: subtree

Zone: delegated portion of a domain

(though terms are often used interchangeably)

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DNS

- It is organized as a worldwide collection of name servers, collectively responsible for
  - maintaining the tree-like database of DNS
  - responding to queries aimed at finding a host IP address, as well as several other services (e.g. mail server)
- Levels in the graph
  - Global
    - the ‘roots’; jointly managed by several administrations
      - 13 replicated servers, named A-M
      - using *anycast* communication with clients
    - ~270+ top level domains, managed by
  - Administrational
    - nodes managed by a single administration (e.g. TU/e)
  - Managerial – book: not part of DNS
    - frequently changing local resources: part in URL after the DNS name
    - file system: e.g. your local website

DNS, extra-functional properties

- modification by different administrations
- extreme robustness
  - even under breaking apart of the distributed system
- scalability
  - usage parameters:
    - geographical spread
    - # machines
    - # queries
  - metrics:
    - query response time
  - scalability criterion
    - constant on average, at worst an occasional spike

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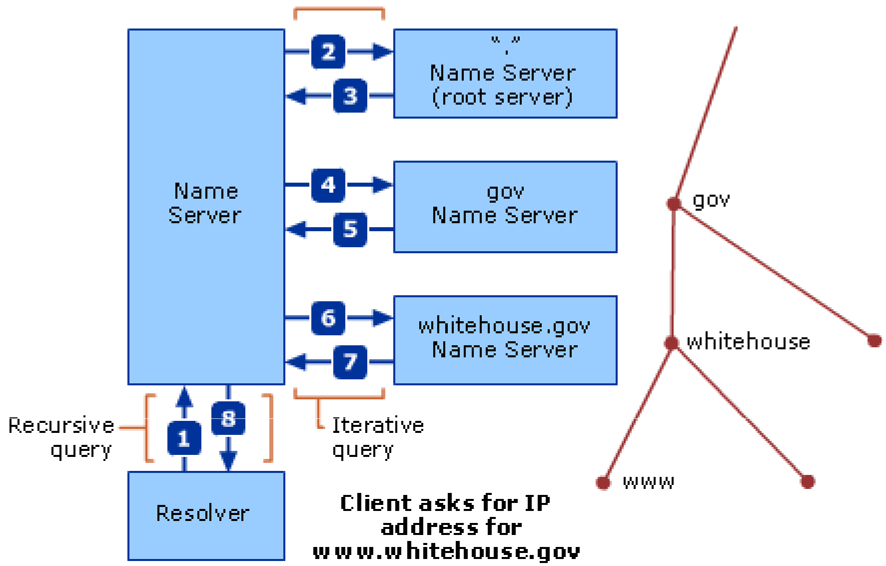
Name servers

- Name server serves a certain *zone*
  - authoritative or cached answer
  - authoritative server for a host: always maintains a record of that host
- Root servers: are authoritative for root and top-level domains
- Name servers are configured with addresses of root servers
- Name servers for a domain
  - know their child domains
  - are typically replicated: *primary* (initialized from file) and *secondary* server (synchronizes with primary)
- DNS is made available to applications as a middleware service
  - typically a library (*resolver*) that calls upon a configured name server
  - that server often uses *BIND (Berkeley Internet Name Daemon), named*



model in process view
from Microsoft technet

Distributed resolution

- Query: **resolve(dir, name1, name2, ...)**
- Server responsible for directory node **dir** performs one step and finds *newServer*
- **Iterative**: return *newServer* to client
  - caching: information becomes distributed
  - communication cost: from client to all named servers
- **Recursive**: pass remaining request on to *newServer*; pass result on to client
  - caching: follows name structure
  - communication cost:
    - exploits locality in name
    - but repeated queries do not enjoy optimization

