Chapter 4: outline

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4.2 virtual circuit and datagram networks

4.3 what's inside a router

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- IPv4 addressing
- ICMP
- IPv6

4.5 routing algorithms
- link state
- distance vector
- hierarchical routing

4.6 routing in the Internet
- RIP
- OSPF
- BGP

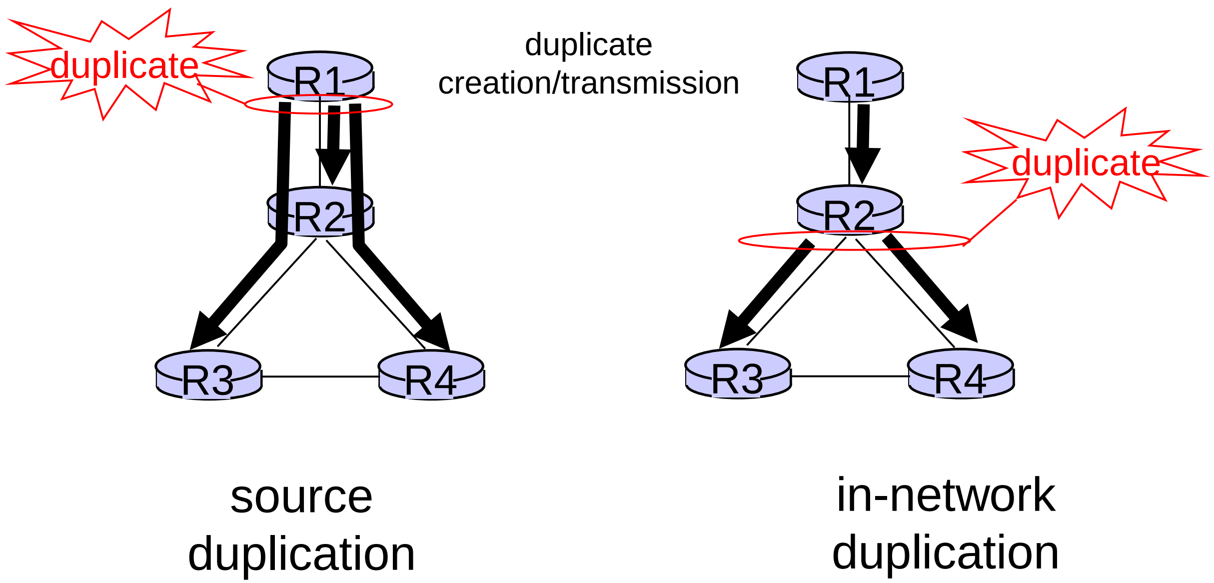
4.7 broadcast and multicast routing

Terminology

- *unicast:* Direct, host-to-host communication. Can be across the entire internet.
- *broadcast:* Communication done from one host to all other hosts on the same subnet.
- *multicast:* Communication done from one or more hosts to a "subscribed" set of hosts across multiple subnets. Note that internet routers block multicast packets, so it's LAN only.
- *anycast:* Communication done to the closest subnet that responds. Google uses this to cache search results physically closer to you. i.e., a subnet is advertised in multiple places!

Broadcast routing

- deliver packets from source to all other nodes
- source duplication is inefficient:



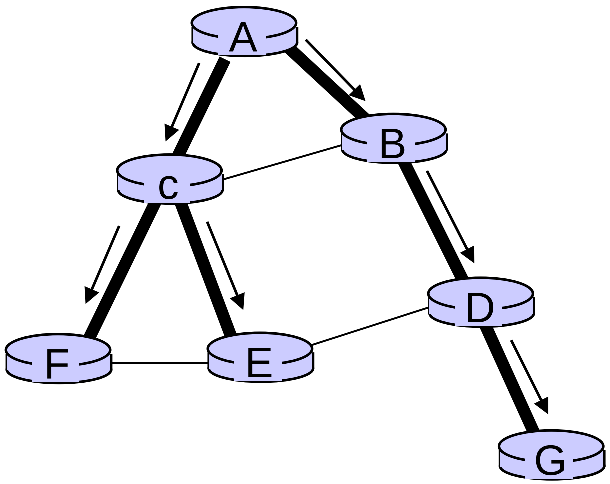
- source duplication: how does source determine all of the recipient addresses?

