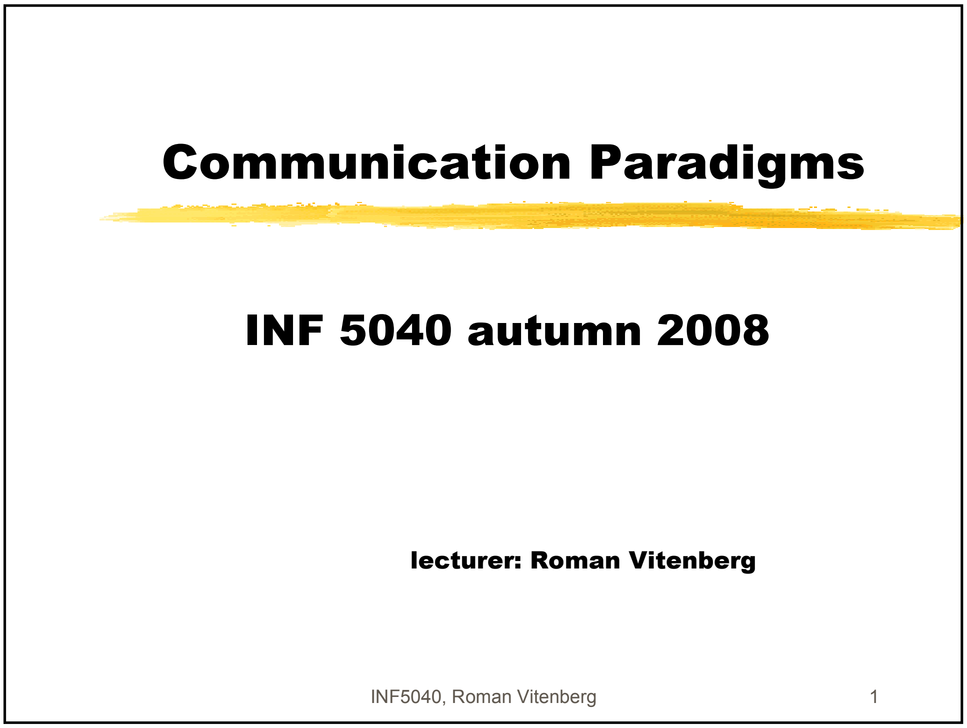
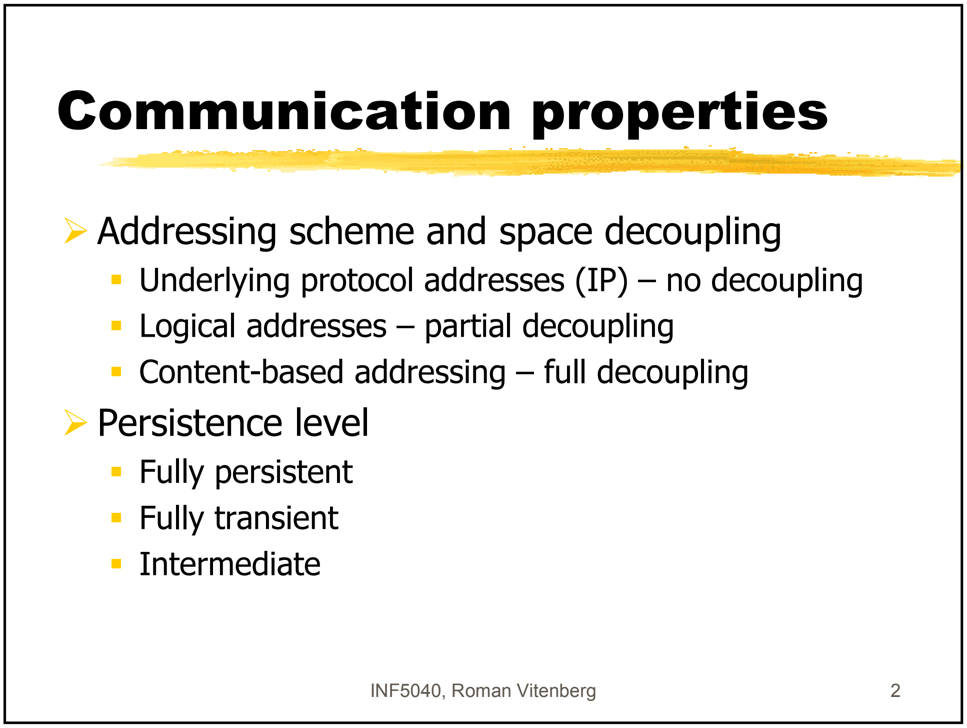


# Communication Paradigms

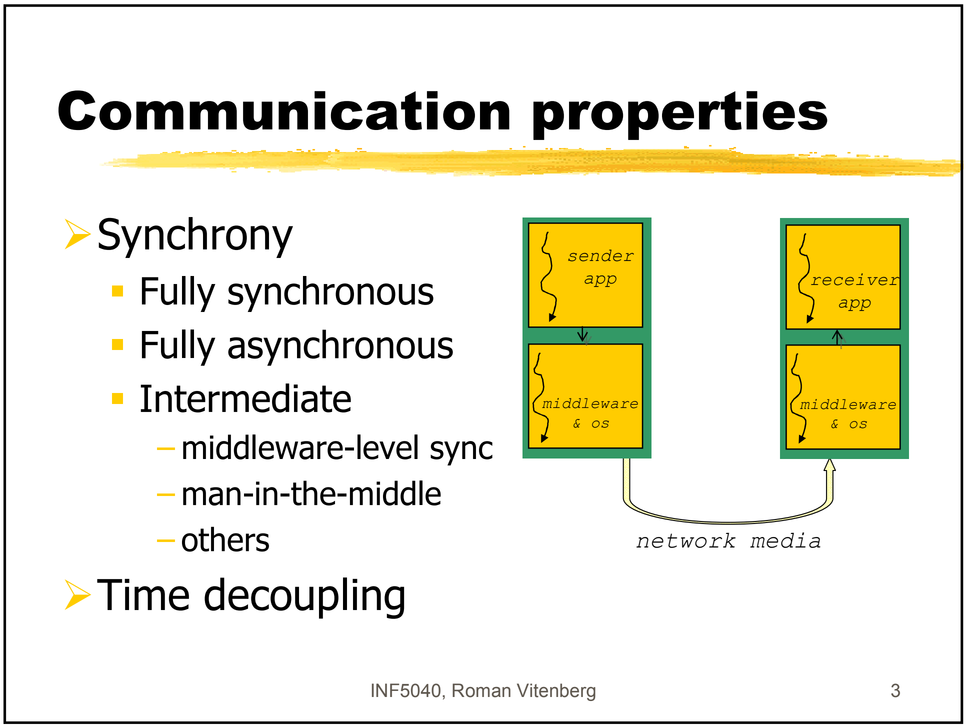
## INF 5040 autumn 2008

**lecturer: Roman Vitenberg**



## Communication properties

- Addressing scheme and space decoupling
  - Underlying protocol addresses (IP) – no decoupling
  - Logical addresses – partial decoupling
  - Content-based addressing – full decoupling
- Persistence level
  - Fully persistent
  - Fully transient
  - Intermediate



## Communication properties

- Synchrony
  - Fully synchronous
  - Fully asynchronous
  - Intermediate
    - middleware-level sync
    - man-in-the-middle
    - others
- Time decoupling