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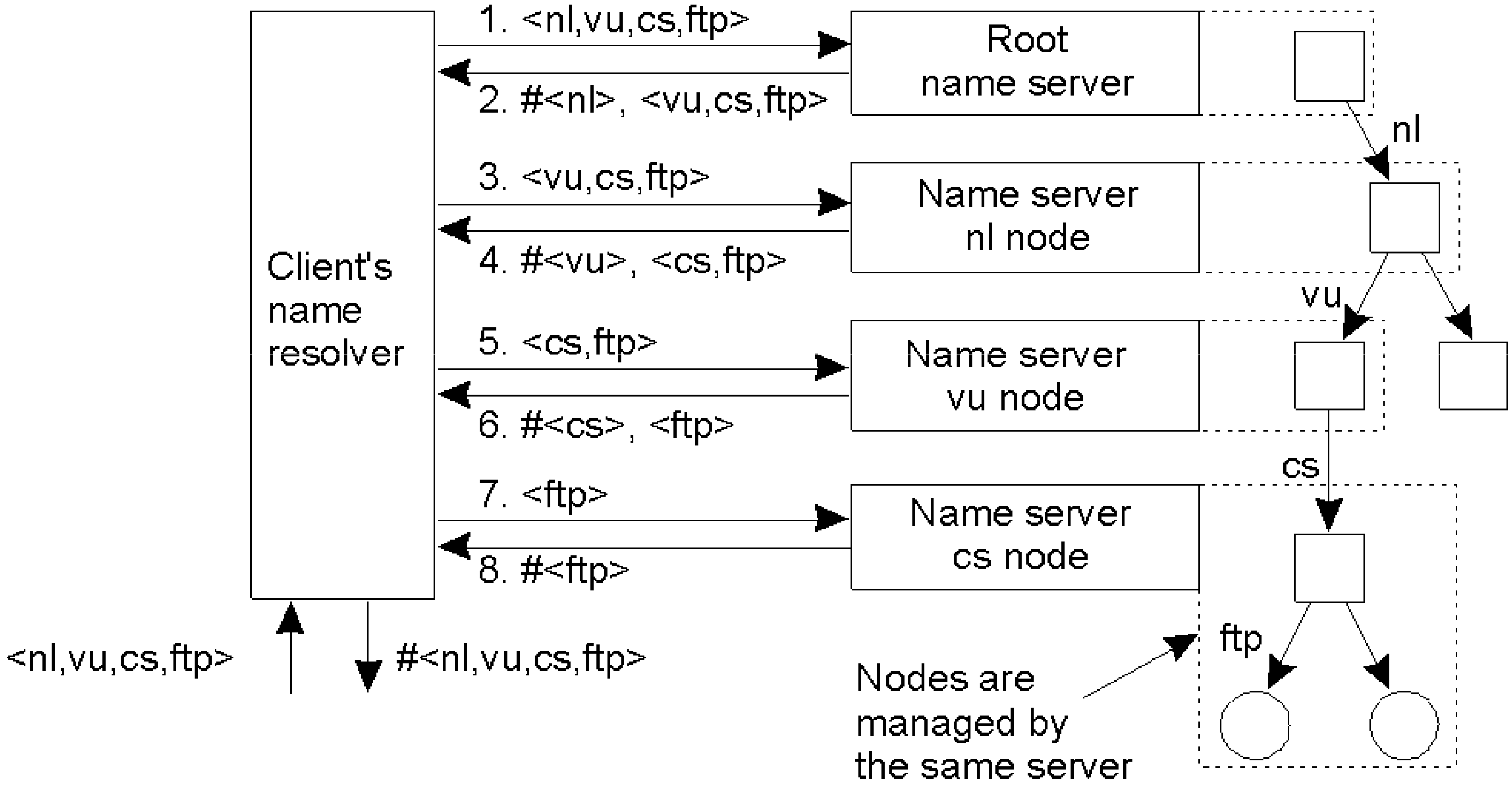
Iterative