In-network duplication

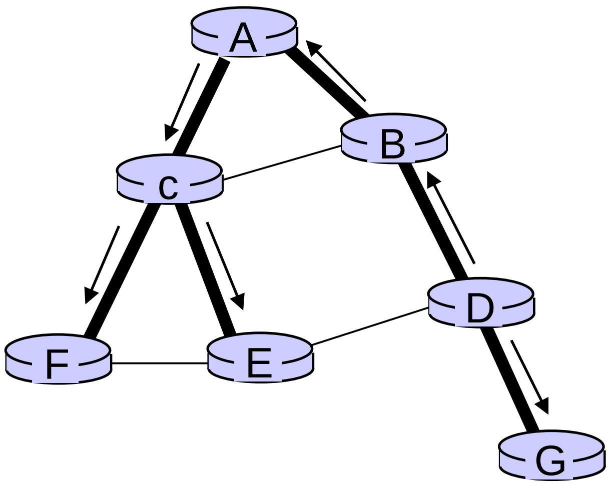
- *flooding:* when node receives broadcast packet, sends copy to *all* neighbors
  - problems: cycles & broadcast storm
- *controlled flooding:* node only broadcasts packet if it hasn't broadcast same packet before
  - node keeps track of packet ids already broadcasted
  - or reverse path forwarding (RPF): only forward packet if it arrived on shortest path between node and source
- *spanning tree:*
  - no redundant packets received by any node

Spanning tree

- first construct a spanning tree
- nodes then forward/make copies only along spanning tree



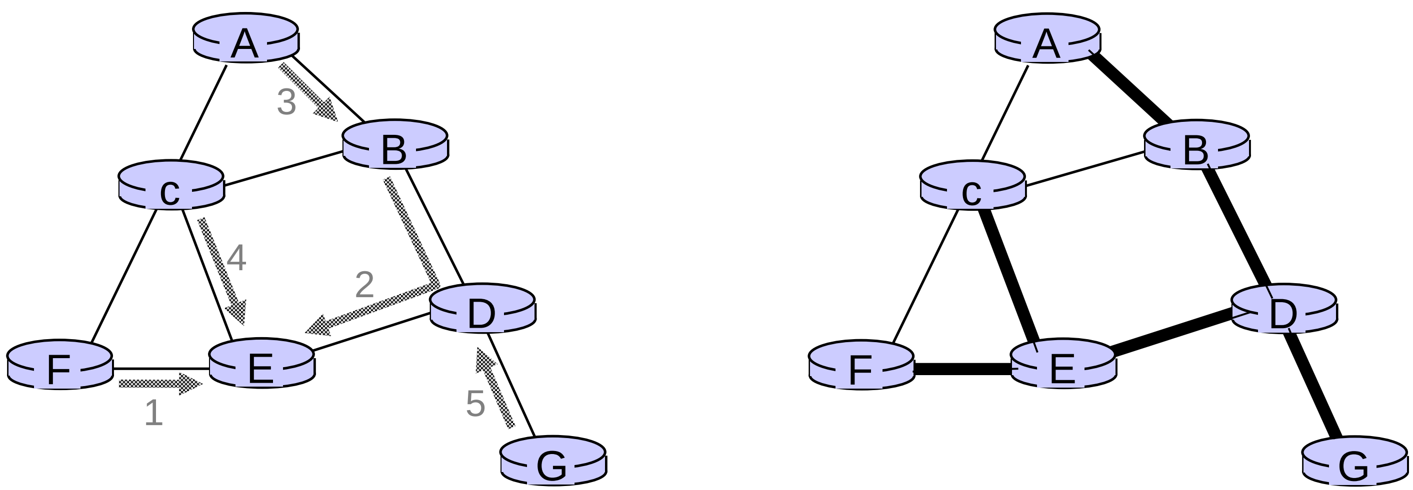
Broadcast initiated at A



Broadcast initiated at D

Spanning tree: creation

- center node
- each node sends unicast join message to center node
  - message forwarded until it arrives at a node already belonging to spanning tree



