Distributed Systems

Group Communication

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Modes of communication

- **unicast**
  - 1↔1
  - Point-to-point
- **anycast**
  - 1→nearest 1 of several identical nodes
  - Introduced with IPv6; used with BGP
- **netcast**
  - 1 →many, 1 at a time
- **multicast**
  - 1→many
  - **group** communication
- **broadcast**
  - 1→all

Groups

Groups are *dynamic*
- Created and destroyed
- Processes can join or leave
  - May belong to 0 or more groups

Send message to one entity
- Deliver to entire group

Deal with collection of processes as one abstraction

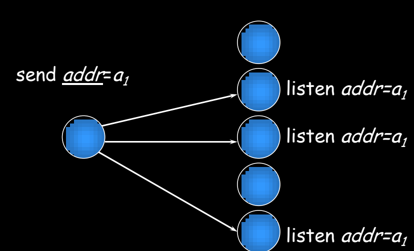
Design Issues

- Closed vs. Open
  - Closed: only group members can sent messages
- Peer vs. Hierarchical
  - Peer: each member communicates with group
  - Hierarchical: go through coordinator
- Managing membership
  - Distributed vs. centralized
- Leaving & joining must be synchronous
- Fault tolerance?

Implementing Group Communication Mechanisms

Hardware multicast

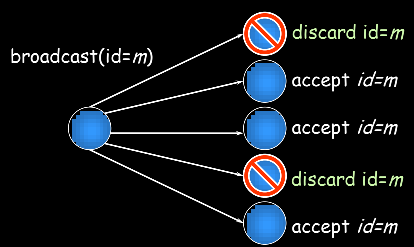
Hardware support for multicast
- Group members listen on network address



Hardware broadcast

Hardware support for broadcast

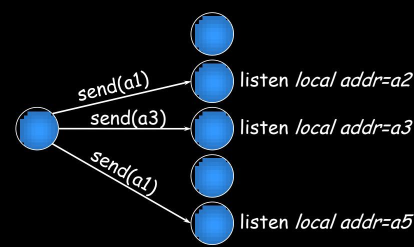
- Software filters multicast address
  - May be auxiliary address



Software: netcast

Multiple unicasts (**netcast**)

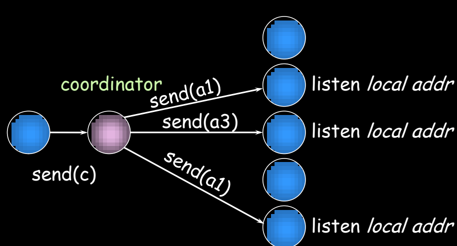
- Sender knows group members



Software

Multiple unicasts via group coordinator

- coordinator knows group members



Reliability of multicasts

Atomic multicast

Atomicity

Message sent to a group arrives at *all* group members

- If it fails to arrive at *any* member, no member will process it.

Problems

Unreliable network

- Each message should be acknowledged
- Acknowledgements can be lost

Message sender might die

Achieving atomicity (2-phase commit variation)

Retry through network failures & system downtime

Sender and receivers maintain **persistent log**

1. Send message to all group members
   - Each receiver acknowledges message
   - Saves message and acknowledgement in log
   - Does not pass message to application
2. Sender waits for **all** acknowledgements
   - Retransmits message to non-responding members
     - Again and again… until response received
3. Sender sends "go" message to all members
   - Each recipient passes message to application
   - Sends reply to server

Achieving atomicity

All members will eventually get the message

Phase 1:
- Make sure that **everyone** gets the message

Phase 2:
- Once everyone has confirmed receipt, let the application see it

Reliable multicast

Best effort
- Assume sender will remain alive
- Retransmit undelivered messages

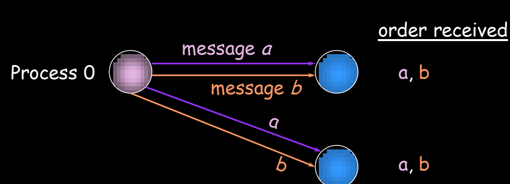
- Send message
- Wait for acknowledgement from each group member
- Retransmit to non-responding members

