Network Basics

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Textbooks

- TANENBAUM A, WETHERALL D. *Computer Networks*. 5th ed. Pearson Prentice Hall, 2011.
- KUROSE J, ROSS K. *Computer Networking: A Top-down Approach*. Pearson, 2013.
- FALL K, STEVENS W. *TCP/IP Illustrated, Volume 1: The Protocols*. Pearson Education, 2011.

Homework

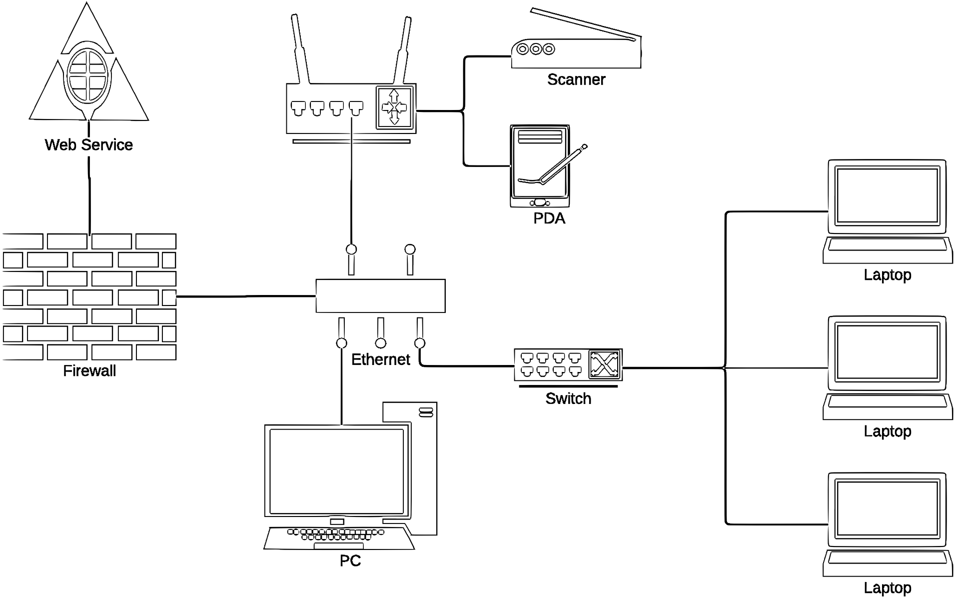
Weekly tech question

1. What was I trying to do?
2. How did I do it? (steps)
3. The expected output? The real output?
4. How did I try to solve it? (steps, books, web links)
5. How many hours did I struggle on it?

- https://cs6.swfu.edu.cn/moodle/mod/forum/view.php?id=98
- `wx672ster+net@gmail.com`
- Preferably in English
- in stackoverflow style

OR simply show me the tech questions you asked on any website

What's A Computer Network?



The History of Internet I

1836: Telegraph
1858-66: Transatlantic cable
1876: Telephone
1957: USSR launches Sputnik
1962-68: *Packet-switching* networks developed
1969: Birth of Internet
1971: People communicate over a network
1972: Computers can connect more freely and easily
1973: Global Networking becomes a reality
1974: Packets become mode of transfer

The History of Internet II

1976: Networking comes to many

1977: E-mail takes off, Internet becomes a reality

1979: News Groups born

1981: Things start to come together

1982: *TCP/IP* defines future communication

1983: Internet gets bigger

1984: Growth of Internet Continues

1986: Power of Internet Realised

1987: Commercialisation of Internet Born

1989: Large growth in Internet

The History of Internet III

- 1990: Expansion of Internet continues
- 1991: Modernisation Begins
- 1992: Multimedia changes the face of the Internet
- 1993: The WWW Revolution truly begins
- 1994: Commercialisation begins
- 1995: Commercialisation continues apace
- 1996: Microsoft enters
- 1998: Google
- Homework: Meanwhile, what happened in China?

What's The Internet?

What pops up in your mind if I say "Internet"?

What’s The Internet?

What pops up in your mind if I say “Internet”?

For me, the answer is...

Google

and...

What's The Internet?

What pops up in your mind if I say “Internet”?

For me, the answer is...

Google

and...

TCP/IP

What's The Internet?

- The network of networks.
- Tech view: `TCP/IP`
- App view: Google

Google Philosophy

Ten things Google has found to be true

1. Focus on the user and all else will follow.
2. It's best to do one thing really, really well.
3. Fast is better than slow.
4. Democracy on the web works.
5. You don't need to be at your desk to need an answer.
6. *You can make money without doing evil.*
7. There's always more information out there.
8. The need for information crosses all borders.
9. You can be serious without a suit.
10. Great just isn't good enough.

Google Philosophy

More about...

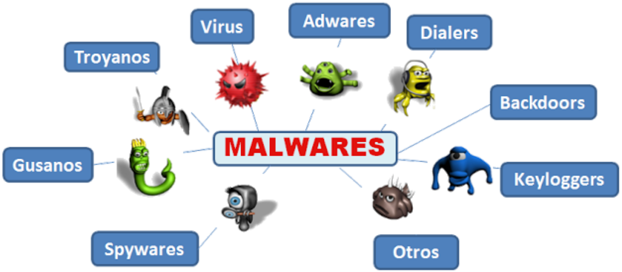
- Software Principles
- Google User Experience
- No pop-ups
- Security

Google Products

Choosing The Right Tools

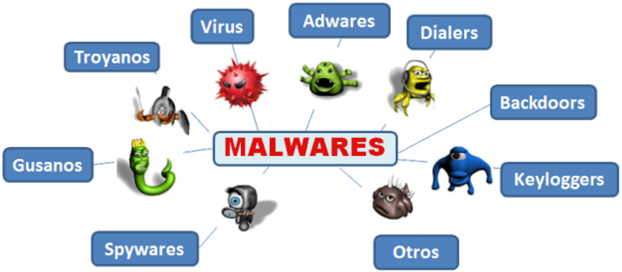
vs.

Danger

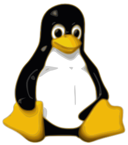


Virus
Adwares
Dialers
Troyanos
Backdoors
MALWARES
Gusanos
Keyloggers
Spywares
Otros

Danger



My solution



Homework

1. try 
2. get a gmail account
3. add your class timetable into google calendar, and then share your calendar to me via gmail
4. in youtube, find a video you like and share it to me

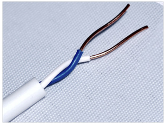
Network Classification

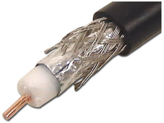
- connection method: wired, wireless...
- topology
- scale
- network architecture: c/s, p2p...

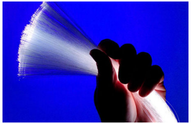
Network Classification

Connection method

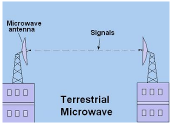
Wired:

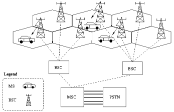






Wireless:



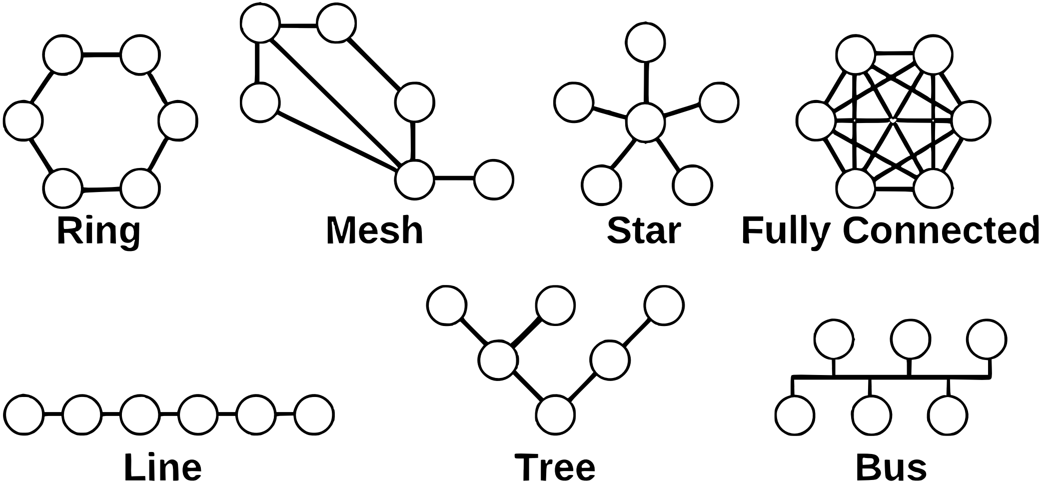


Bluetooth®

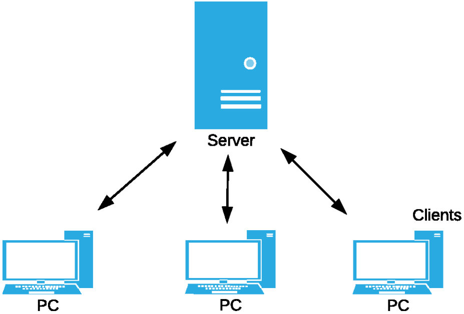
Scale

PAN, LAN, CAN, MAN, WAN ...

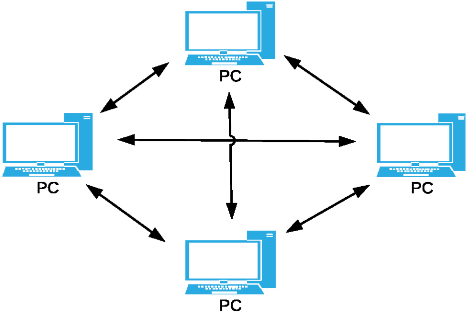
Topology



Network Architecture



Client/Server



Peer to Peer

Basic Hardware Components

IP			Router: 
Link		Bridge: 	Switch: 
PHY	NIC: 	Repeater: 	Hub: 

Repeater, Hub

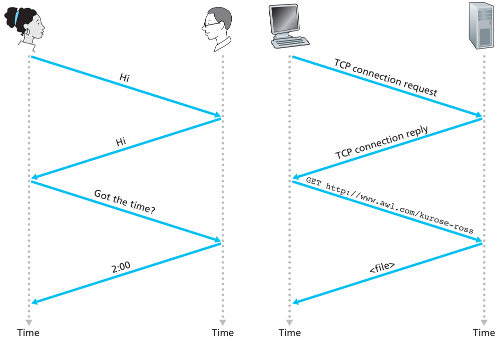
Repeater connects network segments at the physical layer.

Hub a multi-port repeater

- simple, cheap
- Repeaters/Hubs do NOT isolate collision domains.
- 100m maximum

What's a Protocol?

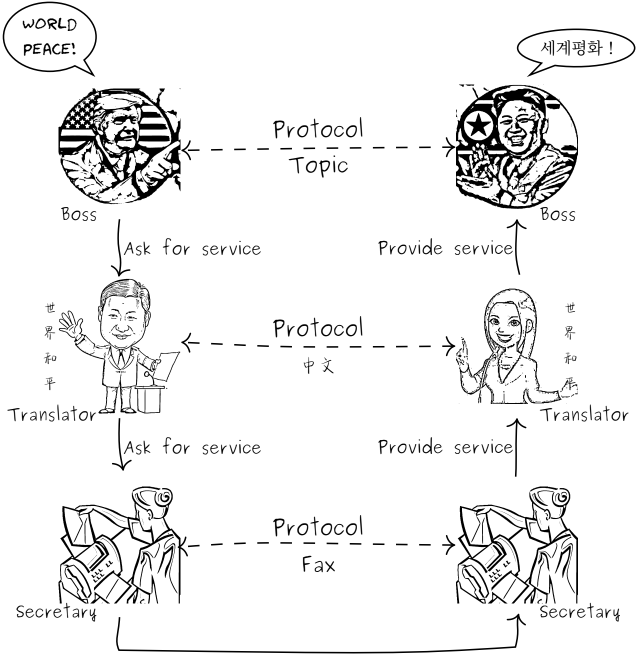
A rule, a treaty, an agreement, ...



What's TCP/IP?

A set of protocols designed for the Internet

```
 ----------------------------------
|      network applications        |  Application layer
|                                  |
|...  \ | /  ..  \ | /  ...        |-
|     -----      -----             |
|     |TCP|      |UDP|             |  Transport layer
|     -----      -----             |
|         \      /                 |-
|         --------                 |
|         |  IP  |                 |
|   ----- -*------                 |  Network layer
|   |ARP|  |                       |
|   -----  |                       |
|      \   |                       |-
|      ------                      |
|      |ENET|                      |  Network interface layer
|      ---@--                      |
 ---------|------------------------
          |
----------o-----Ethernet Cable------
```

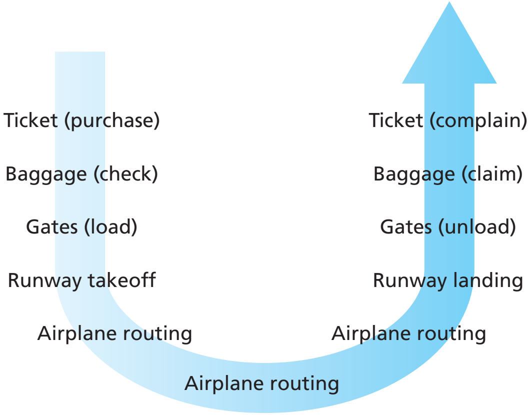


Each protocol is completely independent of the other ones

- The translators (L2) can switch from Chinese to Finnish without touching L1 or L3
- The secretaries (L1) can switch from fax to email without disturbing (or even informing) the other layers

Layered Design Example

Taking an airplane trip

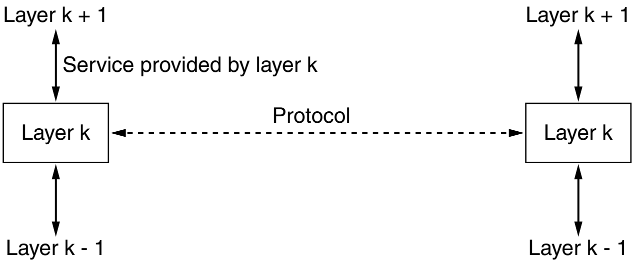


Each layer

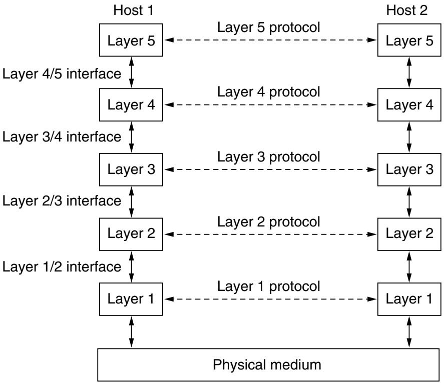
1. has some functions
2. provides services to its upper layer

Layered Design

Services vs. Protocols



Services	**Protocols**
Layer to Layer	Peer to Peer
A set of operations (listen, connect, accept, receive, send, disconnect)	A set of rules (message format, message meanings)



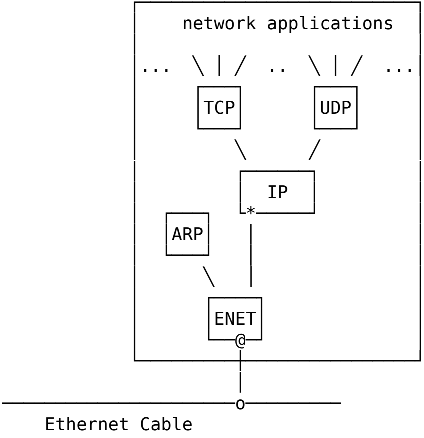
TCP/IP Protocol Stack

Every networked computer has it inside

<table>
<tr><td>Application</td><td rowspan="3">Application</td><td rowspan="3">Application</td></tr>
<tr><td>Presentation</td></tr>
<tr><td>Session</td></tr>
<tr><td>Transport</td><td>Transport</td><td>Transport</td></tr>
<tr><td>Network</td><td>Network</td><td>Network</td></tr>
<tr><td>Data Link</td><td rowspan="2">Network Interface</td><td>Data Link</td></tr>
<tr><td>Physical</td><td>Physical</td></tr>
<tr><td>ISO/OSI RM</td><td>TCP/IP</td><td>My Favor</td></tr>
</table>

TCP/IP Overview

Basic Structure

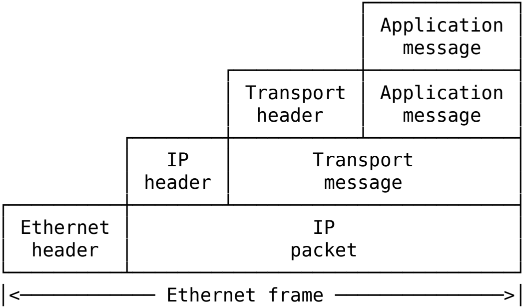


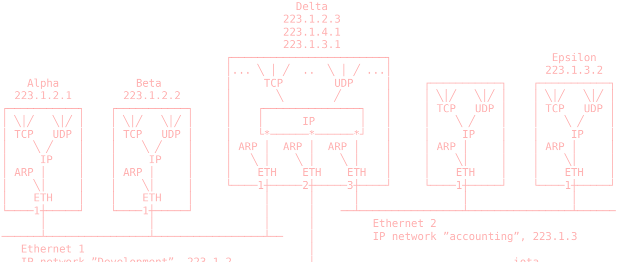
1. Where will an incoming Ethernet frame go?
   - 0x0806 → ARP
   - 0x0800 → IP
2. Where will an incoming IP packet go?
   - 0x06 → TCP
   - 0x11 → UDP
3. Where will an incoming transport message (UDP datagram, TCP segment) go?