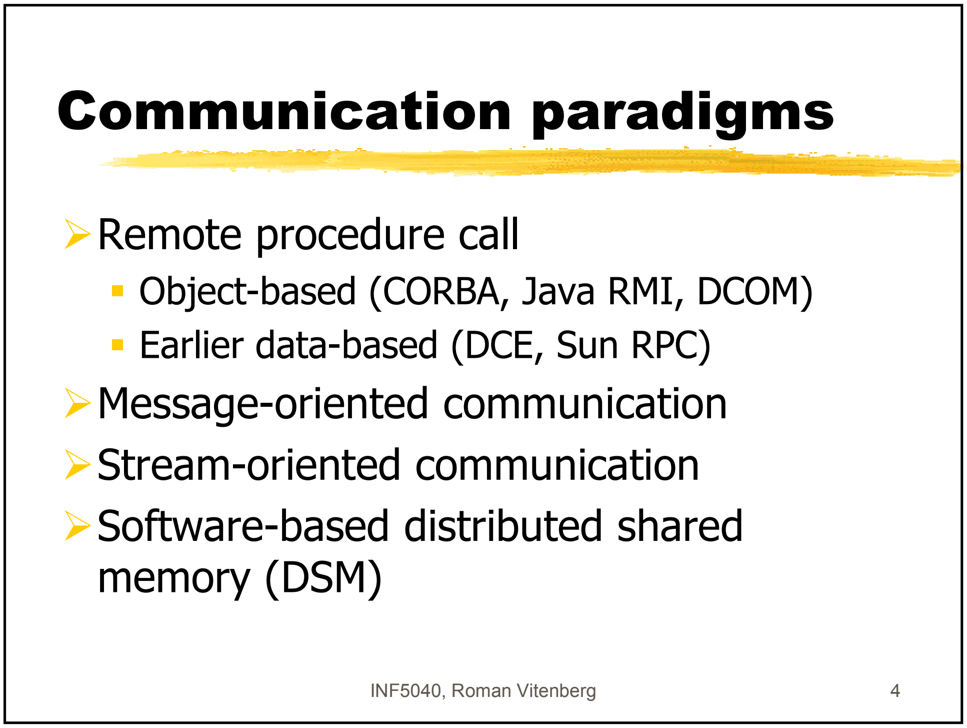
sender app

middleware & os

receiver app

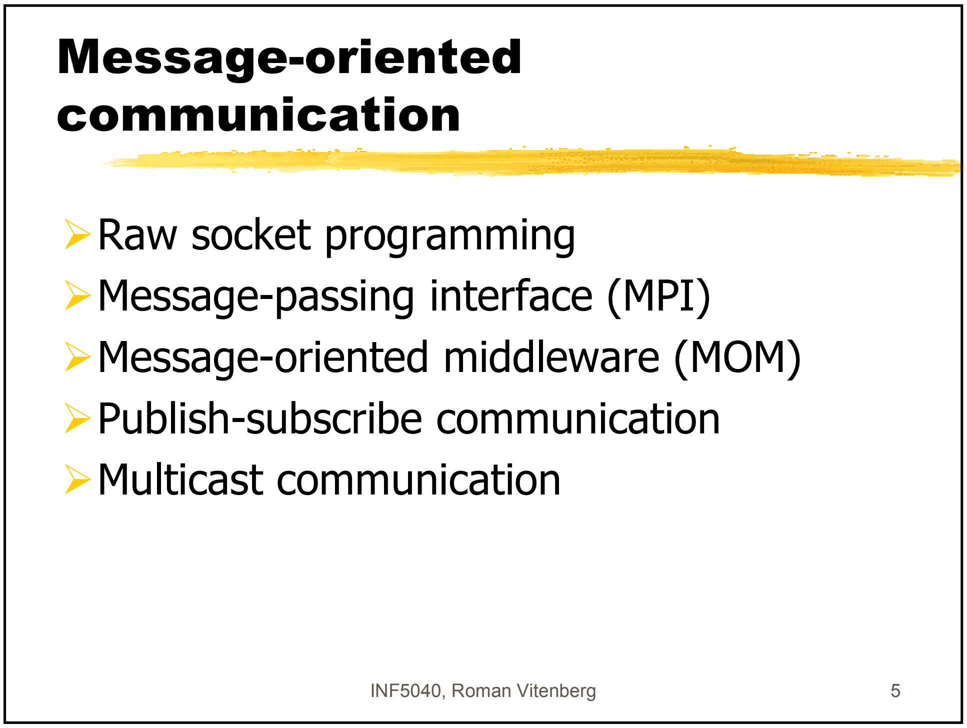
middleware & os

network media



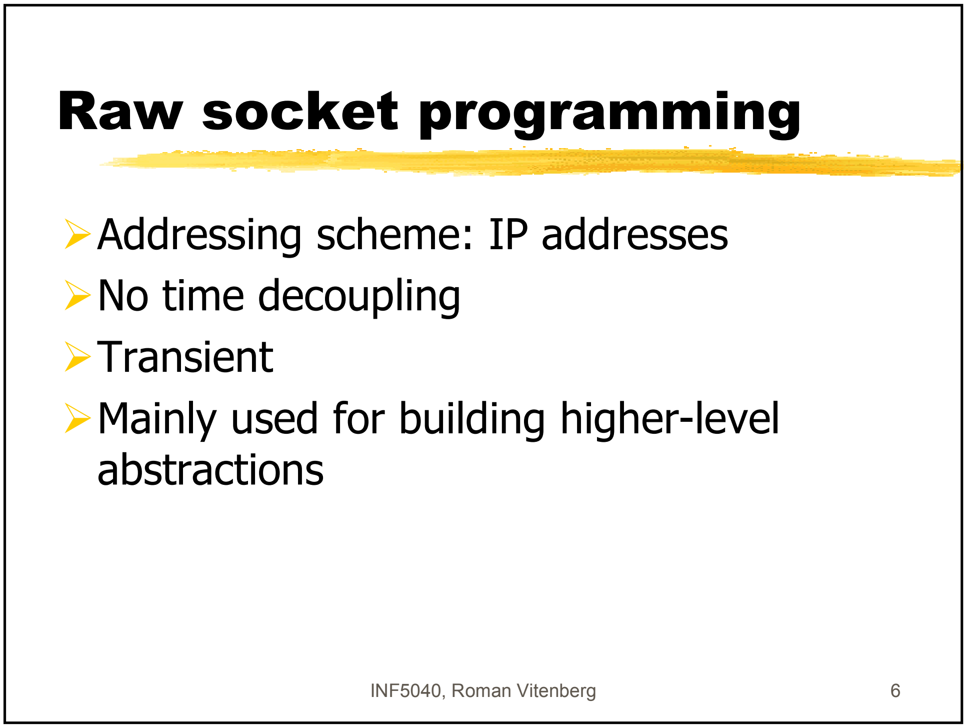
## Communication paradigms

- Remote procedure call
  - Object-based (CORBA, Java RMI, DCOM)
  - Earlier data-based (DCE, Sun RPC)
- Message-oriented communication
- Stream-oriented communication
- Software-based distributed shared memory (DSM)



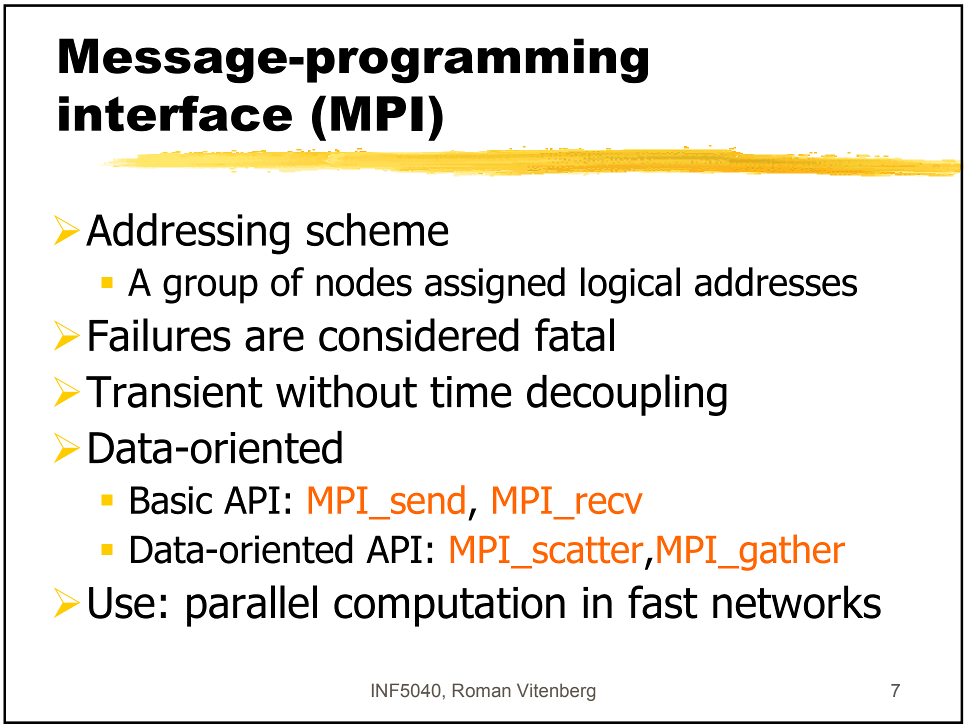
## Message-oriented communication

- Raw socket programming
- Message-passing interface (MPI)
- Message-oriented middleware (MOM)
- Publish-subscribe communication
- Multicast communication



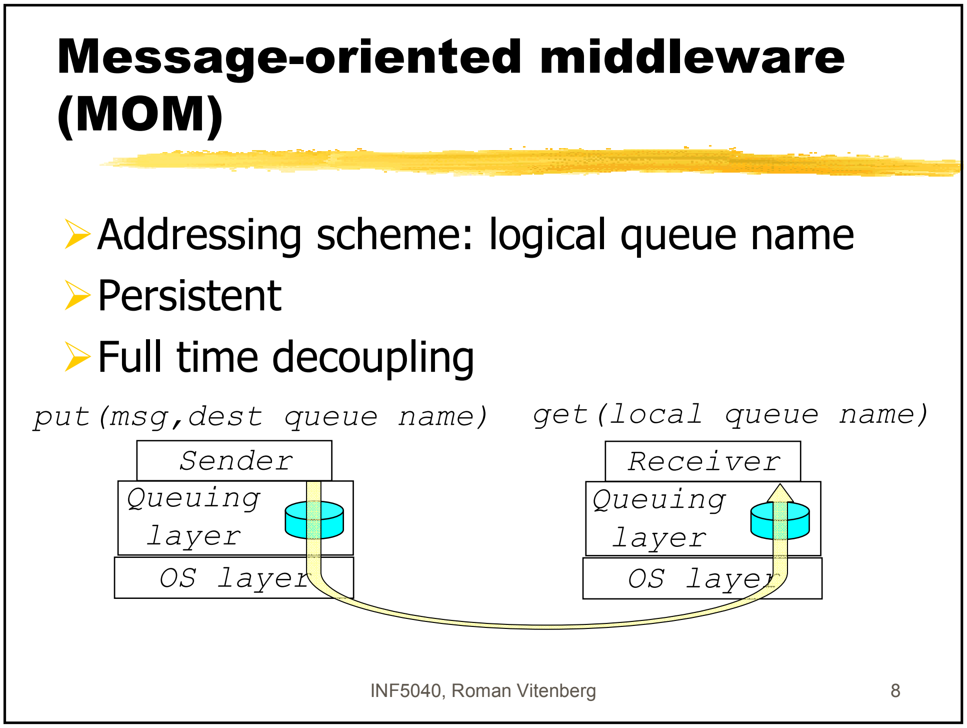
## Raw socket programming

- Addressing scheme: IP addresses
- No time decoupling
- Transient
- Mainly used for building higher-level abstractions



## Message-programming interface (MPI)

- Addressing scheme
  - A group of nodes assigned logical addresses
- Failures are considered fatal
- Transient without time decoupling
- Data-oriented
  - Basic API: MPI_send, MPI_recv
  - Data-oriented API: MPI_scatter,MPI_gather
- Use: parallel computation in fast networks

