Distributed Systems Architectures

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Based on slides by Maarten Van Steen

Basic Idea

- Organize into logically different components, and distribute those components over the various machines.

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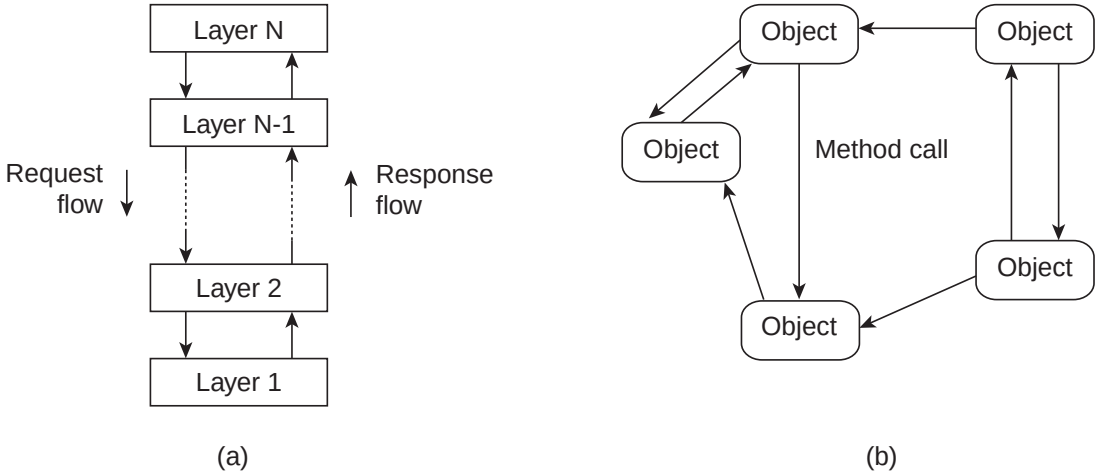

(a) Layered style is used for client-server system
(b) Object-based style for distributed object systems

Architectural Styles

- Decoupling processes in space (anonymous) and also time (asynchronous) has led to alternative styles.

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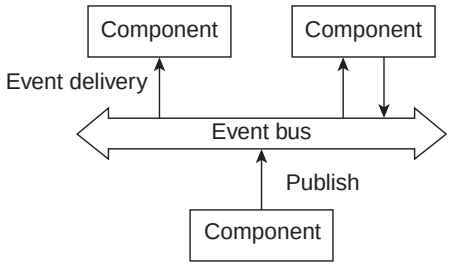
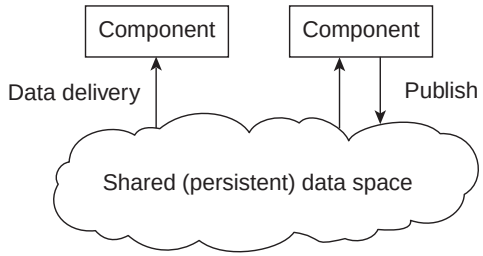


(a)



(b)

(a) Publish/subscribe: decoupled in space
(b) Shared dataspace: decoupled in space and time

System Architectures

- Centralized architectures
- Decentralized architectures
- Hybrid architectures

Centralized Architectures

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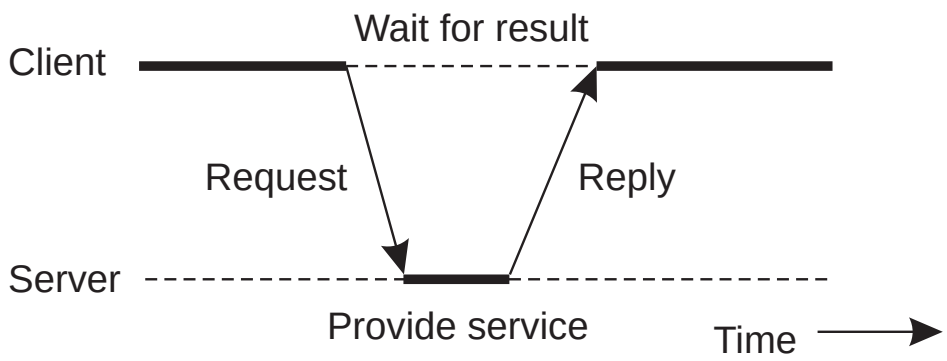
- Basic client-server model



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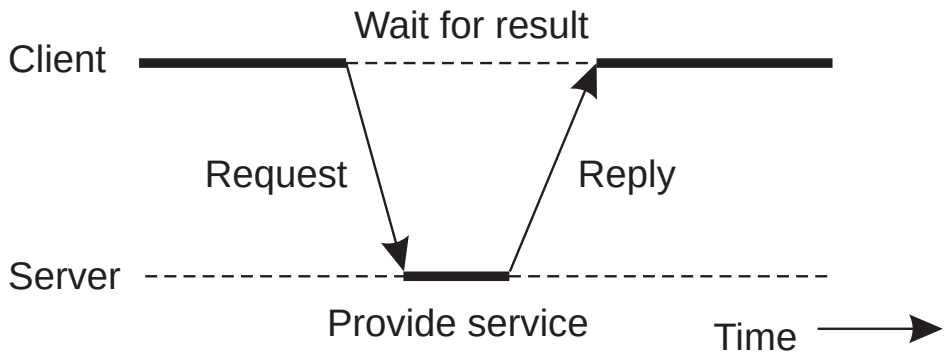

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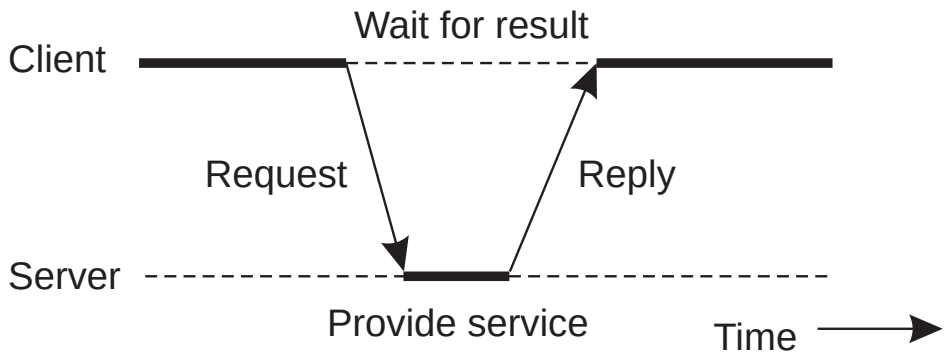

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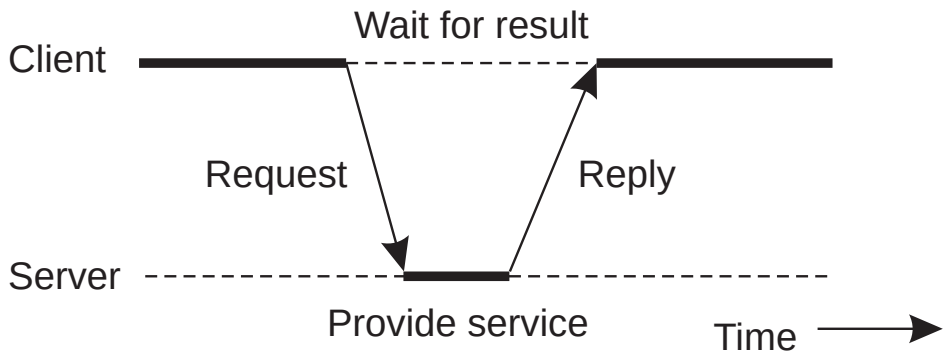

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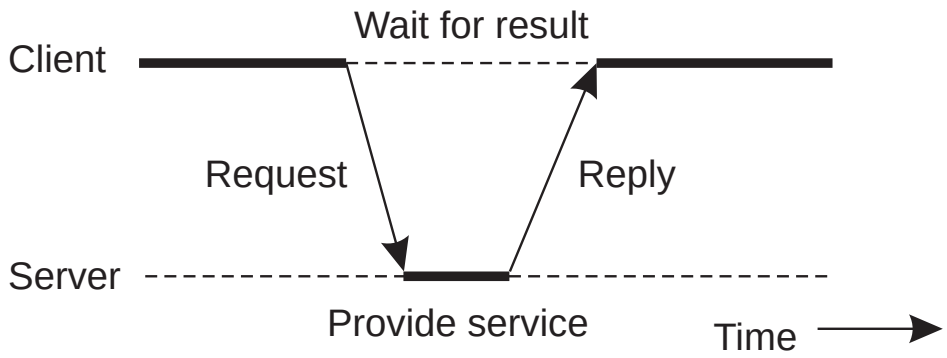

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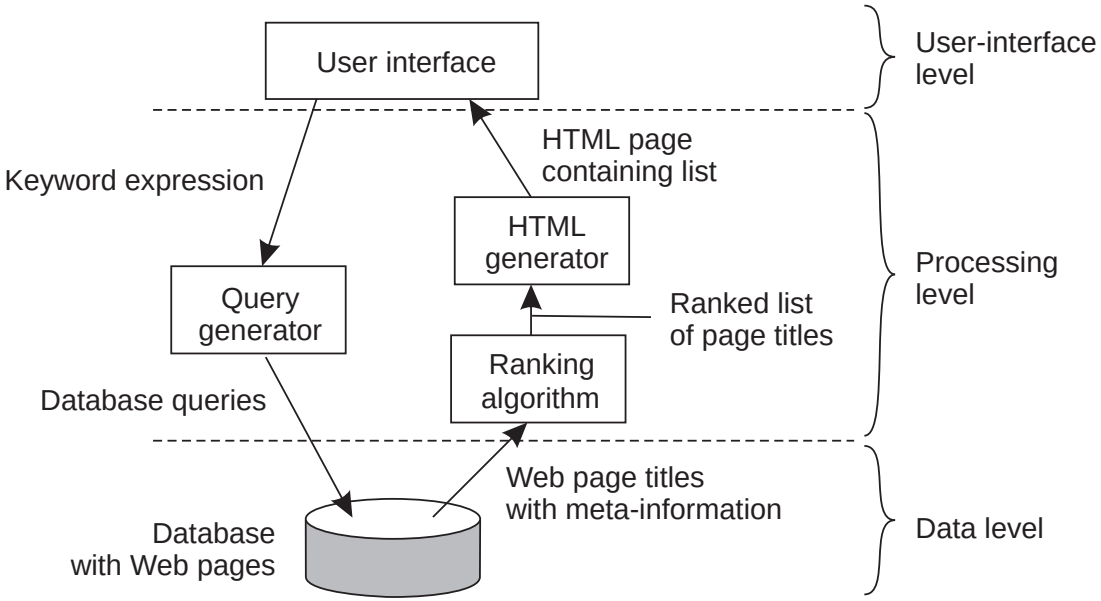
- This layering is found in many distributed information systems, using traditional database technology and accompanying applications.

