Meridian: A Lightweight Network Location Service without Virtual Coordinates

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Network Location Service

- Select nodes based on a set of network properties

- Real-world problems:
  - **Locate closest game server**
  - **Distribute web-crawling to nearby hosts**
  - **Perform efficient application level multicast**
  - **Satisfy a Service Level Agreement**
  - **Provide inter-node latency bounds for clusters**

- Underlying abstract problems
  - **Finding closest node to target**
  - **Finding the closest node to the center of a set of targets**
  - **Finding a node that is $<r_i$ ms from target t_i for all targets**

Current State-of-the-Art: Virtual Coordinates

- Maps Internet latencies into low dimensional space
  - GNP, Vivaldi, Lighthouse, ICS, VL, BBS, PIC, NPS, etc.
- Reduces number of real-time measurements
- 3 practical problems:
  - Introduces inherent embedding error
  - A snapshot in time of the network location of a node
    - Coordinates become stale over time
    - Latency estimates based on coordinates computed at different times can lead to additional errors
  - Requires additional P2P substrate to solve network location problems without centralized servers or *O(N)* state

Meridian Approach

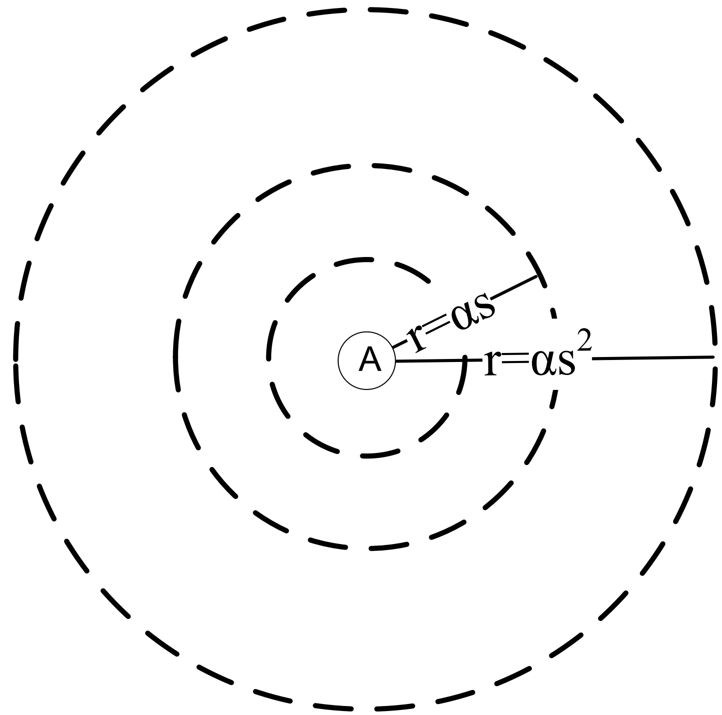
- Solve node selection directly without computing coordinates
  - Combine query routing with active measurements
- 3 Design Goals:
  - Accurate: Find satisfying nodes with high probability
  - General: Users can fully express their network location requirements
  - Scalable: O(log N) state per node, O(log D) hops per query
- Design tradeoffs:
  - Active measurements incur higher query latencies
  - Overhead more dependent on query load

Meridian Operation

- Framework:
  - Loosely structured overlay network
- Algorithms:
  - Solve network location problems in O(log D) hops
- Language:
  - General-purpose language for expressing network location requirements

Multi-resolution Rings

- Organize peers into small fixed number of concentric rings
- Radii of rings grow outwards exponentially
  - Logarithmic # of peers per ring
  - Favors nearby neighbors
  - Retains a sufficient number of pointers to remote regions
- Gossip protocol used for peer discovery



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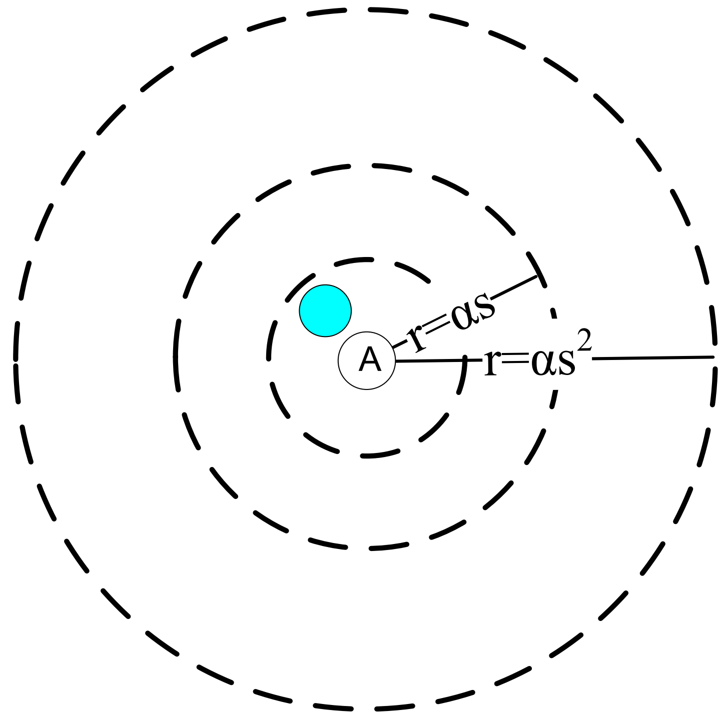

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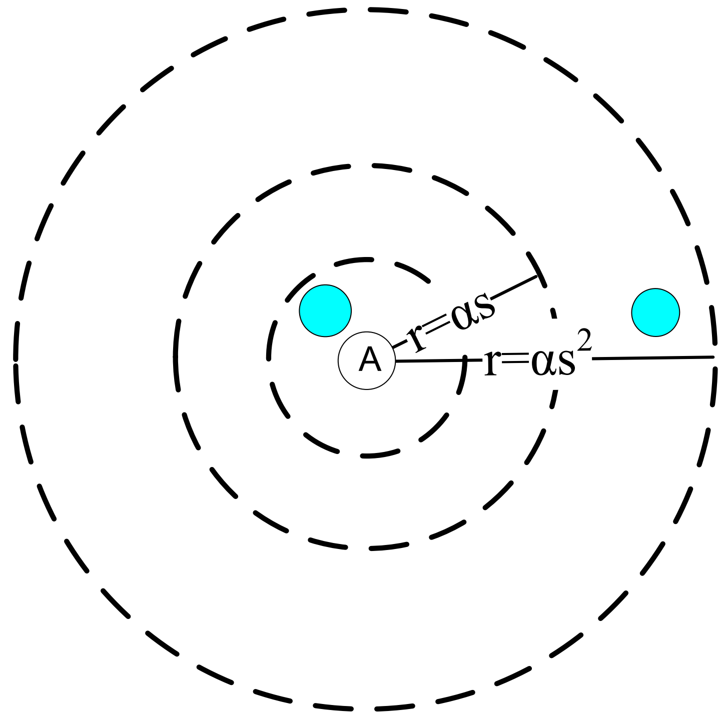

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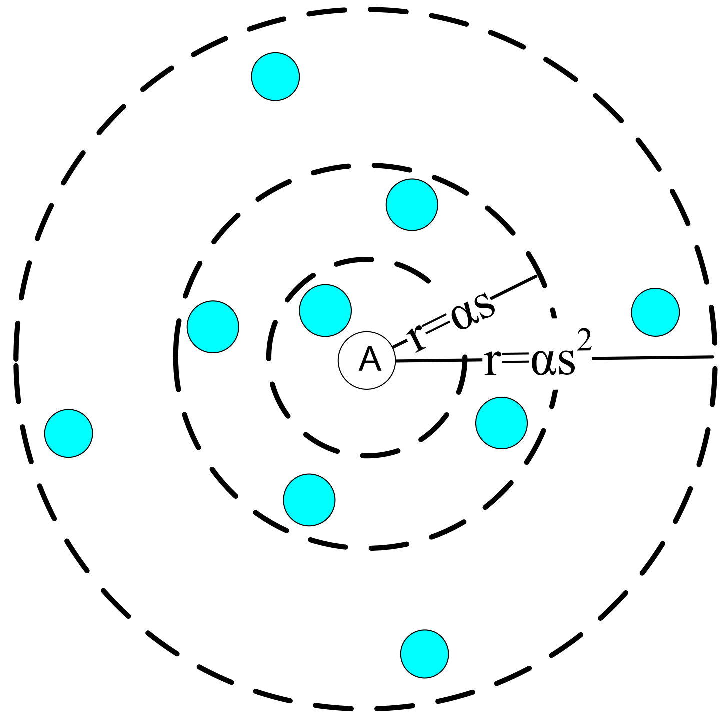
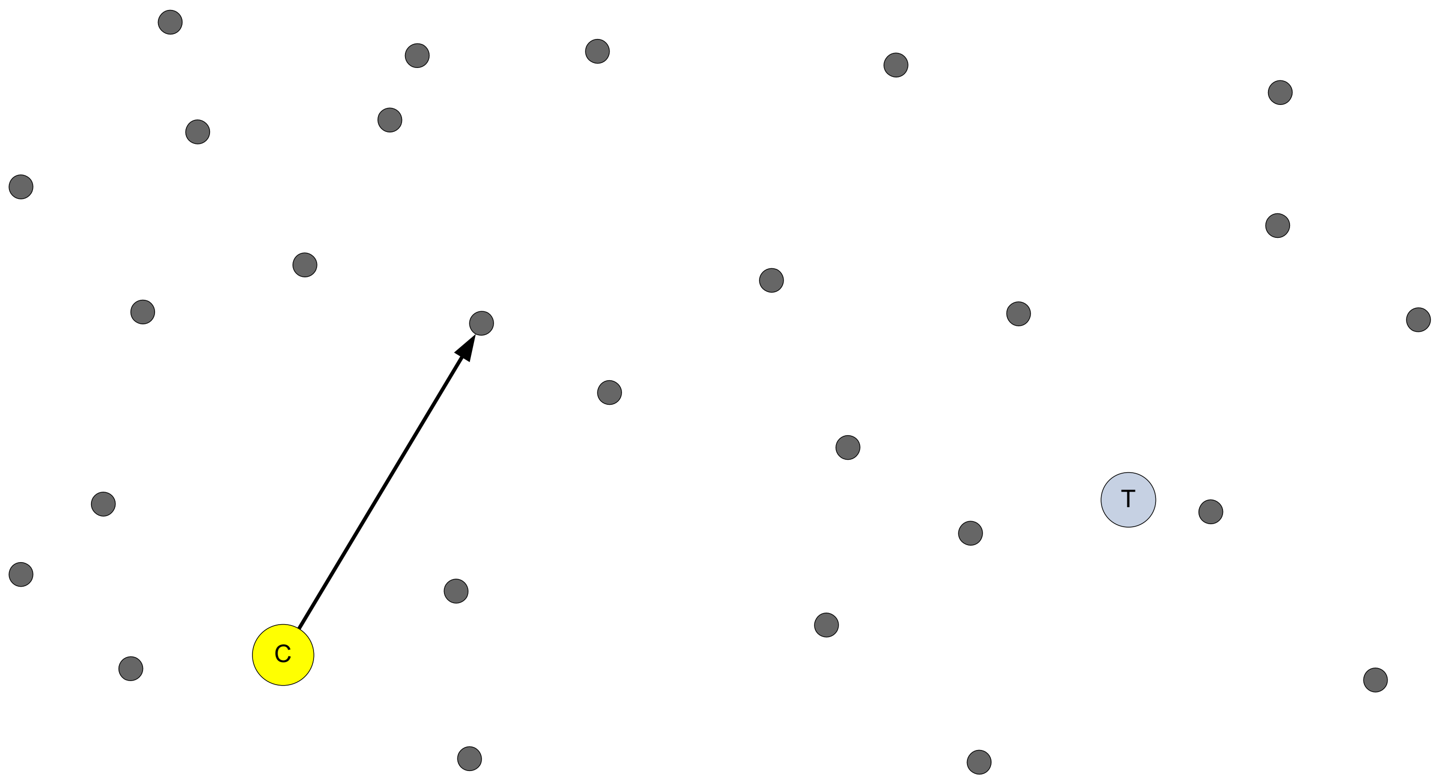


Closest Node Discovery

- Multi-hop search
  - Similar to finding the closest identifier in DHTs
    - Replaces virtual identifiers with physical latencies
  - Each hop exponentially reduces the distance to the target
  - Reduction threshold β for $0 \leq \beta < 1$
    - Only take another hop if a peer node is β times closer
  - Limits # of probed peers through triangle inequality

Closest Node Discovery



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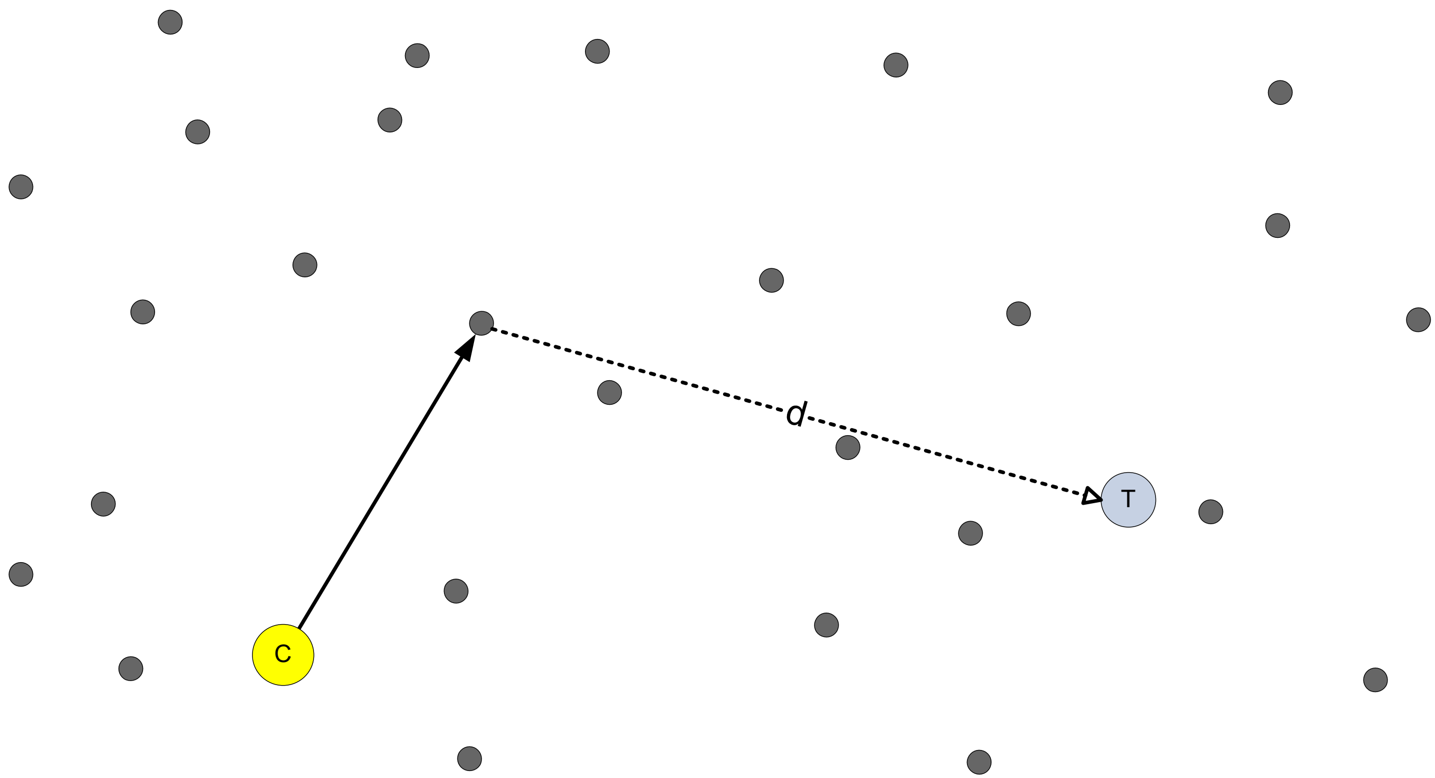

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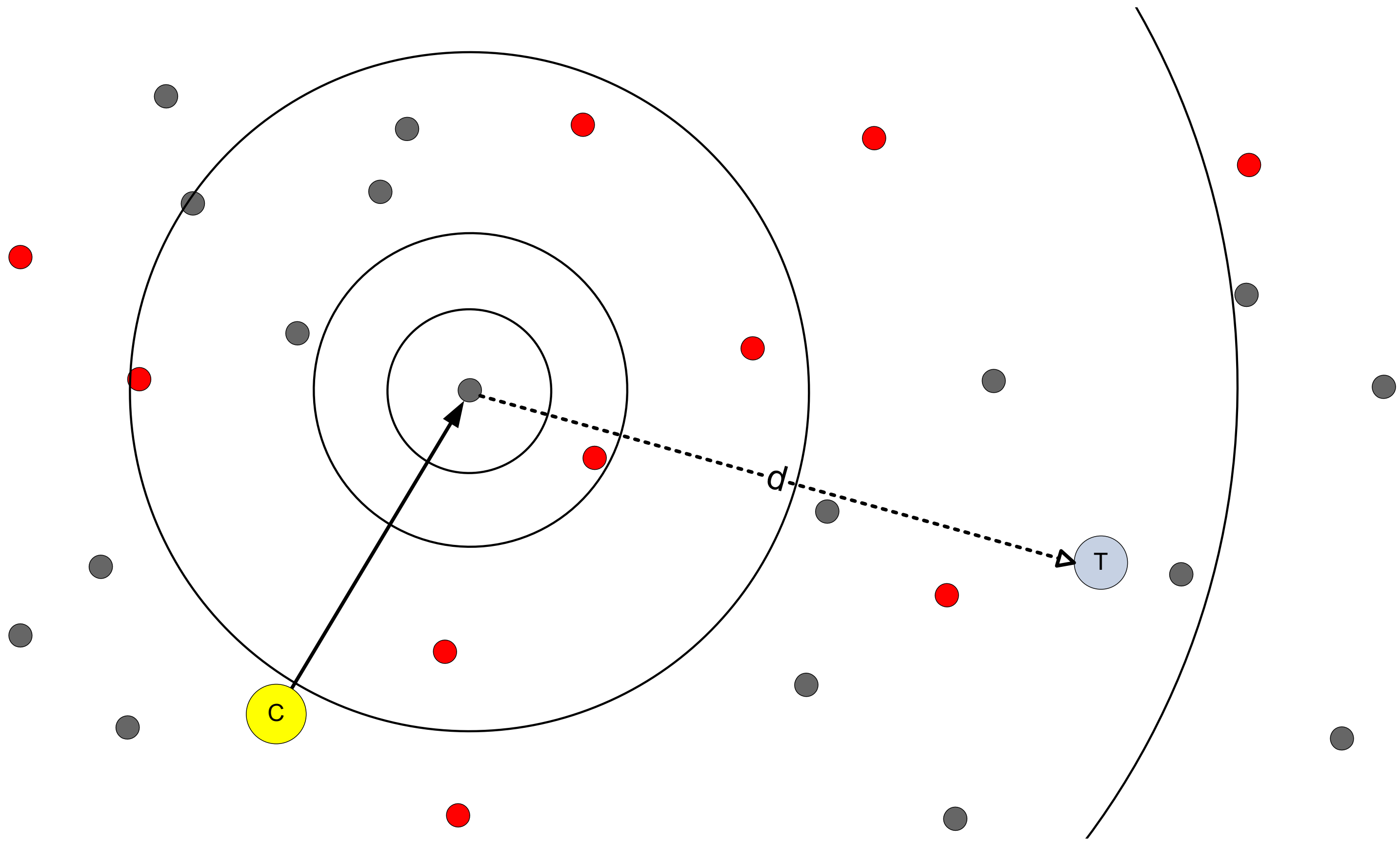