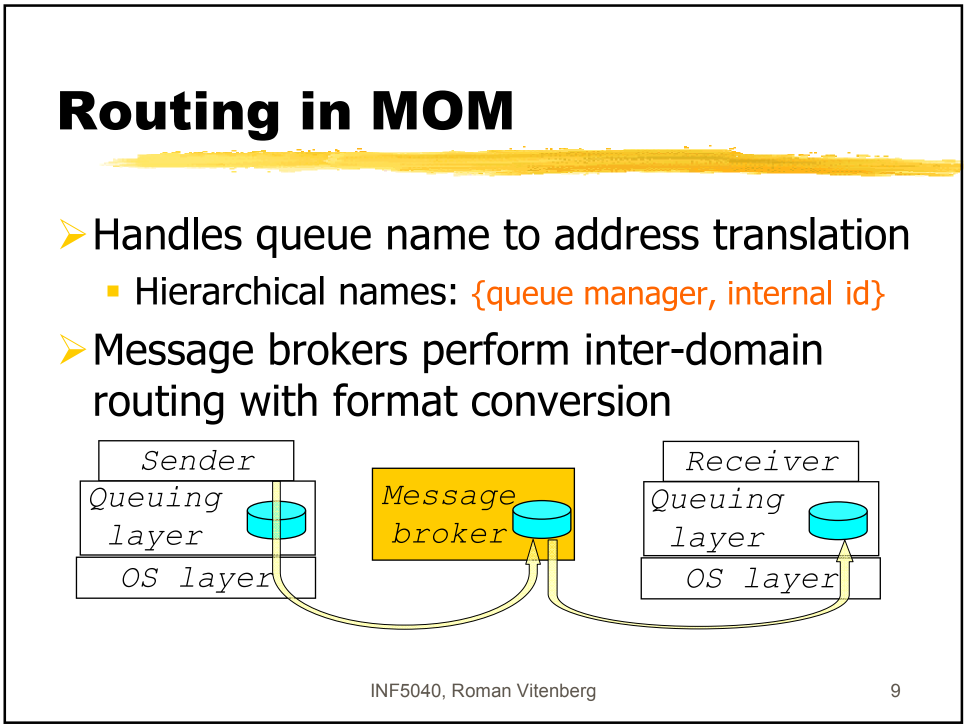


## Message-oriented middleware (MOM)

- Addressing scheme: logical queue name
- Persistent
- Full time decoupling

put(msg,dest queue name)

get(local queue name)



## Routing in MOM

- Handles queue name to address translation
  - Hierarchical names: {queue manager, internal id}
- Message brokers perform inter-domain routing with format conversion

Sender

Queuing layer

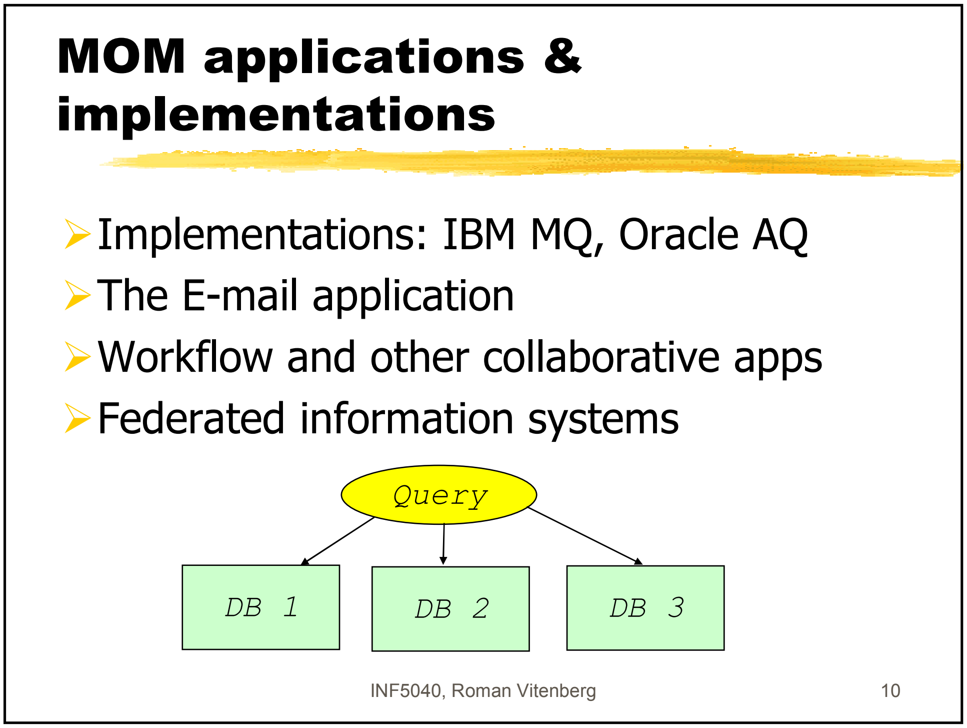
OS layer

Message broker

Receiver

Queuing layer

OS layer



## MOM applications & implementations

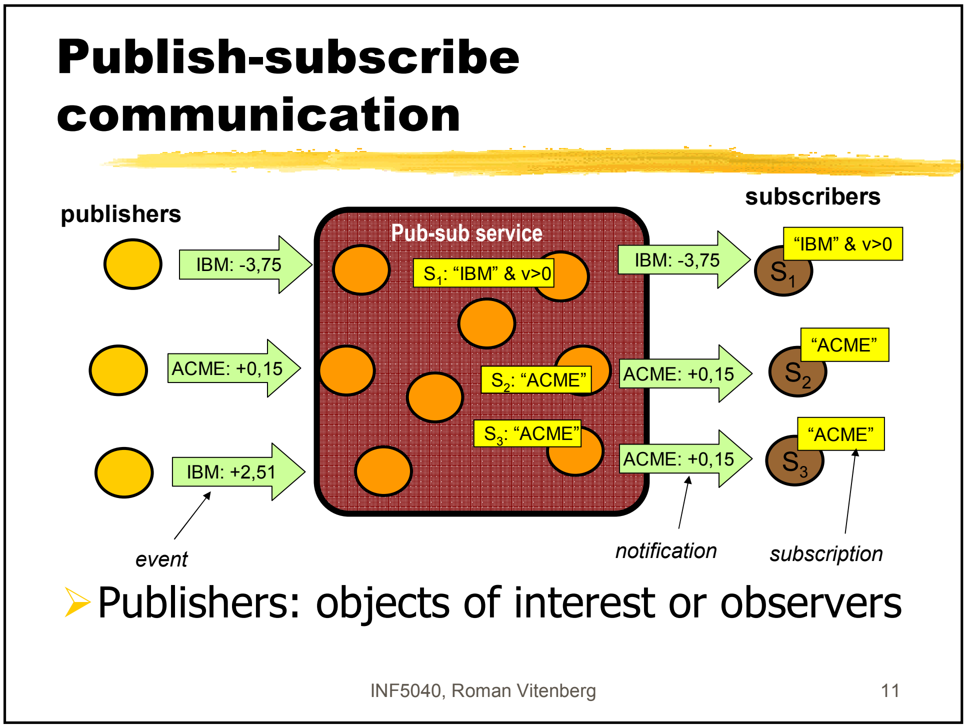
- Implementations: IBM MQ, Oracle AQ
- The E-mail application
- Workflow and other collaborative apps
- Federated information systems

Query

DB 1

DB 2

DB 3



# Publish-subscribe communication

- Publishers: objects of interest or observers

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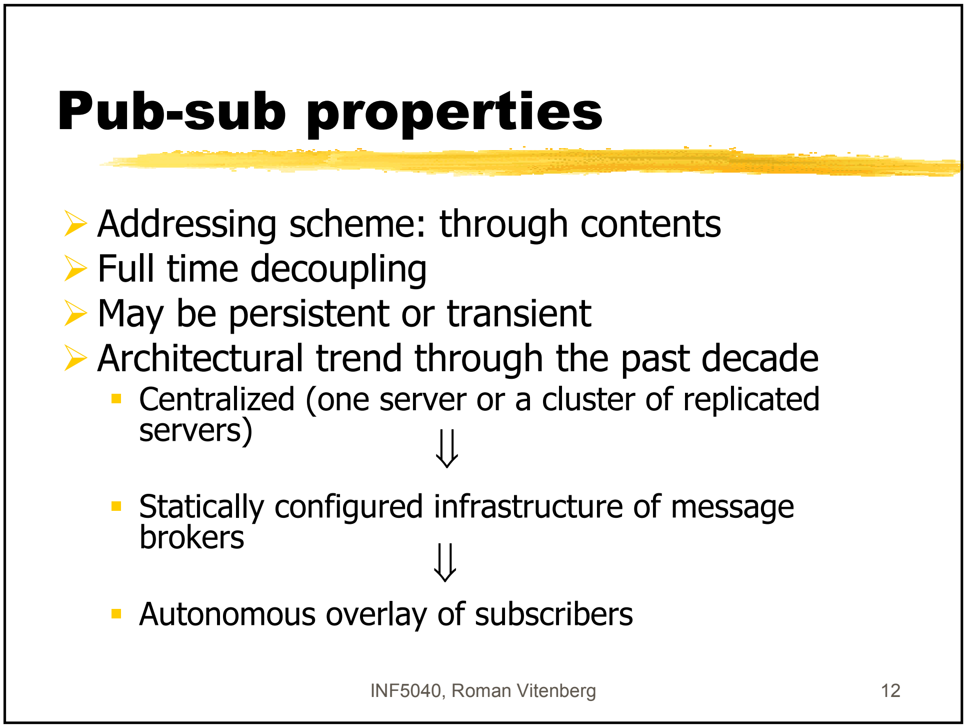

# Pub-sub properties

- Addressing scheme: through contents
- Full time decoupling
- May be persistent or transient
- Architectural trend through the past decade
  - Centralized (one server or a cluster of replicated servers)