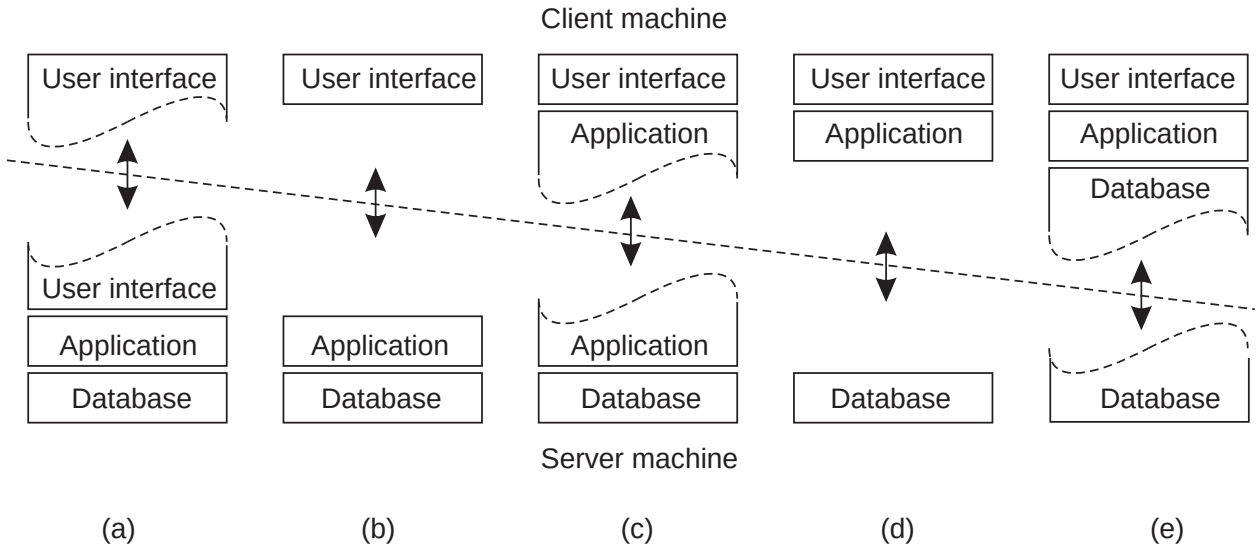
Application Layering (2/2)



Multi-Tiered Architectures

- Single-tiered: dumb terminal/mainframe configuration
- Two-tiered: client/single server configuration
- Three-tiered: each layer on separate machine

Traditional Two-Tiered Configurations



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- In all cases, we are dealing with overlay networks: data is routed over connections setup between the nodes.

Structured P2P Systems

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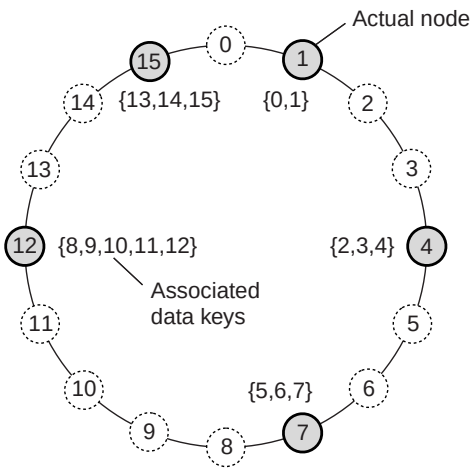
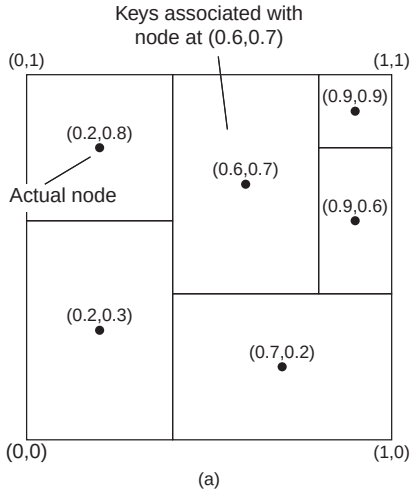
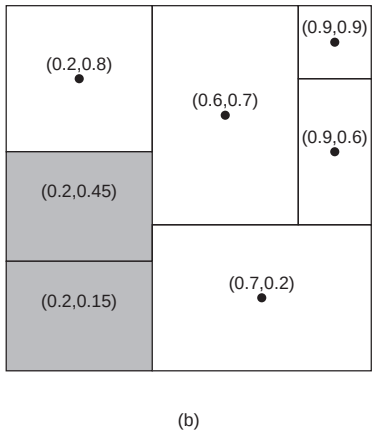
- Organize the nodes in a structured overlay network, e.g., logical ring or a *d*-dimensional space, and make specific nodes responsible for services based only on their ID.



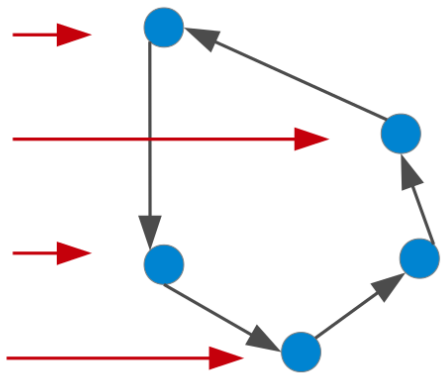




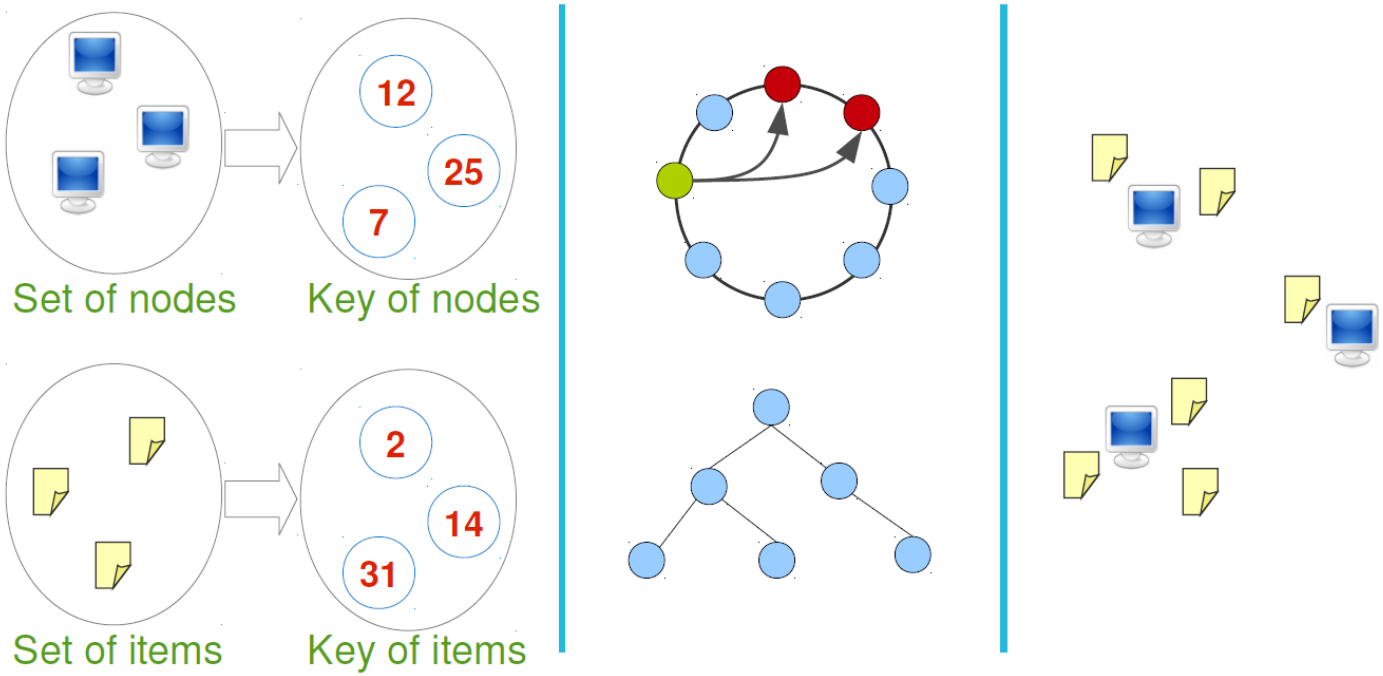
Distributed Hash Table

- An ordinary hash-table, which is distributed.