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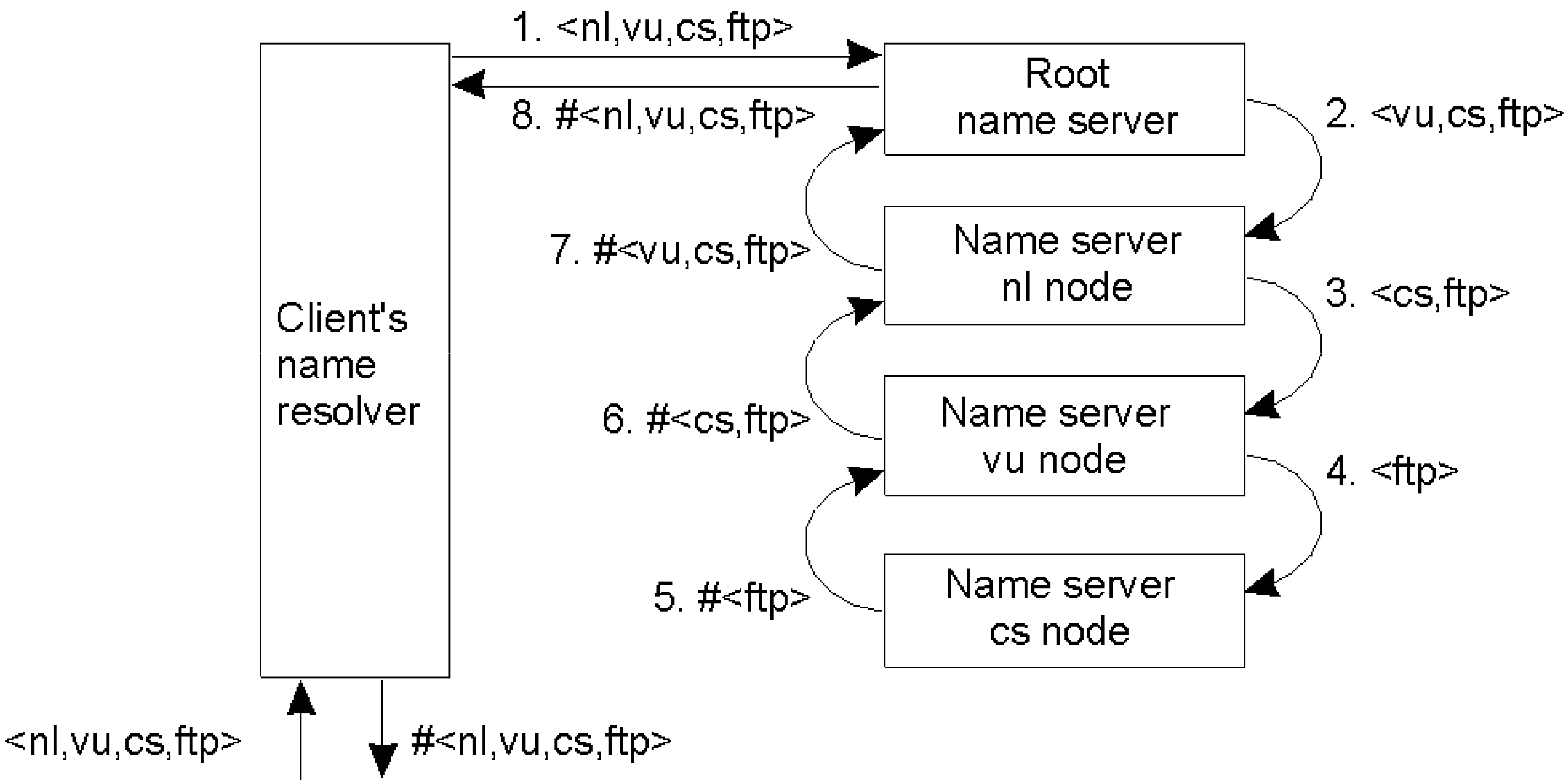
Recursive


1. <nl,vu,cs,ftp>
8. #<nl,vu,cs,ftp>
Root
name server
2. <vu,cs,ftp>
7. #<vu,cs,ftp>
Name server
nl node
3. <cs,ftp>
Client's
name
resolver
6. #<cs,ftp>
Name server
vu node
4. <ftp>
5. #<ftp>
Name server
cs node
<nl,vu,cs,ftp>
#<nl,vu,cs,ftp>

