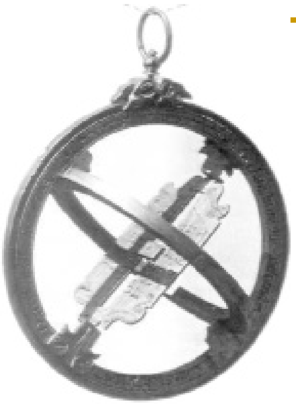
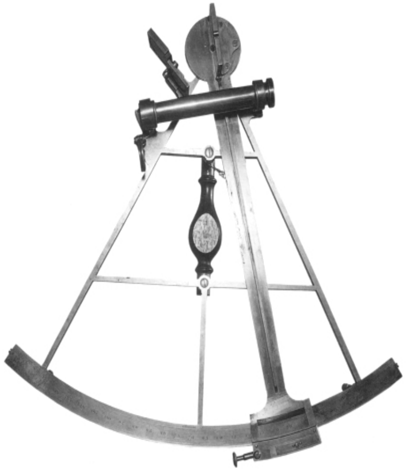


Network Positioning for Wide-Area and Wireless Networks



Emin Gün Sirer

Department of Computer Science
Cornell University

Localization is Critical

- Locality information is the building block for novel services in wired and wireless networks
  - Critical to find out where in the physical world nodes (and other items of interest) are
    - Locality-aware content, computing, routing, service discovery, event tracking in sensor networks, ...
  - Critical to select servers based on the position of target nodes
    - Find closest server, find centrally located node, find node within latency bounds

Sextant

Determining the location of nodes and events in wireless (ad hoc, sensor) networks

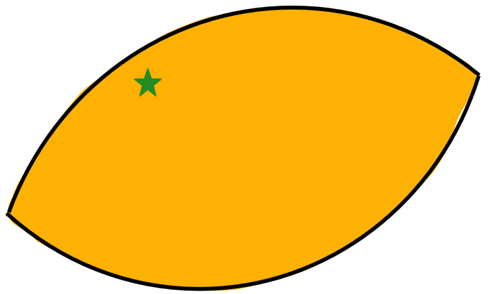
Localization in Wireless Networks

- Infrastructure-based hardware (GPS) is the traditional solution
  - Expensive
  - Power-hungry
  - Does not work indoors, without infrastructure
- How well can we do with intelligent software and cheap, ubiquitous hardware?

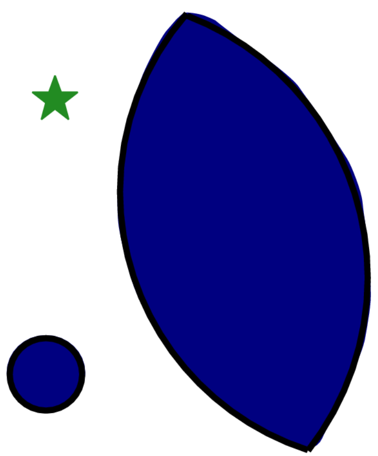
Sextant Approach

- Treat localization as a constraint-satisfaction problem
  - Extract constraints aggressively from the network
  - Disseminate them transitively
  - Solve in a distributed manner

Sextant Properties



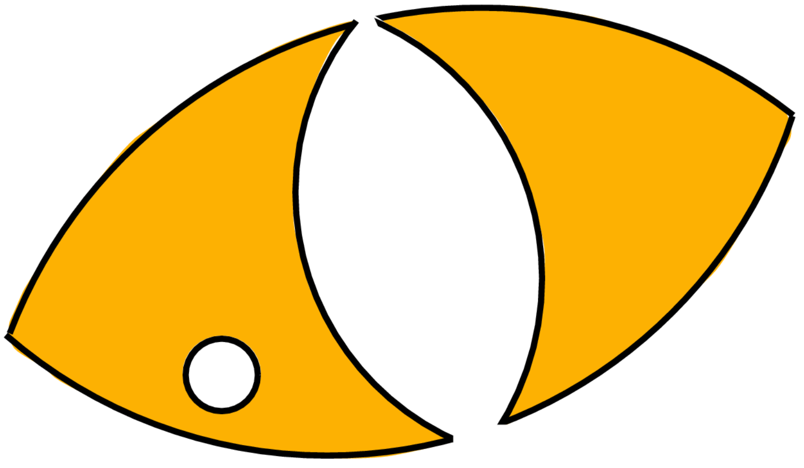
Positive Constraint



Negative Constraint

- Accurate
  - Negative as well as positive information
  - Explicit representation
- Practical
  - Constraint extraction
  - Deployed on Mica-2 motes, PDAs and laptops

Sextant Properties



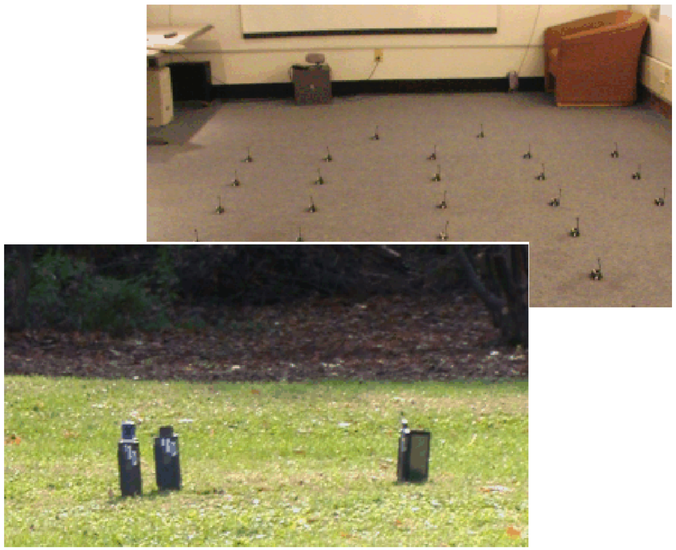
Need not be convex

May have holes

May have disconnected components

- Accurate
  - Negative as well as positive information
  - Explicit representation
- Practical
  - Constraint extraction
  - Deployed on Mica-2 motes, PDAs and laptops

Sextant Properties



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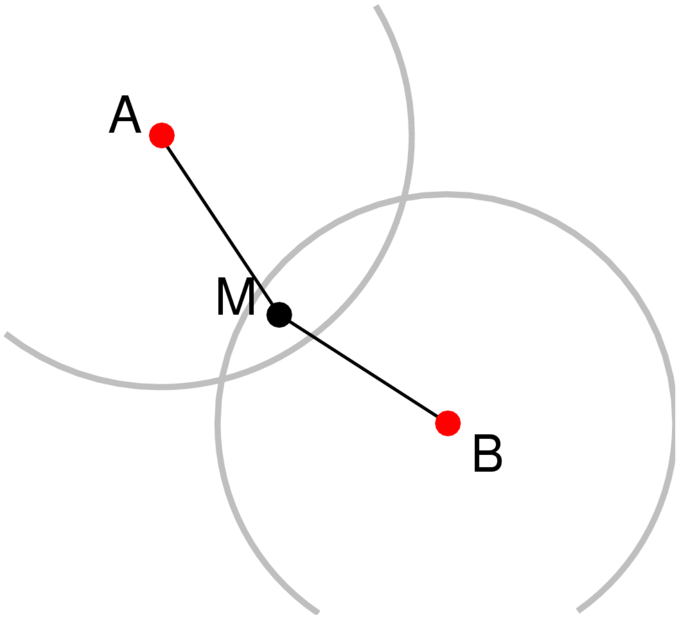
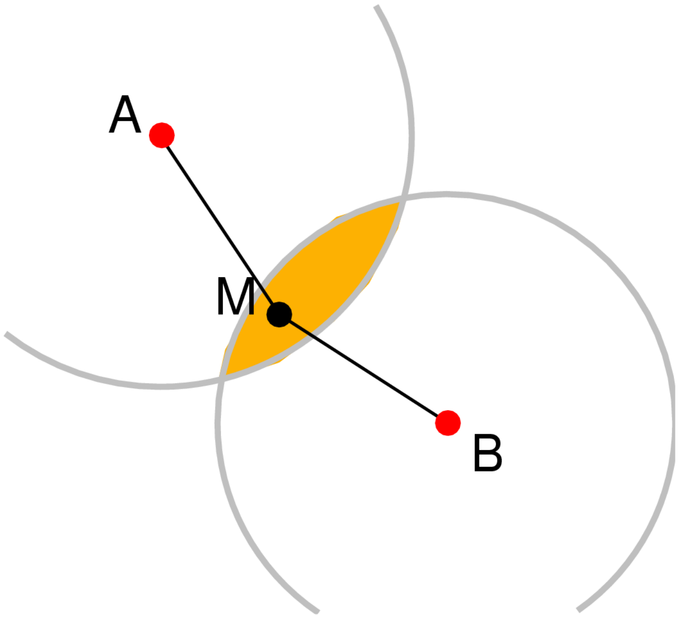
Node Localization



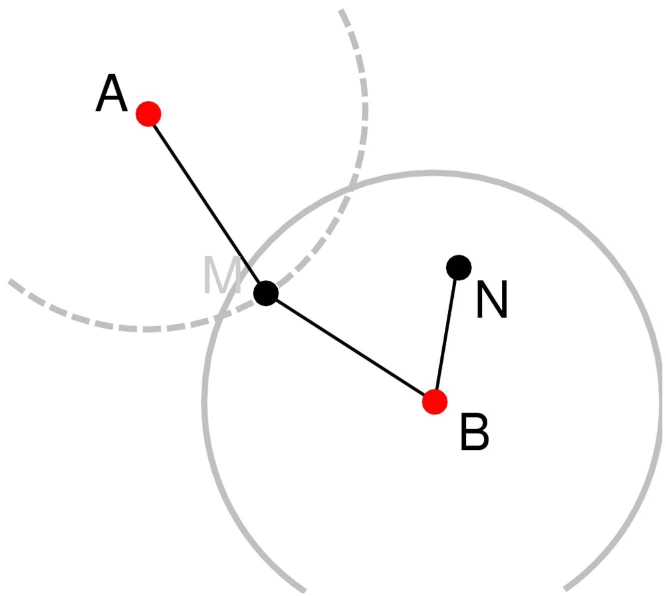
Positive information

Node Localization



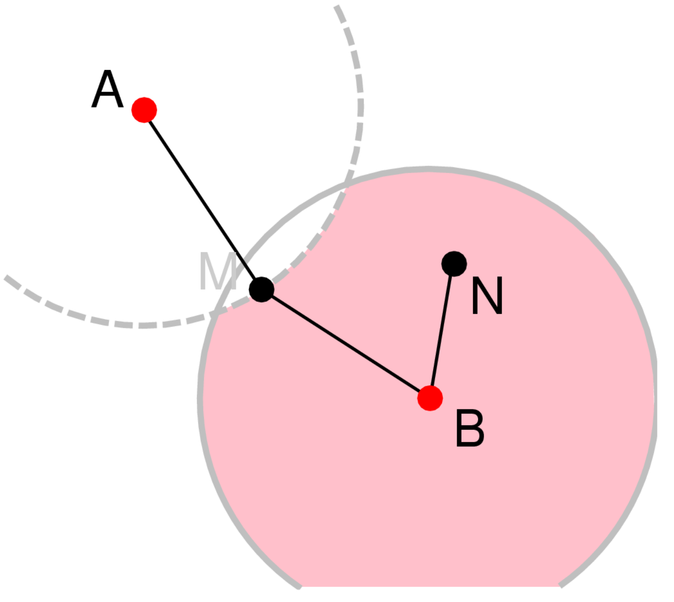
Intersection of Positive information

Node Localization



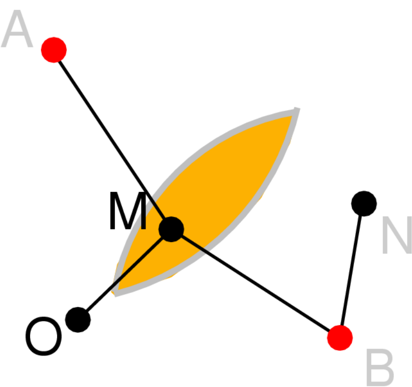
Negative information

Node Localization



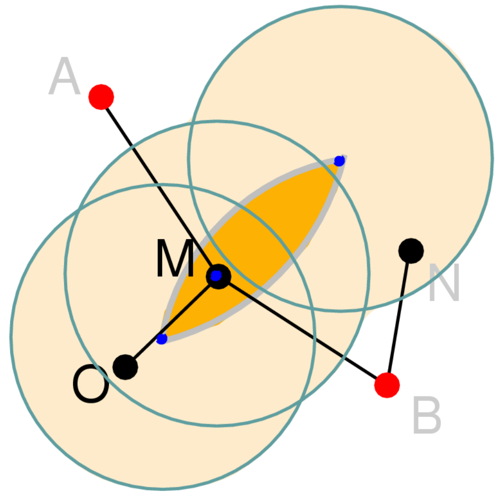
Positive information

Node Localization



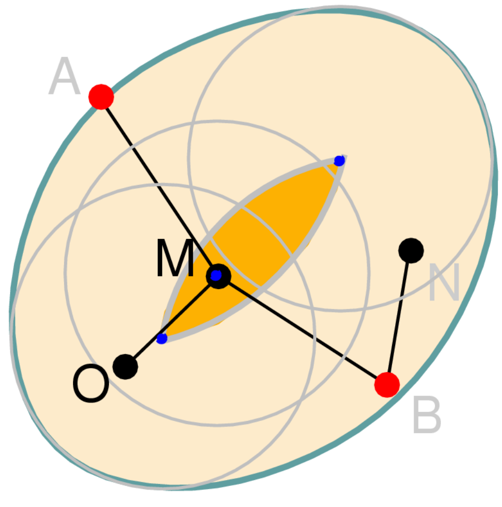
Transitive dissemination of positive information

Node Localization



Transitive dissemination of positive information

Node Localization



Transitive dissemination of positive information

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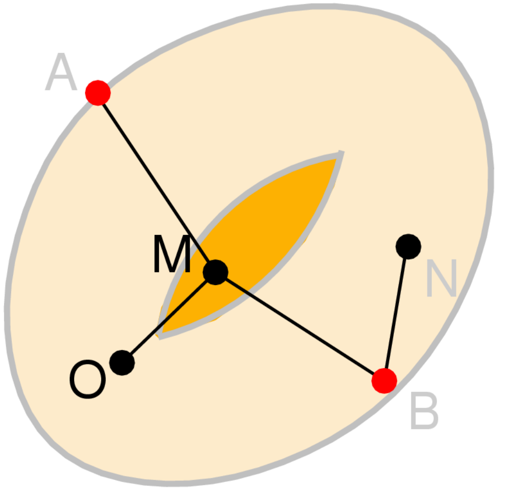

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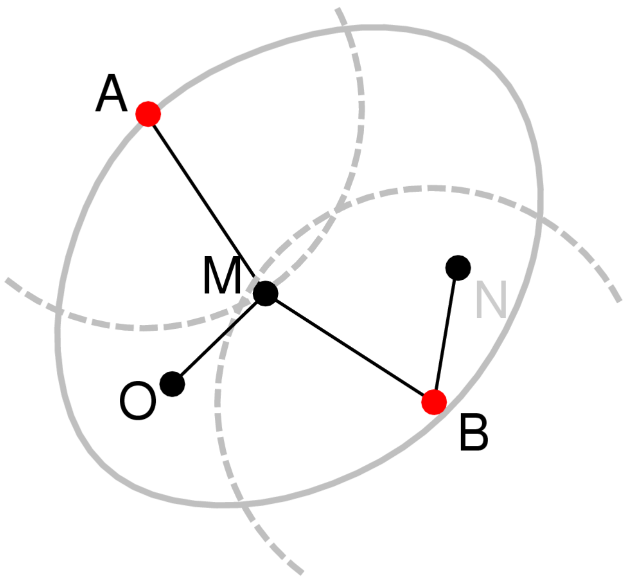
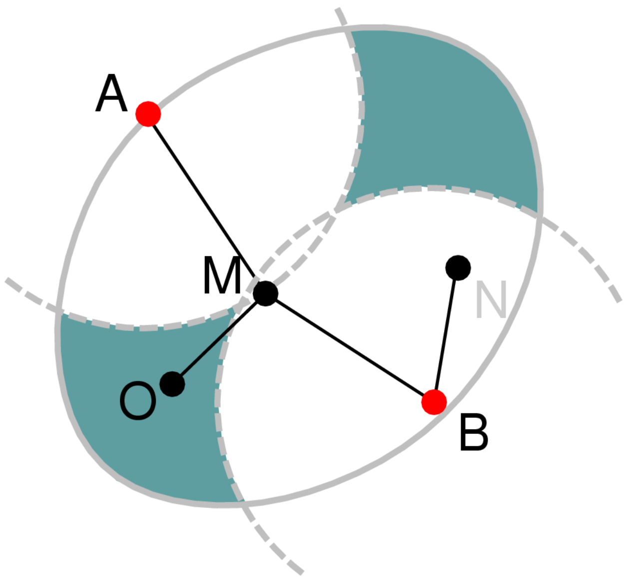


Combining negative and positive information

Node Localization



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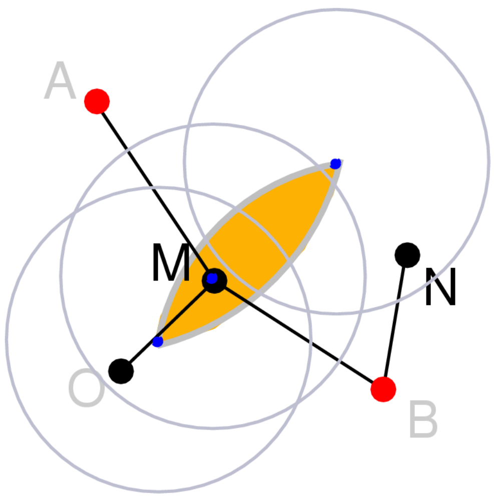