Key	Value
Fatemeh	Stockholm
Ali	California
Tallat	Islamabad
Cosmin	Bucharest
Seif	Stockholm
Amir	Tehran



Steps to Build a DHT



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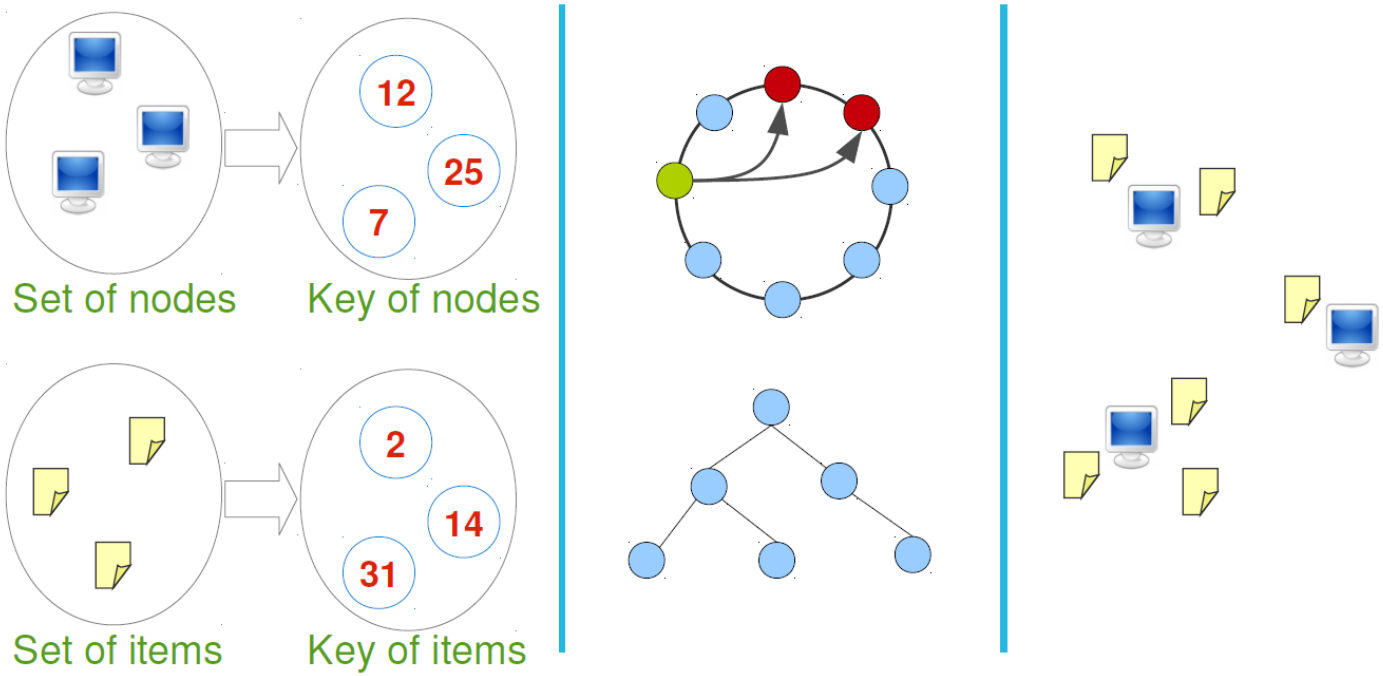

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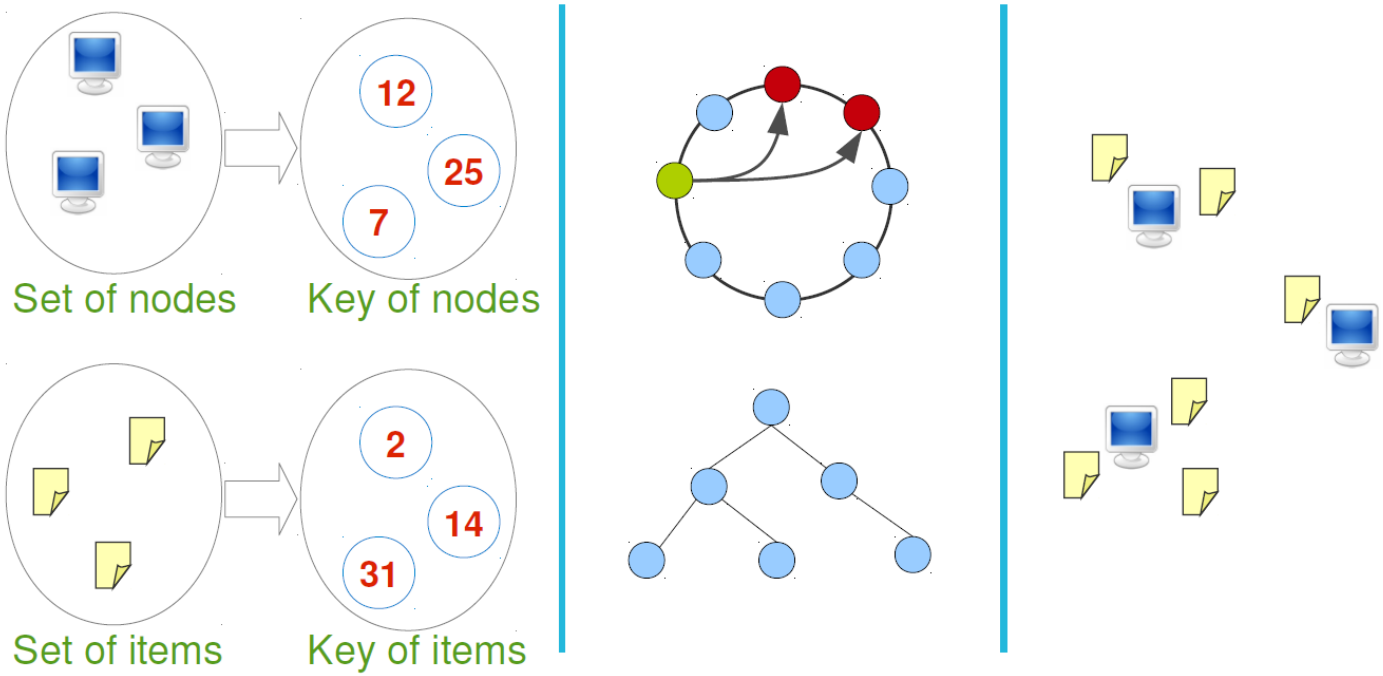

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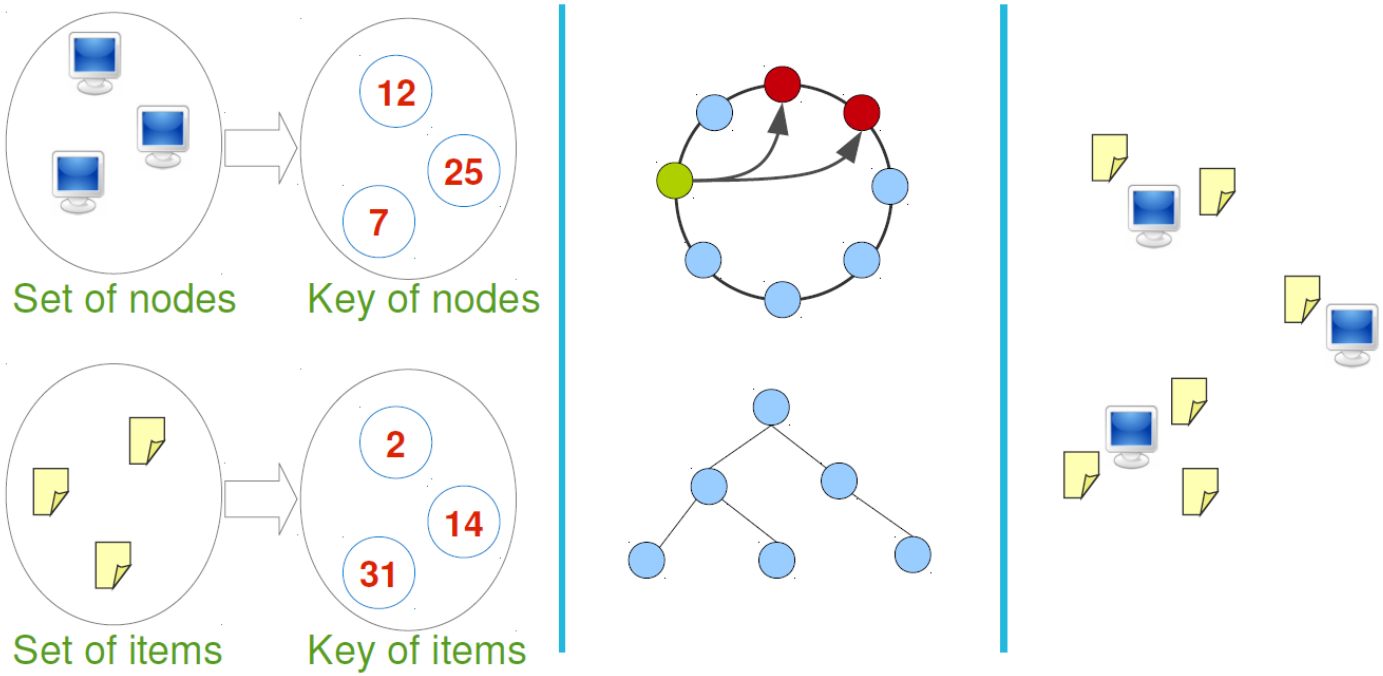
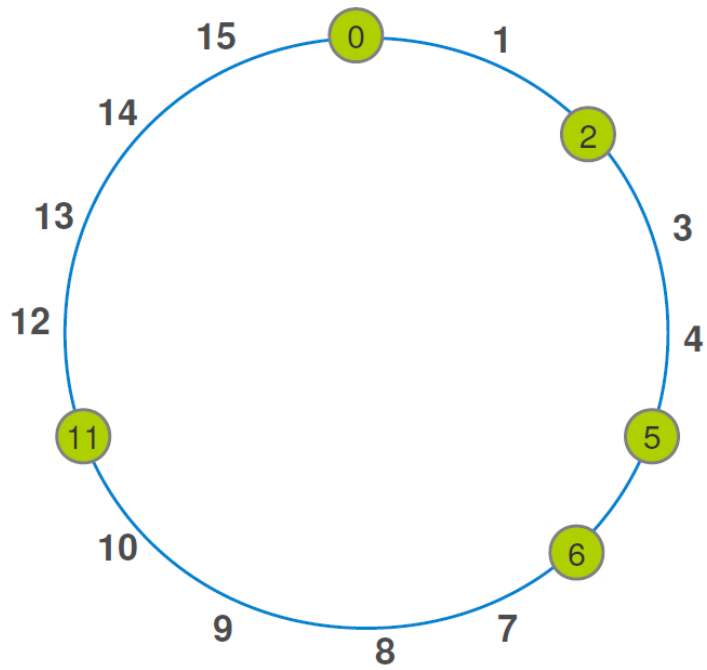


- Step 1: decide on common key space for nodes and values.
- Step 2: connect the nodes smartly.
- Step 3: make a strategy for assigning items to nodes.
- Chord: an example of a DHT

Construct Chord - Step 1

- Use a logical name space, called the id space, consisting of identifiers $\{0, 1, 2, \cdots, N-1\}$.