Unreliable multicast

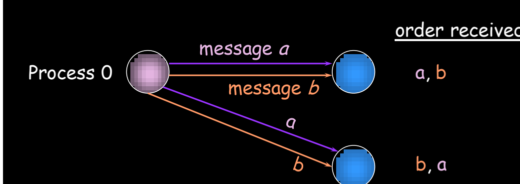
- Basic multicast
- Hope it gets there

Message ordering

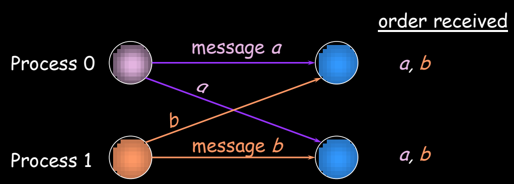
Good Ordering



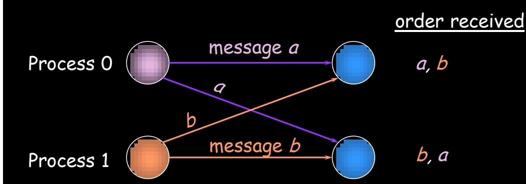
Bad Ordering



Good Ordering



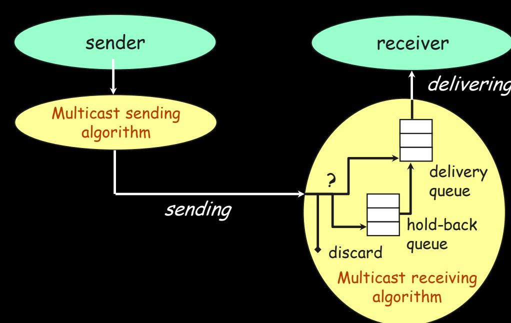
Bad Ordering



Sending versus Delivering

- Multicast receiver algorithm decides when to *deliver* a message to the process.
- A received message may be:
  - Delivered immediately
    (put on a delivery queue that the process reads)
  - Placed on a hold-back queue
    (because we need to wait for an earlier message)
  - Rejected/discarded
    (duplicate or earlier message that we no longer want)

Sending, delivering, holding back



Global time ordering

- All messages arrive in exact order sent
- Assumes two events never happen at the exact same time!
- Difficult (impossible) to achieve

Total ordering

- Consistent ordering everywhere
- All messages arrive at all group members in the same order

1. If a process sends *m* before *m′* then *any* other process that delivers *m′* will have delivered *m*.
2. If a process delivers *m′* before *m″* then *every* other process will have delivered *m′* before *m″*.

- Implementation:
  - Attach unique totally sequenced message ID
  - Receiver delivers a message to the application *only* if it has received all messages with a smaller ID

Causal ordering

- Partial ordering
  - Messages sequenced by Lamport or Vector timestamps

> If multicast(G, m) -> multicast(G, m')
> then *every* process that delivers m' will
> have delivered m

- Implementation
  - Deliver messages in timestamp order per-source.

Sync ordering

- Messages can arrive in any order
- Special message type
  - **Synchronization primitive**
  - Ensure all pending messages are delivered before any additional (post-sync) messages are accepted

FIFO ordering

- Messages can be delivered in different order to different members
- Message *m* must be delivered before message *m'* iff *m* was sent before *m'* from the same host

> If a process issues a multicast of m
> followed by m', then *every process* that
> delivers m' will have already delivered m.

Unordered multicast

- Messages can be delivered in different order to different members
- Order per-source does not matter.