HTTP	FTP	SSH	SMTP
80	21/20	22	25

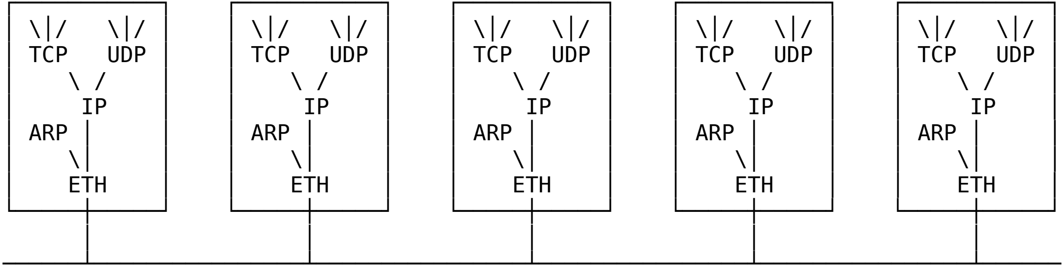
The Name Of A Unit Of Data

APP	Application message
TRANS	TCP segment; UDP datagram
NET	IP packet
LINK	Ethernet frame





Ethernet



1. Frame format?
2. Address format?
3. Broadcast address?
4. CSMA/CD?

Ethernet Frame

<table>
<tr><th>0</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr>
<tr><td colspan="6">Destination MAC Address</td></tr>
<tr><td colspan="6">Source MAC Address</td></tr>
<tr><td colspan="2">Type</td><td colspan="4">MAC Data</td></tr>
<tr><td colspan="6">MAC Data ... (46 – 1500 bytes)</td></tr>
<tr><td colspan="2">MAC Data</td><td colspan="4">FCS</td></tr>
</table>

Examples

Unicast, carrying an IP packet

Destination	Source	Type	MAC Data	
08005A21A722	0800280038A9	0x0800	IP packet	FCS

Unicast, carrying an ARP packet

Destination	Source	Type	MAC Data	
0800280038A9	08005A21A722	0x0806	ARP Response	FCS

Broadcast, carrying an ARP packet

Destination	Source	Type	MAC Data	
FFFFFFFFFFFF	0800280038A9	0x0806	ARP Request	FCS

Bridge, Switch

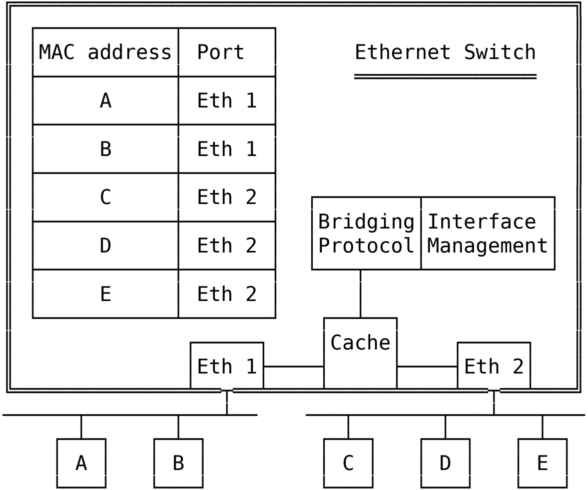
Bridge connects multiple network segments at the data link layer (layer 2)

Switch a multi-port bridge

Transparent bridging

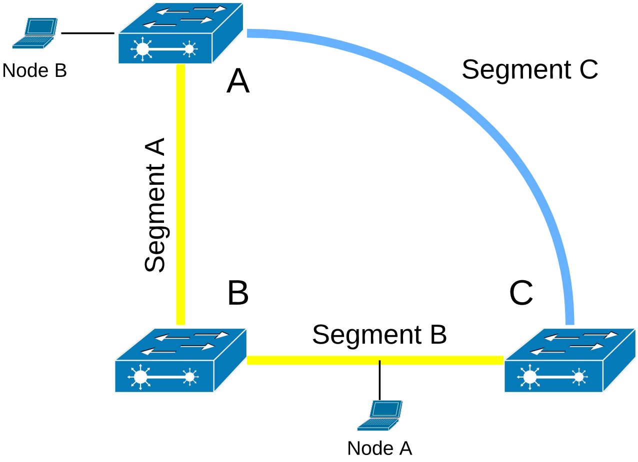
Uses a forwarding database to send frames across network segments

- Learning
- Flooding
- Forwarding
- Filtering
- Aging

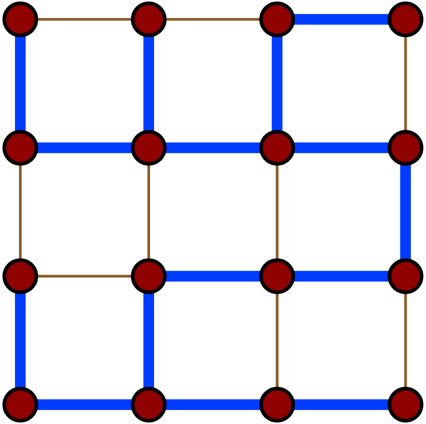


Switch Loop

- ☺ Redundancy — Eliminating the single point of failure
- ☹ Broadcast storm — Resulting in potentially severe network congestion



Spanning Tree Protocol (STP) is a network protocol that ensures a loop-free topology for any bridged Ethernet local area network.



Algorhyme

I think that I shall never see
A graph more lovely than a tree.

A tree whose crucial property
Is loop-free connectivity.

A tree that must be sure to span
So packets can reach every LAN.

First, the root must be selected.
By ID, it is elected.

Least cost paths from root are traced.
In the tree, these paths are placed.

A mesh is made by folks like me
Then bridges find a spanning tree.

— Radia Perlman

Ethernet References

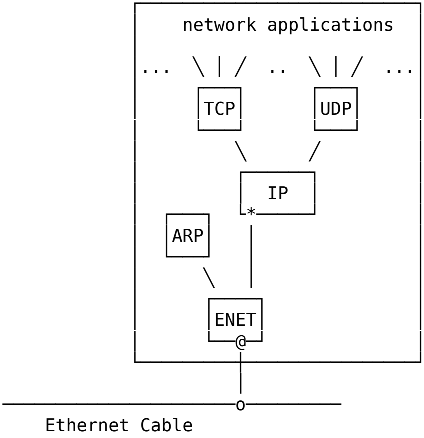
- Wikipedia. *Ethernet — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Ethernet&oldid=648082976.
- Wikipedia. *Ethernet frame — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Ethernet%5C_frame&oldid=653337888.
- Wikipedia. *Carrier sense multiple access with collision detection — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Carrier%5C_sense%5C_multiple%5C_access%5C_with%5C_collision%5C_detection&oldid=648771859.
- POSTEL J, REYNOLDS J. *Standard for the transmission of IP datagrams over IEEE 802 networks*. RFC Editor. 1988. https://www.rfc-editor.org/rfc/rfc1042.txt.
- Wikipedia. *Network switch — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Network%5C_switch&oldid=646928384.
- Wikipedia. *LAN switching — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=LAN%5C_switching&oldid=651228780.

ARP

ARP Looking up the ARP table to find the destination MAC address.

Example ARP table

IP address	Ethernet address
223.1.2.1	08-00-39-00-2F-C3
223.1.2.3	08-00-5A-21-A7-22
223.1.2.4	08-00-10-99-AC-54



Where does the ARP table come from?

Example ARP Request

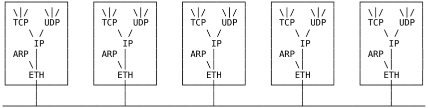
Sender IP Address	223.1.2.1
Sender Eth Address	08-00-39-00-2F-C3
Target IP Address	223.1.2.2
Target Eth Address	00-00-00-00-00-00

Example ARP Response

Sender IP Address	223.1.2.2
Sender Eth Address	08-00-28-00-38-A9
Target IP Address	223.1.2.1
Target Eth Address	08-00-39-00-2F-C3

The updated table

IP address	Ethernet address
223.1.2.1	08-00-39-00-2F-C3
223.1.2.2	08-00-28-00-38-A9
223.1.2.3	08-00-5A-21-A7-22
223.1.2.4	08-00-10-99-AC-54

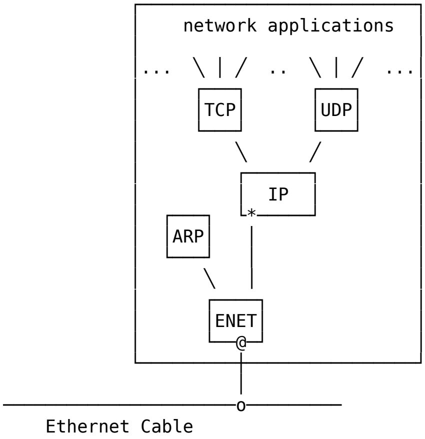


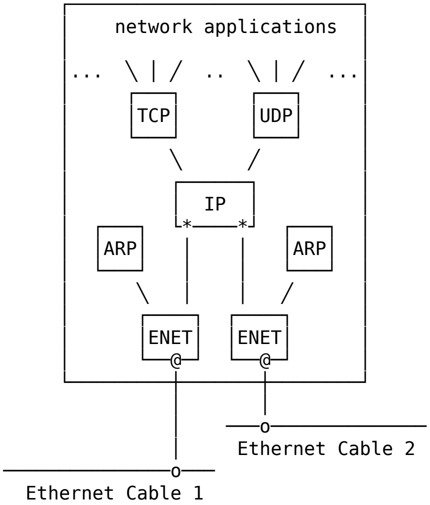
ARP References

- Wikipedia. *Address Resolution Protocol — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Address%5C_Resolution%5C_Protocol&oldid=647148843.
- PLUMMER D. *An Ethernet Address Resolution Protocol: Or Converting Network Protocol Addresses to 48.bit Ethernet Address for Transmission on Ethernet Hardware*. RFC Editor. 1982. https://www.rfc-editor.org/rfc/rfc826.txt.

IP

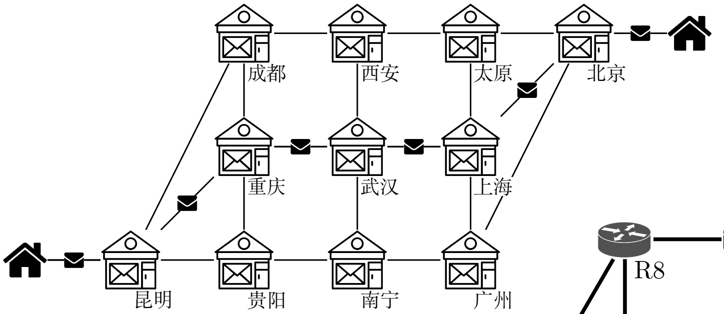
Router

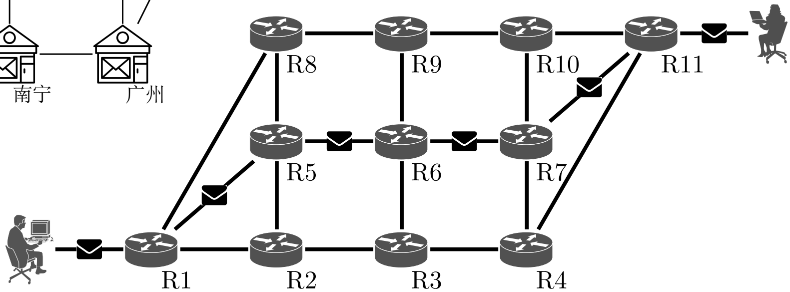




Routing Find a route in the route table.

Mail vs. E-mail





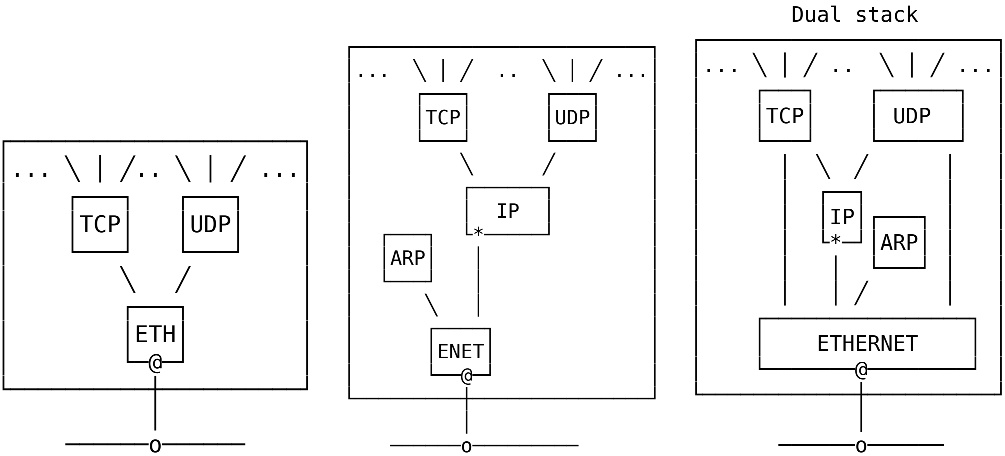
Direct Routing — IP is overhead

```
   A          B          C
   |          |          |
---o----------o----------o---
Ethernet 1
IP network "development"
```

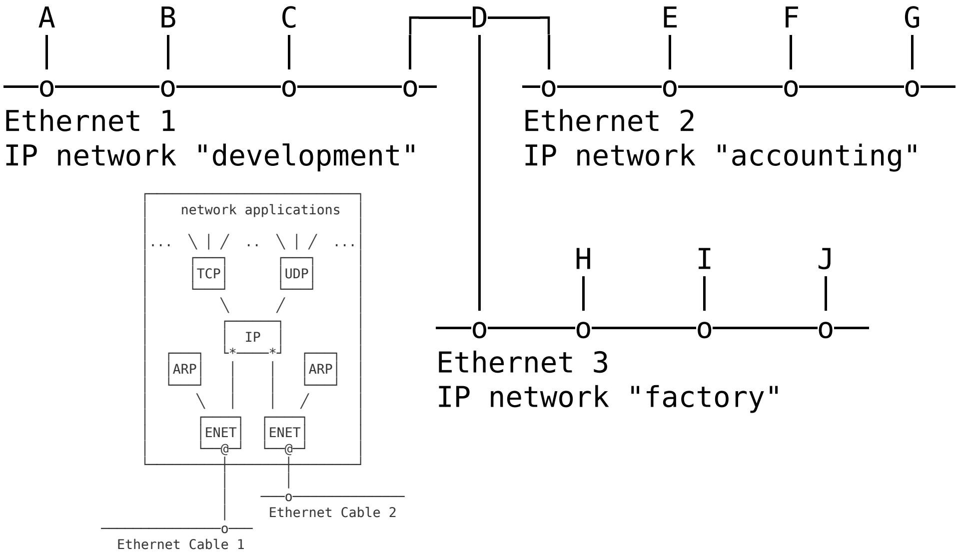
$A \Rightarrow B$

Address	Source	Destination
IP	A	B
Eth	A	B

Is IP Necessary?



Indirect Routing



A ⇒ E

```
        A         B         C         ┌───D───┐        E         F         G
        |         |         |         |   |   |        |         |         |
    ────o─────────o─────────o─────────o─  |  ─o────────o─────────o─────────o──
    Ethernet 1                            |   Ethernet 2
    IP network "development"              |   IP network "accounting"
                                          |
                                          |
                                          |      H         I         J
                                          |      |         |         |
                                        ──o──────o─────────o─────────o──
                                        Ethernet 3
                                        IP network "factory"
```

Before D

address	source	destination
IP	A	E
Eth	A	D

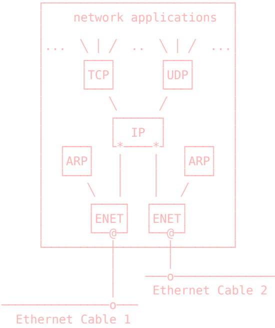
After D

address	source	destination
IP	A	E
Eth	D	E

IP Module Routing Rules

1. For an outgoing IP packet, entering IP from an upper layer, IP must decide
   - whether to send the IP packet directly or indirectly, and
   - IP must choose a lower network interface.

   These choices are made by consulting the route table.
2. For an incoming IP packet, entering IP from a lower interface, IP must decide
   - whether to forward the IP packet or pass it to an upper layer.
   - If the IP packet is being forwarded, it is treated as an outgoing IP packet.
3. When an incoming IP packet arrives it is never forwarded back out through the same network interface.



IP Address

An IPv4 address (dotted-decimal notation)

172 . 16 . 254 . 1

10101100.00010000.11111110.00000001

One byte = Eight bits

Thirty-two bits (4 x 8), or 4 bytes

Address classes

```
A: | 0 | Net bits (8)  |          Local address bits (24)          |
   |     0~127         |

B: | 1 0 |       Net bits (16)       |   Local address bits (16)   |
   |     128~191       |

C: | 1 1 0 |              Net bits (24)               | Local bits (8) |
   |     192~223       |

D: | 1 1 1 |                      Reserved                           |
   |     224~255       |
```

Network bits?

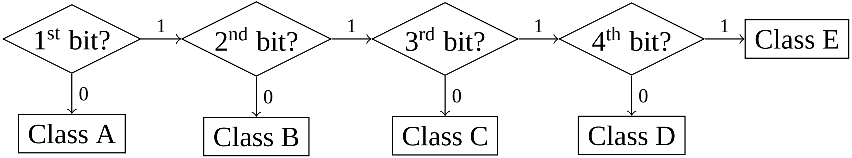
Do maths on the first 8 bits

Dst IP: `11000000.10101000.10101000.10101000`

Example route table

Destination	Gateway	Iface
<u>00001010</u>.00000000.00000000.00000000	*	1
<u>10101100.00010000</u>.00000000.00000000	*	2
<u>11000000.10101000.10101000</u>.00000000	*	3

Prefix — A faster way to decide network bits



Special IP Addresses

- A value of zero in the network field means this network. (source only)
- A value of zero in the host field means network address.
- `127.x.x.x` are loopback address.
- `255.255.255.255` is boardcast address.
- Private address:
  - `10.x.x.x`
  - `172.16.x.x ~ 172.31.x.x`
  - `192.168.x.x`
- CIDR — Classless Inter-Domain Routing — An IP addressing scheme that replaces the older system based on classes A, B and C.

Names

People refer to computers by names, not numbers.

/etc/hosts

```
127.0.0.1        localhost
202.203.132.245  cs3.swfu.edu.cn  cs3
```

/etc/networks

```
localnet    202.203.132.192
```

IP Route Table

Example IP Route Table

```
~$ route
Kernel IP routing table
Destination     Gateway          Iface
localnet        *                eth0
192.168.128.0   *                eth0
default         202.203.132.254  eth0
```

~$ `man route`

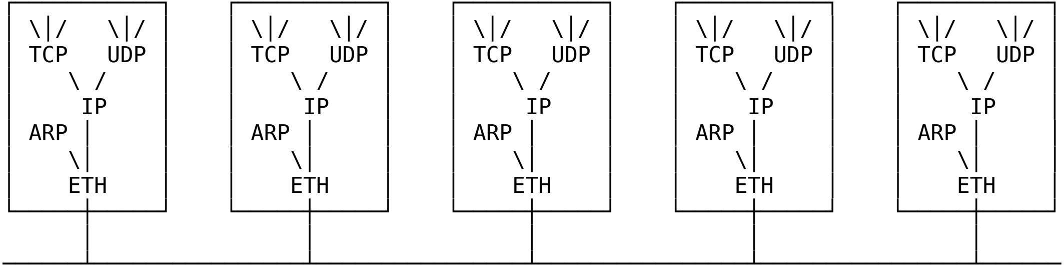
Direct Routing Details

```
   223.1.2.1          223.1.2.2
   ┌───────┐          ┌───────┐
   │ alpha │          │ beta  │
   │    1  │          │  1    │
   └────@──┘          └──@────┘
        │                │
 ───────o────────────────o─────
 Ethernet 1
 IP network "development"
             223.1.2.0
```

The route table inside alpha (simplified)

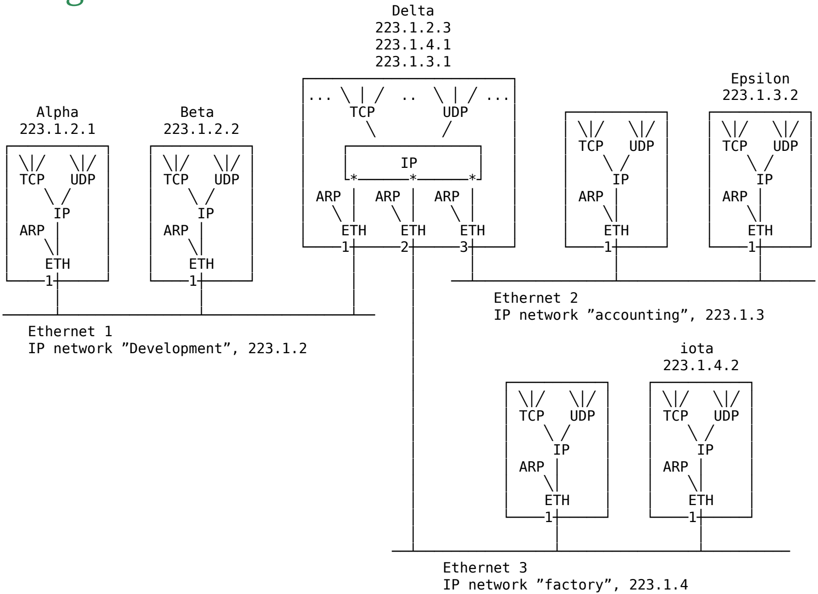
network	flag	router	iface
development	direct	*	1

Homework

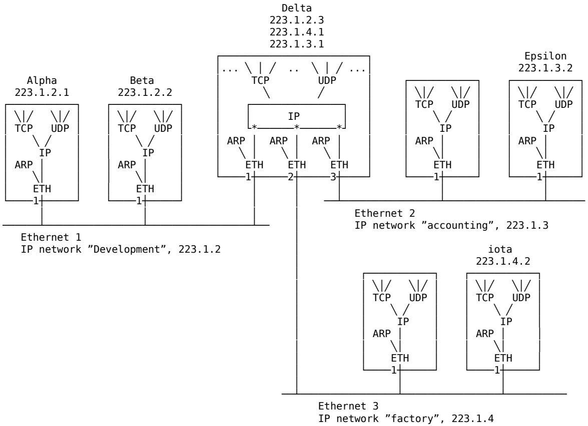


Alpha is sending an IP packet to beta...Please describe.

