Outline
Switch classifications

We’ll consider multiple ways of classifying switches:
1. By location in a hierarchical network
2. By functionality
3. By modularity of implementation
4. By form of switching fabric (details later)
Hierarchical networks

a. A flat view of a network/internetwork is of links that interconnect nodes.
b. We can also consider nodes as being interconnected by networks, which in turn consist of interconnected nodes or even networks.
c. Hierarchical view shows networks with varying distances from terminals.
Benefits of hierarchical switching

[Elements of hierarchy may differ by virtue of who runs/owns them, what technology they use, physical location, etc]

✓ Heterogeneous access networks
✓ Localise problems
✓ Localised traffic needn’t burden core
  Spatial locality – how much usually leaves a workgroup switch to the next level of the hierarchy?
✓ Align network topology with geography?
More benefits of hierarchical switching

Align network topology with geography:

✓ **Distribute** management/administration of network

✓ **Different operators** for different *levels* of the hierarchy:
  - **Local area**: private institutional network
  - **Metropolitan area**: public network providers
    - Few provide physical infrastructure: Telstra, Optus
    - Multiple provide service: infrastructure providers+ISPs
  - **Wide area**: many provide physical infrastructure and service

But benefits of alignment with *organisational boundaries* may be stronger, as we’ll see later when covering Virtual LANs.
Examples of network hierarchy

1. The Bell Telephone system

(before divestiture in 1984, after which it lost its regular structure)

- Regional offices (Class 1)
- Sectional offices (Class 2)
- Primary offices (Class 3)
- Toll offices (Class 4)
- End offices (Class 5)
- Local loops
Examples of network hierarchy

2. The Internet

UNSW
ISP 1
AOL
ISP 2
OzEmail
ISP 3
BigPond
ISP 4

NSP 1
AARnet
UNSW
ISP 1

NSP 2
Optus

NSP 3
Telstra

Internet2

Reach

+“Dot bombs”: Global Crossing, UUnet, ...

NSP = Network Service Provider
ISP = Internet Service Provider
## Hierarchical switching in the Internet

**Exercise:** Use `traceroute` to view which networks packets traverse to reach their destination.

Many servers available through [www.traceroute.org](http://www.traceroute.org)

### Example:

<table>
<thead>
<tr>
<th><a href="http://www.telstra.net">www.telstra.net</a></th>
<th>unsw.edu.au</th>
<th>unsw.edu.au</th>
</tr>
</thead>
<tbody>
<tr>
<td>reach.com</td>
<td>aarnet.net.au</td>
<td>aarnet</td>
</tr>
<tr>
<td>bbnplanet.net</td>
<td>pnw-gigapop.net</td>
<td>pnw-gigapop</td>
</tr>
<tr>
<td></td>
<td>ucaid.edu</td>
<td>ucaid.edu</td>
</tr>
<tr>
<td></td>
<td>nox.org</td>
<td>nox.org</td>
</tr>
<tr>
<td></td>
<td>mit.edu</td>
<td>mit.edu</td>
</tr>
</tbody>
</table>

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Path from UNSW to www.irtf.org

$ traceroute www.irtf.org
traceroute to www.irtf.org (192.150.187.18), 30 hops max, 38 byte packets
1 92.171.149.in-addr.arpa (149.171.92.2) 14.624ms 0.775ms 1.040ms
2 129.94.255.181 (129.94.255.181) 0.436ms 0.409ms 0.384ms
3 gig2-2.nswrnosbb.nswrno.net.au (138.44.1.37) 0.582ms 0.563ms 0.527ms
4 gig2-2.nswrnosbb.nswrno.net.au (138.44.1.37) 0.582ms 0.563ms 0.527ms
4 vlan948.gbe3-0.sccn1.broadway.aarnet.net.au (192.231.212.49) 1.450ms 0.805ms 0.758ms
5 pos1-0.sccn1.seattle.aarnet.net.au (192.231.212.34) 157ms 156ms 157ms
6 Abilene-PWAVE-1.peer.pnw-gigapop.net (198.32.170.43) 166ms 165ms 166ms
7 snvang-sttlng.abilene.ucaid.edu (198.32.8.10) 174ms 173ms 173ms
8 losang-snvang.abilene.ucaid.edu (198.32.8.94) 180ms 180ms 180ms
9 hpr-lax-gsr1--abilene-LA-10ge.cenic.net (137.164.25.2) 190ms 190ms 190ms
10 dc-lax-dc1--lax-hpr1-ge.cenic.net (137.164.22.12) 181ms 181ms 181ms
11 dc-sac-dc1--lax-dc1-pos.cenic.net (137.164.22.127) 190ms 190ms 189ms
12 dc-oak-dc2--csac-dc1-ge.cenic.net (137.164.22.110) 201ms 201ms 201ms
13 dc-oak-dc1--oak-dc2-ge.cenic.net (137.164.22.124) 192ms 193ms 192ms
14 dc-svl-dc1--oak-dc1-10ge.cenic.net (137.164.22.30) 192ms 193ms 193ms
15 ucb--svl-dc1-egm.cenic.net (137.164.23.66) 194ms 194ms 193ms
16 fast4-0-0-0.inr-667-eva.Berkeley.EDU (128.32.0.99) 203ms 203ms 204ms
17 router2-fast0-0-0.ICSI.Berkeley.EDU (169.229.0.30) 195ms 195ms 195ms
18 www.irtf.org (192.150.187.18) 195ms 195ms 194ms