Multicasting considerations

IP Multicasting

IP Broadcasting

- 255.255.255.255
  - Limited broadcast: send to all connected networks
- Host bits all 1 (128.6.255.255, 192.168.0.255)
  - Directed broadcast on subnet

IP Multicasting

Class D network created for IP multicasting

1110	28-bit multicast address

224.0.0.0/4
224.0.0.0 – 239.255.255.255

Host group
- Set of machines listening to a particular multicast address

IP multicasting

- Can span multiple physical networks
- Dynamic membership
  - Machine can join or leave at any time
- No restriction on number of hosts in a group
- Machine does not need to be a member to send messages

IP multicast addresses

- Addresses chosen arbitrarily
- Well-known addresses assigned by IANA
  - Internet Assigned Numbers Authority
  - RFC 1340
  - Similar to ports – service-based allocation
    - FTP: port 21, SMTP: port 25, HTTP: port 80

224.0.0.1:	all systems on this subnet
224.0.0.2:	all multicast routers on subnet
224.0.1.16:	music service
224.0.1.2:	SGI's dogfight
224.0.1.7:	Audionews service

LAN (Ethernet) multicasting

LAN cards support multicast in one (or both) of two ways:

- Packets filtered based on hash(mcast addr)
  - Some unwanted packets may pass through
  - Simplified circuitry
- Exact match on small number of addresses
  - If host needs more, put LAN card in multicast promiscuous mode
    - Receive all hardware multicast packets

Device driver must check to see if the packet was really needed

LAN (Ethernet) multicasting example

Intel 82546EB Dual Port Gigabit Ethernet Controller
10/100/1000 BaseT Ethernet

Supports:
- 16 exact MAC address matches
- 4096-bit hash filter for multicast frames
- promiscuous unicast & promiscuous multicast transfer modes

IP multicast on a LAN

- Sender specifies class D address in packet
- Driver must translate 28-bit IP multicast group to multicast Ethernet address
  - IANA allocated range of Ethernet MAC addresses for multicast
  - Copy least significant 23 bits of IP address to MAC address
    - 01:00:5e:xx:xx:xx

Bottom 23 bits of IP address

- Send out **multicast Ethernet packet**
  - Contains multicast IP packet

IP multicast on a LAN

Joining a multicast group

Receiving process:

- Notifies IP layer that it wants to receive datagrams addressed to a certain host group
- Device driver must enable reception of Ethernet packets for that IP address
  - Then filter exact packets

Beyond the physical network

Packets pass through routers which bridge networks together

Multicast-aware router needs to know:

- *are any hosts on a LAN that belong to a multicast group?*

IGMP:

- Internet Group Management Protocol
- Designed to answer this question
- RFC 1112 (v1), 2236 (v2), 3376 (v3)

IGMP v1

- Datagram-based protocol
- Fixed-size messages:
  - 20 bytes header, 8 bytes data
    - 4-bit version
    - 4-bit operation (1=query by router, 2=response)
    - 16-bit checksum
    - 32-bit IP class D address

Joining multicast group with IGMP

- Machine sends IGMP report:
  - "I'm interested in this multicast address"
- Each multicast router broadcasts IGMP queries at regular intervals
  - See if any machines are still interested
  - One query per network interface
- When machine receives query
  - Send IGMP response packet for each group for which it is still interested in receiving packets

Leaving a multicast group with IGMP

- No response to an IGMP query
  - Machine has no more processes which are interested
- Eventually router will stop forwarding packets to network when it gets no IGMP responses

IGMP enhancements

- IGMP v2
  - **Leave group** messages added
  - Useful for high-bandwidth applications
- IGMP v3
  - Hosts can specify list of hosts from which they want to receive traffic.
  - Traffic from other (unwanted) hosts is blocked by the routers and hosts.

IP Multicast in use

- Initially exciting:
  - Internet radio, NASA shuttle missions, collaborative gaming
- But:
  - Few ISPs enabled it
  - Required tapping into existing streams (not good for on-demand content)
  - Industry embraced unicast instead

IP Multicast in use

- IPTV is emerging as the biggest user of IP multicast
- Traffic is within the provider's network
  - QoS: typically mix of ATM and/or IP
    - 2.5 Mbps VBR video
    - 256 kbps CBR voice
    - Remainder: ABR for IP traffic
  - Unicast for video on demand
  - Multicast for live content
    - Send IGMPv2 message to join a channel when switching
    - Burst of unicast data to get the I-frame to ensure 150 msec channel switching times.

The end.