Self-Management of Large Scale Distributed Systems

Boriss Mejías

Université catholique de Louvain,
Louvain-la-Neuve, Belgium
boriss.mejias@uclouvain.be

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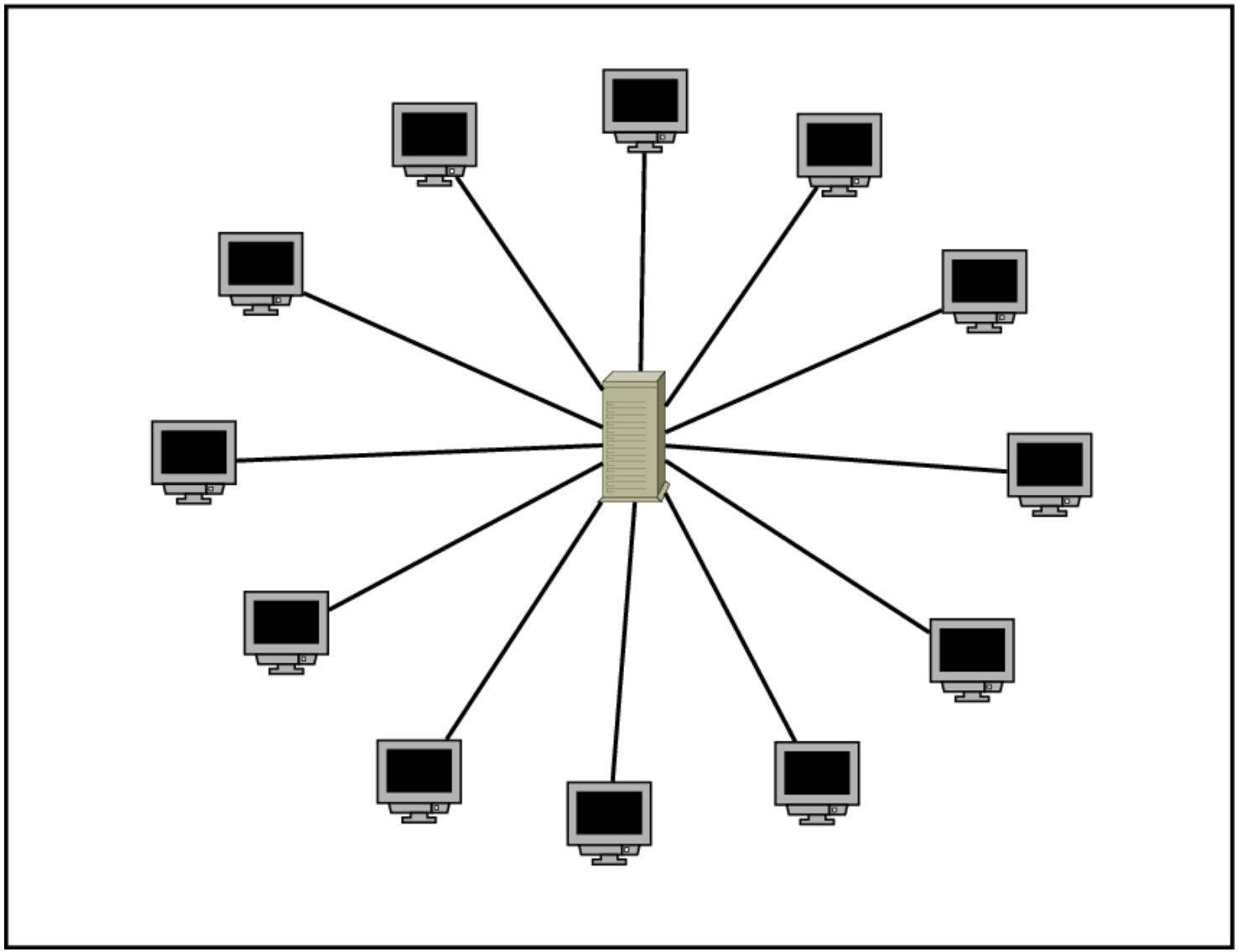
Motivation



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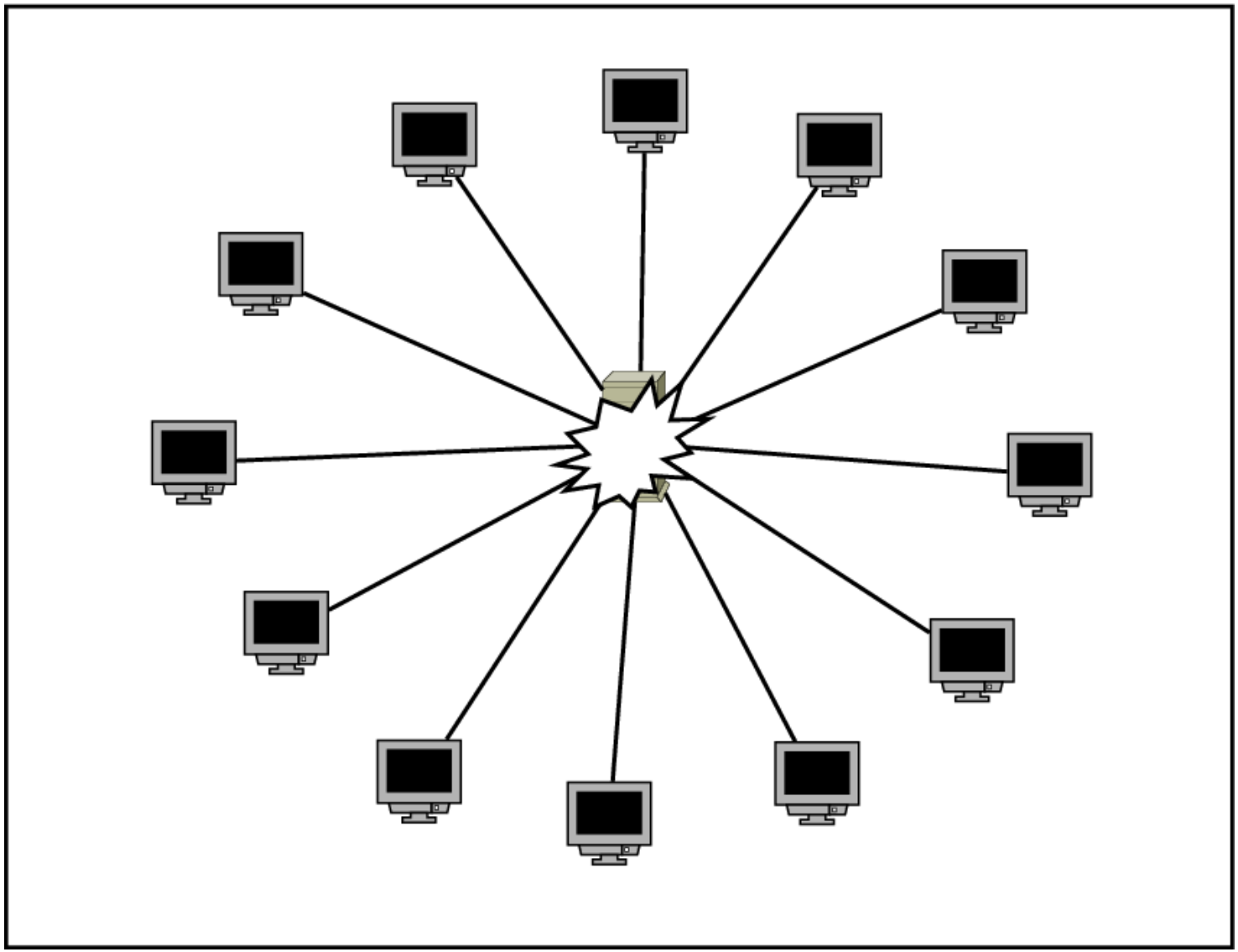

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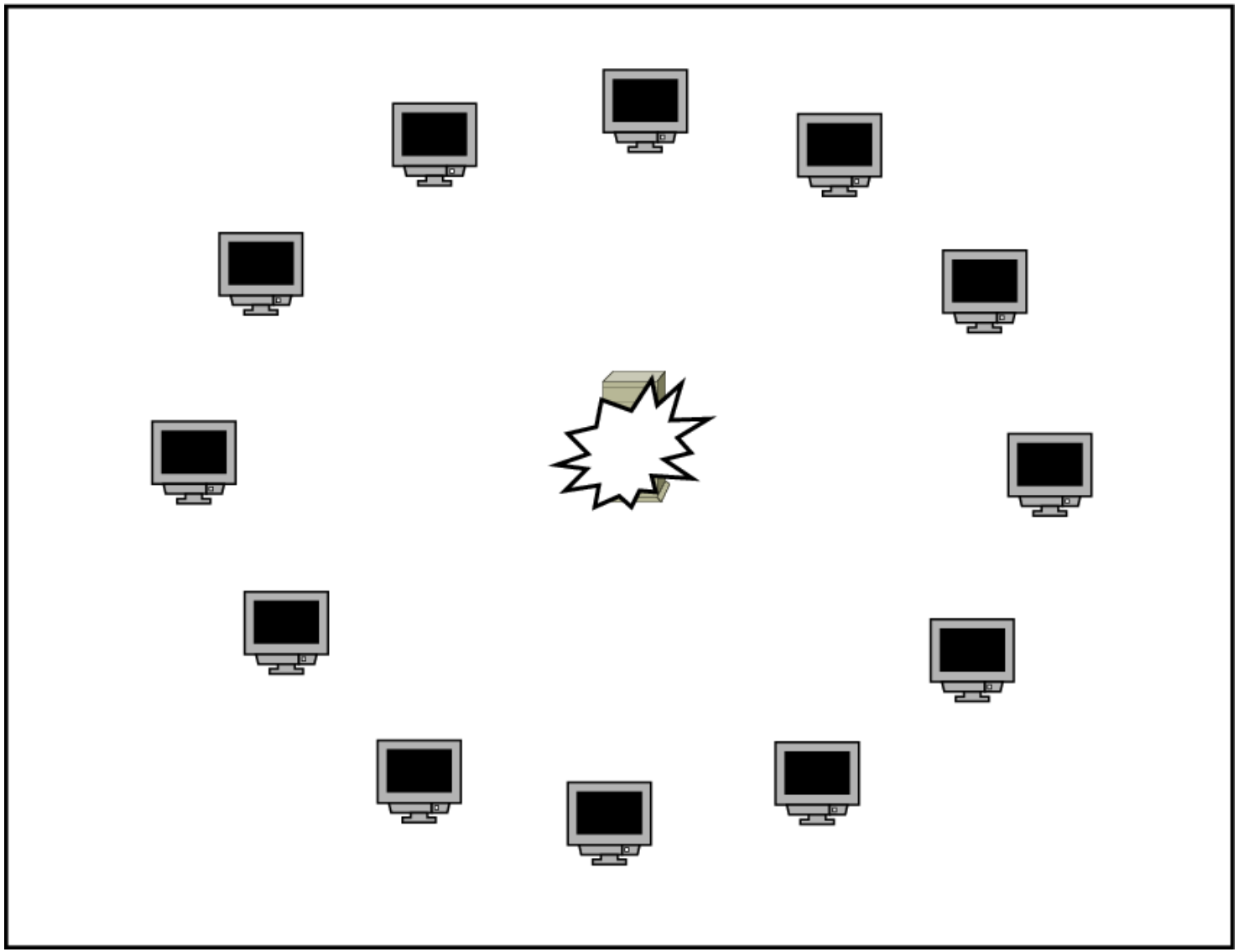

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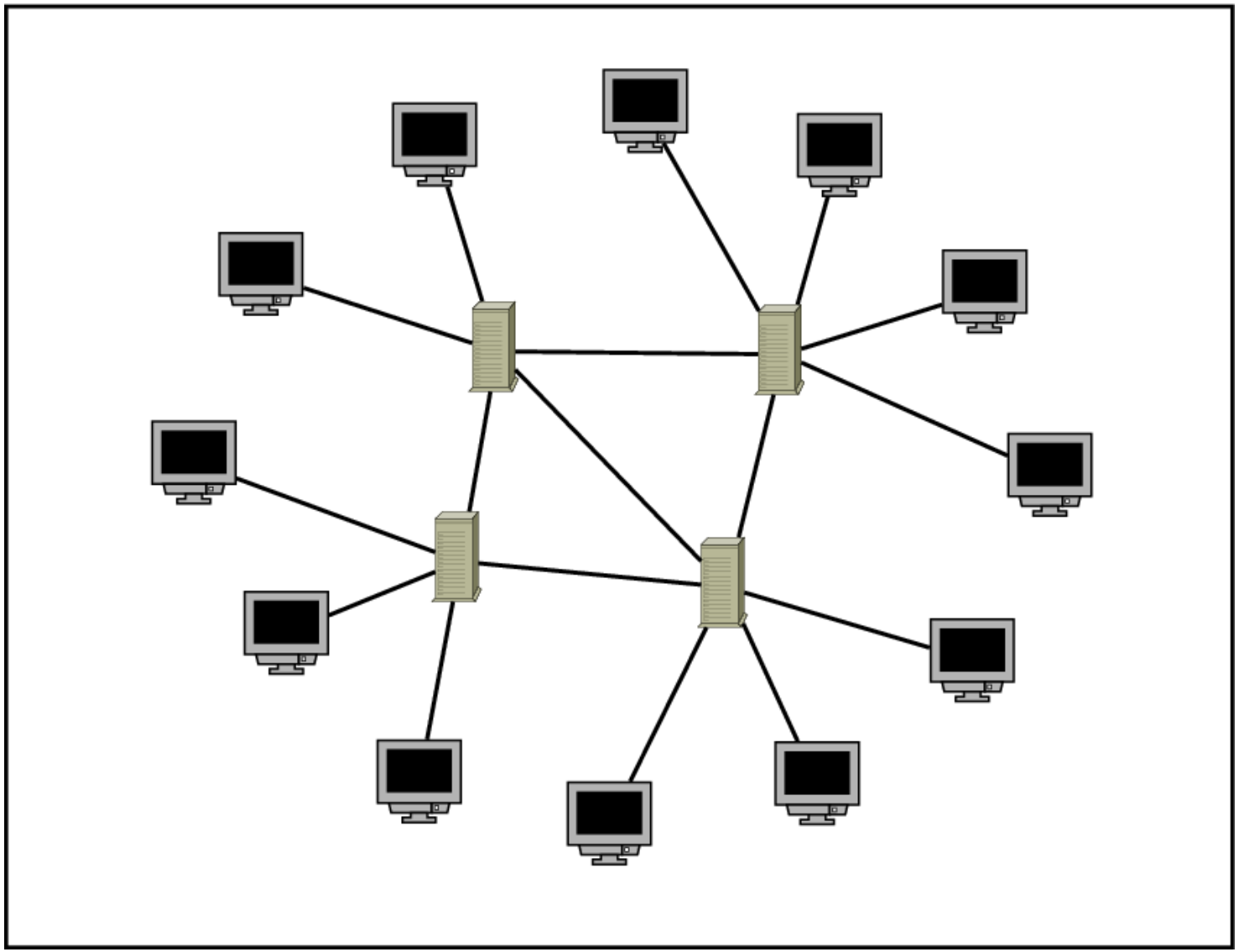

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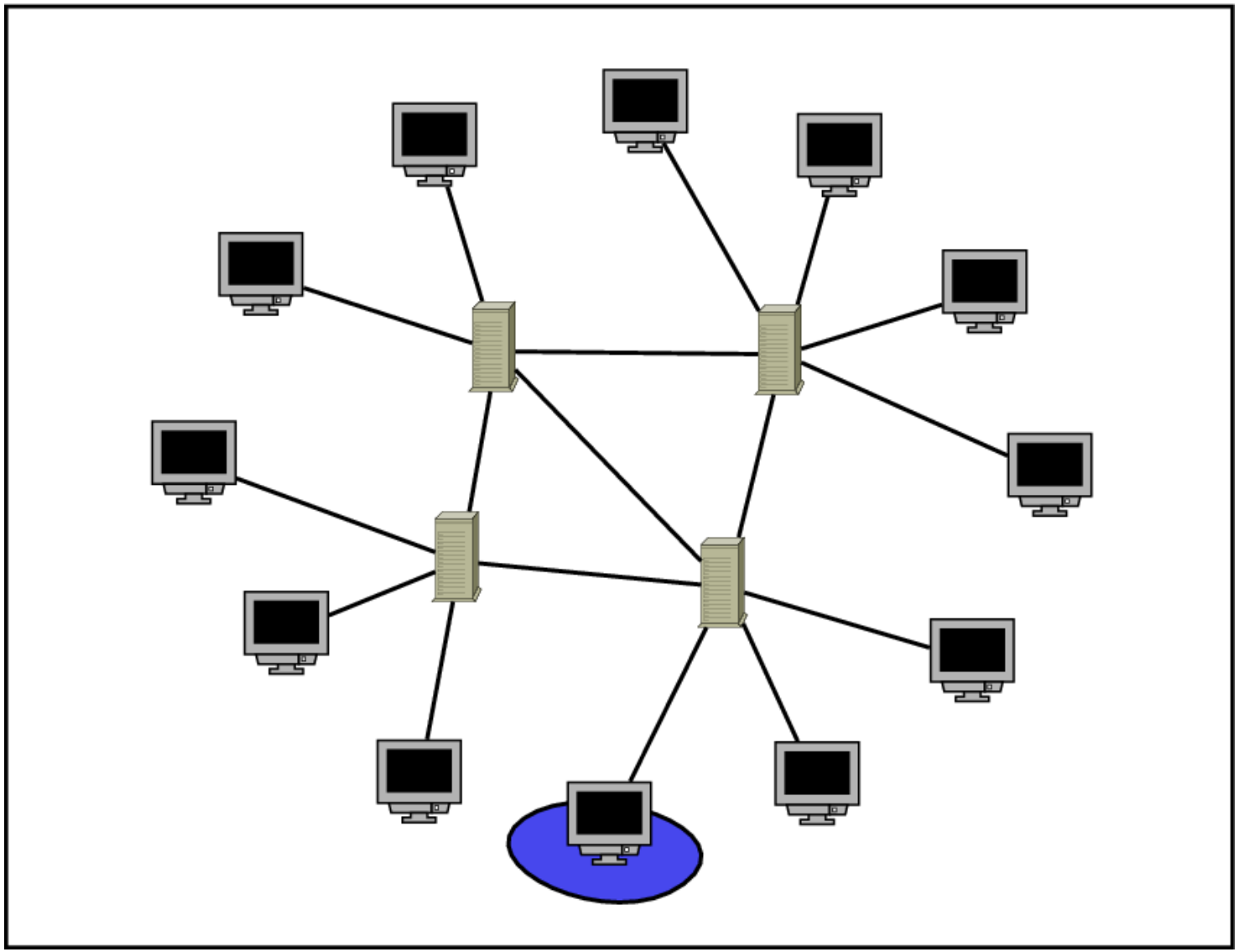

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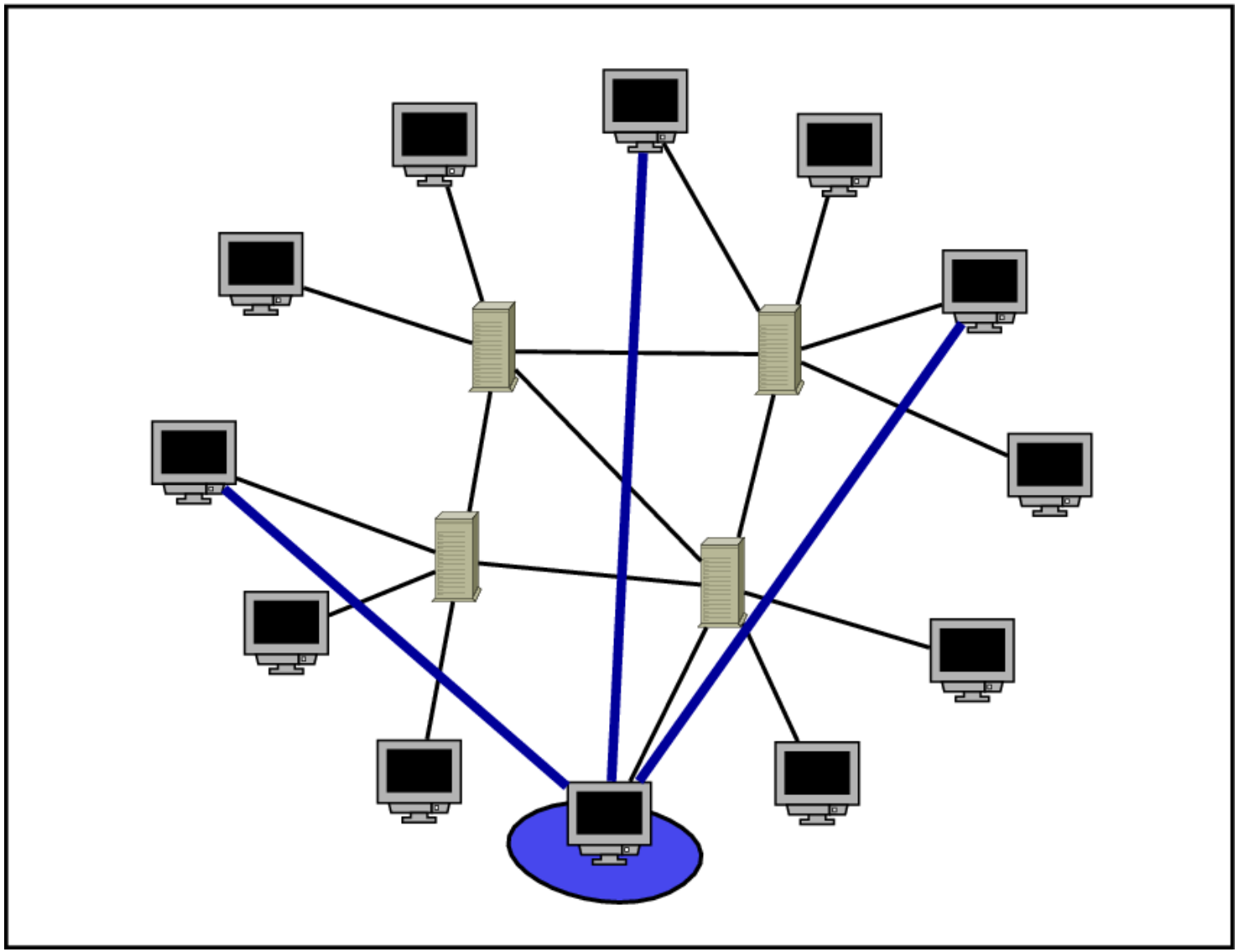