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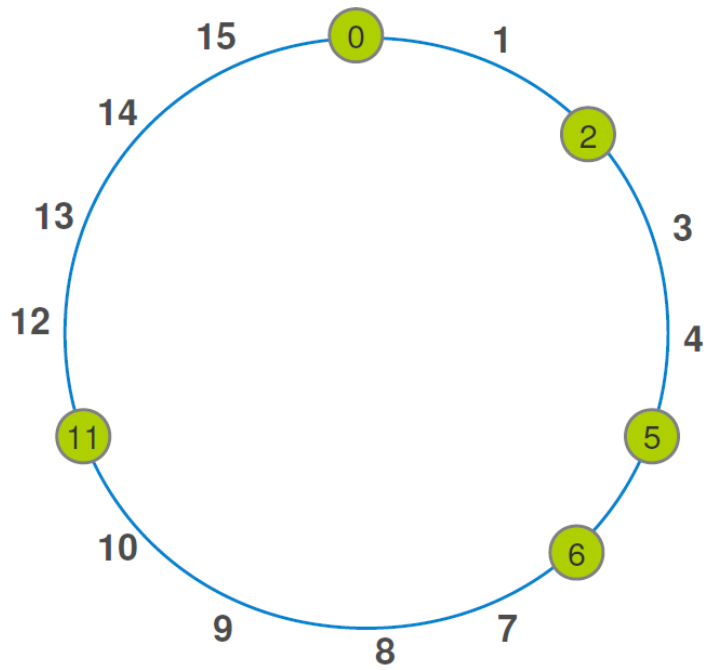

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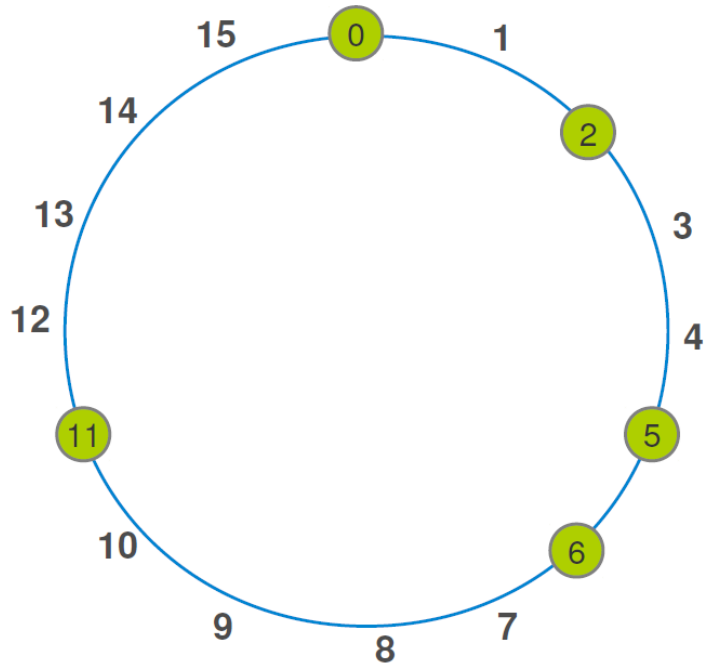

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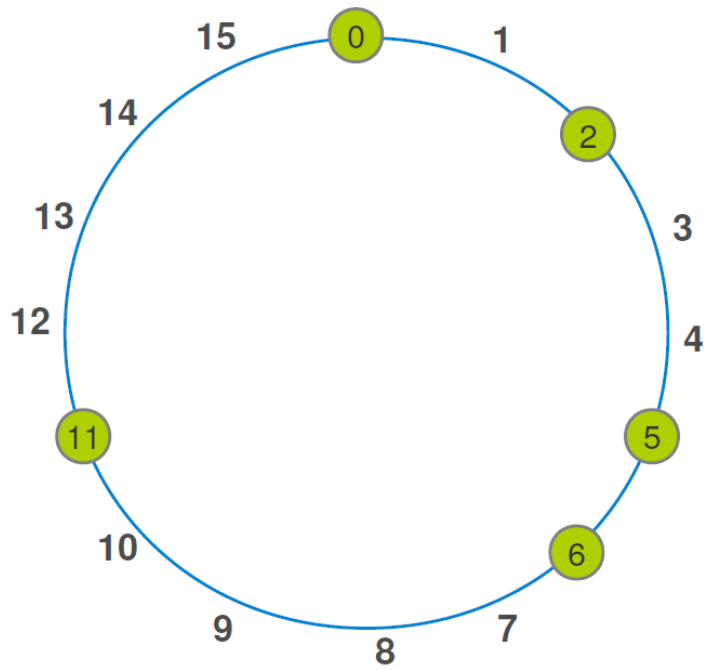
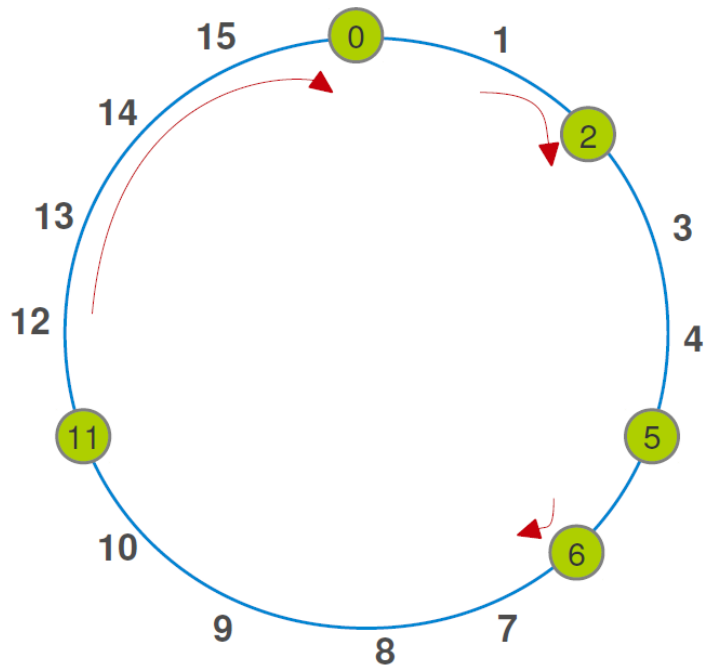
- Example:
  - Space $N = 16\{0, \cdots, 15\}$
  - Five nodes a, b, c, d, e.
  - $H(a) = 6$
  - $H(b) = 5$
  - $H(c) = 0$
  - $H(d) = 11$
  - $H(e) = 2$



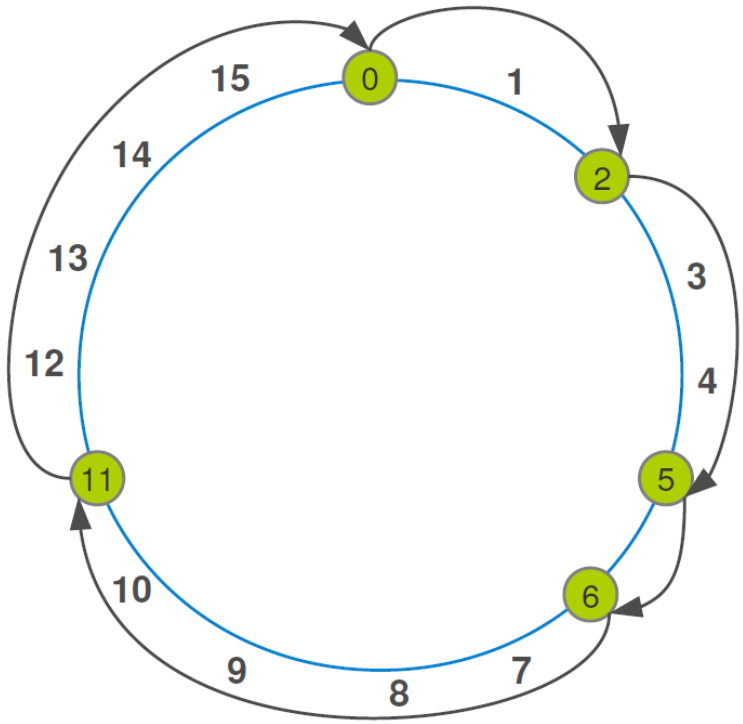
Construct Chord - Step 2 (1/2)

- The successor of an id is the first node met going in clockwise direction starting at the id.
- $succ(x)$: is the first node on the ring with id greater than or equal x.
  - $succ(12) = 0$
  - $succ(1) = 2$
  - $succ(6) = 6$



Construct Chord - Step 2 (2/2)

- Each node points to its successor.
- The successor of a node n is $succ(n+1)$.
  - 0's successor is $succ(1) = 2$.
  - 2's successor is $succ(3) = 5$.
  - 11's successor is $succ(12) = 0$.