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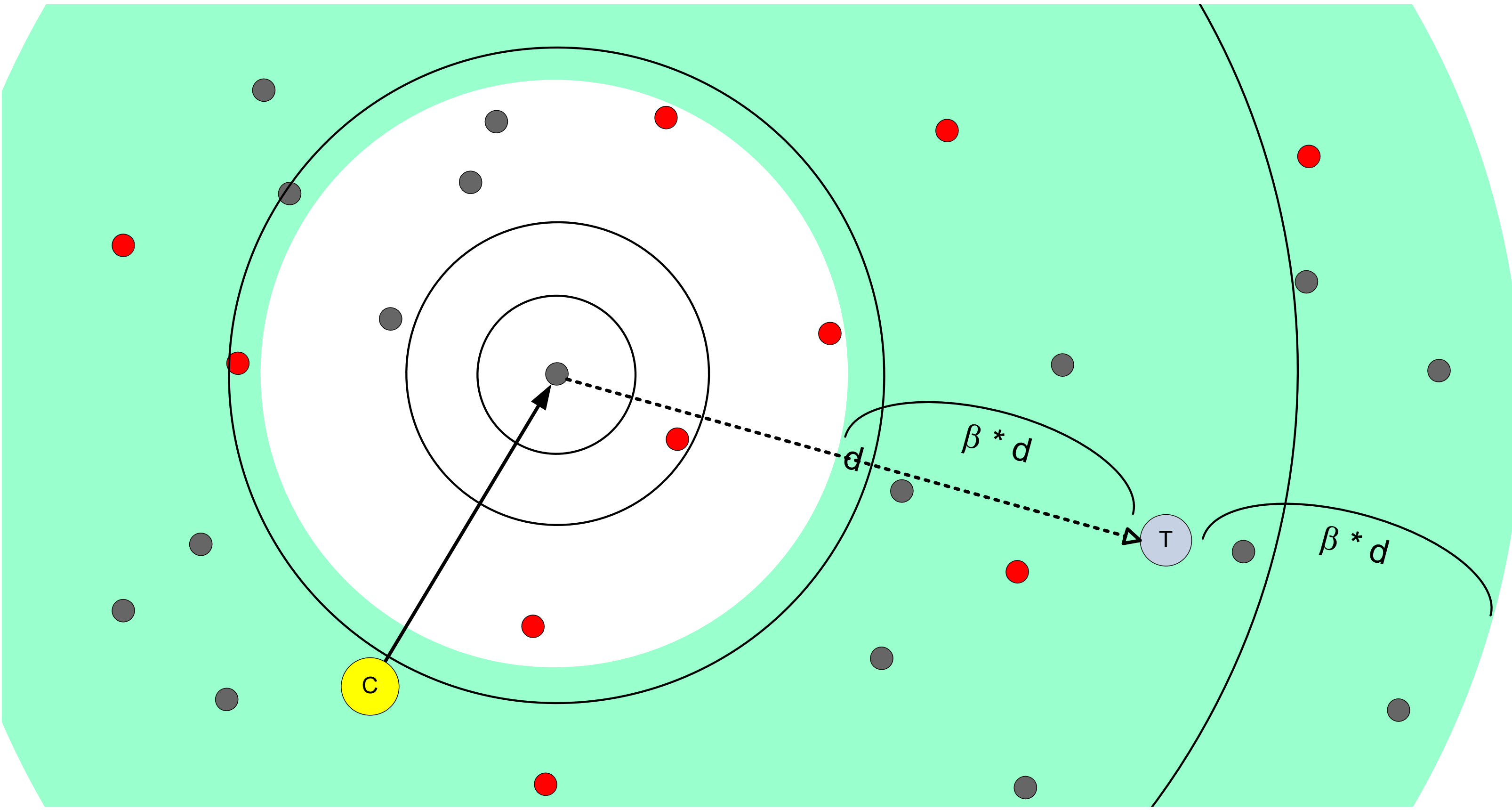

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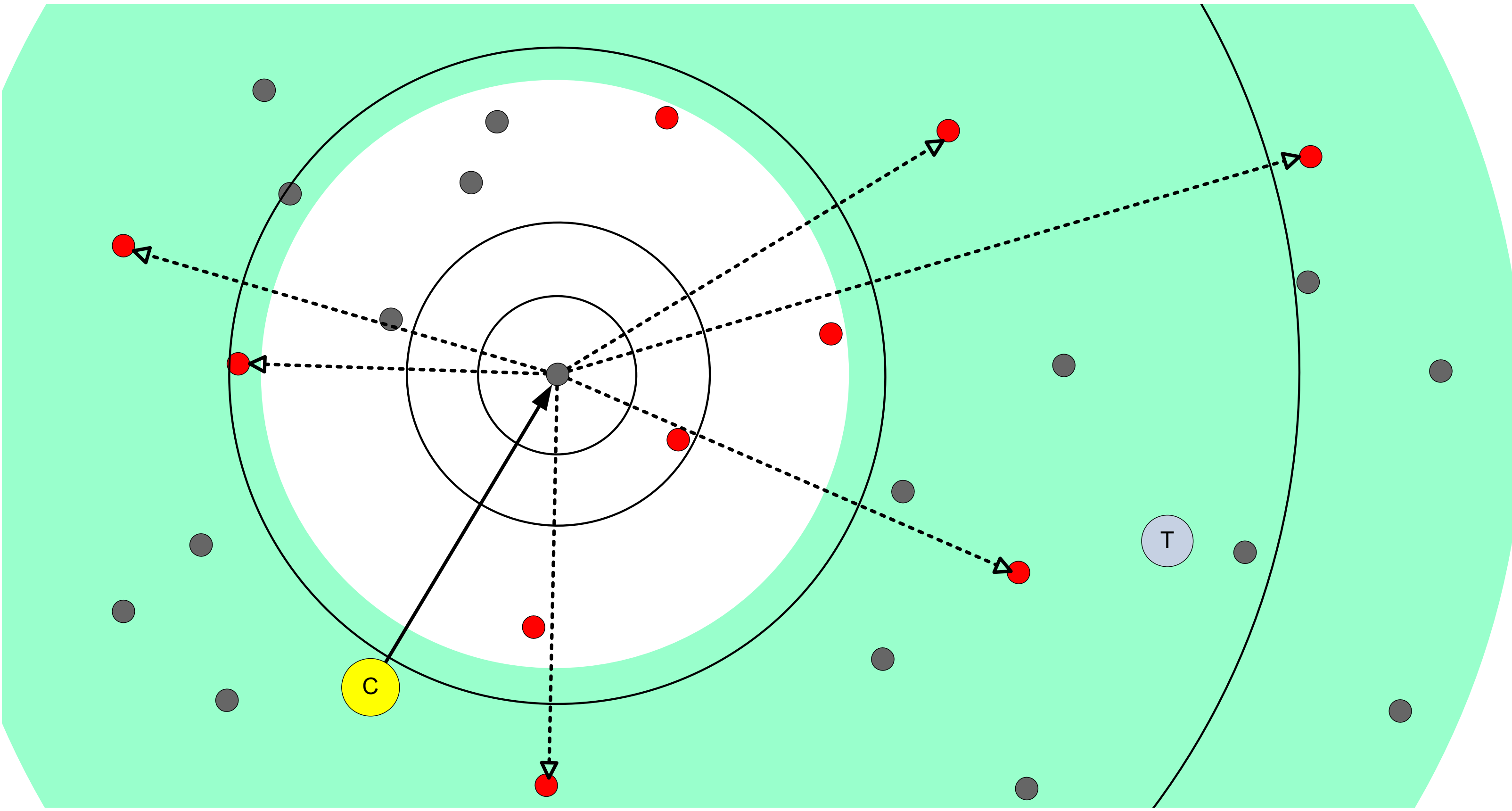

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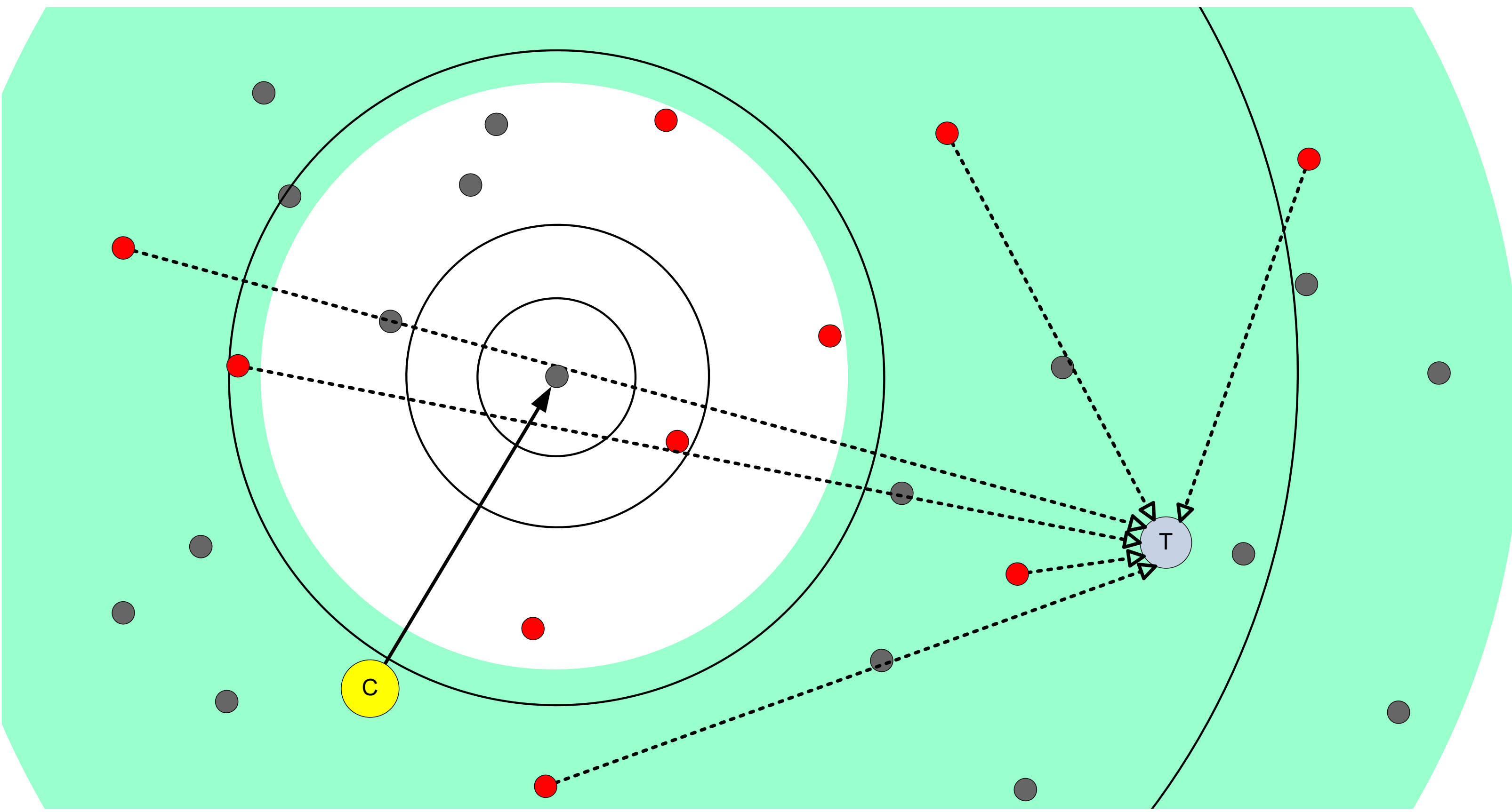

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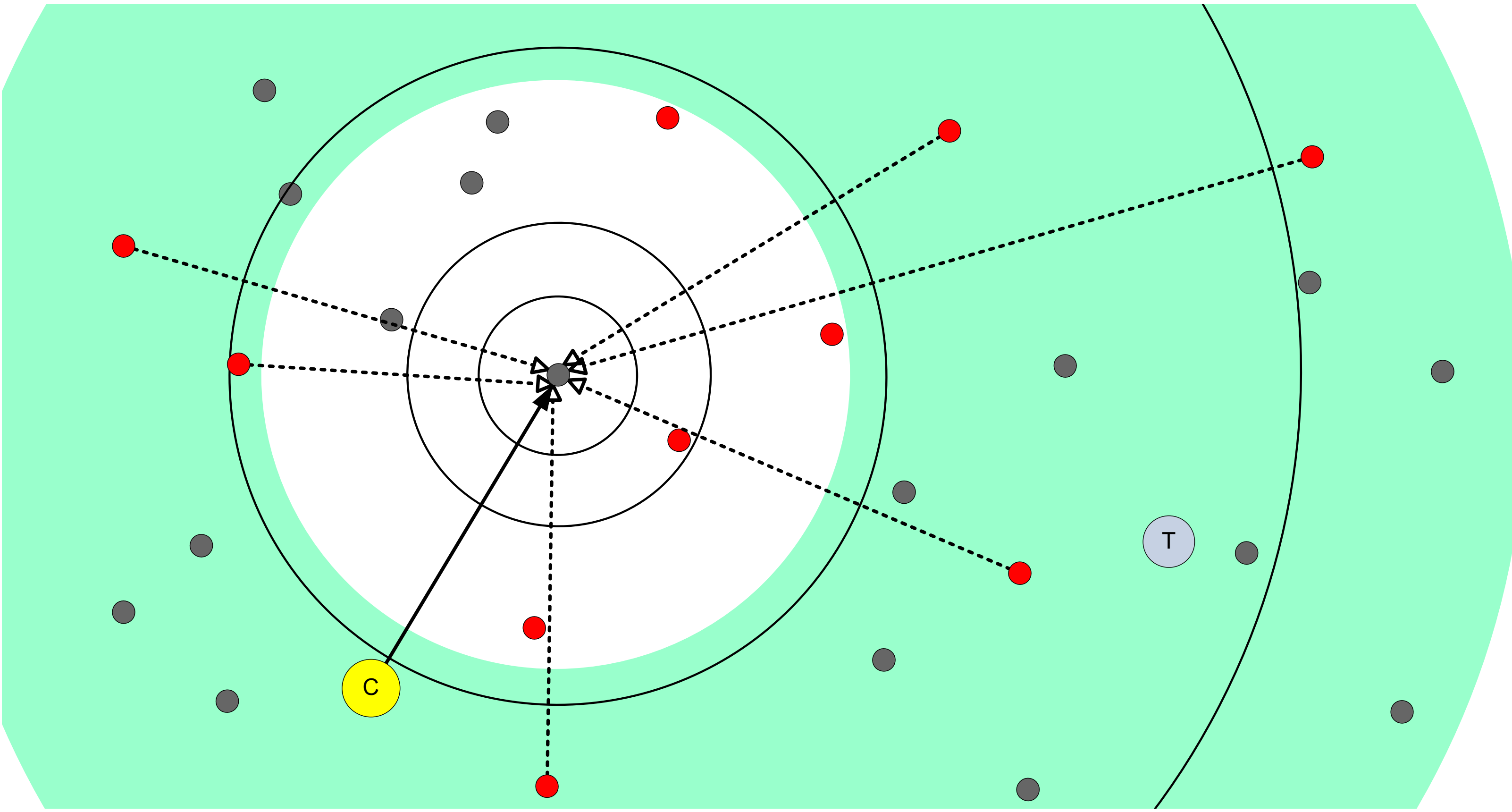

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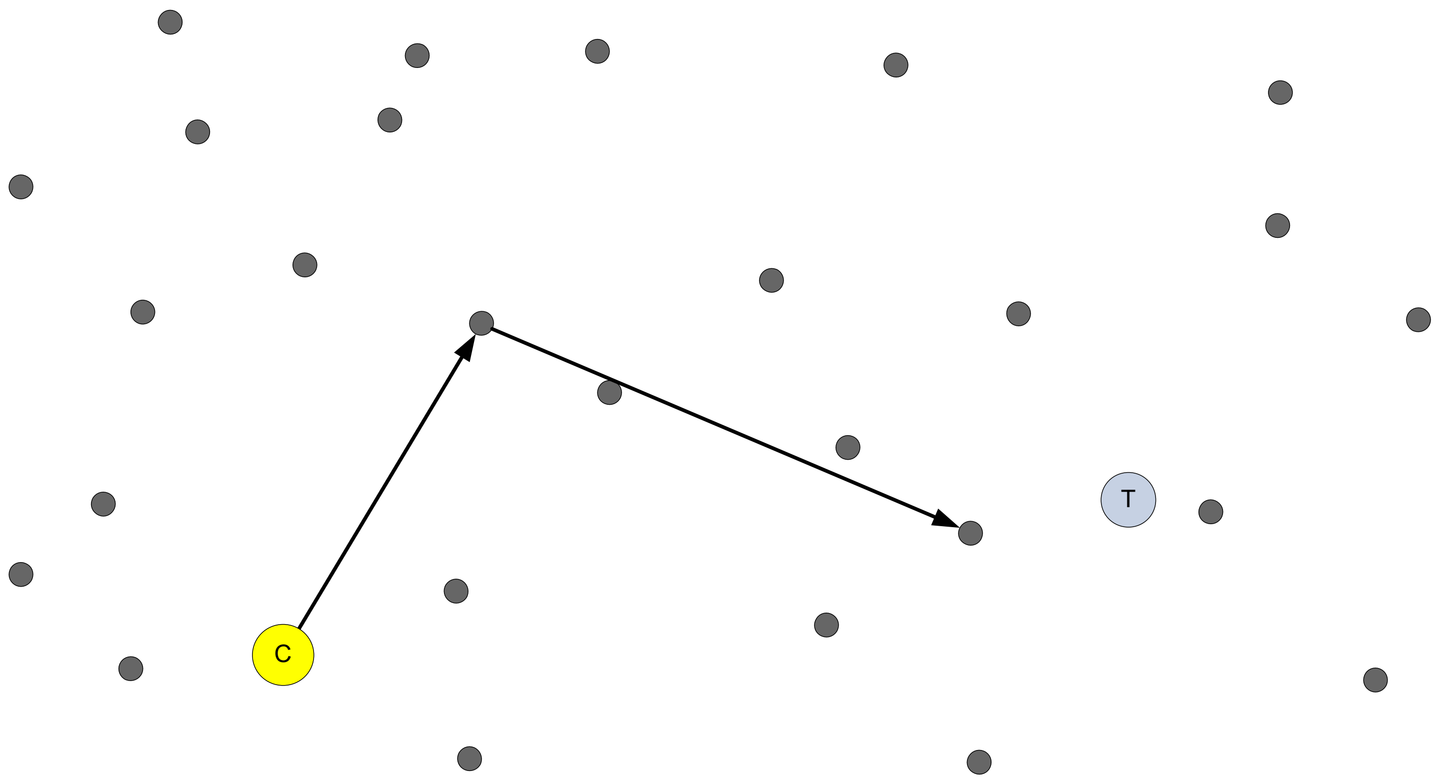

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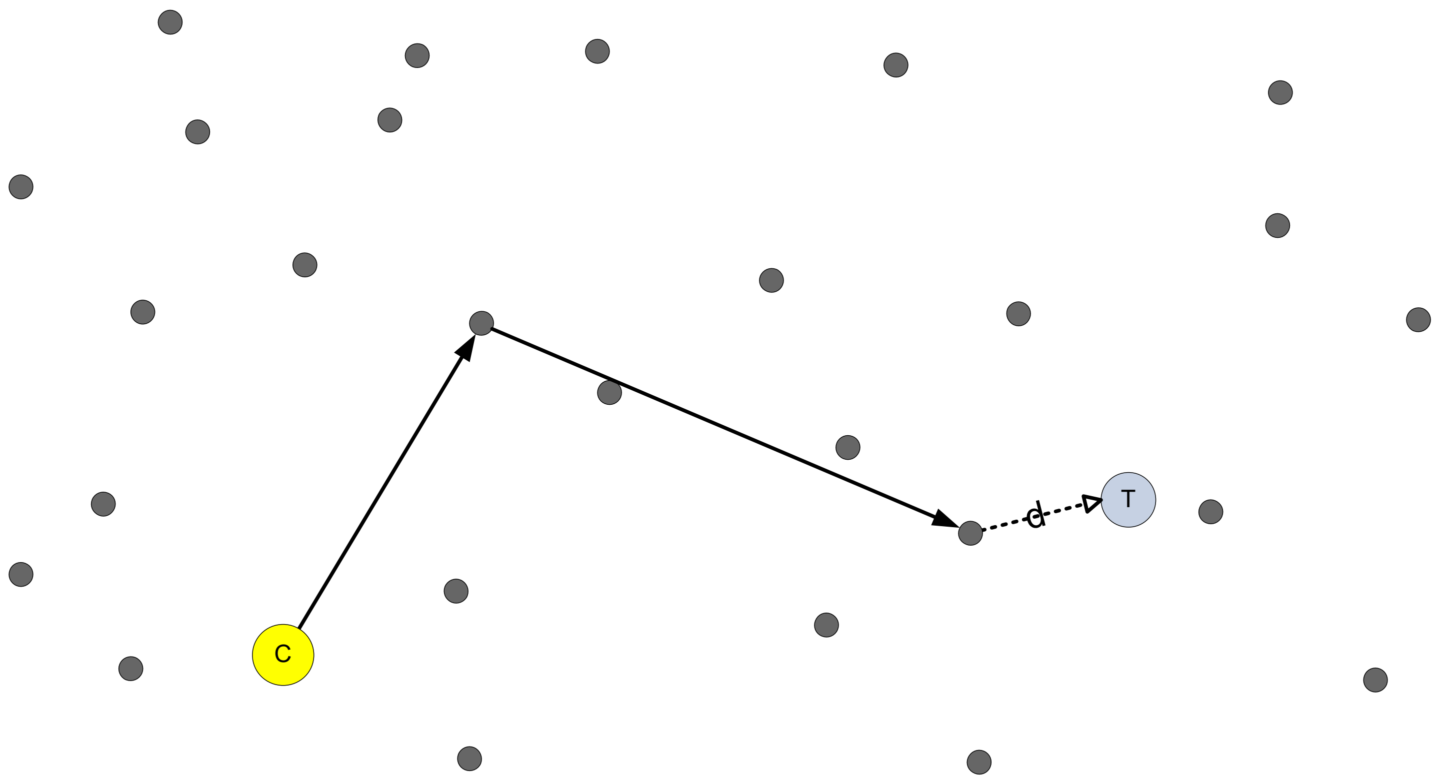