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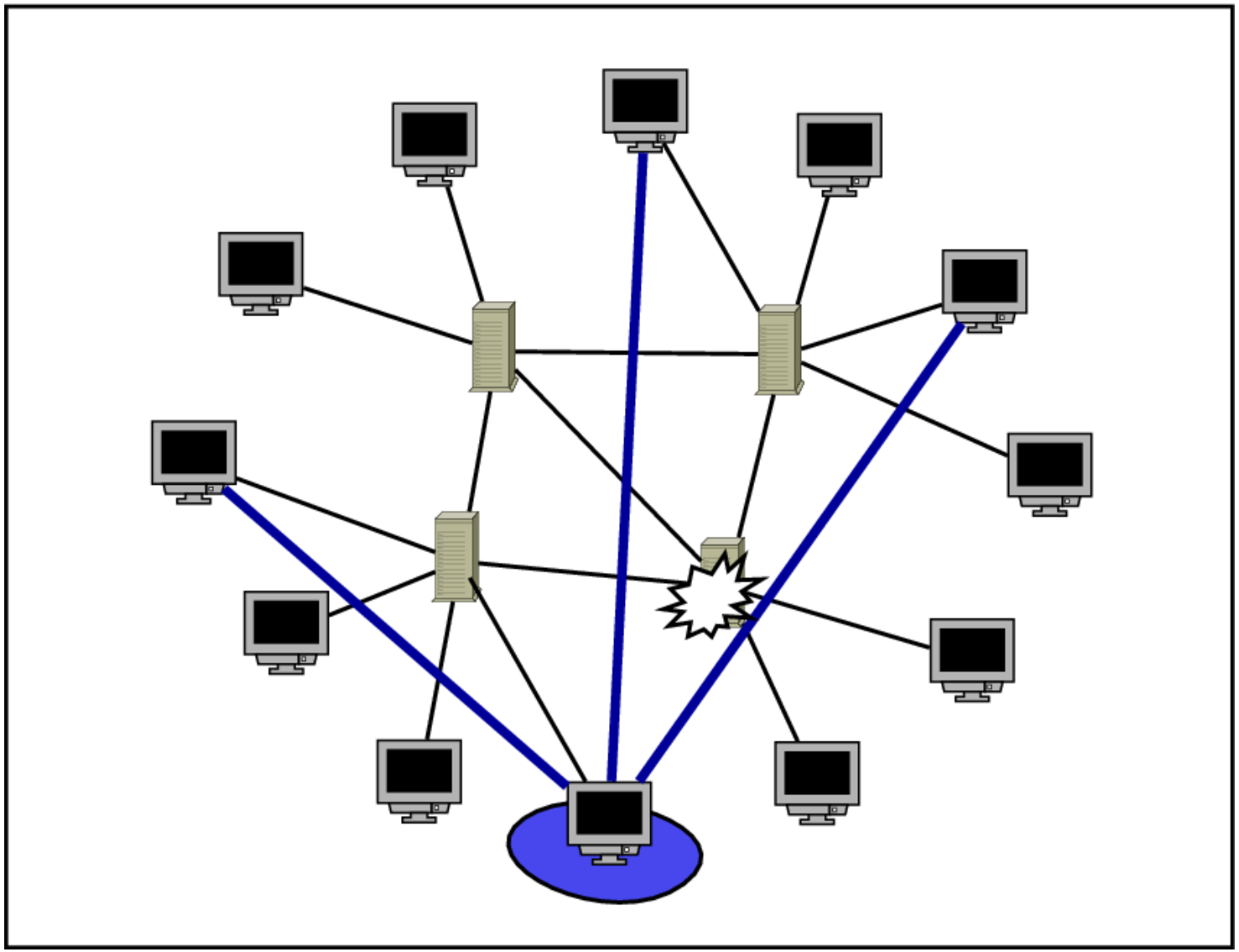

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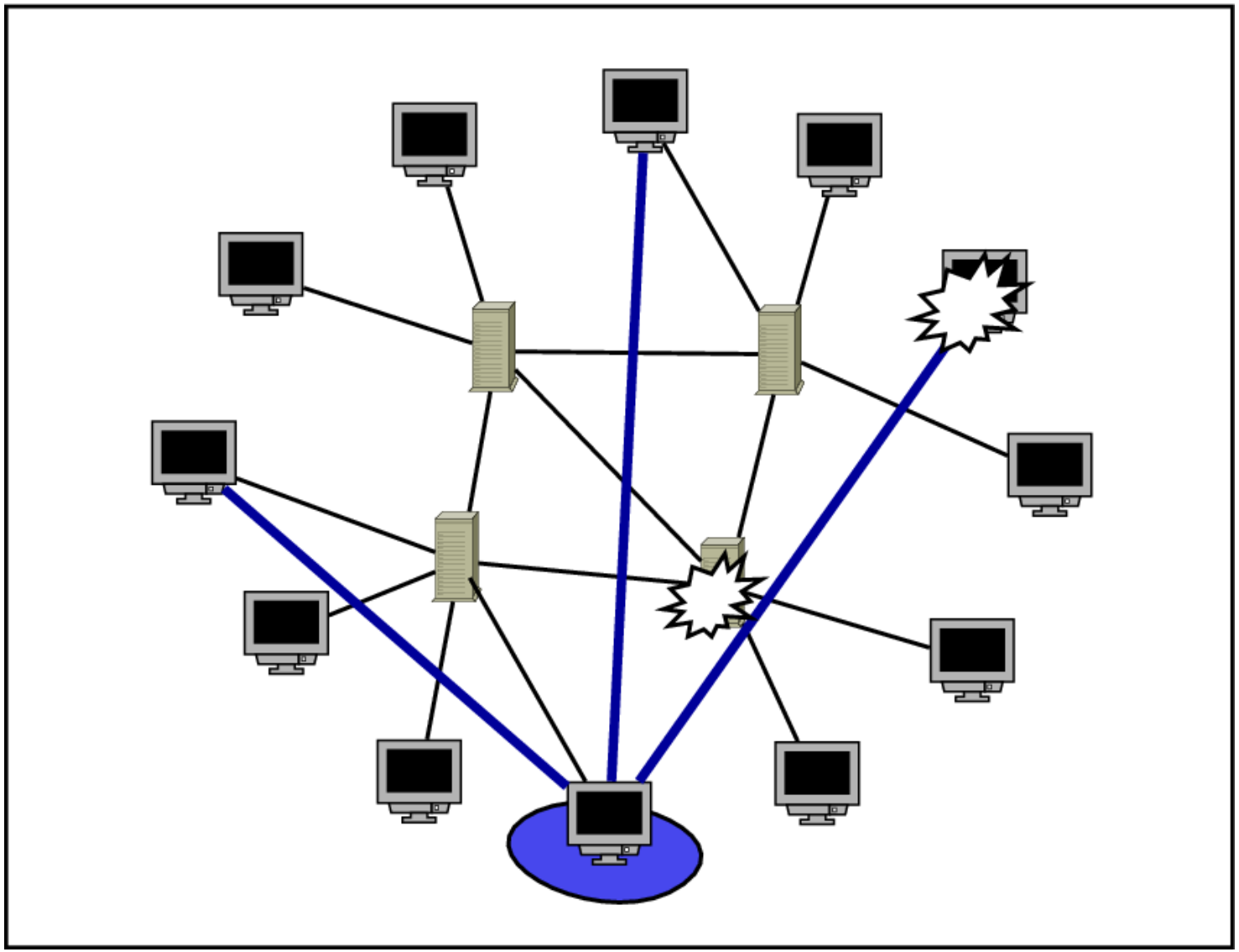

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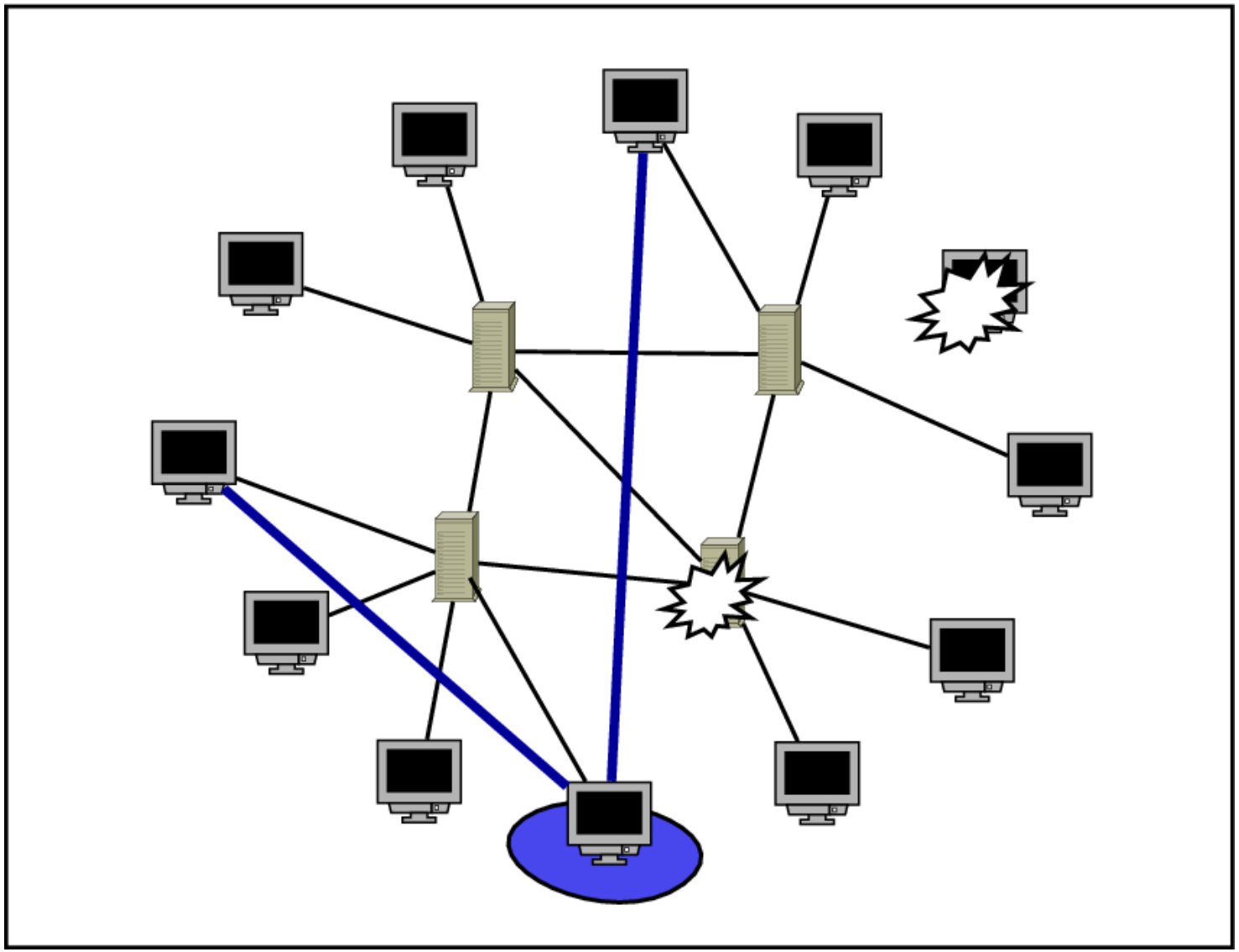

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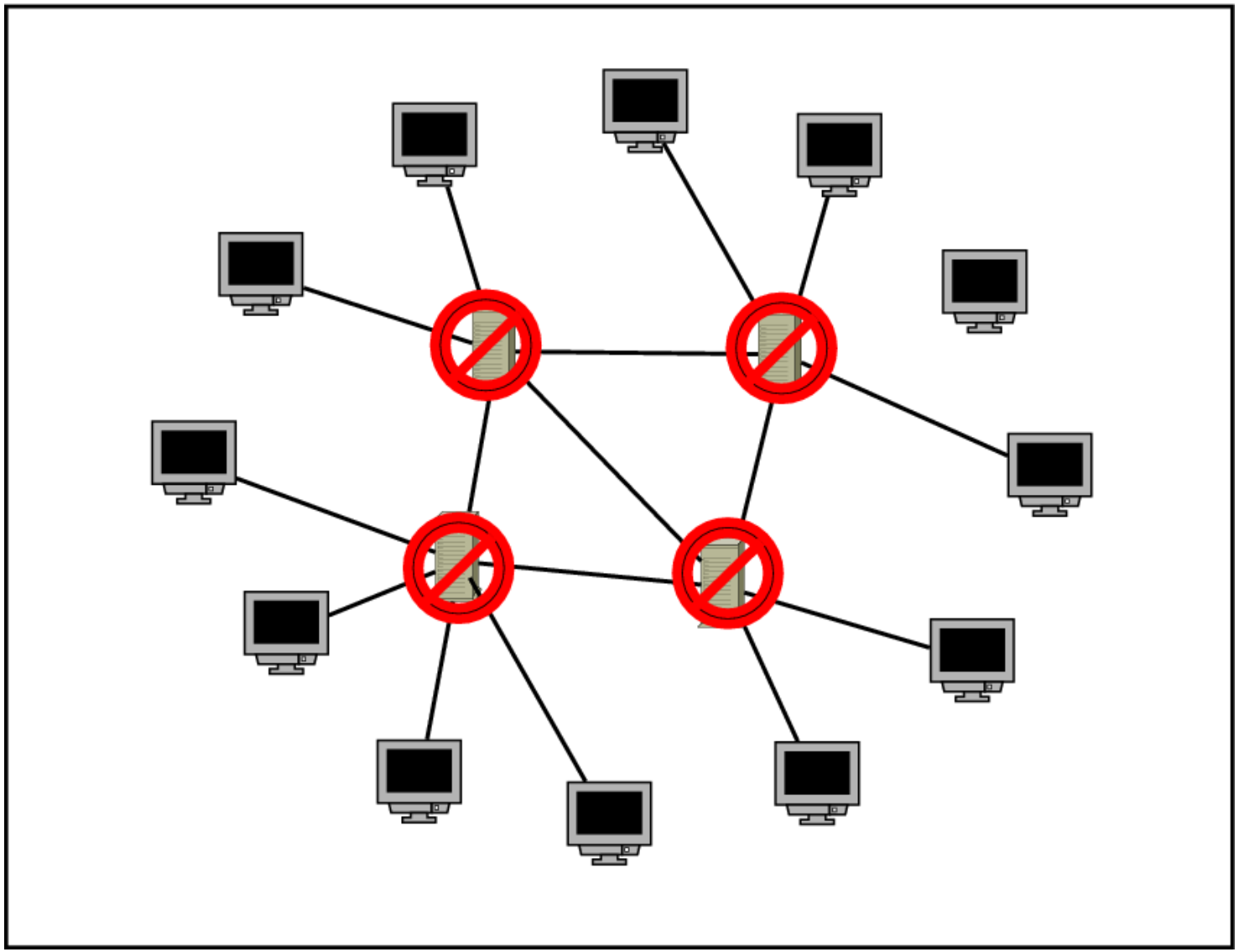

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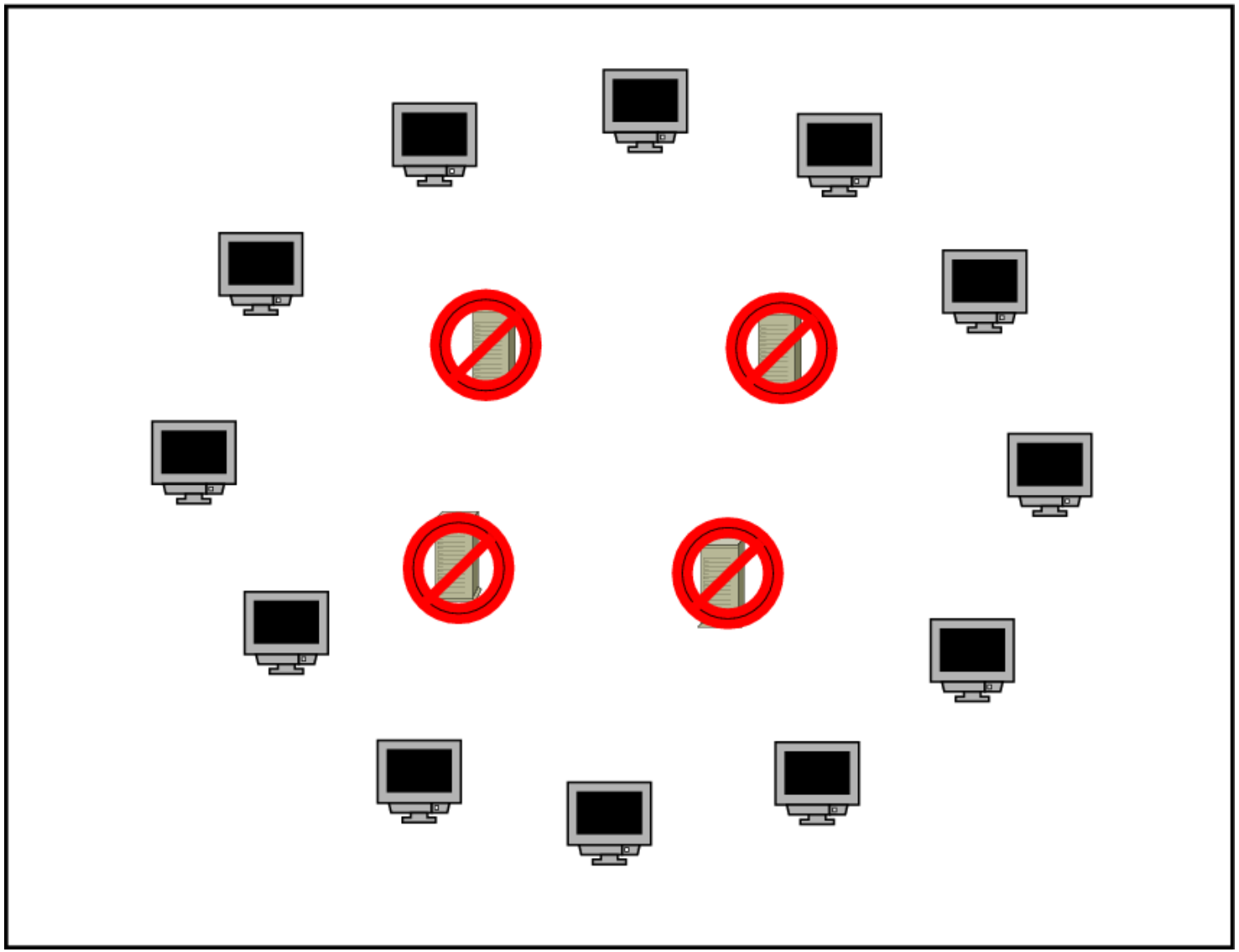