Caching

Server for node	Should resolve	Looks up	Passes to child	Receives and caches	Returns to requester
cs	<ftp>	#<ftp>	--	--	#<ftp>
vu	<cs,ftp>	#<cs>	<ftp>	#<ftp>	#<cs> #<cs, ftp>
ni	<vu,cs,ftp>	#<vu>	<cs,ftp>	#<cs> #<cs,ftp>	#<vu> #<vu,cs> #<vu,cs,ftp>
root	<ni,vu,cs,ftp>	#<nl>	<vu,cs,ftp>	#<vu> #<vu,cs> #<vu,cs,ftp>	#<nl> #<nl,vu> #<nl,vu,cs> #<nl,vu,cs,ftp>

- For the recursive case: see table
- For the iterative case: the iterative server caches all information
  - hence: client asks *local name server* (and not the root server) in a recursive way
  - name server operates iteratively to improve caching

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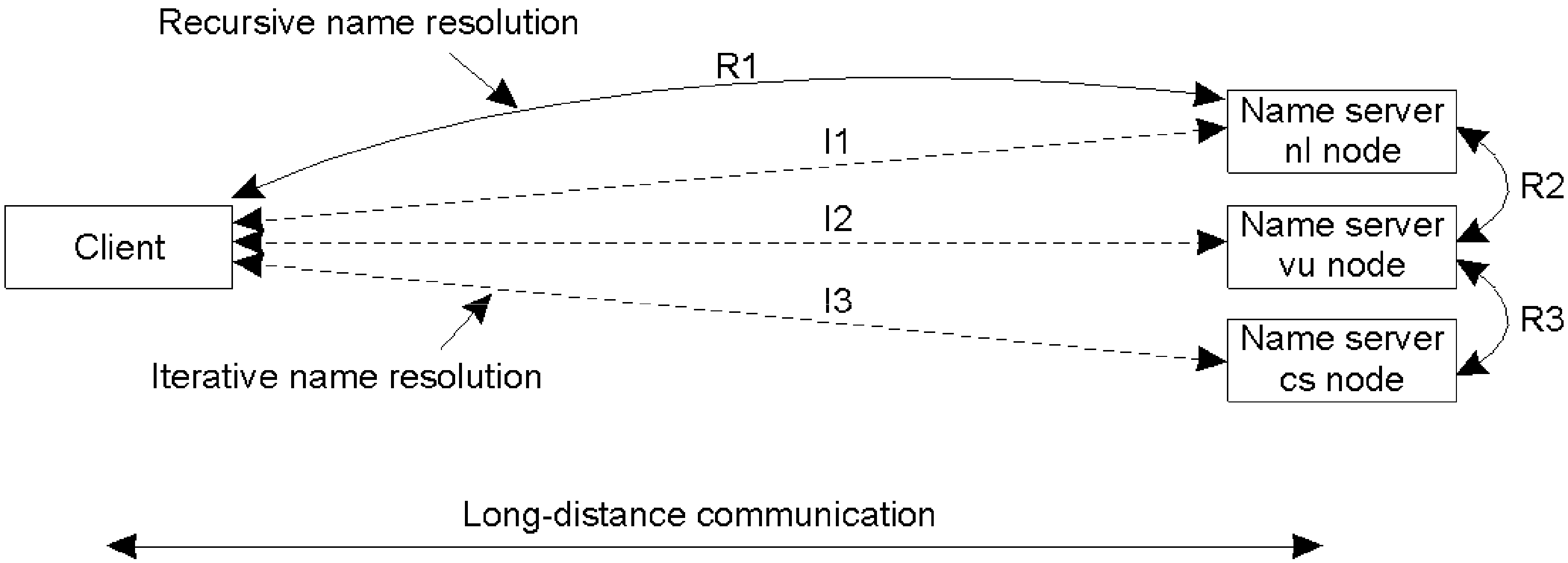
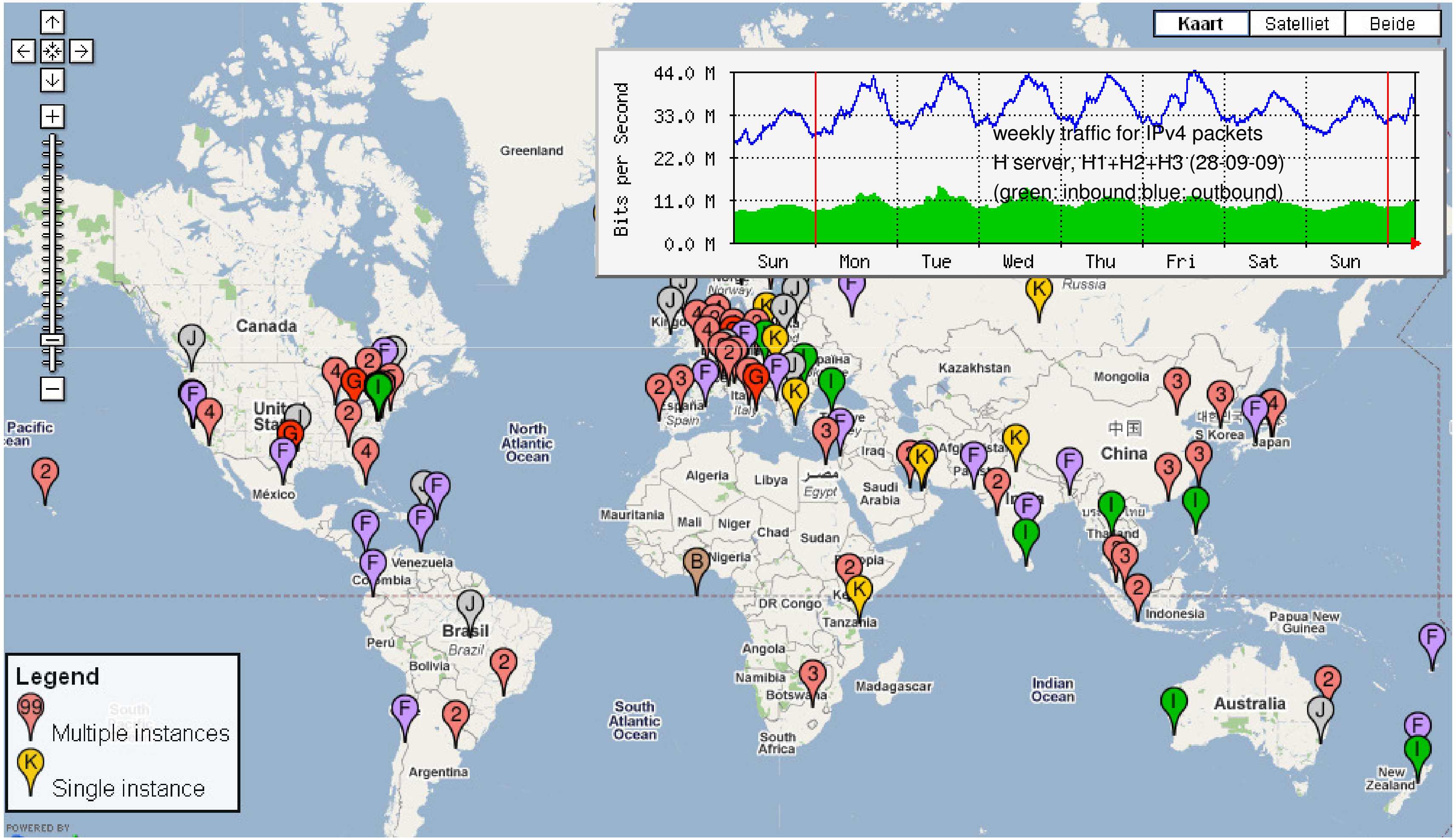
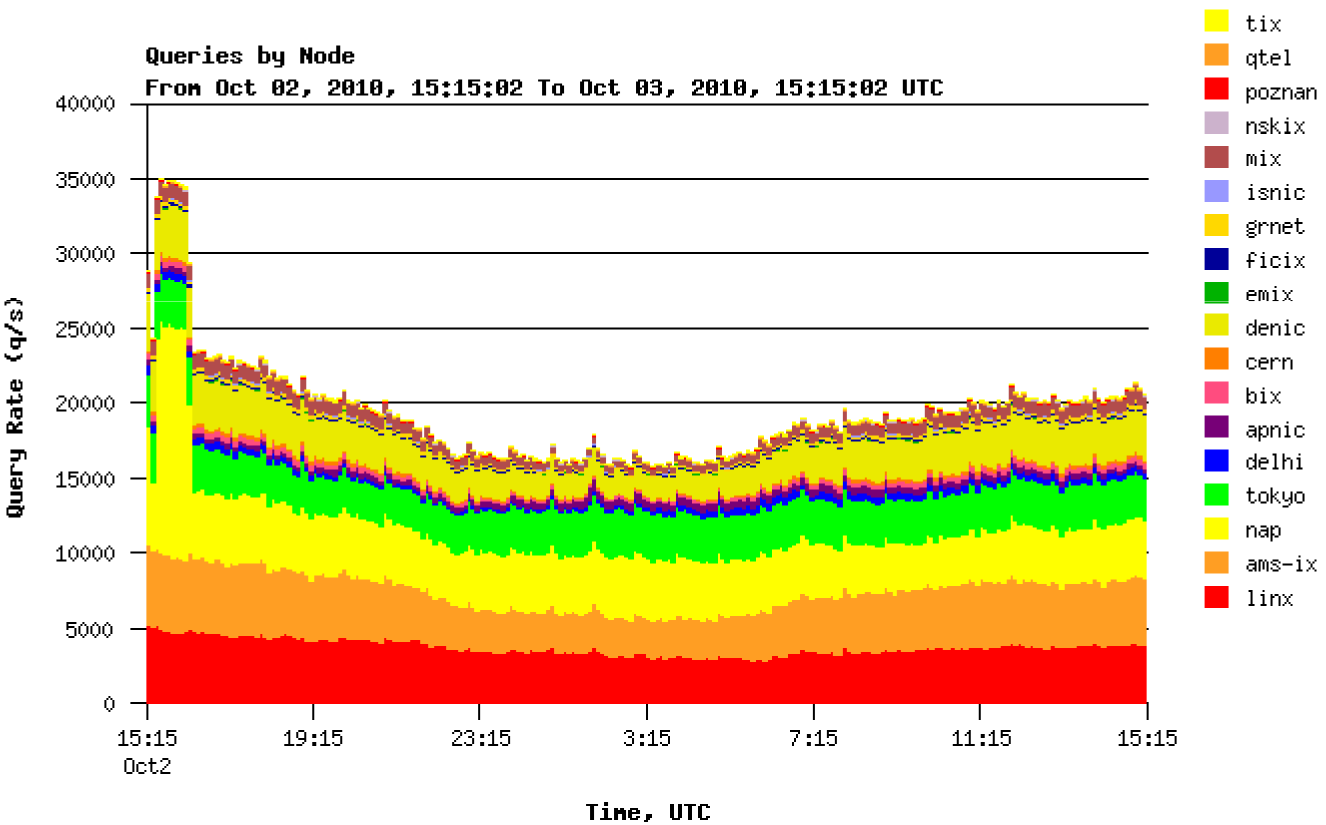
Communication cost