    ⇓
  - Statically configured infrastructure of message brokers

    ⇓
  - Autonomous overlay of subscribers

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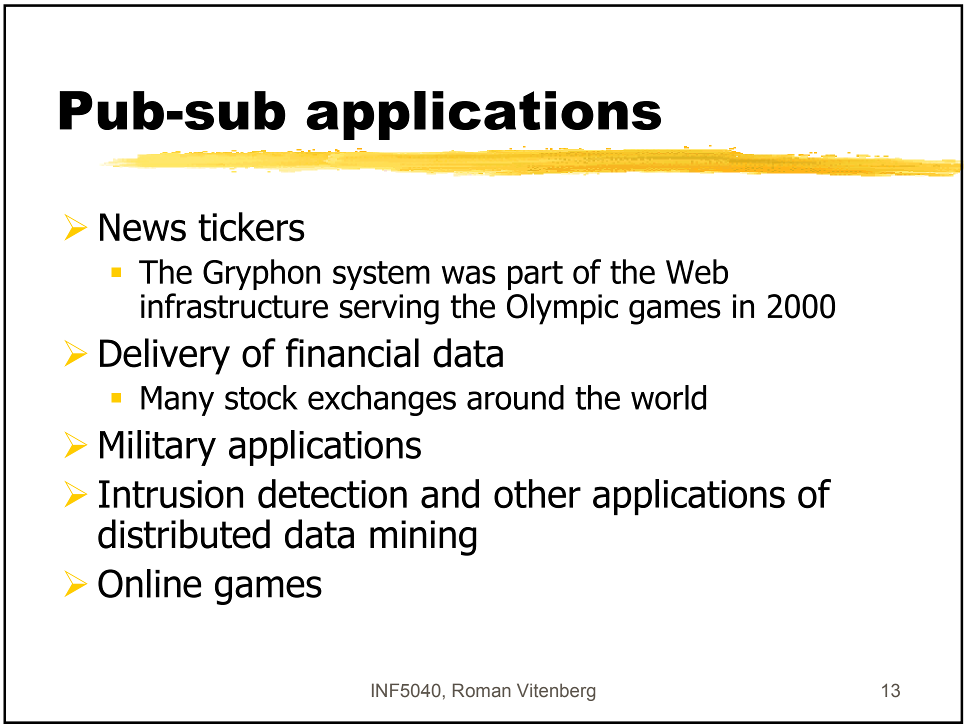

# Pub-sub applications

- News tickers
  - The Gryphon system was part of the Web infrastructure serving the Olympic games in 2000
- Delivery of financial data
  - Many stock exchanges around the world
- Military applications
- Intrusion detection and other applications of distributed data mining
- Online games

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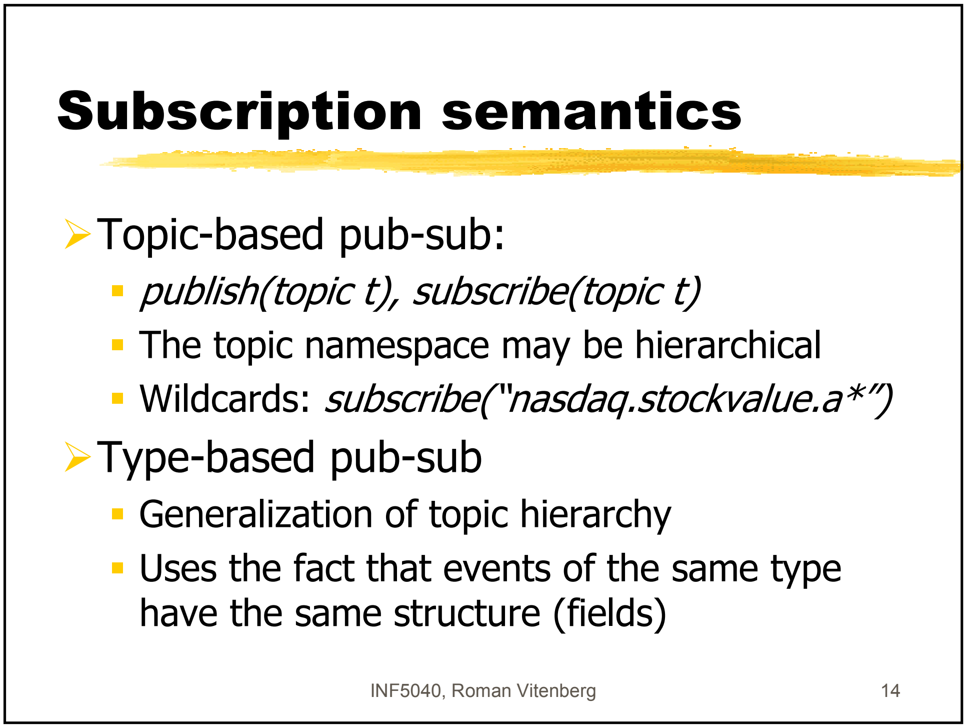

# Subscription semantics

- Topic-based pub-sub:
  - *publish(topic t), subscribe(topic t)*
  - The topic namespace may be hierarchical
  - Wildcards: *subscribe(“nasdaq.stockvalue.a*”)*
- Type-based pub-sub
  - Generalization of topic hierarchy
  - Uses the fact that events of the same type have the same structure (fields)

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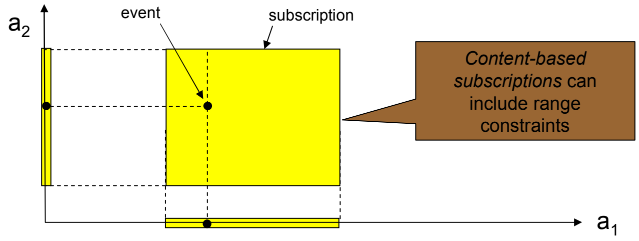
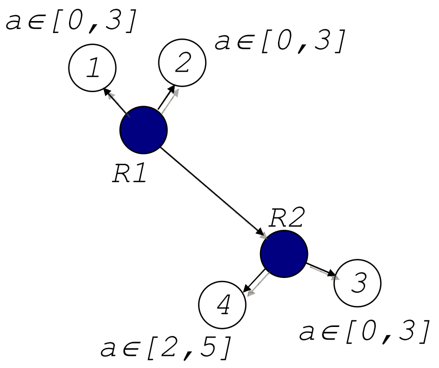
# Subscription semantics

- Content-based pub-sub
  - Universally known list of event attributes
  - Event represented as a set of attribute values
    - A point in the multi-dimensional event space
  - Subscription is a cuboid in the event space



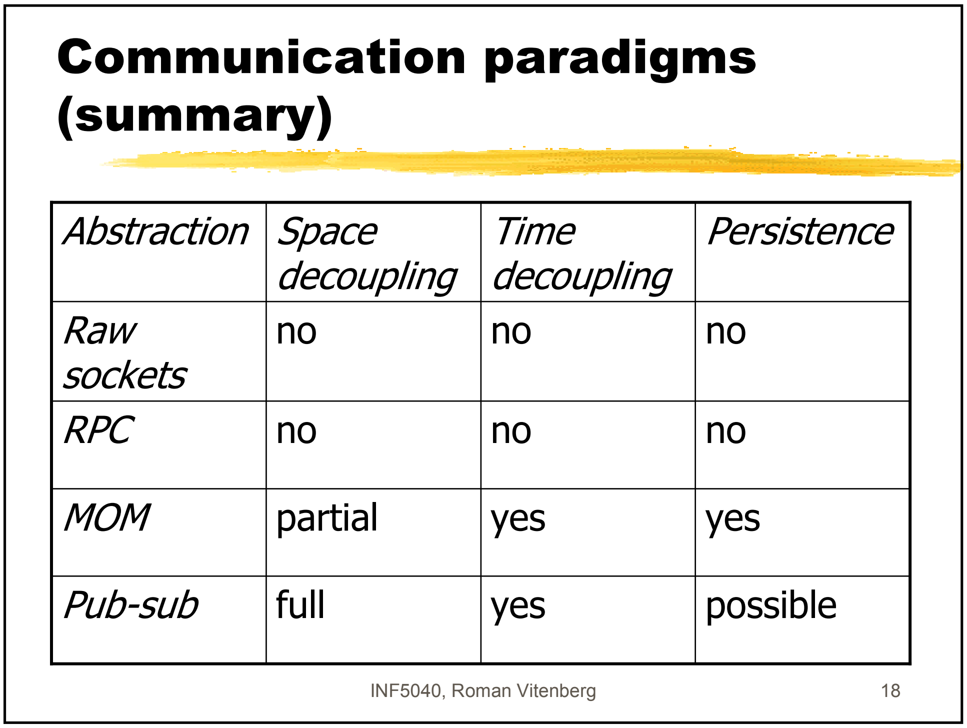
*Content-based subscriptions* can include range constraints

# Content-based routing



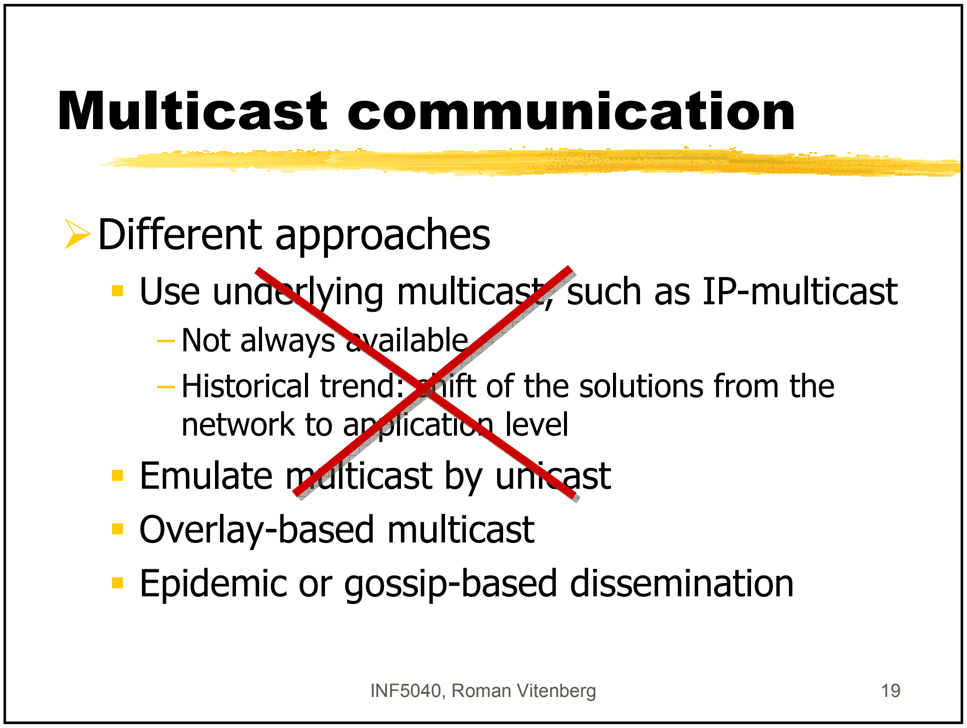
*The routing table of R1*

| ***Interface*** | ***Filter*** |
|---|---|
| *To node 1* | *a∈[0,3]* |
| *To node 2* | *a∈[0,3]* |
| *Toward R2* | *a∈[0,5]* |