Indirect Routing Details



Indirect Routing Details



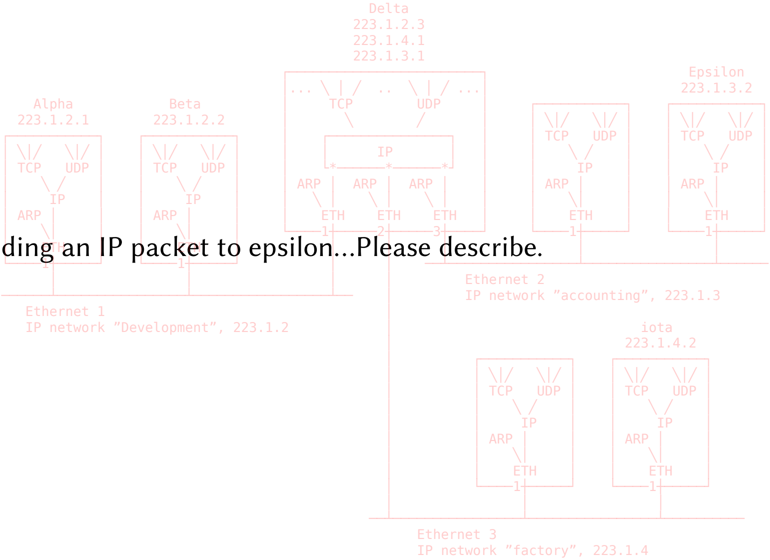
The route table inside alpha

Network	Flag	Router	Iface
223.1.2	direct	*	1
223.1.3	indirect	223.1.2.3	1
223.1.4	indirect	223.1.2.3	1

The route table inside delta

Network	Flag	Router	Iface
223.1.2	direct	*	1
223.1.3	direct	*	3
223.1.4	direct	*	2

Homework

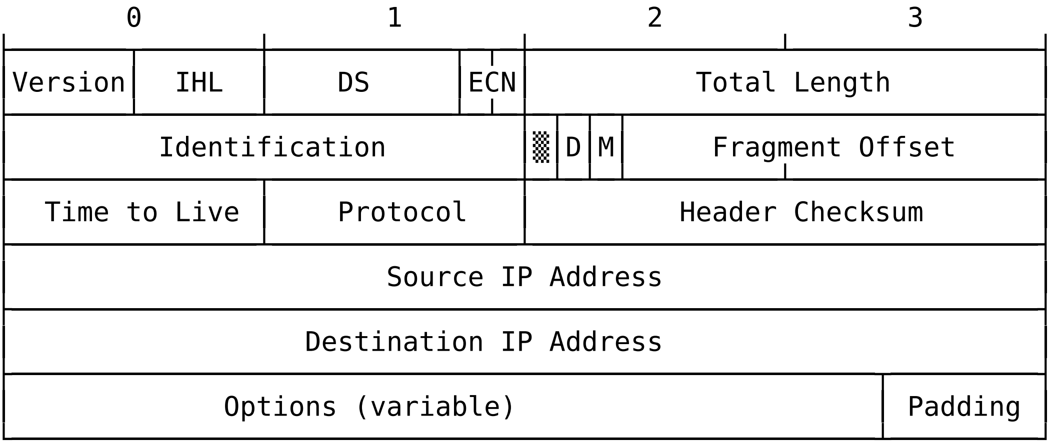


Alpha is sending an IP packet to epsilon...Please describe.

Managing The Routes

- Manually maintained by administrator
- ICMP can report some routing problems
- For larger networks, routing protocols are used.

IP Packet


0
1
2
3
Version
IHL
DS
ECN
Total Length
Identification
D
M
Fragment Offset
Time to Live
Protocol
Header Checksum
Source IP Address
Destination IP Address
Options (variable)
Padding

Fragmentation And Reassembly

ID	D	M	Offset	Data
88	0	0	0	3980 bytes

ID	D	M	Offset	Data
88	0	1	0	1480 bytes

Fragment 1

ID	D	M	Offset	Data
88	0	1	185	1480 bytes

Fragment 2

ID	D	M	Offset	Data
88	0	0	370	1020 bytes

Fragment 3

Don’t Fragment?

Various link layer networks

Ethernet: 1500 bytes; FDDI: 4770 bytes; ...

Path MTU

```
$ ping -c3 -Mdo -s1500 cs6.swfu.edu.cn
PING cs6.swfu.edu.cn (39.129.9.40) 1500(1528) bytes of data.
ping: local error: message too long, mtu=1500
ping: local error: message too long, mtu=1500
ping: local error: message too long, mtu=1500

--- cs6.swfu.edu.cn ping statistics ---
3 packets transmitted, 0 received, +3 errors, 100% packet loss, time 2054ms
```

Ethernet header	IP header (20 bytes)	ICMP header (8 bytes)	ICMP data (variable)	Ethernet trailer

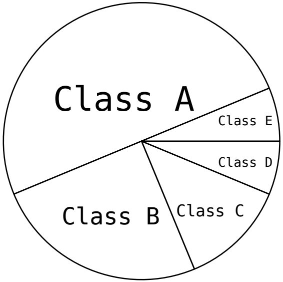
Try `-s1472`.

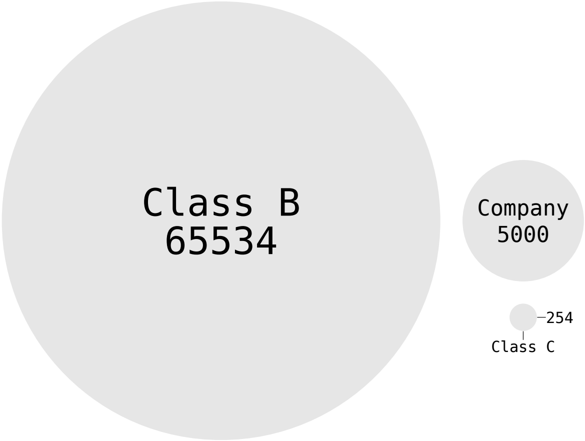
IP References

- Wikipedia. *Internet Protocol — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Internet%5C_Protocol&oldid=645719875.
- Wikipedia. *IP address — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=IP%5C_address&oldid=651153507.
- POSTEL J. *Internet Protocol*. IETF. 1981. http://www.ietf.org/rfc/rfc791.txt.
- Wikipedia. *IPv4 header checksum — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=IPv4%5C_header%5C_checksum&oldid=645516564.

Why Subnetting?

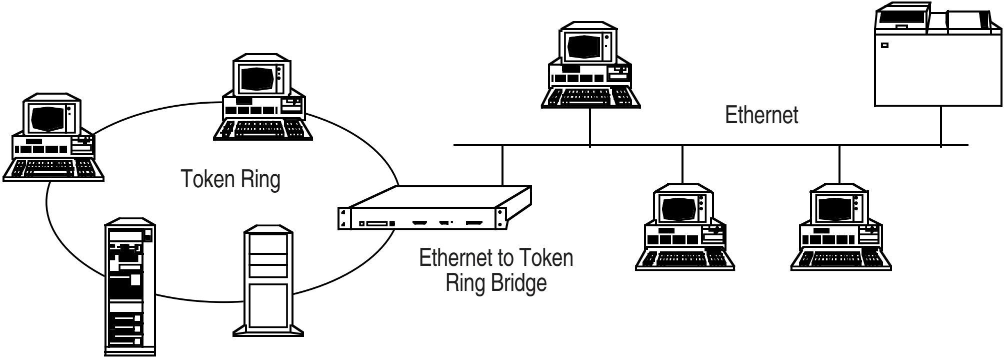
- save address space
- restrict collision domain
- security
- physical media (Ethernet, FDDI, ...)



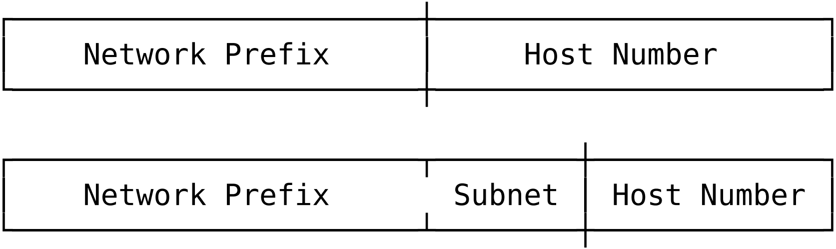


Without Subnetting

A data-link layer solution



How?



Subnet mask

11111111 . 11111111 . 11111100 . 00000000

255 . 255 . 252 . 0

- What are masked?
- Who cares?

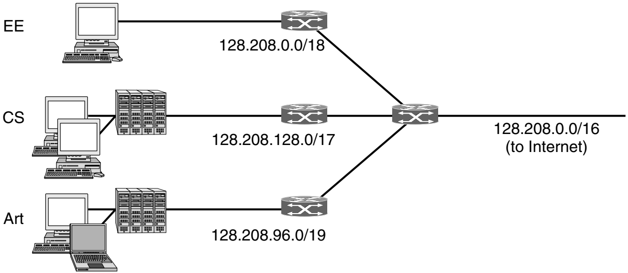
Example: Subnetting a Class B Network

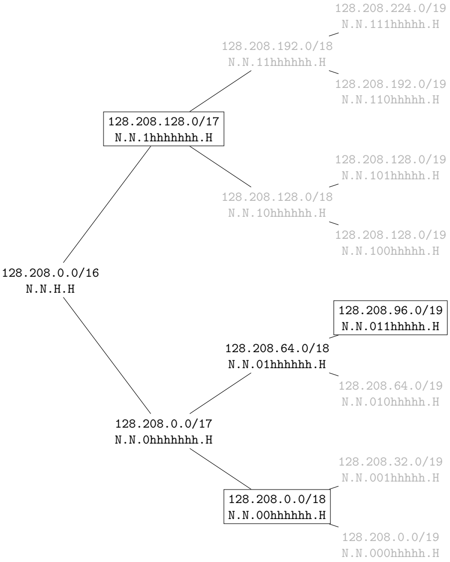
```
             WAN                                               WAN
              │                                                 │
              │                                                 │
  ┌───────────┴0─────────────┐          ┌───────────────────────┴0──────────────────────────┐
  │ Gateway router           │          │                  Gateway router                   │
  └───────────┬1─────────────┘          └───┬1───────┬2───────┬3───────┬4───────┬5──────────┘
              │                             │        │        │        │        │
              │                             │        │        │        │        │
──────────────┴───LAN──────       =>     ───┴───  ───┴───  ───┴───  ───┴───  ───┴───  ......
Net: 172.12.0.0                          Subnets: 2^6 = 64
Mask: 255.255.0.0                        Mask: 255.255.252.0 (255.255.11111100.0)
Hosts: 65534                             Hosts per subnet: 2^10 - 2 = 1022
```

```
$ sipcalc -n64 172.12.0.0/22
```

Dst	GW	Mask	Iface
172.12.0.0	*	255.255.252.0	1
172.12.4.0	*	255.255.252.0	2
172.12.8.0	*	255.255.252.0	3
		...	
Default	*	0.0.0.0	0

Example: VLSM





CS: 10000000.11010000.1hhhhhhh.hhhhhhhh

EE: 10000000.11010000.00hhhhhh.hhhhhhhh

ART: 10000000.11010000.011hhhhh.hhhhhhhh

$2^n - 2$

Example

IP address:	11001010	.	11001011	.	10000100	.	11110001
	202	.	203	.	132	.	241
Subnet mask:	11111111	.	11111111	.	11111111	.	11000000
	255	.	255	.	255	.	192

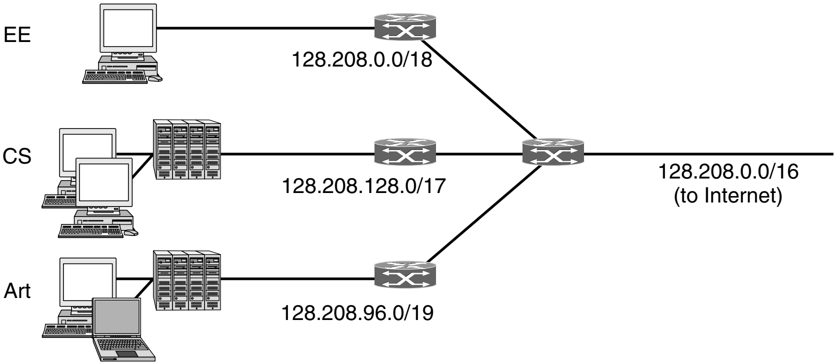
- There are $2^2 - 2 = 2$ subnets
- Each subnet has $2^6 - 2 = 62$ nodes
- Subtract 2? All "0"s and all "1"s. (old story)

Subnet Calculator

Free IP subnet calculators

```
$ subnetcalc 202.203.132.244/26
$ ipcalc 202.203.132.244/26
$ sipcalc 202.203.132.244/26
```

Quiz



Consider a packet addressing `128.208.2.251`

Q1: Which subnet it belongs to?

Q2: The route table inside each router?

Subnetting References

- Wikipedia. *Subnetwork — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Subnetwork&oldid=645854808.
- Wikipedia. *IPv4 subnetting reference — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=IPv4%5C_subnetting%5C_reference&oldid=652583338.
- Wikipedia. *Private network — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Private%5C_network&oldid=649931709.
- MOGUL J. *Internet subnets*. RFC Editor. 1984. https://www.rfc-editor.org/rfc/rfc917.txt.
- MOGUL J, POSTEL J. *Internet Standard Subnetting Procedure*. IETF. 1985. http://www.ietf.org/rfc/rfc950.txt.

CIDR—Classless Inter-Domain Routing

CIDR An IP addressing scheme that replaces the older system based on classes A, B and C.

Why?

With a new network being connected to the Internet every 30 minutes the Internet was faced with two critical problems:

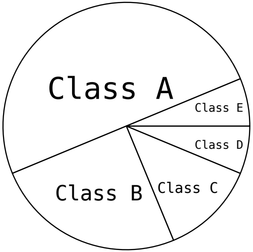
- Running out of IP addresses
- Running out of capacity in the global routing tables

Running out of IP addresses

Using the old addressing scheme, the Internet could support:

- 126 Class A networks that could include up to 16,777,214 hosts each
- Plus 65,000 Class B networks that could include up to 65,534 hosts each
- Plus over 2 million Class C networks that could include up to 254 hosts each

Only 3% of the assigned addresses were actually being used



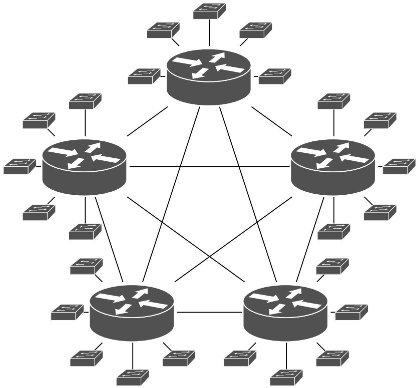
Restructuring IP Address Assignments

Instead of being limited to network identifiers (or ”prefixes”) of 8, 16 or 24 bits, CIDR currently uses prefixes anywhere from 13 to 27 bits.

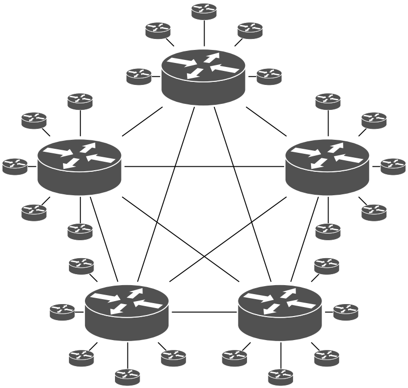
/27	1/8 of a Class C	32 hosts
/26	1/4 of a Class C	64 hosts
/25	1/2 of a Class C	128 hosts
/24	1 Class C	256 hosts
/16	256 Class C 1 Class B	65,536 hosts
/13	2,408 Class C	524,288 hosts

Two-Level vs. Multi-Level Network

Flat routing vs. Hierarchical routing



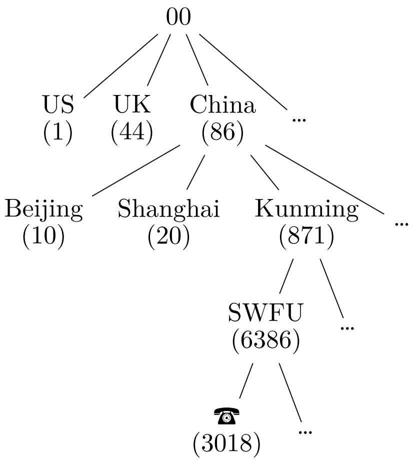
(a) "Network – Host" two level

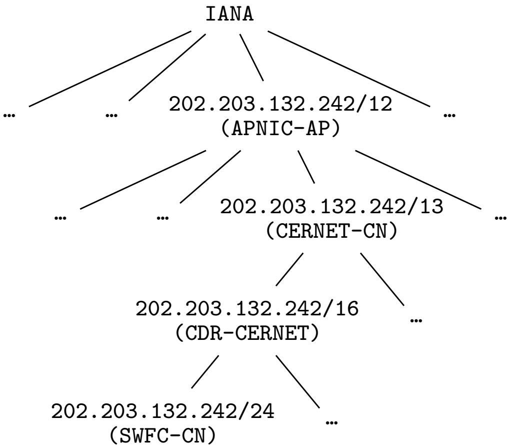


(b) Multi-level

Hierarchical Routing Aggregation

Route Aggregation a single high-level route entry can represent many lower-level routes in the global routing tables. Similar to the telephone network.