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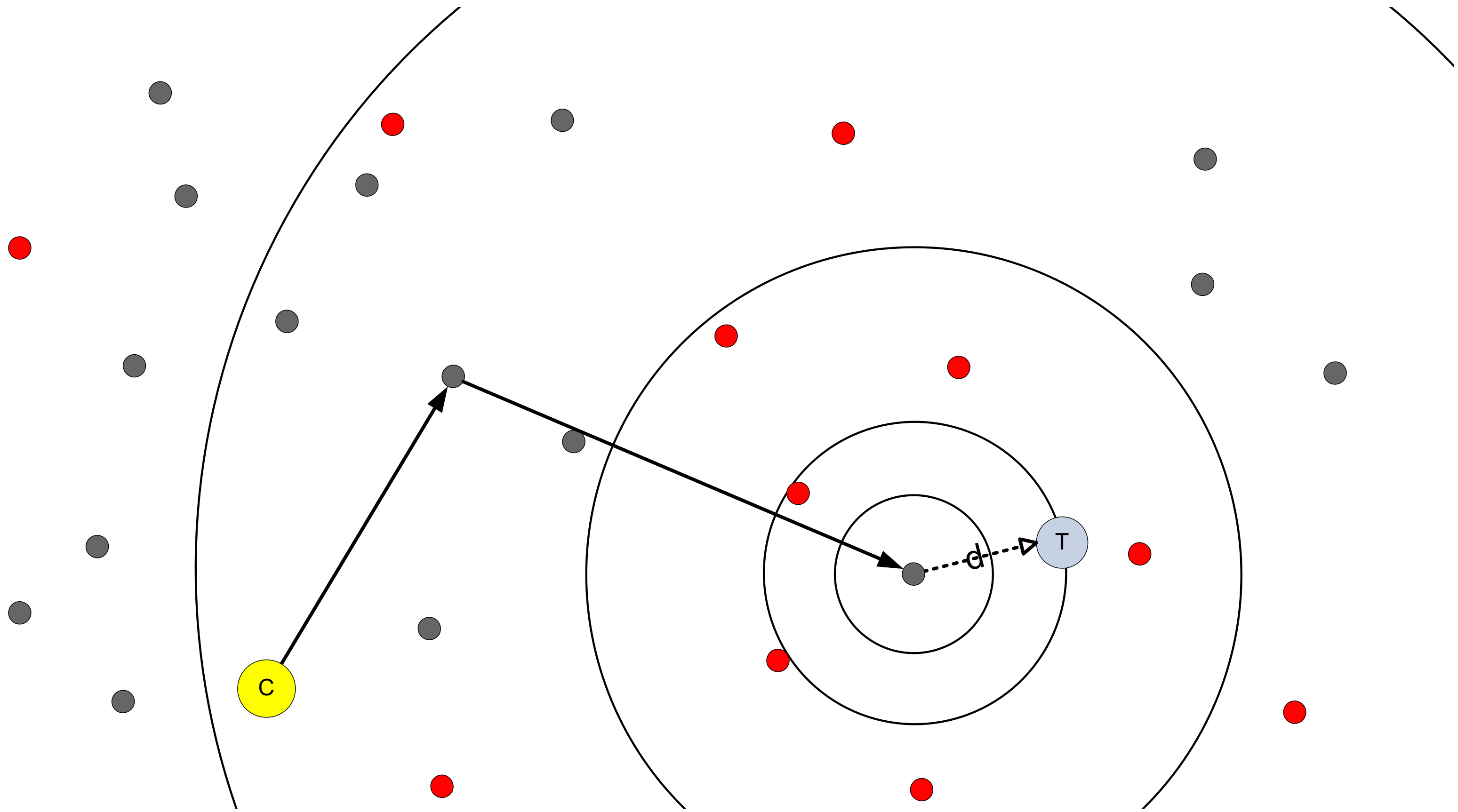

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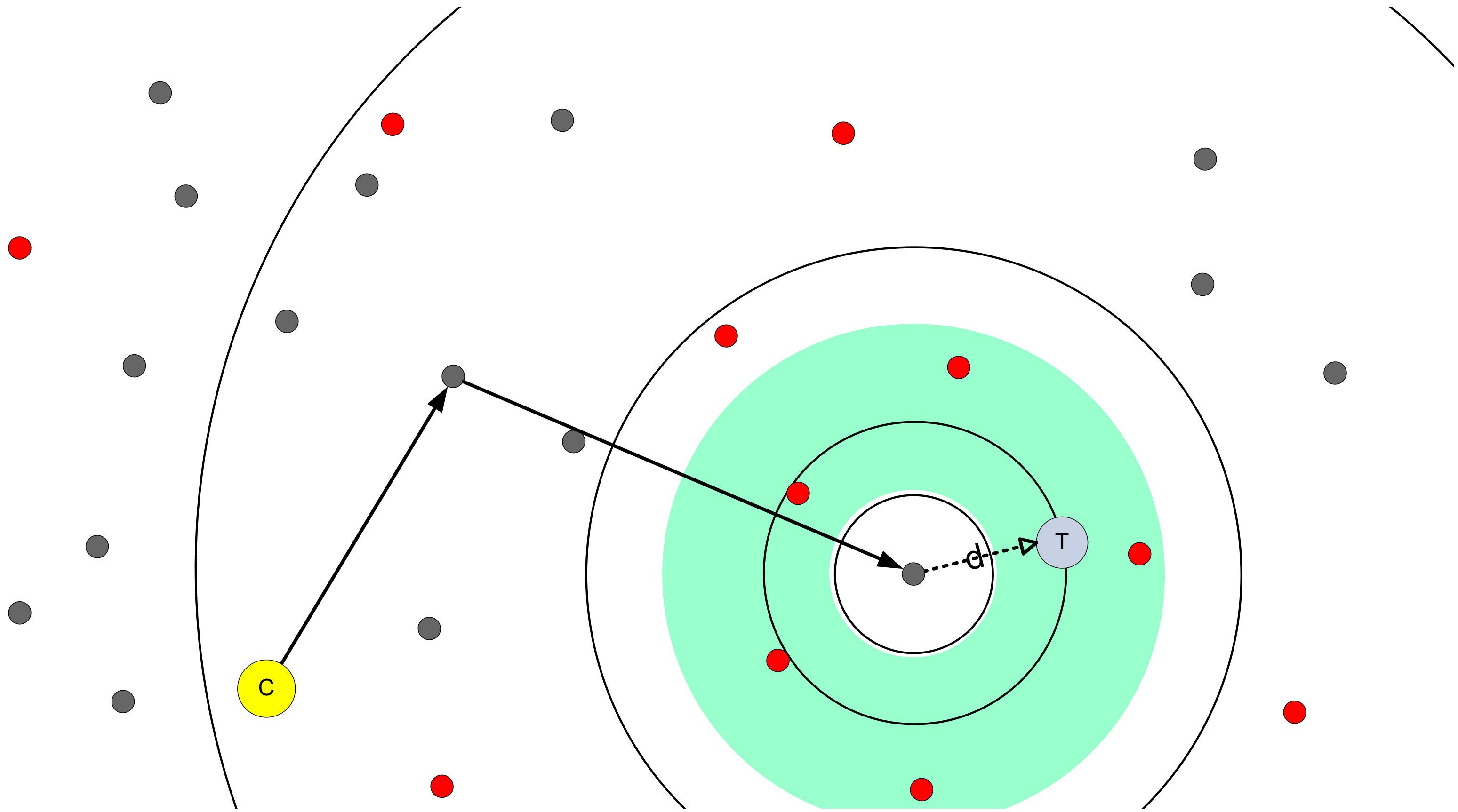

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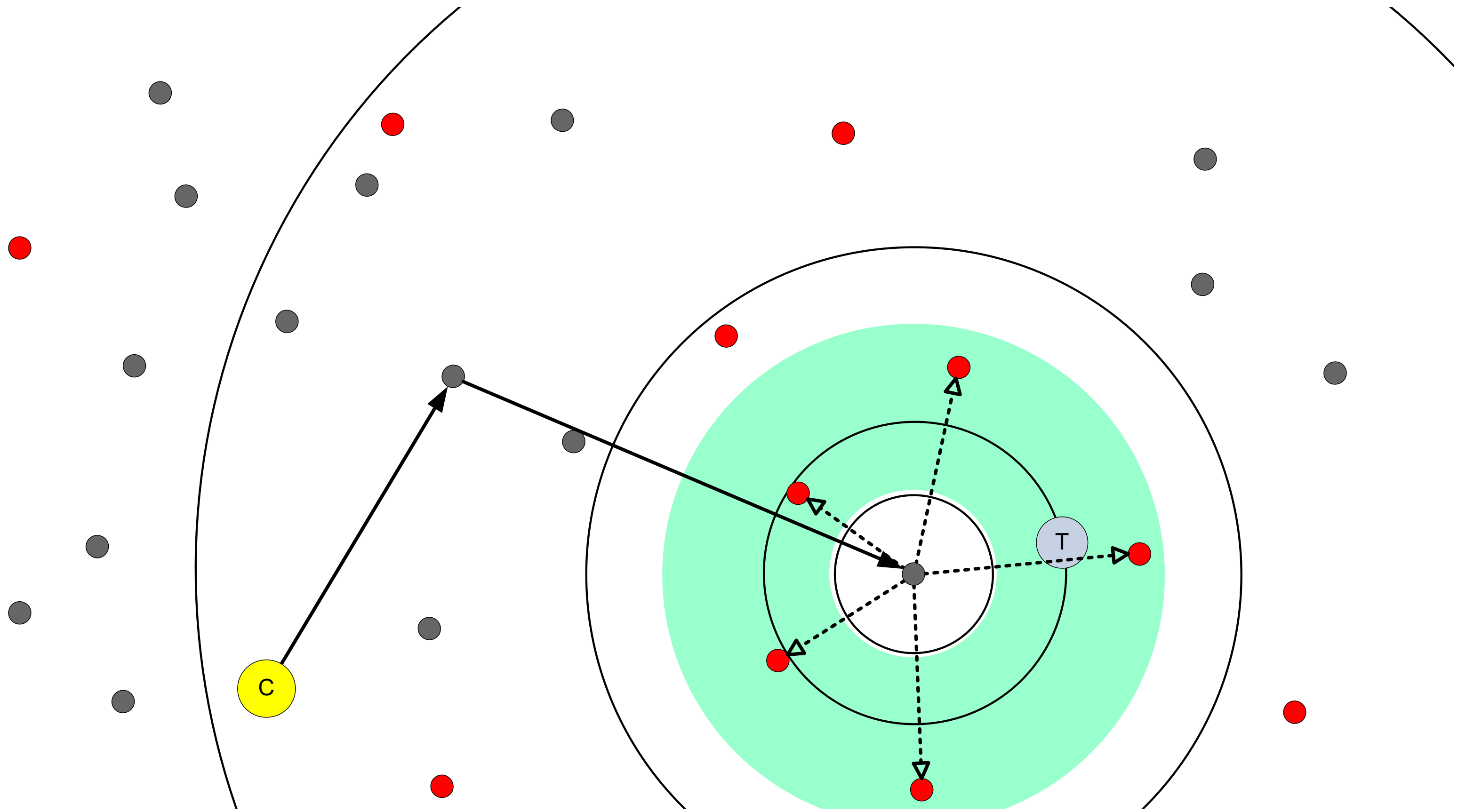

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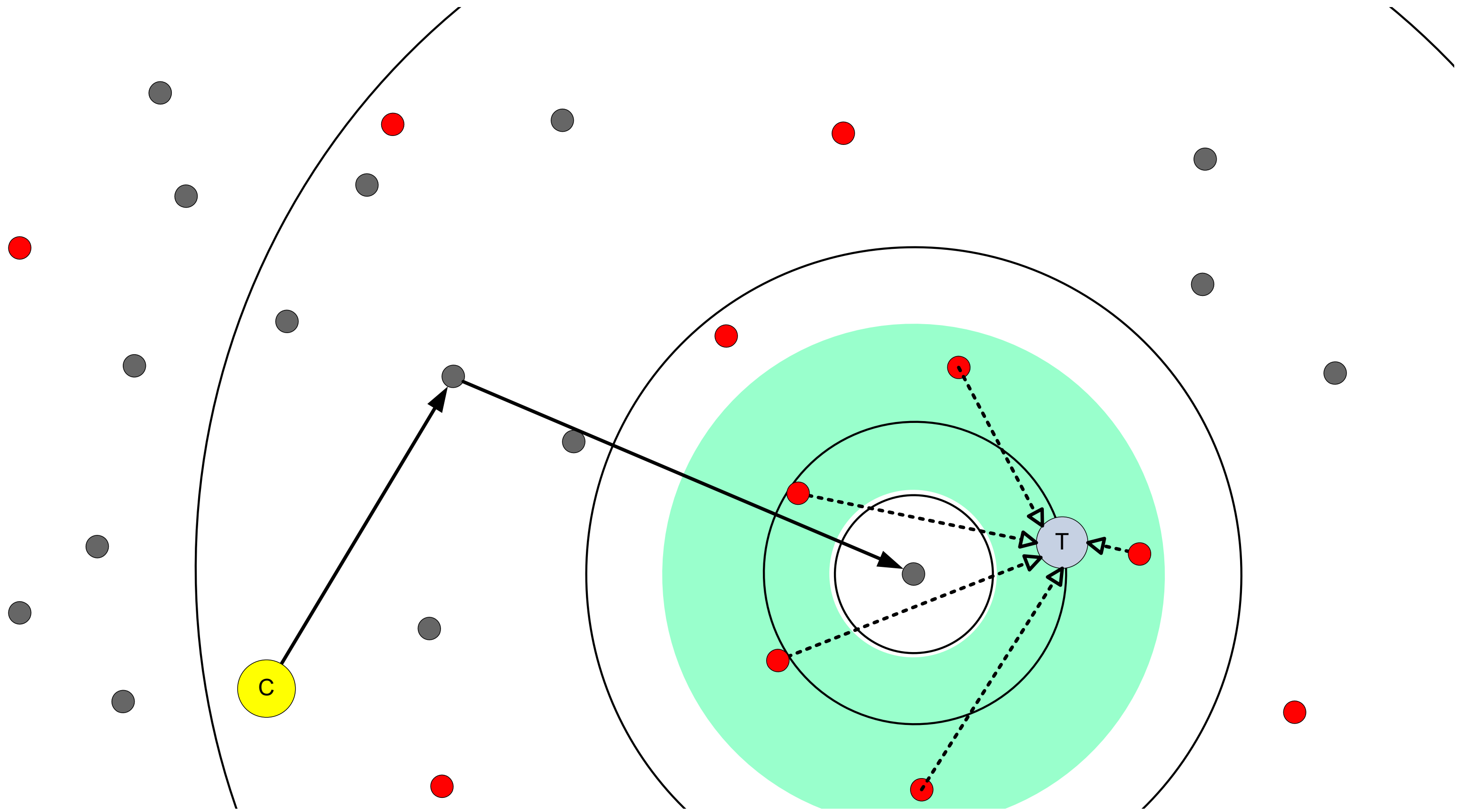

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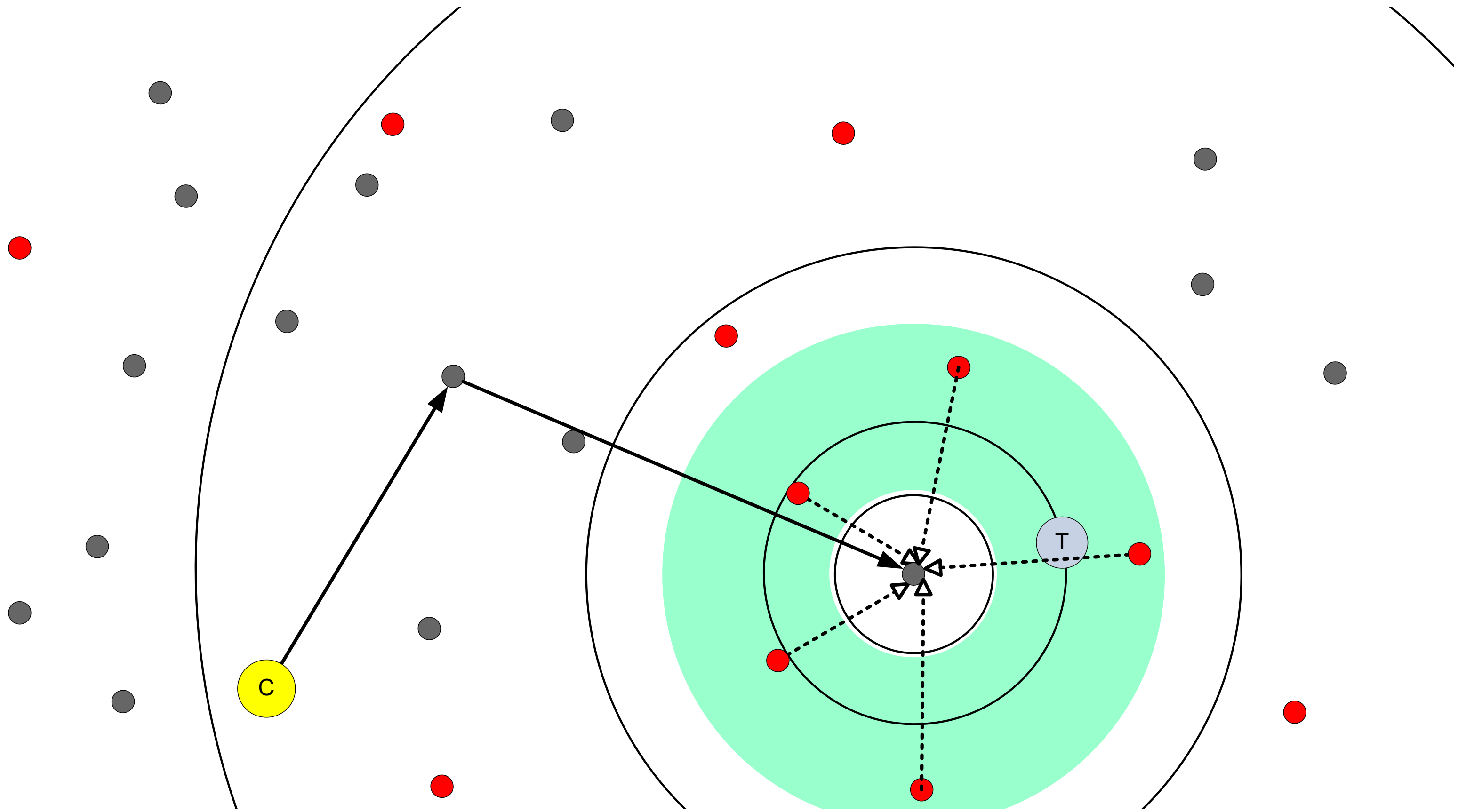

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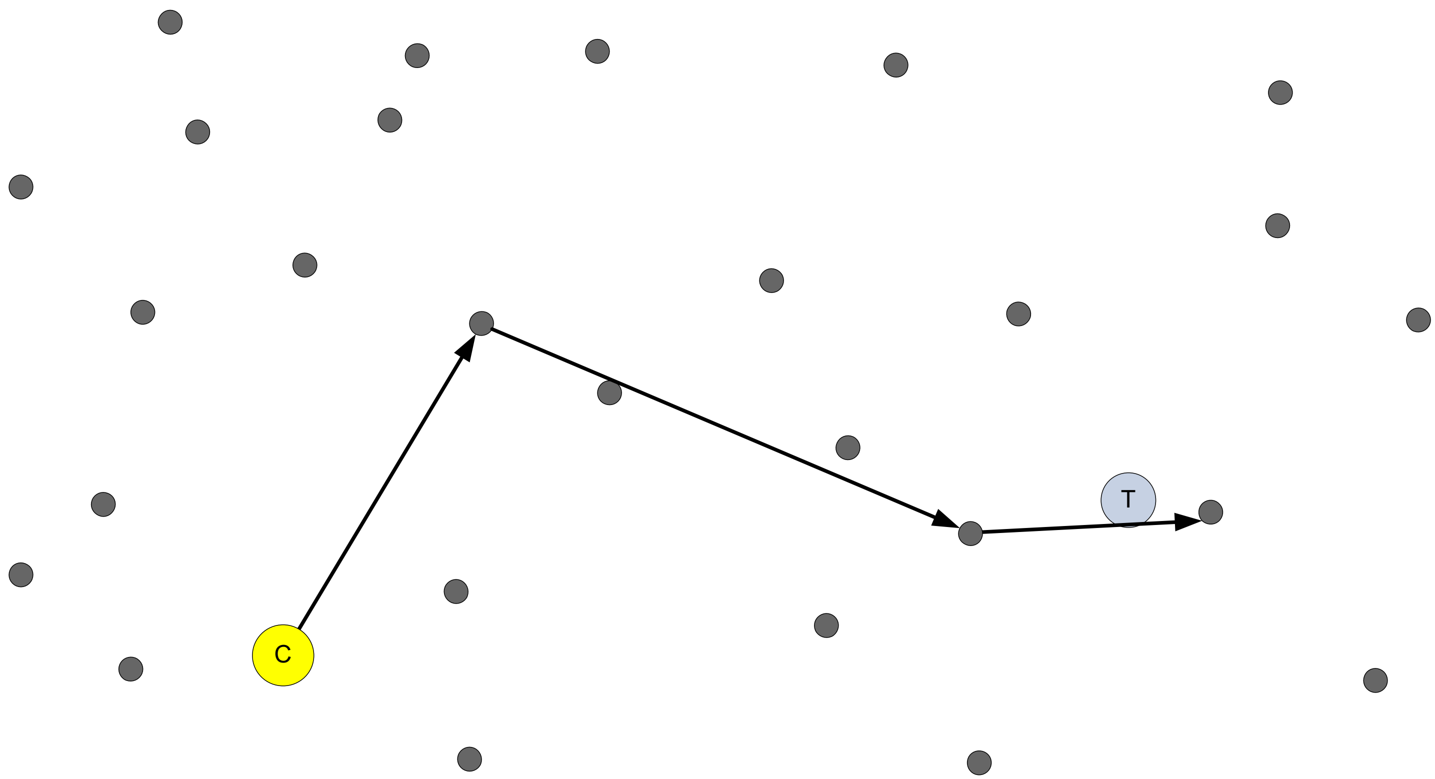