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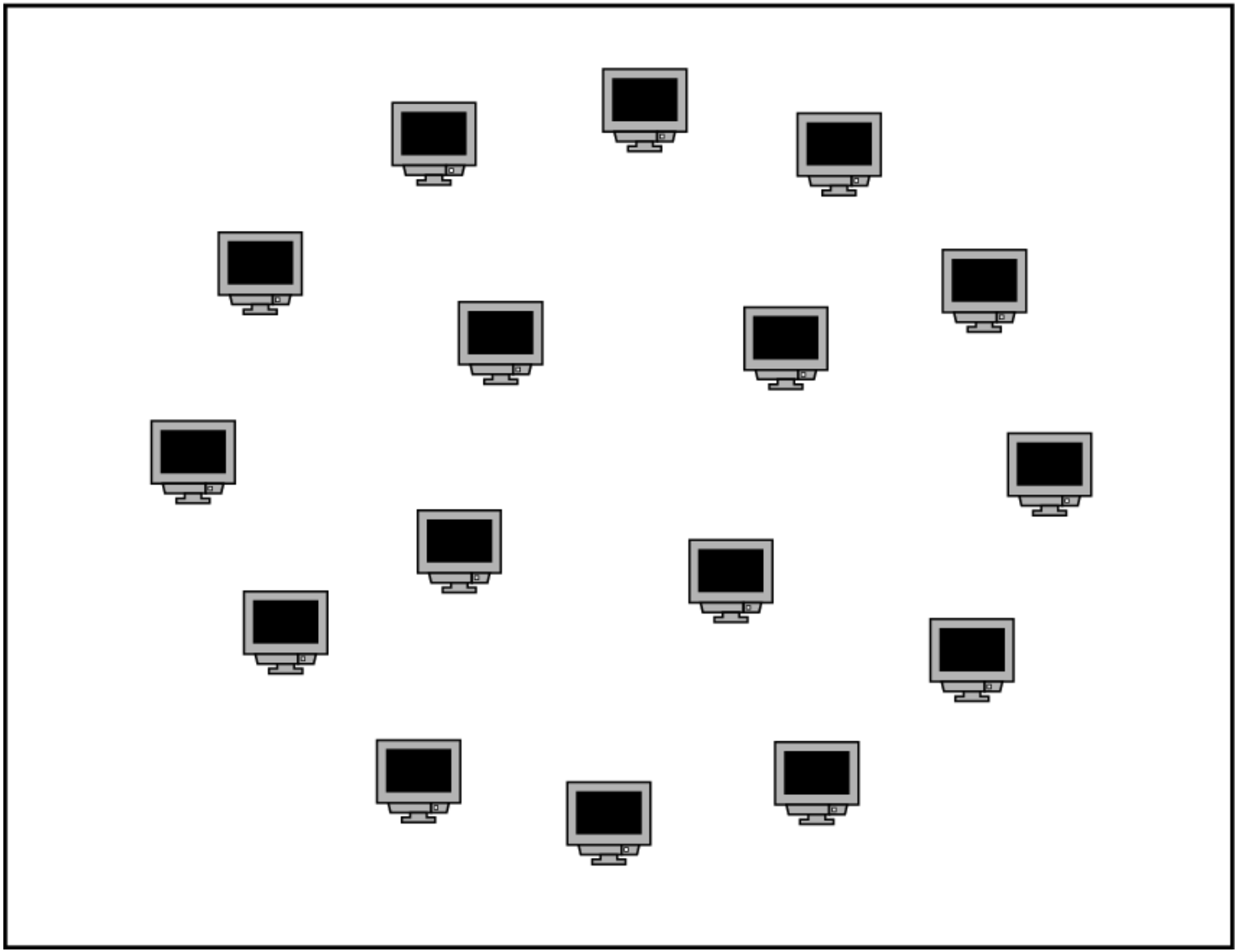

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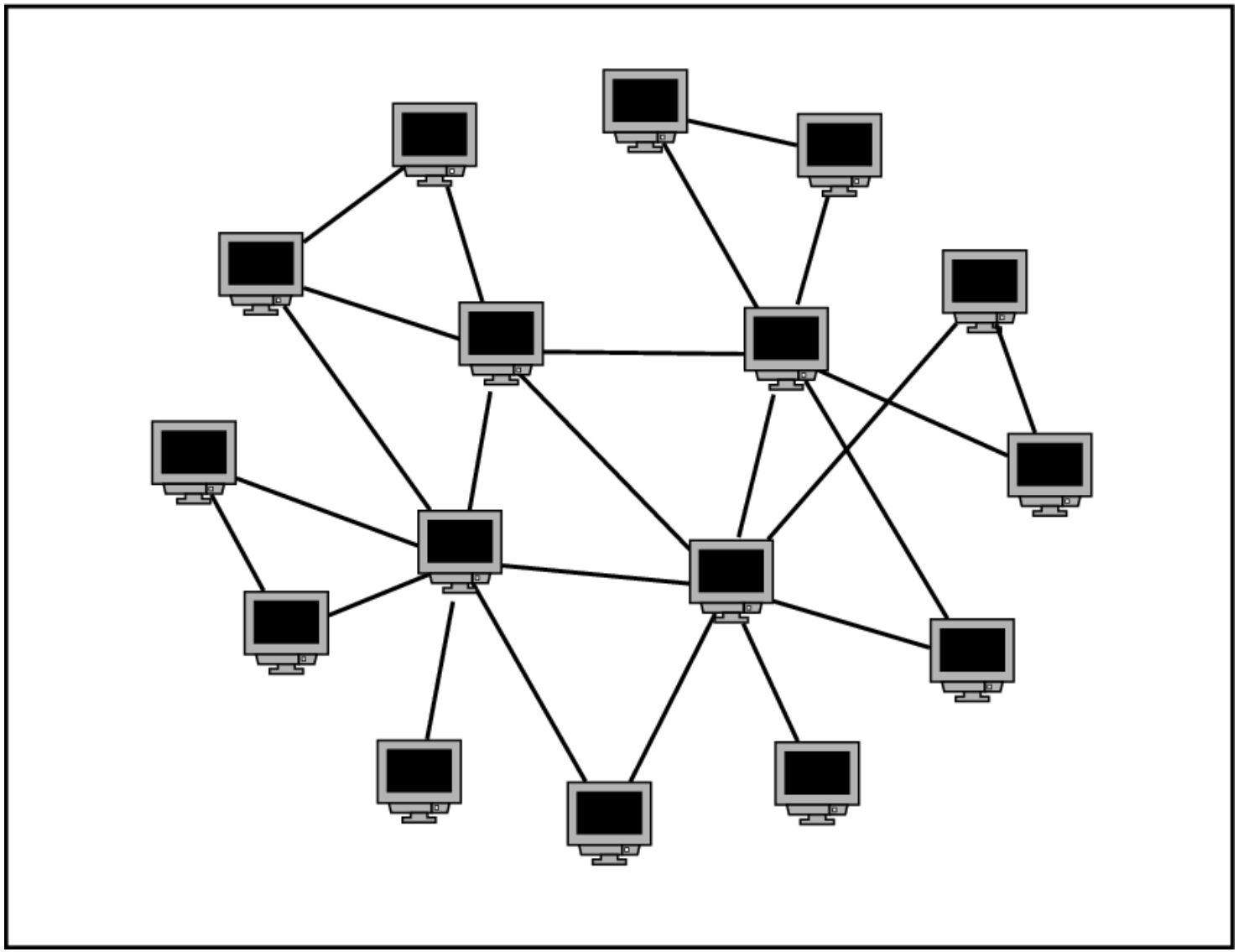

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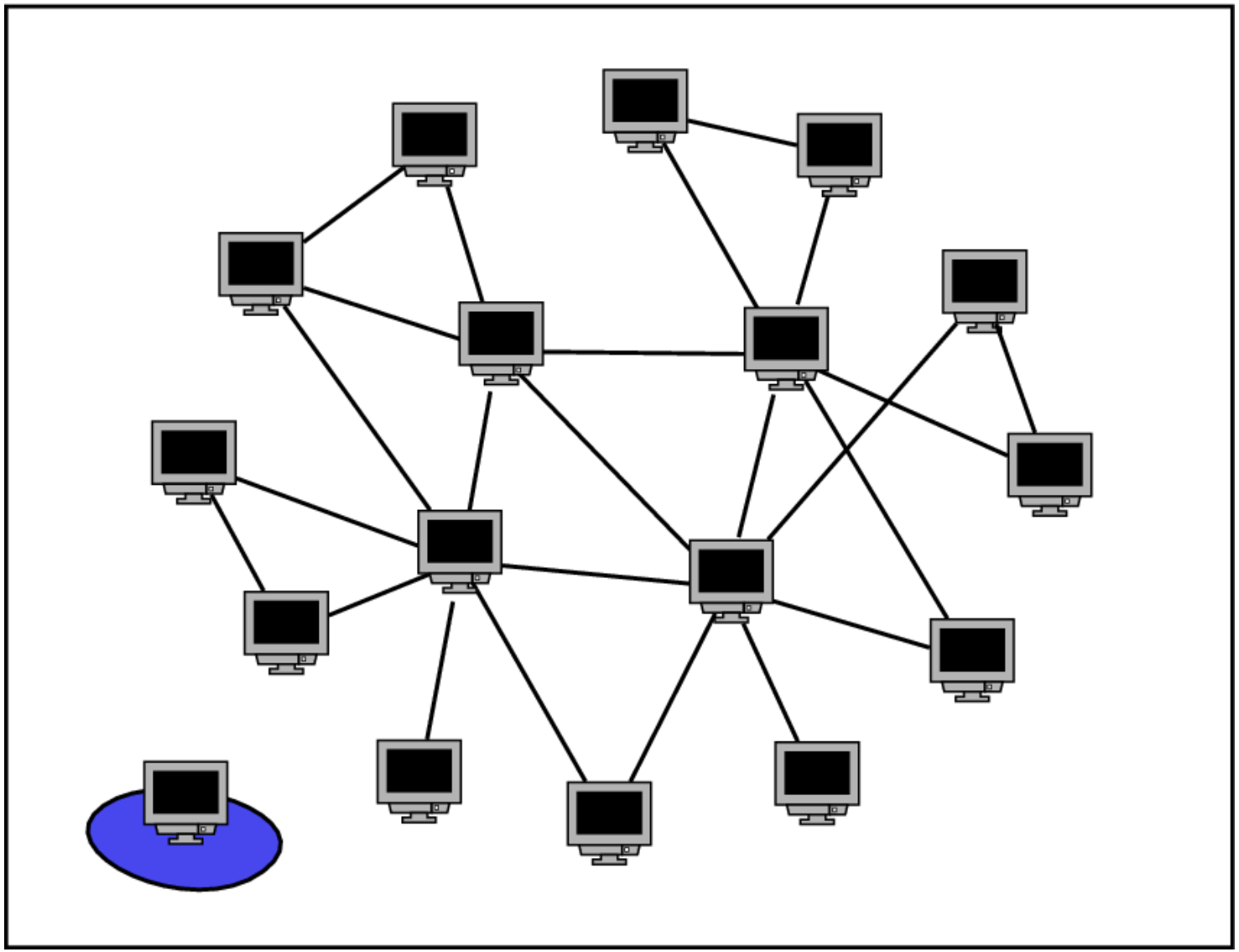

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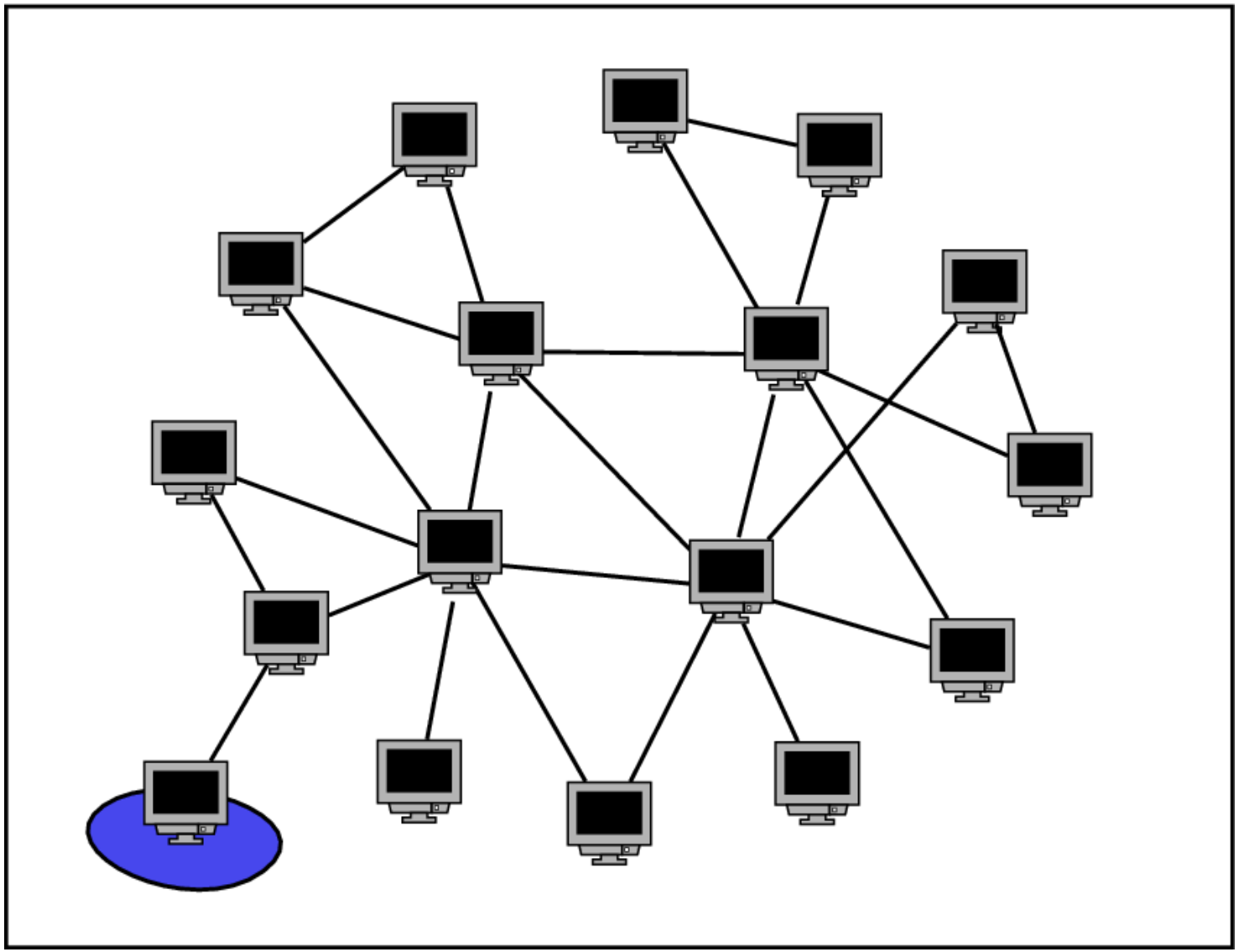

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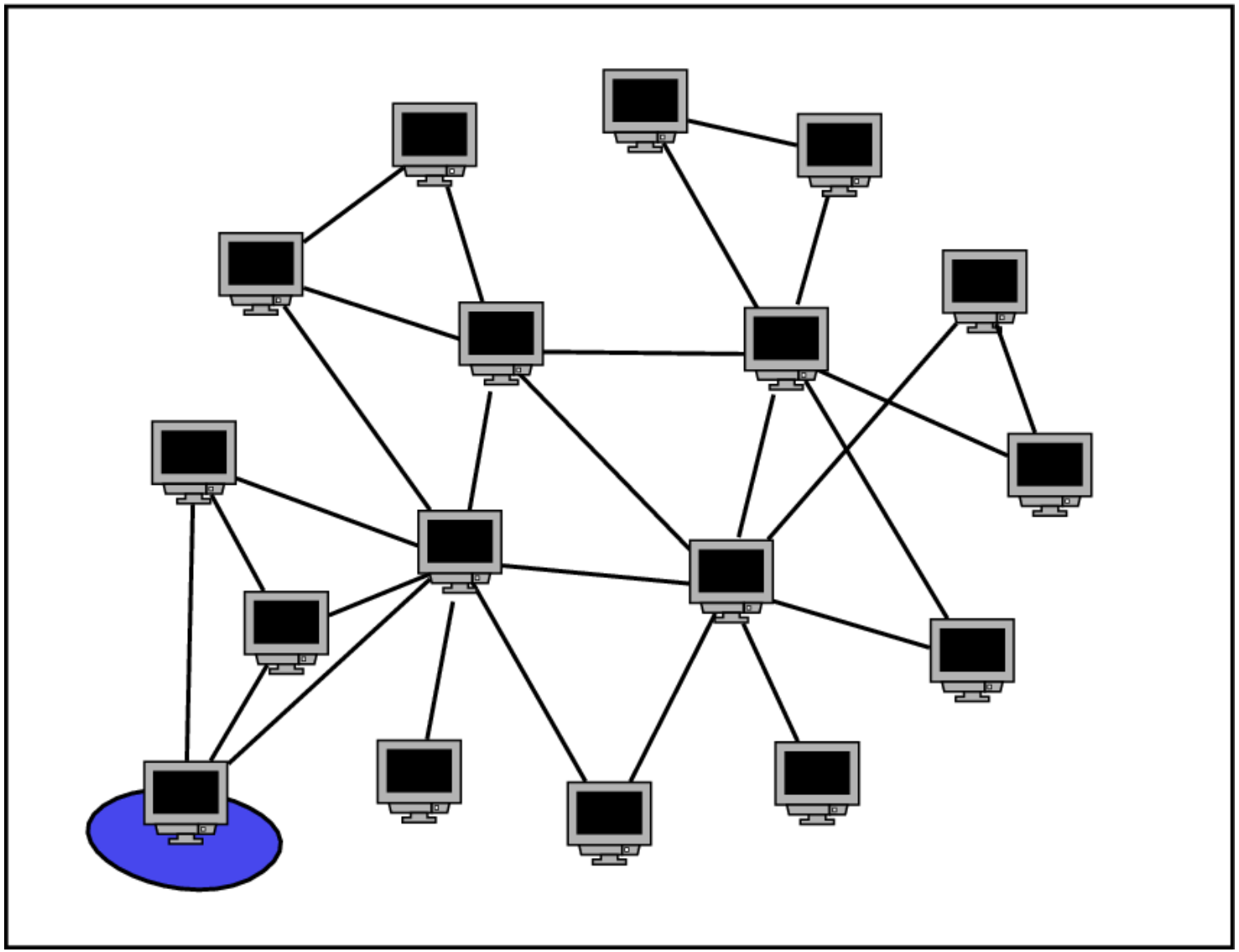

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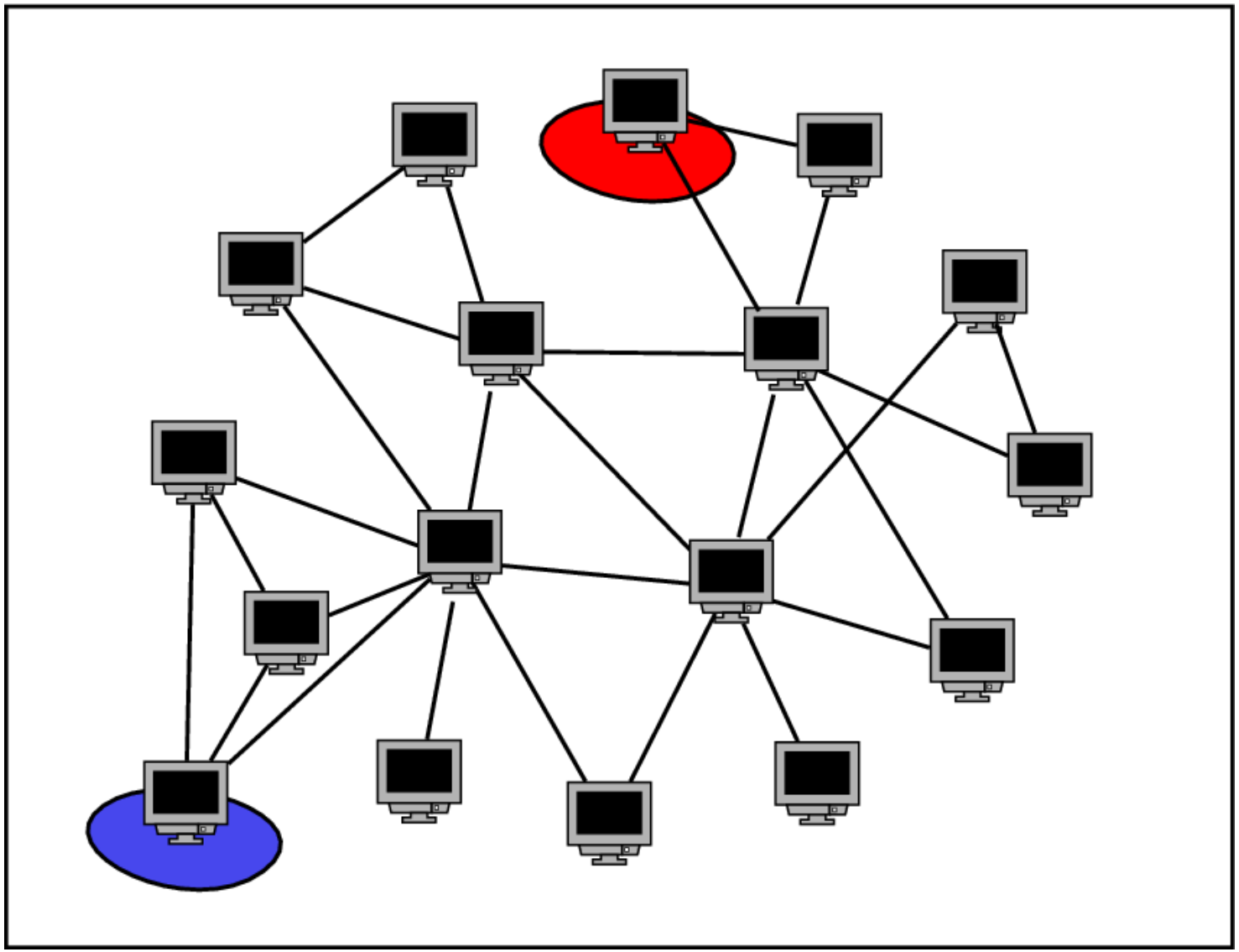