Example

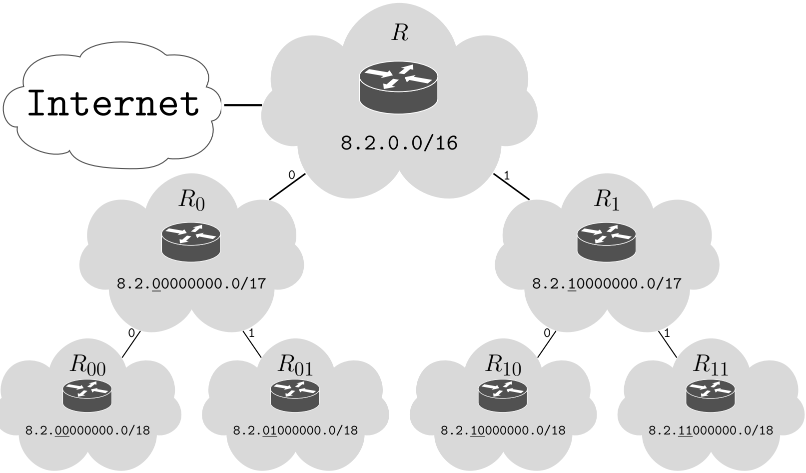
Dst: 8.2.129.2

At R

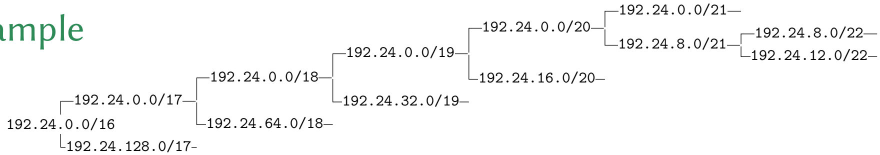
Dst:	8 . 2 . 10000001 . 2
Mask:	255 . 255 . 10000000 . 0
Net:	8 . 2 . 128 . 0

At R_1

Dst:	8 . 2 . 10000001 . 2
Mask:	255 . 255 . 11000000 . 0
Net:	8 . 2 . 128 . 0



Example

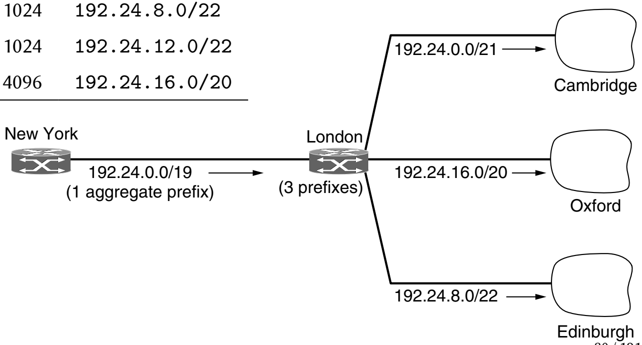


IP address assignments

University	First addr	Last addr	IPs	Network
Cambridge	192.24.0.0	192.24.7.255	2048	192.24.0.0/21
Edinburgh	192.24.8.0	192.24.11.255	1024	192.24.8.0/22
(Available)	192.24.12.0	192.24.15.255	1024	192.24.12.0/22
Oxford	192.24.16.0	192.24.31.255	4096	192.24.16.0/20

London

Destination	GW	Iface
192.24.0.0/21	*	1
192.24.8.0/22	*	3
192.24.16.0/20	*	2



The Router in New York

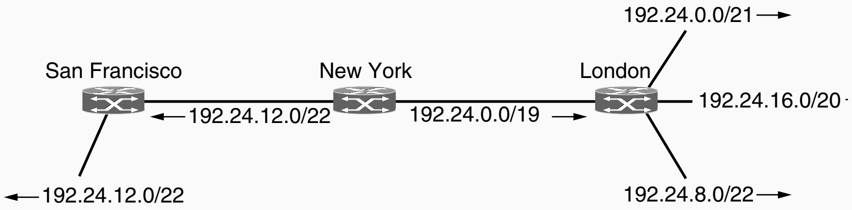
Option 1:

Destination	Flag	Gateway	Iface
	...		
192.24.0.0/21	indirect	London	1
192.24.8.0/22	indirect	London	1
192.24.16.0/20	indirect	London	1
	...		

Option 2:

Destination	Flag	Gateway	Iface
	...		
192.24.0.0/19	direct	*	1
	...		

Given dst addr: `192.24.12.8`, how to route it?



The /22 is a subnet inside /19.

Longest Matching Prefix

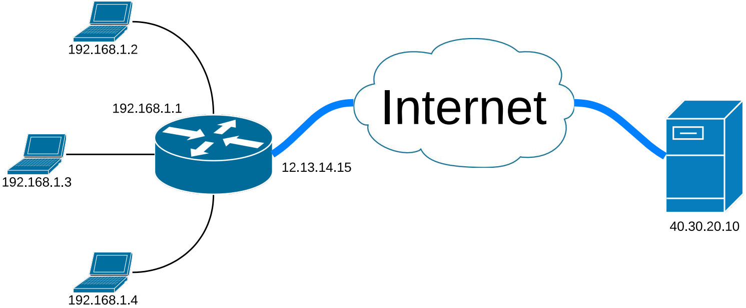
The router in New York:

Destination	Flag	Gateway	Iface
`192.24.0.0/19`	`direct`	`*`	`1`
`192.24.12.0/22`	`direct`	`*`	`2`
...			

CIDR References

- Wikipedia. *Classless Inter-Domain Routing — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Classless%5C_Inter-Domain%5C_Routing&oldid=641285826.
- FULLER V, LI T. *Classless Inter-domain Routing (CIDR): The Internet Address Assignment and Aggregation Plan*. RFC Editor. 2006. https://www.rfc-editor.org/rfc/rfc4632.txt.

Network Address Translation (NAT)



Source	NAT Router
IP : Port	IP : Port
192.168.1.2 : 3456	12.13.14.15 : 1
192.168.1.3 : 6789	12.13.14.15 : 2
192.168.1.3 : 8910	12.13.14.15 : 3
192.168.1.4 : 3750	12.13.14.15 : 4

Why IPv6?

No enough addresses!

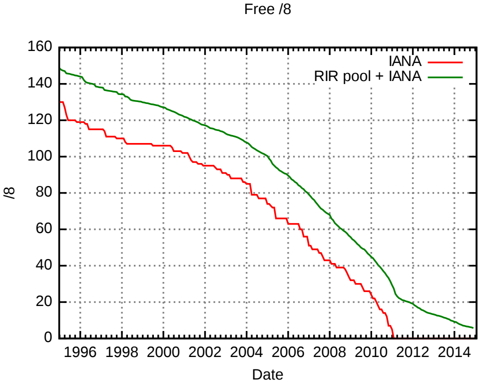
Kidding? We have:

- 2^{32} address space
- NAT
- CIDR

No kidding. All gone.

- IANA: 31 January 2011
- Asia-Pacific: 15 April 2011
- Europe: 14 September 2012
- Latin America: 10 June 2014

So, we need a larger address space (2^{128}).



2^{128}

Why such a high number of bits?

For a larger address space

- Think about mobile phones, cars (inside devices), toasters, refrigerators, light switches, and so on...

Why not higher?

More bits ➠ bigger header ➠ more overhead

	min MTU (octets)	header length (octets)	overhead
IPv4	576	20~60	3.4%
IPv6	1280	40	3.8%

Why not IPv5?

4: is already used for IPv4

5: is reserved for the Stream Protocol (STP, RFC 1819 / Internet Stream Protocol Version 2) (which never really made it to the public)

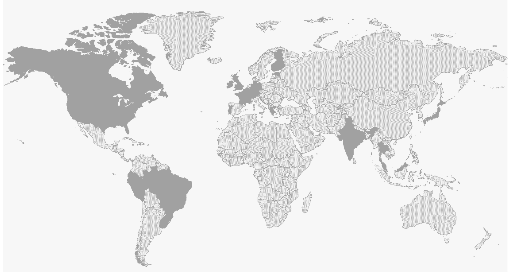
6: The next free number. Hence IPv6 was born!

More than a larger address space (2^{128})

- Simplified header makes routing faster
- End-to-end connectivity (public IP for everyone)
- Auto-configuration
- No broadcast
- Anycast
- Mobility — same IP address everywhere
- Network-layer security
- Extensibility
- and more ...

Deployment (2018)

$>$ 15%: 24 countries

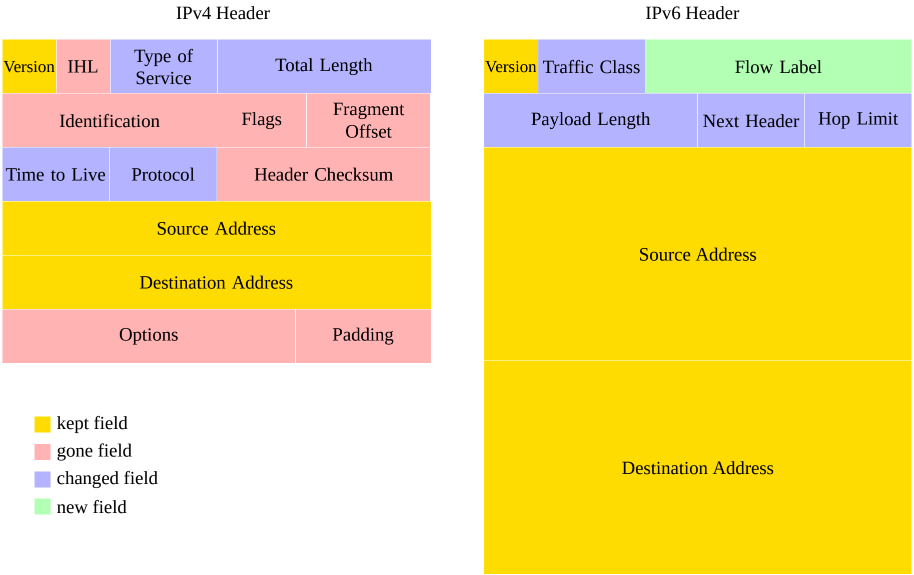


$>$ 5%: 49 countries

DEERING S, HINDEN R. *Internet Protocol, Version 6 (IPv6) Specification*. IETF. 1998. http://www.ietf.org/rfc/rfc2460.txt.

1998 — 2018, what took it so long?

Simplification



IPv6 Extension Header

IPv6 header Next Header = TCP	TCP header + data

IPv6 header Next Header = Routing	Routing header Next Header = TCP	TCP header + data

IPv6 header Next Header = Routing	Routing header Next Header = Fragment	Fragment header Next Header = TCP	fragment of TCP header + data

IPv6 Addresses

A real life address example

`3ffe:ffff:0100:f101:0210:a4ff:fee3:9566`

➥ `3ffe:ffff:100:f101:210:a4ff:fee3:9566`

More simplifications

`3ffe:ffff:100:f101:0:0:0:1`

➥ `3ffe:ffff:100:f101::1`

The biggest simplification

IPv6 localhost address

`0000:0000:0000:0000:0000:0000:0000:0001` ➠ `::1`

Address types

Global unicast addresses begin with `[23]xxx`

e.g. `2001:db8:85a3::8a2e:370:7334`

Unique local addresses begin with `fc00::/7`

e.g. `fdf8:f53b:82e4::53`

Similiar to private IPs in IPv4

Link local addresses begin with `fe80::/64`

e.g. `fe80::62d8:19ff:fece:44f6/64`

Similiar to `169.254.0.0/16`

Localhost address `::1`

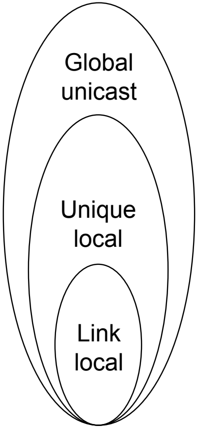
Similiar to IPv4 with its “`127.0.0.1`”

Multicast addresses begin with `ffxy::/8`

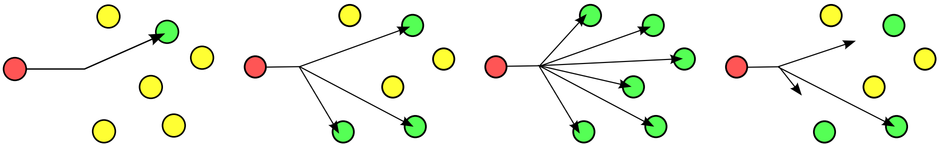
e.g. `ff01::2`

Unspecified address `::`

- Like “`any`” or “`0.0.0.0`” in IPv4



Anycast addresses



(a) Unicast (1-to-1) **(b)** Multicast (1-to-n) **(c)** Broadcast (1-to-all) **(d)** Anycast (1-to-$\frac{1}{n}$)

Anycast

- is assigned to more than one interface
- a packet sent to an anycast address is routed to the “nearest” interface having that address
- is allocated from the unicast address space

IPv6 References

- Wikipedia. *IPv6 — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=IPv6&oldid=648071002.
- Wikipedia. *IPv6 packet — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=IPv6%5C_packet&oldid=651199118.
- Wikipedia. *IPv6 address — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=IPv6%5C_address&oldid=645435688.
- DEERING S, HINDEN R. *Internet Protocol, Version 6 (IPv6) Specification*. IETF. 1998. http://www.ietf.org/rfc/rfc2460.txt.
- HINDEN R, DEERING S. *IP Version 6 Addressing Architecture*. IETF. 2006. http://www.ietf.org/rfc/rfc4291.txt.

Bridging vs. Routing

- A switch connects devices to create a network
- A router connects networks

Bridging	Routing
L2	L3
MAC addr.(local)	IP addr.(global)
intranet	internet
Forwarding DB	Routing table
relearn, flooding	more efficient

- to put multiple segments into one bridged network, or
- to divide it into different networks interconnected by routers

More About Networking Devices

Wikipedia. *Router (computing) — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Router%5C_(computing)&oldid=646784918.

Wikipedia. *Routing table — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Routing%5C_table&oldid=644938703.

Wikipedia. *Network switch — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Network%5C_switch&oldid=646928384.

Wikipedia. *LAN switching — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=LAN%5C_switching&oldid=651228780.

What's A Packet Filter?

A packet filter is a piece of software which looks at the `header` of packets as they pass through, and decides the fate of the entire packet. It might decide to

- `DROP` the packet (i.e., discard the packet as if it had never received it),
- `ACCEPT` the packet (i.e., let the packet go through), or
- something more complicated.

Packet Filter Under Linux

iptables talks to the kernel and tells it what packets to filter.

The iptables tool inserts/deletes rules from the kernel's packet filtering table.

Iptables

```
$ sudo apt install iptables
$ sudo iptables -A INPUT -s 147.8.212.123 -p all -j DROP
$ sudo iptables -D INPUT -s 147.8.212.123 -p all -j DROP
$ man iptables
$ qutebrowser http://www.netfilter.org/documentation/
```

Terminology

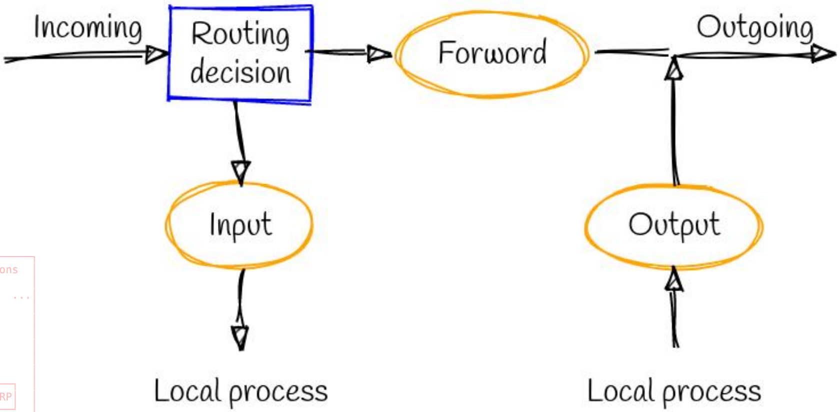
Filter table is in the kernel, contains `chains`.

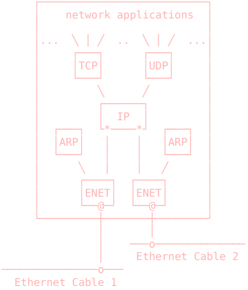
Chains a.k.a. firewall chains, are lists of filtering rules. The three kernel built-in chains are called `INPUT`, `OUTPUT`, and `FORWARD`.

Rules Each rule says:

- `if` the packet header looks like this
- `then` here's what to do with the packet

How Chains Work?





Using iptables

To manage whole chains:

- `-N` Create a new chain.
- `-X` Delete an empty chain.
- `-P` Change the policy for a built-in chain.
- `-L` List the rules in a chain.
- `-F` Flush the rules out of a chain.
- `-Z` Zero the packet and byte counters on all rules in a chain.

To manipulate rules inside a chain:

- `-A` Append a new rule to a chain.
- `-I` Insert a new rule at some position in a chain.
- `-R` Replace a rule at some position in a chain.
- `-D` Delete a rule at some position in a chain, or the first that matches.

Examples

```
$ ping 127.0.0.1
$ sudo iptables -A INPUT -s 127.0.0.1 -p icmp -j DROP
$ sudo iptables -D INPUT -s 127.0.0.1 -p icmp -j DROP
$ sudo iptables -A INPUT -s ! 127.0.0.1 -p all -j DROP
$ sudo iptables -A INPUT -s 192.168.1.0/24 -p all -j DROP
```

More Examples

```
$ # Syn-flood protection:
$ sudo iptables -A FORWARD -p tcp --syn -m limit --limit 1/s -j ACCEPT

$ # Furtive port scanner:
$ sudo iptables -A FORWARD -p tcp --tcp-flags SYN,ACK,FIN,RST RST -m
  limit --limit 1/s -j ACCEPT

$ # Ping of death:
$ sudo iptables -A FORWARD -p icmp --icmp-type echo-request -m limit
  --limit 1/s -j ACCEPT
```

NAT & Packet Filtering References

- Wikipedia. *Network address translation — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Network%5C_address%5C_translation&oldid=652836698.
- EGEVANG K, FRANCIS P. *The IP Network Address Translator (NAT)*. RFC Editor. 1994. https://www.rfc-editor.org/rfc/rfc1631.txt.
- TYSON J. *How Network Address Translation Works — HowStuffWorks.com*. 2001. %5Curl%7Bhttp://computer.howstuffworks.com/nat.htm%7D.
- CONTRIBUTORS W. *Iptables — Wikipedia, The Free Encyclopedia*. 2017. https://en.wikipedia.org/w/index.php?title=Iptables&oldid=817424711.