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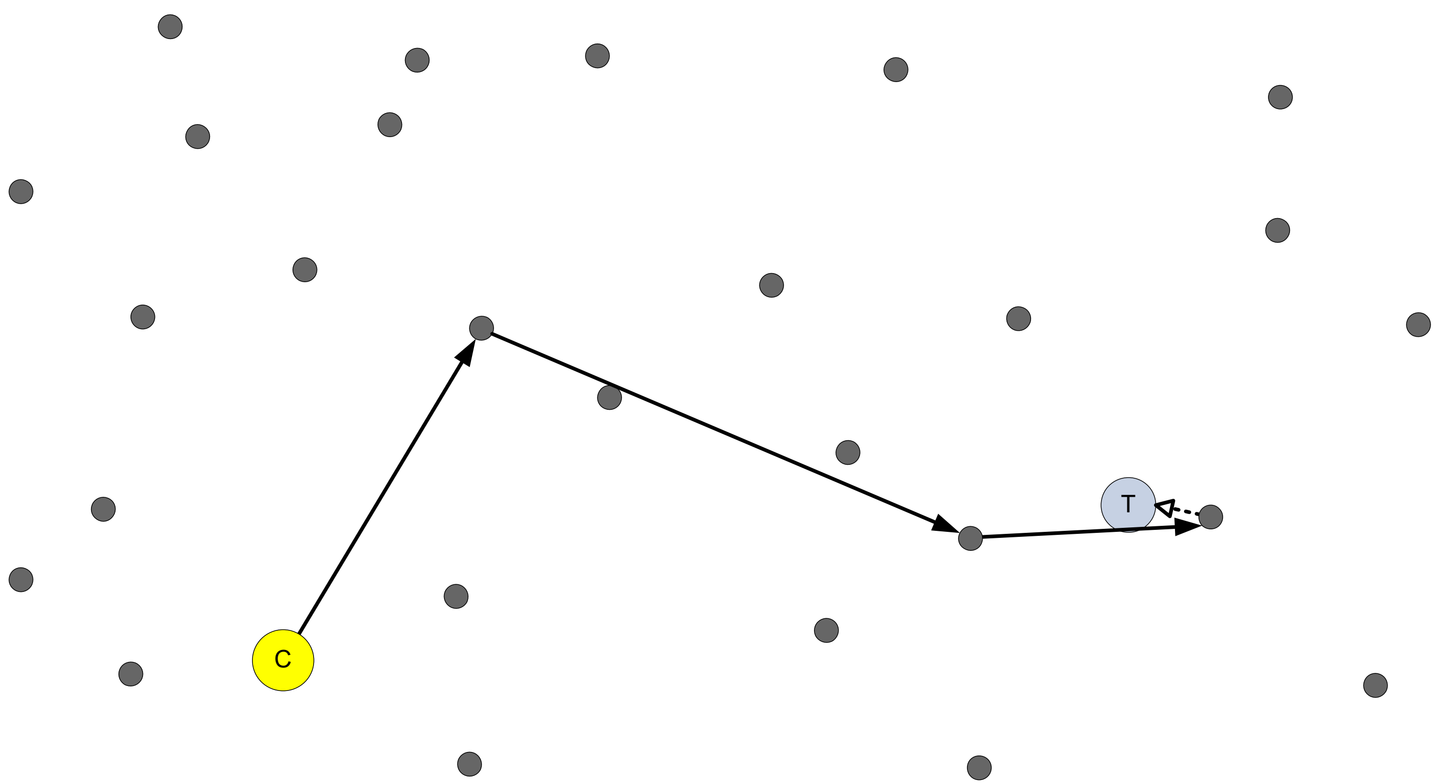

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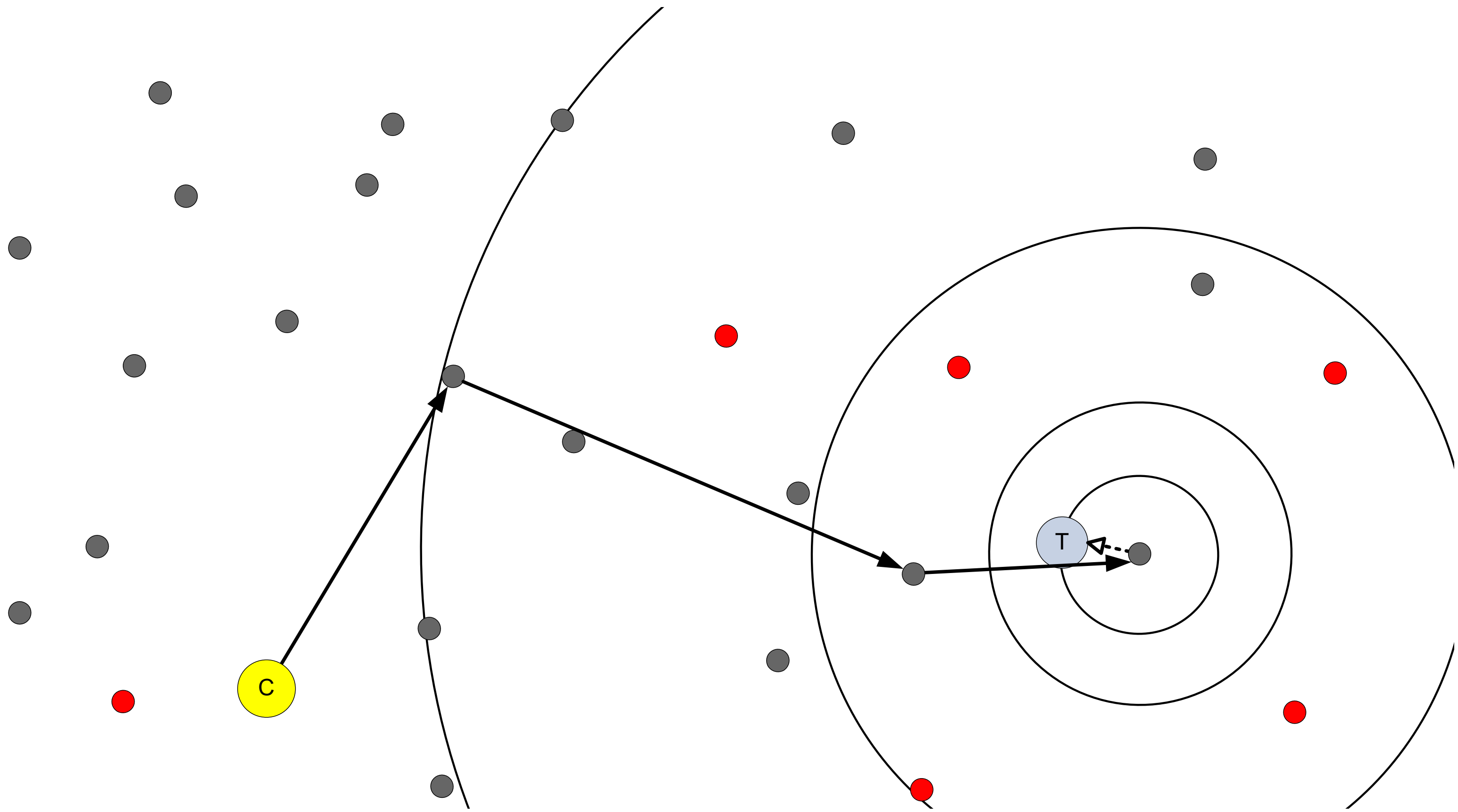

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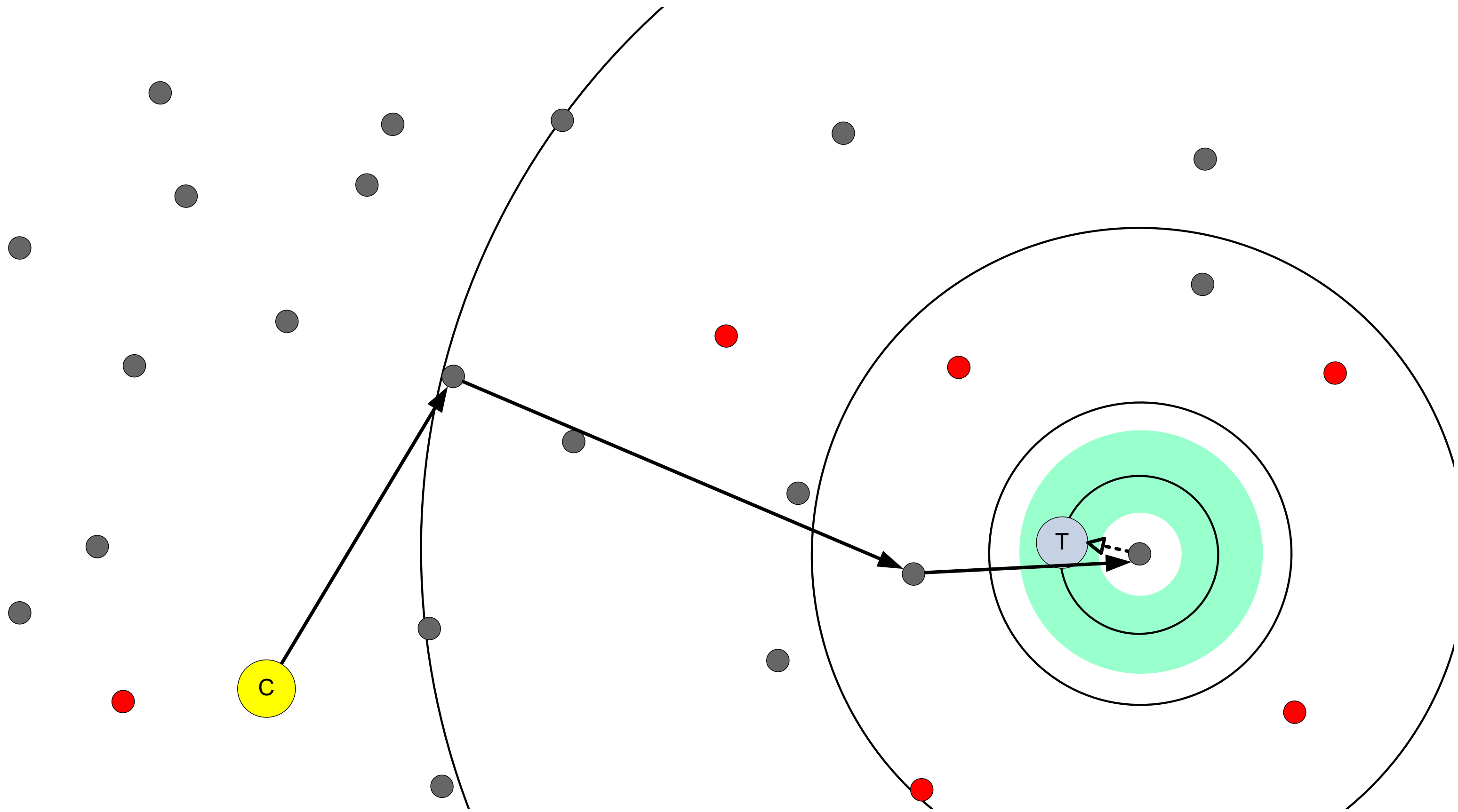

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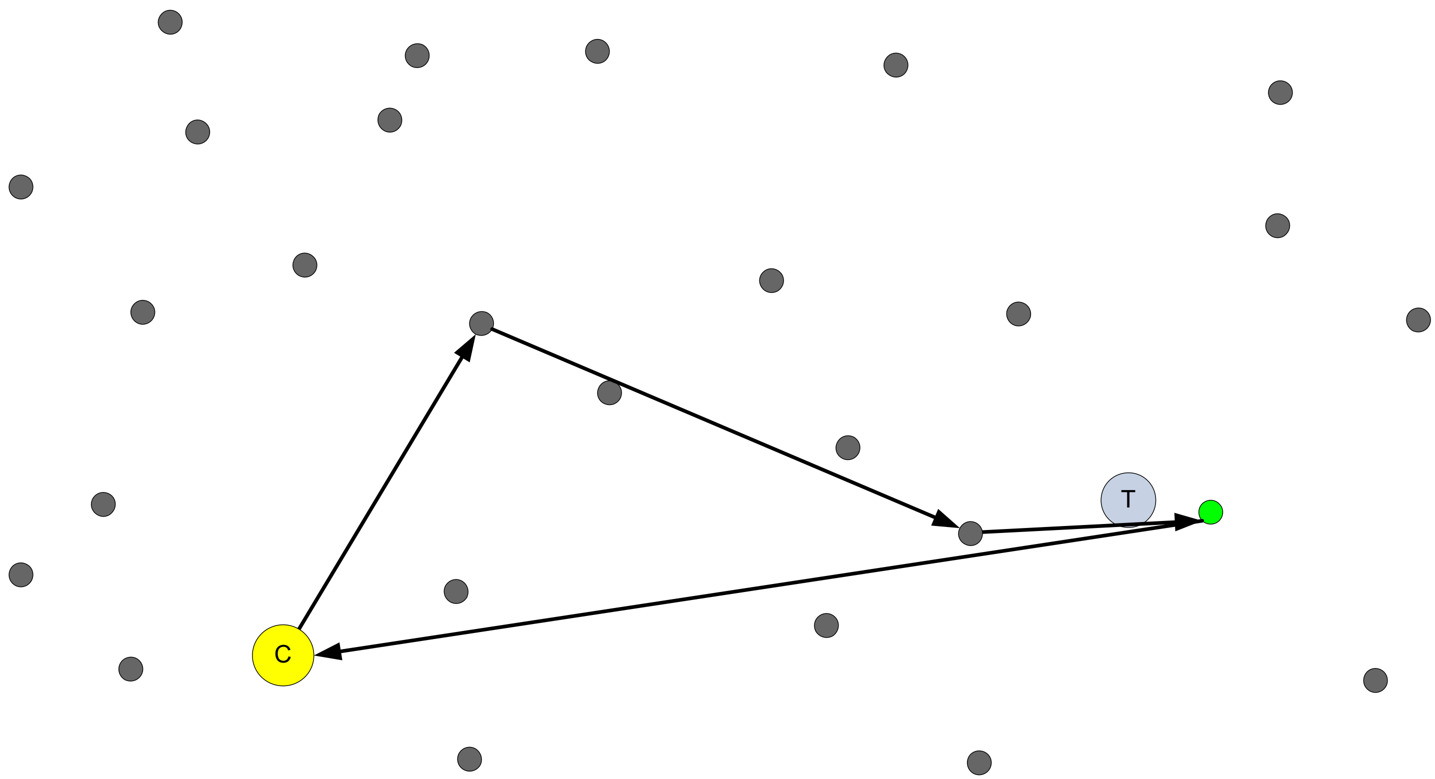


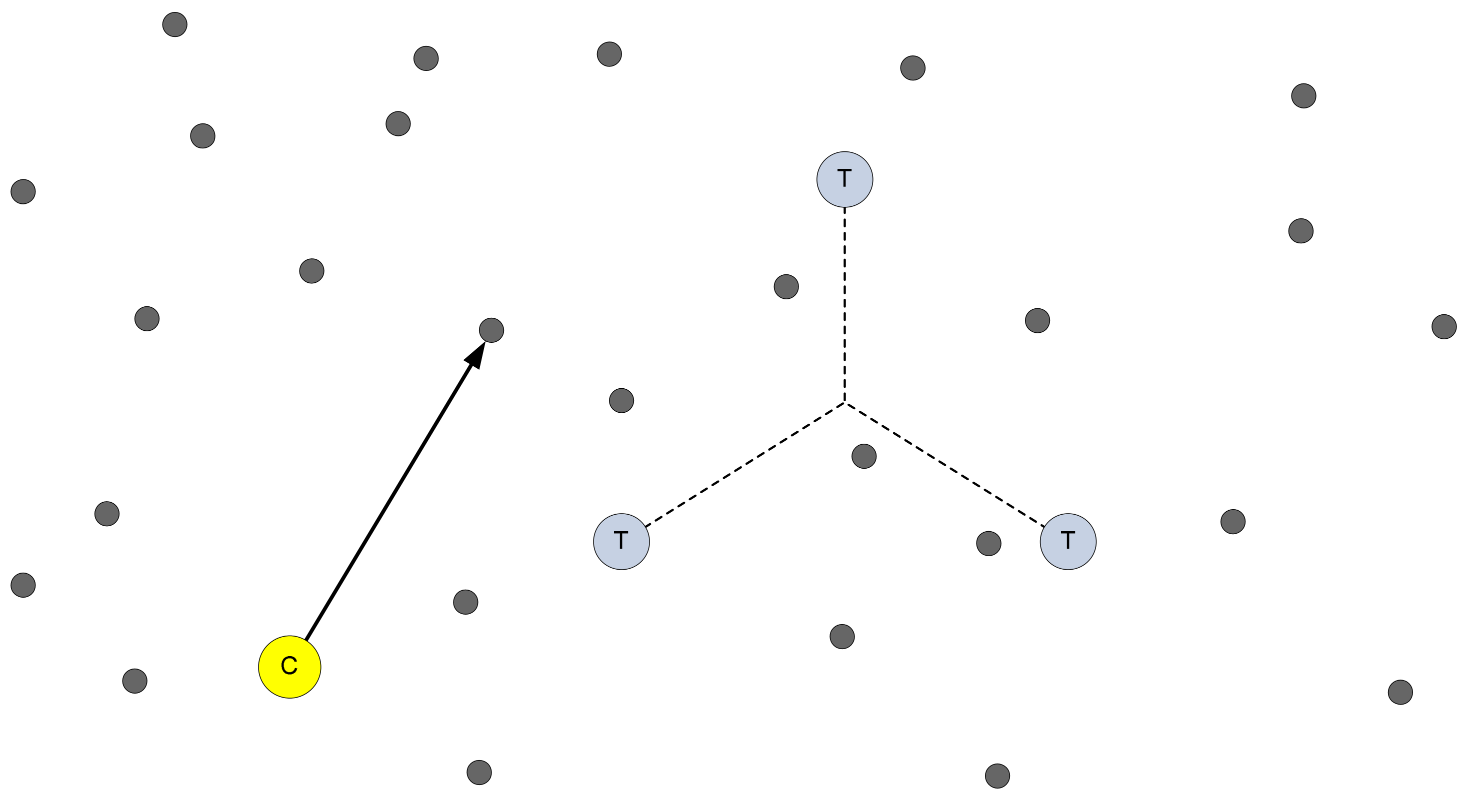
Meridian Theoretical Analysis

- Analytical guarantees for closest node discovery
- Meridian can find the closest node with high probability
  - Given nodes in a space with a *doubling* metric
  - As well as a *growth constrained* metric
- Scales well with increasing system size
- Does not lead to hot spots

Central Leader Election

- Select the closest node to the center of a set of targets
  - Multi-cast trees can place central nodes higher in the hierarchy
- Algorithm similar to closest node discovery
- Minimizes avg. latency to a set of targets instead of one target
  - Uses distance metric d_{avg} instead of d
- Inter-node latencies of targets not known
  - Need to be conservative in pruning peers

Central Leader Election



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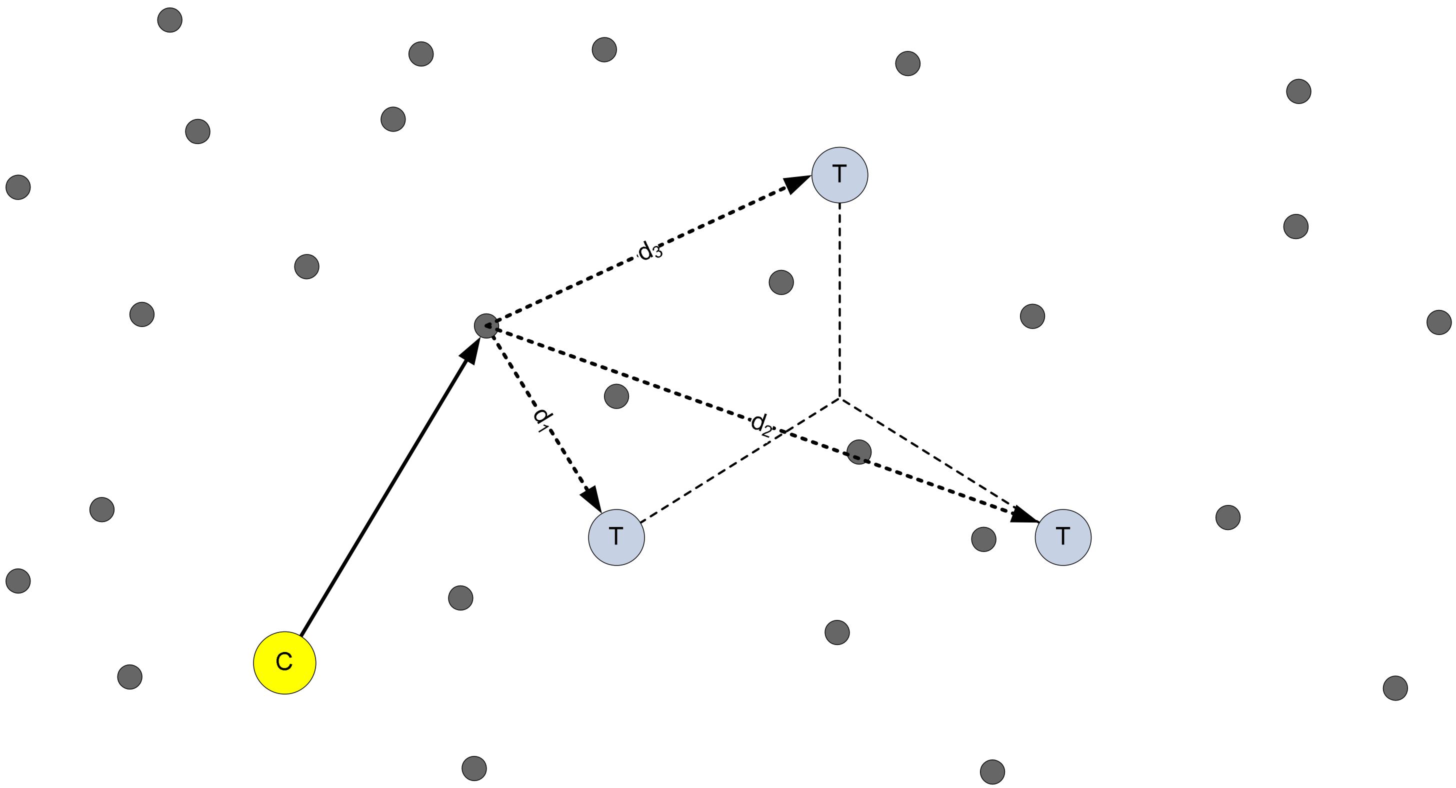