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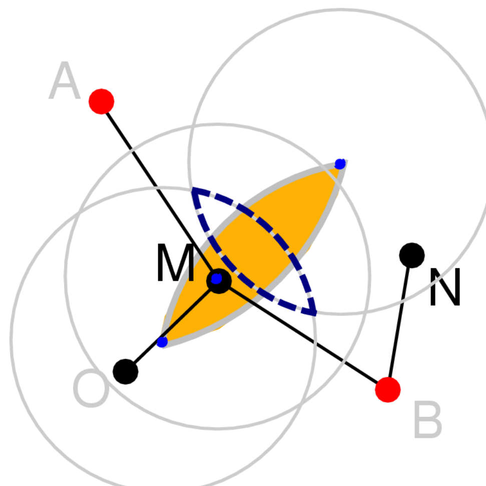

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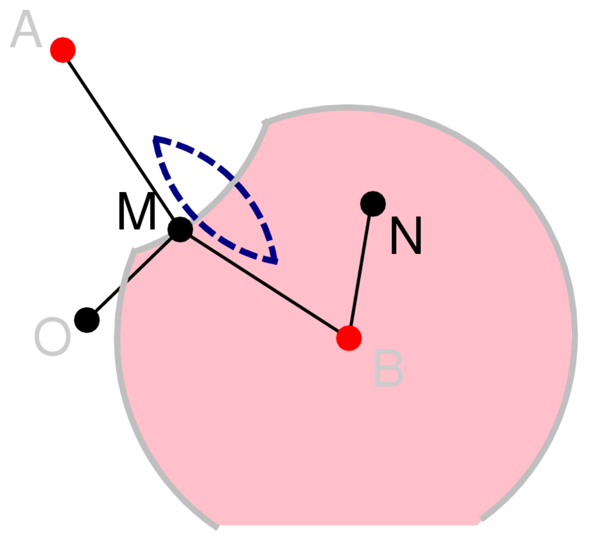
Node Localization



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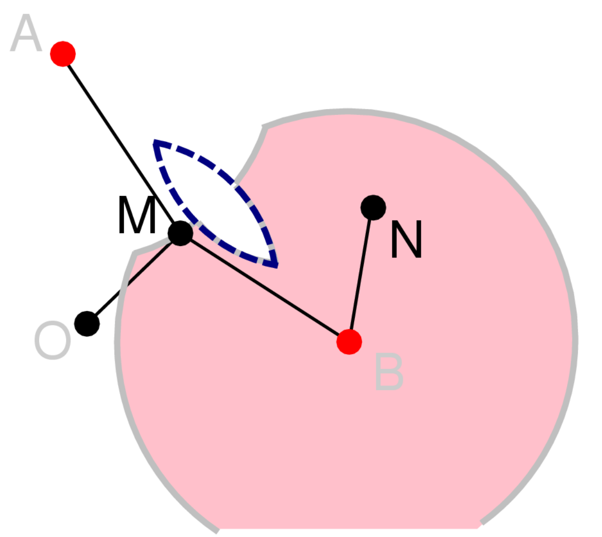
Node Localization



Refining position estimates

Sextant Approach

Location estimate: $ß_x$

Set of positive constraints: Γ_x

Set of negative constraints: Θ_x

$$ß_x = \bigcap (p \in \Gamma_x) \setminus \bigcup (n \in \Theta_x)$$

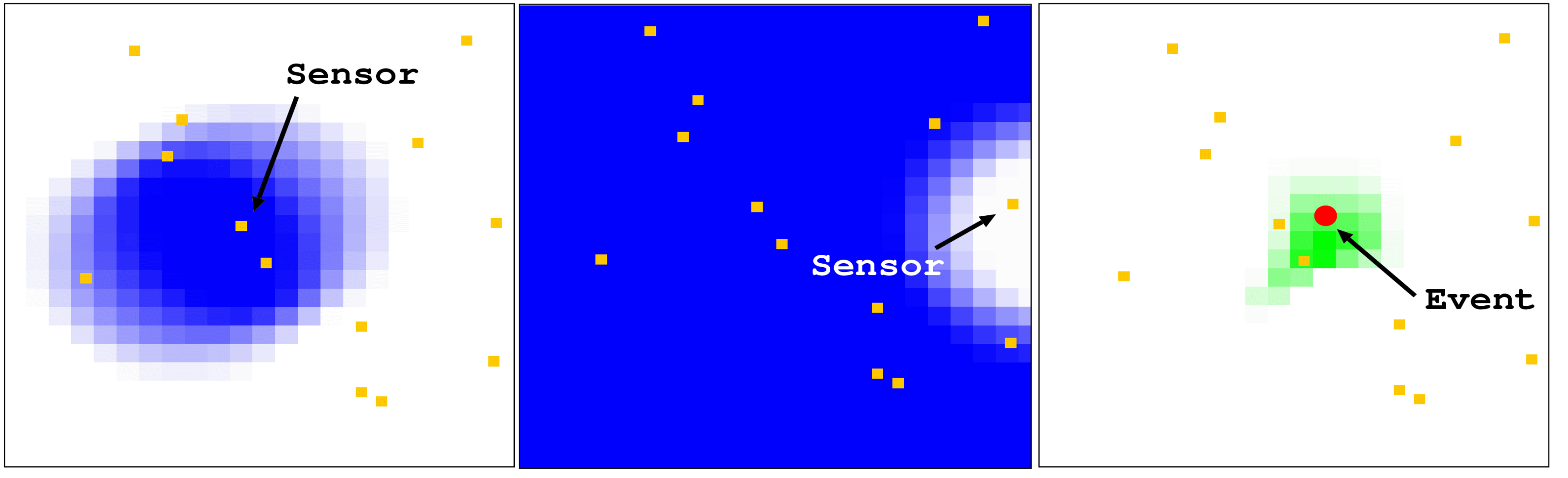
Sextant Areas

- Represent areas explicitly
  - Use Bezier curves to bound bezier regions
  - Four control points define a curve
  - Union and intersection are implemented efficiently
- Not a point estimate!
  - Ideally, applications should take the bezier region as input
  - Can generate point estimate from bezier regions

Localizing Events

- Hot area in sensor networks
- The Sextant approach provides a comprehensive, unified framework
- Differences from node localization
  - Constraints from sensors, not wireless radios
  - Boolean connected/not connected to sensed/not sensed
  - Annotate resulting areas with probabilities

Event localization



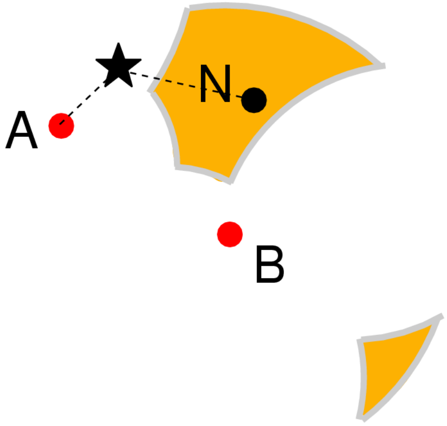
Decompose space into a grid, propagate probabilities

Calculate normalized Bayesian probabilities

Event Localization

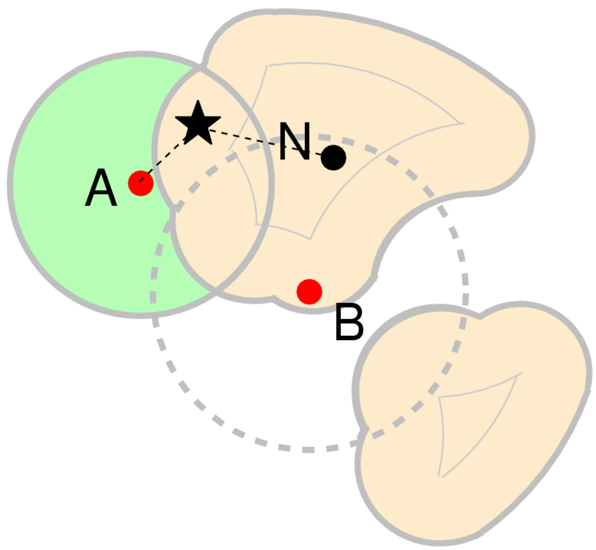
Start with initial Sextant node regions

Event Localization



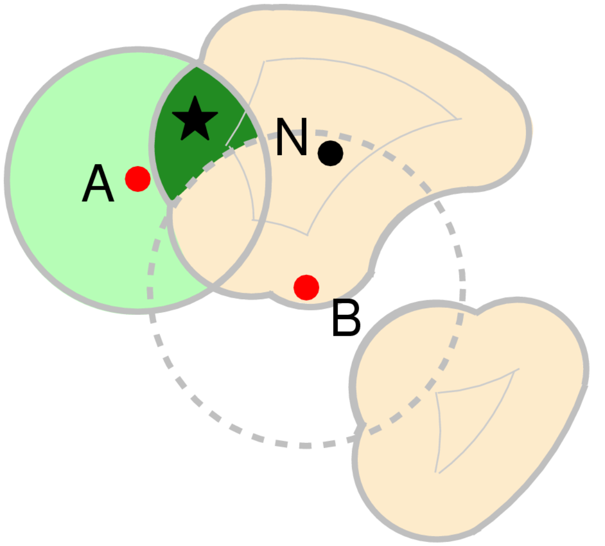
An event occurs

Event Localization



Sextant is used for event localization

Event Localization



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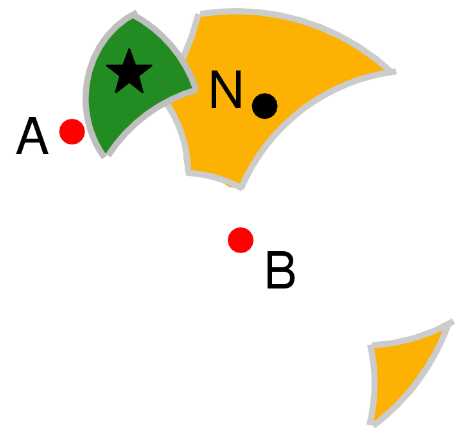
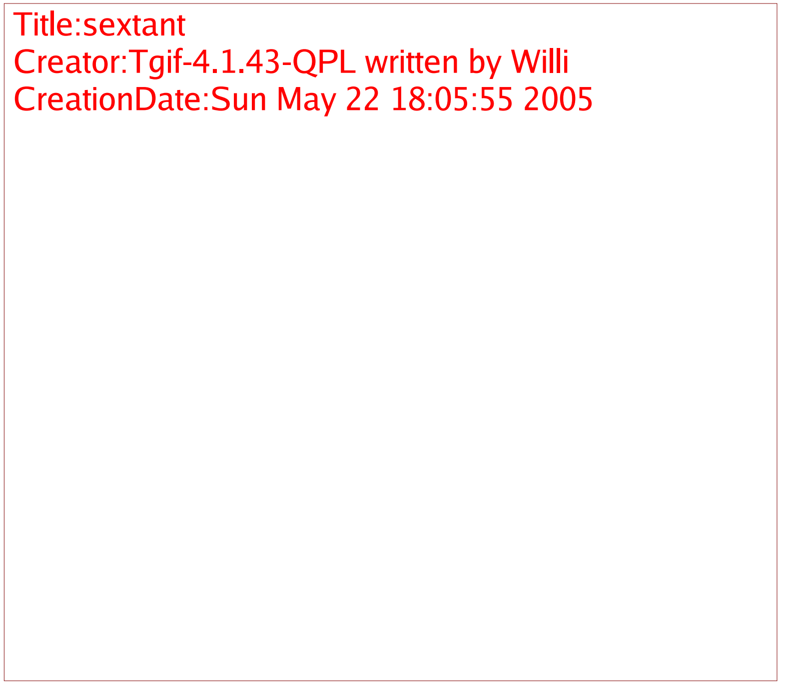


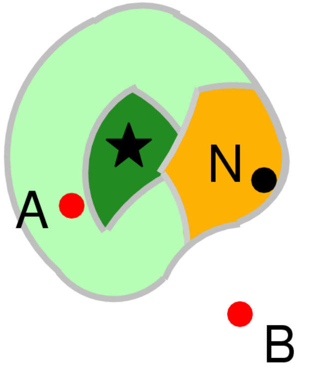
Event localized

Event Localization



Event used for node localization!

Event Localization

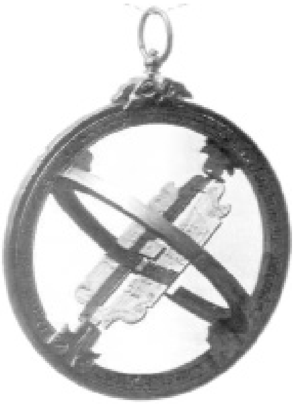


Event used to refine node location!

Event Localization

Event detection helps refine node positions!

Meridian



Selecting nodes based on location

(without knowing their actual location in the real world)

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:

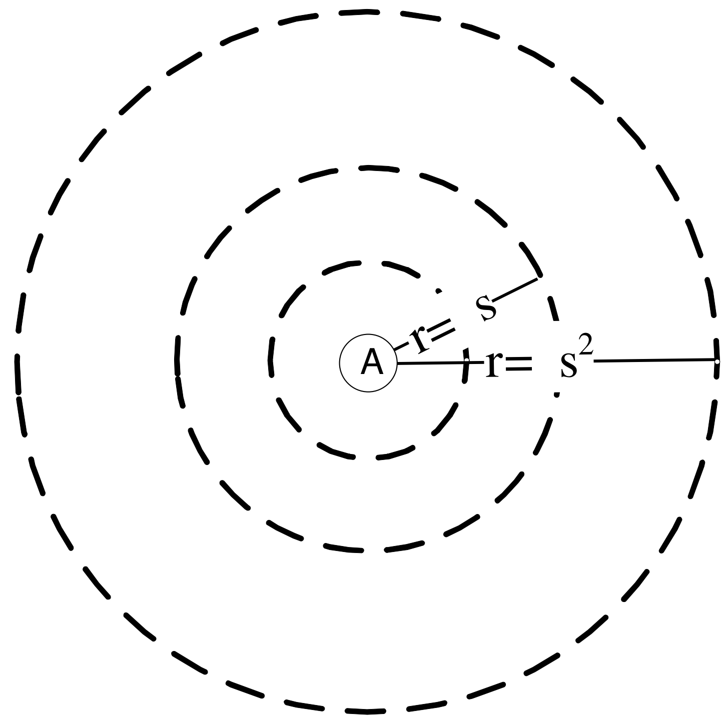
Solve network location problems in O(log D) hops

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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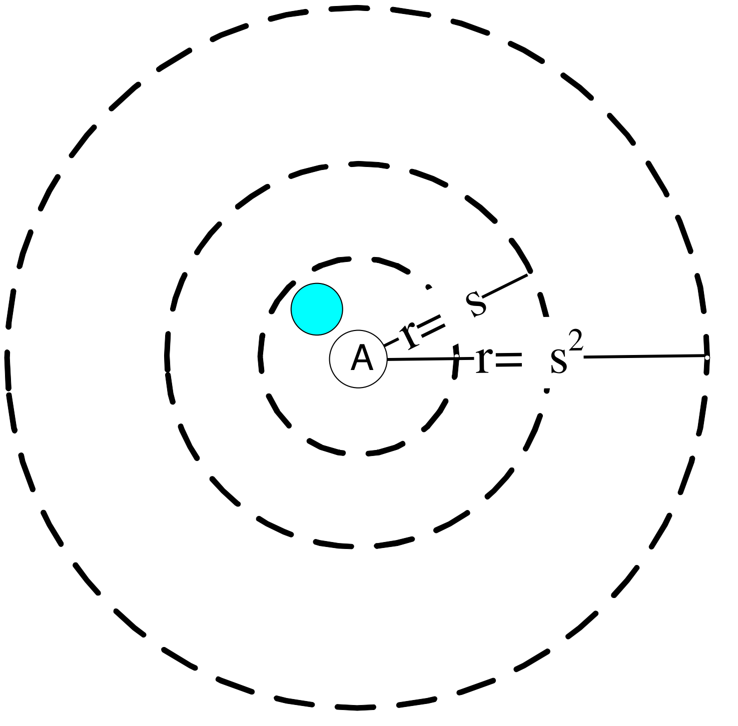

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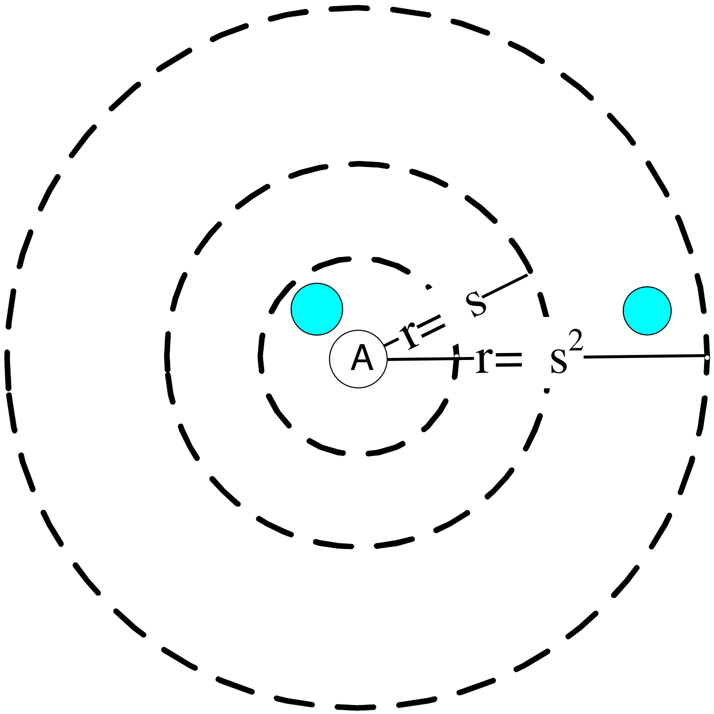