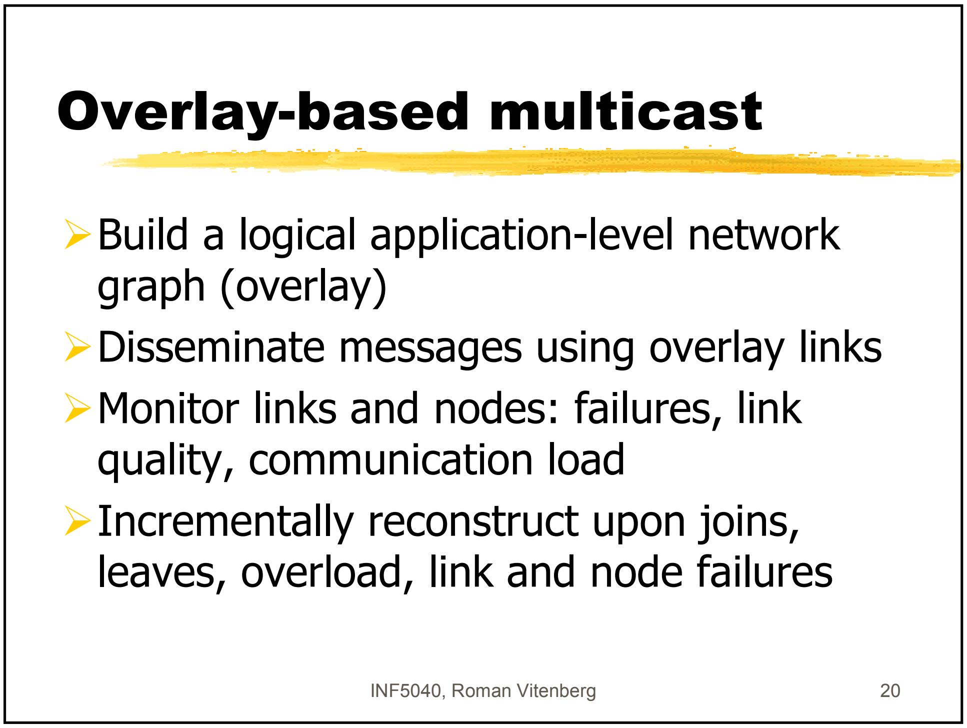
## Communication paradigms (summary)

| *Abstraction* | *Space decoupling* | *Time decoupling* | *Persistence* |
|---|---|---|---|
| *Raw sockets* | no | no | no |
| *RPC* | no | no | no |
| *MOM* | partial | yes | yes |
| *Pub-sub* | full | yes | possible |



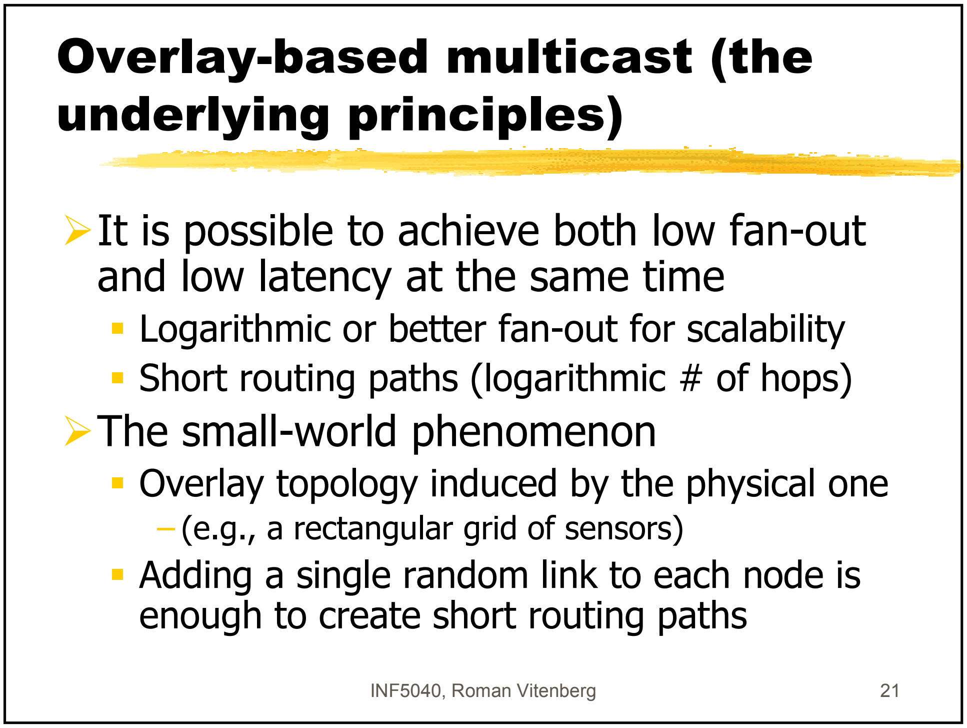
## Multicast communication

- Different approaches
  - ~~Use underlying multicast, such as IP-multicast~~
    - ~~Not always available~~
    - ~~Historical trend: shift of the solutions from the network to application level~~
  - ~~Emulate multicast by unicast~~
  - Overlay-based multicast
  - Epidemic or gossip-based dissemination



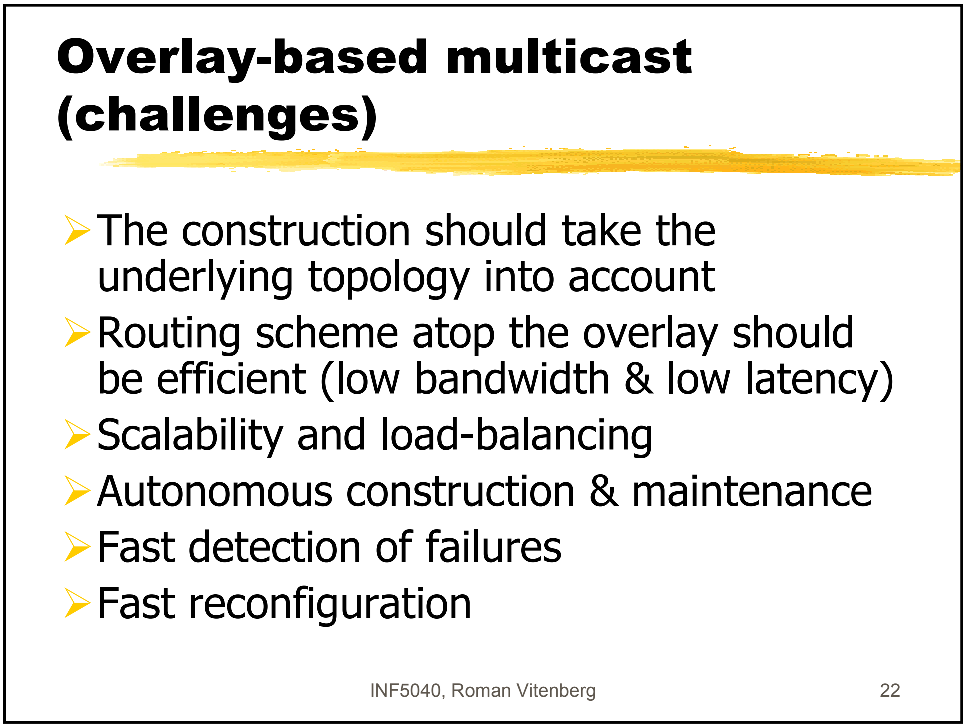
## Overlay-based multicast

- Build a logical application-level network graph (overlay)
- Disseminate messages using overlay links
- Monitor links and nodes: failures, link quality, communication load
- Incrementally reconstruct upon joins, leaves, overload, link and node failures



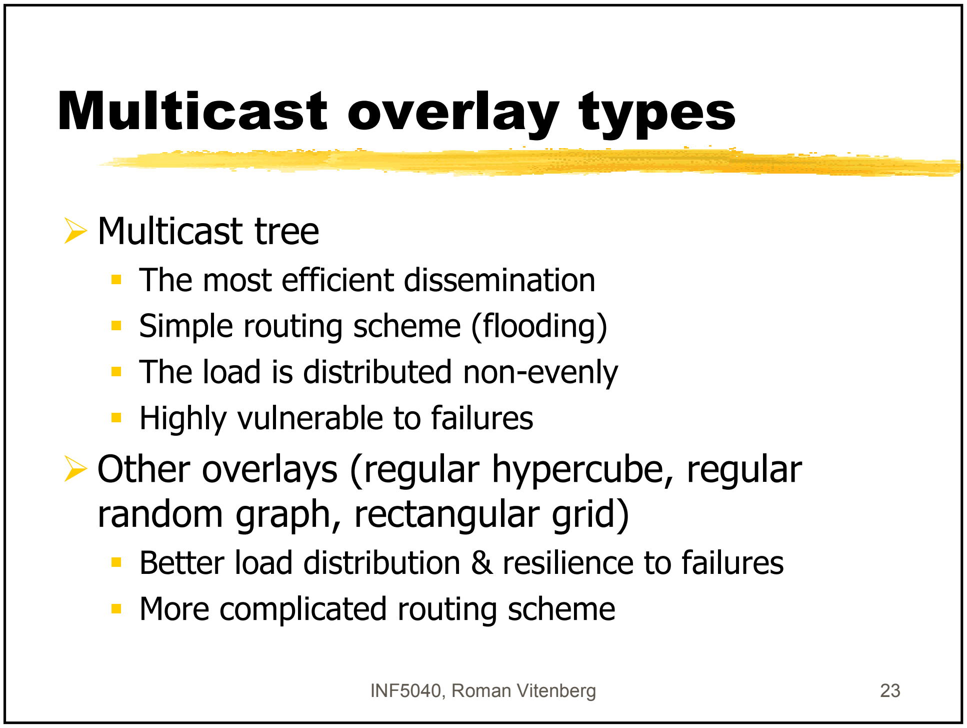
## Overlay-based multicast (the underlying principles)