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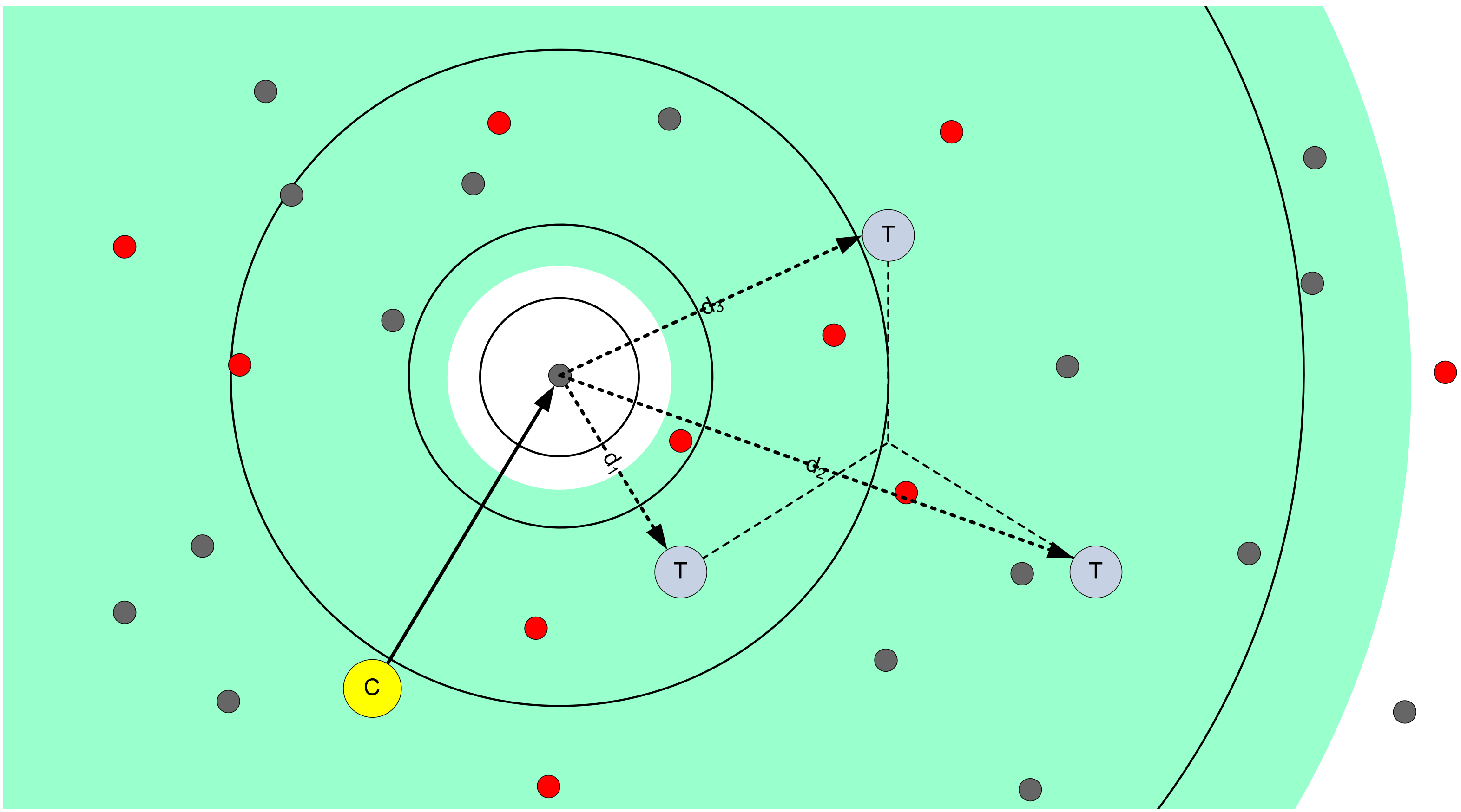

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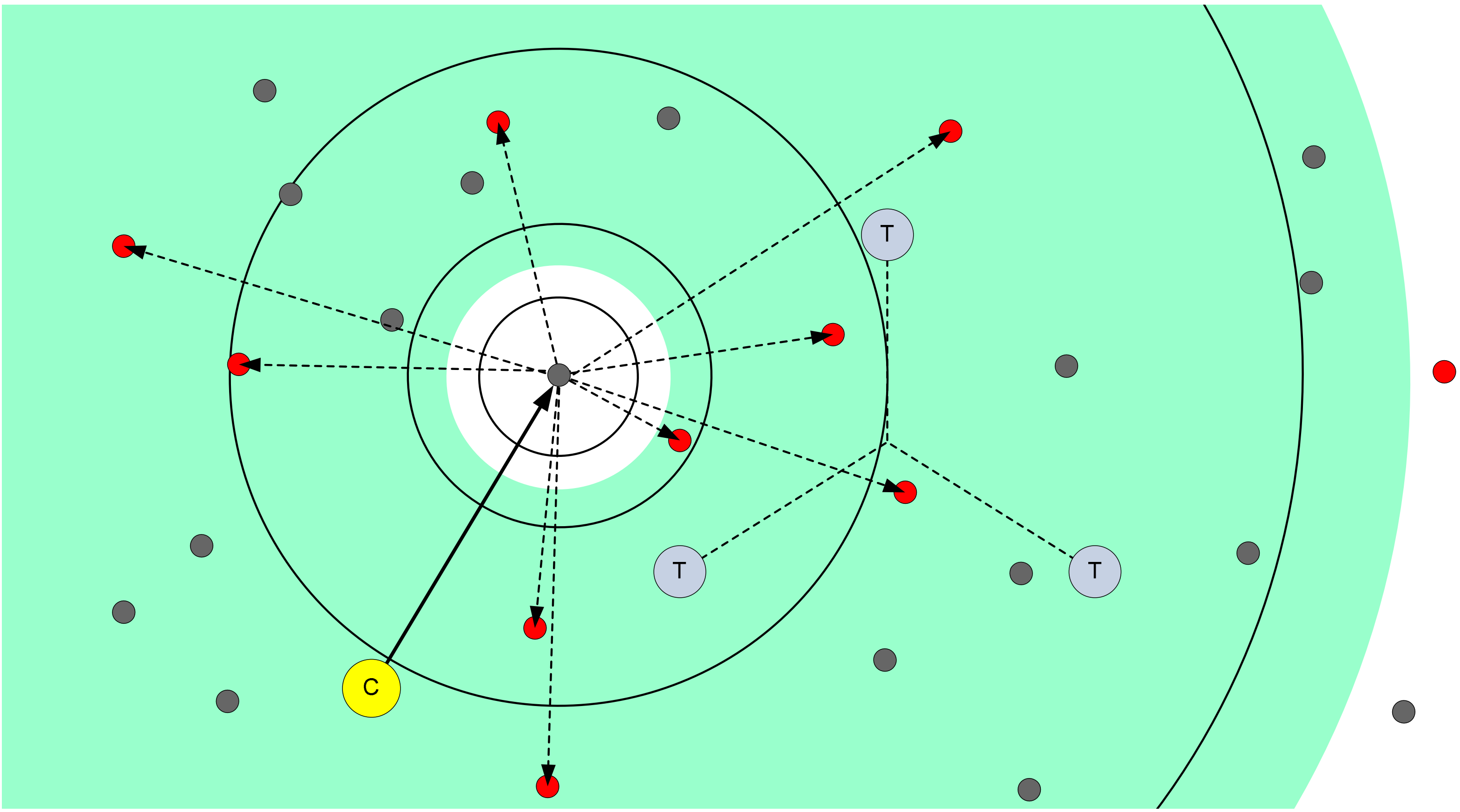

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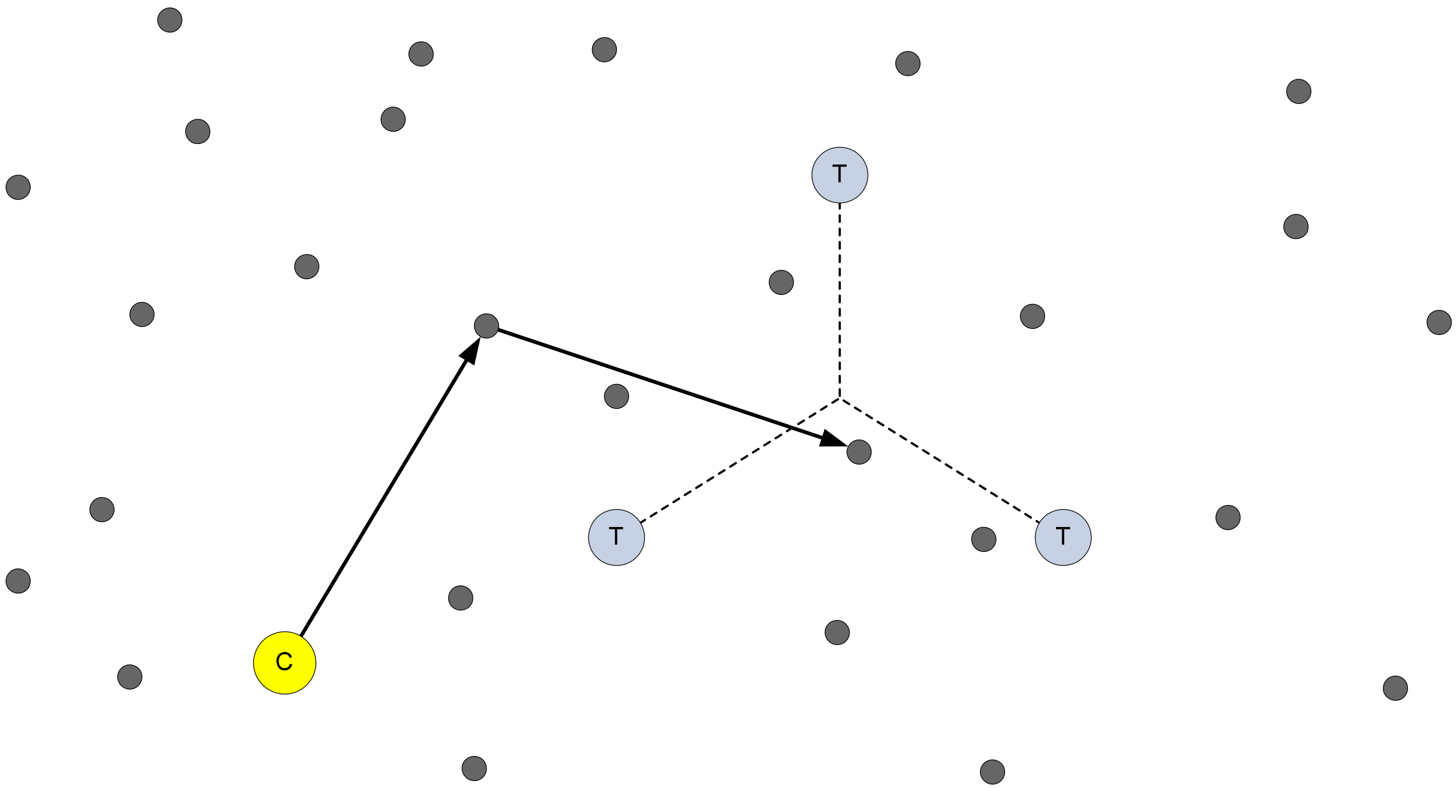

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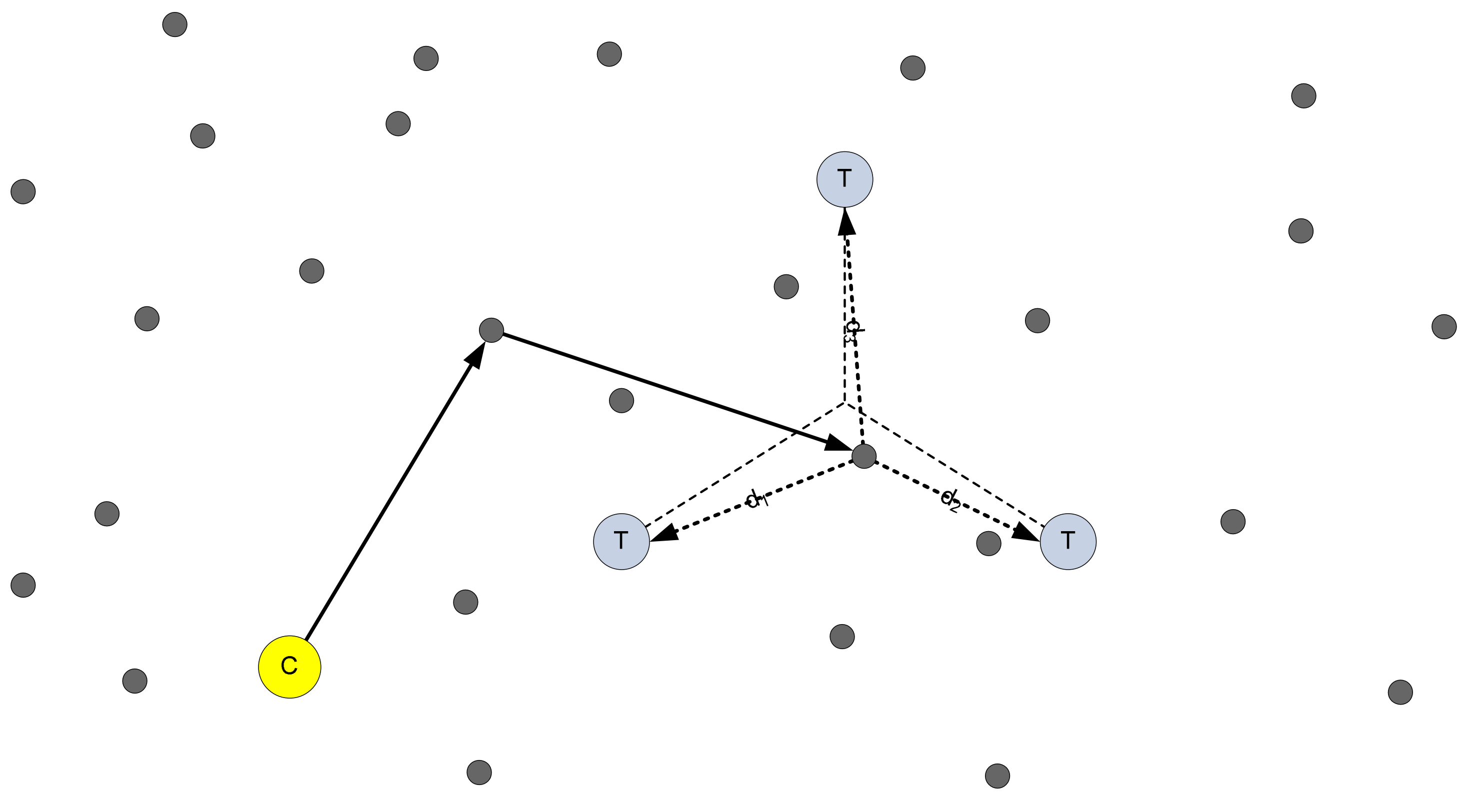

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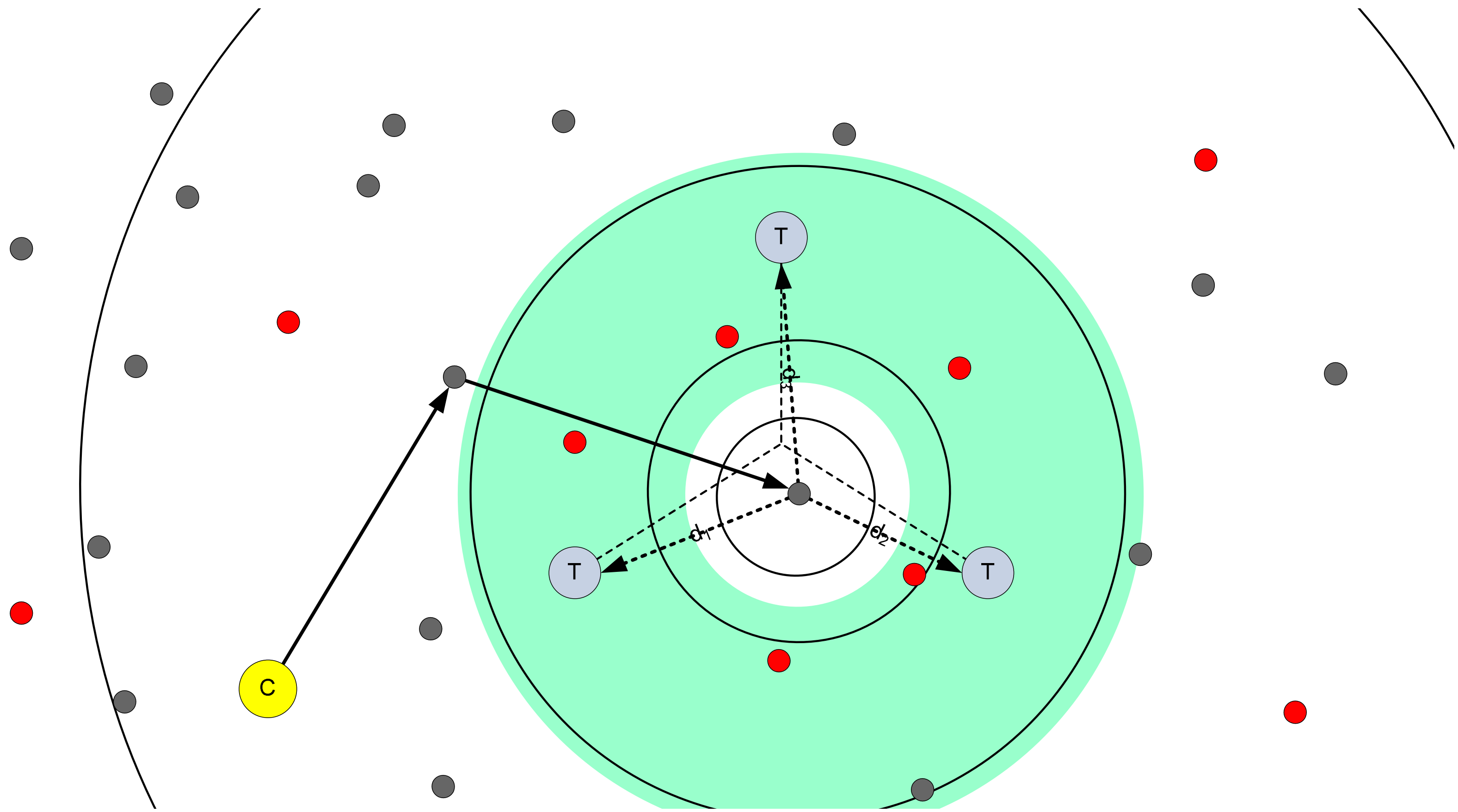