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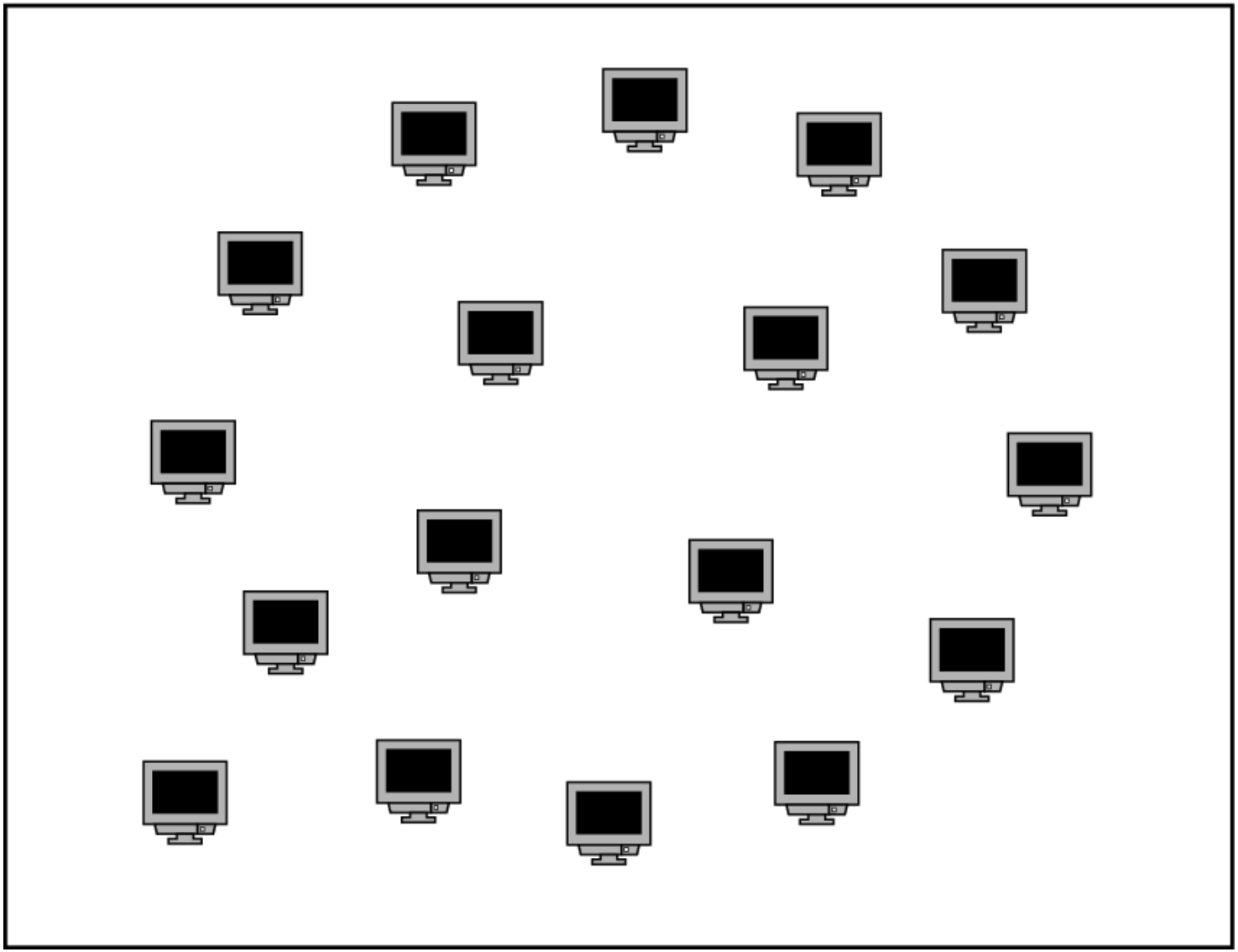

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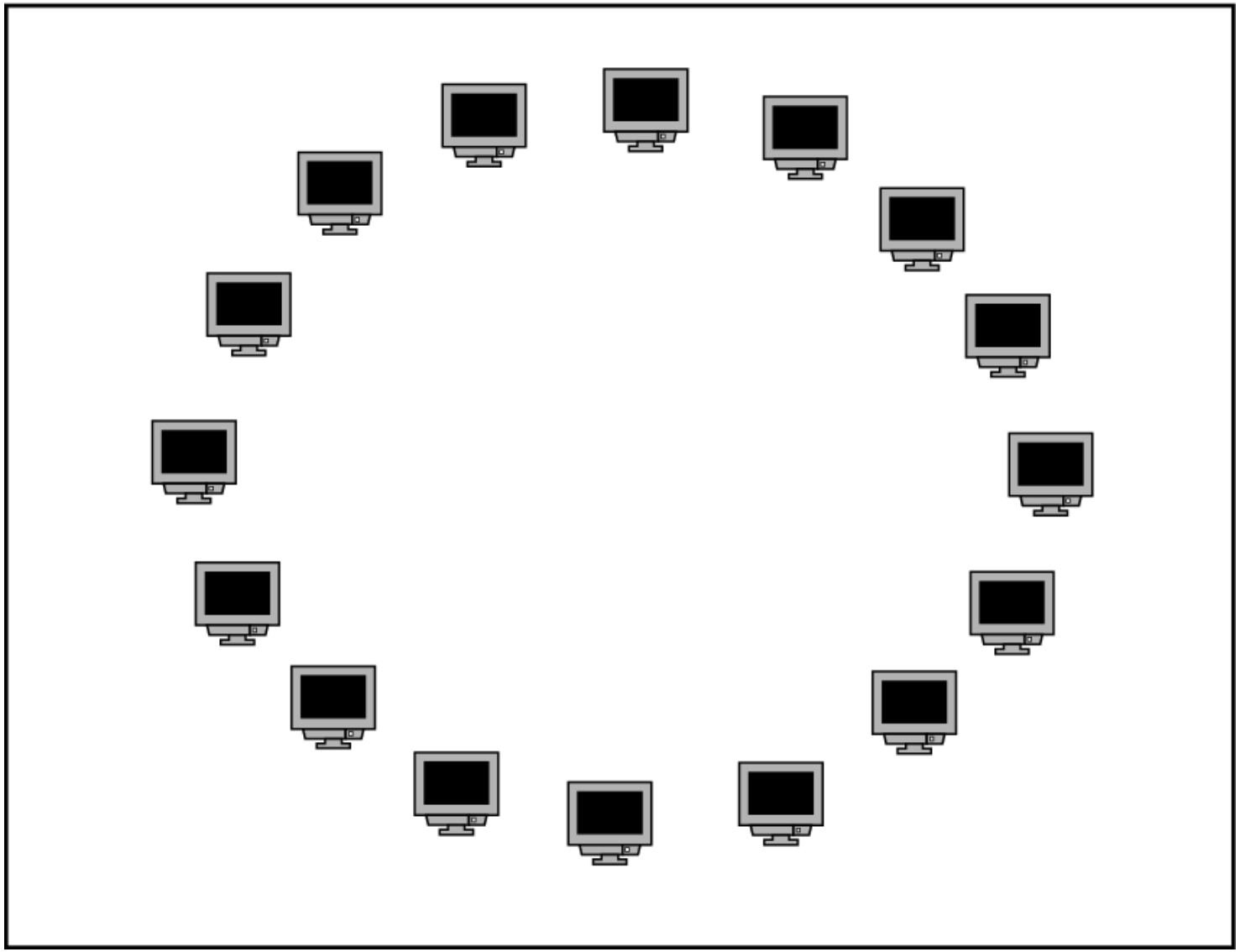

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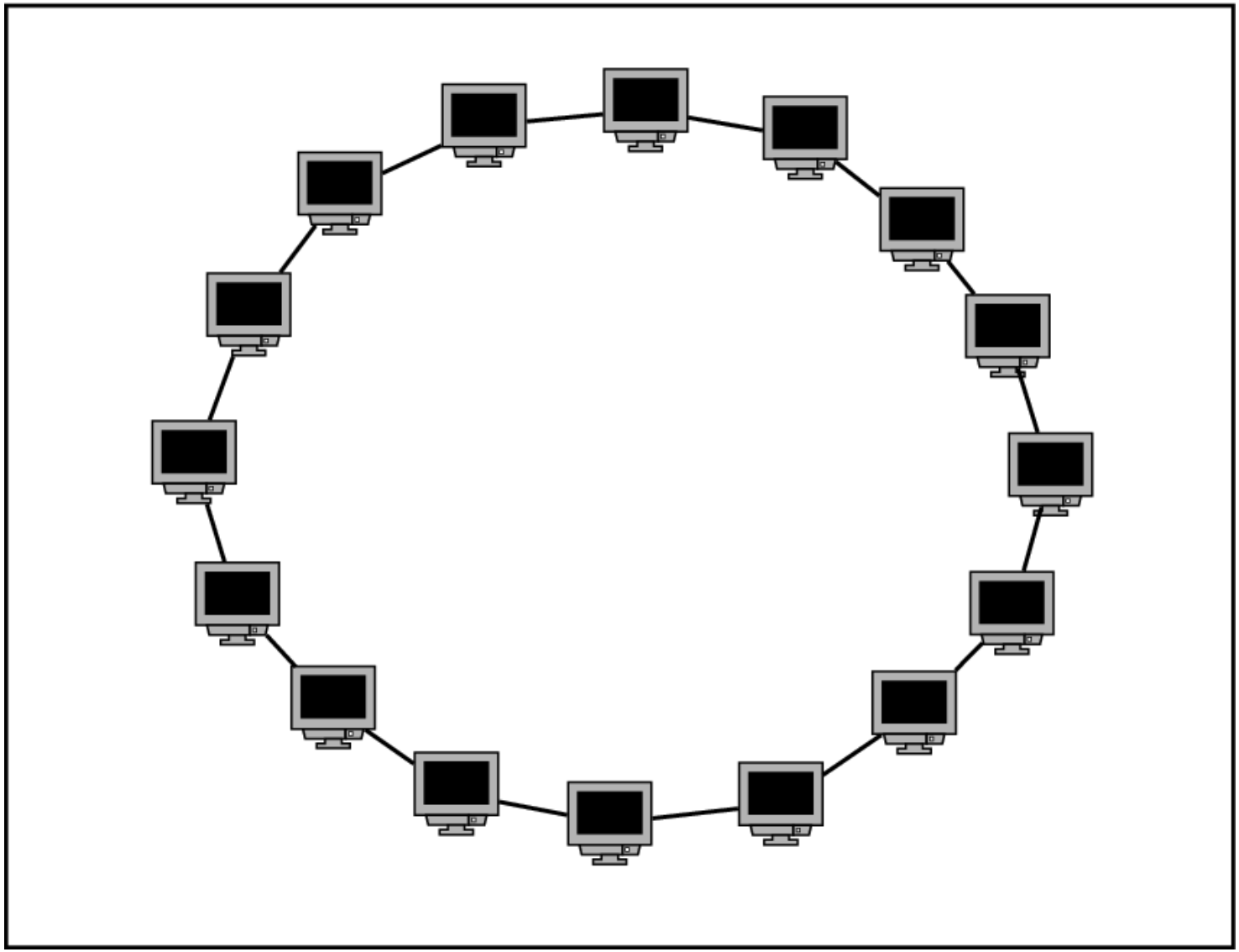
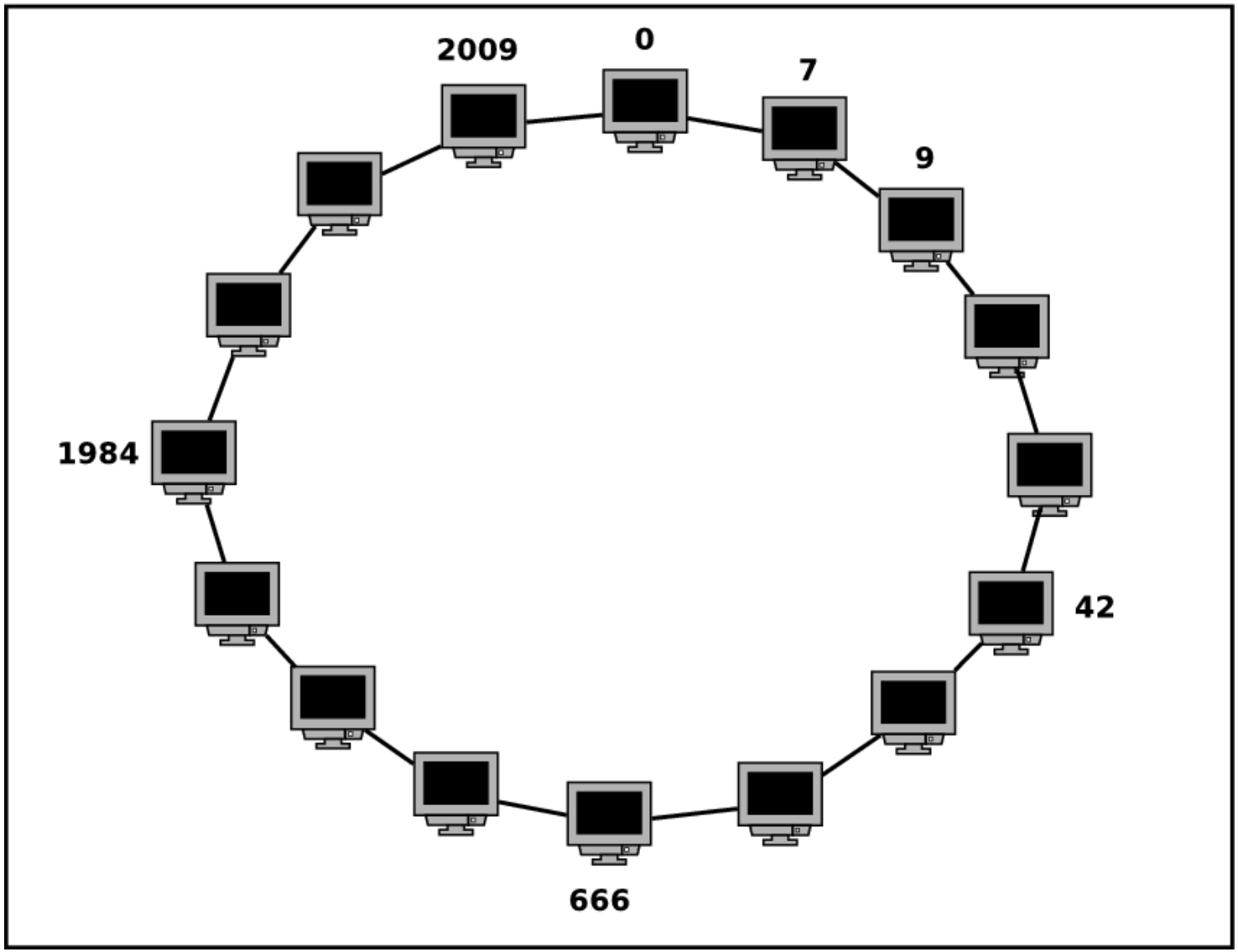


One ring to rule them all



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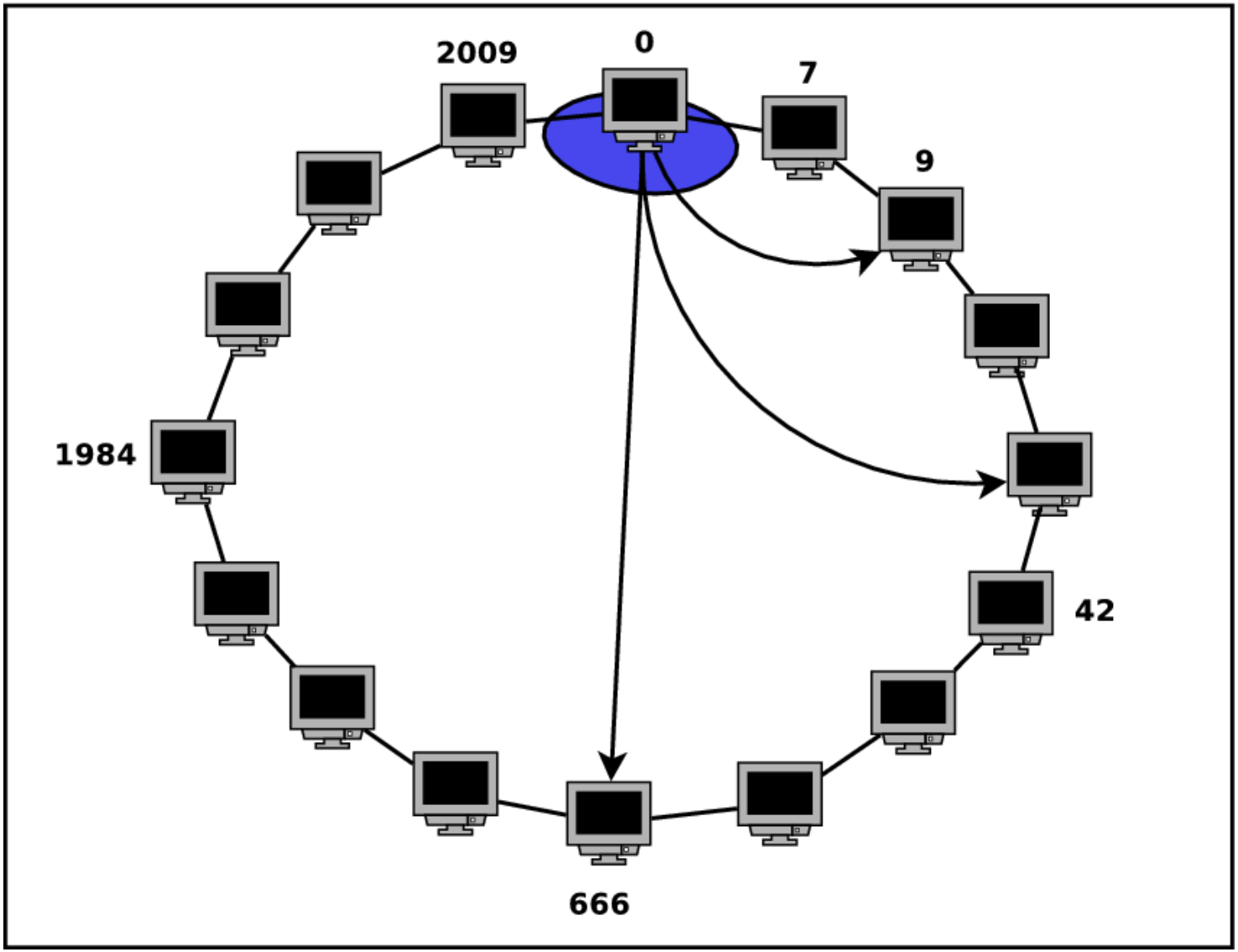

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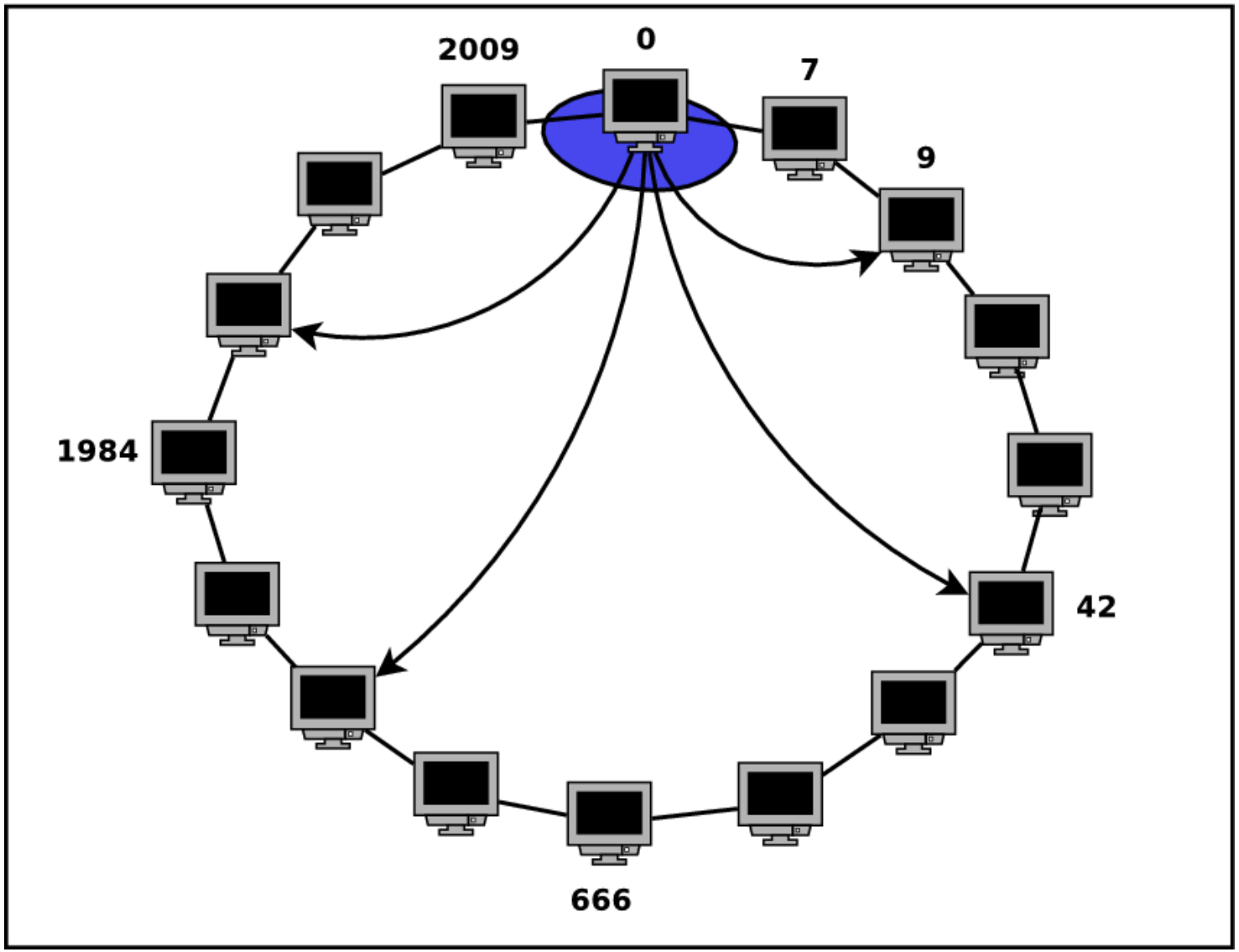