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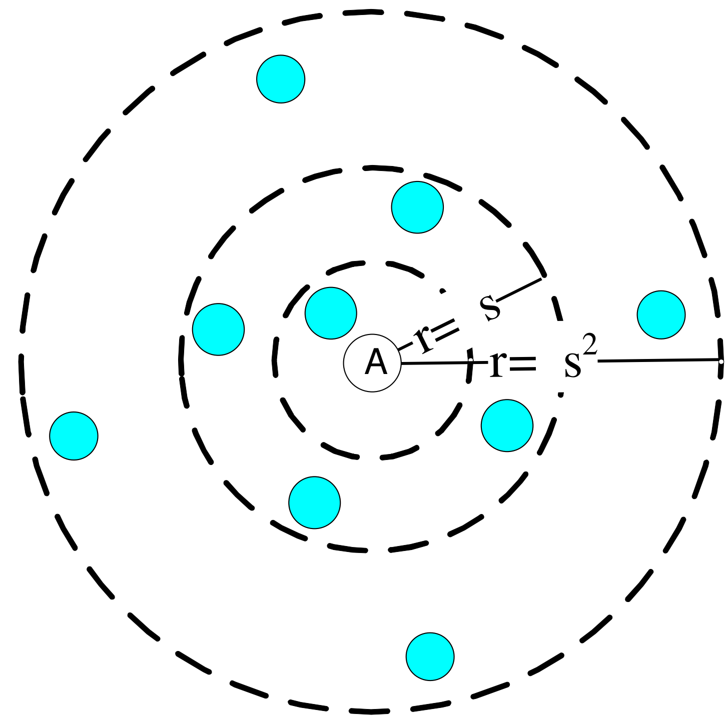
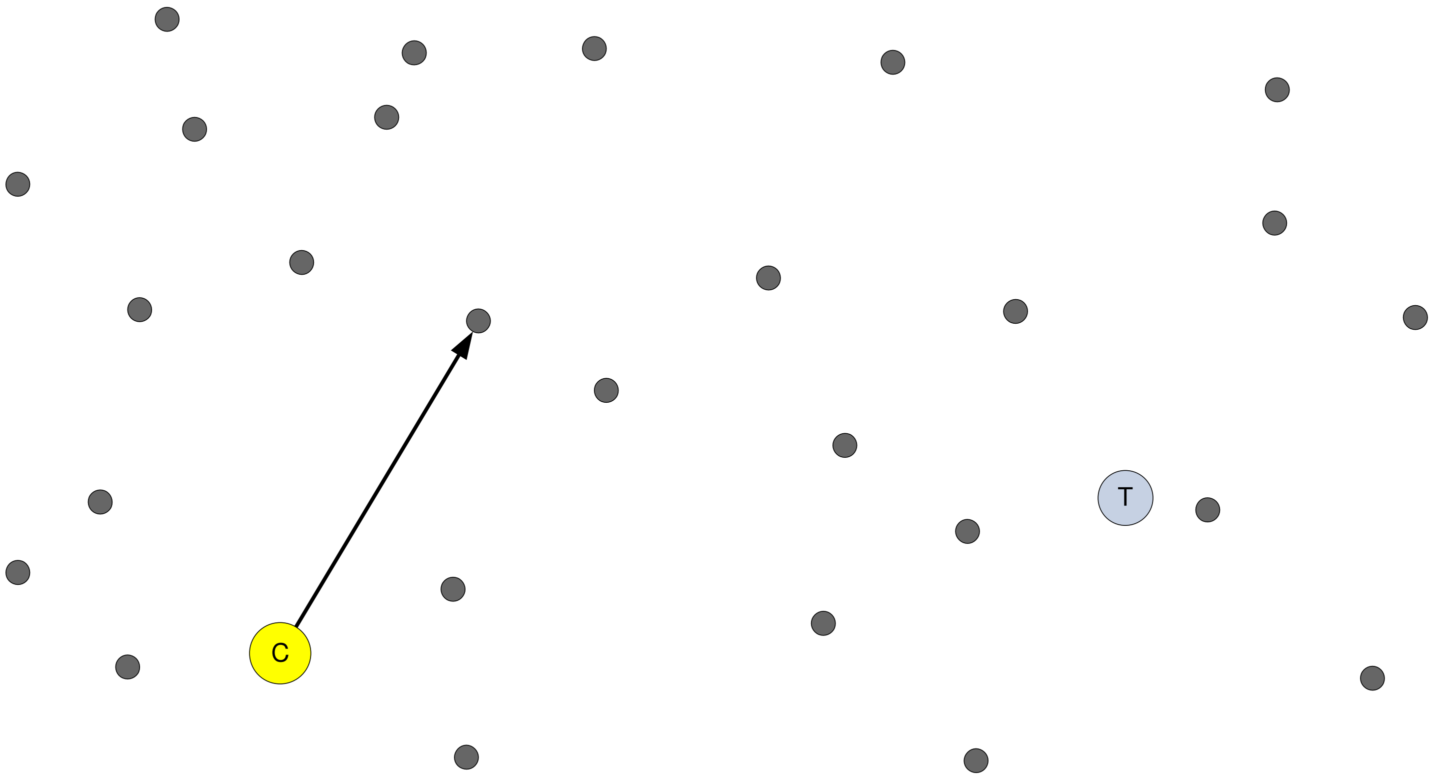


Closest Node Discovery

- 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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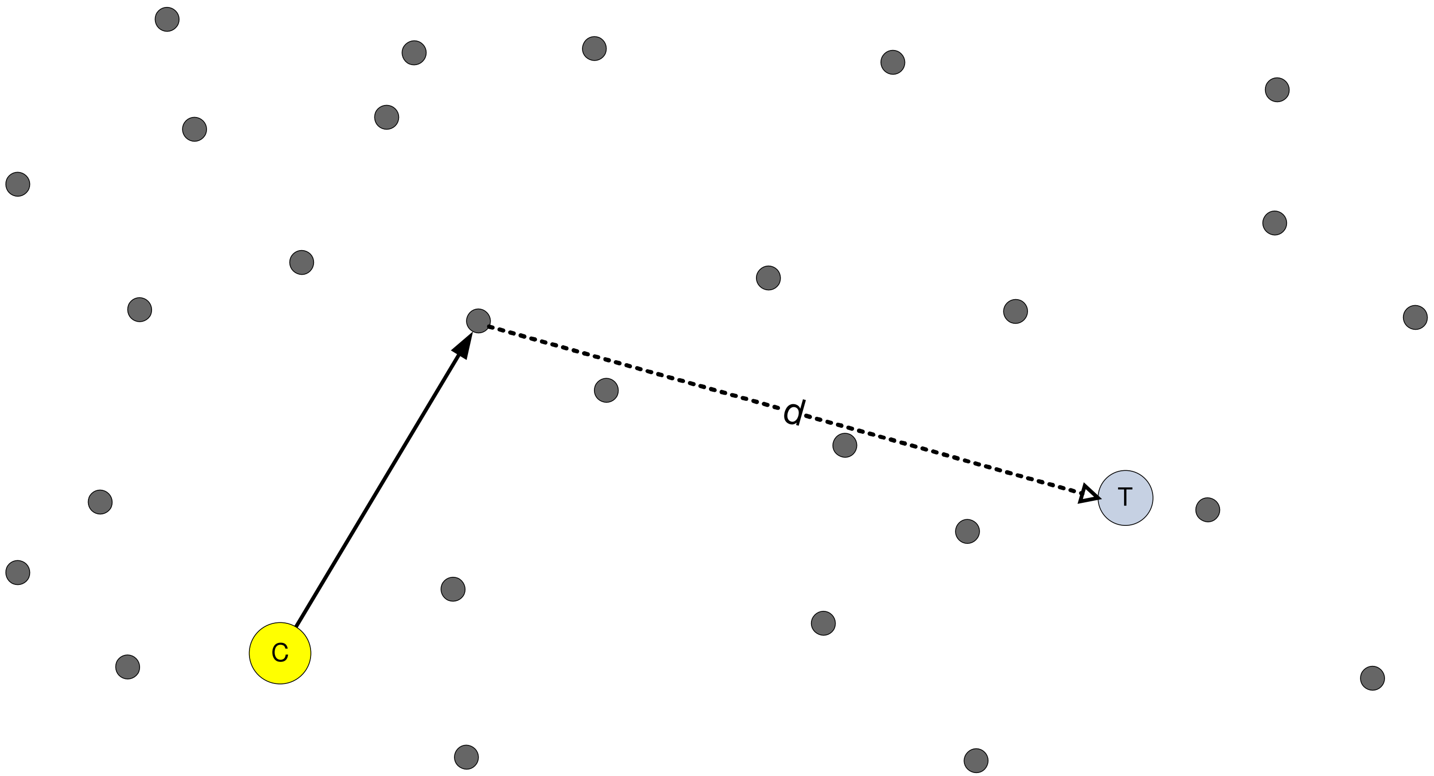

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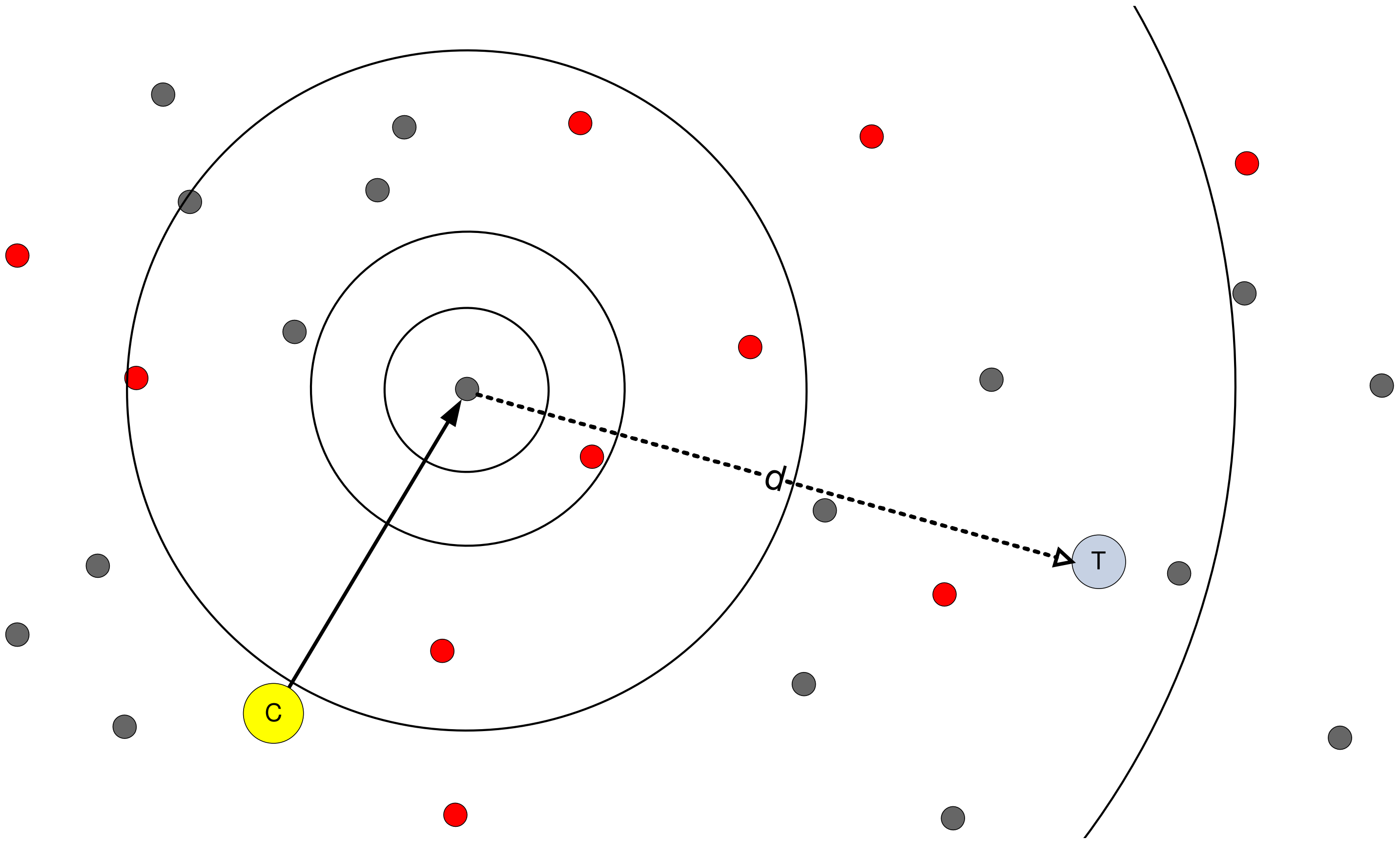

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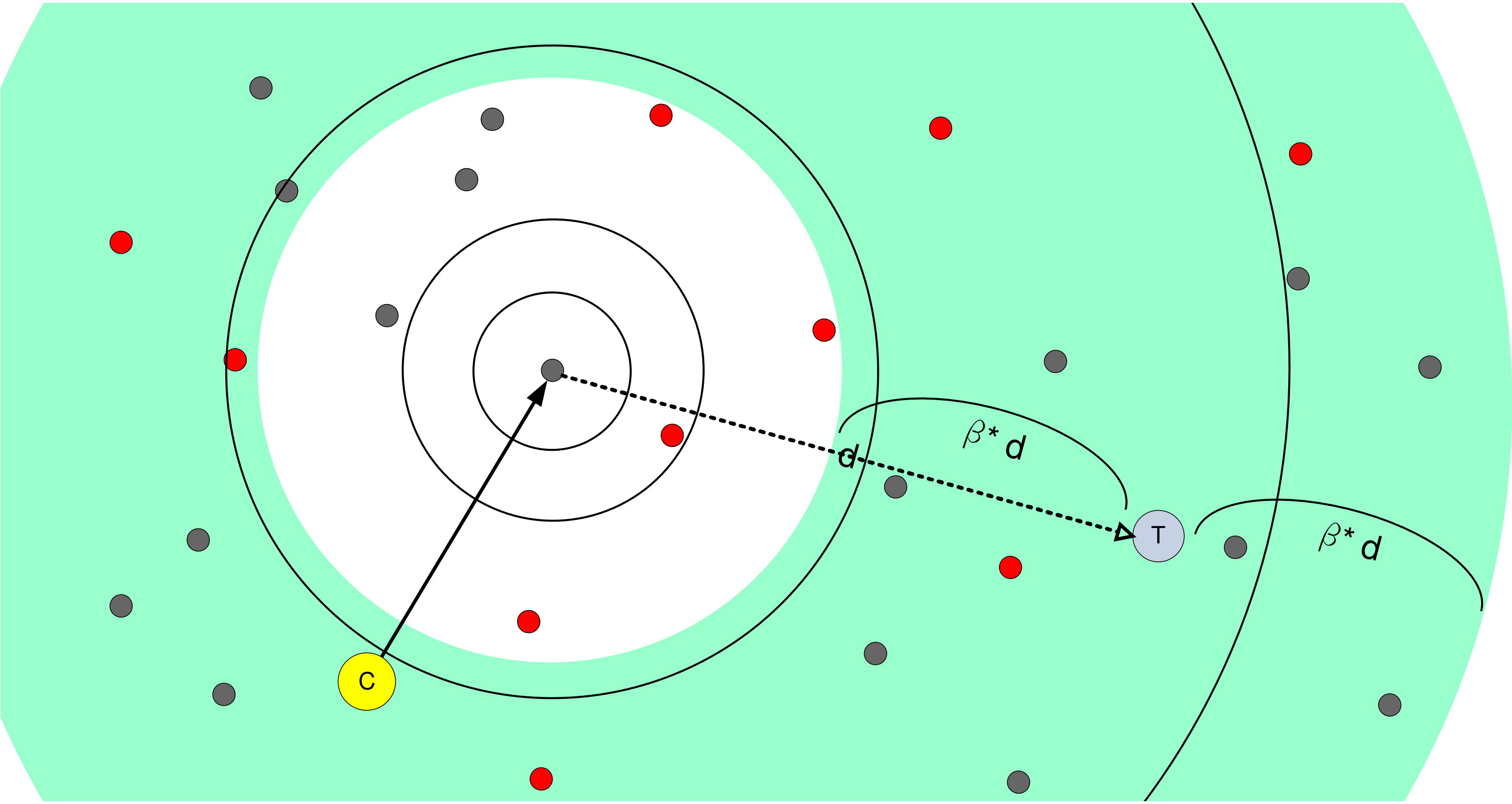

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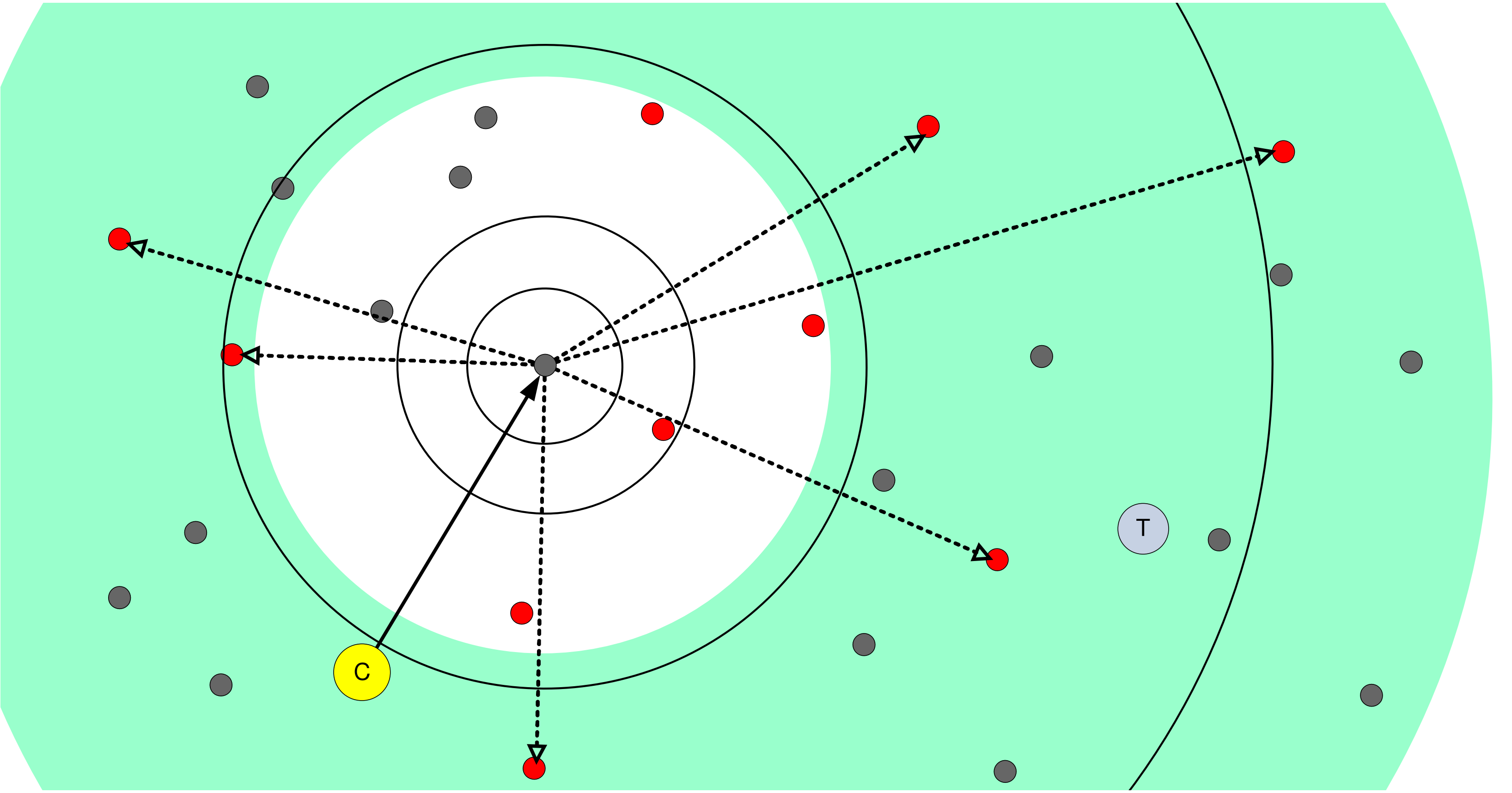