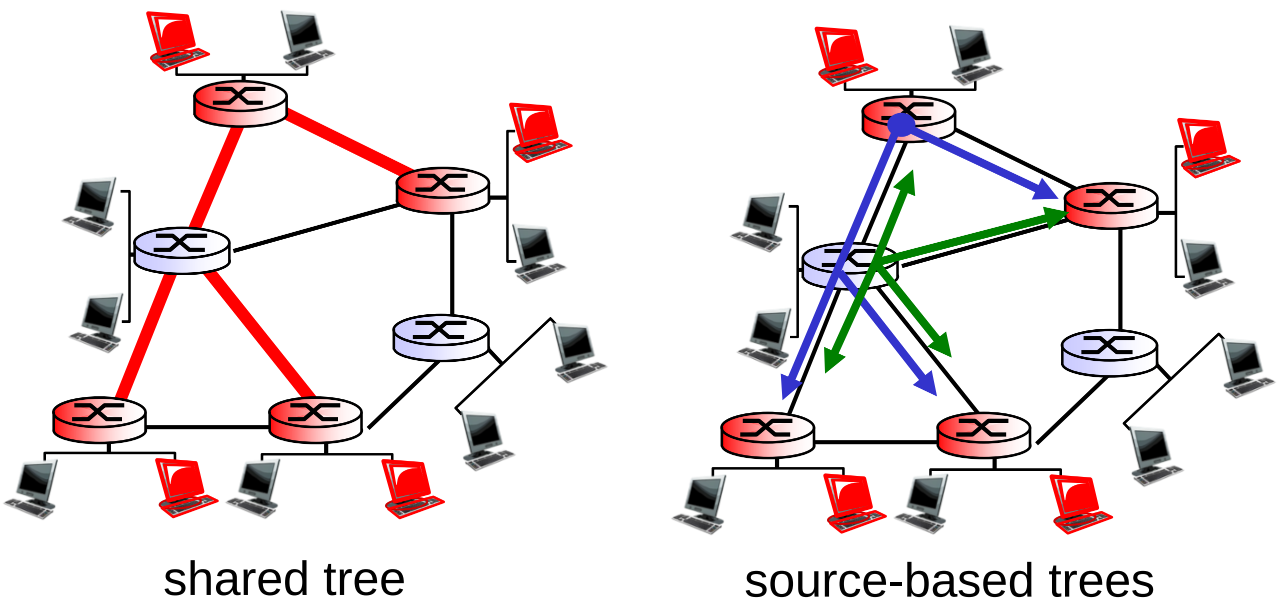
(a) stepwise construction of spanning tree (center: E)

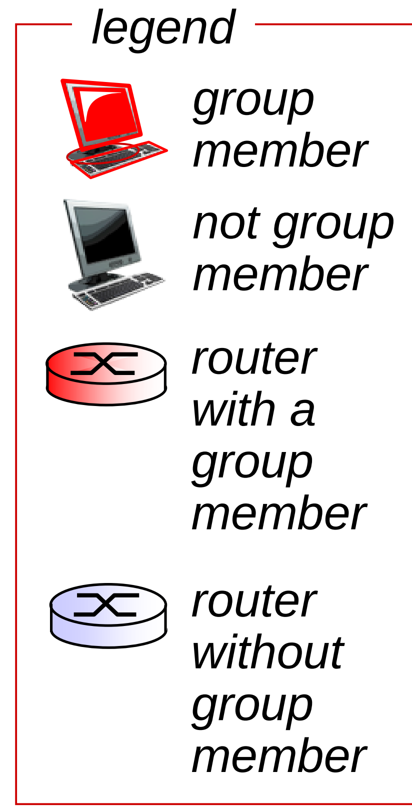
(b) constructed spanning tree

Multicast routing: problem statement

goal: find a tree (or trees) connecting routers having local multicast group members

- *tree:* not all paths between routers used
- *shared-tree:* same tree used by all group members
- *source-based:* different tree from each sender to rcvrs