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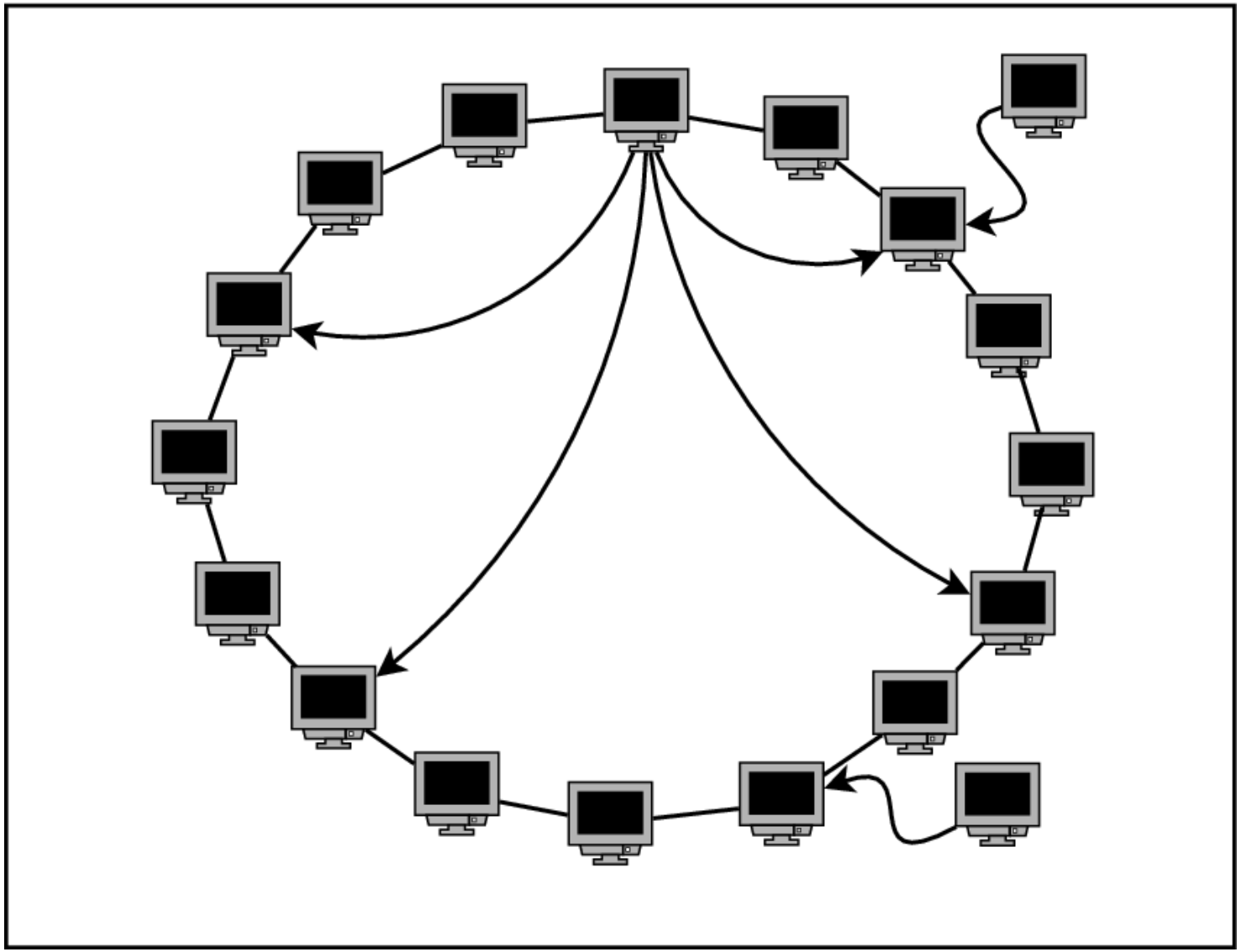

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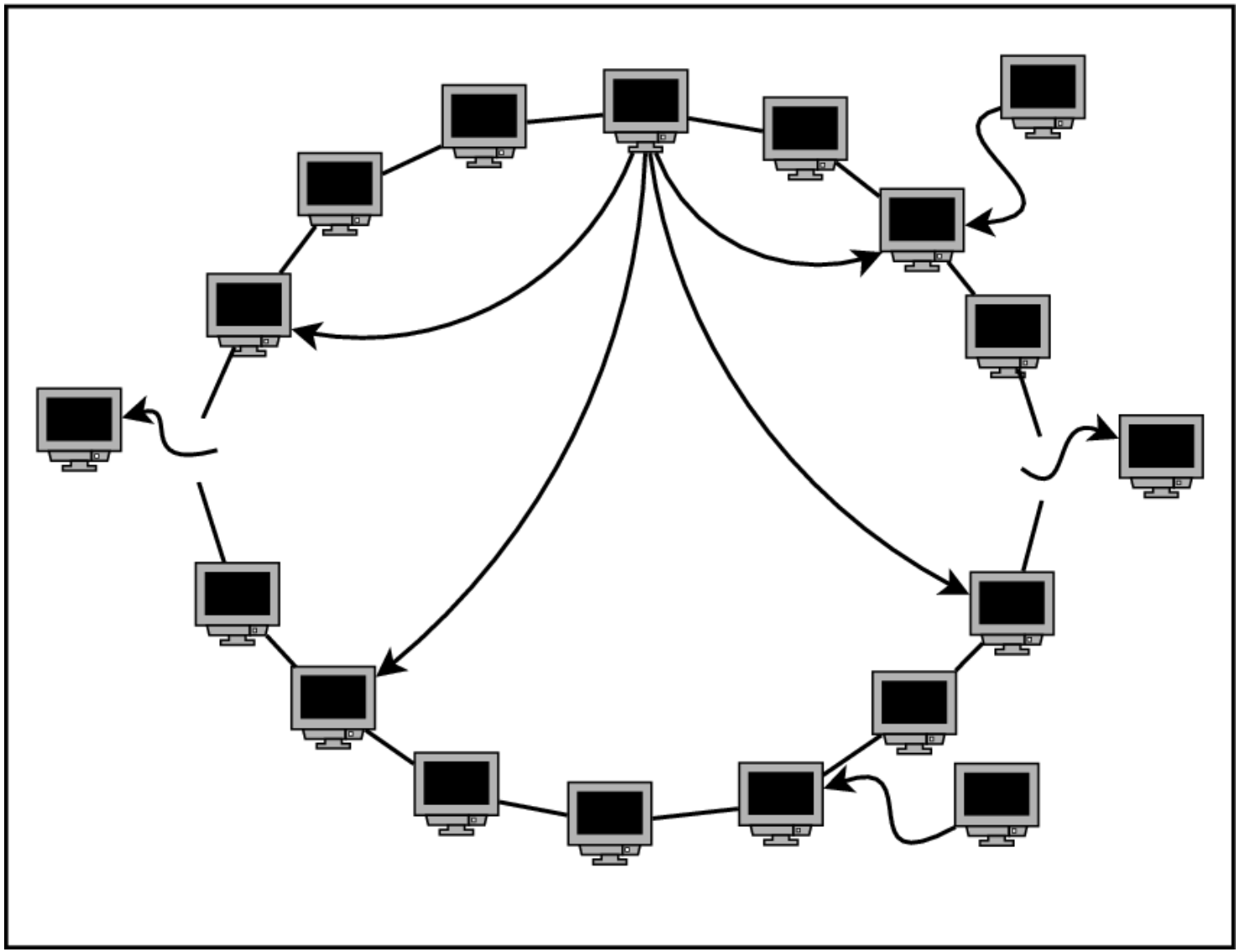

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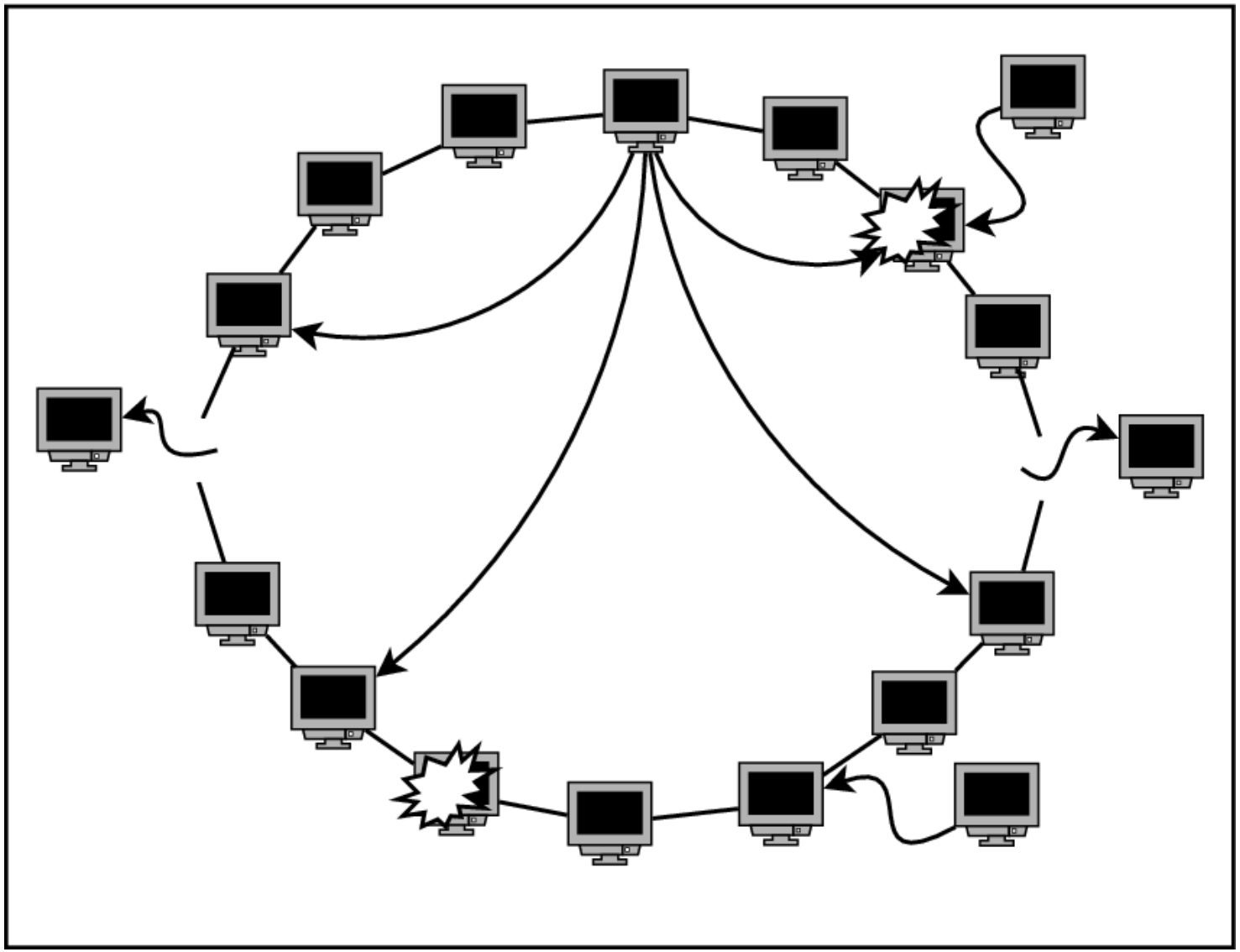

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Decentralized systems to replace Client-Server

- Some problems of client-server architecture
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- We can get rid of this architecture
  - Clients are much powerful now and they can also play the role of a server
  - Increase of Internet bandwidth and better reliability
- Why do we want to change?
  - Decentralized systems suit better strategies such as replication, load-balancing, failure-recovery
  - No single point of failure
  - It's more fun

New challenges

- No central point of control or synchronization.
- Good network organisation approach
- Guarantee reachability of all nodes
- Provide efficient routing
- Guarantee consistency of the distributed storage
- Need for consensus
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To reduce complexity we need to introduce Self-Management

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- The system should be able to reconfigure itself to handle changes in its environment or its requirements without human intervention but according to high-level management policies
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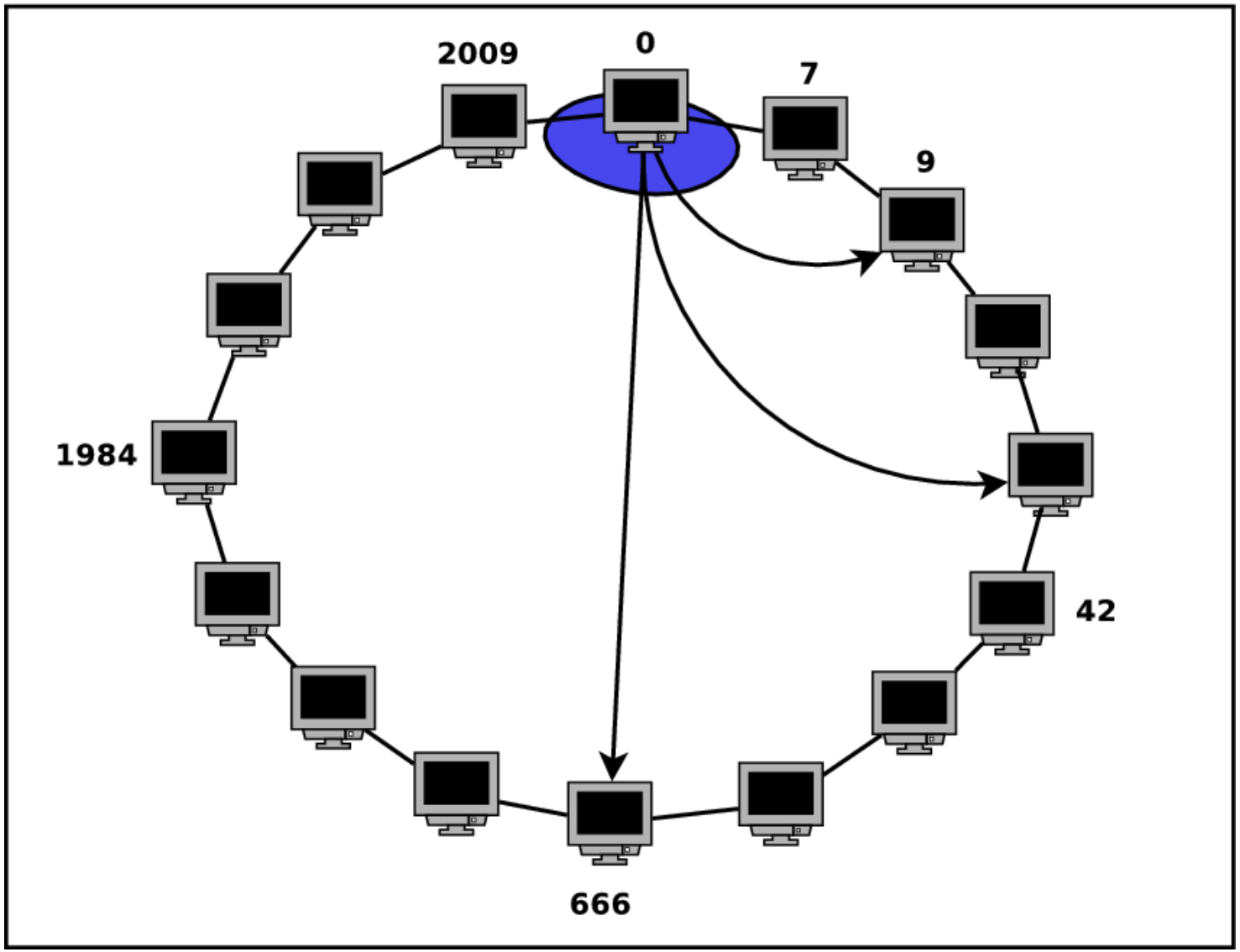
- Human intervention is lifted to the level of the policies
- Typical self-management operations include:
  - add/remove nodes
  - tune performance
  - auto-configure
  - replicate data
  - failure detection and recovery
  - intrusion detection and recovery

The Rest of the Talk

- Structured Overlay Networks
- Decentralized Transactions

The one ring



Distributed Hash Tables (DHT)

- Every peer is identified with a hash key
- Two basic operations: `put(key, value)` and `get(key)`
- Every peer is responsible for all keys contained in the range delimited by its predecessor and itself `(pred, self]`
- Operation `lookup(key)` finds the responsible for a key
- Fingers are chosen in order to provide efficient routing $log_k(N)$
- Lookup consistency implies that there will be only one responsible for any key at any time, or the responsible is temporary unavailable.

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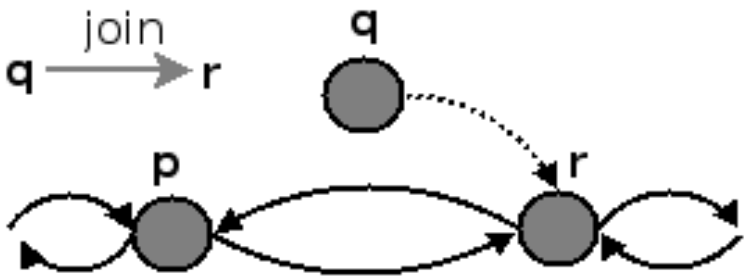
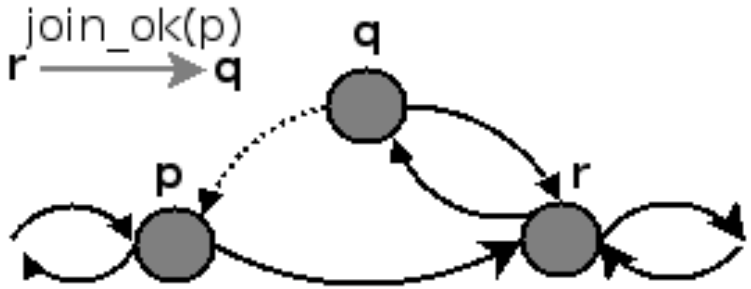
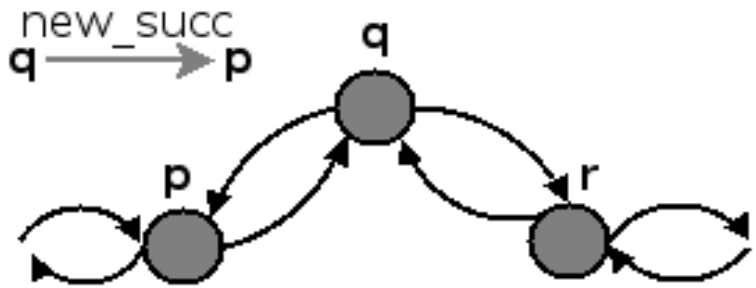
- and the failures?