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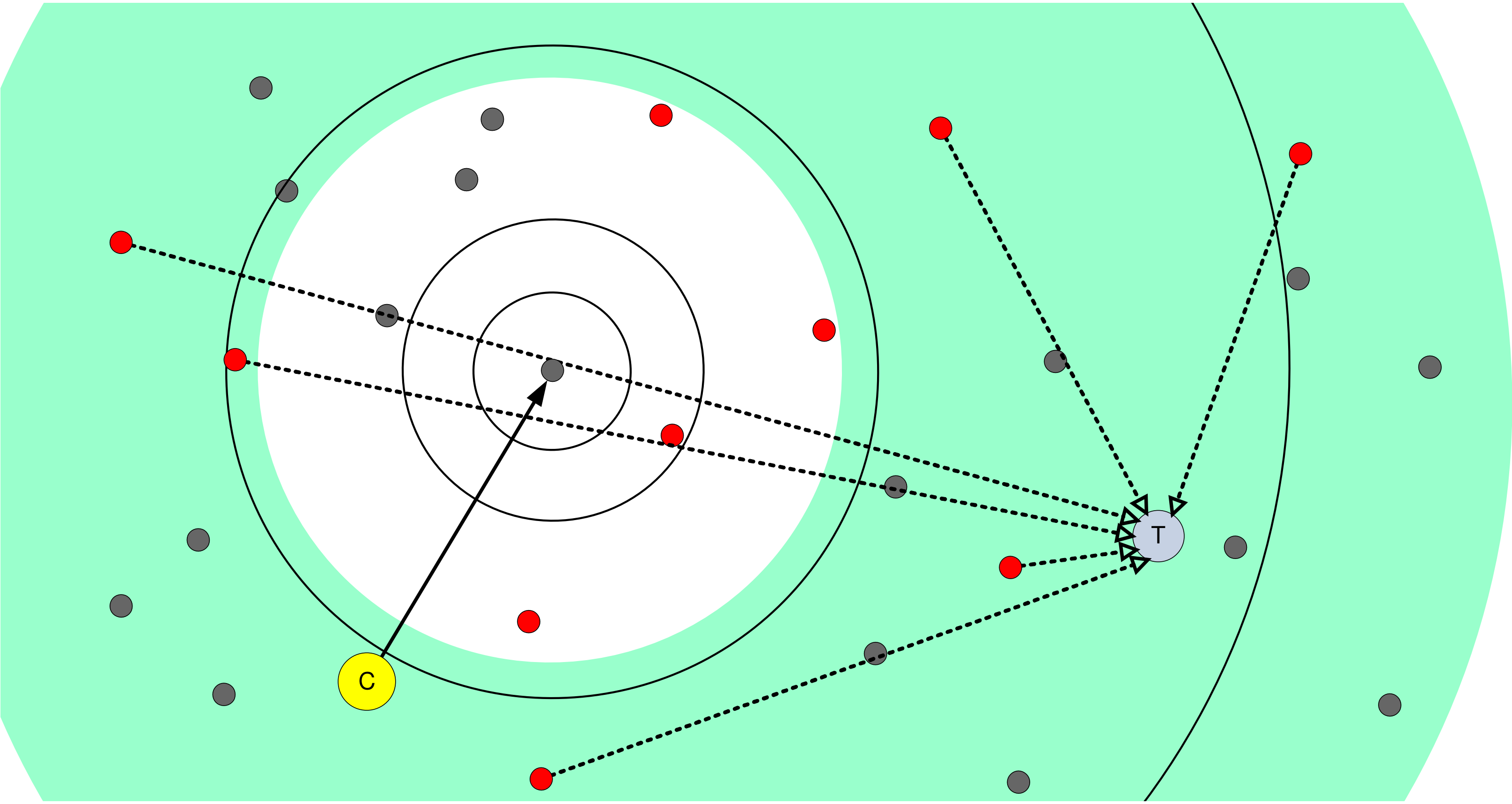

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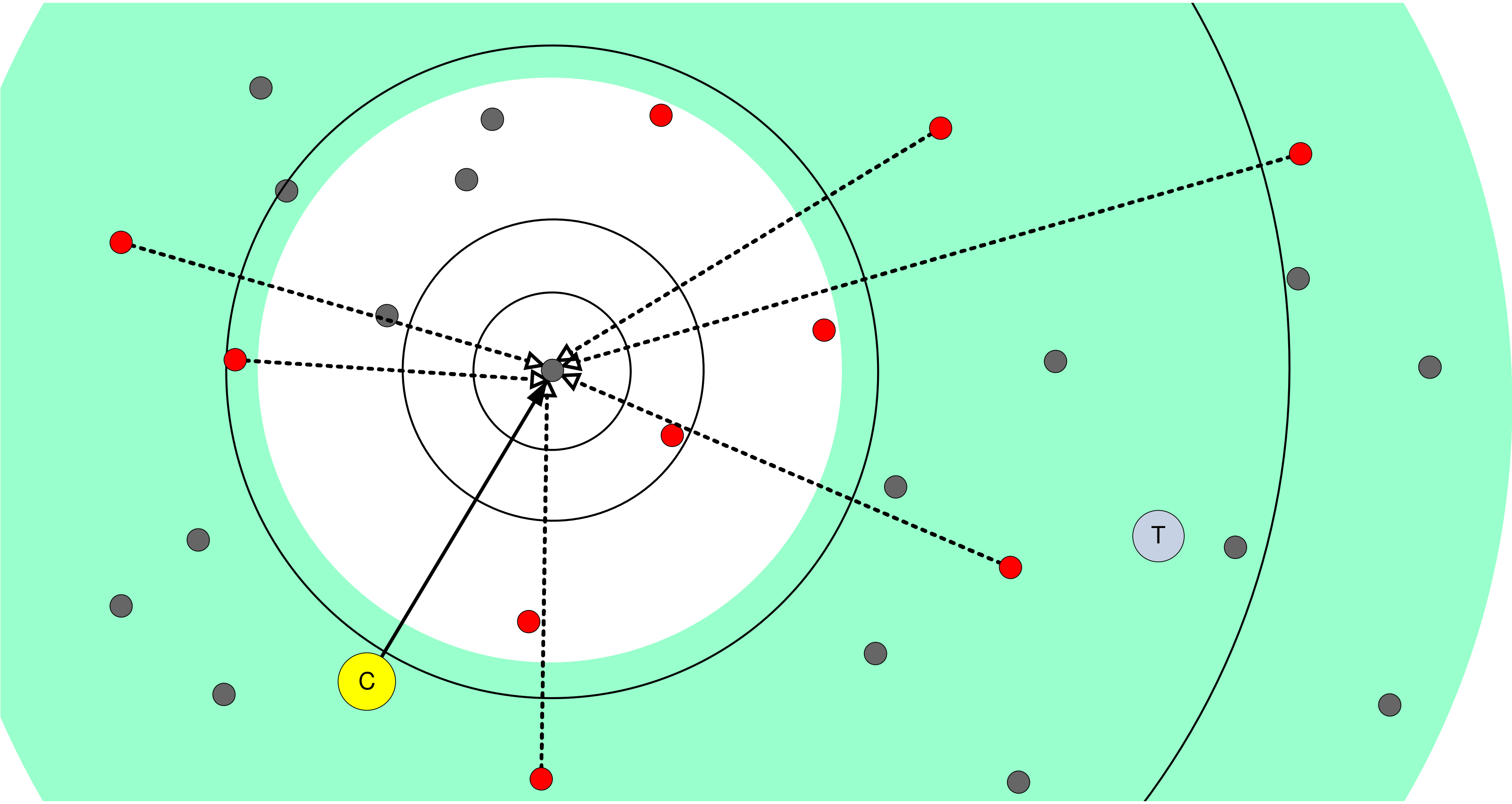

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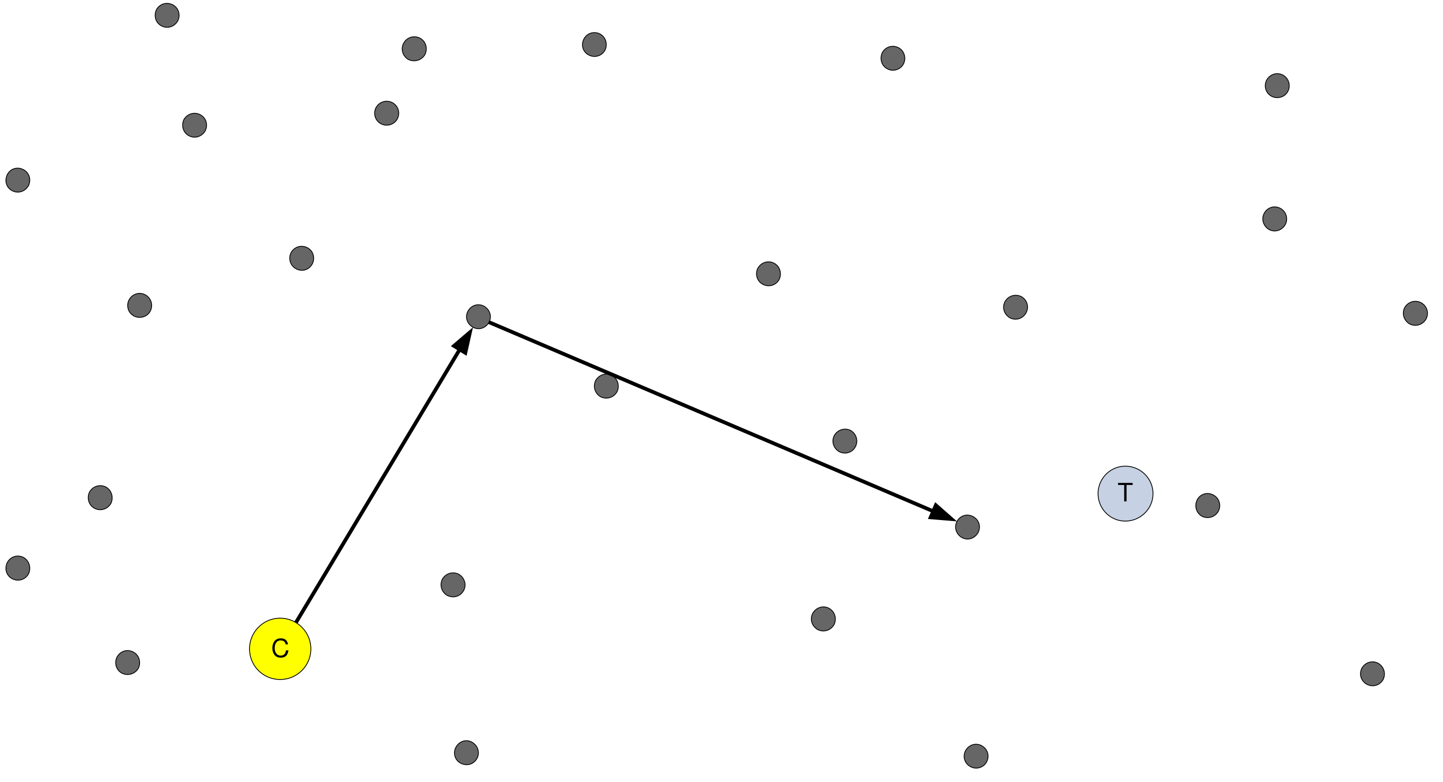

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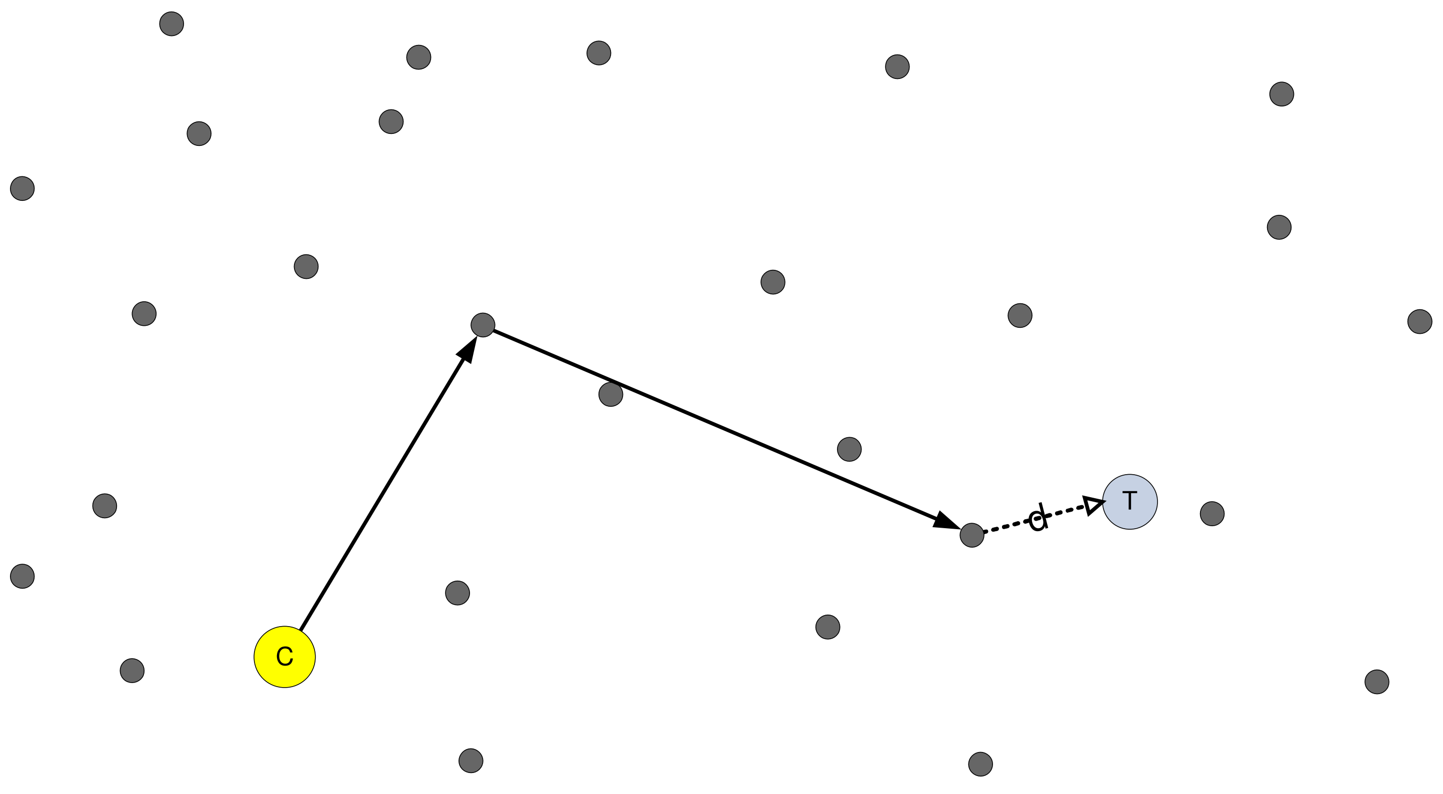

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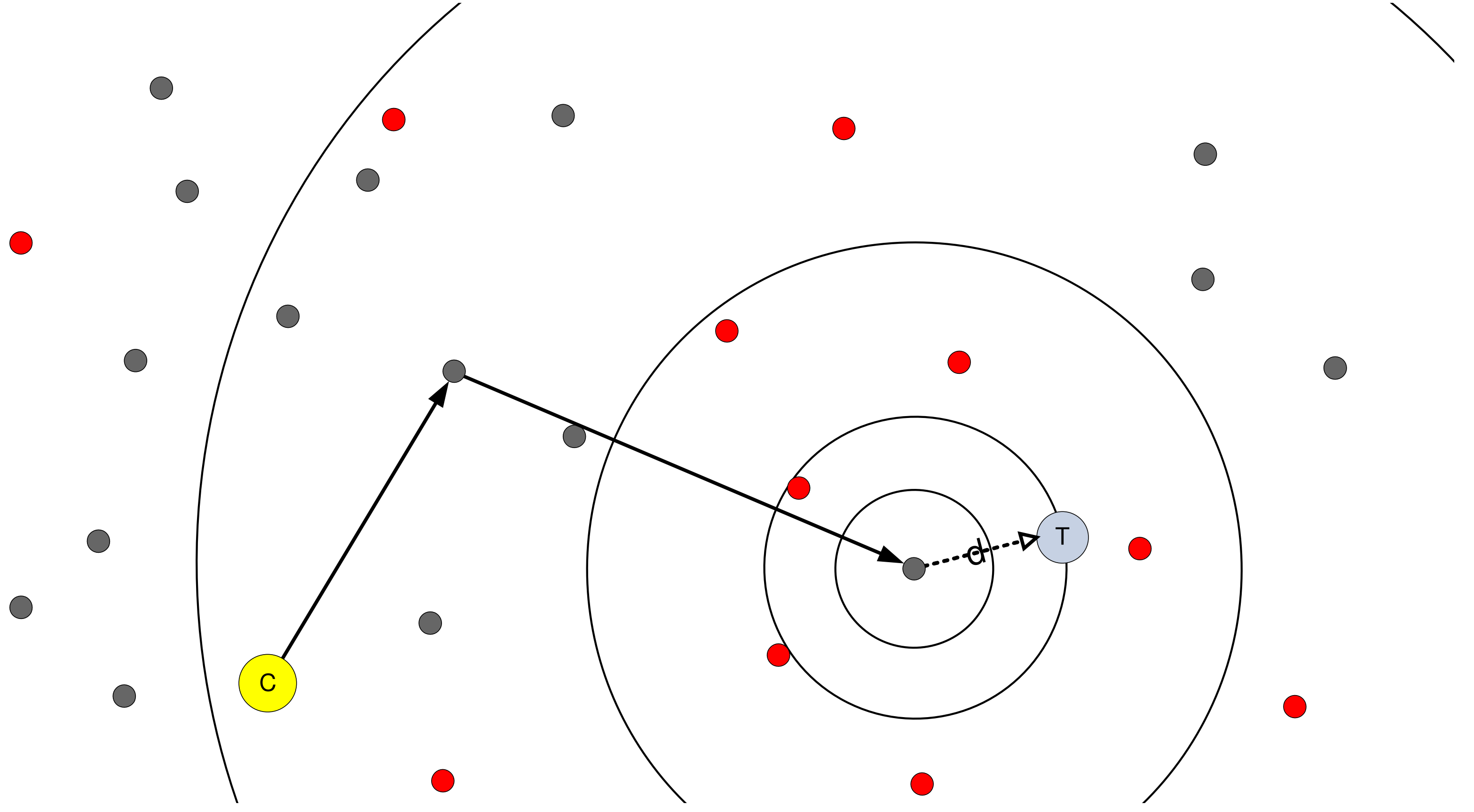