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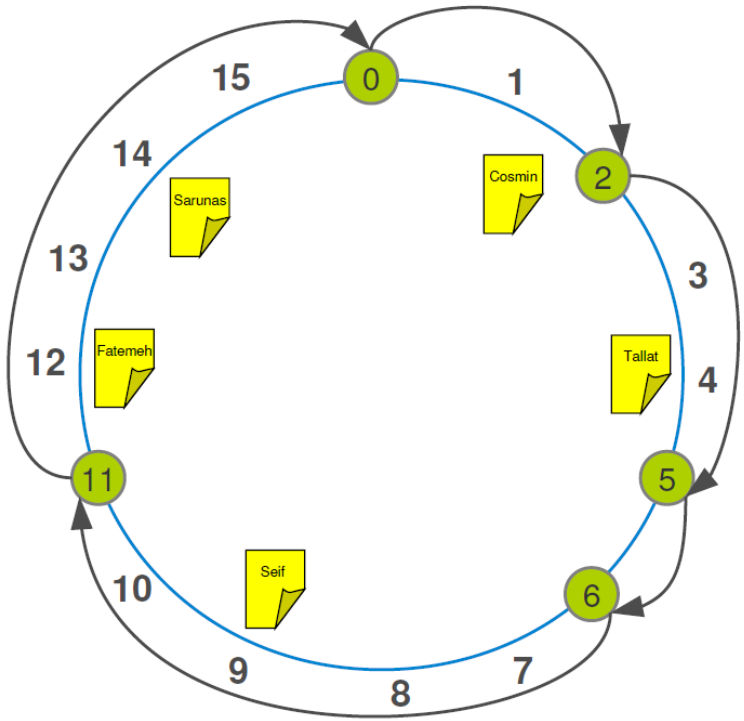

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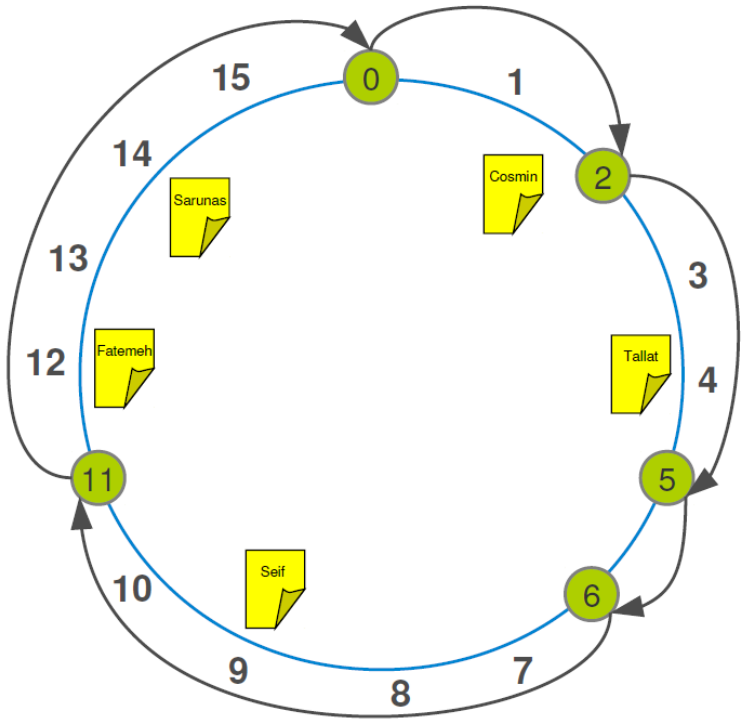
- Use globally known hash function H.
- Each item $\langle key, value \rangle$ gets identifier $H(key) = k$.
  - Space $N = 16\{0, \cdots, 15\}$
  - Five nodes a, b, c, d, e.
  - $H(Fatemeh) = 12$
  - $H(Cosmin) = 2$
  - $H(Seif) = 9$
  - $H(Sarunas) = 14$
  - $H(Tallat) = 4$



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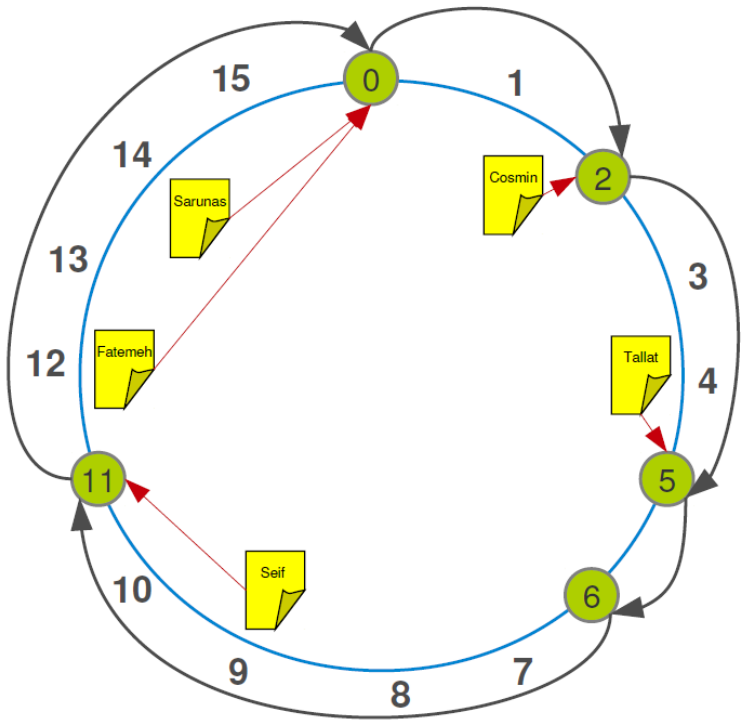

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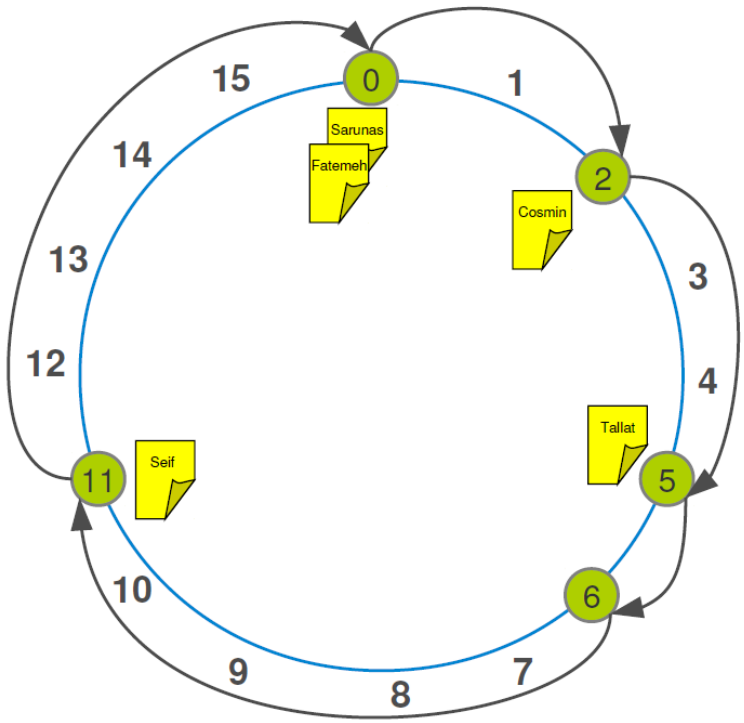

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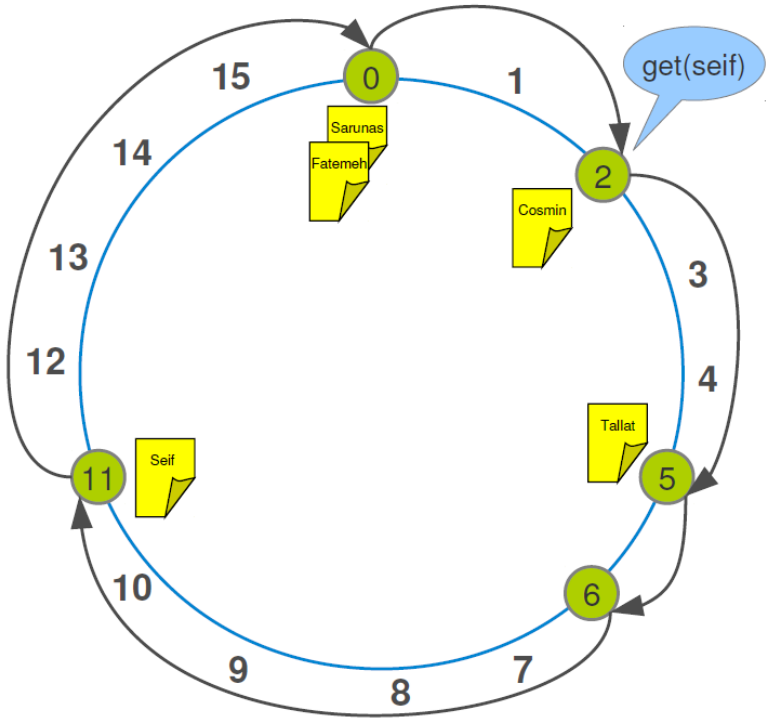
- Example:
  - Lookup Seif at node 2.
  - $H(Seif) = 9$
  - Traverse nodes: 2, 5, 6, 11
  - Return Stockholm to initiator

Key	Value
Seif	Stockholm



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- It turns out that, depending on the exchange, randomness, but also robustness of the network can be maintained.