The Relaxed-Ring

- joining peer *q* requests a lookup for its key
- *q* sends the *join* message to its successor candidate *r*
- *r* accepts new pred and sends reference *p* to *q*
- *q* contacts *p* to inform that it is its new succ







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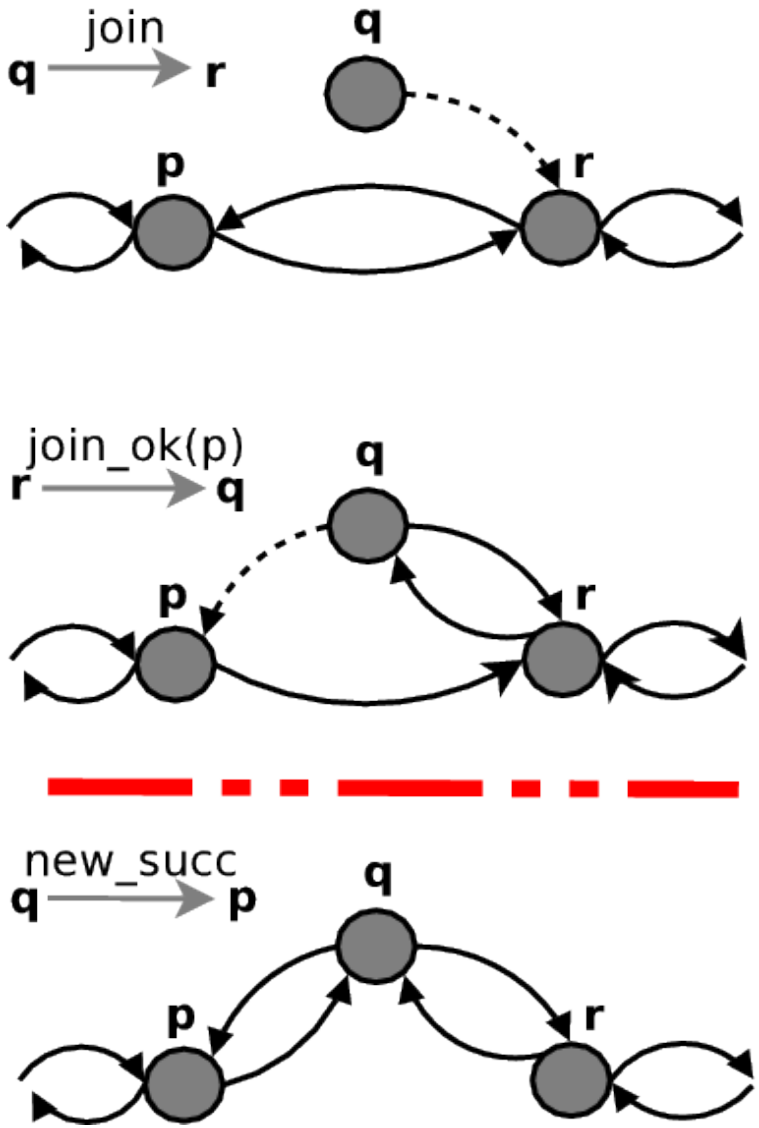

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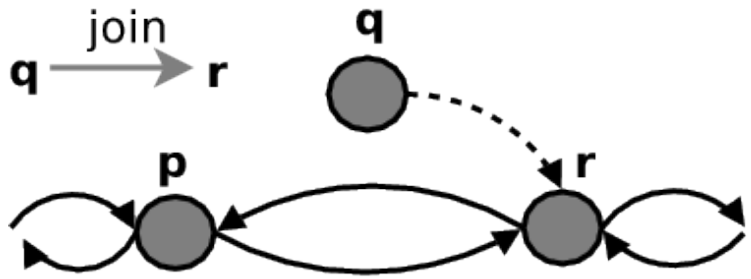
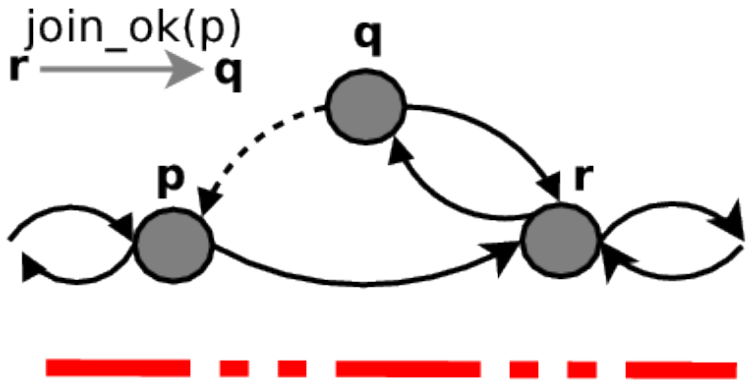
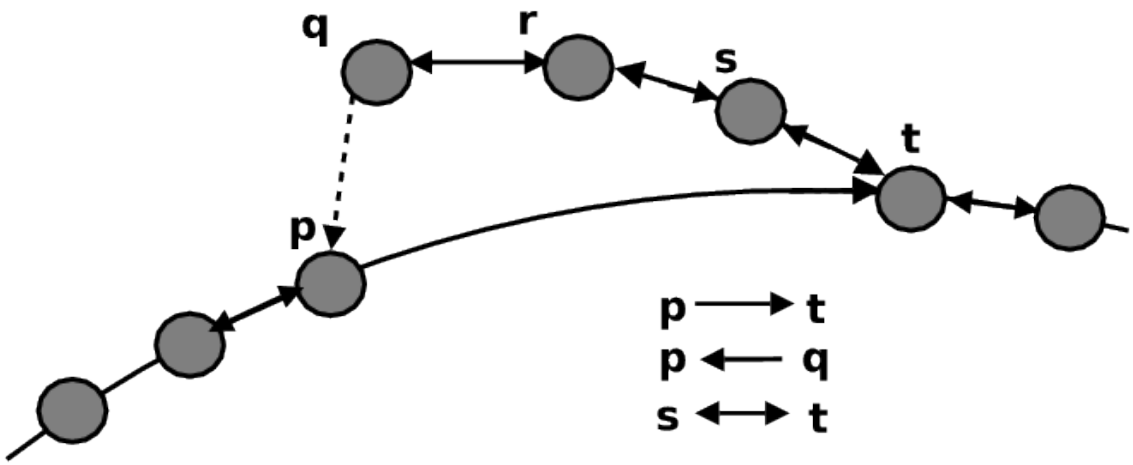
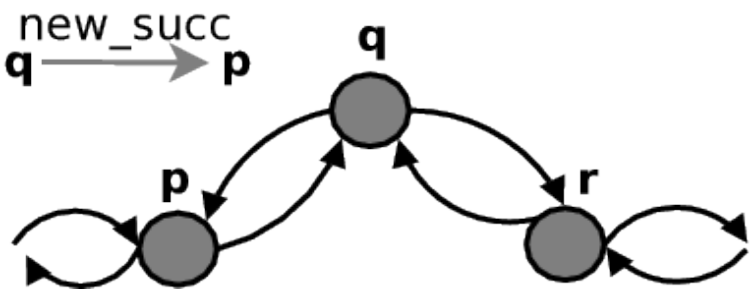
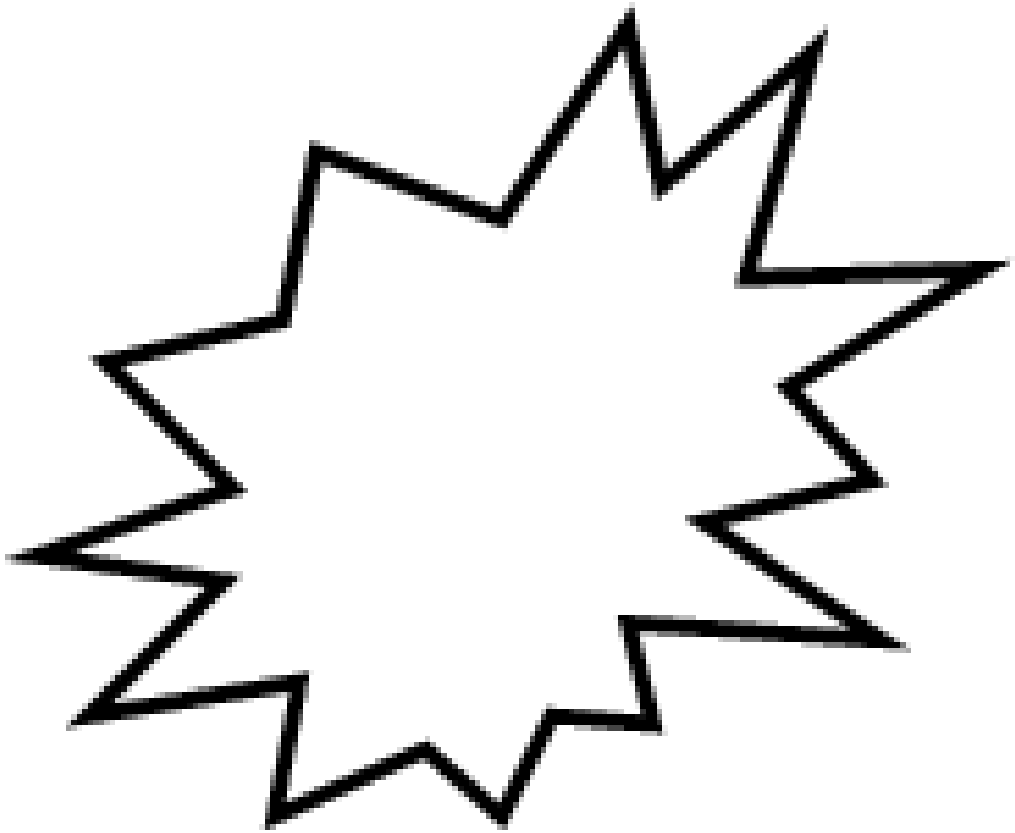








Failures

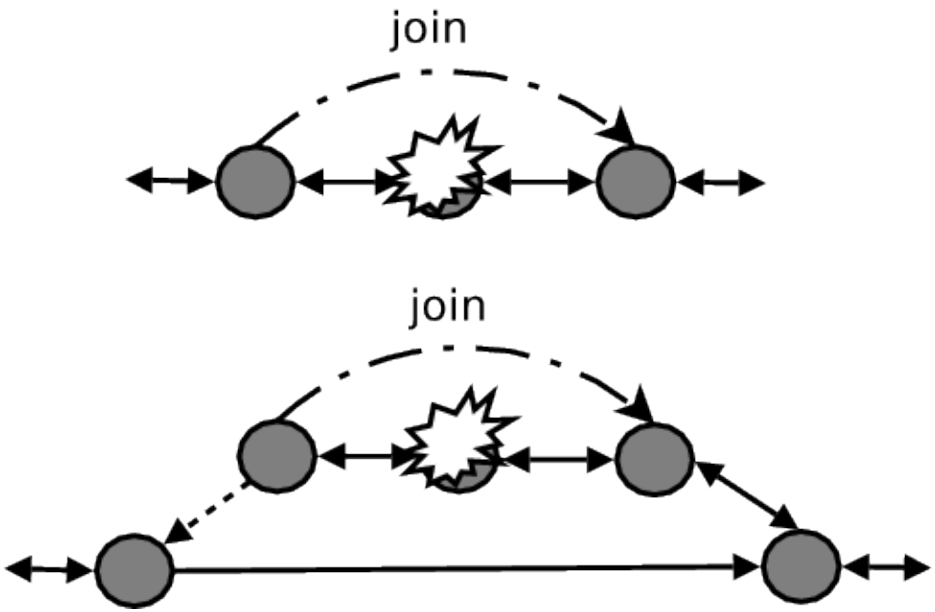


Failure Recovery

- We cannot assume perfect failure detection
- We assume imperfect failure detection with the following properties (Internet-style):
  - Strongly complete: all failed nodes are detected
  - Eventually accurate: false suspicions will be corrected
- Broken links cannot be ignored
- We do not assume symmetric links
- Limitations:
  - It survives network partitioning but lookup consistency is broken (Brewer's conjecture with respect to consistent available partition-tolerant services)
  - Resilience is given by the size of successors list

Failure Recovery

- When a peer detects that its successor has crashed, it contacts the first peer in its successor list for recovery



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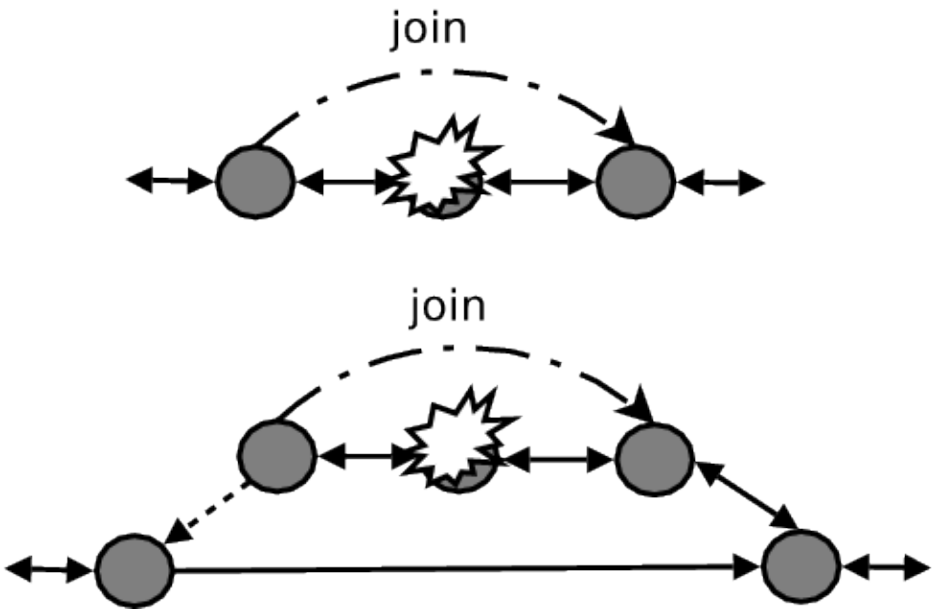
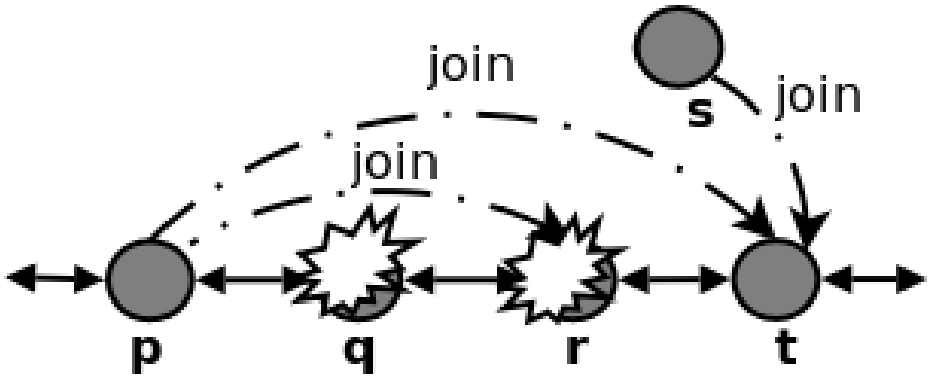
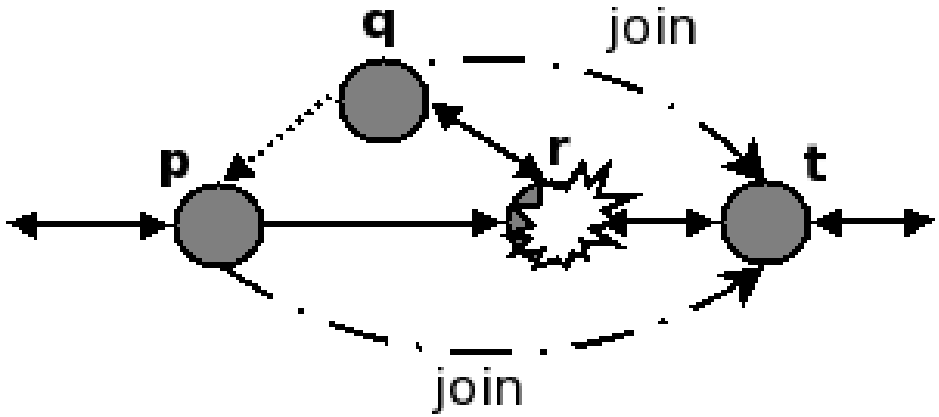


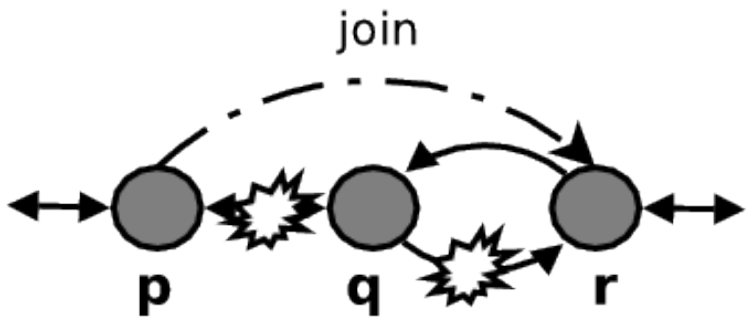


Limitations - Crash of the root of a branch



- If *r* the root of a branch crashes, it may introduce temporary inconsistent lookup if *p* contacts *t* for recovery before *q*. The inconsistency will involve the range $(p, q]$, and it will be corrected as soon as *q* contacts *t* for recovery
- Peer *q* does not have a valid successor during the inconsistency

Limitations - False suspicions with asymmetric links



- Broken link between peers p and $q \Rightarrow$ *false suspicion*
- Peer r cannot hear $q \Rightarrow$ *false suspicion* with *asymmetric link*
- Peer q considers r as valid successor $\Rightarrow$ inconsistency in the range $(p, q]$

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- No transitivity: if $a \rightarrow b$ and $b \rightarrow c$ does not imply $a \rightarrow c$
- join/fail algorithms requires the agreement of only two nodes (2 steps with 2 nodes, instead of 1 step with three)
- Almost no lookup-inconsistency
- Cost-efficient ring maintenance (no periodic stabilization)
- Efficient routing $O(\log(N) + b)$

Intermezzo

This talk is brought to you by

Decentralized Transactions

- Provide a decentralized transactional distributed database with strong data consistency
- DHT is the underlying infrastructure
- Use replication of data to achieve higher availability and fault tolerance
- Required properties:
  - Concurrency control
  - Atomic commit protocol

Consistency of Replicated Data

- Main ideas
  - All operations on data include a majority of replicas
  - Use version numbers to determine the current version
- Each operation maintains the invariant that a majority of replicas contains the latest version of an item
  - Write has to update at least a majority
  - Read includes a majority
  - Maintenance of replication degree (handling of node failure): Restore replication degree by reading from a majority
  - Node join/leave will not violate the invariant

Distributed Transactions

- A transaction consists of a set of operations on data
- Main issues of transactions:
  - Isolate concurrent transactions from each other (Serializability)
  - Either all operations take place or none of them (Atomicity)
- Data involved in the transaction is distributed over several nodes

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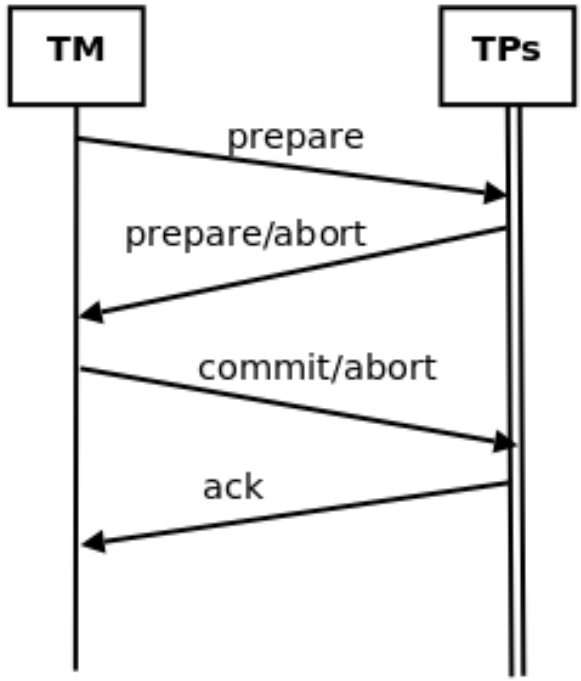
- Data involved in the transaction is distributed over several nodes
- One node acts as the transaction manager (TM)
- Nodes that are responsible for data involved in the transaction act as transaction participants (TP)
- A transaction is processed on three steps:
  - **Read**: Collection of operations which are part of the transaction
  - **Validation**: Each TP checks whether it can execute the operation
  - **Write**: If the validation is successful for all TPs, each TP has to make changes permanent

Atomic Commit in Distributed Systems

- The outcome of the protocol is:
  - **Commit**, if all TPs can successfully validate the operations
  - **Abort**, if there exists at least one TP that cannot validate an operation
- Most common commit protocol: 2-Phase-Commit