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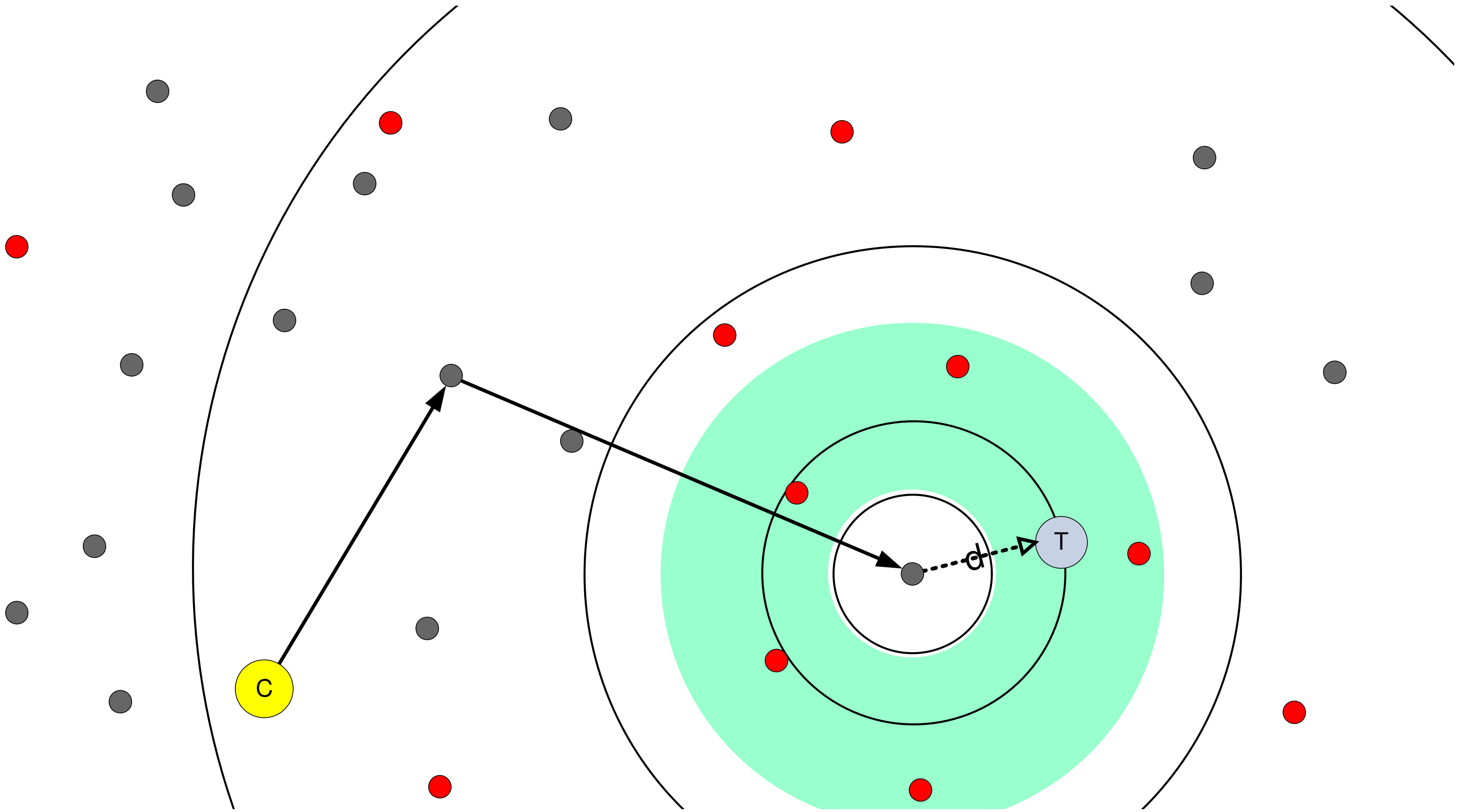

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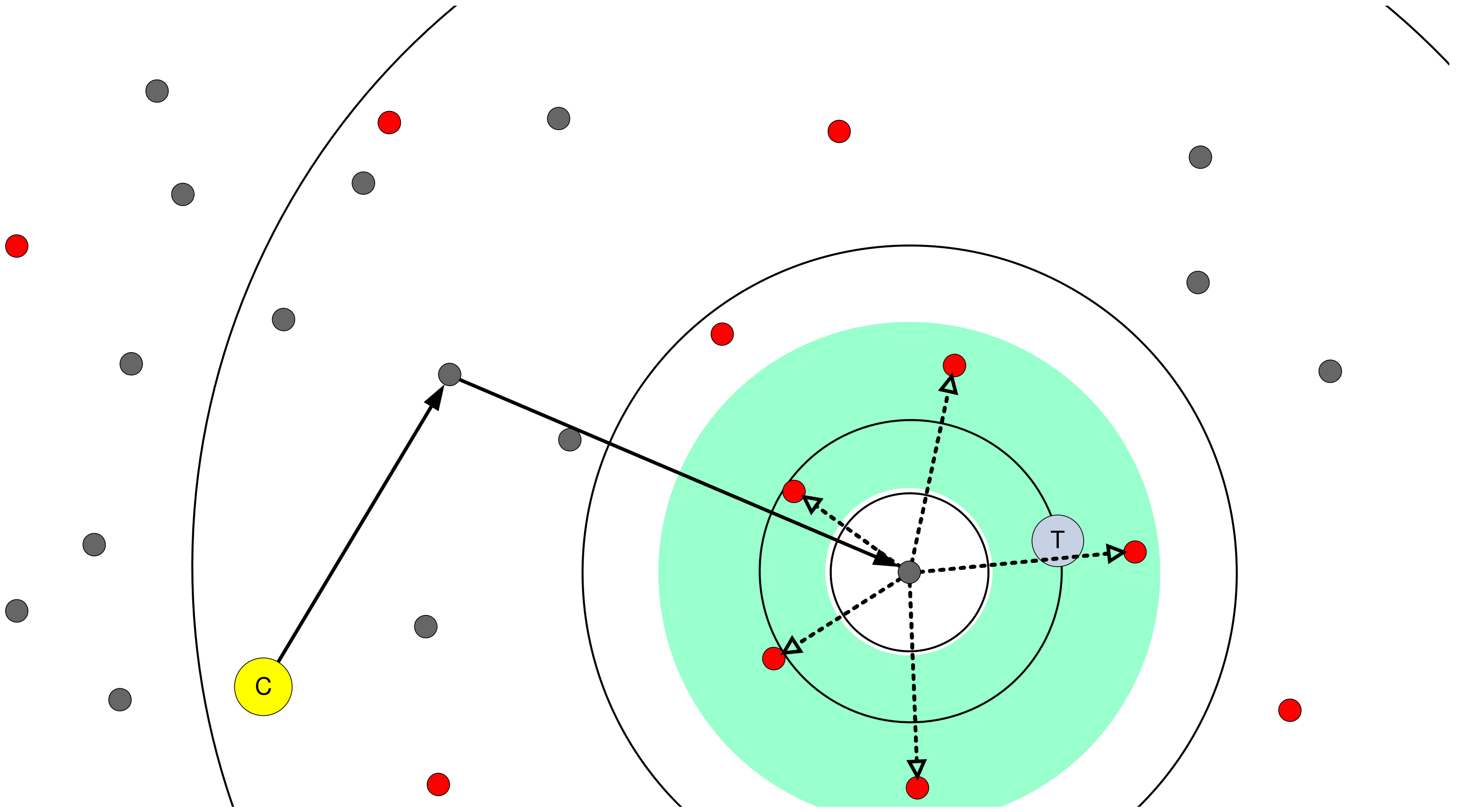

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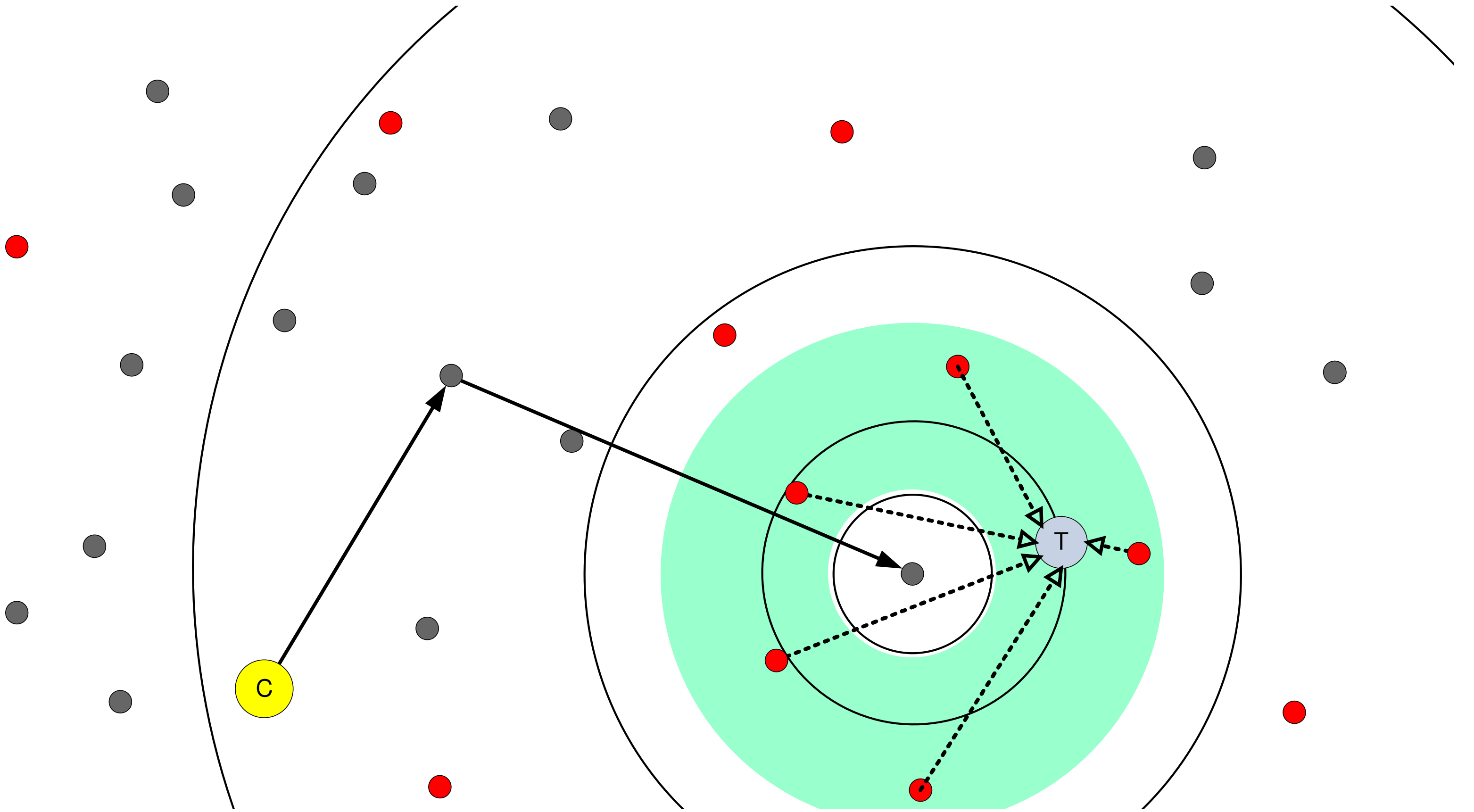

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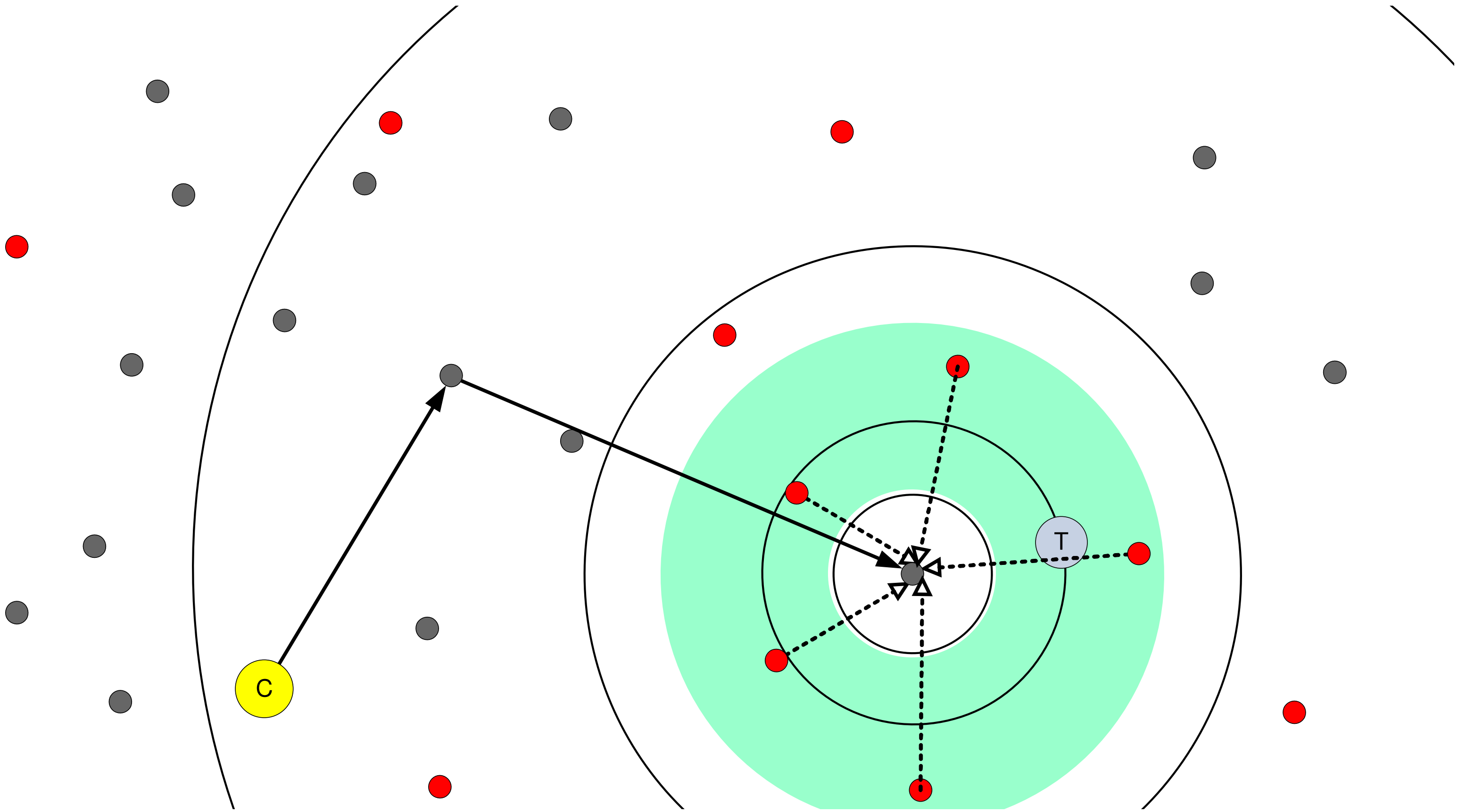