Root servers (25-09-09) and replications



k-servers traffic



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Some information about root servers

- Investigation in 2002 on f-servers: 19% of the calling hosts and 98% of all queries is not legitimate, e.g.,
  - query a local address
  - query an IP address rather than a DNS name
  - query a non-existent TLD
  - lousy installations of DNS clients or erroneous implementations
    - e.g. filtering inbound DNS but not outbound traffic (blocking responses)
  - 'stub' servers call a root server directly
- Servers are fast (see figure)
- Many servers are replicated
  - e.g. F has 46 sites (in 2009)

Server	Best	Average	Worst	Timeouts	Avg Response Time	Graph
a.root-servers.net	36ms	37ms	39ms	0%	1ms	
b.root-servers.net	38ms	41ms	90ms	0%	3ms	
c.root-servers.net	29ms	30ms	39ms	0%	1ms	
d.root-servers.net	38ms	38ms	40ms	0%	0ms	
e.root-servers.net	114ms	117ms	121ms	0%	3ms	
f.root-servers.net	43ms	44ms	48ms	0%	1ms	
g.root-servers.net	152ms	157ms	221ms	0%	5ms	
h.root-servers.net	43ms	43ms	51ms	0%	0ms	
i.root-servers.net	44ms	46ms	59ms	0%	2ms	
j.root-servers.net	2ms	3ms	21ms	0%	1ms	
k.root-servers.net	63ms	64ms	91ms	0%	1ms	
l.root-servers.net	44ms	44ms	53ms	0%	0ms	
m.root-servers.net	120ms	128ms	142ms	0%	8ms	
a.gtld-servers.net	54ms	58ms	86ms	0%	4ms	
b.gtld-servers.net	129ms	131ms	185ms	0%	2ms	
c.gtld-servers.net	43ms	45ms	63ms	0%	2ms	
d.gtld-servers.net	26ms	30ms	46ms	0%	4ms	

from DNSstuff.com

Scaling

- Response time depends on depth of search
- Global servers get lots of requests
  - need to limit traffic / source
- Strategies
  - replicate
    - multiple servers at global and administrational level
    - using anycast and geoDNS
      - geoDNS: respond with server IP closest to query source
  - closure mechanism: start at local server that uses caching
  - addresses are assumed not to change very frequent
    - e.g. 24h-48h for TLD
    - does not work with highly mobile devices

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DNS: database

- Each domain has a set of associated *resource records*
  - for a single host: just its IP address
- A name server can give an *authorative* answer about the resource records it manages
  - for which is has a *Start of Authority* record
- Record contains
  - domain name
  - time to live
  - class – mostly IN(ternet)
  - type
  - value

Resource record in DNS

Type of record	Associated entity	Description
SOA	Zone	Holds information on the represented zone
A	Host	Contains an IP address of the host this node represents
MX	Domain	Refers to a mail server to handle mail addressed to this domain
SRV	Domain	Refers to a server handling a specific service
NS	Zone	Refers to a name server that implements the represented zone
CNAME	Node	Symbolic link with the primary name of the represented node
PTR	Host	Contains the canonical name of a host
HINFO	Host	Holds information on the host this node represents
TXT	Any kind	Contains any entity-specific information considered useful