Approaches for building mcast trees

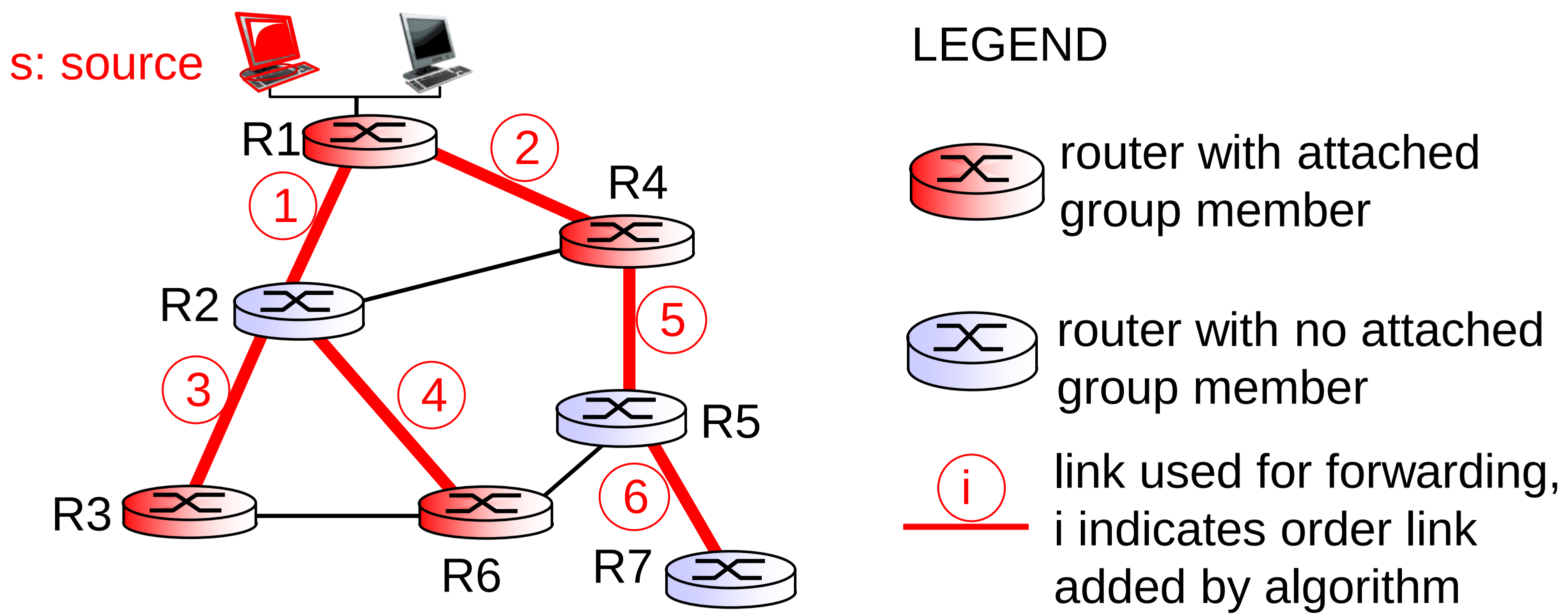
approaches:

- *source-based tree:* one tree per source
  - shortest path trees
  - reverse path forwarding
- *group-shared tree:* group uses one tree
  - minimal spanning (Steiner)
  - center-based trees

…we first look at basic approaches, then specific protocols adopting these approaches

Shortest path tree

- multicast forwarding tree: tree of shortest path routes from source to all receivers
  - Dijkstra's algorithm