- It is possible to achieve both low fan-out and low latency at the same time
  - Logarithmic or better fan-out for scalability
  - Short routing paths (logarithmic # of hops)
- The small-world phenomenon
  - Overlay topology induced by the physical one
    - (e.g., a rectangular grid of sensors)
  - Adding a single random link to each node is enough to create short routing paths



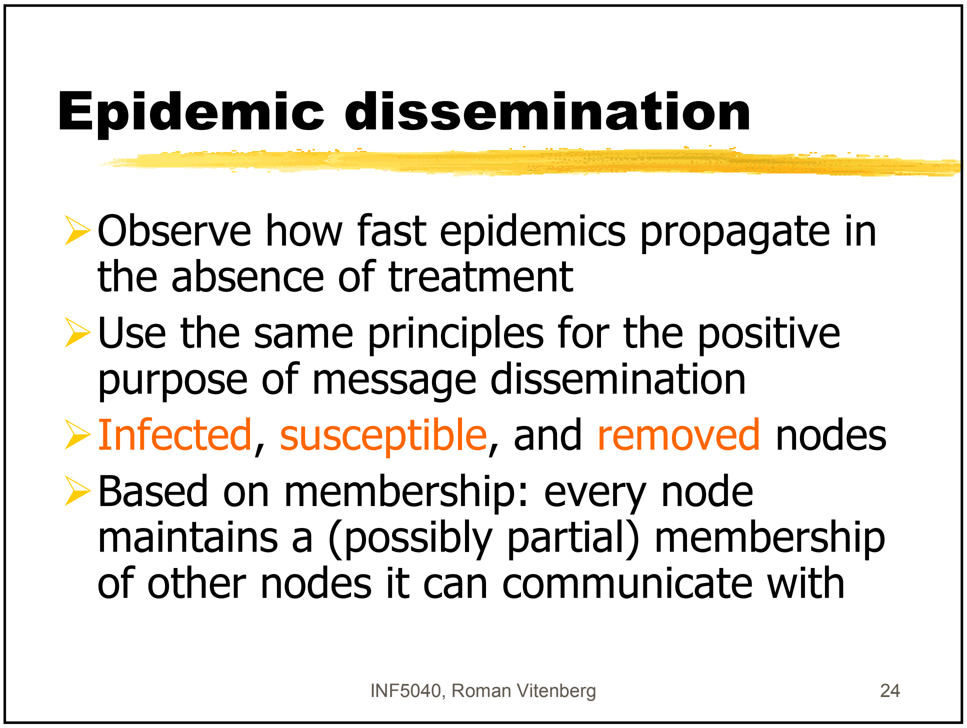
## Overlay-based multicast (challenges)

- The construction should take the underlying topology into account
- Routing scheme atop the overlay should be efficient (low bandwidth & low latency)
- Scalability and load-balancing
- Autonomous construction & maintenance
- Fast detection of failures
- Fast reconfiguration



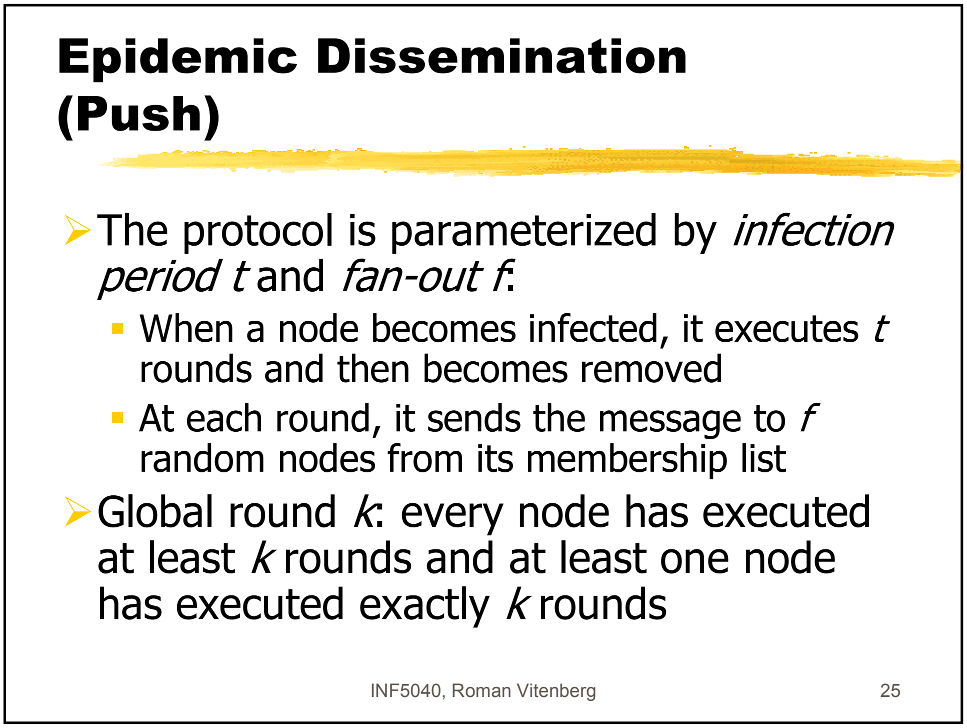
## Multicast overlay types

- Multicast tree
  - The most efficient dissemination
  - Simple routing scheme (flooding)
  - The load is distributed non-evenly
  - Highly vulnerable to failures
- Other overlays (regular hypercube, regular random graph, rectangular grid)
  - Better load distribution & resilience to failures
  - More complicated routing scheme



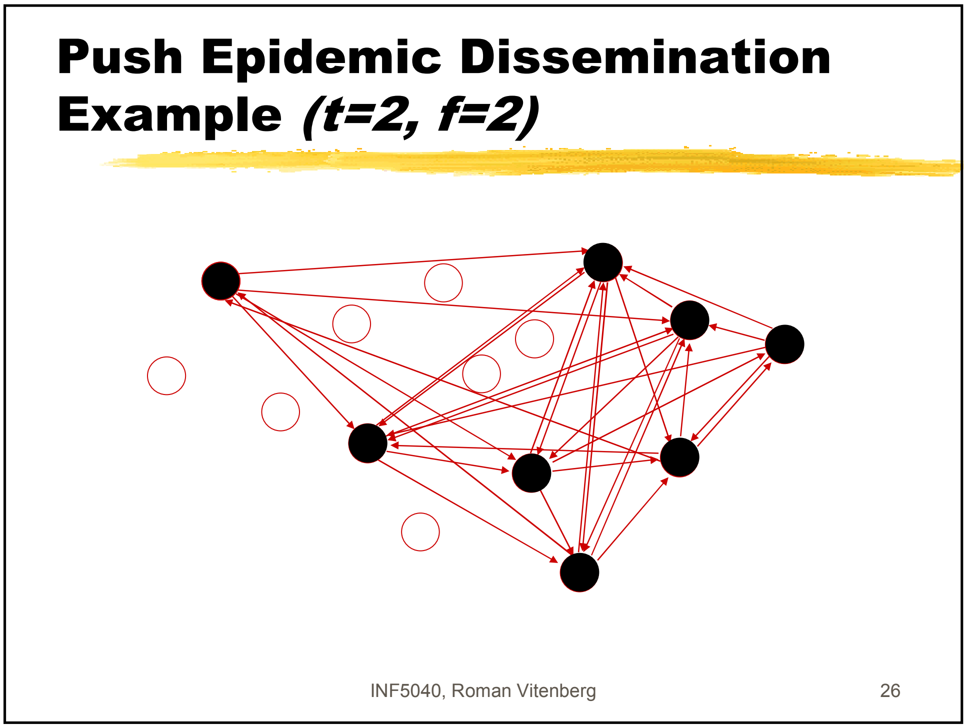
## Epidemic dissemination

- Observe how fast epidemics propagate in the absence of treatment
- Use the same principles for the positive purpose of message dissemination
- Infected, susceptible, and removed nodes
- Based on membership: every node maintains a (possibly partial) membership of other nodes it can communicate with