Gossiping and Aggregation

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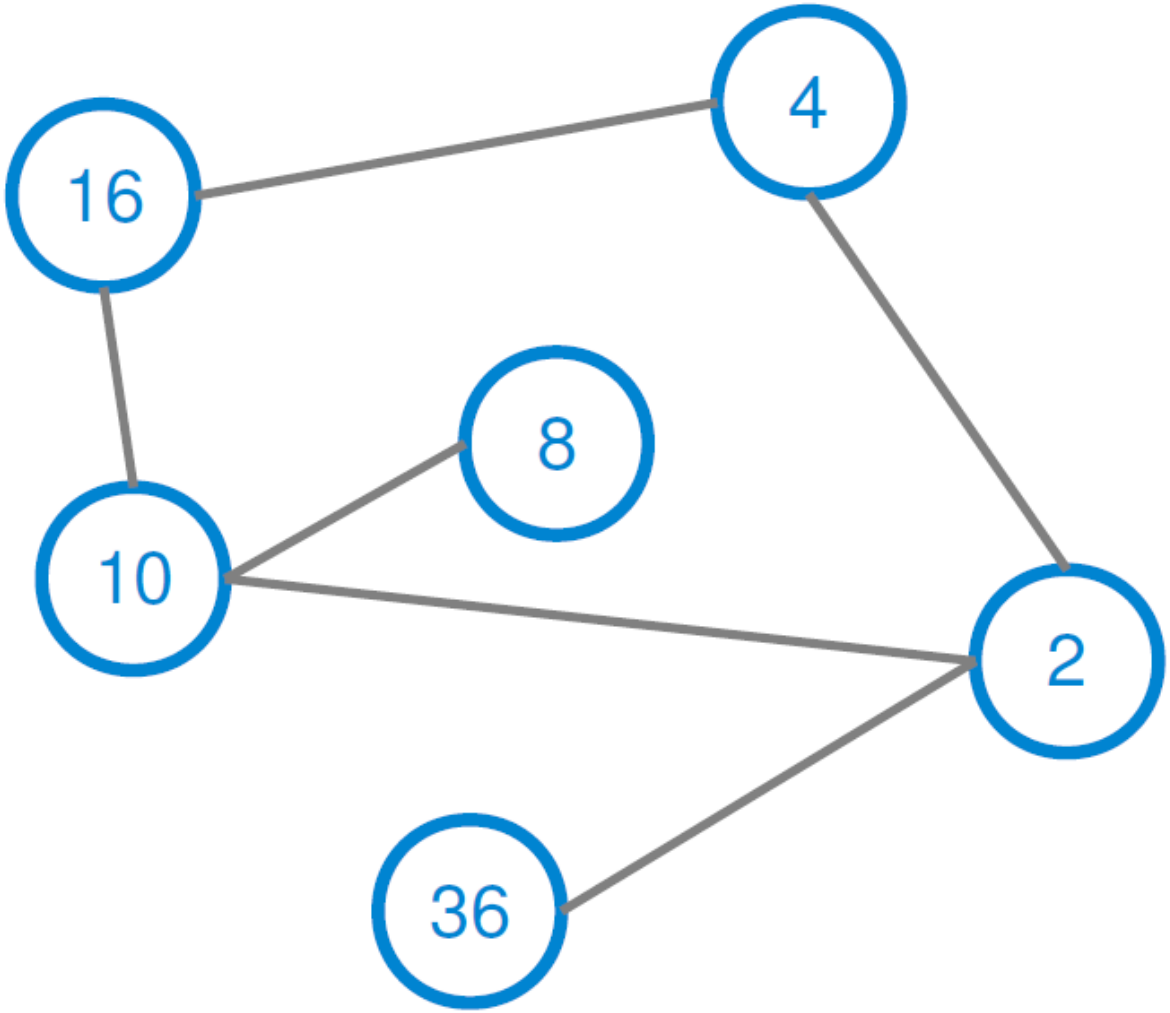
- Examples of aggregation functions:
  - The average load of nodes in a cluster.
  - The sum of free space in a distributed storage.
  - The total number of nodes in a P2P system.

Aggregation Example (1/5)

- Taking the average of the numbers in the nodes.



Aggregation Example (2/5)

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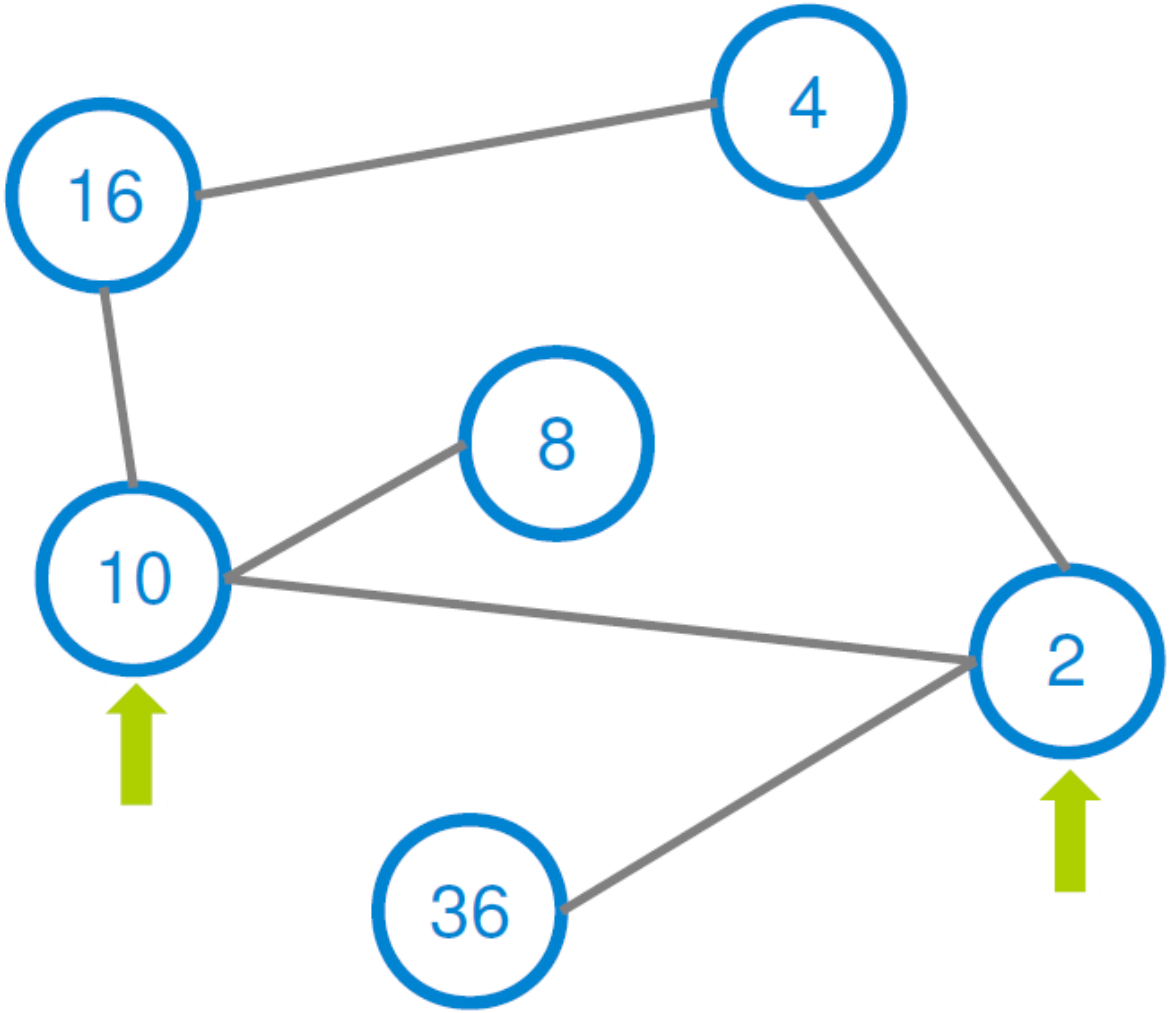