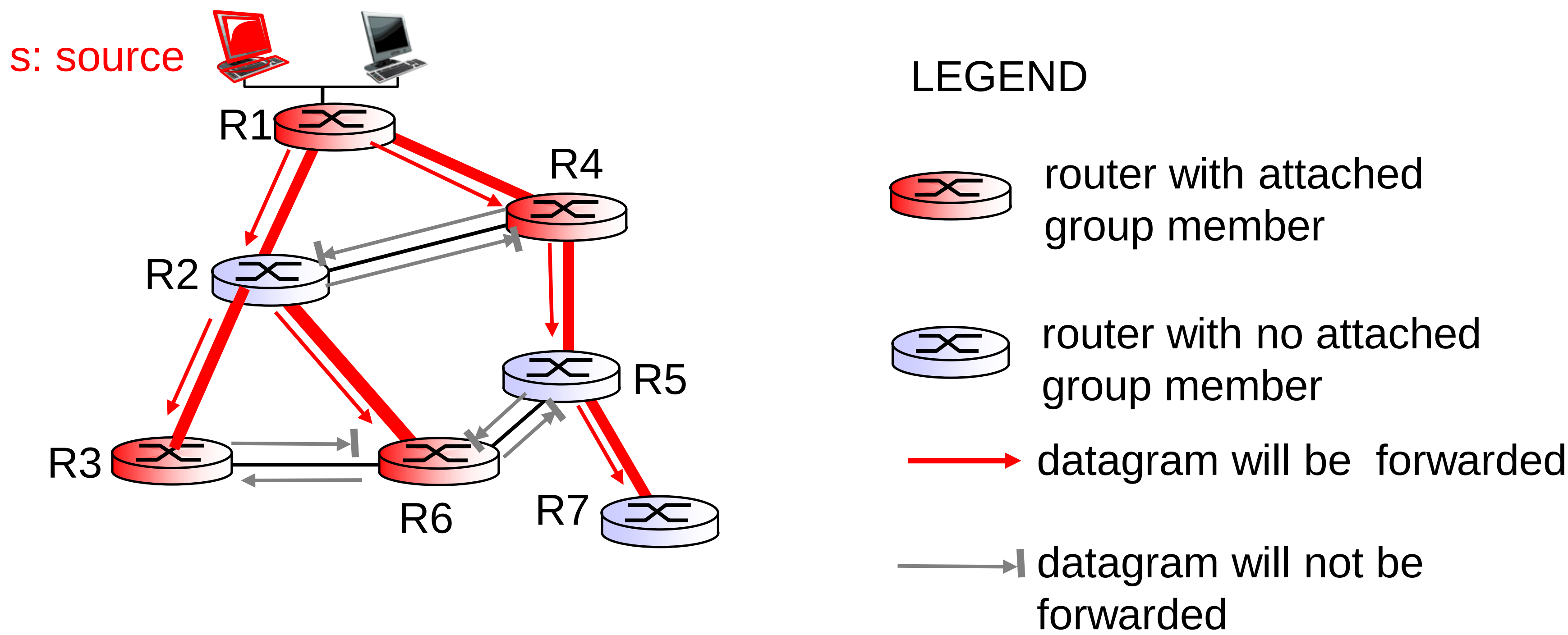


Reverse path forwarding

- rely on router's knowledge of unicast shortest path from it to sender
- each router has simple forwarding behavior:

> ***if*** (multicast datagram received on incoming link on shortest path back to center)
> ***then*** flood datagram onto all outgoing links
> ***else*** ignore datagram