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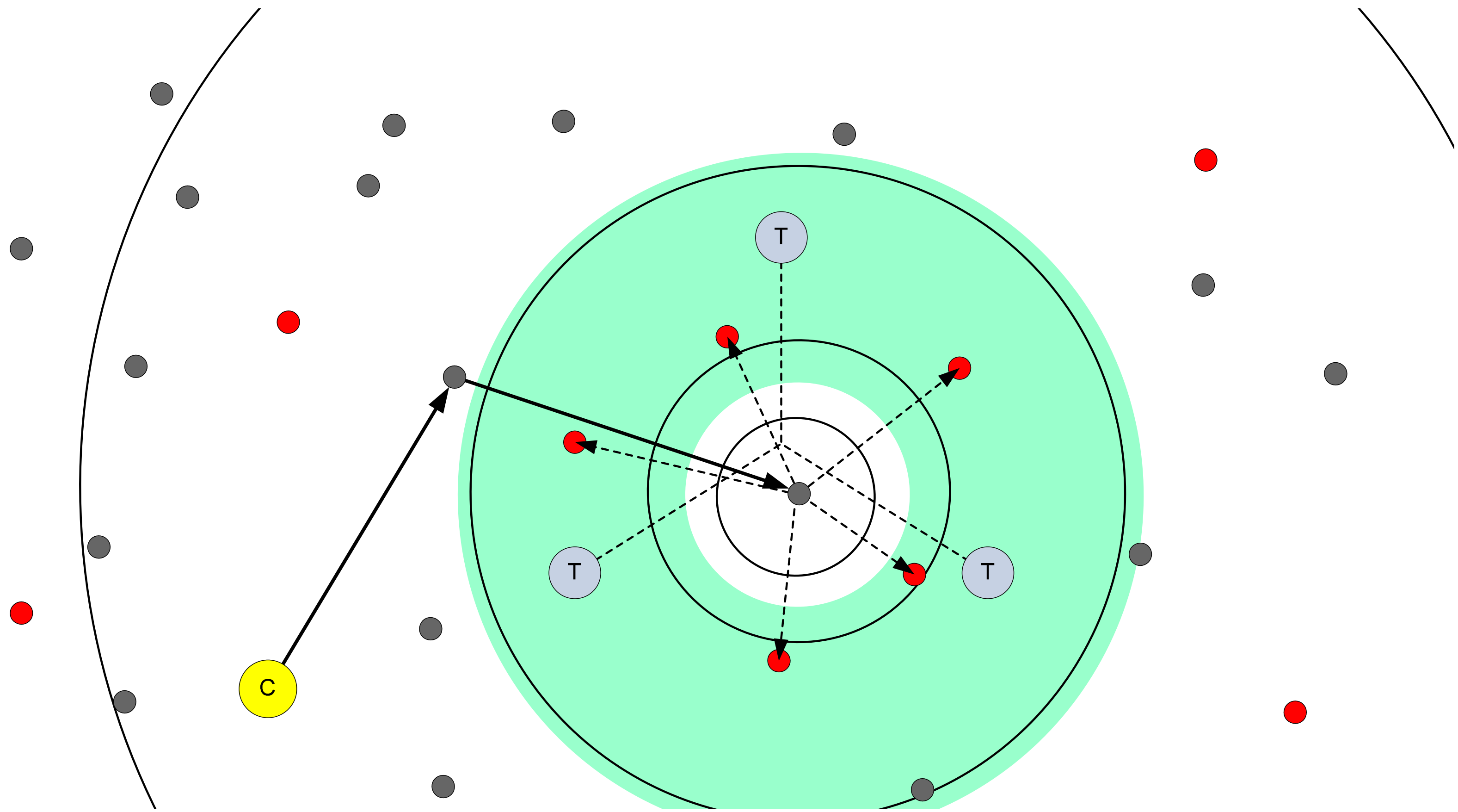

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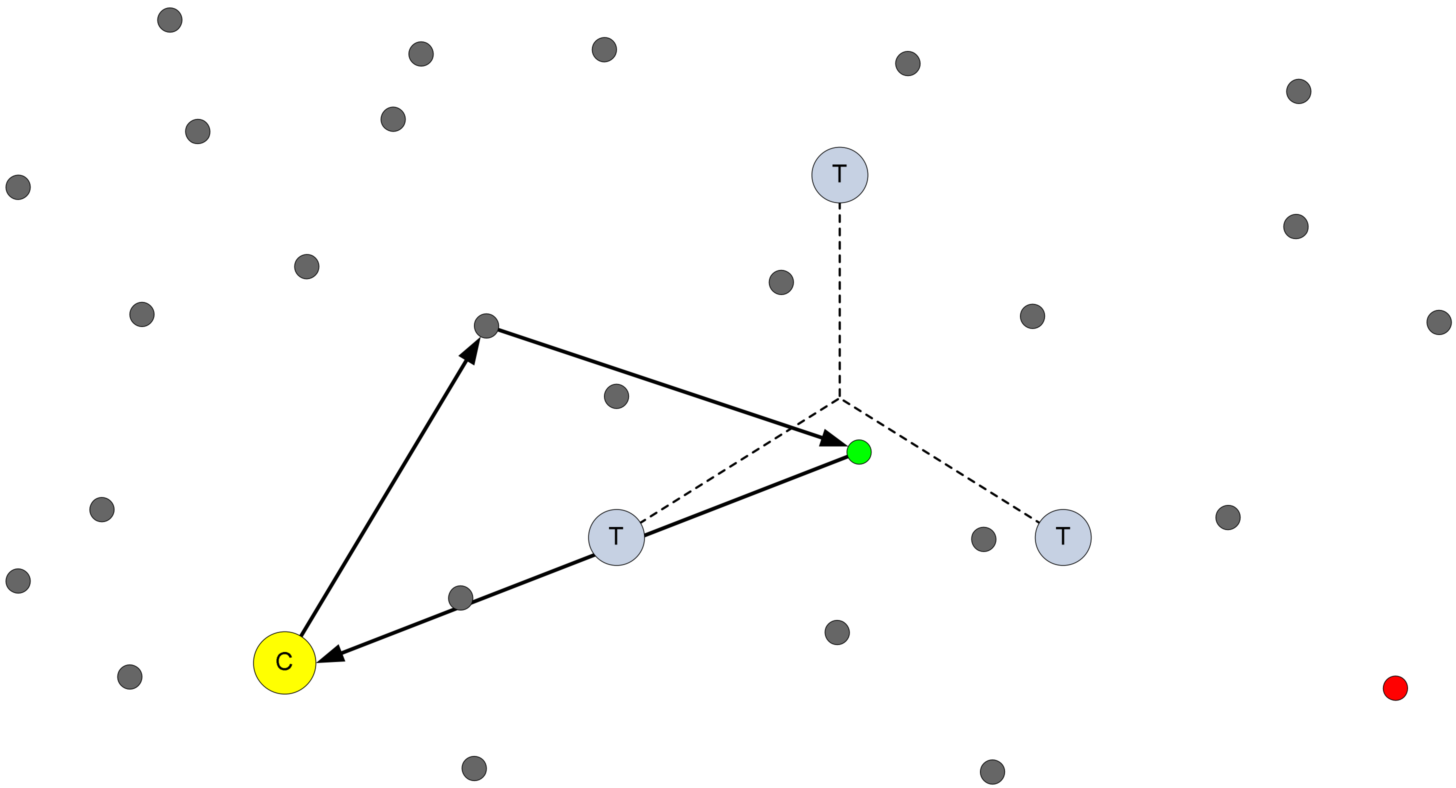
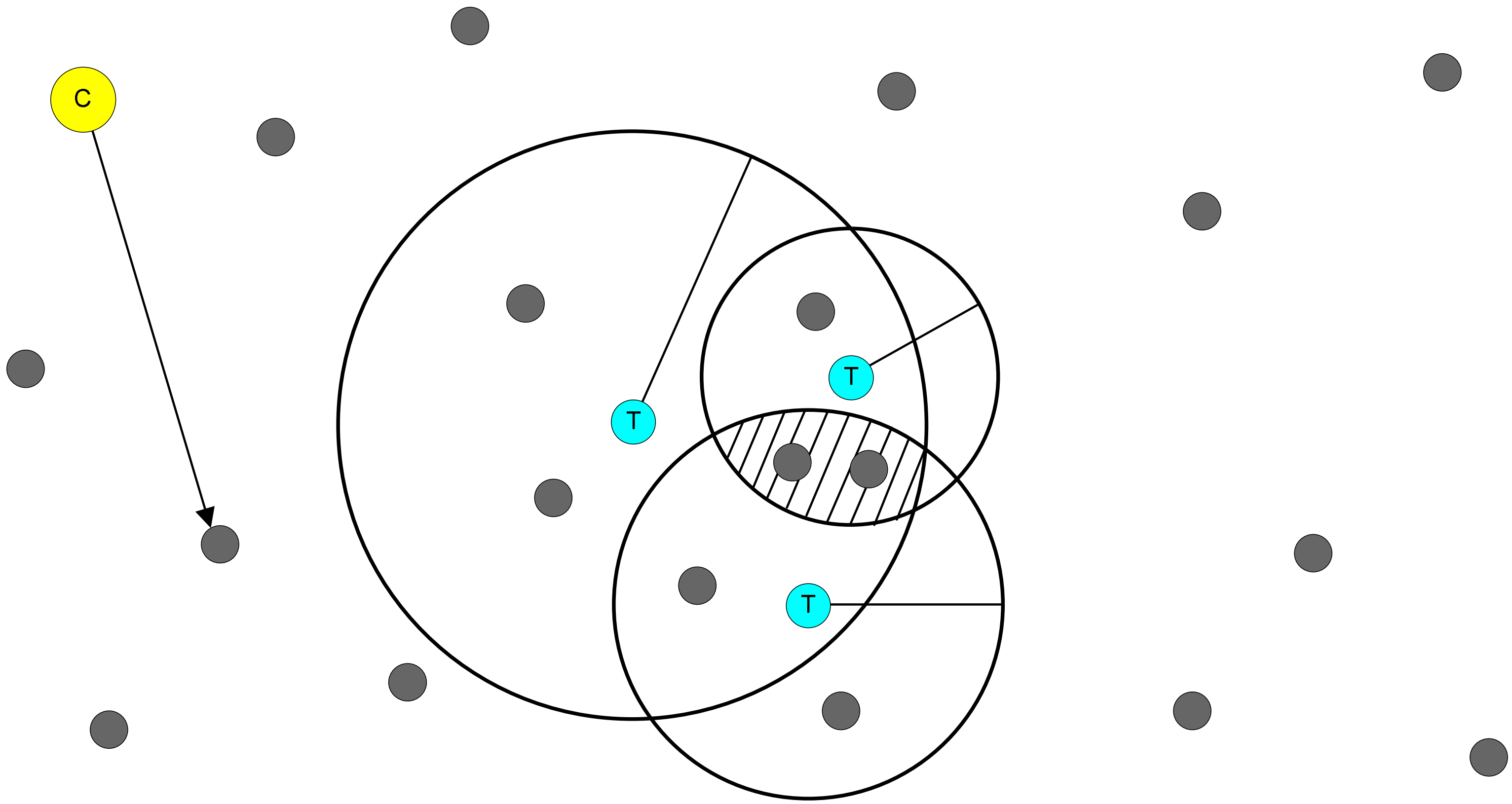


Multi-constraint System

- Find a node that satisfies a set of latency constraints
  - ISP can find a server that can satisfy a SLA with a client
  - Grid users can find a set of nodes with a bounded inter-node latency
- There exists a solution space, containing 0 or more nodes
  - Only a solution point in previous problems
- Requires a different distance metric *s* :
  - $s = \sum_{i=1}^{u} \max(0, d_i - range_i)^2$
  - s = 0 when all constraints are satisfied
  - Sum of squares places more weight on fringe constraints
    - Allows for faster convergence to solution space
  - Other metrics can be used, square works well in practice

Multi-constraint System



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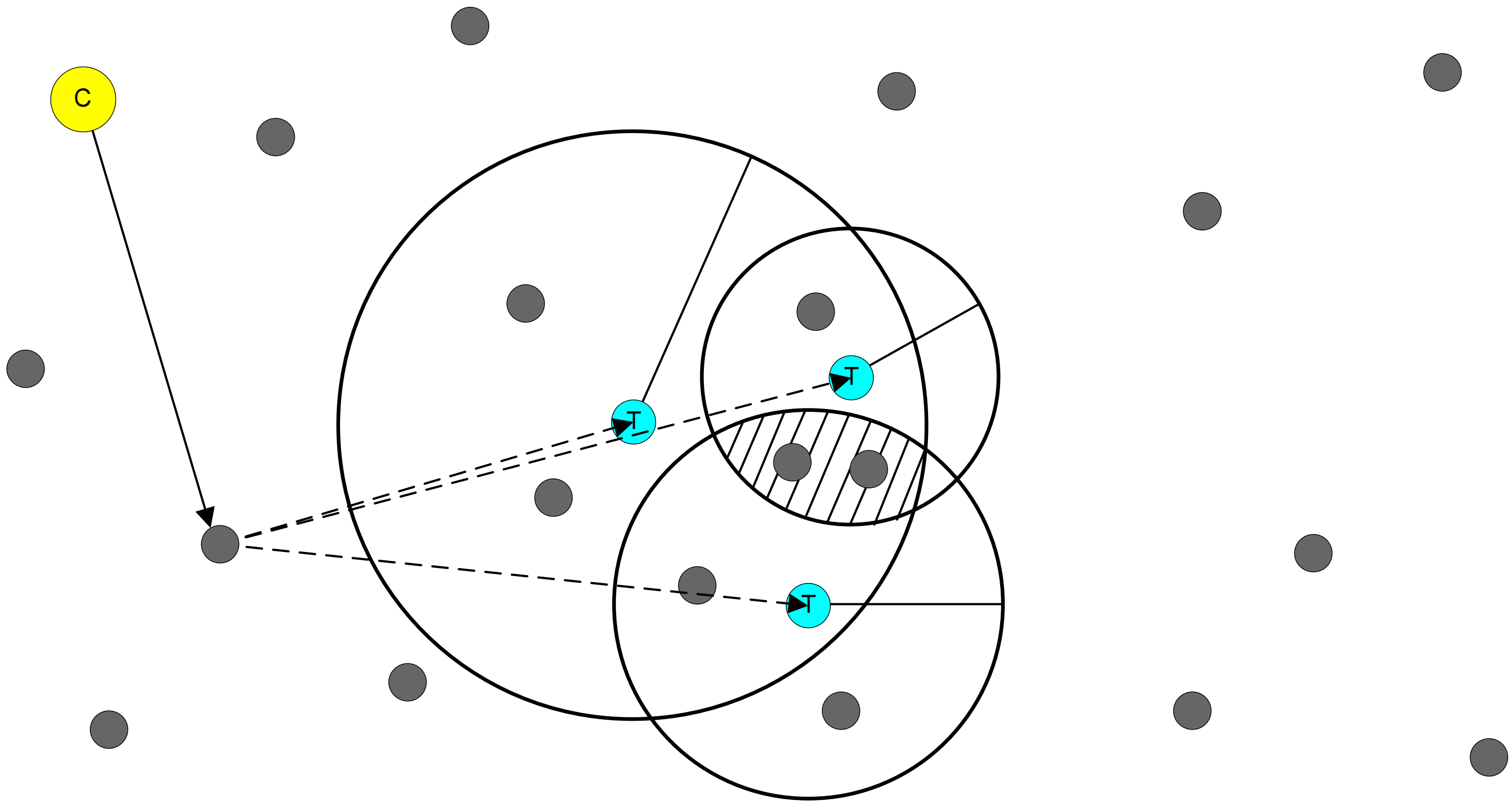

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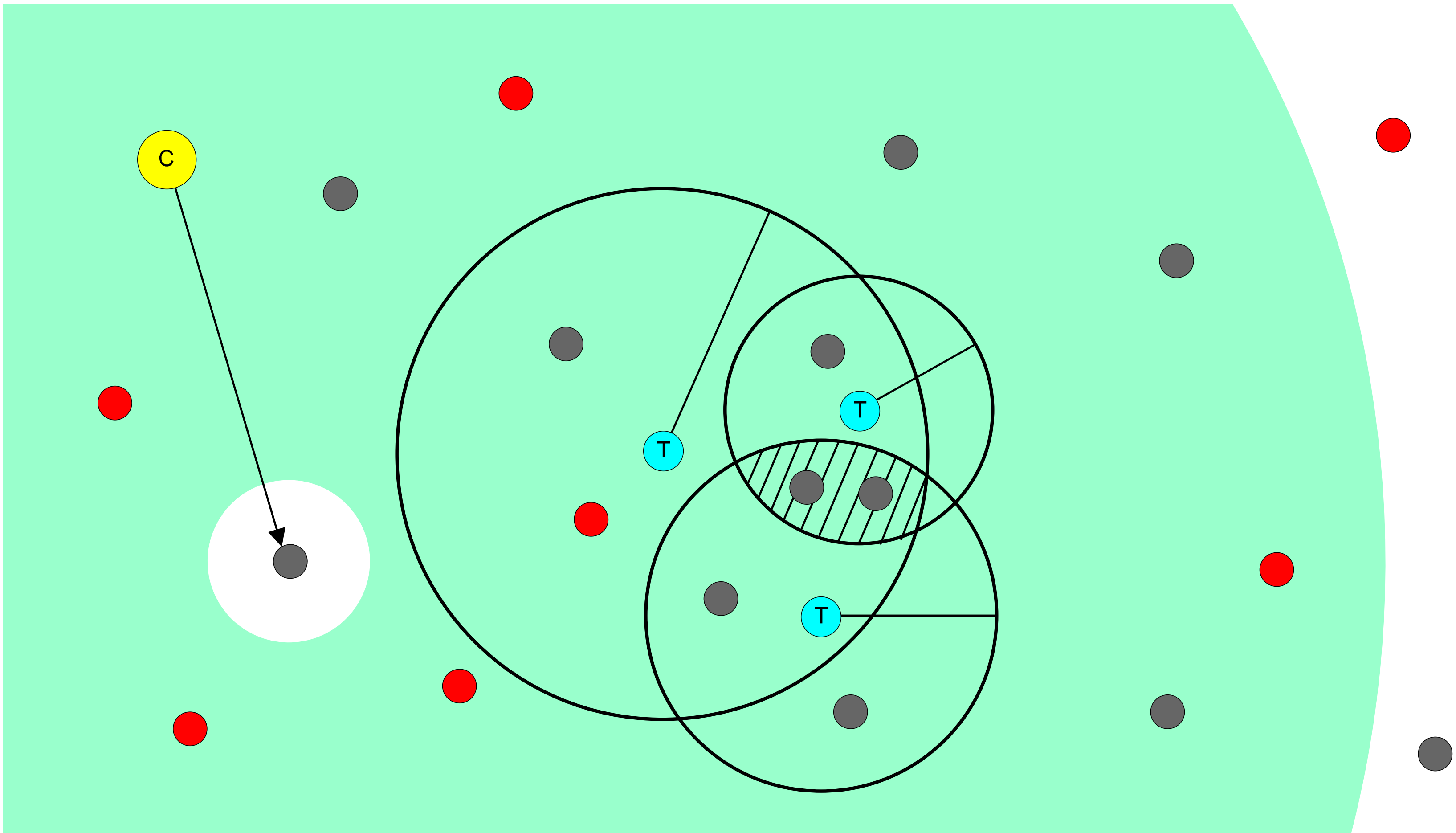

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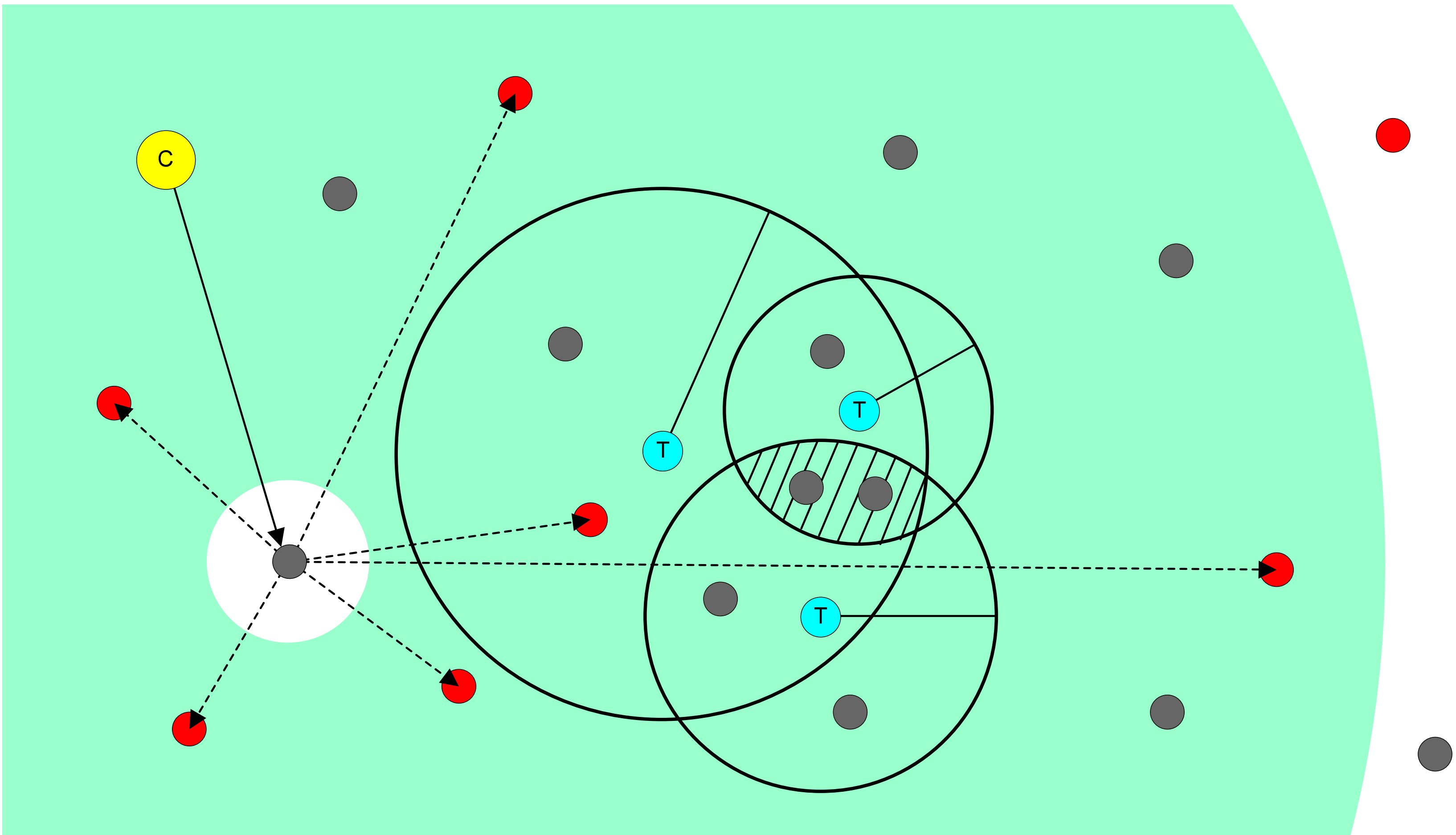