3 delay measurements for each hop
Delays vary with link congestion

Large increase in delay as packets pass over the Pacific Ocean

common phrases:
gig, ge: Gigabit Ethernet
pos: Packet Over SONET
Networking terms borrowed from trees

Certain networking terms come from the structural similarities between networks and trees

**Leaves:** The perimeter of the network, e.g. end-users.

**Branches:** Join leaves & branches together.

**Trunk:** High capacity, joins everything together.

**Root (singular):** Foundation for remainder.
Examples of hierarchical network terms

Terms borrowed from trees:
Spanning Tree Protocol - Bridges elect a root for the tree.
Multicast - “leaf-initiated join”; pruning and grafting

Other terms that describe hierarchy:
Core/backbone vs periphery/edge
Switch classification 1:  
By location in hierarchical network

**Private networks**
- **Desktop** switch (may merely be a shared-media LAN)
- **Workgroup / Campus** LAN switches
- **Enterprise** switch

**Public networks**
- **Access** networks
- **Distribution / “transport”** networks

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- **DLink** DES-1250G
- **Cisco** Catalyst 4006
- **Cisco** 12000 router

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Switch trends as location in hierarchy changes

How do switches change as you move into the network core?:

1. **Availability** becomes increasingly important
   - High-reliability components
   - Redundancy in power supplies, even redundant fabrics
   - Hot swapping of line interfaces & power supplies
   - May employ “protection switches” to bypass failed switches (low switching rate, high throughput)

2. **Throughput** becomes increasingly important
   (though load may be less variable)

3. **Reduced functionality**, e.g. NAT, DHCP servers, firewalls, QOS tend to be implemented in workgroup switches but not core switches.
Switch trends as location in hierarchy changes (continued)

4. Fewer interfaces with higher capacity (& cost)
   e.g. fiber (not twisted pair), single mode (not multi-mode) fibre
   May also offer public-network interfaces, e.g. ISDN – low-speed, pay-per-use

5. More heterogeneous interfaces (although workgroup switch often has fast link for trunks)

6. More symmetrical data flow

7. Transit switching (anycast), rather than line switching (unicast)
Outline
Switching network taxonomy

Each network at one level of a public network usually connects to multiple networks at higher levels in order to provide fault tolerance.
Unicast and anycast switching

Terms used in public networks:

**Line switches**: unicast: specific input to specific output

**Transit switches**: anycast: specific input to one of several outputs, e.g. several lines connecting this switch to another.
Switch classification 2: By functionality

Terms used for components in space-division networks†:

**Connection network** *(unicast)*: Any specified unused input may be connected to any specified unused output.

**Concentrator network** *(anycast)*: Any specified input may be connected to any unspecified output. (e.g. select any telephone operator who is available; select any available trunk)

**Expansion network** *(multicast)*: A specified input may be connected to several specified outputs.

† Which we’ll define next week. This basically means that spatially separated paths through the switch can concurrently carry different information through the switch.
Outline
Switch classification 3: By modularity of implementation

**Bounded systems:** fixed, pre-determined configuration.

**Stackable switches:** intra-stack connection:
- high-speed port (e.g., Gigabit Ethernet)
- Low Voltage Differential Signaling (LVDS)

**Chassis switches:**

Increasing
- cost
- performance
- flexibility

Image sources unknown
Dominant manufacturers

**Computing background**
(common in access networks)
- Consumer devices: *D-Link, Netgear, Linksys*
  - Extreme
  - 3Com
  - Cisco
  - Juniper, Avici

**Telephony background**
(common in core networks)
- NEC
- Lucent
- Nortel
- Marconi
- Alcatel
- Siemens
- Ericsson

Newer Chinese manufacturers: Huawei Technologies, ZTE
Cisco

One of the pioneers
Established Internet Operating System (IOS) that provides consistent interface to their systems
Preaches IOS and products through certification programs, e.g. CCNA, CCNP, CCIE
Good support “networks”
Expensive

Online tour of Carrier Routing System (CRS)-1
Outline
History

Switching (and hence switches) preceded routing.
⇒ separation between “switch” (e.g. phone switch) and packet networks (using gateways, routers, etc)

In the 1990s, the “need for speed” led to new “switching” techniques ⇒ association between “switch” and “fast”.