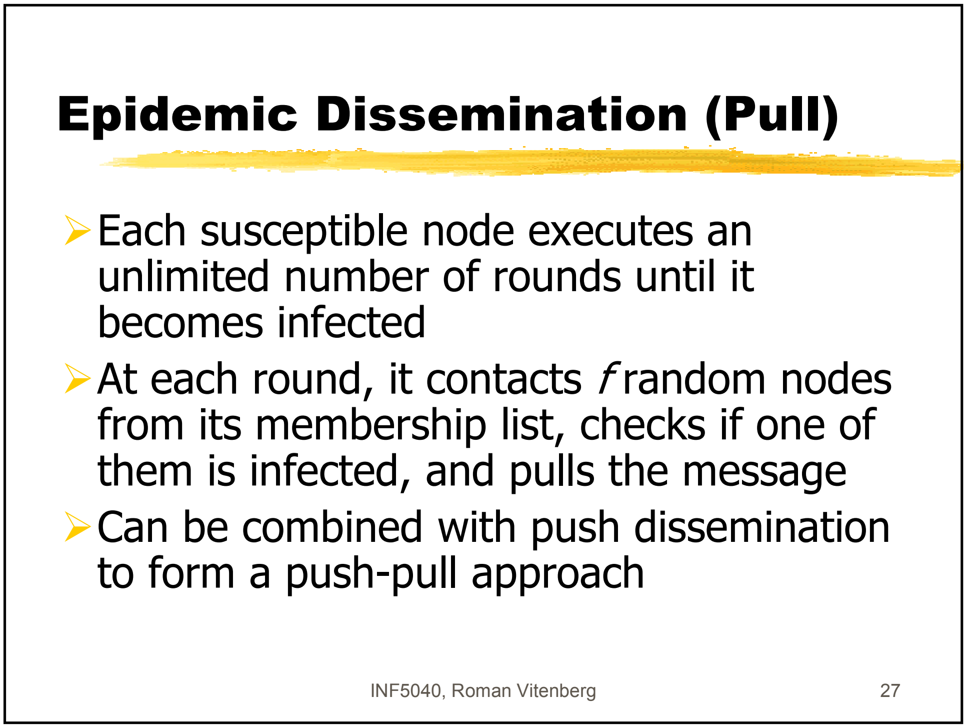


## Epidemic Dissemination (Push)

- The protocol is parameterized by *infection period t* and *fan-out f*:
  - When a node becomes infected, it executes *t* rounds and then becomes removed
  - At each round, it sends the message to *f* random nodes from its membership list
- Global round *k*: every node has executed at least *k* rounds and at least one node has executed exactly *k* rounds

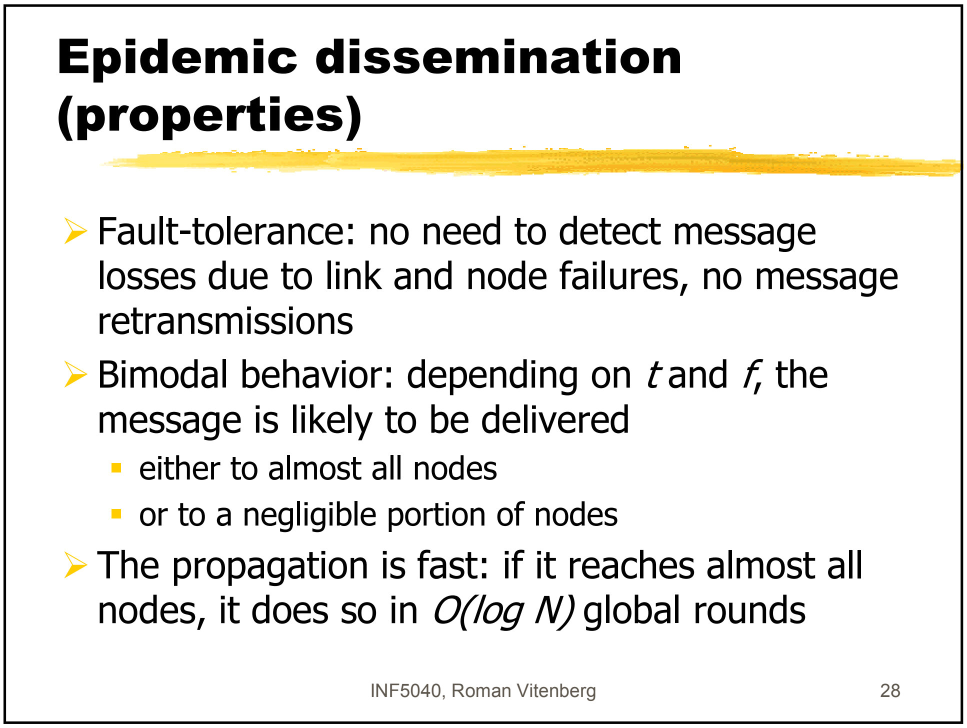


## Push Epidemic Dissemination Example *(t=2, f=2)*



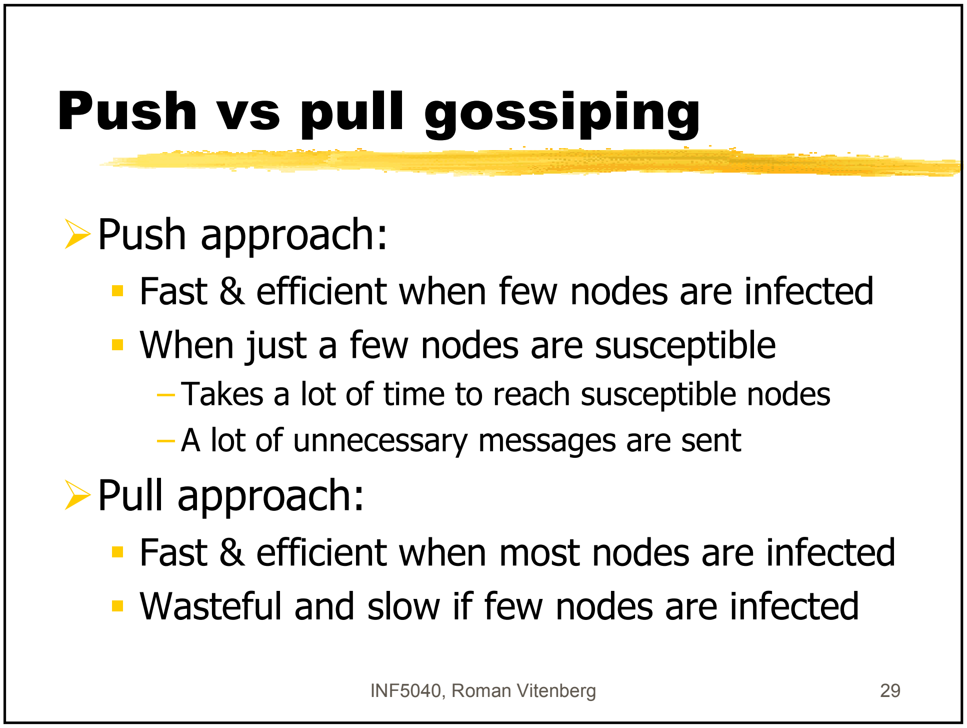
## Epidemic Dissemination (Pull)

- Each susceptible node executes an unlimited number of rounds until it becomes infected
- At each round, it contacts *f* random nodes from its membership list, checks if one of them is infected, and pulls the message
- Can be combined with push dissemination to form a push-pull approach



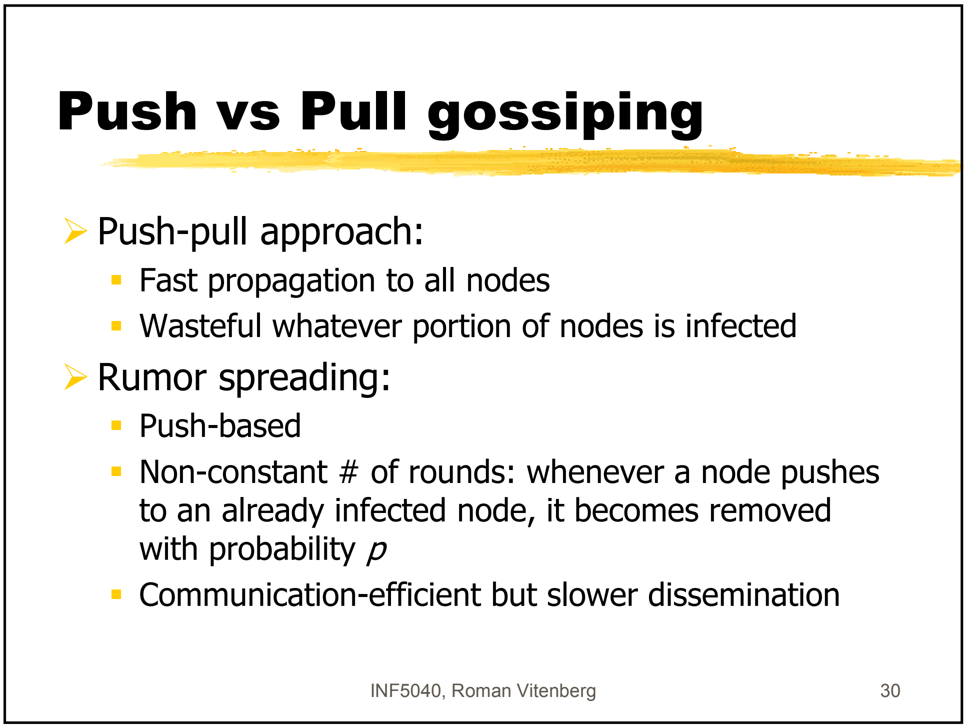
## Epidemic dissemination (properties)

- Fault-tolerance: no need to detect message losses due to link and node failures, no message retransmissions
- Bimodal behavior: depending on *t* and *f*, the message is likely to be delivered
  - either to almost all nodes
  - or to a negligible portion of nodes
- The propagation is fast: if it reaches almost all nodes, it does so in *O(log N)* global rounds