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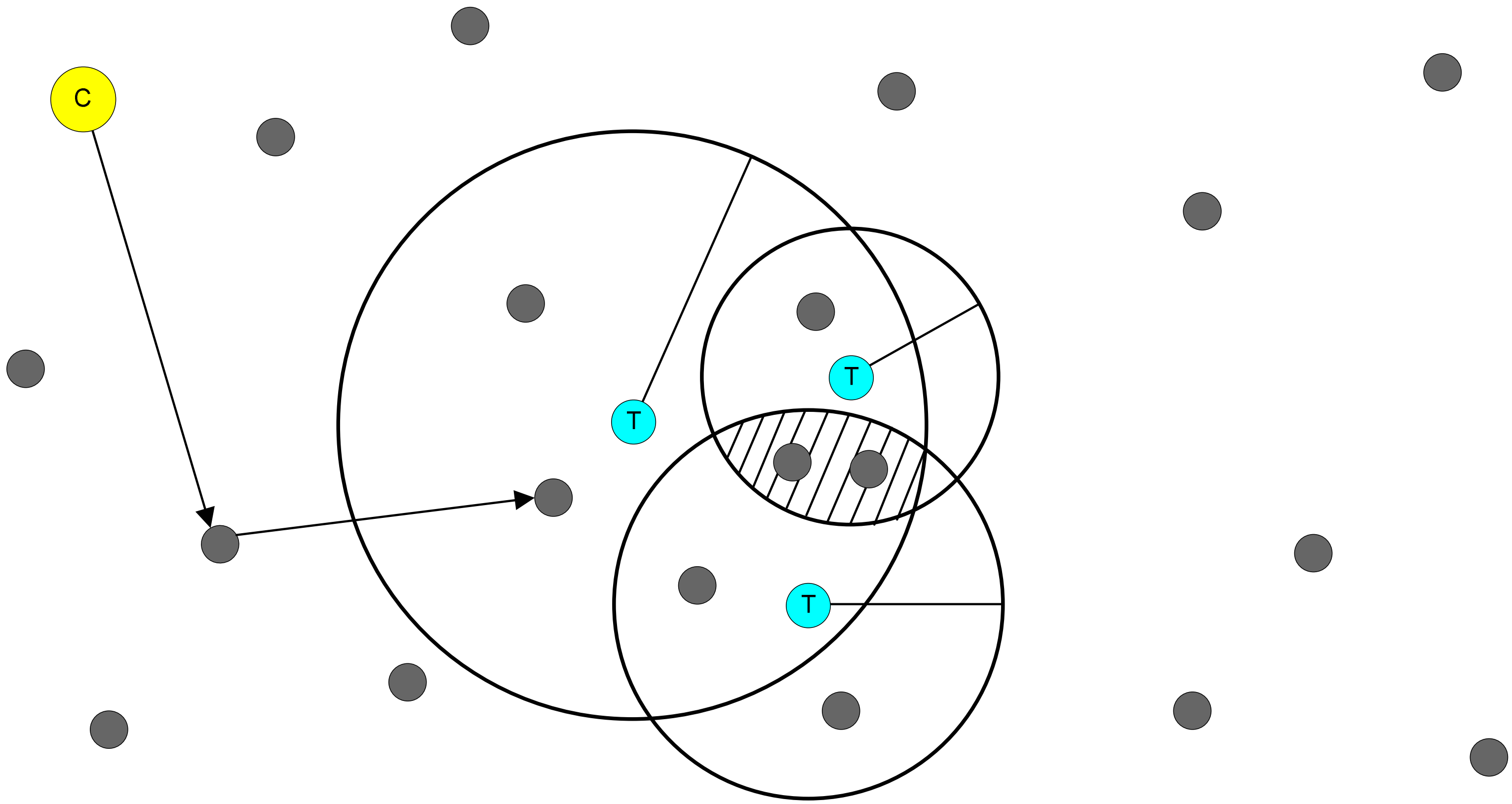

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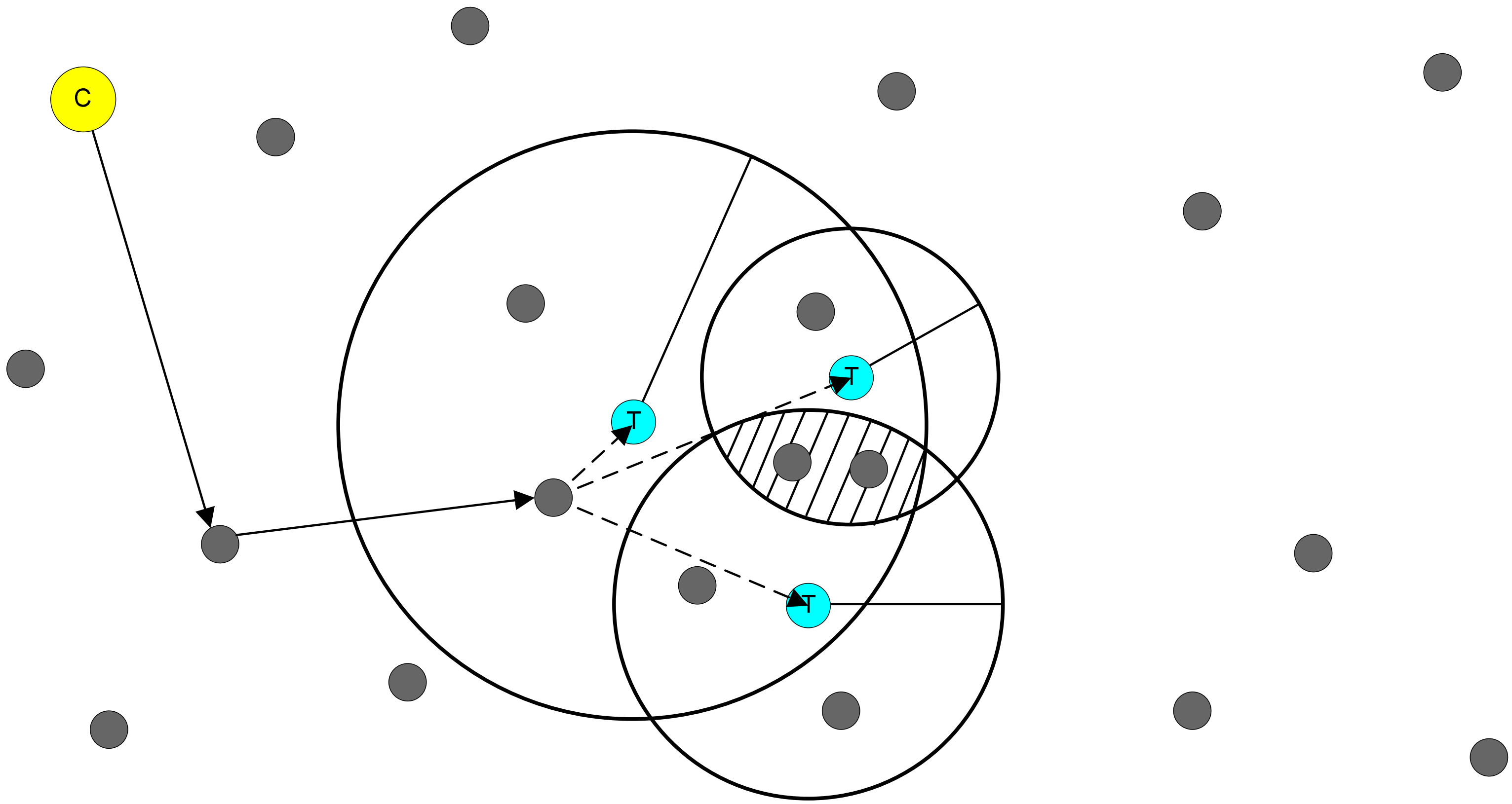

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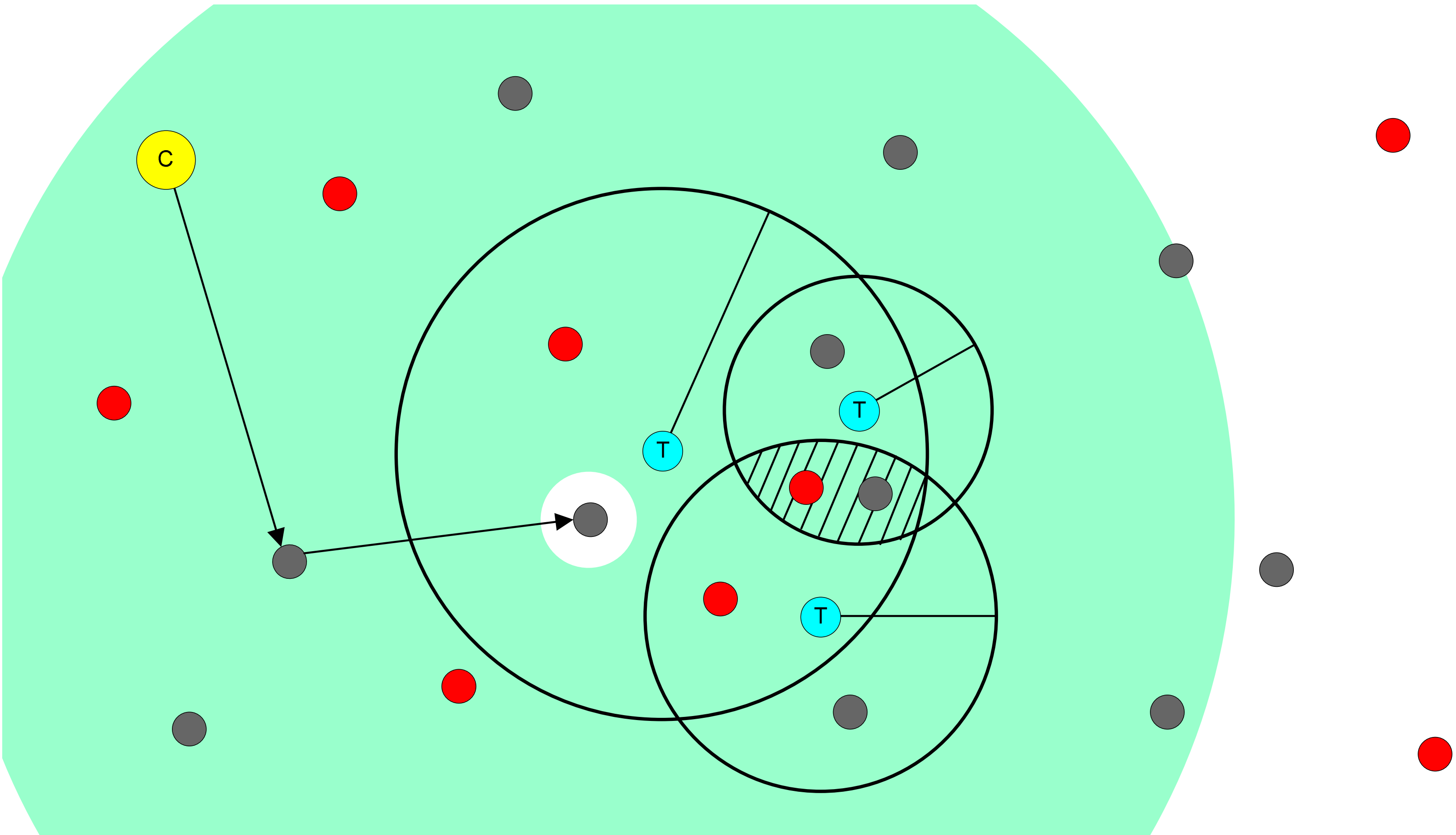

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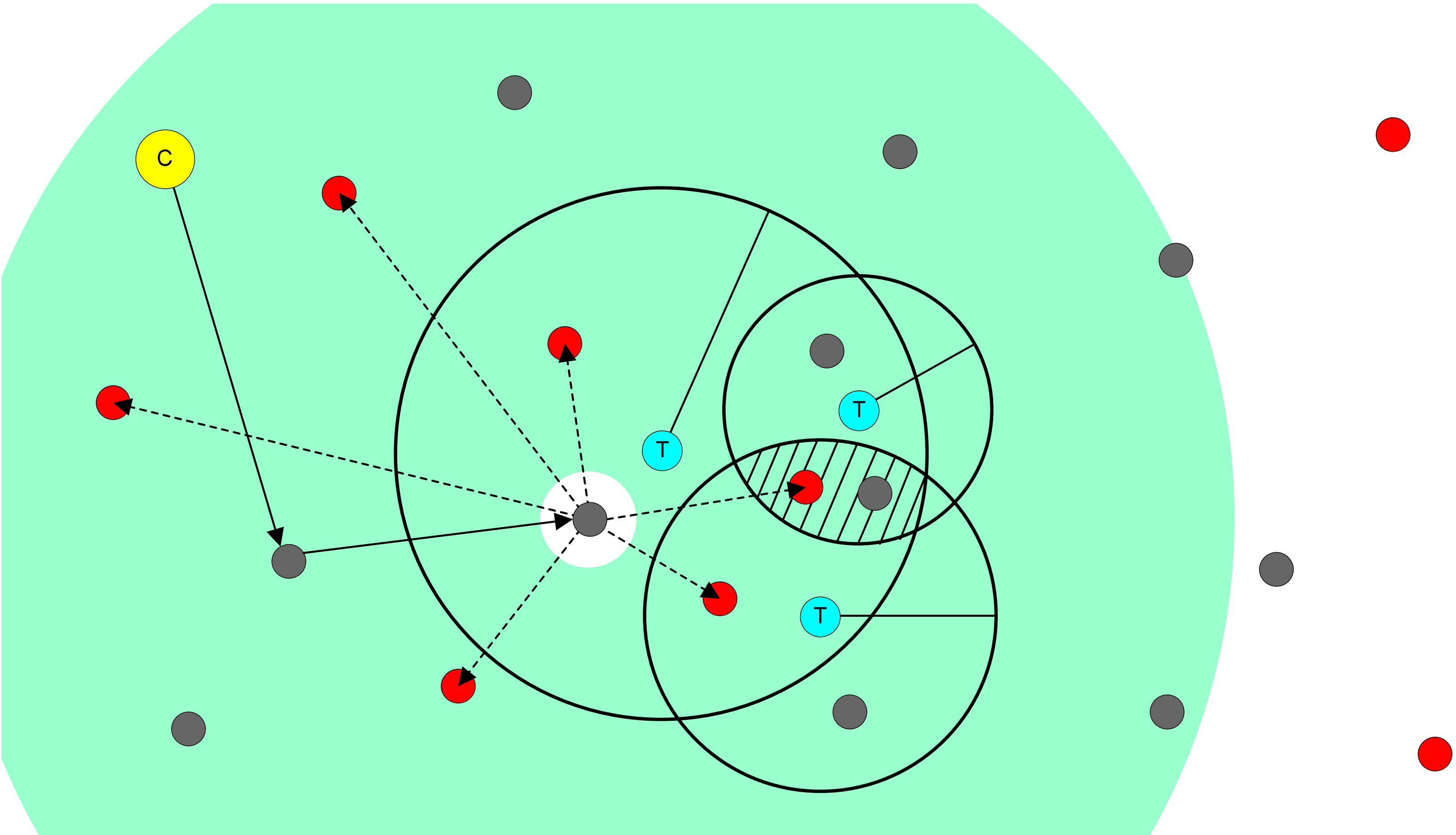

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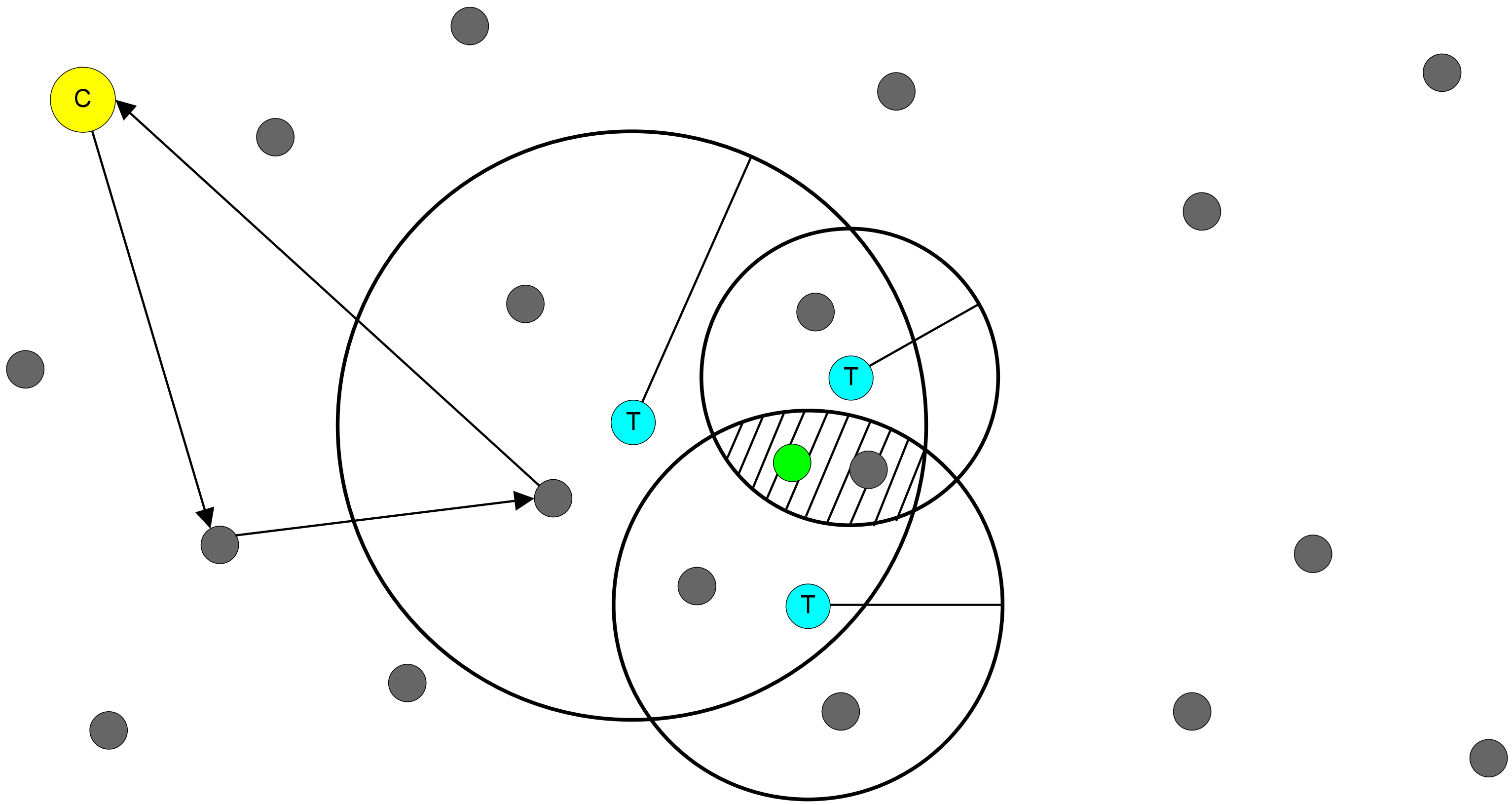