‡ The first RFCs to mention routers were RFC 898 (1984) and RFC 1009 (1987)
Pronunciation of “routing”

“‘Roo’·ting” is what fans do at a football game, what pigs do for truffles under oak trees in the Vaucluse, and what nursery workers intent on propagation do to cuttings from plants.

“Rou’·ting” is how one creates a beveled edge on a tabletop or sends a corps of infantrymen into full-scale, disorganized retreat.

Either pronunciation is correct for routing, which refers to the process of discovering, selecting, and employing paths from one place to another (or to many others) in a network.”


Or more succinctly: “there are two different ways to pronounce the word router, either as “rootor” or as “rowter,” and people waste a lot of time arguing over the proper pronunciation [Perlman 1999].” [Kurose and Ross, p. 475]
Marketing classification

The most widespread, and eventually you have to use it to purchase products
Designed/evolved to earn revenue for manufacturers: It’s easy to upsell to a bewilderred customer

**Router:** A multiport device that uses network layer (e.g. IP) headers to decide which port to forward packets on
  e.g. Cisco 7000 series *router*

**Switch:** A multiport device that uses link layer (e.g. Ethernet) headers to decide which port to forward packets on
  e.g. Cisco Catalyst 2900 Series

This course deals with the design of both routers *and* switches, in the marketing sense.
Concerns about marketing terms

- Classification according to layer (switch=link, router=network) doesn’t say anything about different functionality; just examining different header bits

- Doesn’t this just shift the question to one of numbering layers?
  e.g. Q: Is ATM a link layer or a network layer technology?
  A1: ATM is a link layer: You can send IP packets over it ⇒ ATM switches
  A2: ATM is a network layer: It concatenates links to form a path between systems connected to the ATM network. ⇒ ATM routers (term isn’t used despite justification from definitions)

- What is a “layer 3 switch”?, e.g. Cisco Catalyst 4840G
  or for that matter, a “switch router”, e.g. Cisco Catalyst 8500
  Answer: A fast router.

- And questions arising in other layers (apart from link/network):
  Layer 4: What is layer 4 switching? (A: switching affected by transport headers)
    e.g. Cisco Catalyst 6500 Series Content Switching Module
  Layer 2: Do switches differ from bridges?
  Layer 1: What do we call a device that operates only at the physical layer (e.g. MEMS photonic switch using mirrors)? Why are some such devices are called “lambda routers”?
The issue of speed

A “router” may require more processing than a “switch”, so may operate slower† (packets/sec) for a given technology.

**Ethernet switch:**
1. Use frame addresses to index a database, indicating which outgoing port to use.
2. Start forwarding to outgoing port (needn’t wait to check CRC)

**Router:**
1,2: Ethernet processing (check destination address, check CRC, frame validity checks), and only once that is complete, pass the packet up to the network layer
+ 3. IP processing (check destination address, decrement TTL, packet validity checks, IPv4 segmentation & reassembly)

⇒ perception that routers are slower than (Ethernet) switches

Heaven forbid us marketing a device whose name has “slow” connotations!
→ “switch router” “layer 3 switch” = fast router (e.g. lots of hardware, start IP processing before receive Ethernet CRC).

† A router may process fewer data units per second than a switch, but can make more informed forwarding decisions, finding better paths etc
⇒ network performance may be better
Classification by implementation

Packet switches traditionally operated on datagrams: self-contained data units.
Routing/switching/forwarding decisions (e.g. which port, which queue, etc) can be made:

- **Each time** a datagram arrives. This causes appreciable load:
  - processing to make these decisions
  - transmission capacity to convey information used for decision making
- **At the beginning** of a flow of packets. Store the state, and refer back to those decisions whenever subsequent packets arrive. Couldn’t this reduce the processing load?