☎ vs. 🖂

Circuit switching (☎)

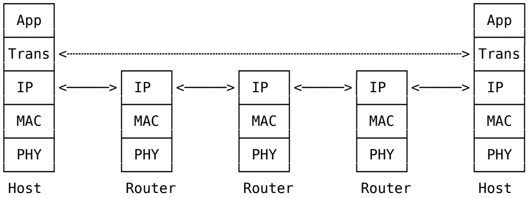
- ☺ guaranteed performance
- ☺ fast transfers (once circuit is established)
- ☹ wastes bandwidth if traffic is “bursty”
- ☹ connection setup adds delay
- ☹ recovery from failure is slow

Packet switching (🖂)

- ☹ no guaranteed performance
- ☹ header overhead per packet
- ☹ queues and queuing delay
- ☺ efficient use of bandwidth
- ☺ no connection setup
- ☺ can “route around trouble”

IP: host ↔ host

TCP/UDP: process ↔ process



IP: Best-effort, no guarantee

- ? segment delivery
- ? orderly delivery of segments
- ? the integrity of the data in the segments

QoS on data link layer or IP layer?

- ☹ Efficiency
- ☹ Upgrade all the routers

TCP: Receive it correctly and orderly or none

- ✔ correctness — acknowledgement, checksum
- ✔ order — sequence numbers
- ✔ packet lost — timers
- ✔ flow control — sliding window
- ✔ congestion control

A TCP Connection Over A Connectionless IP Layer

```
$ ss -4t state established
```

Recv-Q	Send-Q	Local Address:Port	Peer Address:Port
0	0	127.0.0.1:3333	127.0.0.1:14624
0	0	127.0.0.1:14624	127.0.0.1:3333
		Socket	Socket
		Connection	

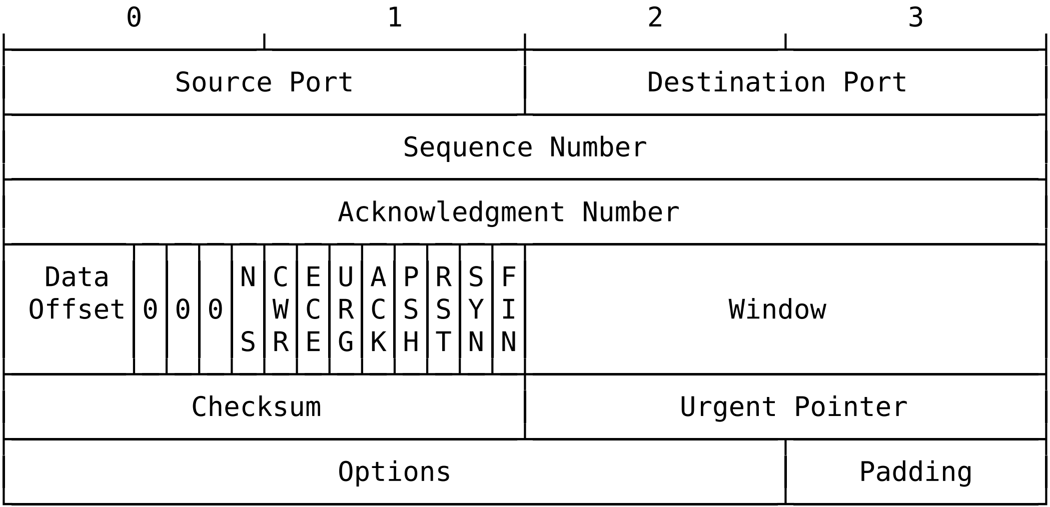
Port numbers

port range: 0 ~ 65535

well-known ports: 0 ~ 1023

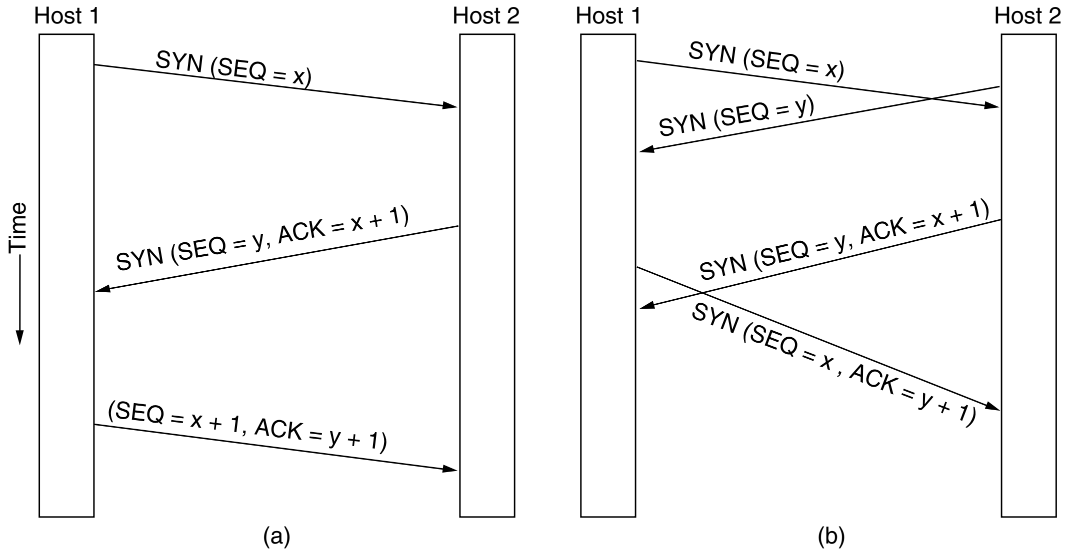
FTP	20/21	SSH	22	Telnet	23
SMTP	25	DNS	53	DHCP	67/68
HTTP	80	POP3	110	HTTPS	443
IMAP4	143				

TCP Header



0
1
2
3
Source Port
Destination Port
Sequence Number
Acknowledgment Number
Data Offset
0
0
0
NS
CWR
ECE
URG
ACK
PSH
RST
SYN
FIN
Window
Checksum
Urgent Pointer
Options
Padding

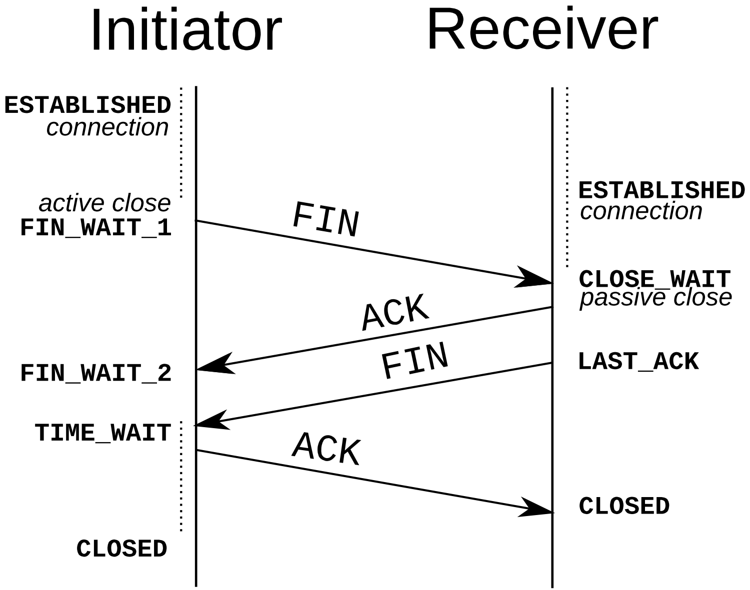
Establishing a TCP Connection



SYN-flood

```
$ sudo apt install hping3
$ sudo tcpdump -ilo port 3333
$ ss -anto state syn-recv
$ sudo hping3 --flood -I lo -S -p 3333 127.0.0.1
$ sudo iptables -A OUTPUT -p tcp -m tcp --tcp-flags RST RST -j DROP
$ sudo python3 -m http.server 3333
```

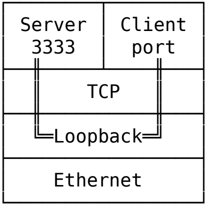
Closing a TCP Connection



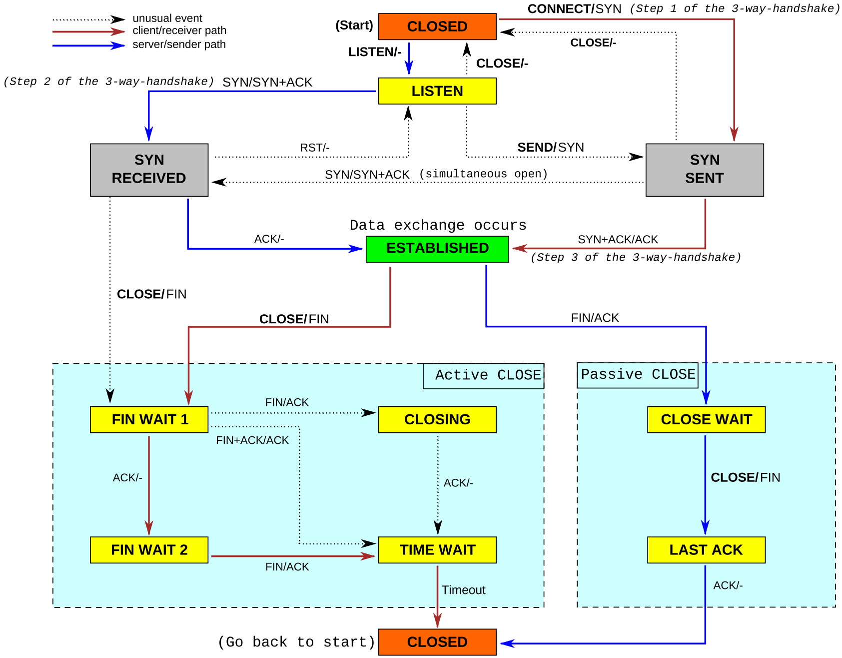
Terminal A: `nc -l 3333`

Terminal B: `nc localhost 3333`

Terminal C: `sudo tcpdump -i lo -S port 3333`




```
12:47:09.106903 IP localhost.37831 > localhost.3333:
  Flags [S], seq 2485057335, win 32792, ..., length 0
12:47:09.106923 IP localhost.3333 > localhost.37831:
  Flags [S.], seq 2476477986, ack 2485057336, win 32768, ..., length 0
12:47:09.106936 IP localhost.37831 > localhost.3333:
  Flags [.], ack 2476477987, win 257, ..., length 0
12:47:26.963149 IP localhost.37831 > localhost.3333:
  Flags [F.], seq 2485057336, ack 2476477987, win 257, ..., length 0
12:47:26.963244 IP localhost.3333 > localhost.37831:
  Flags [F.], seq 2476477987, ack 2485057337, win 256, ..., length 0
12:47:26.963264 IP localhost.37831 > localhost.3333:
  Flags [.], ack 2476477988, win 257, ..., length 0
```



unusual event
client/receiver path
server/sender path
(Start)
CLOSED
CONNECT/SYN (Step 1 of the 3-way-handshake)
CLOSE/-
LISTEN/-
CLOSE/-
LISTEN
(Step 2 of the 3-way-handshake) SYN/SYN+ACK
SYN RECEIVED
RST/-
SEND/SYN
SYN SENT
SYN/SYN+ACK (simultaneous open)
Data exchange occurs
ACK/-
ESTABLISHED
SYN+ACK/ACK
(Step 3 of the 3-way-handshake)
CLOSE/FIN
CLOSE/FIN
FIN/ACK
Active CLOSE
Passive CLOSE
FIN WAIT 1
FIN/ACK
CLOSING
FIN+ACK/ACK
CLOSE WAIT
ACK/-
ACK/-
CLOSE/FIN
FIN WAIT 2
TIME WAIT
LAST ACK
FIN/ACK
Timeout
ACK/-
(Go back to start)
CLOSED

netstat

```
$ sudo apt install net-tools
```

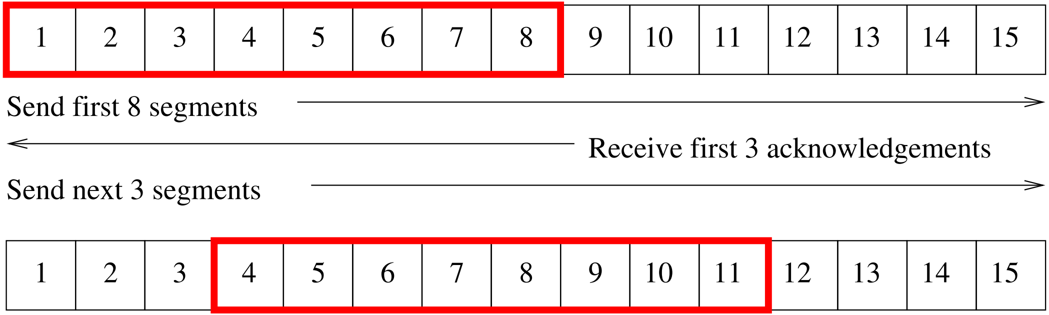
```
$ netstat -ant
$ netstat -antp
$ netstat -antpe
$ netstat -nr
```

```
$ netstat -ie
$ netstat -antp | grep ESTAB
$ netstat -nlp | grep :80
$ man netstat
```

ss — a netstat replacement

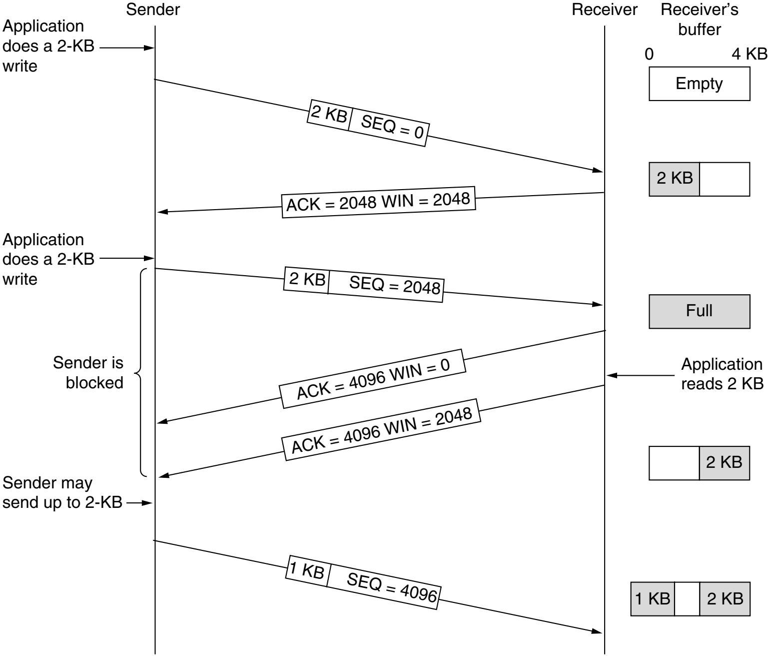
```
$ ss -t "( sport = 3333 or dport = 3333 )"
$ man ss
```

Sliding Window

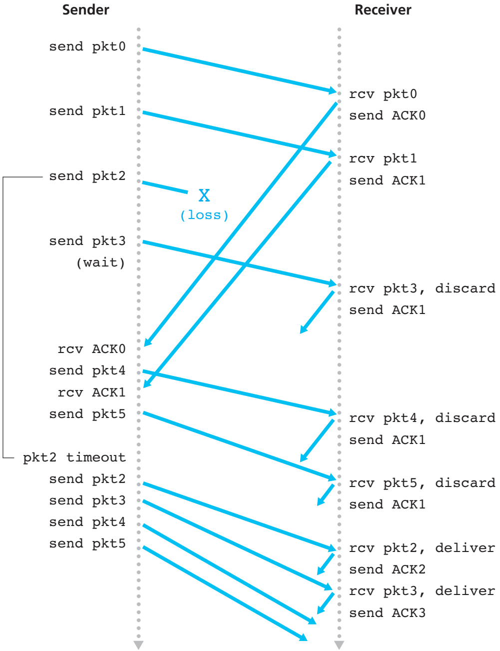


The sliding window serves several purposes:

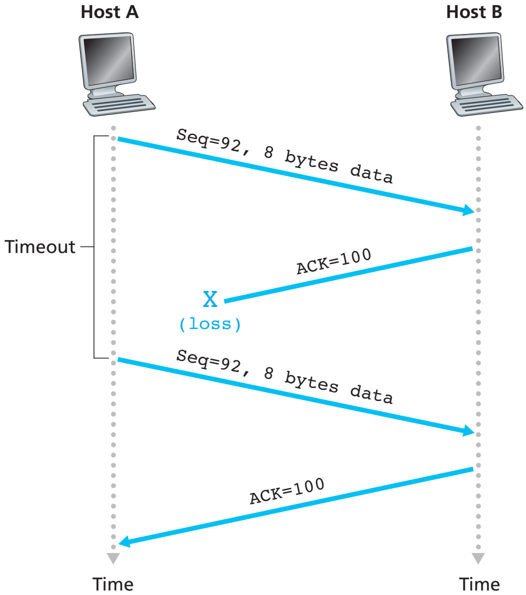
- guarantees the reliable delivery of data
- ensures that the data is delivered in order
- enforces flow control between the sender and the receiver.


Sender
Receiver
Receiver's buffer
0
4 KB
Application does a 2-KB write
Empty
2 KB
SEQ = 0
2 KB
ACK = 2048 WIN = 2048
Application does a 2-KB write
2 KB
SEQ = 2048
Full
Sender is blocked
ACK = 4096 WIN = 0
Application reads 2 KB
ACK = 4096 WIN = 2048
2 KB
Sender may send up to 2-KB
1 KB
SEQ = 4096
1 KB
2 KB

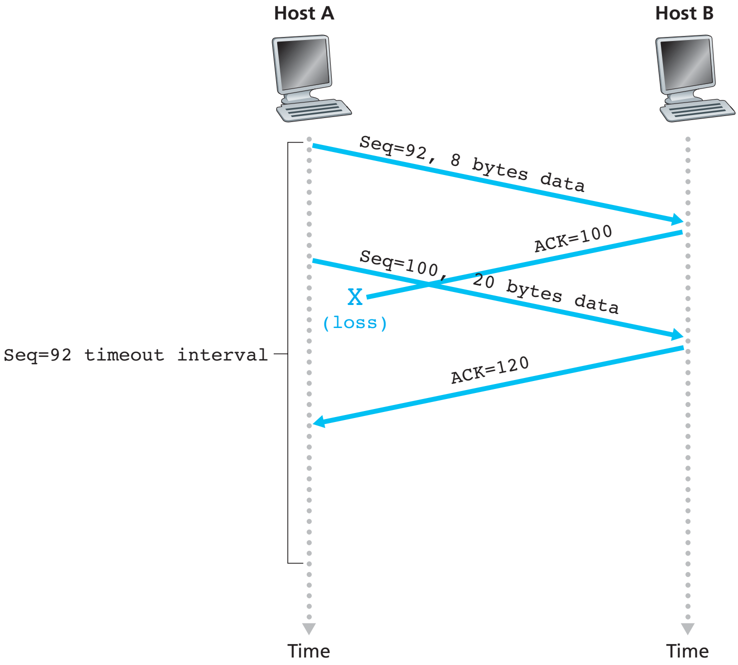
Packet Lost? Go-Back-N



ACK lost?