Meridian Query Language

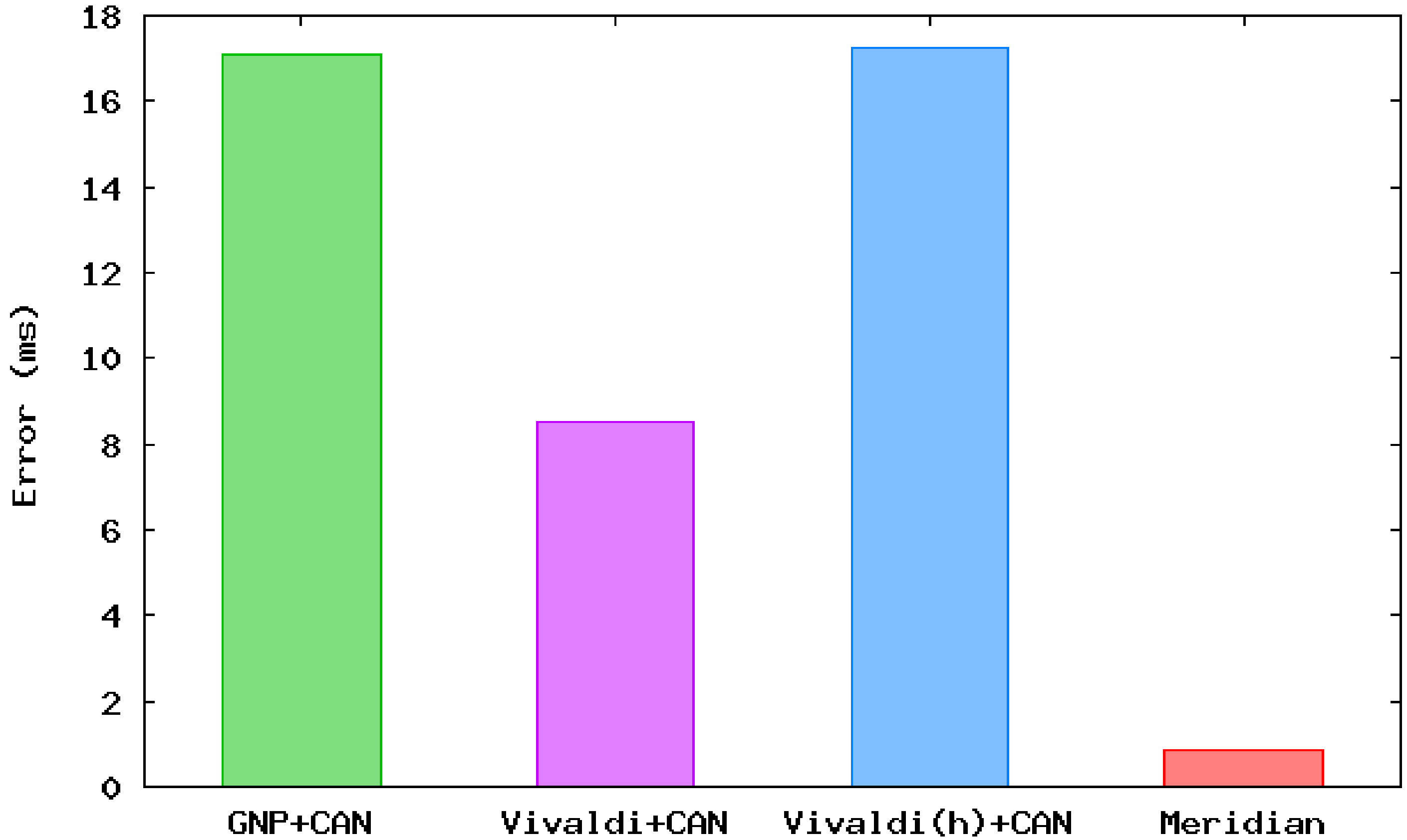
- Variant of C/Python
  - Safe, polymorphic, and dynamically-typed
  - Includes an extensive set of library functions
- Allows users to:
  - Access multi-resolution rings
  - Issue latency probes
  - Forward queries to peers
- Tight resource limits on:
  - Execution time of query
  - Number of hops
  - Amount of memory allocated

Evaluation

- Evaluated our system through a large scale simulation and a PlanetLab deployment
- Simulation parameterized by real latency measurements
  - 2500 DNS servers, latency between 6.25 million node pairs
  - DNS servers are authorities name servers for domains found in the Yahoo! web directory
- We evaluated system sizes of up to 2000 nodes
  - 500 nodes reserved as targets

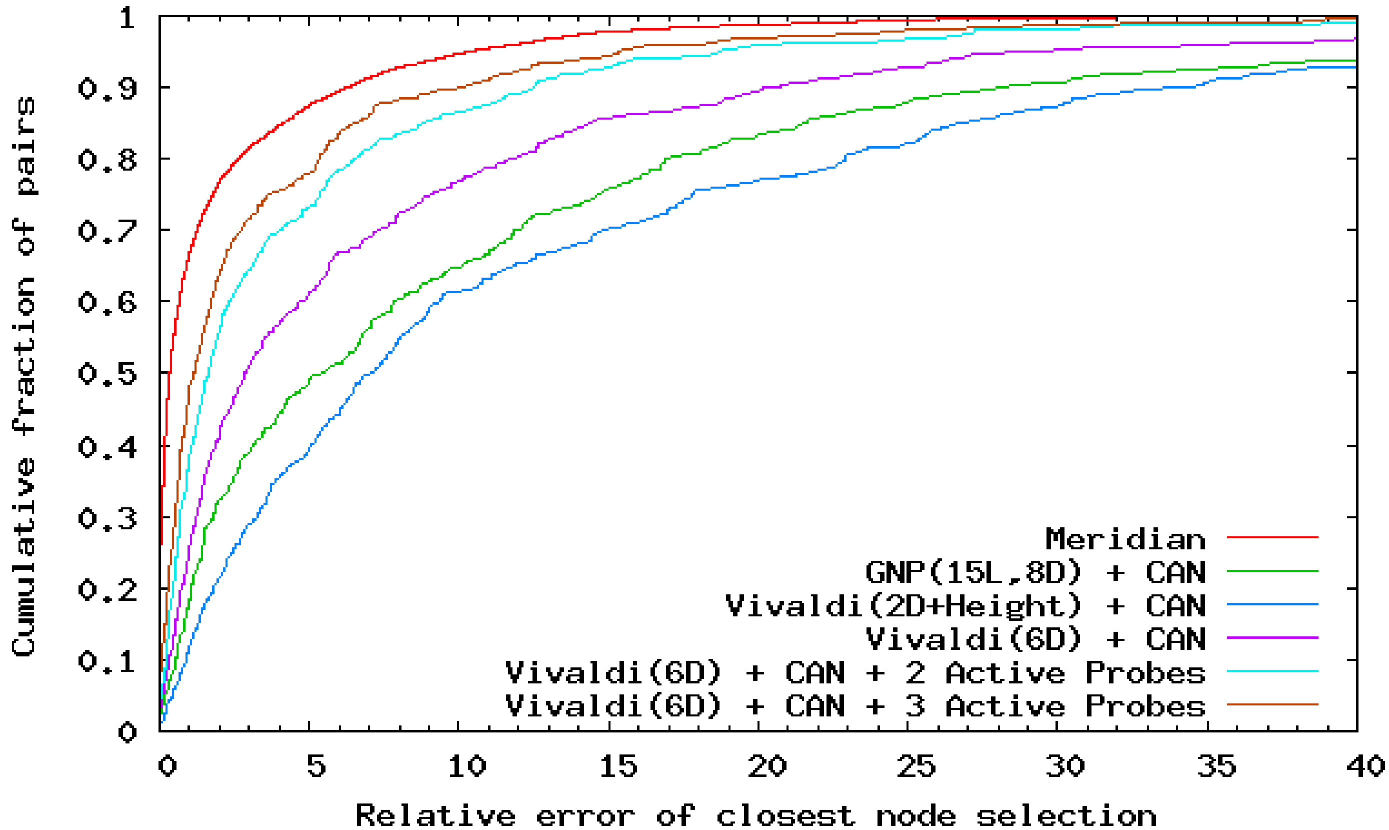
Evaluation: Closest Node Discovery

- Meridian has an order of magnitude less error than virtual coordinate schemes



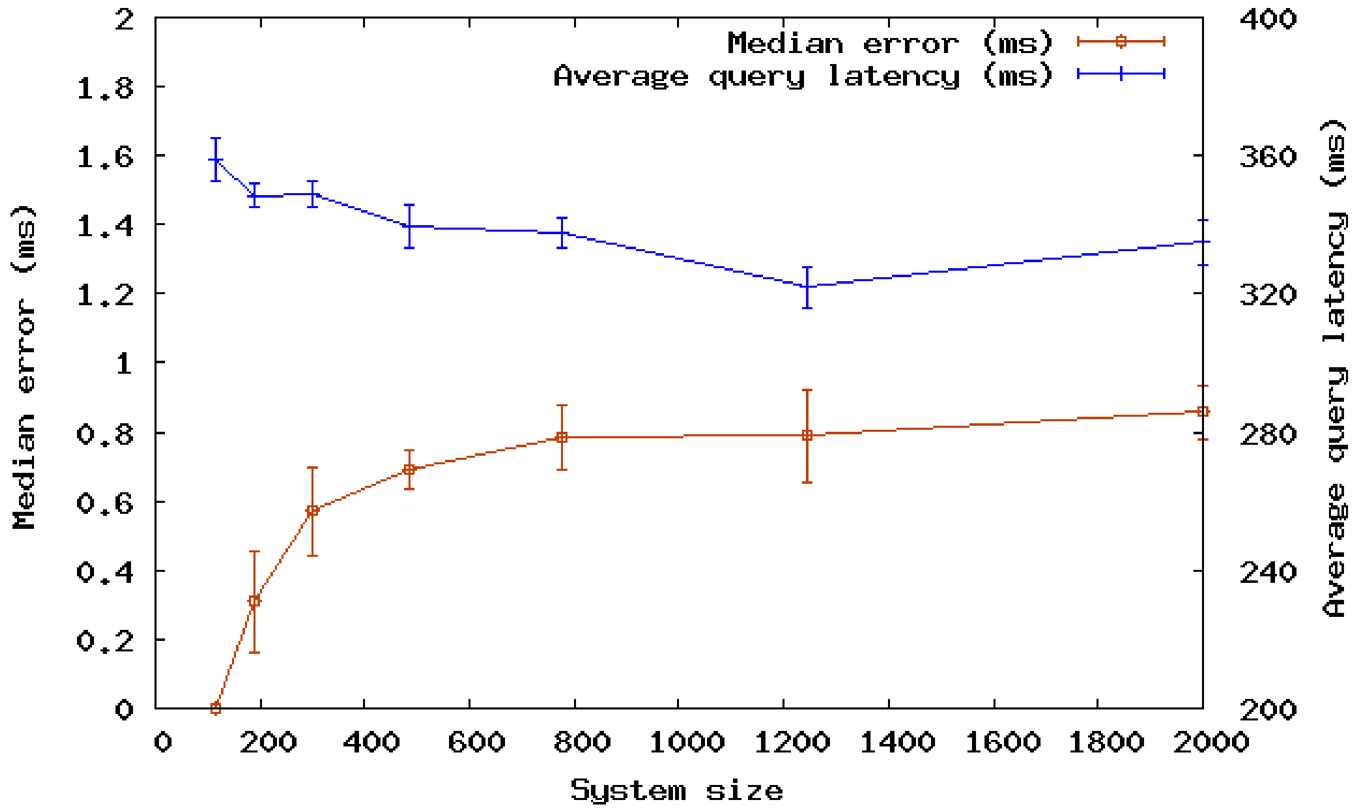
Evaluation: Closest Node Discovery

- CDF of relative error shows Meridian is more accurate for both typical nodes and fringe nodes



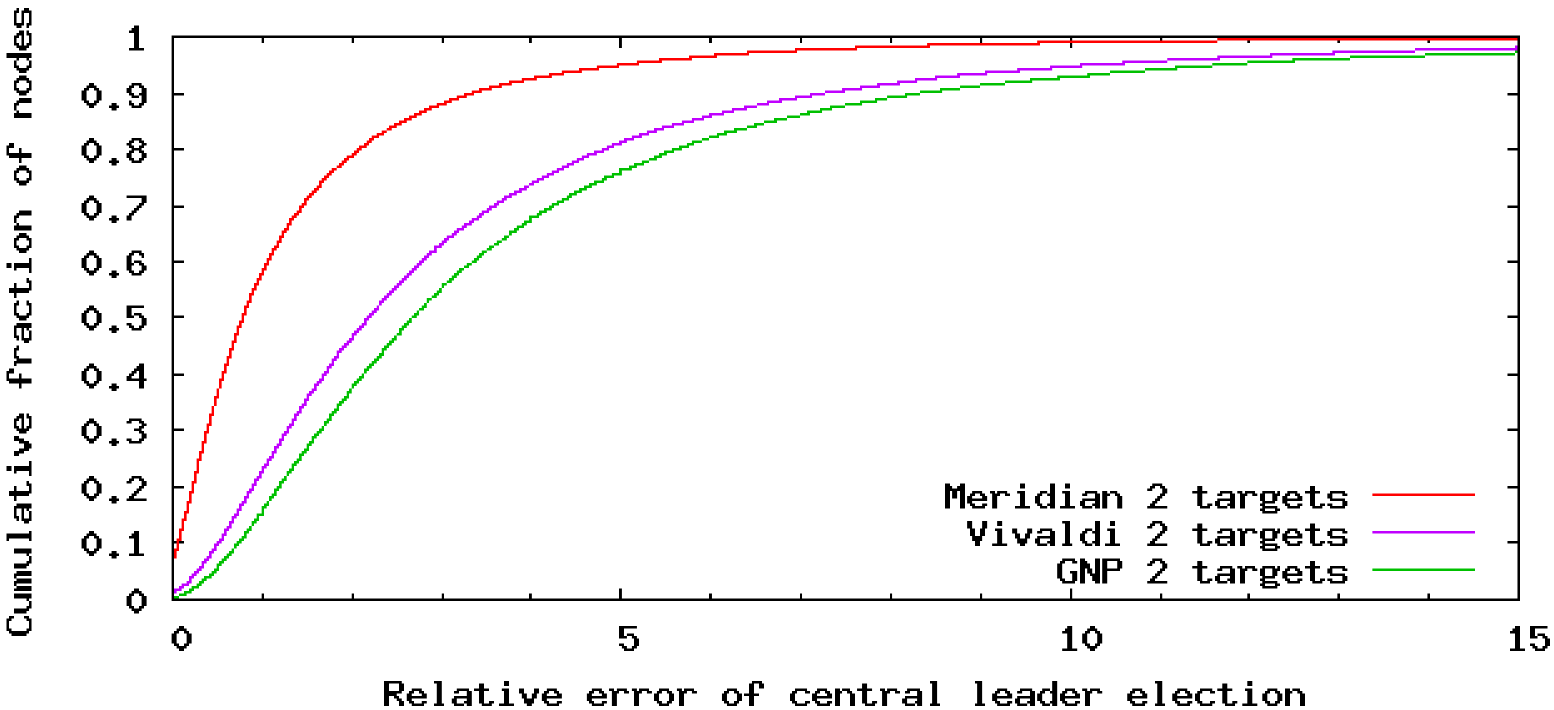
Evaluation: Closest Node Discovery

- With $k = \lfloor \log_{1.6} N \rfloor$, error and query latency remain constant as N increases
- Average query latency determined by slowest node in each ring



Evaluation: Central Leader Election

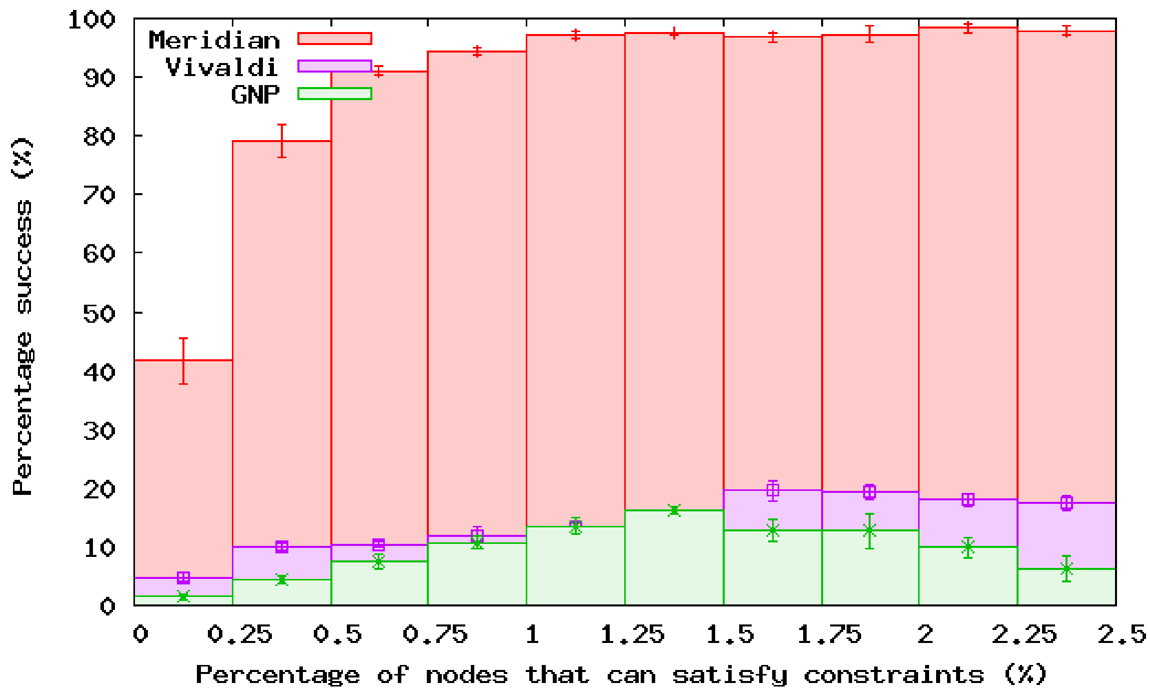
- Meridian incurs significantly less relative error



Evaluation: Multi-constraint System

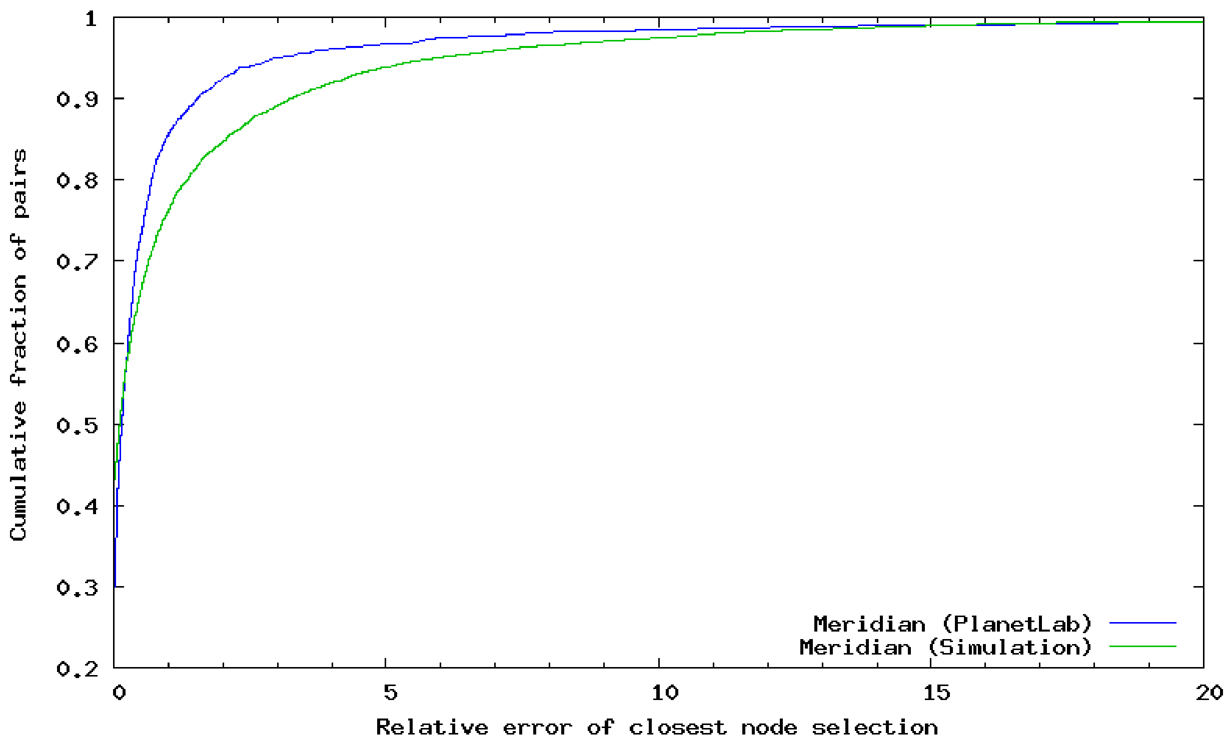
- Categorized multi-constraint queries by its difficulty
  - Difficulty a measure of the number of nodes in solution space
- Success rate for queries that can be satisfied by only 0.5% of the nodes:

2 Constraints		3 Constraints		4 Constraints	
Meridian: 91%	VC: 35%	Meridian: 90%	VC: 19%	Meridian: 91%	VC: 11%



Evaluation: PlanetLab Deployment

- A PlanetLab deployment of 166 nodes shows the closest node discovery accuracy to be very close to the simulation results
- Have expanded deployment to 325 PlanetLab nodes supporting all 3 applications and MQL



Implementation

- Includes query language and the 3 protocols
- Works with firewalled hosts
- Can use DNS queries, TCP connect times, and Meridian UDP packets to measure latency
- Optimizations:
  - Measurement cache reduces query latency
  - Ring management scheme to select more diverse peers

ClosestNode.com

- ClosestNode.com is a DNS redirection service that returns the IP address of closest node to the client
  - e.g. cobweb.closestnode.com will resolve to the closest *CobWeb* DHT node to the requesting client
- Requires minimal changes to the service
  - Linking the Meridian library and calling one function at startup
  - Or add standalone Meridian server to start script
- No changes required for the client
- Can register your service at:
  - http://www.closestnode.com

Conclusions

- A lightweight accurate system for selecting nodes
- Combines query routing with active measurements
- An order of magnitude less error than virtual coordinates
- Solves the network location problem directly
  - Does not need to be paired with CAN
- Code, data, demos and more information at

  http://www.cs.cornell.edu/People/egs/meridian