  ⇒ “Fast Packet Switching” (e.g. ATM):
  1. Set up state info in switches
  2. Transfer data
  3. Release state info in switches

e.g. “switches” contain more state information than “routers” & this state info is explicitly established and released for each flow/connection.
Functional classification of verbs

Functional sense of the words:

**Routing**: Determining *how* to get there: Which output port should be used to get to the destination?

**Switching**: The process of going there: Moving information from input ports to appropriate output ports.

Automotive analogy:
Routing = Navigating, Switching (lanes) = driving the vehicle

The 2 functions can be physically separated
e.g. ATM & MPLS: device that determines routes may be separate (e.g. it could be centralised & omniscient) from the devices that actually do the switching

**This course deals with switching** in the general sense.
We care about achieving functionality, not with naming products.
It does *not* deal with routing, neither algorithms (e.g. Bellman-Ford) nor protocols (e.g. BGP). (It does deal with routers.)

† Sometimes called “forwarding” to avoid confusion about switching being only part of the role of a switch.
Bottom-line definitions

“Switch”: Any device with multiple ports that aims to direct unicast traffic only to one output port that leads to the destination.

**Router**: A switch that deals with network layer headers.

“a type of switch” $\Rightarrow$ switch functions (fabrics, packet classification, scheduling, buffer management etc) are used in routers.

**Bridge**: A switch that deals with link layer headers.
A variety of textbook definitions

Sources:
• Keshav
• Peterson and Davie
• Kurose and Ross
• Tanenbaum
• McDysan
• Telecom Glossary 2000 [http://www.atis.org/tg2k/]
Keshav’s definitions

**Switch**: “A switch allows data arriving at any of its inputs to be transferred to any of its outputs.” p. 6 & details in Chapter 8

**Routing**: “How can we determine the shortest path from a source to a destination, or the best tree along which to distribute data from a source to a set of destinations? This is the problem of *routing*” p. 7 & details in Chapter 11
Peterson & Davie’s definitions

“the core job of a switch is to take packets that arrive on an input and
forward (or switch) them to the right output so that they will reach
their appropriate destination. Knowing which output is the right one
requires the switch to know something about the possible routes to the
destination. The process of accumulating and sharing this knowledge,
the second problem for a packet switch, is called routing.”

– L. Peterson and B. Davie: Computer Networks: A Systems Approach,
Morgan Kaufmann, 1996, p. 150

and they go into depth about the distinction between bridges, switches,
and routers on pp. 234-237
"routers are store-and-forward packet switches that forward packets using network-layer addresses. Although a switch is also a store-and-forward packet switch, it is fundamentally different from a router in that it forwards packets using MAC addresses. Whereas a router is a layer-3 packet switch, a switch is a layer-2 packet switch.”

Problems:

✘ Tying definitions to layers (see earlier slide)

✘ Recursive definitions:
  switch ? packet switch ? layer 3 packet switch ? router
  ? layer 2 packet switch
Tanenbaum’s definitions

“As an aside, some people make a distinction between routing and switching. Routing is the process of looking up a destination address in a table to find where to send it. In contrast, switching uses a label taken from the packet as an index into a forwarding table. These definitions are far from universal, however.”


Notes:
“some people” but not Tanenbaum?
The distinction here is the method used for classification, with routing presumably being necessary when identifiers are large (globally unique)
Semester 1 module 10:
"10.2.2 Routing versus switching
Routing is often contrasted with switching. ... The primary difference is that switching occurs at Layer 2, the data link layer, of the OSI model and routing occurs at Layer 3. This distinction means routing and switching use different information in the process of moving data from source to destination.
...
Another difference between switched and routed networks is switched networks do not block broadcasts."

Semester 3, module 4.2.7 “The features and functionality of Layer 3 switches and routers have numerous similarities. The only major difference between the packet switching operation of a router and a Layer 3 switch is the physical implementation. In general-purpose routers, packet switching takes place in software, using microprocessor-based engines, whereas a Layer 3 switch performs packet forwarding using application specific integrated circuit (ASIC) hardware.”

module 4.3.4: “Today, switches are also able to filter according to the network-layer protocol. This blurs the demarcation between switches and routers. A router operates on the network layer using a routing protocol to direct traffic around the network. A switch that implements advanced filtering techniques is usually called a brouter. Brouters filter by looking at network layer information but they do not use a routing protocol.”
References in Keshav

Datagrams and virtual circuits, pp. 48-53, 175-6

See also Keshav’s Infocom97 panel presentation on “Routing vs. Switching” http://www.cs.cornell.edu/skeshav/talks/infocom97panel/

Switching vs routing terminology:
- Keshav: pp. 6-7: Definitions, Ch. 8: Switches, Ch. 11: Routing