Atomic Commit in Distributed Systems

- The outcome of the protocol is:
  - **Commit**, if all TPs can successfully validate the operations
  - **Abort**, if there exists at least one TP that cannot validate an operation
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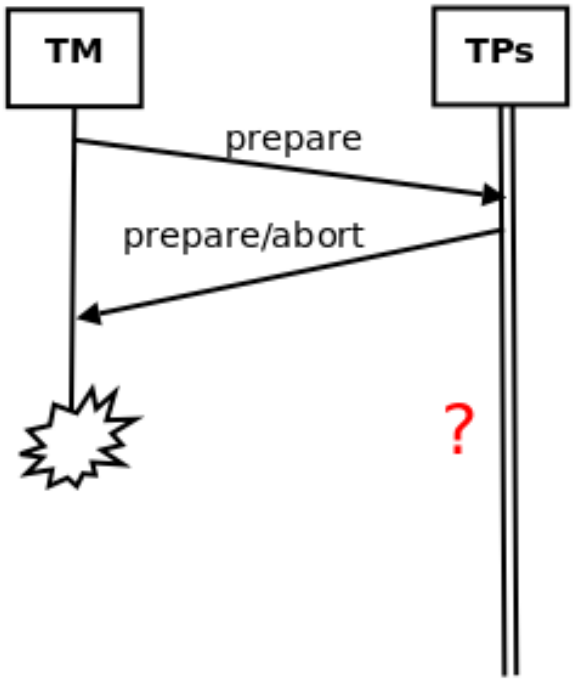
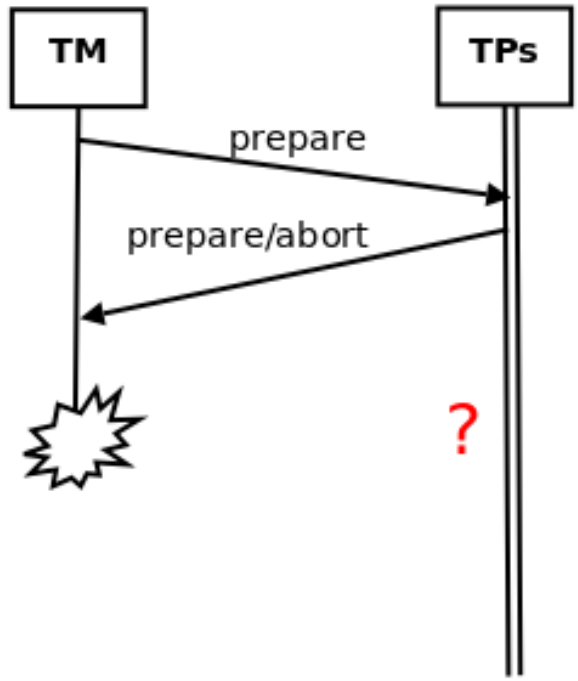
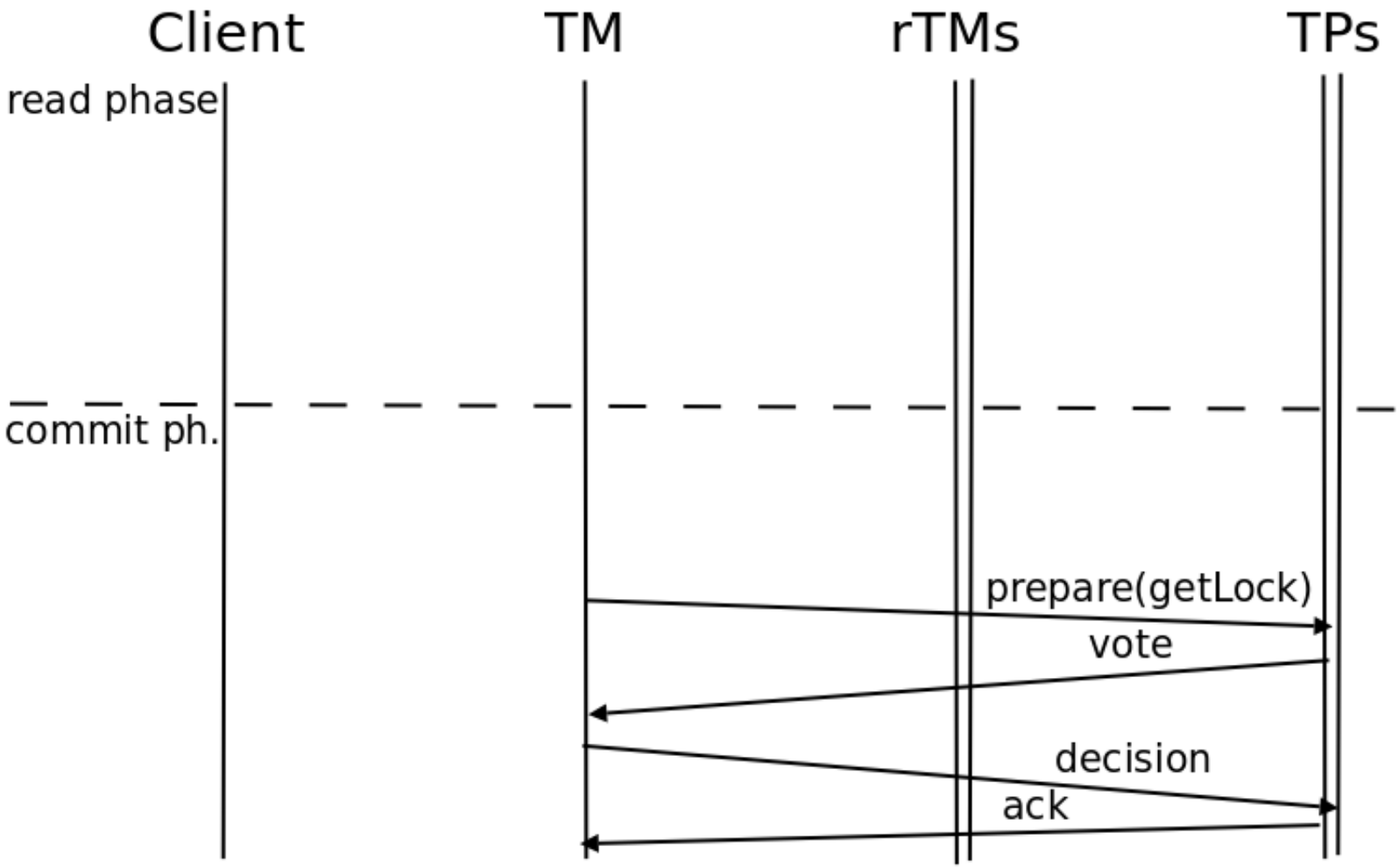


Atomic Commit in Distributed Systems

- The outcome of the protocol is:
  - **Commit**, if all TPs can successfully validate the operations
  - **Abort**, if there exists at least one TP that cannot validate an operation
- Most common commit protocol: 2-Phase-Commit
- It blocks the participants!
- Designed for LAN
- It uses reliable nodes
- 3-Phase-Commit?



Atomic Paxos Commit



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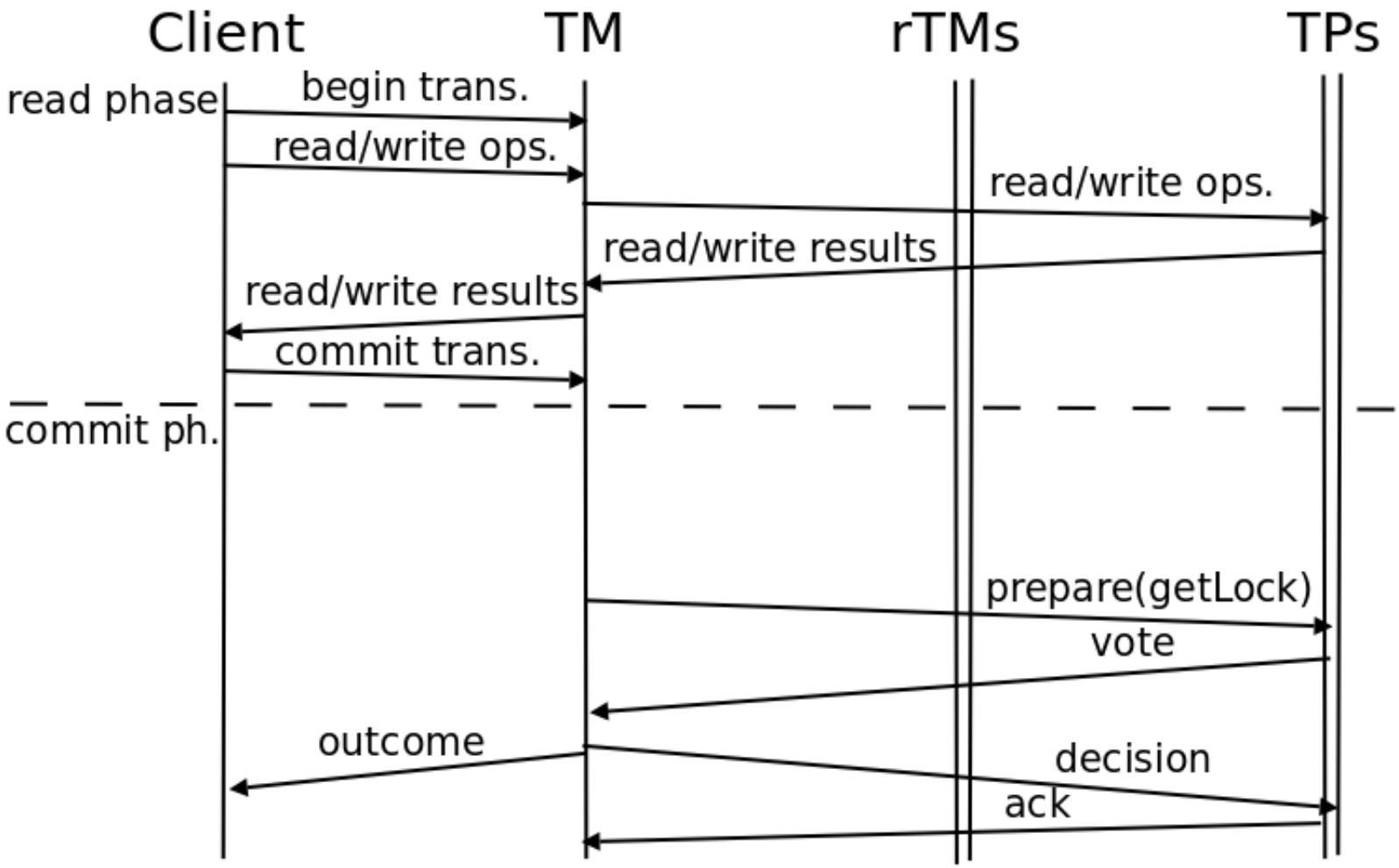
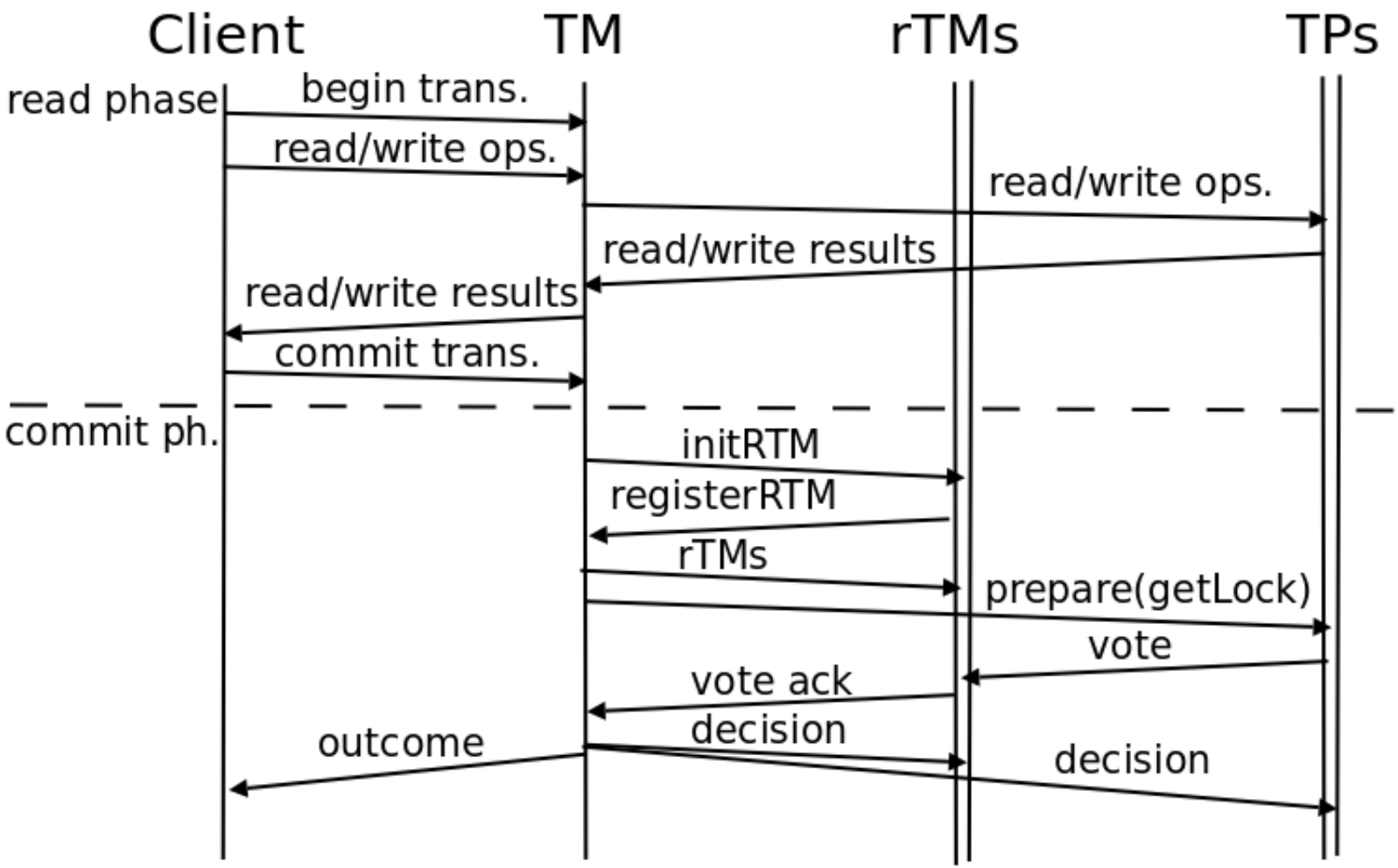


Atomic Paxos Commit

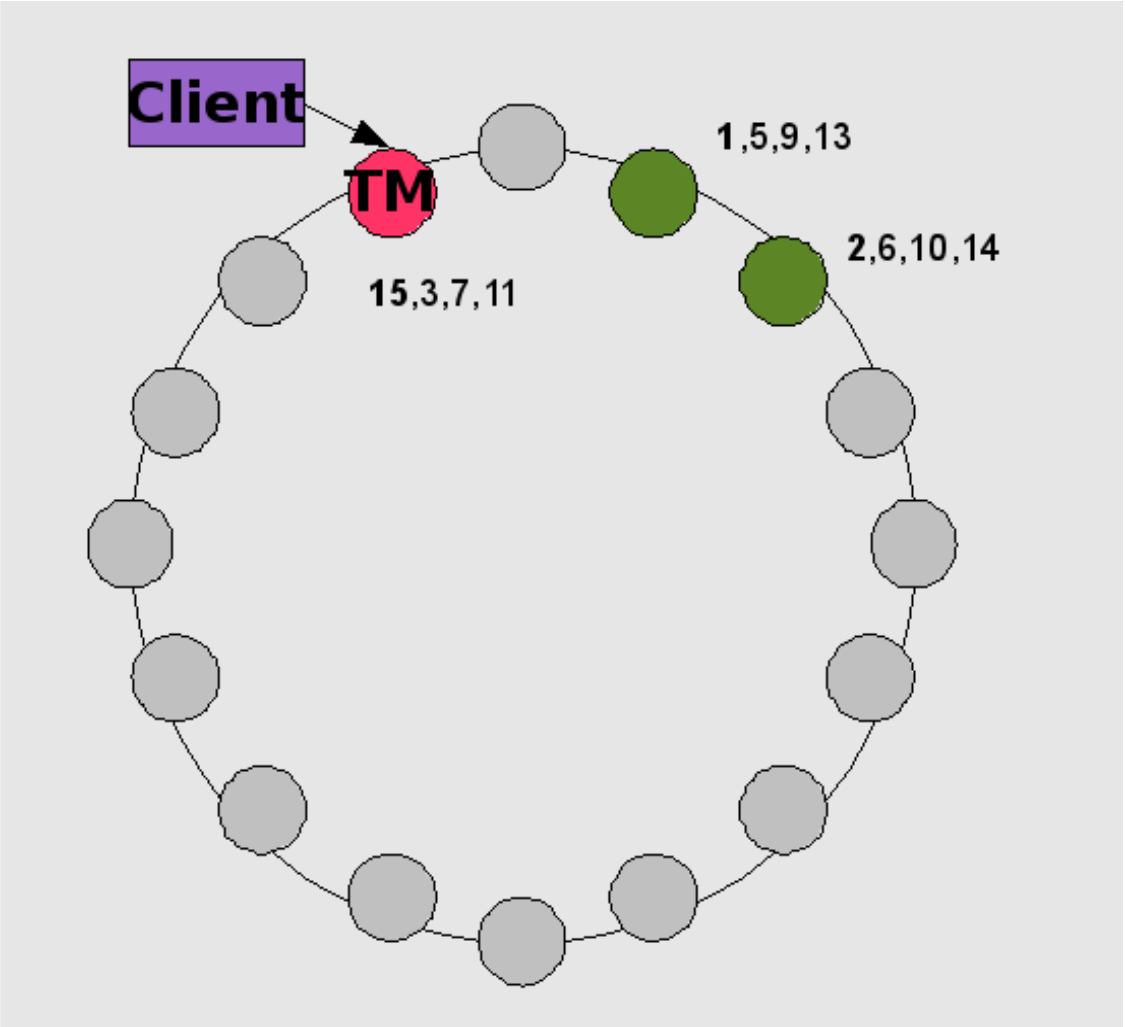


Atomic Paxos Commit

- Participants and Roles:
  - Transaction Manager (*TM*) + replicated *TMs* (*rTMs*) which act as acceptors
  - Transaction Participants (*TPs*) act as proposers
- Exploit the symmetric replication existing in the DKS DHT to determine the set of *rTMs*
- Collect the votes of the *TPs* per item
  - We need the majority of participants per item
  - We need all items to vote for commit

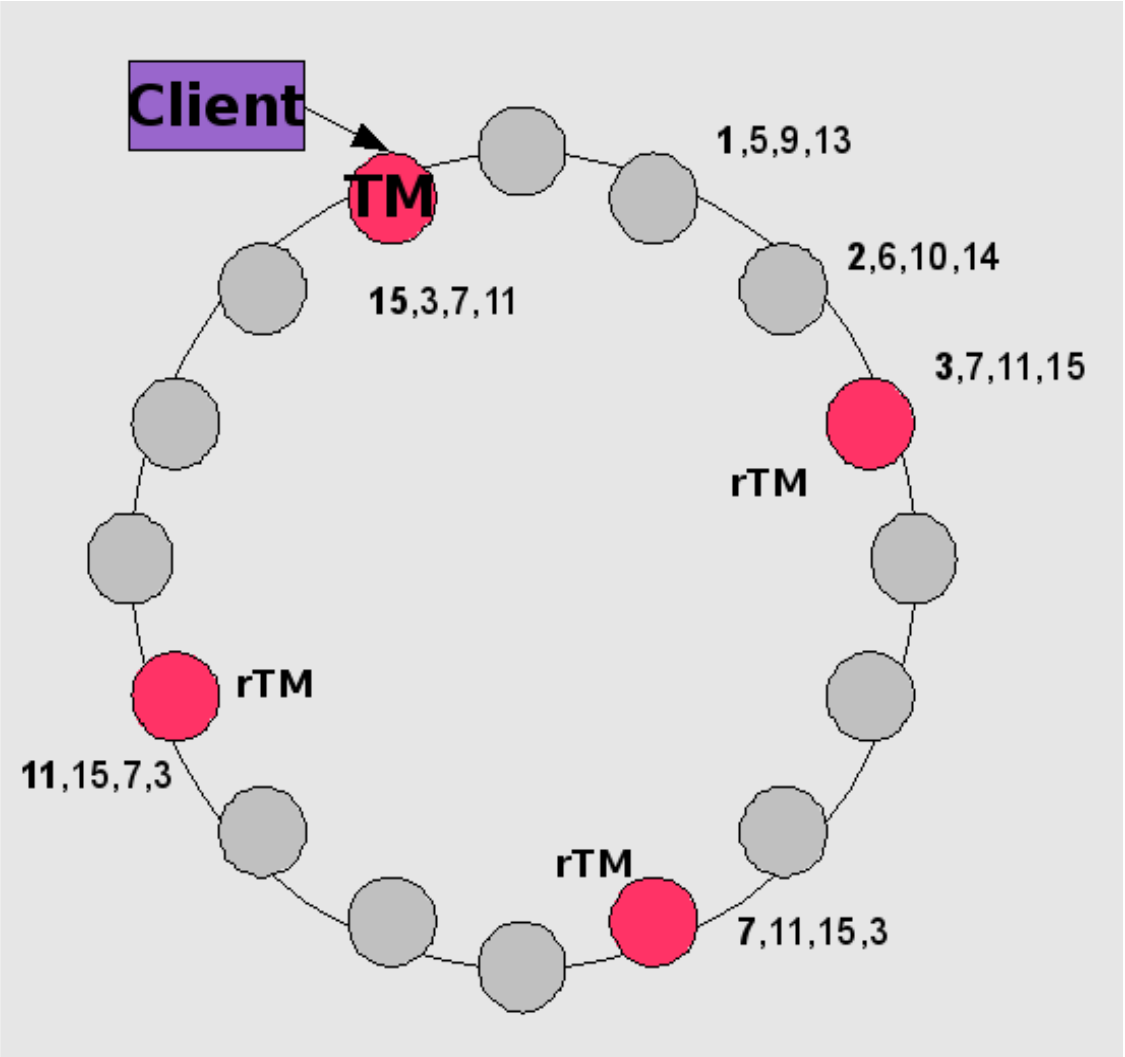
Atomic Commit in a DHT

- Client:
  ```
  BOT
  write item(1)
  write item(2)
  EOT
  ```
- Node 15 becomes the Transaction Manager (*TM*)
- *TM* creates a transaction item with a key for which it is responsible for (*key* = 15)