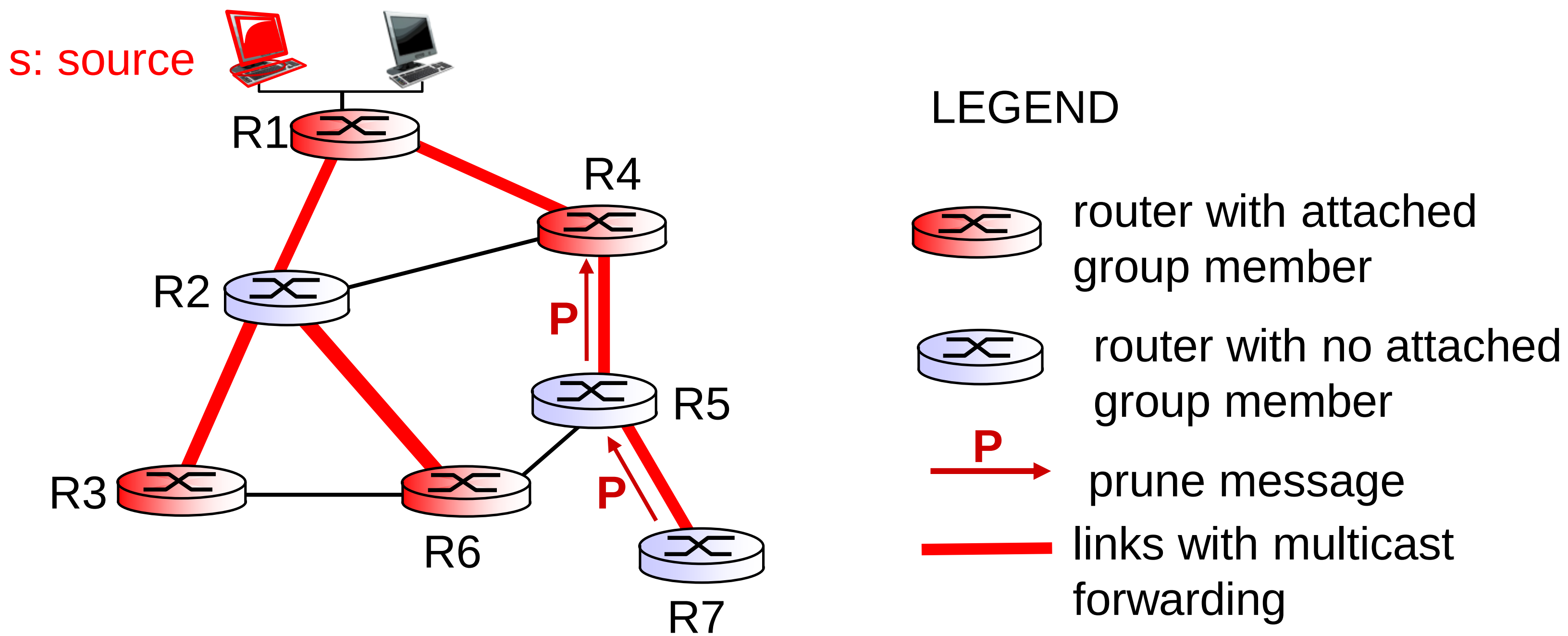
Reverse path forwarding: example



- result is a source-specific *reverse* SPT
  - may be a bad choice with asymmetric links

Reverse path forwarding: pruning

- forwarding tree contains subtrees with no multicast group members
  - no need to forward datagrams down subtree
  - "prune" messages sent upstream by router with no downstream group members



Shared-tree: steiner tree

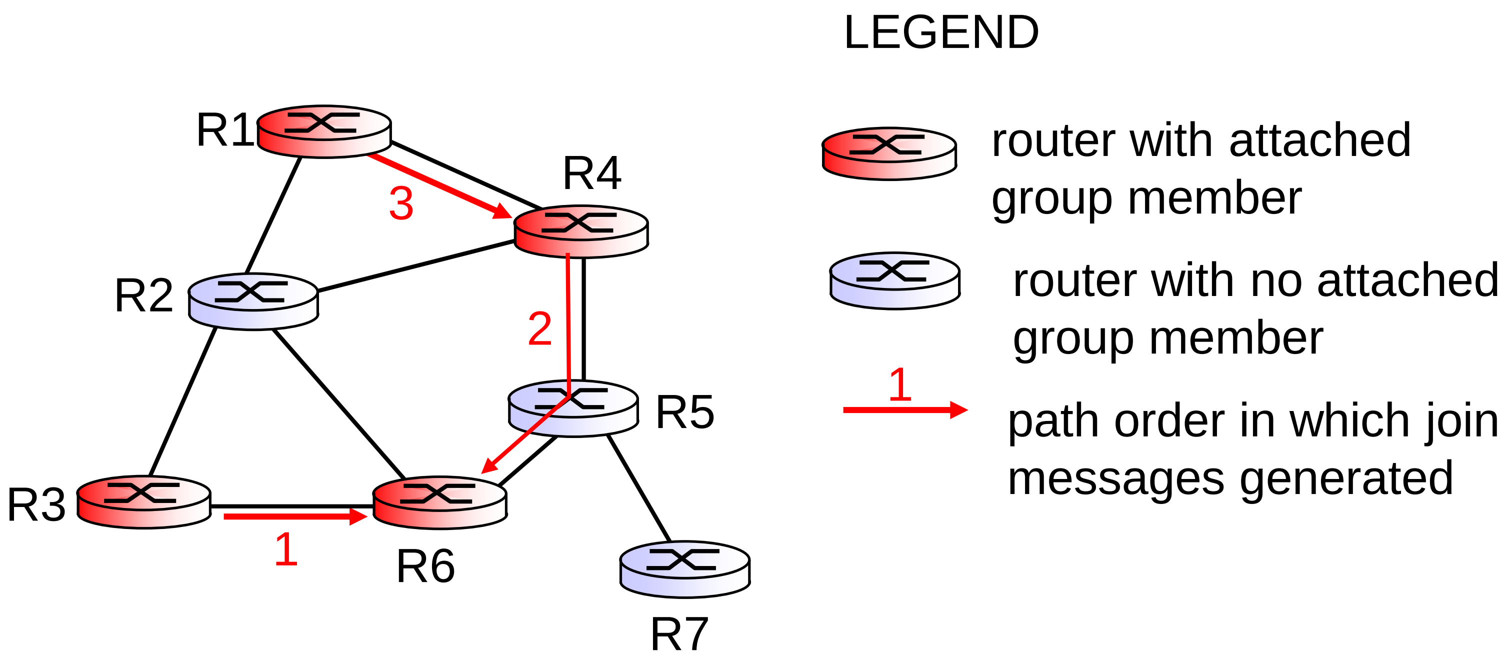
- *steiner tree:* minimum cost tree connecting all routers with attached group members
- problem is NP-complete
- excellent heuristics exists
- not used in practice:
  - computational complexity
  - information about entire network needed
  - monolithic: rerun whenever a router needs to join/leave