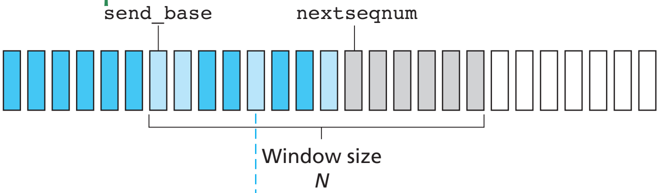


Host A
Host B
Seq=92, 8 bytes data
ACK=100
X
(loss)
Timeout
Seq=92, 8 bytes data
ACK=100
Time
Time



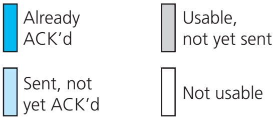
Host A
Host B
Seq=92, 8 bytes data
ACK=100
Seq=100, 20 bytes data
X
(loss)
Seq=92 timeout interval
ACK=120
Time
Time

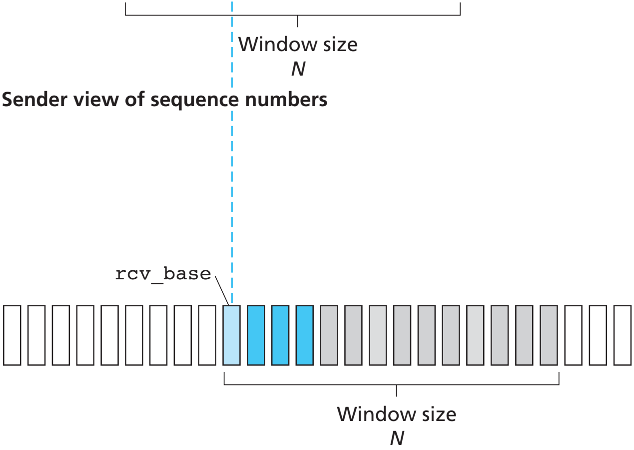
Selective-repeat



a. Sender view of sequence numbers

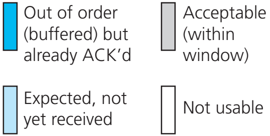
Key:

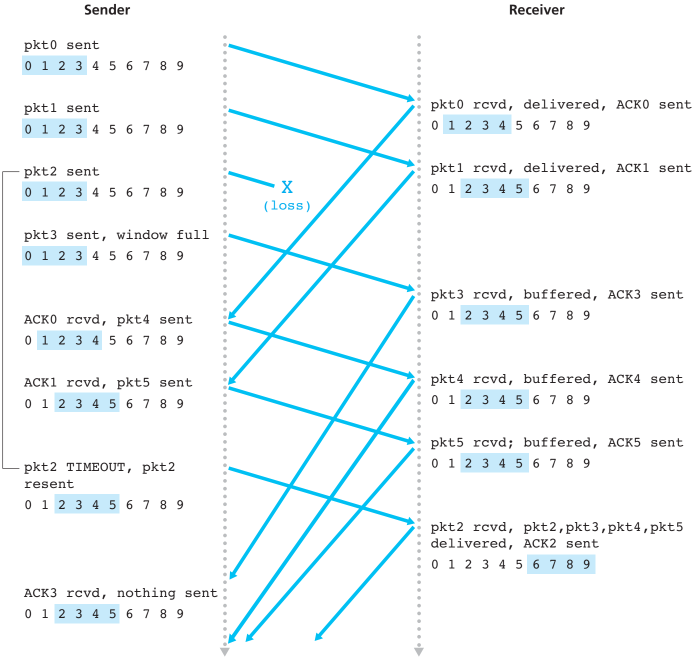




b. Receiver view of sequence numbers

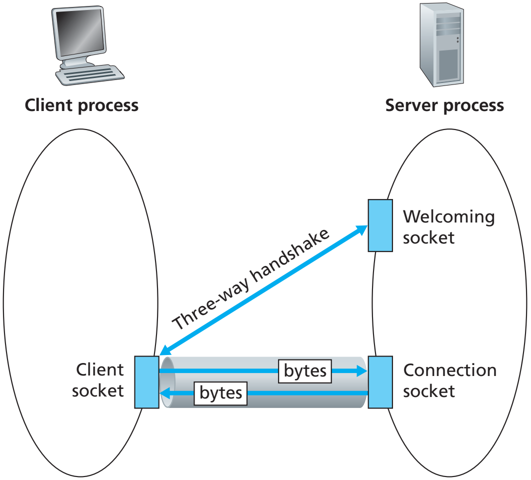
Key:

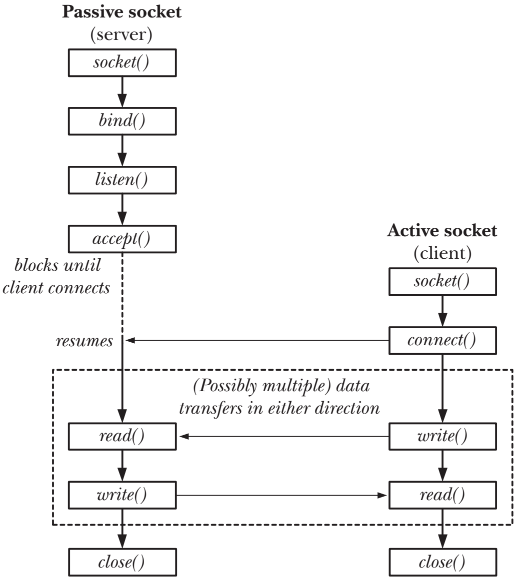



Sender
Receiver
pkt0 sent
0 1 2 3 4 5 6 7 8 9
pkt1 sent
0 1 2 3 4 5 6 7 8 9
pkt2 sent
0 1 2 3 4 5 6 7 8 9
X
(loss)
pkt3 sent, window full
0 1 2 3 4 5 6 7 8 9
ACK0 rcvd, pkt4 sent
0 1 2 3 4 5 6 7 8 9
ACK1 rcvd, pkt5 sent
0 1 2 3 4 5 6 7 8 9
pkt2 TIMEOUT, pkt2 resent
0 1 2 3 4 5 6 7 8 9
ACK3 rcvd, nothing sent
0 1 2 3 4 5 6 7 8 9
pkt0 rcvd, delivered, ACK0 sent
0 1 2 3 4 5 6 7 8 9
pkt1 rcvd, delivered, ACK1 sent
0 1 2 3 4 5 6 7 8 9
pkt3 rcvd, buffered, ACK3 sent
0 1 2 3 4 5 6 7 8 9
pkt4 rcvd, buffered, ACK4 sent
0 1 2 3 4 5 6 7 8 9
pkt5 rcvd; buffered, ACK5 sent
0 1 2 3 4 5 6 7 8 9
pkt2 rcvd, pkt2,pkt3,pkt4,pkt5 delivered, ACK2 sent
0 1 2 3 4 5 6 7 8 9

TCP Sockets

Two Sockets at the Server




Passive socket
(server)
socket()
bind()
listen()
accept()
blocks until
client connects
resumes
Active socket
(client)
socket()
connect()
(Possibly multiple) data
transfers in either direction
read()
write()
write()
read()
close()
close()

TCPServer.py

```python
#!/usr/bin/python2

from socket import *
serverPort = 12000
serverSocket = socket(AF_INET,SOCK_STREAM)
serverSocket.bind(('',serverPort))
serverSocket.listen(0)
print serverSocket.getsockname()
print 'The server is ready to receive'
while 1:
    connectionSocket, addr = serverSocket.accept()
    print connectionSocket.getsockname()
    sentence = connectionSocket.recv(1024)
    capitalizedSentence = sentence.upper()
    connectionSocket.send(capitalizedSentence)
    connectionSocket.close()
```

`serverSocket`: the welcoming socket

`connectionSocket`: a socket dedicated to a client

`listen(backlog)`: the server listens for connection requests

- `backlog`: How many non-accepted connection requests are allowed to be queueing

`accept()`: whenever a connection request coming, creates a new *connectionSocket*

TCPClient.py

```python
#!/usr/bin/python2

from time import *
from socket import *
serverName = '127.0.0.1'
serverPort = 12000
clientSocket = socket(AF_INET, SOCK_STREAM)
clientSocket.connect((serverName,serverPort))
print clientSocket.getsockname()
sentence = raw_input('Input lowercase sentence:')
clientSocket.send(sentence)
modifiedSentence = clientSocket.recv(1024)
print 'From Server:', modifiedSentence
# while 1:
#     sleep(3)
clientSocket.close()
```

- Re-write it in C or Python3

SOCK_STREAM: TCP socket

connect(): initiate the TCP connection (3-way handshake)

send(): send out *sentence* through the client's socket. No destination address needs to be specified

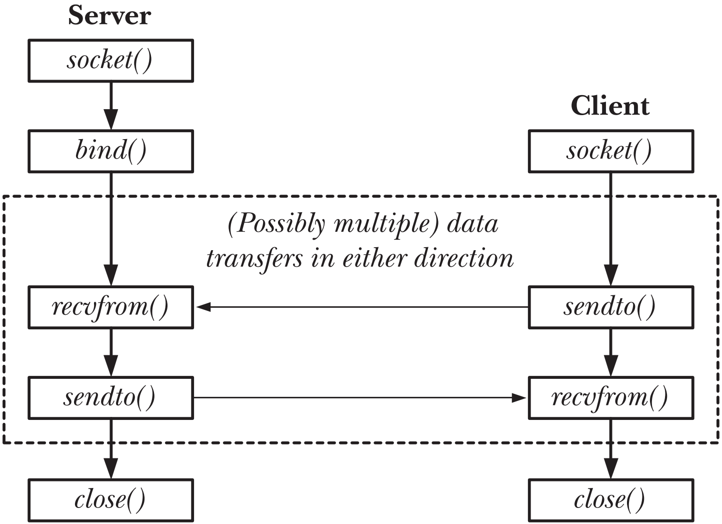
UDP Datagram

0	1	2	3
Src Port		Dst Port	
Length		Checksum	
Data ...			

UDP Example

```
T1:$ nc -4ul 3333 #server
T2:$ nc -4u localhost 3333 #client, or
   $ echo hello > /dev/udp/127.0.0.1/3333
T3:$ sudo tcpdump -ilo udp port 3333
T4:$ watch -tn.1 \
   > 'ss -4au "( sport = 3333 or dport = 3333 )"'
```

Datagram Sockets



UDPServer.py

```
#!/usr/bin/python

from socket import *
serverPort = 12000
serverSocket = socket(AF_INET, SOCK_DGRAM)
serverSocket.bind(('', serverPort))
print "The server is ready to receive"
while 1:
    message, clientAddress = serverSocket.recvfrom(2048)
    modifiedMessage = message.upper()
    serverSocket.sendto(modifiedMessage, clientAddress)
```

`serverSocket.bind(('', serverPort))`

- explicitly assigns 12000 to the server's socket

UDPClient.py I

```
#!/usr/bin/python

from socket import *
serverName = '127.0.0.1'
serverPort = 12000
clientSocket = socket(AF_INET, SOCK_DGRAM)
message = raw_input('Input lowercase sentence:')
clientSocket.sendto(message,(serverName, serverPort))
modifiedMessage, serverAddress = clientSocket.recvfrom(2048)
print modifiedMessage
clientSocket.close()
```

UDPClient.py II

`socket(AF_INET, SOCK_DGRAM)`

- `AF_INET`: using IPv4
- `SOCK_DGRAM`: UDP socket
- `clientPort` will be generated automatically

`clientSocket.sendto(message,(serverName, serverPort))`

1. attaches both the destination address (`serverName, serverPort`) and the source address (`clientIP, clientPort`) to the message
2. send the message

UDPClient.py III

```
modifiedMessage, serverAddress = clientSocket.recvfrom(2048)
```

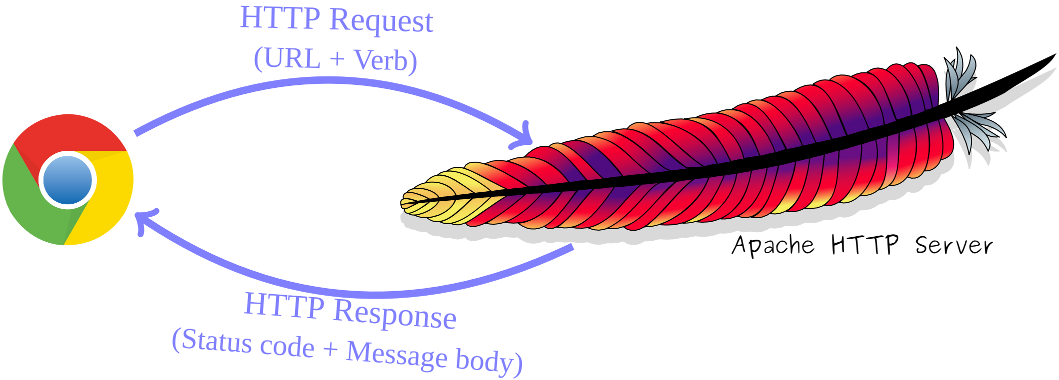
1. puts the received message data into `modifiedMessage`
2. puts the source address `(IP, Port)` into `serverAddress`

- 2048: buffer size

TCP/UDP References

- Wikipedia. *Transmission Control Protocol — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Transmission%5C_Control%5C_Protocol&oldid=647944260.
- Wikipedia. *User Datagram Protocol — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=User%5C_Datagram%5C_Protocol&oldid=643803508.
- Wikipedia. *Checksum — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Checksum&oldid=645584712.
- POSTEL J. *Transmission Control Protocol*. IETF. 1981. http://www.ietf.org/rfc/rfc793.txt.
- POSTEL J. *User Datagram Protocol*. RFC Editor. 1980. https://www.rfc-editor.org/rfc/rfc768.txt.
- Wikipedia. *Network socket — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Network%5C_socket&oldid=643452418.
- HALL B. *Beej's Guide to Network Programming: Using Internet Sockets*. 2012.

HTTP



HTTP Request
(URL + Verb)
Apache HTTP Server
HTTP Response
(Status code + Message body)

HTTP Request (URL + Verb)

URL

$$\underbrace{\texttt{http}}_{\text{protocol}}\texttt{://}\overbrace{\texttt{en.wikipedia.org}}^{\text{host}}\texttt{/}\underbrace{\texttt{w/index.php}}_{\text{resource path}}\overbrace{\texttt{?title=Hello\&oldid=636846770}}^{\text{query}}$$

```
~$ curl -v cs2.swfu.edu.cn/index.html
* Connected to cs2.swfu.edu.cn port 80
> GET /index.html HTTP/1.1           ← Request line
> User-Agent: curl/7.38.0
> Host: cs2.swfu.edu.cn              ← Header lines
> Accept: */*
>                                    ← Empty line
```

Verbs

GET	POST	PUT	PATCH	
HEAD	OPTIONS	DELETE	TRACE	CONNECT

HTTP Response (Status Code + Message Body)

```
< HTTP/1.1 200 OK
< Date: Thu, 15 Jan 2015 08:18:50 GMT
< Server: Apache/2.4.10 (Debian)
< Last-Modified: Tue, 02 Sep 2014 03:49:24 GMT
< ETag: "1fd-5020d015e5e4a"
< Accept-Ranges: bytes
< Content-Length: 509
< Vary: Accept-Encoding
< Content-Type: text/html
<
<html>
<head>
<title>Hello, world!</title>
</head>
<body>
<h1>Hello, world!</h1>
</body>
</html>
* Connection #0 to host cs2.swfu.edu.cn left intact
```

Status line

Header lines

Empty line

Data

Status Codes

1xx Informational Messages

e.g. `104 Connection Reset by Peer`

2xx Successful

e.g. `200 OK`

3xx Redirection

e.g. `301 Moved Permanently`

4xx Client Error

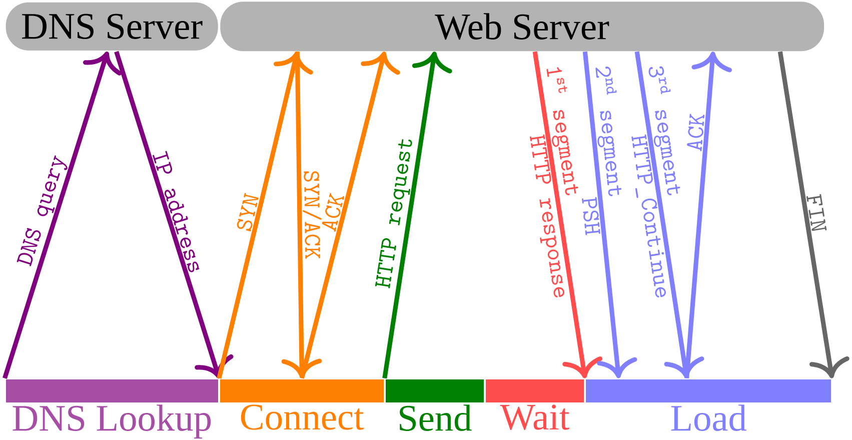
e.g. `404 Not Found`

5xx Server Error

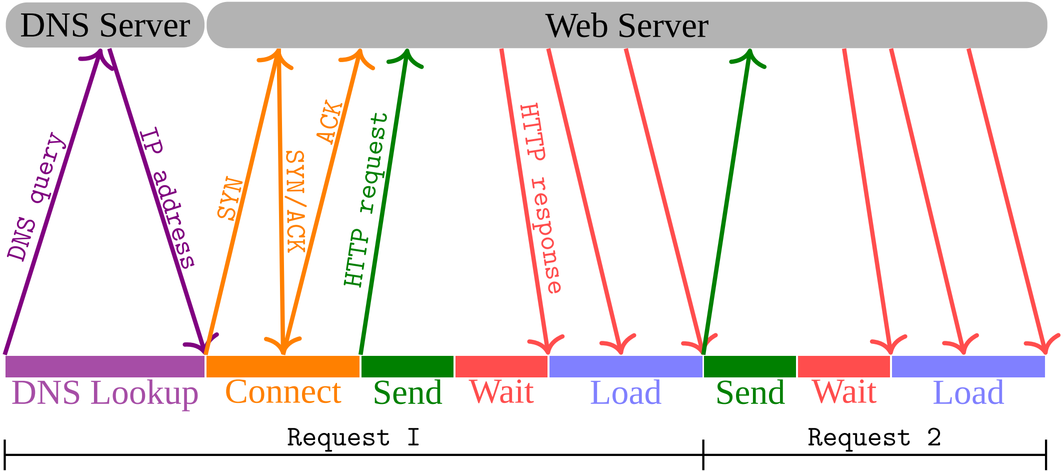
e.g. `500 Internal Server Error`

HTTP Transaction

Non-persistent — separate TCP connection



Persistent — same TCP connection

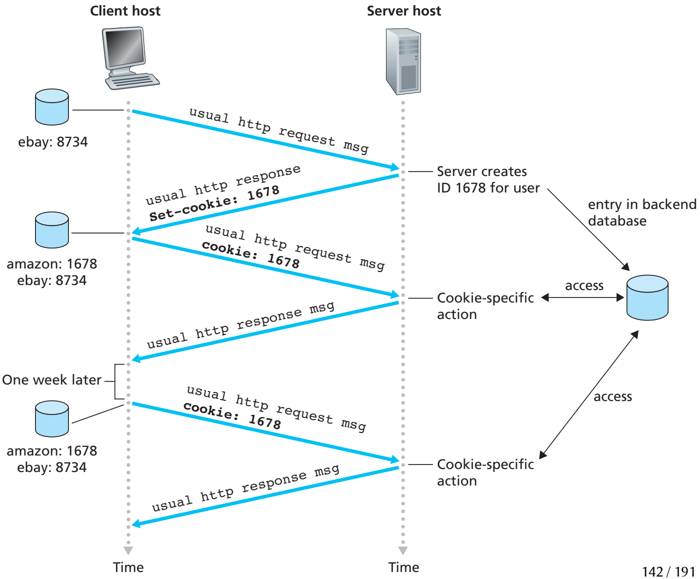


Stateless Protocol

A HTTP server maintains no information about the clients.