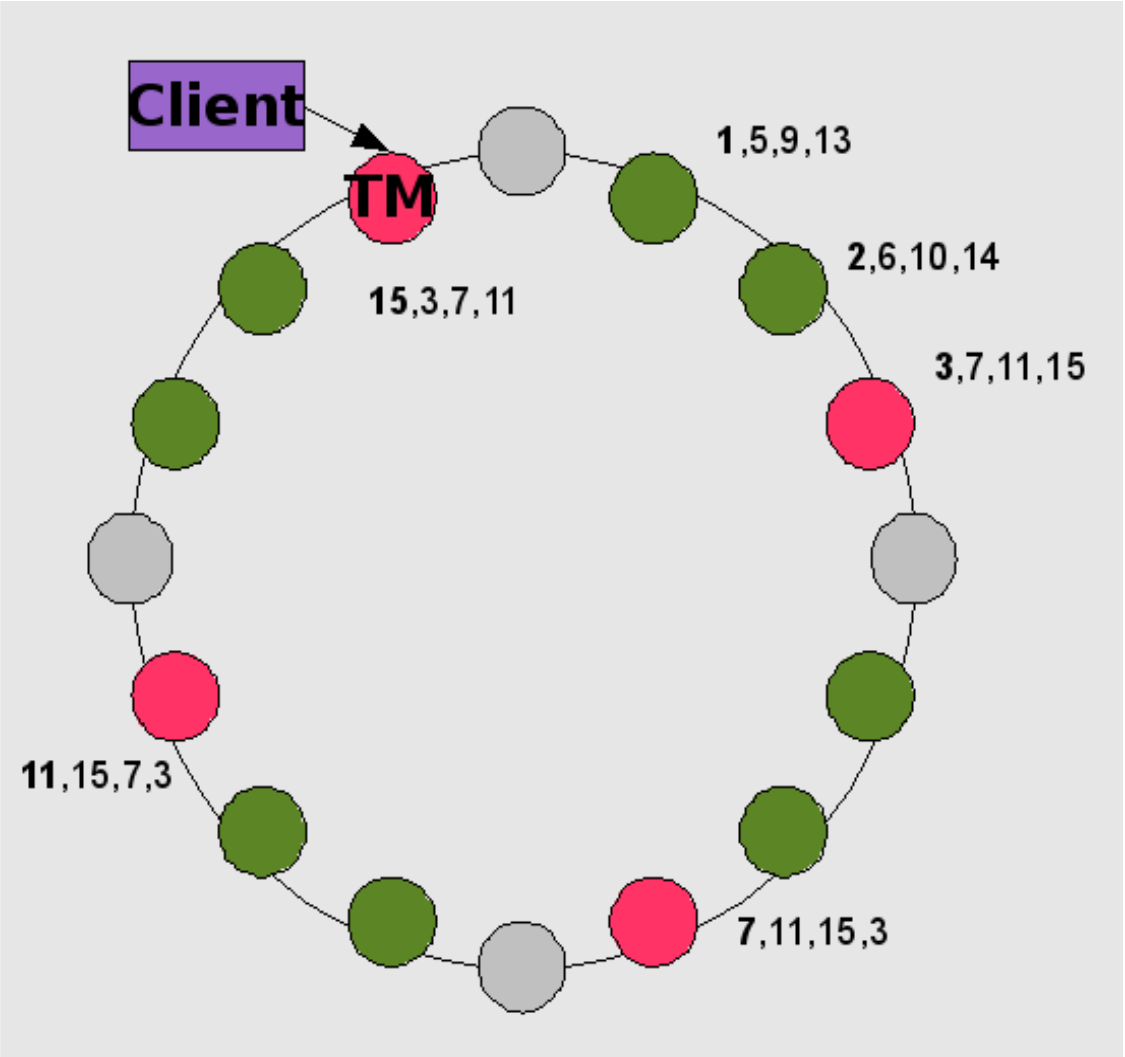
Atomic Commit in a DHT

- Node 15 becomes the Transaction Manager (*TM*)
- Nodes 3, 7, 11 become replicated Transaction Managers (*rTM*), according to the replication of the transaction item



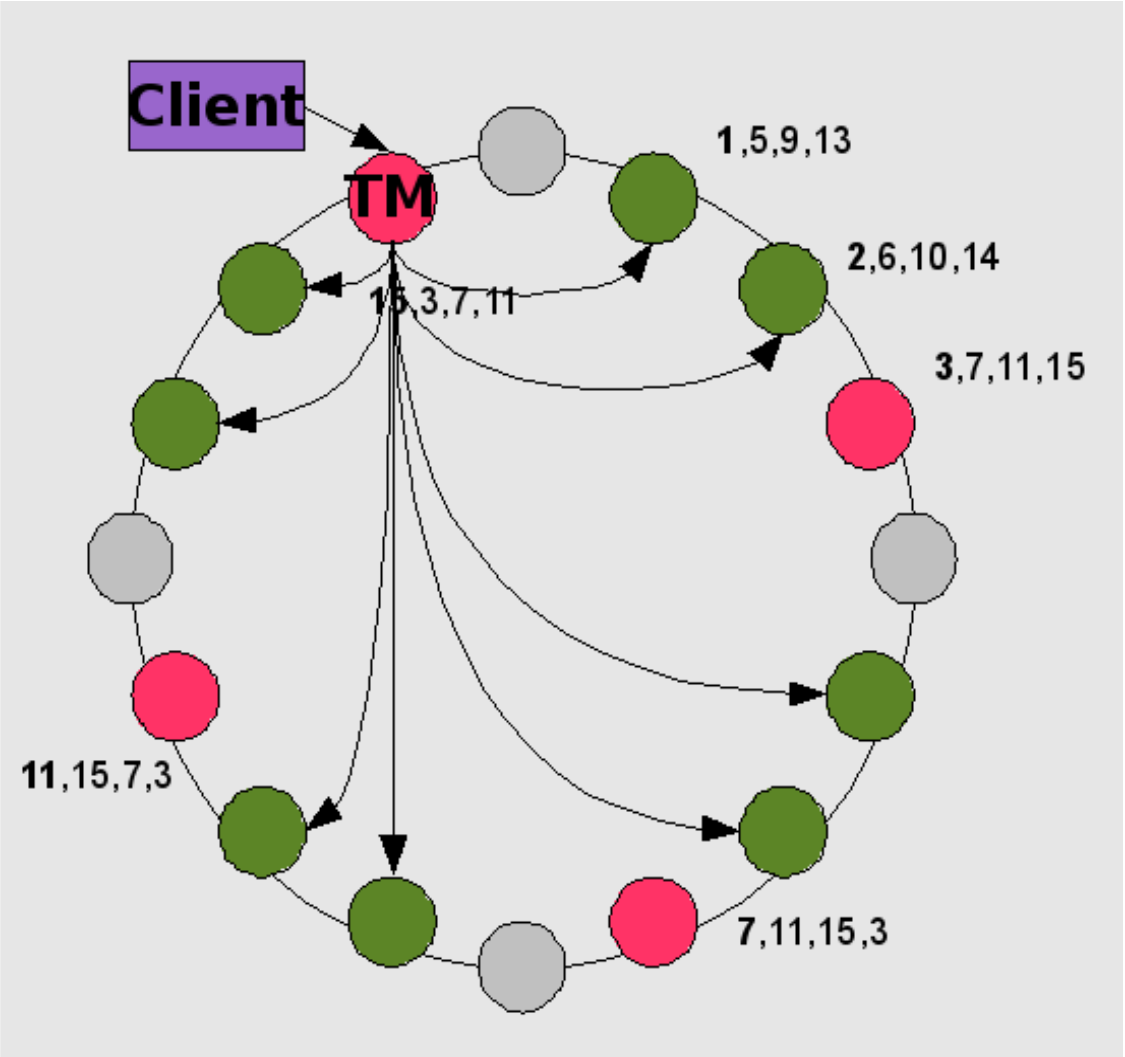
Atomic Commit in a DHT

- Nodes 1,2,5,6,9,10,13,14 become Transaction Participants (*TP*)



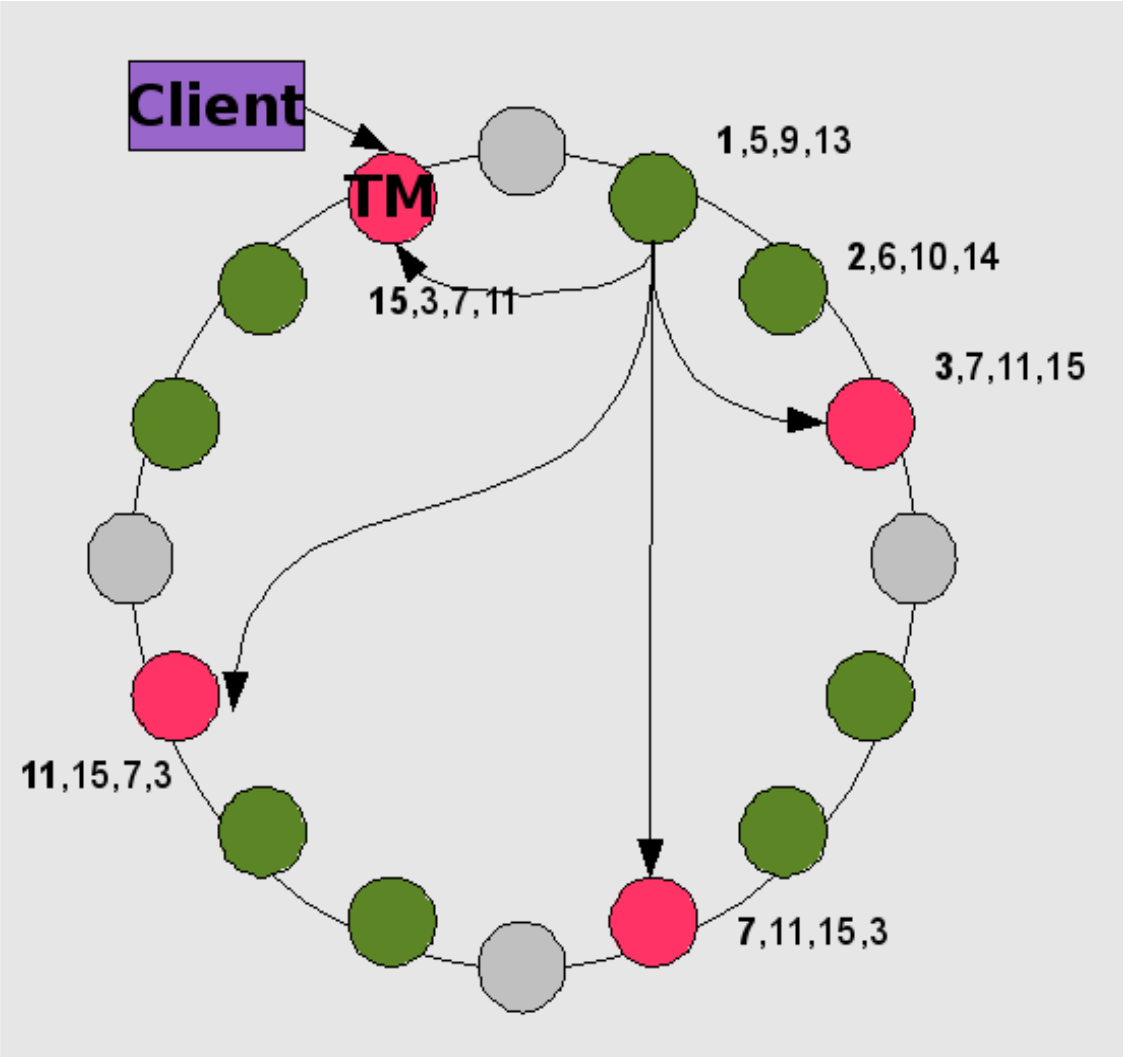
Atomic Commit in a DHT

- *TM* sends `prepare` together with the information needed for validation to all *TPs*



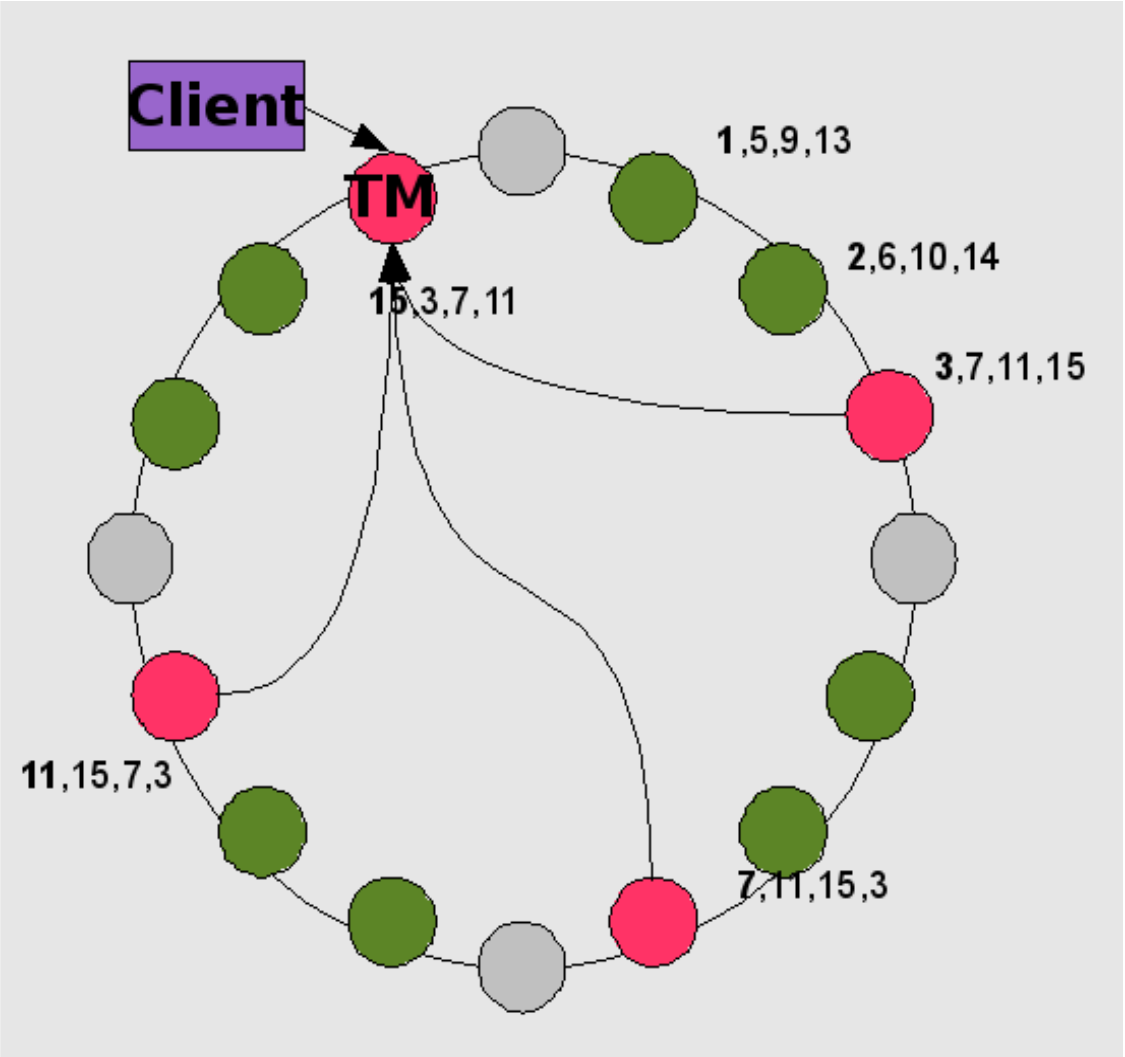
Atomic Commit in a DHT

- After having received `repare` from the *TM*, each *TP* sends it's `prepare` message to all *rTMs*, if it can successfully validate the operation on its item, otherwise it sends `abort`



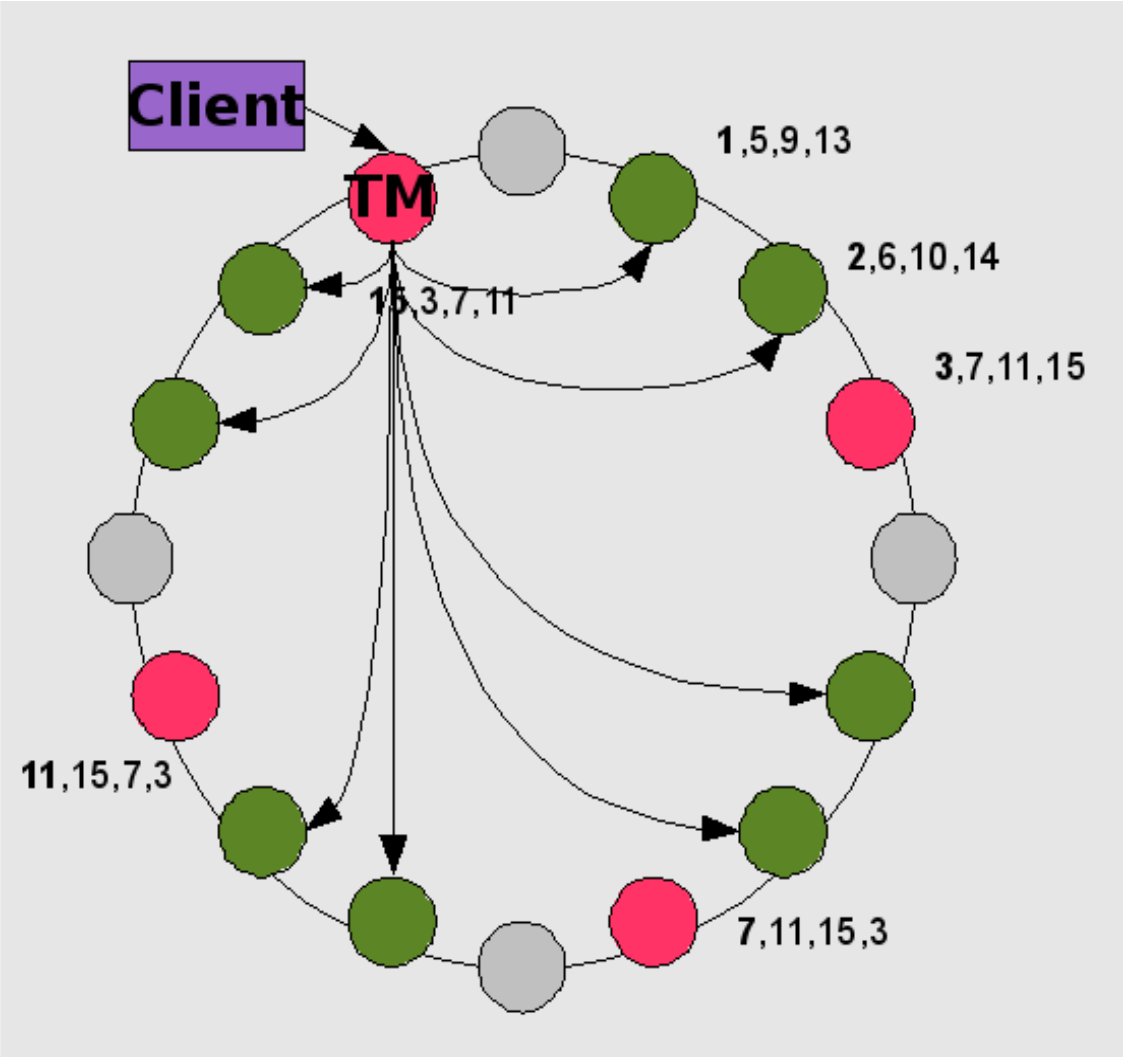
Atomic Commit in a DHT

- The *rTMs* collect the votes from a majority of *TPs* per item and locally decides on `abort` or `commit`
- Each *rTM* sends the outcome to the leading *TM*



Atomic Commit in a DHT

- The *TM* has to collect the outcome from at least a majority of *rTMs*
- After having collected a majority, the *TM* sends the decision to all *TPs*



Beernet

- Mozart-Oz implementation of the relaxed-ring (P2PS's successor)
- Component-based architecture
- Event-driven algorithms with asynchronous message passing and no shared state concurrency
- DHT + Symmetric replication
- Transaction layer with Paxos consensus algorithm (M. Moser)
- Survives network partition
- Ring merge based on gossip algorithm (T. Mahmood)

Conclusion

- The Relaxed-Ring
  - Consistent lookup
  - Realistic failure detection
  - Self-organisation: It handles joins/leaves of peers re-organising the network in a autonomous fashion.
  - Self-healing: It recovers from failures and survives network partitioning.

Conclusion and Future Work

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  - Realistic failure detection
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- Distributed Transactions
  - Non-blocking atomic commit protocol for DHTs
  - Decentralized algorithm with replicated transaction manager
  - Fault tolerance and availability based on symmetric replication
- Beernet: implementation of relaxed-ring with transactional layer

Conclusion and Future Work

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  - Decentralized algorithm with replicated transaction manager
  - Fault tolerance and availability based on symmetric replication
- Beernet: implementation of relaxed-ring with transactional layer
- **Future Work**
  - Implement an application with Beernet to conquer the world
  - Work on reversible phase transitions

Last slide where I should ask for *questions*
or simply put a big *question mark*