Center-based trees

- single delivery tree shared by all
- one router identified as *"center"* of tree
- to join:
  - edge router sends unicast *join-msg* addressed to center router
  - *join-msg* "processed" by intermediate routers and forwarded towards center
  - *join-msg* either hits existing tree branch for this center, or arrives at center
  - path taken by *join-msg* becomes new branch of tree for this router

Center-based trees: example

suppose R6 chosen as center:



Internet Multicasting Routing: DVMRP

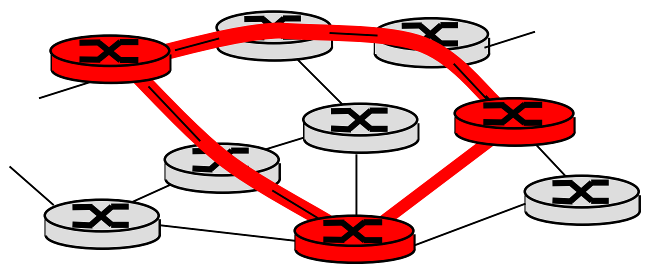
- DVMRP: distance vector multicast routing protocol, RFC1075
- *flood and prune:* reverse path forwarding, source-based tree
  - RPF tree based on DVMRP's own routing tables constructed by communicating DVMRP routers
  - no assumptions about underlying unicast
  - initial datagram to multicast group flooded everywhere via RPF
  - routers not wanting group: send upstream prune messages

DVMRP: continued…

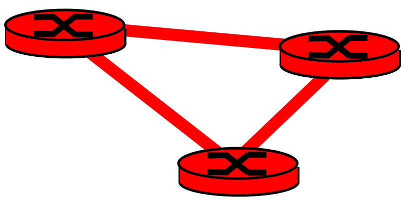
- *soft state:* DVMRP router periodically (1 min.) "forgets" branches are pruned:
  - multicast data again flows down unpruned branch
  - downstream router: reprune or else continue to receive data
- routers can quickly regraft to tree
  - following IGMP join at leaf
- odds and ends
  - commonly implemented in commercial router

Tunneling

Q: how to connect "islands" of multicast routers in a "sea" of unicast routers?



physical topology



logical topology

- multicast datagram encapsulated inside "normal" (non-multicast-addressed) datagram
- normal IP datagram sent through "tunnel" via regular IP unicast to receiving multicast router (recall IPv6 inside IPv4 tunneling)
- receiving multicast router un-encapsulates to get multicast datagram

PIM: Protocol Independent Multicast

- not dependent on any specific underlying unicast routing algorithm (works with all)
- two different multicast distribution scenarios :

dense:

- group members densely packed, in "close" proximity.
- bandwidth more plentiful

sparse:

- # networks with group members small wrt # interconnected networks
- group members "widely dispersed"
- bandwidth not plentiful

Consequences of sparse-dense dichotomy:

dense

- group membership by routers *assumed* until routers explicitly prune
- *data-driven* construction on multicast tree (e.g., RPF)
- bandwidth and non-group-router processing is *profligate*

sparse:

- no membership until routers explicitly join
- *receiver-driven* construction of multicast tree (e.g., center-based)
- bandwidth and non-group-router processing is *conservative*