- ☺ Simplifies server design
- ☺ Save server resources
- ☺ Serve more users
- ☹ Missing information

Keeping user state with cookies



HTTP/2

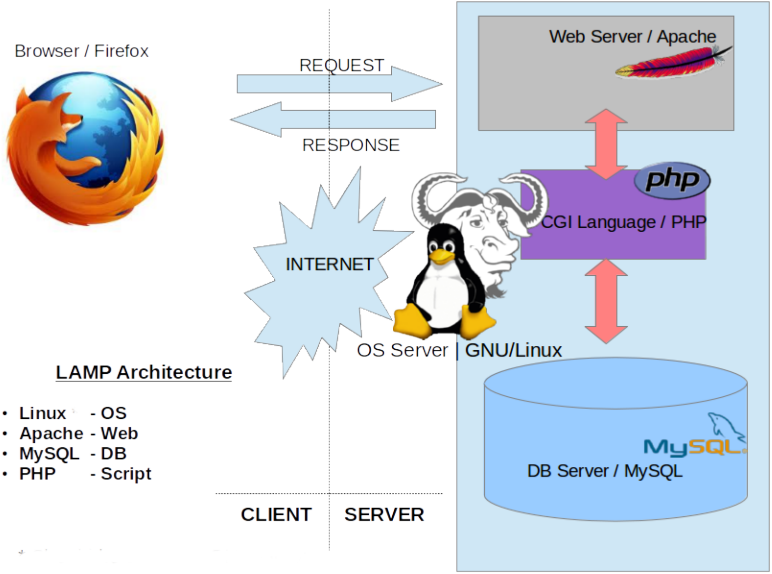
Quoted from http://http2.github.io/faq/

- is binary, instead of textual
- is fully multiplexed, instead of ordered and blocking
- can therefore use one connection for parallelism
- uses header compression to reduce overhead
- allows servers to “push” responses proactively into client caches

May 2015 Publish HTTP/2 as RFC7540/7541

HTML

```html
<html>
    <head>
        <title>Hello, world!</title>
    </head>
    <body>
        <H1>Hello, world!</H1>
    </body>
</html>
```



LAMP Architecture

- Linux - OS
- Apache - Web
- MySQL - DB
- PHP - Script

HTTP References I

- Wikipedia. *Hypertext Transfer Protocol — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Hypertext%5C_Transfer%5C_Protocol&oldid=648108367.
- Wikipedia. *HTTP/2 — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=HTTP/2&oldid=648155546.
- Wikipedia. *HTTP cookie — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=HTTP%5C_cookie&oldid=648216857.
- Wikipedia. *Stateless protocol — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Stateless%5C_protocol&oldid=645610703.
- Wikipedia. *HTML — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=HTML&oldid=648021866.
- Wikipedia. *LAMP (software bundle) — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=LAMP%5C_(software%5C_bundle)&oldid=646364288.
- FIELDING R, GETTYS J, MOGUL J, et al. *Hypertext Transfer Protocol – HTTP/1.1*. RFC Editor. 1999. https://www.rfc-editor.org/rfc/rfc2616.txt.

HTTP References II

- BELSHE M, PEON R, THOMSON (ED.) M. *Hypertext Transfer Protocol Version 2 (HTTP/2)*. RFC Editor. 2015. https://www.rfc-editor.org/rfc/rfc7540.txt.
- PEON R, RUELLAN H. *HPACK: Header Compression for HTTP/2*. RFC Editor. 2015. https://www.rfc-editor.org/rfc/rfc7541.txt.

DNS

Names and Addresses

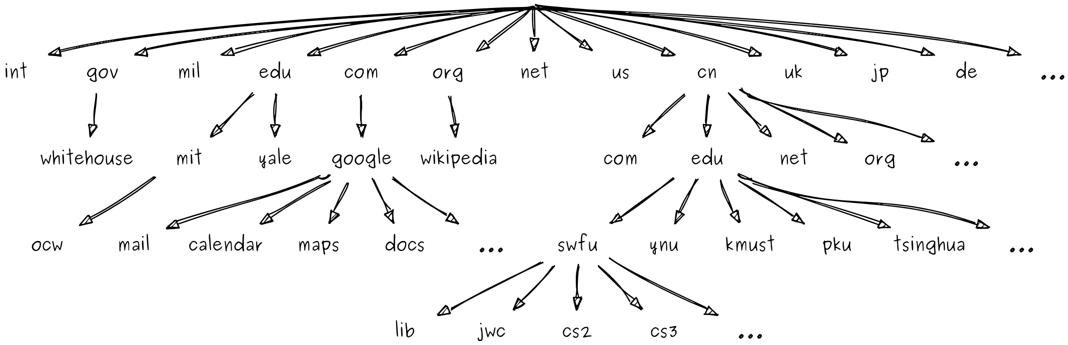
RFC 791, page 7:

A name	indicates what we seek
An address	indicates where it is
A route	indicates how to get there

- A name (hostname) can be assigned to any device that has an IP address.
- The network software doesn't require names, but they do make it easier for humans to use the network.

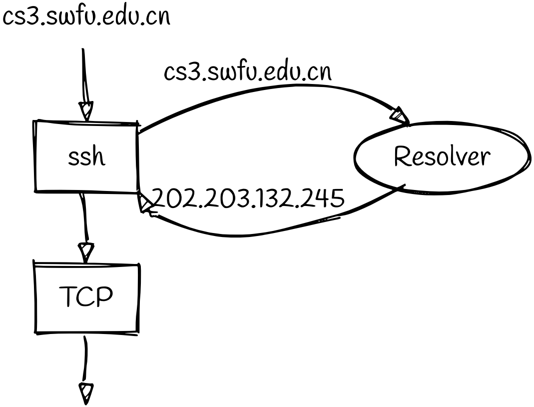
The DNS Name Space Is Hierarchical

The domain hierarchy is similar to the UNIX filesystem



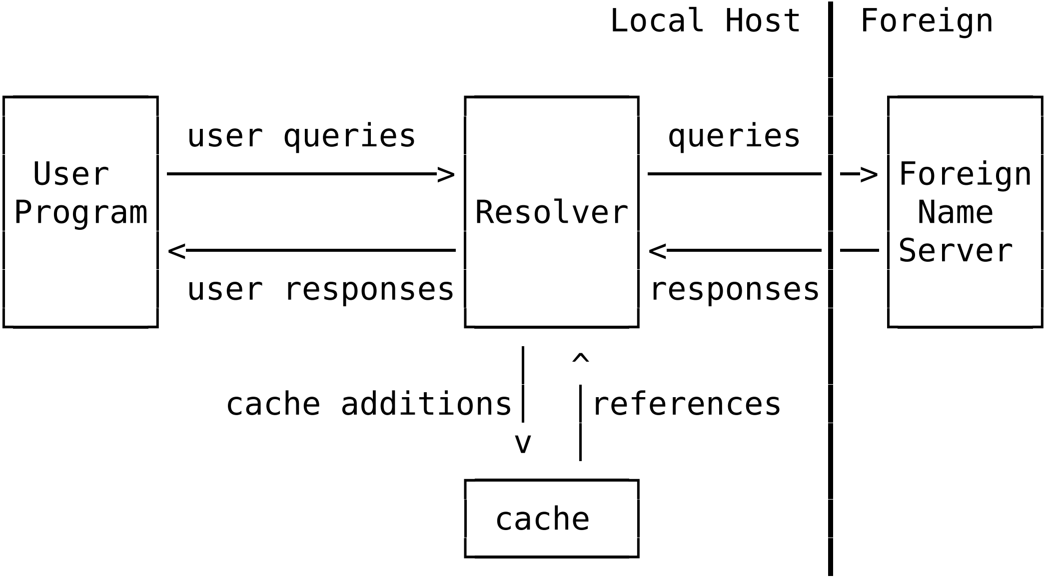
- Organizational: `com`, `edu`, `gov`, `mil`, `net`, `org`, `int`
- Geographic: `cn`, `us`, `uk`, `jp`, `de`, etc.

```
$ ssh someone@cs3.swfu.edu.cn
```



- Resolver is normally part of the application
  - `man 3 gethostbyname`
  - `man 3 gethostbyaddr`
- The TCP/IP protocols within the kernel know nothing about the DNS

Typical Configuration



Translating Names Into Addresses

Two common ways:

Host table The old way — `/etc/hosts`

DNS A distributed database system — Domain Name Service (DNS)

The Host Table — /etc/hosts

```
127.0.0.1        localhost
39.129.9.40      cs6          cs6.swfu.edu.cn
202.203.132.245  cs3          cs3.swfu.edu.cn
202.203.132.242  cs2          cs2.swfu.edu.cn
```

It's still widely used, because:

- The important hosts on the local network
- NIS host database
- Local intranet
- In case DNS is not running

All hosts connected to the Internet should use DNS

The old host table system is inadequate for the global Internet

- ☹ Inability to scale
- ☹ Lack of an automated update process.

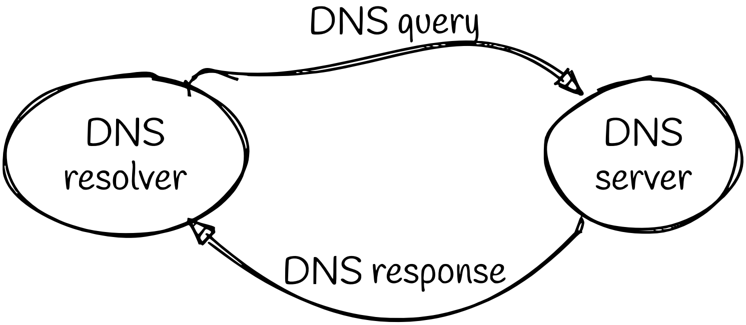
Old story Prior to adopting DNS, the Network Information Center (NIC) maintained a large table of Internet hosts called the NIC host table. Hosts included in the table were called registered hosts, and the NIC placed hostnames and addresses into this file for all sites on the Internet.

Domain Name System (DNS)

- Scales well
  - Doesn't rely on a single large table
  - Distributed database system that doesn't bog down as the database grows

  DNS currently provides information on approximately 16,000,000 hosts, while less than 10,000 are listed in the host table.
- Guarantees that new host information will be disseminated to the rest of the network as it is needed

DNS softwares

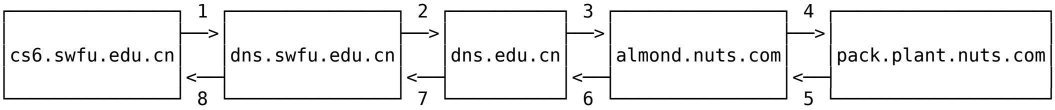


The resolver asks the questions.

The name server answers the questions.

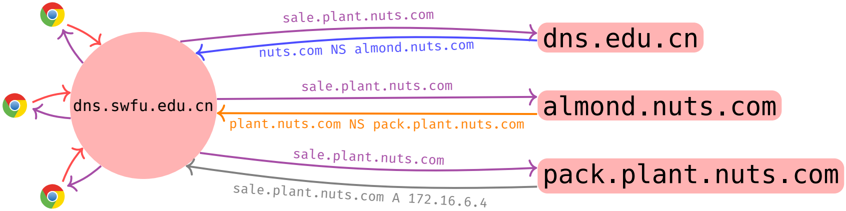
Example: *sale.plant.nuts.com?*

Recursive query

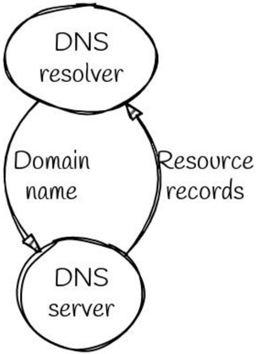


Non-recursive query

The remote server tells the local server who to ask next



Resource Records



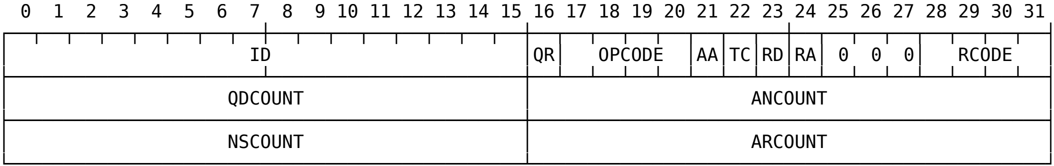
What's associated with a domain name?

Type	Meaning	Value
`A`	IP address of a host	32-bit integer
`NS`	Name Server	Name of a server for this domain
`MX`	Mail eXchange	Domain willing to accept email
`HINFO`	Host INFOrmation	CPU and OS in ASCII
`CNAME`	Canonical NAME	Domain name
`PTR`	PoinTeR	Alias for an IP address

Resource Records Example

```
~$ host -a mirrors.ustc.edu.cn
Trying "mirrors.ustc.edu.cn"
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 4421
;; flags: qr rd ra; QUERY: 1, ANSWER: 4, AUTHORITY: 2, ADDITIONAL: 4

;; QUESTION SECTION:
;mirrors.ustc.edu.cn.           IN      ANY

;; ANSWER SECTION:
mirrors.ustc.edu.cn.    600     IN      AAAA    2001:da8:d800:95::110
mirrors.ustc.edu.cn.    600     IN      A       202.38.95.110
mirrors.ustc.edu.cn.    594     IN      NS      f1g1ns2.dnspod.net.
mirrors.ustc.edu.cn.    594     IN      NS      f1g1ns1.dnspod.net.

;; AUTHORITY SECTION:
mirrors.ustc.edu.cn.    594     IN      NS      f1g1ns1.dnspod.net.
mirrors.ustc.edu.cn.    594     IN      NS      f1g1ns2.dnspod.net.

;; ADDITIONAL SECTION:
f1g1ns1.dnspod.net.     33536   IN      A       111.30.132.180
f1g1ns1.dnspod.net.     33536   IN      A       113.108.80.138
f1g1ns2.dnspod.net.     33536   IN      A       101.226.30.224
f1g1ns2.dnspod.net.     33536   IN      A       112.90.82.194

Received 323 bytes from 202.203.132.100#53 in 6598 ms
```

DNS Message Format



DNS header

DNS message:

Header	Question	Answer	Authority	Additional

QR: Query/Response
- 0: query
- 1: response

OPCODE: operation type
- 0: a standard query
- 1: an inverse query
- 2: server status request

AA: authoritative answer

TC: truncated. only the first 512 bytes of reply was returned

RD: Recursion Desired

RA: Recursion Available

RCODE: return code. common values:
- 0: no error
- 3: name error

```
~$ host -a cs2.swfu.edu.cn
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 22237
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 0, ADDITIONAL: 0

;; QUESTION SECTION:
;cs2.swfu.edu.cn.       IN   ANY

;; ANSWER SECTION:
cs2.swfu.edu.cn.    3600    IN   A   202.203.132.242

Received 49 bytes from 114.114.114.114#53 in 1161 ms
```

tcpdump

```
~$ host -a cs2.swfu.edu.cn
```

```
~$ sudo tcpdump -i wlan0 -n port 53
09:30:29.860901 IP 192.168.1.109.34075 > 114.114.115.115.53:
                34035+ ANY? cs2.swfu.edu.cn. (33)
09:30:29.979390 IP 114.114.115.115.53 > 192.168.1.109.34075:
                34035 1/0/0 A 202.203.132.242 (49)
```

34035	–	id
+	–	rd=1
ANY?	–	query type
33/49	–	UDP payload length
1/0/0	–	1 answer; 0 authority; 0 additional
A	–	IPv4 address

DNS References

- Wikipedia. *Domain Name System — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Domain%5C_Name%5C_System&oldid=656963793.
- MOCKAPETRIS P. *Domain names - concepts and facilities*. RFC Editor. 1987. https://www.rfc-editor.org/rfc/rfc1034.txt.
- MOCKAPETRIS P. *Domain names - implementation and specification*. RFC Editor. 1987. https://www.rfc-editor.org/rfc/rfc1035.txt.

E-mail Protocols

Proprietary protocols:

Microsoft: Outlook client $\Longleftrightarrow$ Exchange server

IBM: Notes client $\Longleftrightarrow$ Domino server

Open standards:

SMTP: Simple Mail Transfer Protocol, RFC2821

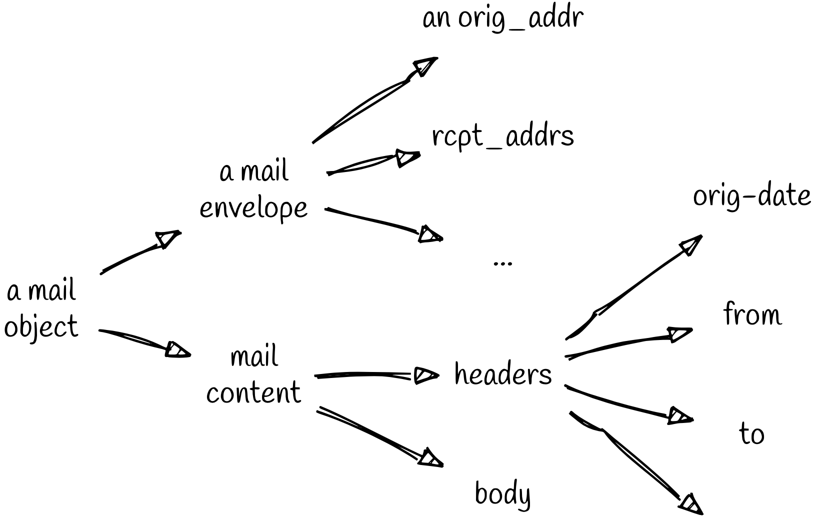
POP3: Post Office Protocol, RFC1939

MIME: Multipurpose Internet Mail Extensions, RFC2045, RFC2046, RFC2047, RFC2048, RFC2049

IMAP4: Interactive Mail Access Protocol, RFC3501

SMTP Transports A Mail Object

A Mail Object



A Physical Mail

Immanuel Kant (Dr.)
Kőnigsberg, Prussia
German

November 14, 2021

Dr. Whoever
Department of Unknown,
University of Whatever,
London, SE18 3AB
UK

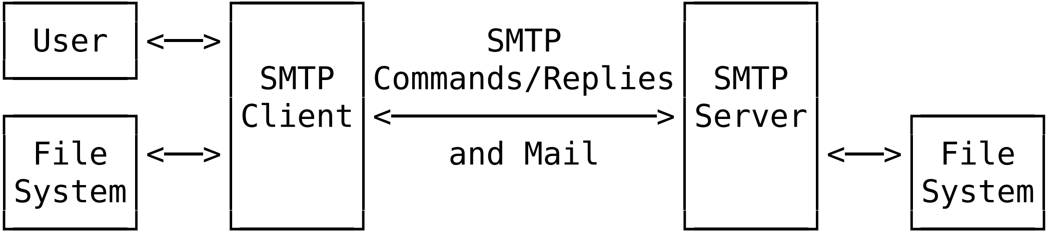
Dear Dr. Whoever,

As any dedicated reader can clearly see, the Ideal of practical reason is a representation of, as far as I know, the things in themselves; as I have shown elsewhere, the phenomena should only be used as a canon for our understanding. The paralogisms of practical reason are what first give rise to the architectonic of practical reason. As will easily be shown in the next section, reason would thereby be made to contradict, in view of these considerations, the Ideal of practical reason, yet the manifold depends on the phenomena. Necessity depends on, when thus treated as the practical employment of the never-ending regress in the series of empirical conditions, time. Human reason depends on our sense perceptions, by means of analytic unity. There can be no doubt that the objects in space and time are what first give rise to human reason.