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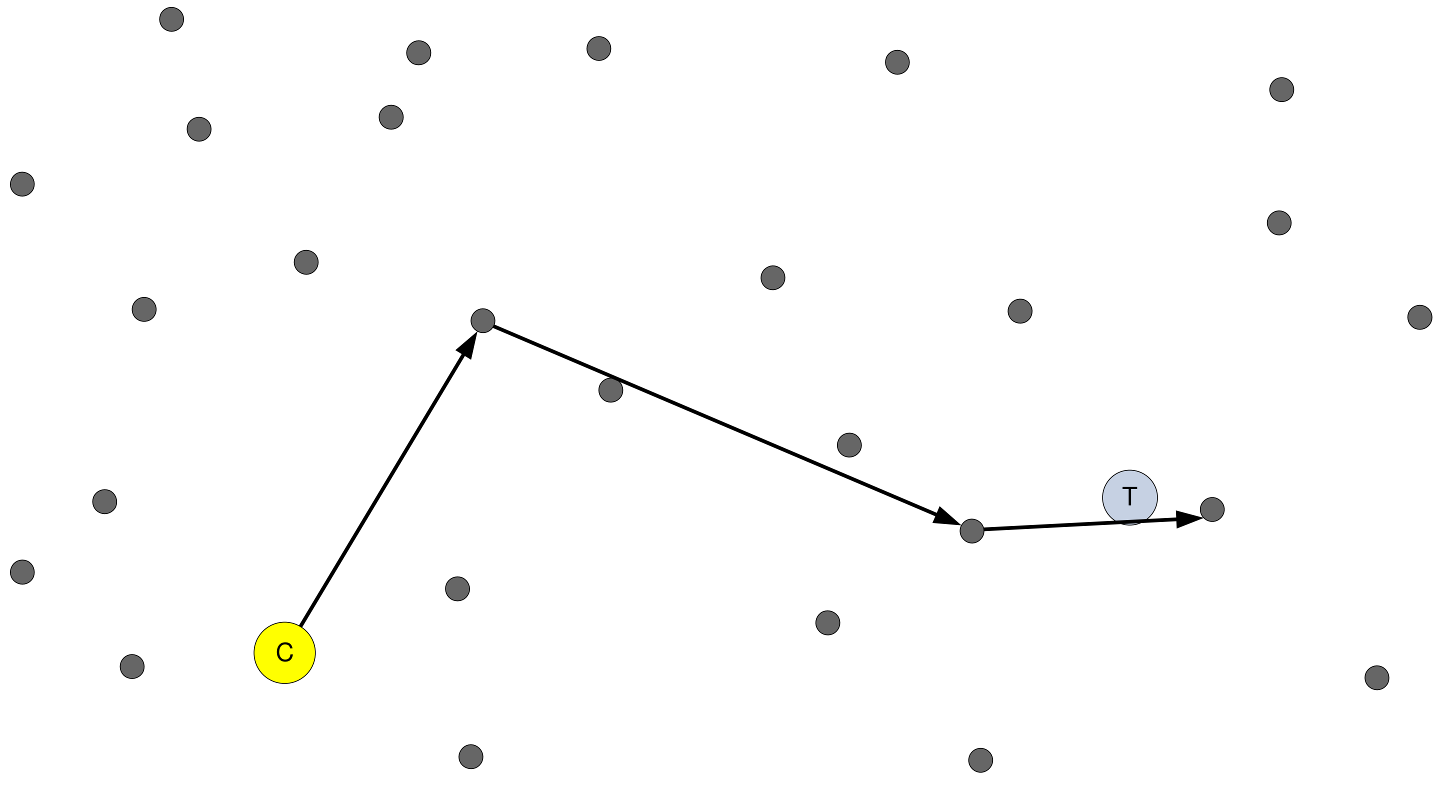

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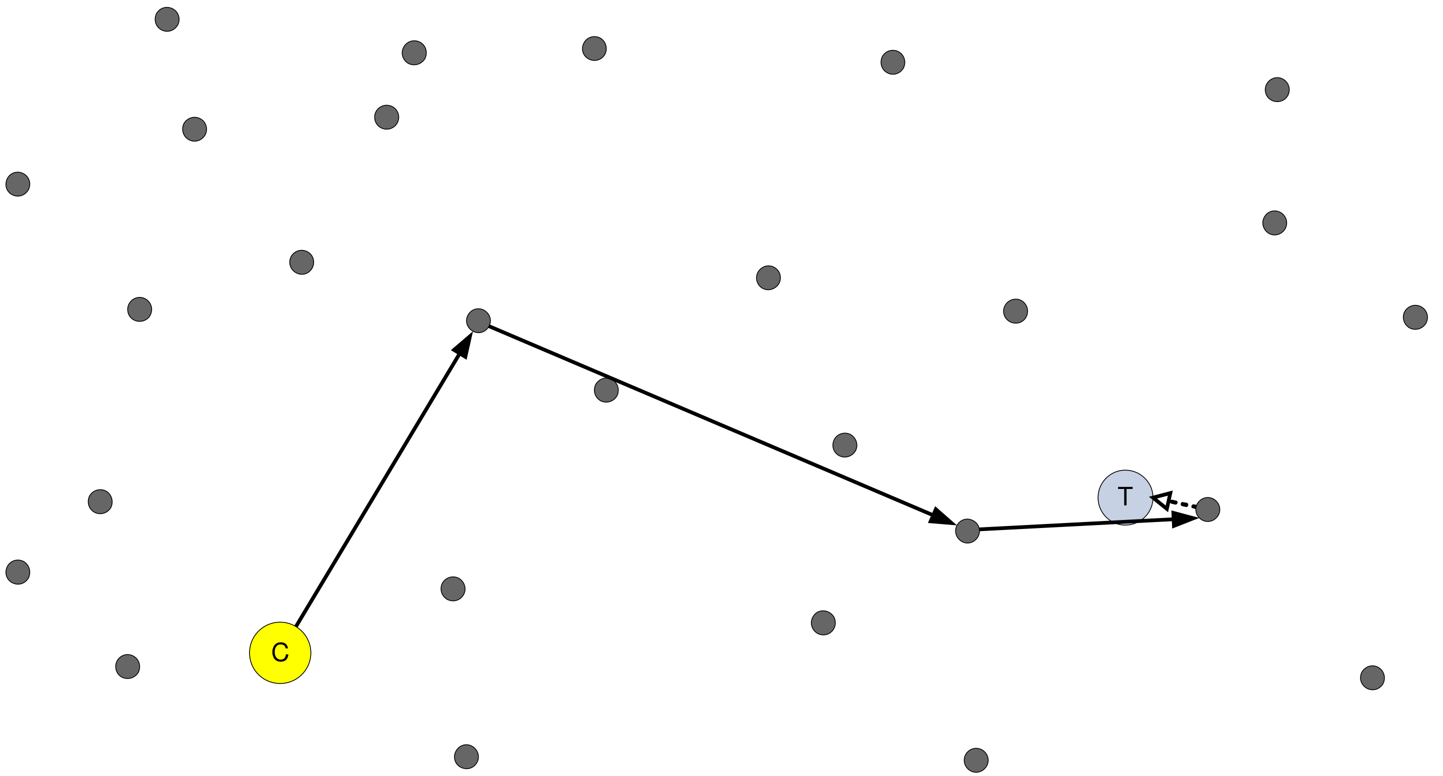

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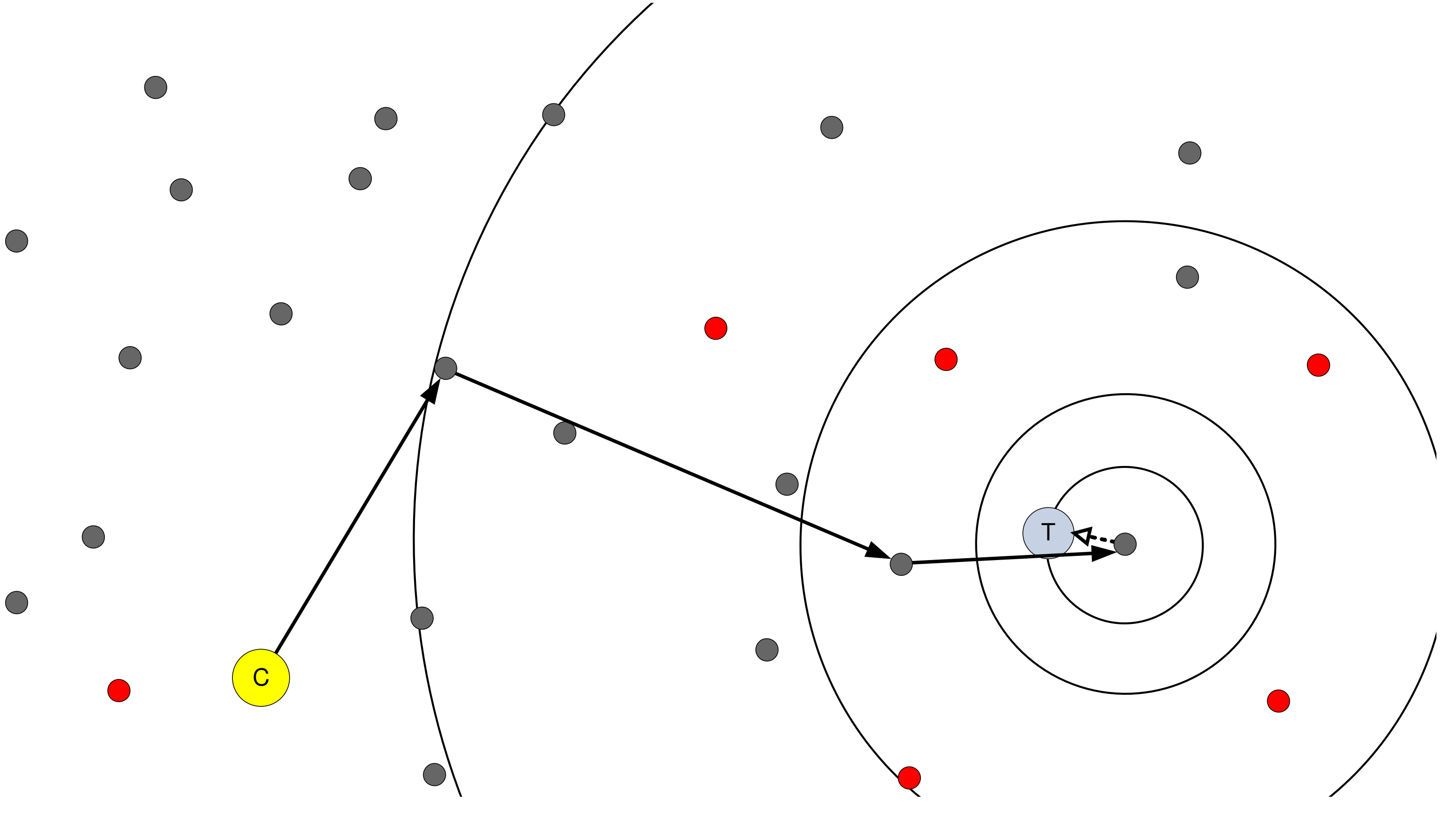

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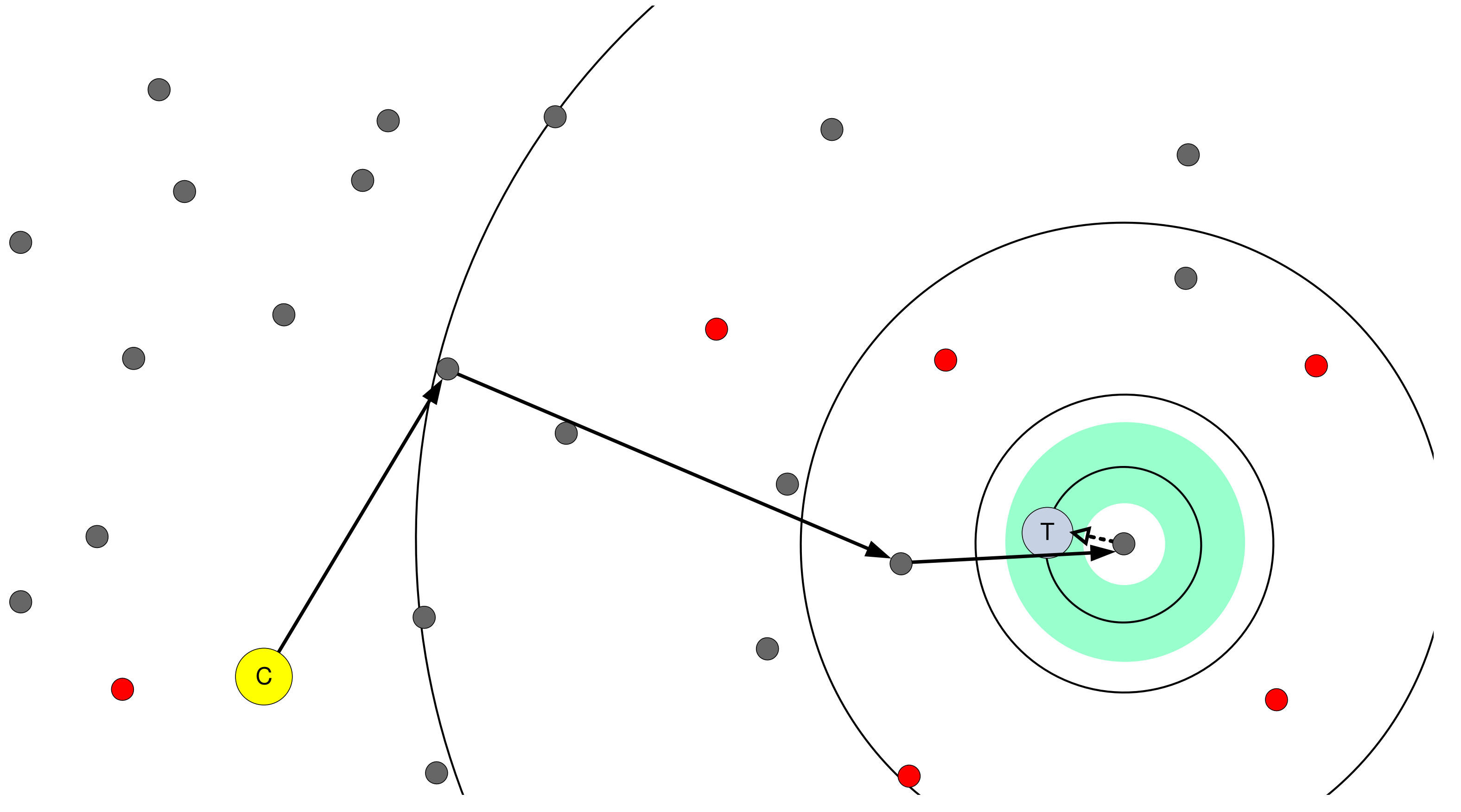

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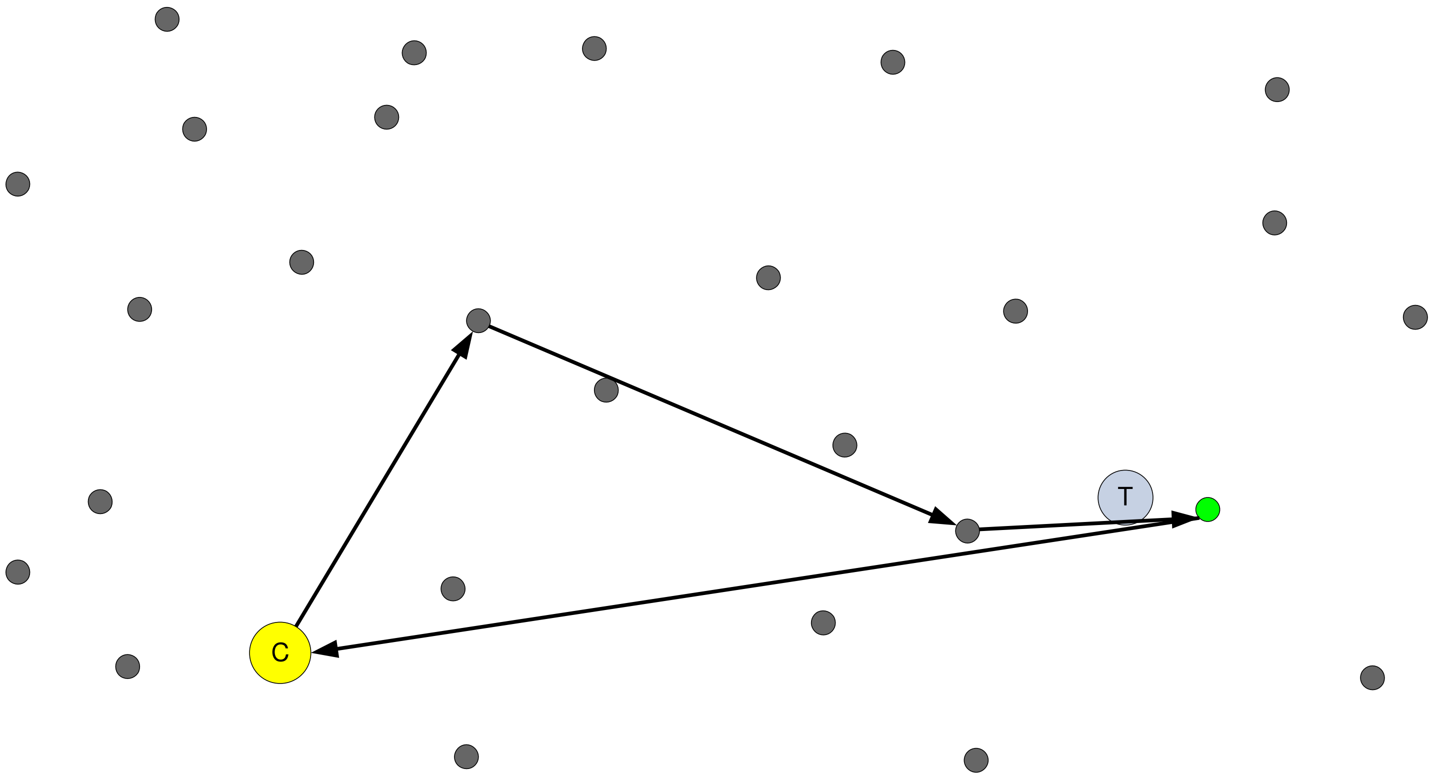