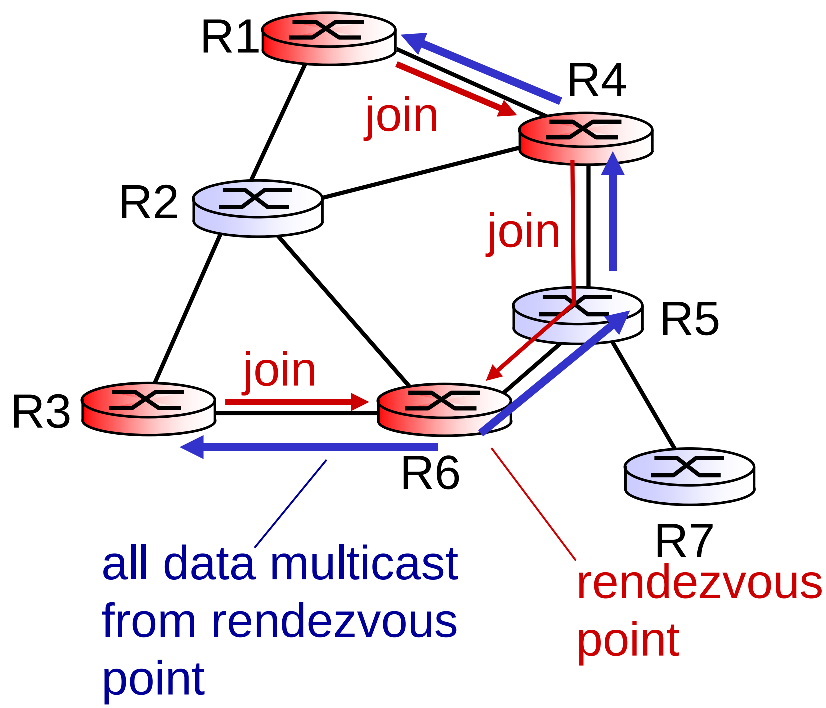
PIM- dense mode

flood-and-prune RPF: similar to DVMRP but…

- underlying unicast protocol provides RPF info for incoming datagram
- less complicated (less efficient) downstream flood than DVMRP reduces reliance on underlying routing algorithm
- has protocol mechanism for router to detect it is a leaf-node router

PIM - sparse mode

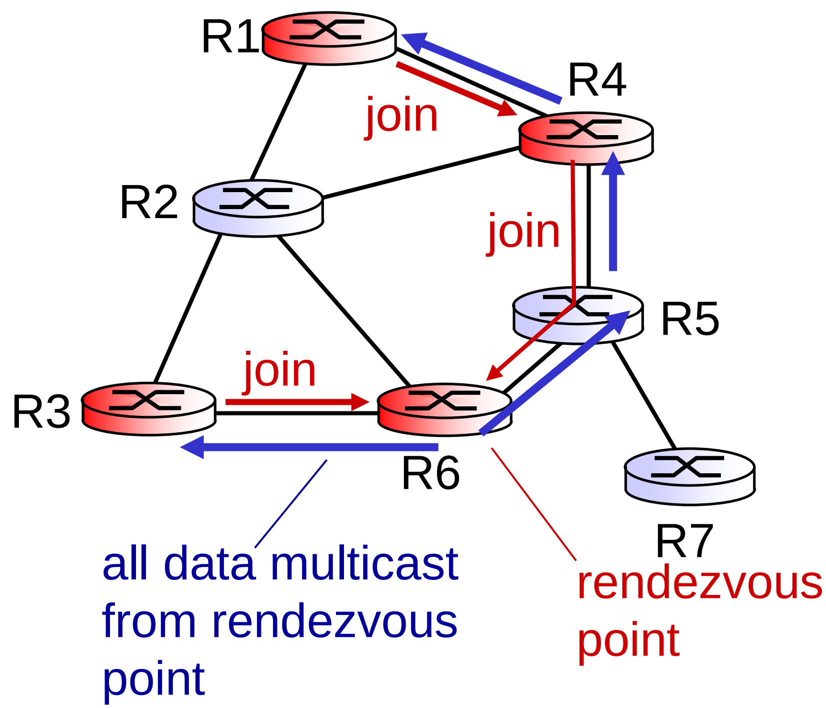
- center-based approach
- router sends *join* msg to rendezvous point (RP)
  - intermediate routers update state and forward *join*
- after joining via RP, router can switch to source-specific tree
  - increased performance: less concentration, shorter paths



PIM - sparse mode

sender(s):

- unicast data to RP, which distributes down RP-rooted tree
- RP can extend multicast tree upstream to source
- RP can send *stop* message if no attached receivers
  - "no one is listening!"



Chapter 4: *done!*

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- understand principles behind network layer services:
  - network layer service models, forwarding versus routing how a router works, routing (path selection), broadcast, multicast
- instantiation, implementation in the Internet