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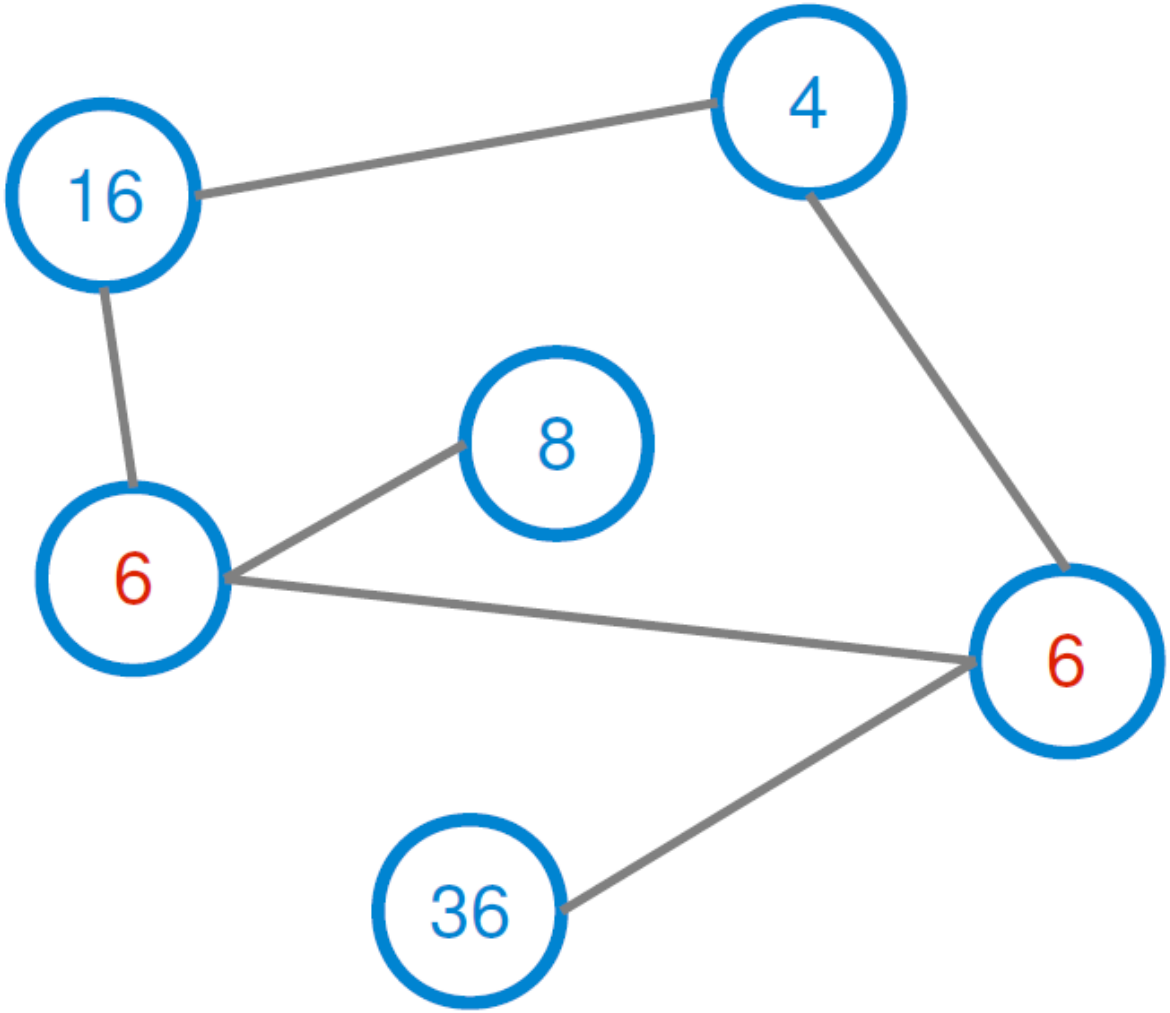
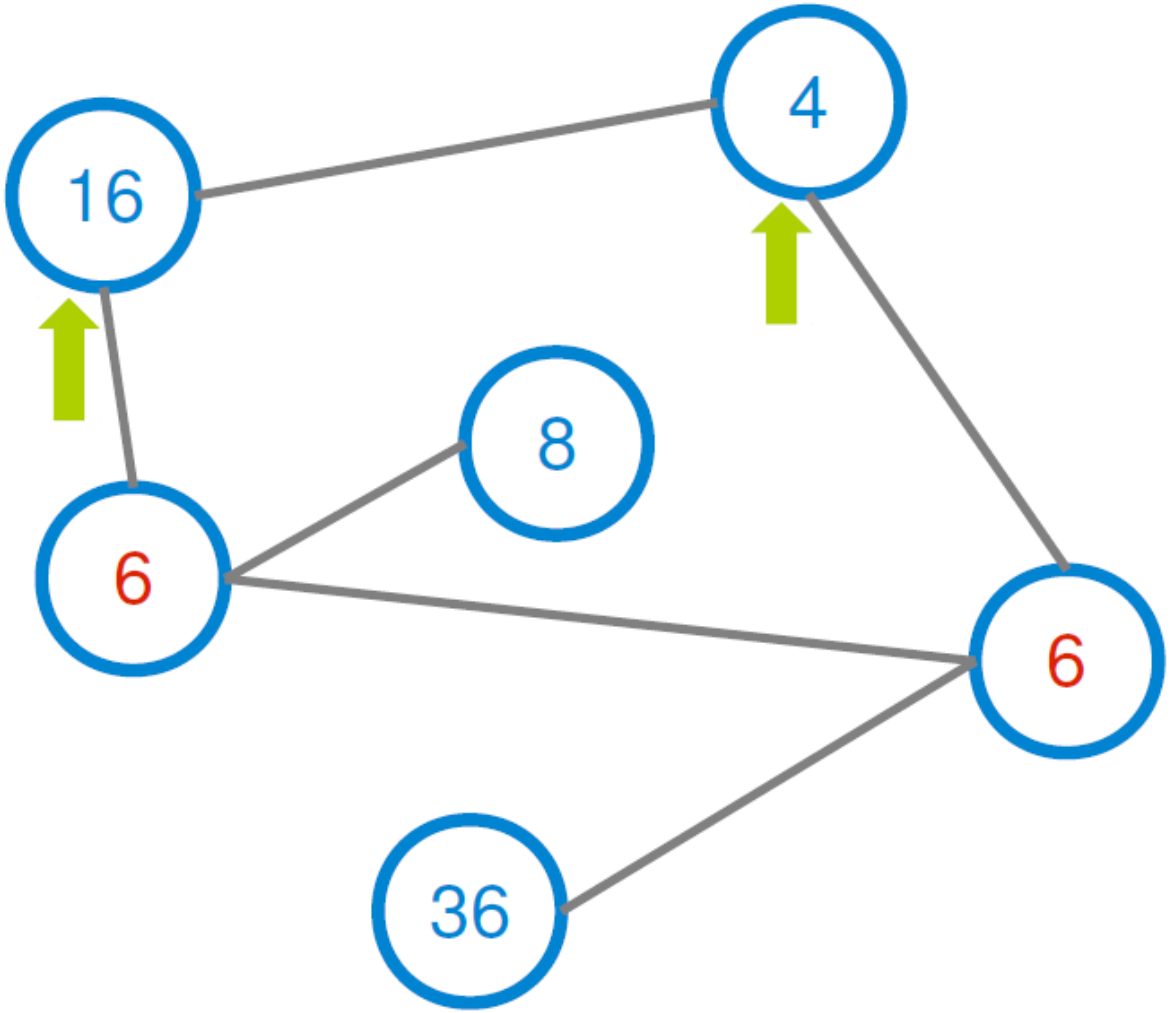


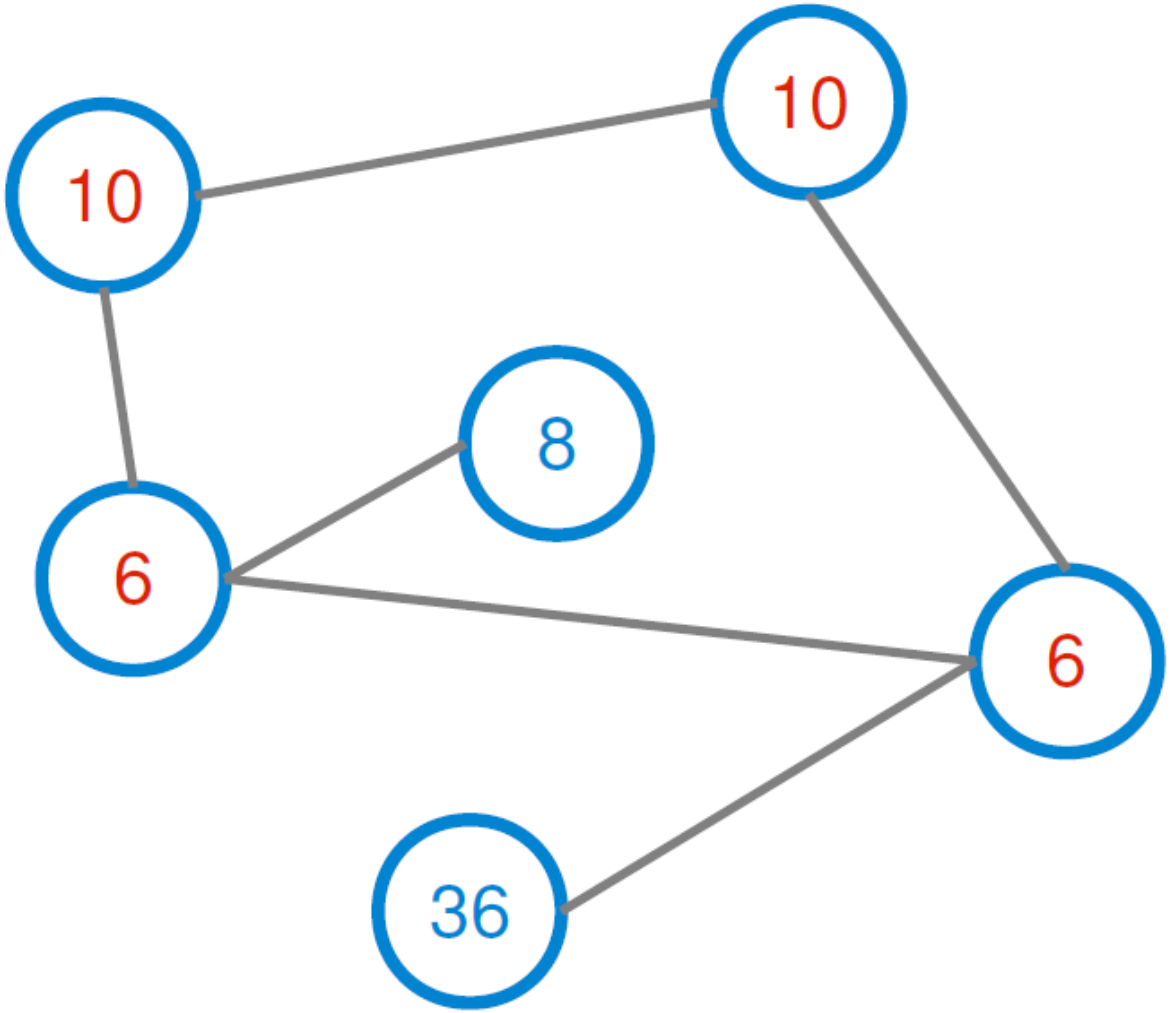
Aggregation Example (4/5)

- Taking the average of the numbers in the nodes.



Aggregation Example (5/5)

- Taking the average of the numbers in the nodes.



Gossiping-Based Peer Sampling

Gossip Protocols

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- The choice of this subset is crucial.
- Ideally, the nodes should be selected following a uniform random sample of all nodes currently in the system.

Achieving a Uniform Random Sample

- Each node may be assumed to know every other node in the system.

Achieving a Uniform Random Sample

- Each node may be assumed to know every other node in the system.
- Providing each node with a complete membership table is unrealistic in a large scale dynamic system.

Peer Sampling

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- Every node maintains a relatively small local membership table that provides a partial view on the complete set of nodes.

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- Every node maintains a relatively small local membership table that provides a partial view on the complete set of nodes.
- Periodically refreshes the table using a gossiping procedure.

Gossip-based Peer Sampling

- Unify partial view and local cache $\Rightarrow$ exchange neighbors

Active thread

Passive thread

Gossip-based Peer Sampling

- Unify partial view and local cache $\Rightarrow$ exchange neighbors

Active thread

```
selectPeer(&B);
```

Passive thread

- `selectPeer`: randomly select a neighbor.

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- Unify partial view and local cache $\Rightarrow$ exchange neighbors

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selectPeer(&B);
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Passive thread

- `selectPeer`: randomly select a neighbor.
- `selectToSend`: select s references to neighbors.