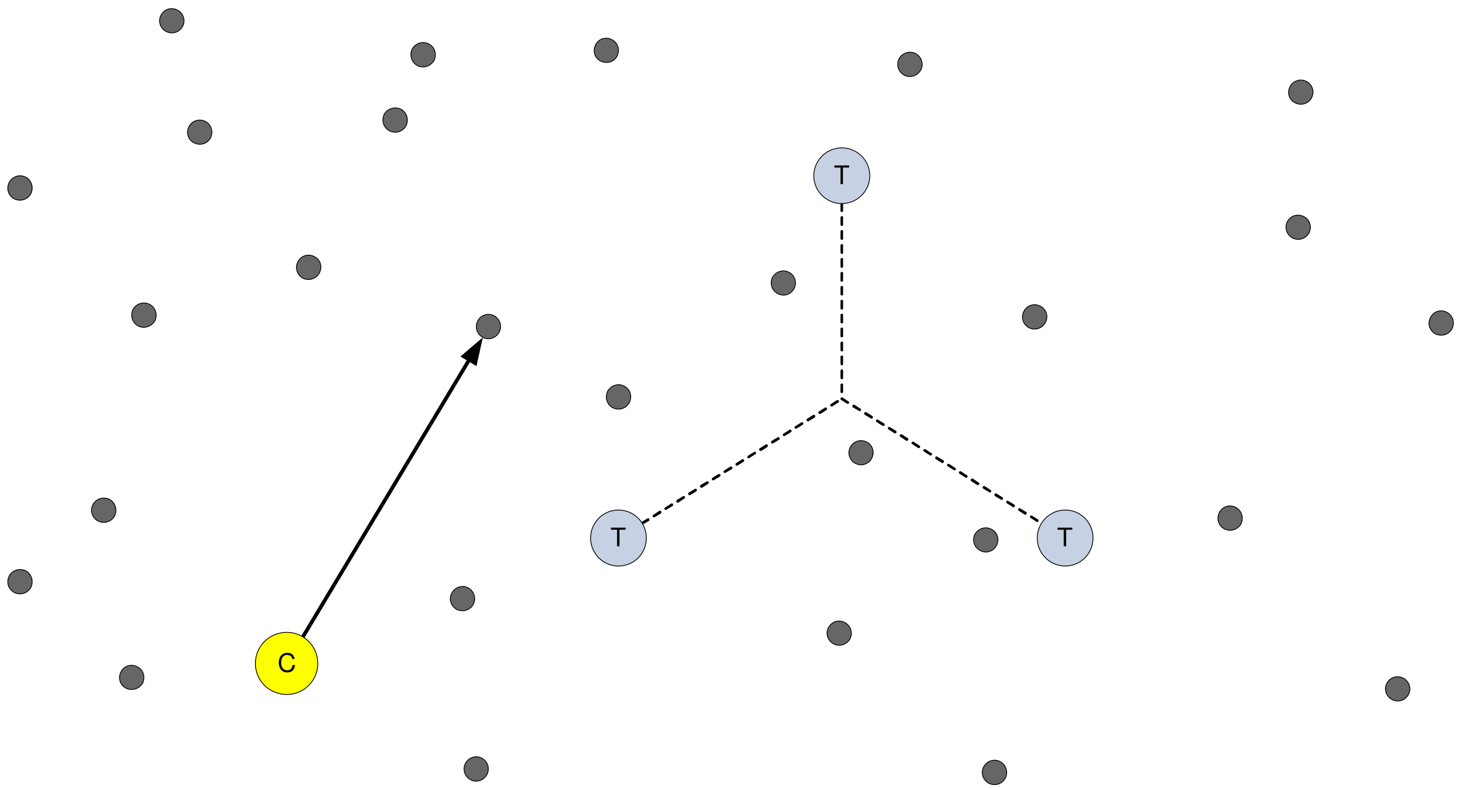
Meridian Theoretical Analysis

- 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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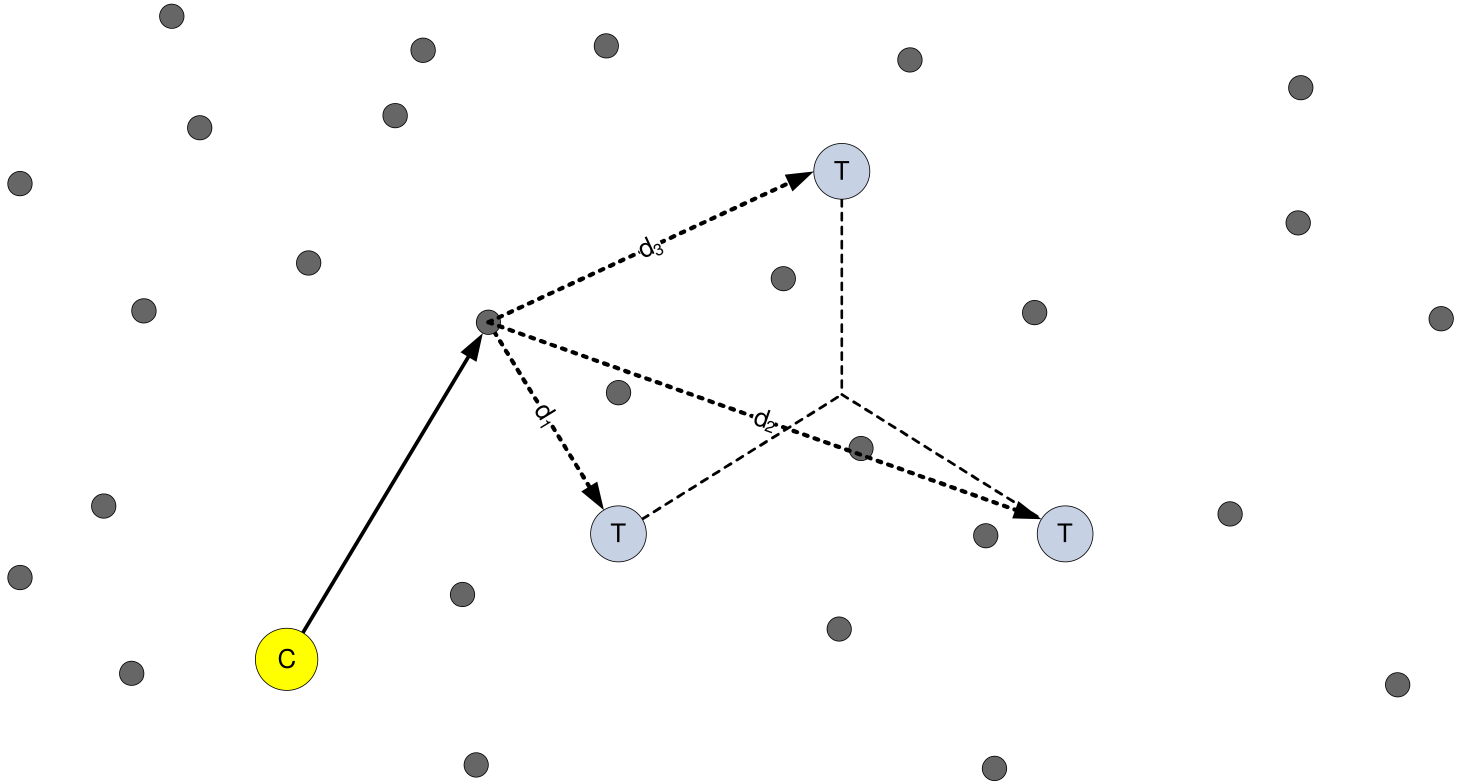

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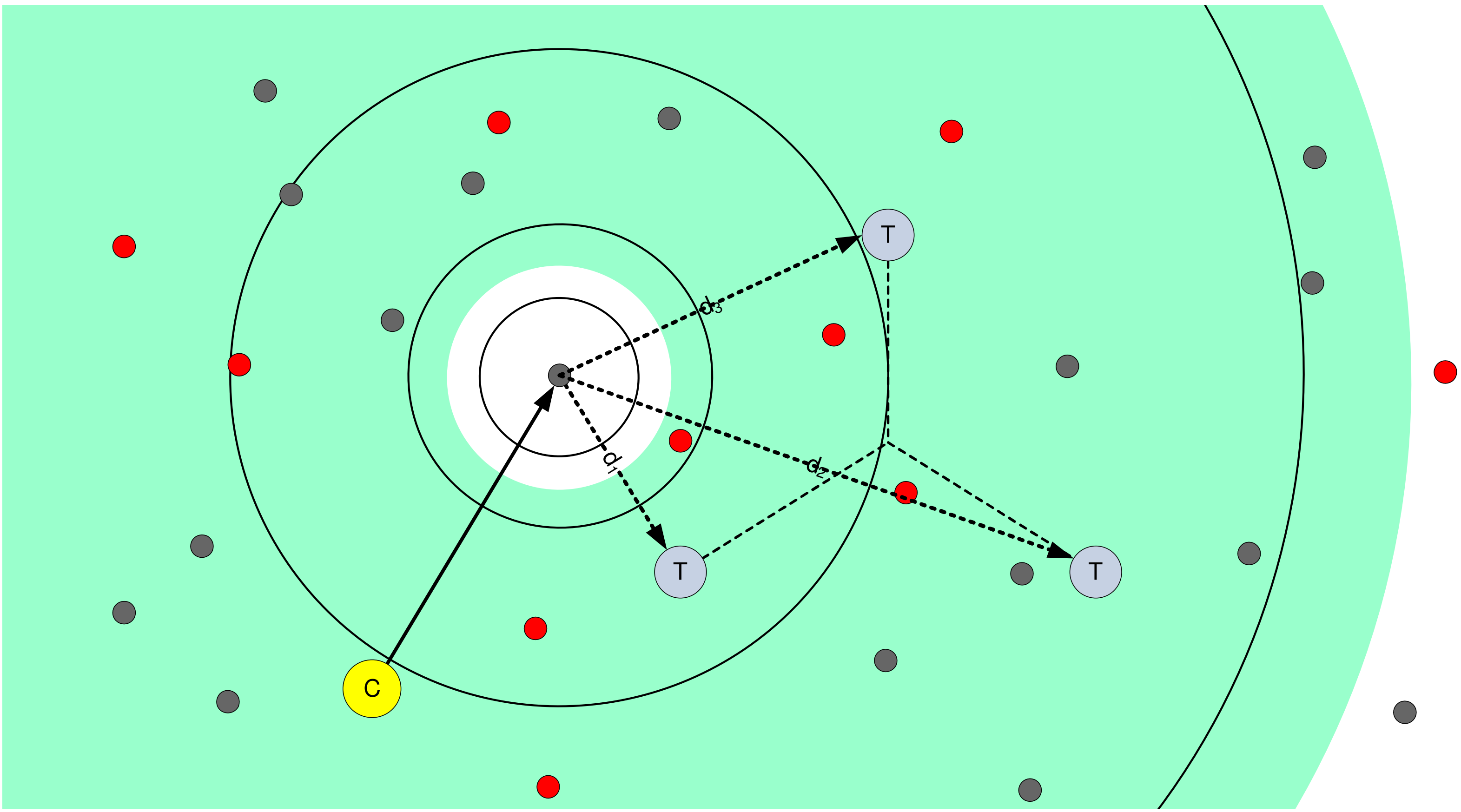

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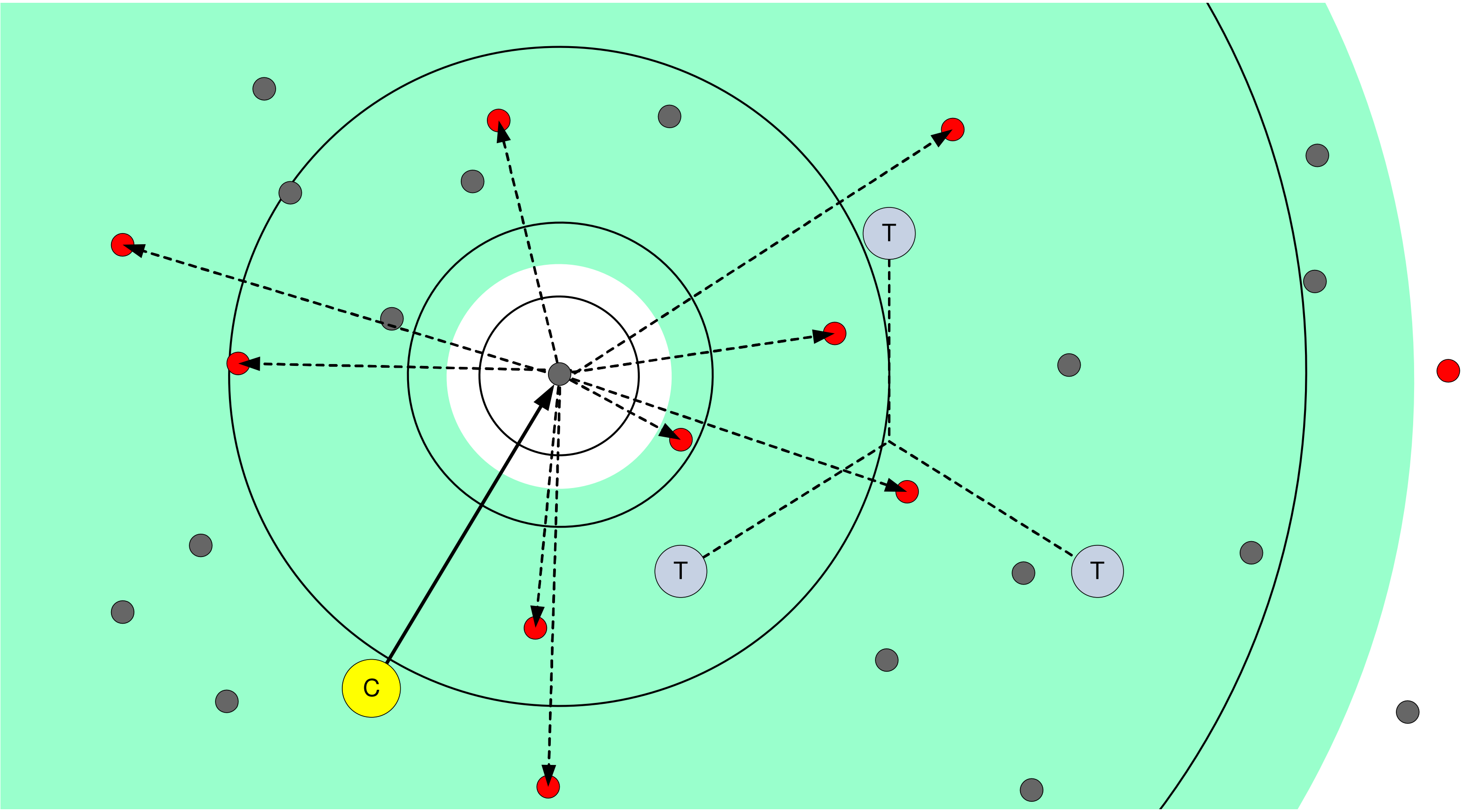

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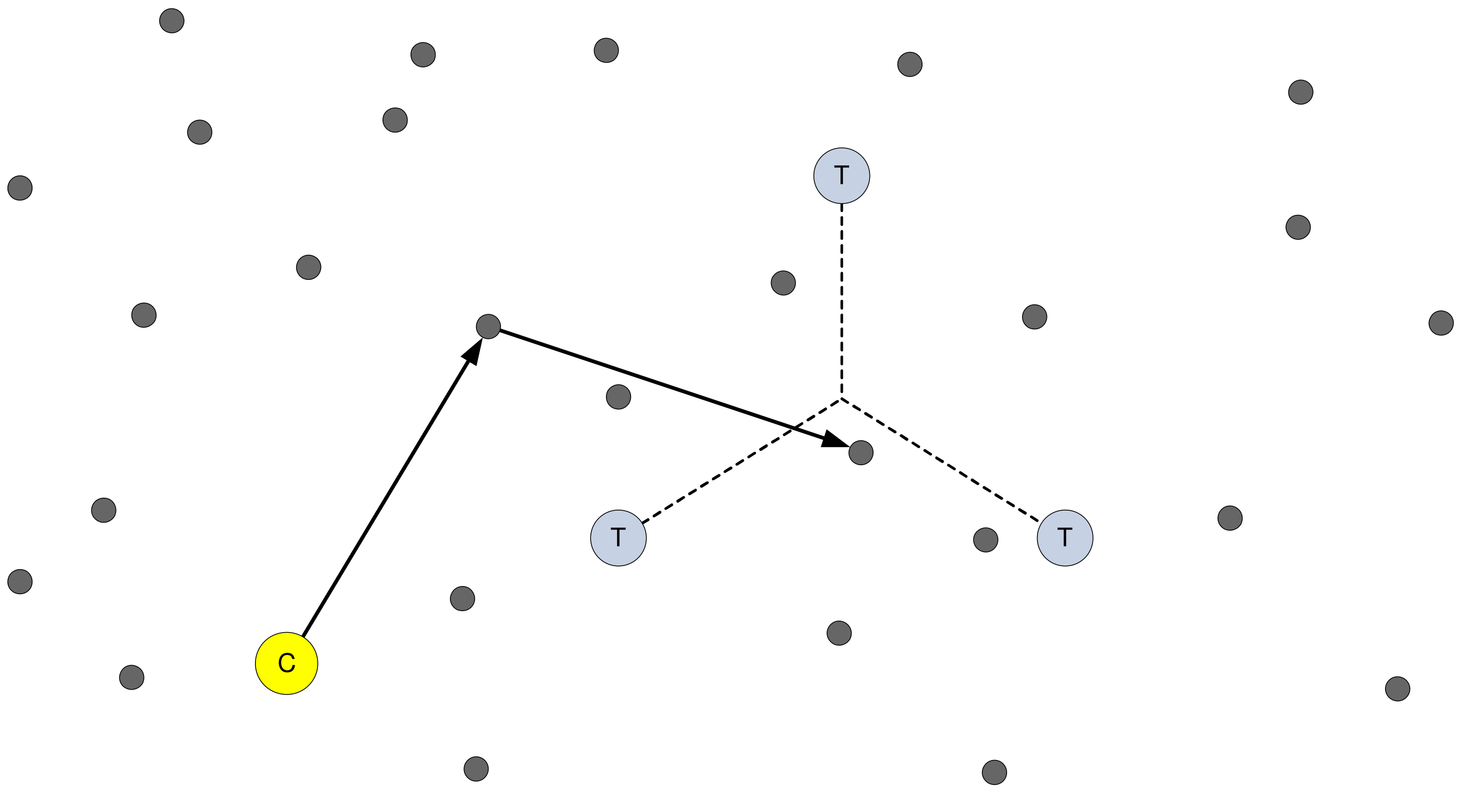