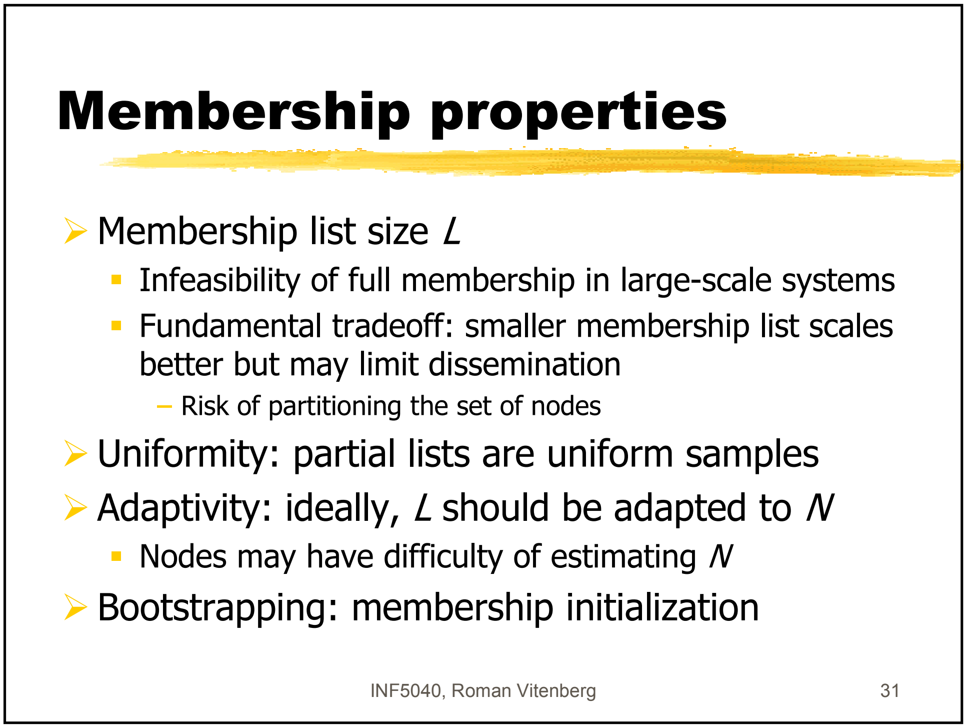
## Push vs pull gossiping

- Push approach:
  - Fast & efficient when few nodes are infected
  - When just a few nodes are susceptible
    - Takes a lot of time to reach susceptible nodes
    - A lot of unnecessary messages are sent
- Pull approach:
  - Fast & efficient when most nodes are infected
  - Wasteful and slow if few nodes are infected



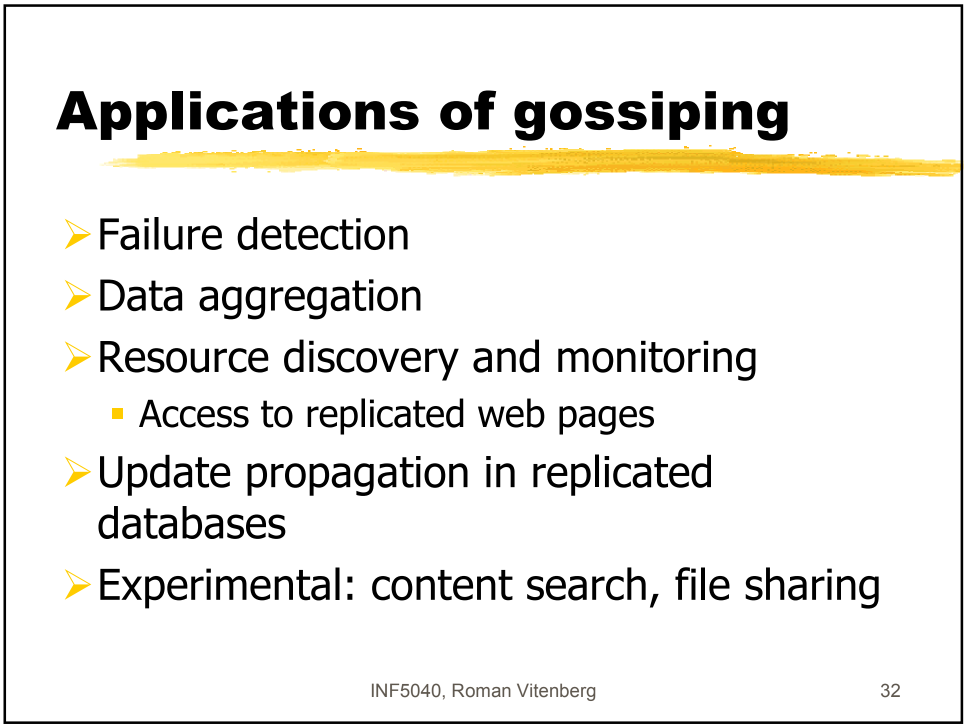
# Push vs Pull gossiping

- Push-pull approach:
  - Fast propagation to all nodes
  - Wasteful whatever portion of nodes is infected
- Rumor spreading:
  - Push-based
  - Non-constant # of rounds: whenever a node pushes to an already infected node, it becomes removed with probability *p*
  - Communication-efficient but slower dissemination



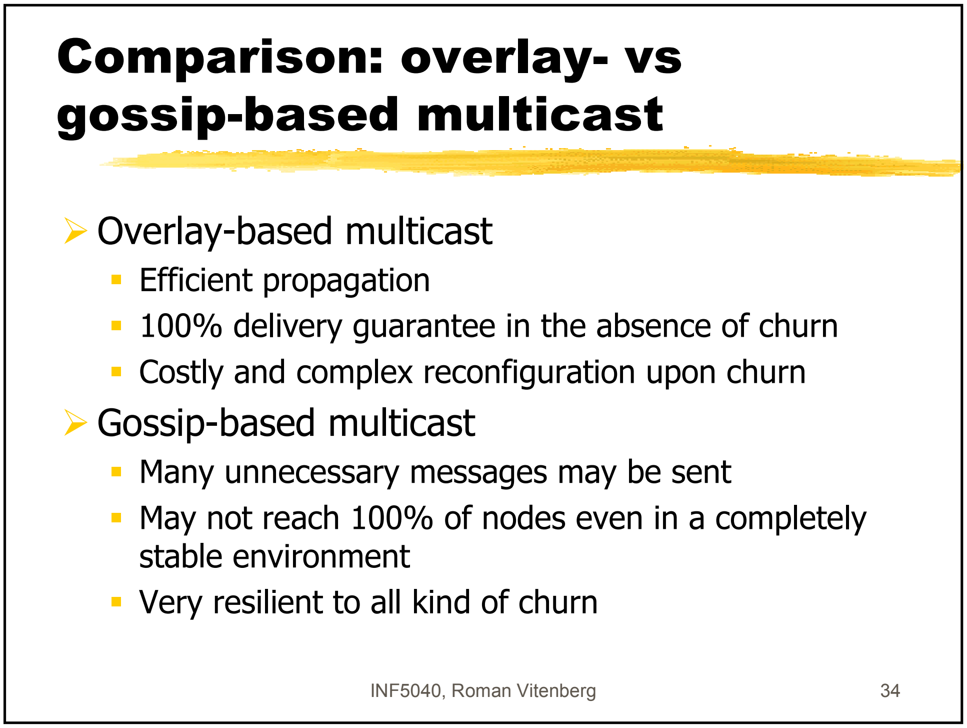
# Membership properties

- Membership list size *L*
  - Infeasibility of full membership in large-scale systems
  - Fundamental tradeoff: smaller membership list scales better but may limit dissemination
    - Risk of partitioning the set of nodes
- Uniformity: partial lists are uniform samples
- Adaptivity: ideally, *L* should be adapted to *N*
  - Nodes may have difficulty of estimating *N*
- Bootstrapping: membership initialization



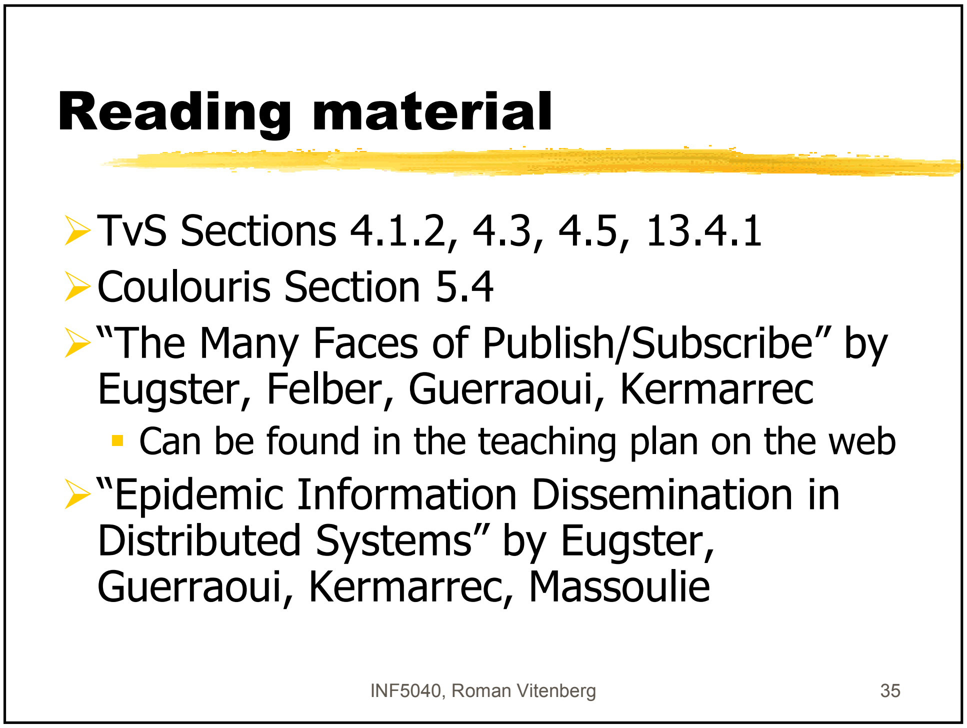
## Applications of gossiping

- Failure detection
- Data aggregation
- Resource discovery and monitoring
  - Access to replicated web pages
- Update propagation in replicated databases
- Experimental: content search, file sharing



## Comparison: overlay- vs gossip-based multicast

- Overlay-based multicast
  - Efficient propagation
  - 100% delivery guarantee in the absence of churn
  - Costly and complex reconfiguration upon churn
- Gossip-based multicast
  - Many unnecessary messages may be sent
  - May not reach 100% of nodes even in a completely stable environment
  - Very resilient to all kind of churn



## Reading material

- TvS Sections 4.1.2, 4.3, 4.5, 13.4.1
- Coulouris Section 5.4
- "The Many Faces of Publish/Subscribe" by Eugster, Felber, Guerraoui, Kermarrec
  - Can be found in the teaching plan on the web
- "Epidemic Information Dissemination in Distributed Systems" by Eugster, Guerraoui, Kermarrec, Massoulie