Gossip-based Peer Sampling

- Unify partial view and local cache $\Rightarrow$ exchange neighbors

Active thread

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selectPeer(&B);
selectToSend(&peers_s);
sendTo(B, peers_s);
```

Passive thread

```
receiveFromAny(&A, &peers_r);
```

- `selectPeer`: randomly select a neighbor.
- `selectToSend`: select s references to neighbors.
- `selectToKeep`:
  1. add received references to partial view.
  2. remove repeated refs.
  3. shrink view to size c by randomly removing sent refs (but never received ones).

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Gossip-based Peer Sampling

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sendTo(B, peers_s);

receiveFrom(B, &peers_r);
selectToKeep(pview, peers_r);
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Passive thread

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Topology Management

Topology Management of Overlay Networks (1/3)

- A protocol to construct and maintain any topology with the help of a ranking function.

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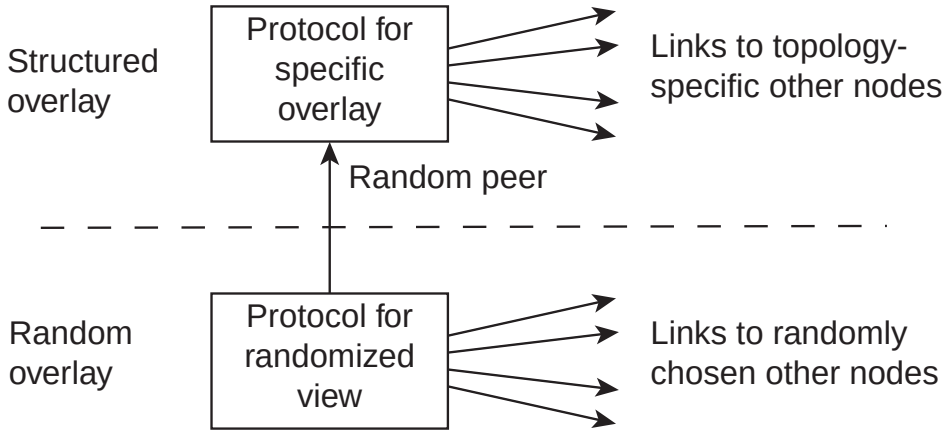
- A protocol to construct and maintain any topology with the help of a ranking function.
- The ranking function orders any set of nodes according to their desirability to be neighbors of a given node.

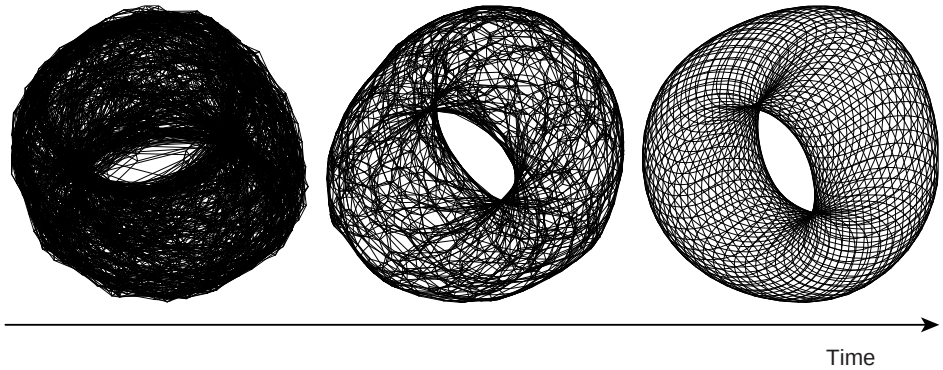
Topology Management of Overlay Networks (2/3)

- Distinguish two layers:
  1. The lower layer: maintains random partial views in lowest layer
  2. The upper layer: be selective on who you keep in higher-layer partial view
- Lower layer feeds upper layer with random nodes; upper layer is selective when it comes to keeping references.



Topology Management of Overlay Networks (3/3)

- Constructing a torus: consider a $N \times N$ grid.
- Keep only references to nearest neighbors in the upper layer:
  - Line: $d(a, b) = |a - b|$
  - Ring: $d(a, b) = min(N - |a - b|, |a - b|)$



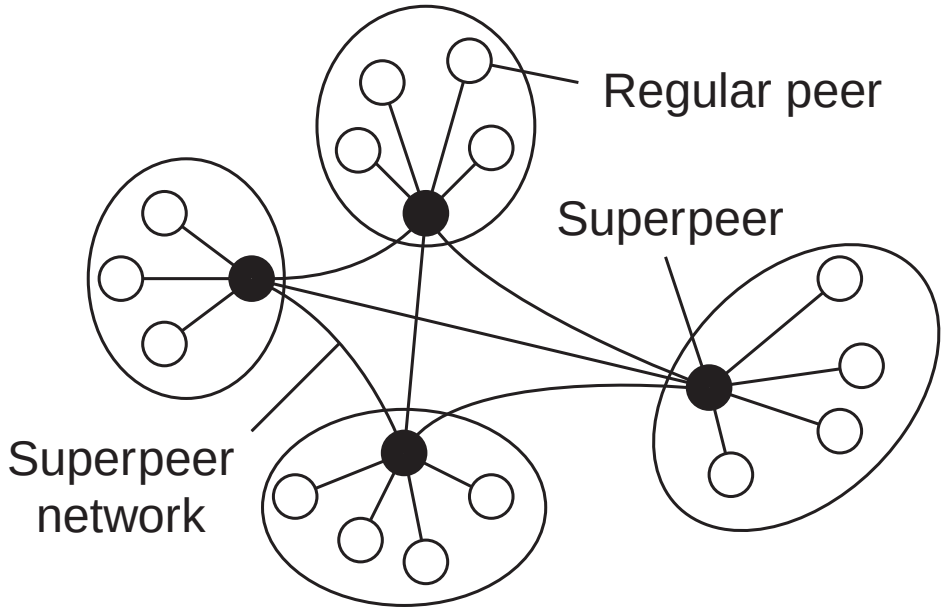
Hybrid P2P Systems

Superpeers

- Sometimes it helps to select a few nodes to do specific work: superpeer.

Superpeers

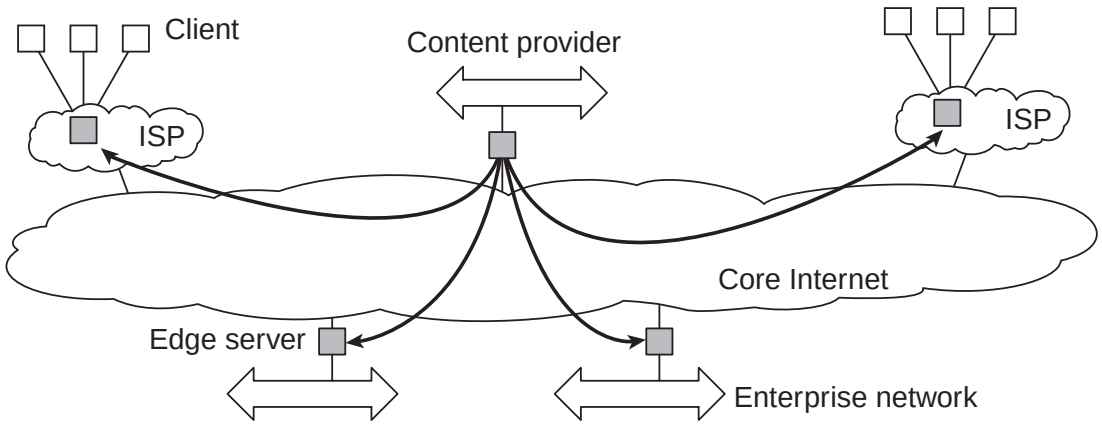
- Sometimes it helps to select a few nodes to do specific work: superpeer.
- Examples:
  - Peers maintaining an index (for search)
  - Peers monitoring the state of the network
  - Peers being able to setup connections



Hybrid Architectures

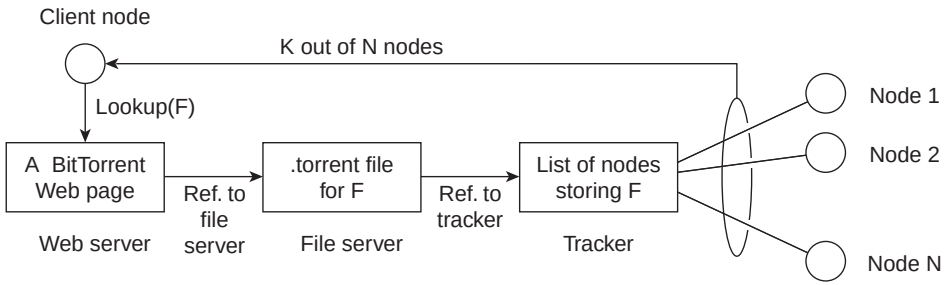
Hybrid Architectures (1/2)

- Client-server combined with P2P
- Edge-server architectures, which are often used for Content Delivery Networks (CDN)



Hybrid Architectures (2/2)

- Example: Bittorrent
- Once a node has identified where to download a file from, it joins a swarm of downloaders who in parallel get file chunks from the source, but also distribute these chunks amongst each other.



Summary

Summary

- Client-Server
  - Application layers, e.g., two-tier, three-tier
- P2P
  - Structured: DHT
  - Unstructured: gossip, peer sampling, topology management
  - Hybrid: superpeers
- Hybrid P2P and client-server: CDN + P2P

Reading

- Chapter 2 of the Distributed Systems: Principles and Paradigms.
- Stoica, Ion, et al., Chord: a scalable peer-to-peer lookup protocol for internet applications, Networking, IEEE/ACM Transactions on 11.1 (2003): 17-32.
- Jelasity, Mark, and Alberto Montresor, Epidemic-style proactive aggregation in large overlay networks, Distributed Computing Systems, 2004. Proceedings. 24th International Conference on. IEEE, 2004.
- Jelasity, Mark, et al., Gossip-based peer sampling, ACM Transactions on Computer Systems (TOCS) 25.3 (2007): 8.
- Jelasity, Mark, and Ozalp Babaoglu., T-Man: Gossip-based overlay topology management, Engineering Self-Organising Systems. Springer Berlin Heidelberg, 2006. 1-15.

Questions?