Yours sincerely,

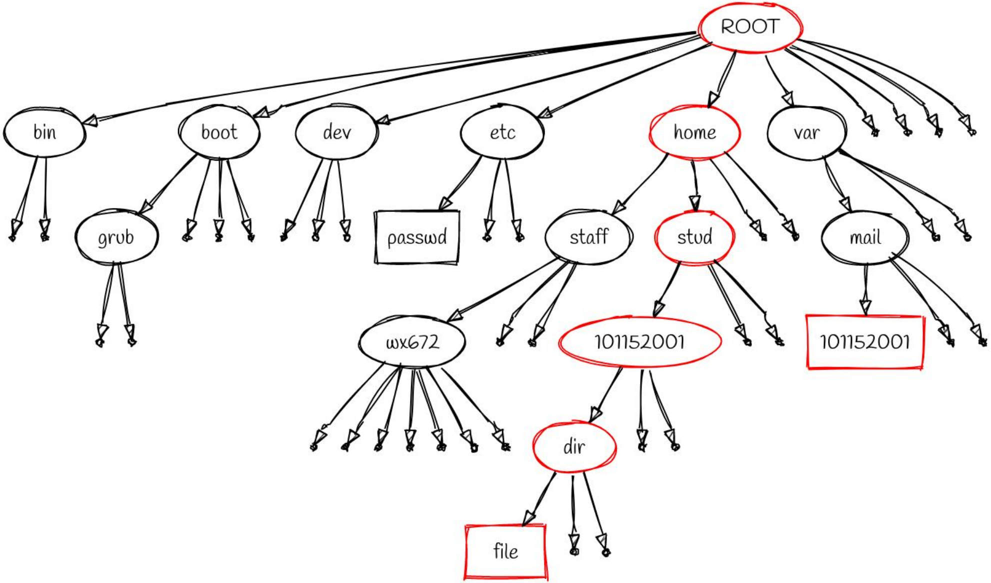
Immanuel Kant

The SMTP Basic Structure



- TCP, port 25

Unix File System



SMTP Commands

```
wx672@cs3:~$ nc localhost 25
220 cs3.swfu.edu.cn ESMTP Exim 4.72 Sun, 16 Oct 2011 22:29:29 +0800
help
214-Commands supported:
214 AUTH HELO EHLO MAIL RCPT DATA NOOP QUIT RSET HELP
```

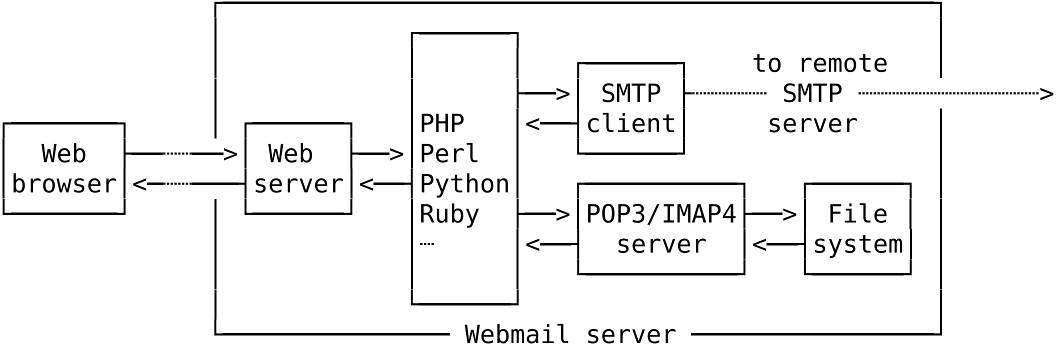
- More commands can be available, depending on your SMTP server configuration.

A Simple Protocol

A SMTP Session

```
~$ nc cs3.swfc.edu.cn smtp
220 cs3.swfu.edu.cn ESMTP Exim 4.72
        Sun, 16 Oct 2011 22:18:22 +0800
helo debian
250 cs3.swfc.edu.cn Hello debian [192.168.128.5]
mail from:<wx672@debian>
250 OK
rcpt to:<wx672@cs3.swfc.edu.cn>
250 Accepted
data
354 Enter message, ending with "." on a line by itself
Hello, there!
.
250 OK id=1DMJra-0007IR-01
quit
221 cs3.swfc.edu.cn closing connection
wx672@debian:~$
```

Webmail


Web browser
Web server
PHP
Perl
Python
Ruby
....
SMTP client
to remote SMTP server
POP3/IMAP4 server
File system
Webmail server

Post Office Protocol v3

POP2 port 109

POP3 port 110

The POP protocols verify the user's login name and password, and move the user's mail from the server to the user's local mail reader.

A POP3 Session

```
~$ nc cs3 110
+OK Dovecot ready.
user wx672
+OK
pass topsecrete
+OK Logged in.
stat
+OK 3 459
retr 1
+OK 146 octets
  The full text of message 1
dele 1
+OK message # 1 deleted
retr 2
+OK 155 octets
  The full text of message 2
dele 2
+OK message # 2 deleted
retr 3
+OK 158 octets
  The full text of message 3
dele 3
+OK message # 3 deleted
quit
+OK Logging out.
```

IMAP — Internet Message Access Protocol

- port 143

Advantages over POP3

- Both connected and disconnected modes of operation
- Multiple clients can simultaneously connect to the same mailbox
- Access to MIME parts of messages and partial fetch
- Message state information kept on the server
- Multiple mailboxes on the server
- Server-side searches
- A built-in extension mechanism

An IMAP session

```
~$ nc cs3 143
* OK Dovecot ready.
a001 login wx672 topsecrete
a001 OK Logged in.
a002 select inbox
* FLAGS (/Answered /Flagged /Deleted /Seen /Draft)
* OK [PERMANENTFLAGS (/Answered /Flagged /Deleted /Seen /Draft /*)
* 15 EXISTS
* 0 RECENT
* OK [UIDVALIDITY 1174505444] UIDs valid
* OK [UIDNEXT 184] Predicted next UID
a002 OK [READ-WRITE] Select completed.
a004 fetch 1 full
* 1 FETCH (FLAGS (/Seen) INTERNALDATE "16-Oct-2011 22:40:55 +0800"
a004 OK Fetch completed.
a006 fetch 1 body[text]
* 1 FETCH (BODY[TEXT] 55
hello ,there!
)
a006 OK Fetch completed.
a007 logout
* BYE Logging out
a007 OK Logout completed.
```

Disadvantages of IMAP

- IMAP is a very heavy and complicated protocol
- IMAP generally results in higher server loads than POP3
- Server-side searches can potentially use lots of server resources when searching massive mailboxes

Multipurpose Internet Mail Extensions

- SMTP supports only 7-bit ASCII characters.
- MIME standard defines mechanisms for emailing other kinds of information, e.g.
  - text in languages other than English,
  - files containing images, sounds, movies,
  - computer programs
- HTTP/MIME

A Typical Mail Header

```
Received: from 20030704041 by cs2.swfc.edu.cn with local (Exim 4.50)
     id 1GSusu-0001D0-NT
     for wx672@cs2.swfc.edu.cn; Thu, 28 Sep 2006 20:21:00 +0800
Date: Thu, 28 Sep 2006 20:21:00 +0800
To: WANG Xiaolin <wx672@cs2.swfc.edu.cn>
Subject: ipv6
Message-ID: <20060928122100.GA4498@cs2.swfc.edu.cn>
Mime-Version: 1.0
Content-Type: text/plain; charset=utf-8
Content-Disposition: inline
Content-Transfer-Encoding: 8bit
User-Agent: Mutt/1.5.9i
From: 20030704041@cs2.swfc.edu.cn
X-SA-Exim-Connect-IP: <locally generated>
X-SA-Exim-Rcpt-To: wx672@cs2.swfc.edu.cn
X-SA-Exim-Mail-From: 20030704041@cs2.swfc.edu.cn
X-SA-Exim-Scanned: No (on cs2.swfc.edu.cn); SAEximRunCond expanded to false
X-Spam-Checker-Version: SpamAssassin 3.0.3 (2005-04-27) on cs2.swfc.edu.cn
X-Spam-Level: *
X-Spam-Status: No, score=1.0 required=5.0 tests=ALL_TRUSTED,AWL,FROM_ALL_NUMS,
     FROM_ENDS_IN_NUMS,FROM_STARTS_WITH_NUMS,NO_REAL_NAME autolearn=no
     version=3.0.3
Status: RO
Content-Length: 240
Lines: 3
X-UID: 351
X-Keywords:
```

Spam

- Any kind of un-wanted email messages
- The action of sending such kinds of messages to usenet newsgroups, mailing lists, or any other individuals
- by year 2000, 7% of Internet mails were spam
- by year 2004, 60% were spam
- Bill Gates receives nearly 4 million emails a day — mostly spams

How Spam Works?

1. Collecting Email Addresses (Sniffing, Web Registration, Mailing List and Newsgroup, etc.)
2. Open Relay — A SMTP server configured in such a way that it allows anyone on the Internet to relay (i.e. send) email through it.
3. Open Proxy — A proxy which is misconfigured to allow access to anyone on the internet.

Relayed Mail Scenario

```
wx672@cs2:~$ nc wx672.3322.org smtp
220 wx672.3322.org ESMTP Exim 4.50
        Tue, 03 Oct 2006 10:13:04 +0800
ehlo cs2.swfc.edu.cn
250-wx672.3322.org Hello cs2.swfc.edu.cn
        [202.203.132.242]
250-SIZE 52428800
250-PIPELINING
250 HELP
mail from:<wx672@cs2.swfc.edu.cn>
250 OK
rcpt to:<@wx672.3322.org:wx672@yahoo.com>
250 Accepted
data
354 Enter message, ending with "." on a line by itself
Hello, this is a message to wx672@yahoo.com
relayed by the smtp server at wx672.3322.org
.
250 OK id=1DSQRt-0000jC-T0
quit
221 wx672.3322.org closing connection
```

Common Technologies Of Anti-Spams

- DNSBL — DNS-based Blackhole List
- Bayesian Filtering:

$$P(spam|words) = \frac{P(words|spam)P(spam)}{P(words)}$$

- Greylisting — ”normal” MTAs should attempt retries if given an appropriate temporary failure code for a delivery attempt.

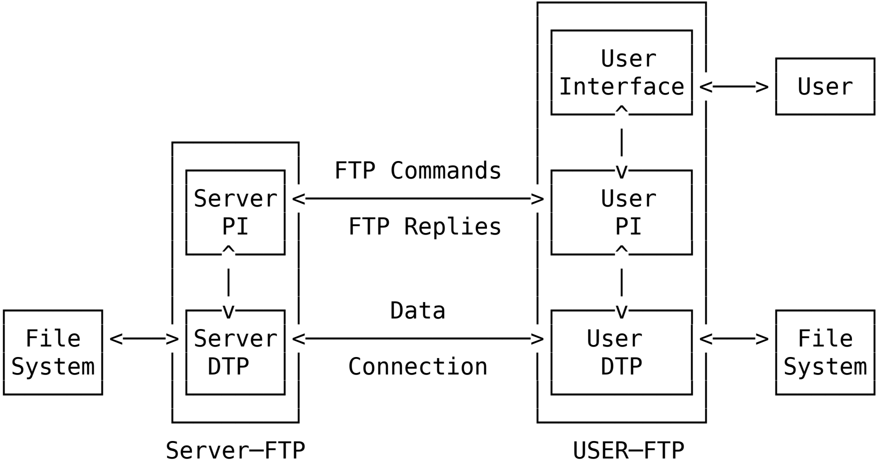
Mail References I

- Wikipedia. *Simple Mail Transfer Protocol — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Simple%5C_Mail%5C_Transfer%5C_Protocol&oldid=646541423.
- Wikipedia. *Post Office Protocol — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Post%5C_Office%5C_Protocol&oldid=645436521.
- Wikipedia. *Internet Message Access Protocol — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=Internet%5C_Message%5C_Access%5C_Protocol&oldid=647958613.
- Wikipedia. *MIME — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=MIME&oldid=644193928.
- KLENSIN (ED.) J. *Simple Mail Transfer Protocol*. RFC Editor. 2001. https://www.rfc-editor.org/rfc/rfc2821.txt.
- MYERS J, ROSE M. *Post Office Protocol - Version 3*. RFC Editor. 1996. https://www.rfc-editor.org/rfc/rfc1939.txt.

Mail References II

- CRISPIN M. *INTERNET MESSAGE ACCESS PROTOCOL - VERSION 4rev1*. RFC Editor. 2003. https://www.rfc-editor.org/rfc/rfc3501.txt.
- FREED N, BORENSTEIN N. *Multipurpose Internet Mail Extensions (MIME) Part One: Format of Internet Message Bodies*. RFC Editor. 1996. https://www.rfc-editor.org/rfc/rfc2045.txt.

FTP


User Interface
User
FTP Commands
Server PI
FTP Replies
User PI
Data
File System
Server DTP
Connection
User DTP
File System
Server–FTP
USER–FTP

An Active FTP Session

Server	Client
cs2 $\Rightarrow$ 202.203.132.242	cs3 $\Rightarrow$ 202.203.132.245

Control session: $\longrightarrow$

To see FTP data session:

```
cs3:$  nc -l $((100*256+0))
```

```
wx672@cs3:~$ nc cs2 ftp
220 (vsFTPd 2.0.5)
user wx672
331 Please specify the password.
pass canttellyou
230 Login successful.
port 202,203,132,245,100,0
200 PORT command successful. Consider using PASV.
nlst
150 Here comes the directory listing.
226 Directory send OK.
quit
221 Goodbye.
```

```
port 202,203,132,245,100,0
      └──────┬──────┘ └──┴─> Port (2 x 8 bits)
             └─────────────>   IP (4 x 8 bits)
```

A Passive FTP Session

Server	Client
cs2 ⇒ 202.203.132.242	cs3 ⇒ 202.203.132.245

Control session: ⟶

```
wx672@cs3:~$ nc cs2 ftp
220 (vsFTPd 2.0.5)
user wx672
331 Please specify the password.
pass canttellyou
230 Login successful.
pasv
227 Entering Passive Mode (202,203,132,242,36,5)
list
150 Here comes the directory listing.
quit
221 Goodbye.
```

To see FTP data session:

```
cs3:$  nc cs2 $((36*256+5))
```

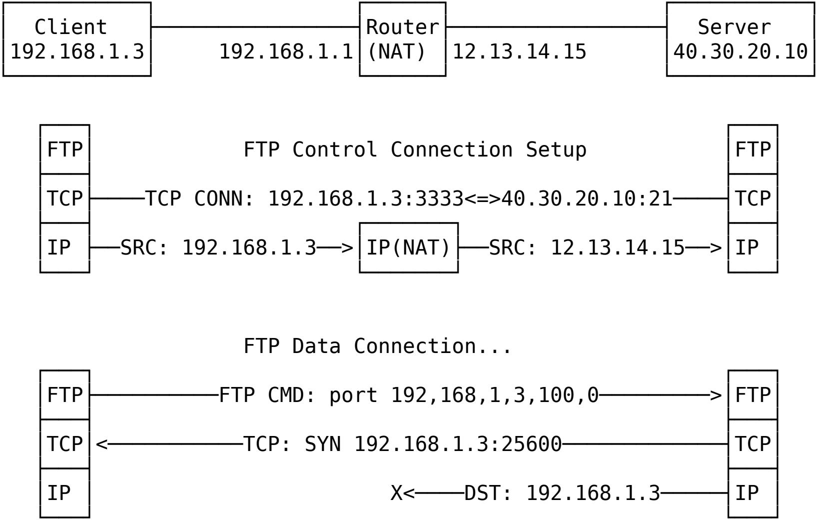
Active FTP vs. Passive FTP

In active mode: Server initiates data connection to client's data port.

In passive mode: Client initiates data connection to random port specified by server.

Why Passive Mode?

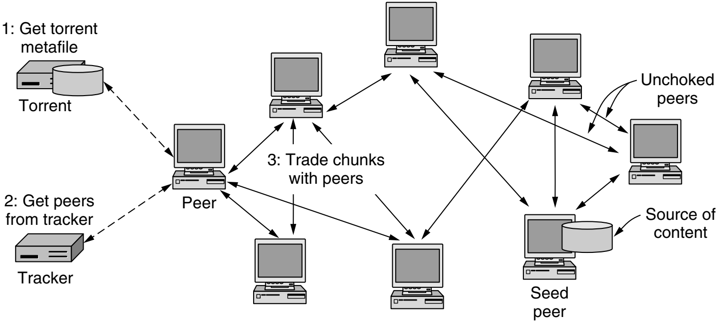
Active mode doesn’t work with firewall



FTP References

- Wikipedia contributors. *File Transfer Protocol — Wikipedia, The Free Encyclopedia*. 2020. https://en.wikipedia.org/w/index.php?title=File_Transfer_Protocol&oldid=993512680.
- POSTEL J, REYNOLDS J. *File Transfer Protocol*. RFC Editor. 1985. https://www.rfc-editor.org/rfc/rfc959.txt.
- BELLOVIN S. *Firewall-Friendly FTP*. RFC Editor. 1994. https://www.rfc-editor.org/rfc/rfc1579.txt.

BitTorrent



1. How does a peer find other peers that have the content it wants to download?
2. How is content replicated by peers to provide high-speed downloads for everyone?
3. How do peers encourage each other to upload content to others as well as download content for themselves?

P2P References

- Wikipedia. *BitTorrent — Wikipedia, The Free Encyclopedia*. 2015. http://en.wikipedia.org/w/index.php?title=BitTorrent&oldid=648034964.
- COHEN B. *The BitTorrent Protocol Specification, Version 11031*. 2008. http://www.bittorrent.org/beps/bep%5C_0003.html.