Example database for domain cs.vu.nl

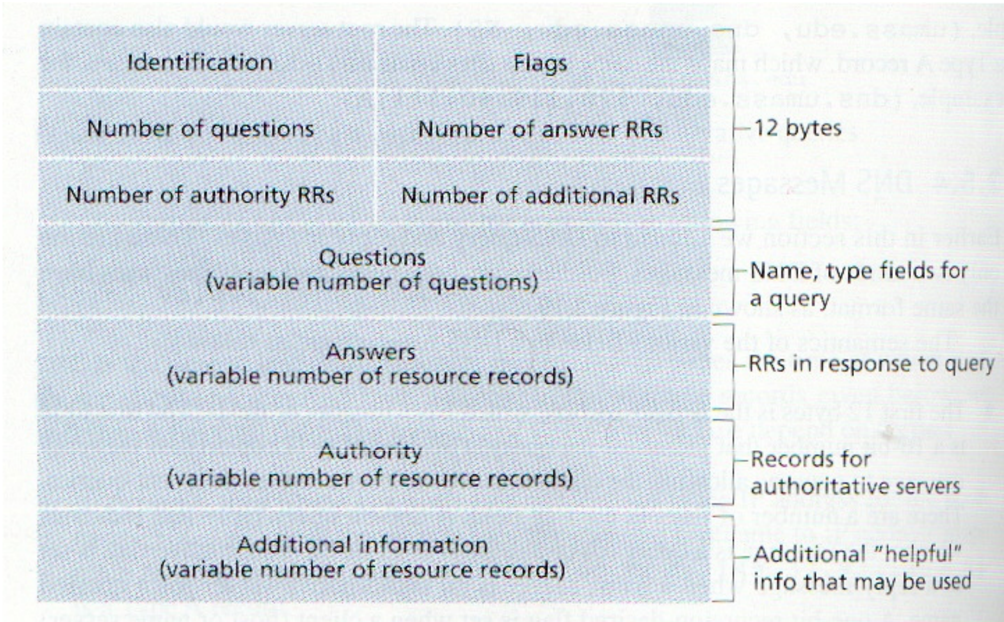
Name	Record type	Record value
cs.vu.nl.	SOA	star.cs.vu.nl. hostmaster.cs.vu.nl. 2005092900 7200 3600 2419200 3600
cs.vu.nl.	TXT	"Vrije Universiteit - Math. & Comp. Sc."
cs.vu.nl.	MX	1 mail.few.vu.nl.
cs.vu.nl.	NS	ns.vu.nl.
cs.vu.nl.	NS	top.cs.vu.nl.
cs.vu.nl.	NS	solo.cs.vu.nl.
cs.vu.nl.	NS	star.cs.vu.nl.
star.cs.vu.nl.	A	130.37.24.6
star.cs.vu.nl.	A	192.31.231.42
star.cs.vu.nl.	MX	1 star.cs.vu.nl.
star.cs.vu.nl.	MX	666 zephyr.cs.vu.nl.
star.cs.vu.nl.	HINFO	"Sun" "Unix"
zephyr.cs.vu.nl.	A	130.37.20.10
zephyr.cs.vu.nl.	MX	1 zephyr.cs.vu.nl.
zephyr.cs.vu.nl.	MX	2 tornado.cs.vu.nl.
zephyr.cs.vu.nl.	HINFO	"Sun" "Unix"

Example (cnt'd)

ftp.cs.vu.nl.	CNAME	soling.cs.vu.nl.
www.cs.vu.nl.	CNAME	soling.cs.vu.nl.
soling.cs.vu.nl.	A	130.37.20.20
soling.cs.vu.nl.	MX	1 soling.cs.vu.nl.
soling.cs.vu.nl.	MX	666 zephyr.cs.vu.nl.
soling.cs.vu.nl.	HINFO	"Sun" "Unix"
vucs-das1.cs.vu.nl.	PTR	0.198.37.130.in-addr.arpa.
vucs-das1.cs.vu.nl.	A	130.37.198.0
inkt.cs.vu.nl.	HINFO	"OCE" "Proprietary"
inkt.cs.vu.nl.	A	192.168.4.3
pen.cs.vu.nl.	HINFO	"OCE" "Proprietary"
pen.cs.vu.nl.	A	192.168.4.2
localhost.cs.vu.nl.	A	127.0.0.1

Packet format

- UDP carrier
- Header:
  - id(16),
  - query?(1),
  - opcode (standard, inverse, server status)(4)
  - authoritative?(1)
  - truncated?(1) [lost bytes beyond the 512]
  - recursion desired?(1)
  - recursion available(1)
    - server response
- Later, extended with security measures to avoid tampering
  - secure carrier
  - signing



- The limit of 512 bytes has consequences

  The query: 'who serves the root' ('.', or the empty domain) has as answer: the list of root servers

  This list consists of

  NS records: name of name server

  A records: address of name server

  Of these, only 13 fit in a single packet

  Hence, 13 root servers

Concluding remarks

- A DHT-based implementation of DNS where names are hashed is possible as well
  - this can be done for *any* naming system in which we can derive some serial representation systematically
  - although the structure then disappears

- The DNS lookup (or structured lookup) is, in fact, based on a *key*

- Instead, a lookup based on attribute values – including searching and wildcards – can be needed
  - a list of (attribute, value) pairs is called a *directory*
  - service is termed:, *directory services*, in contrast to a *naming service*
    - OSI X.500 directory service
    - LDAP, Lightweight Directory Access Protocol
      - MS Active Directory