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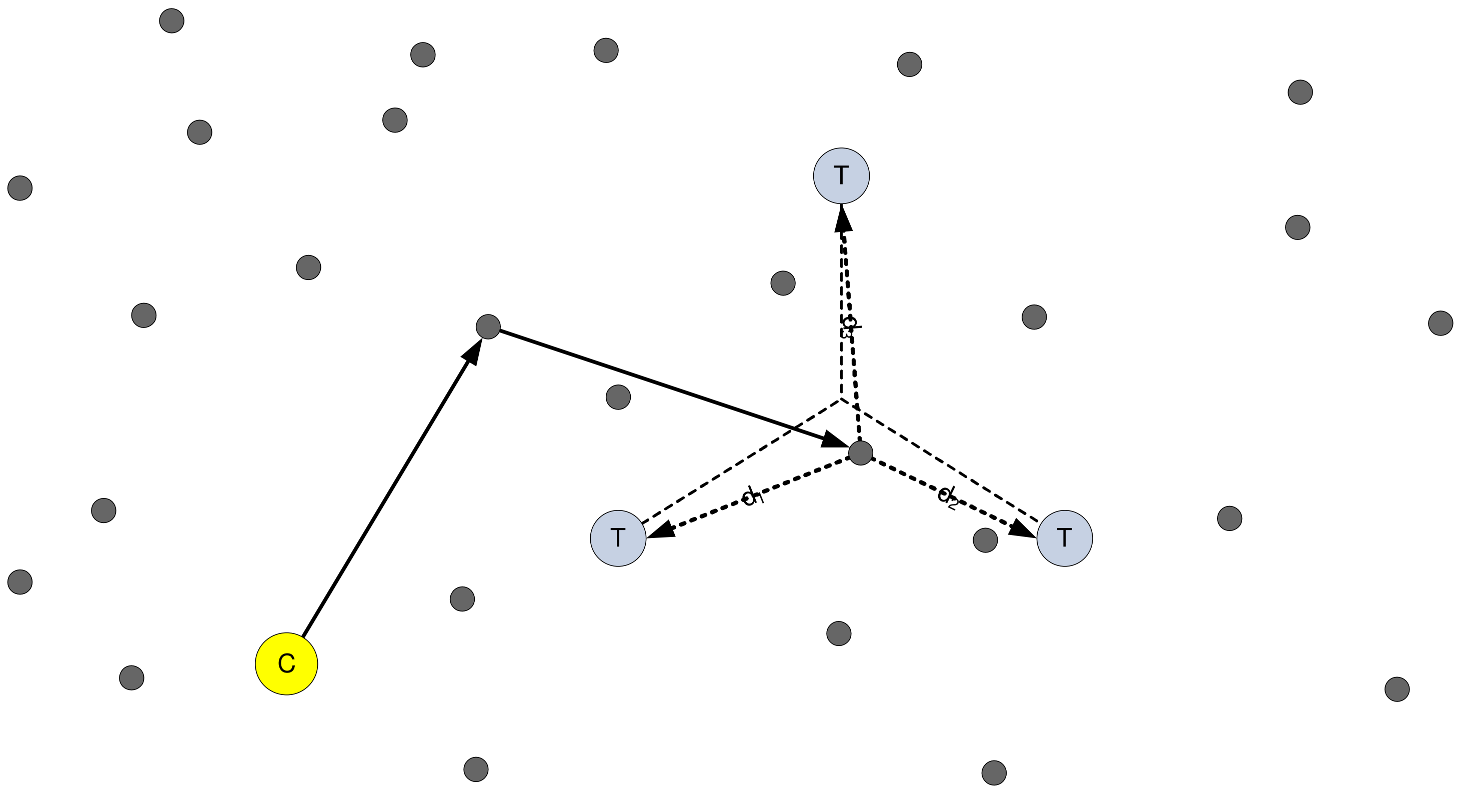
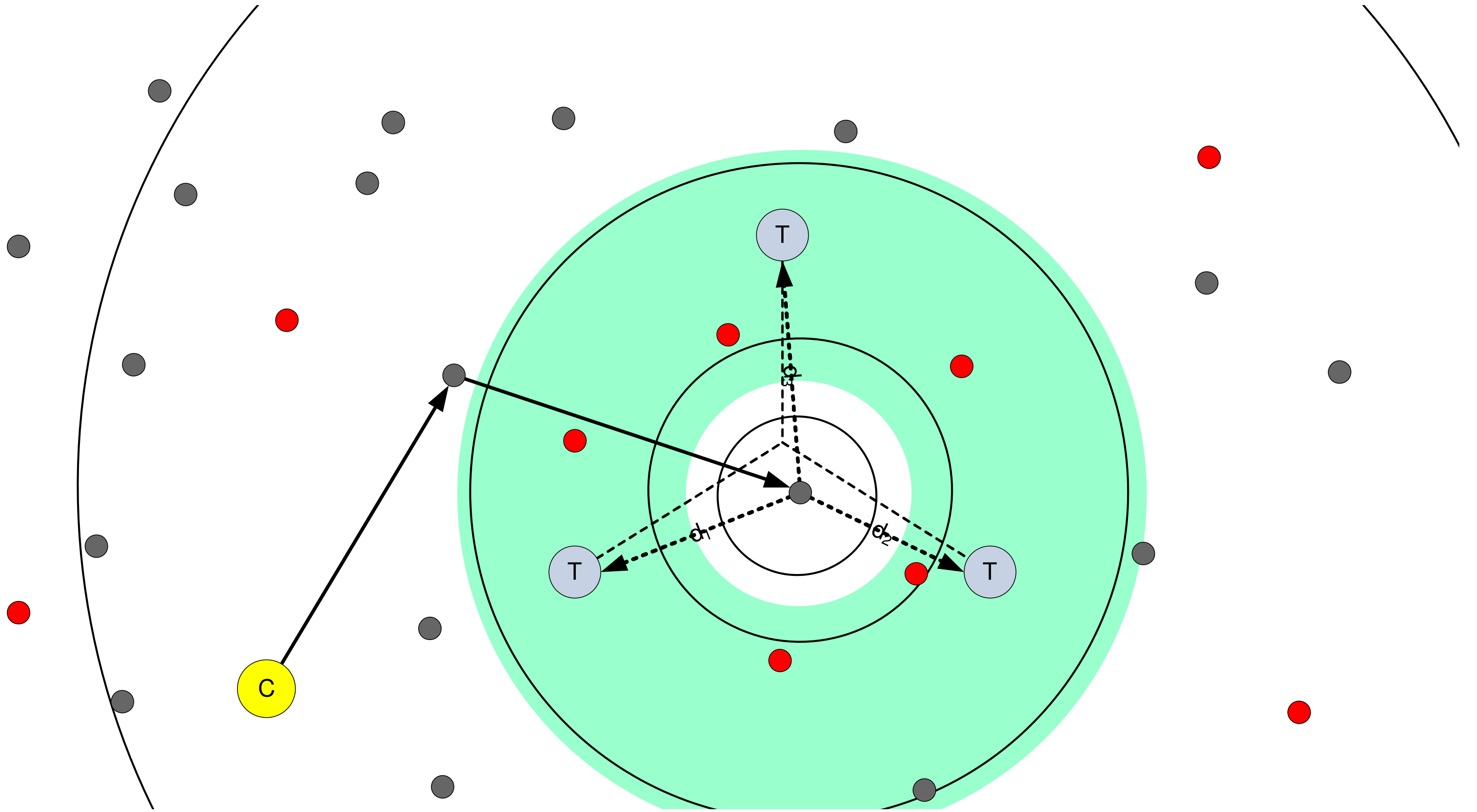
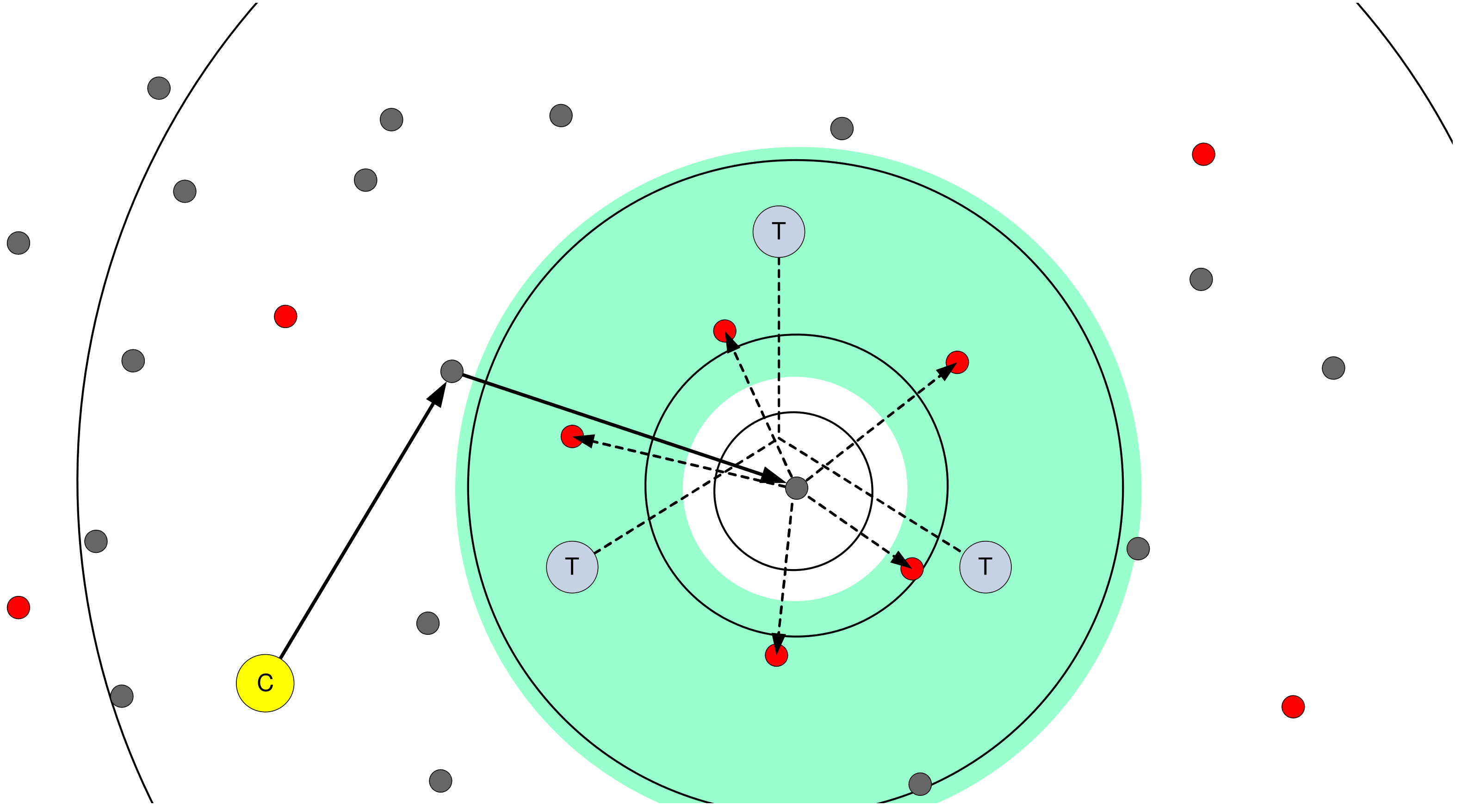


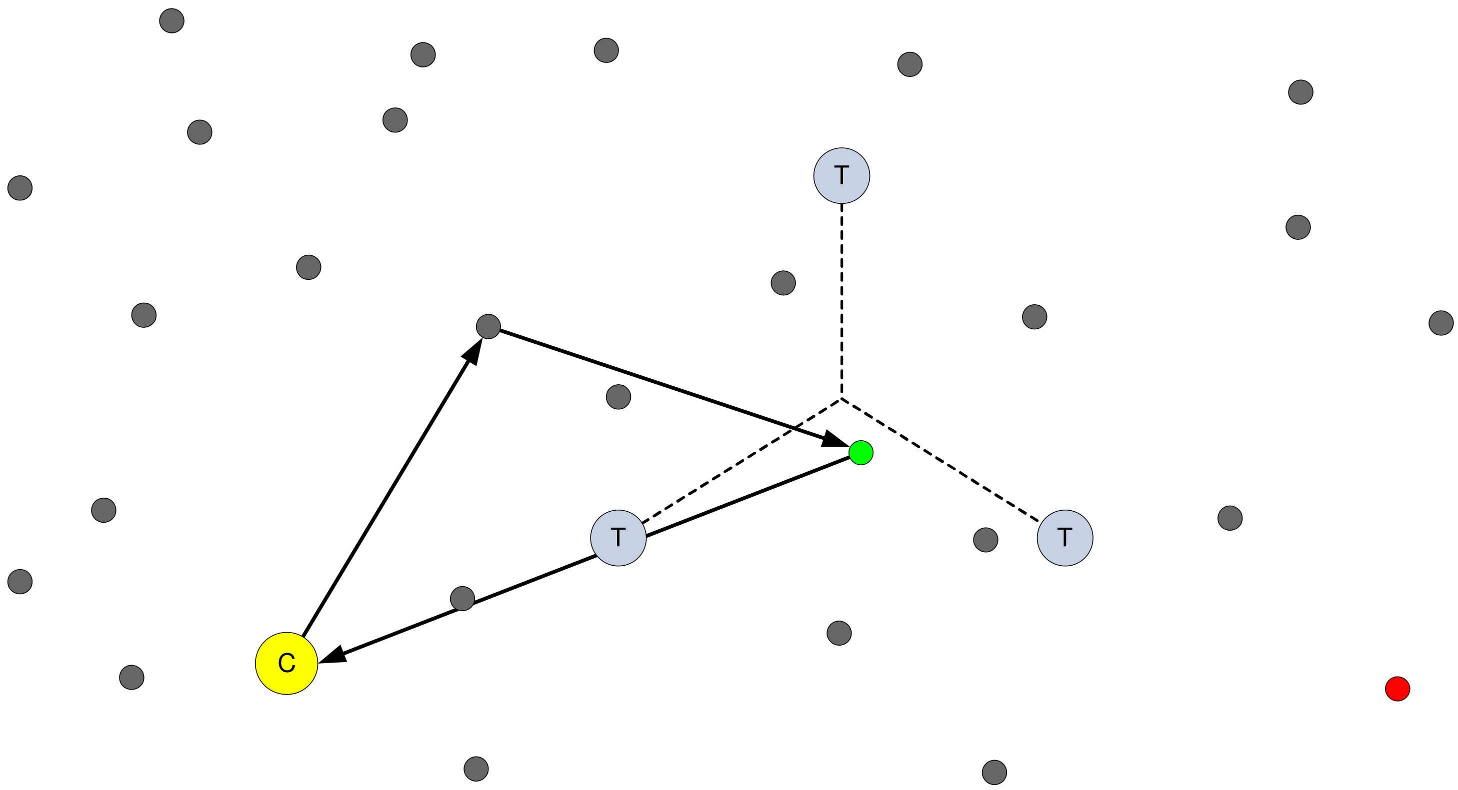
Central Leader Election



Central Leader Election



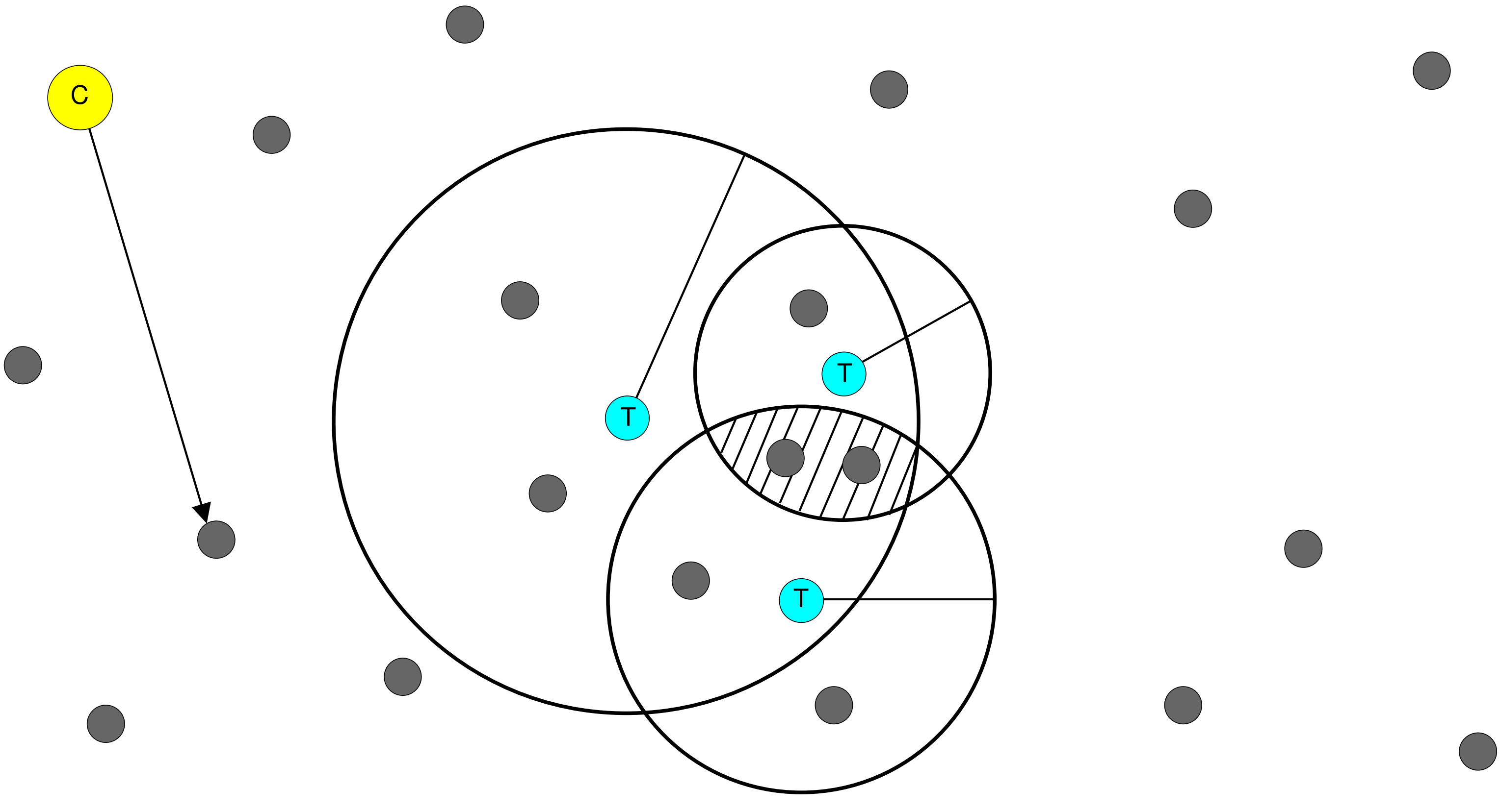
Central Leader Election



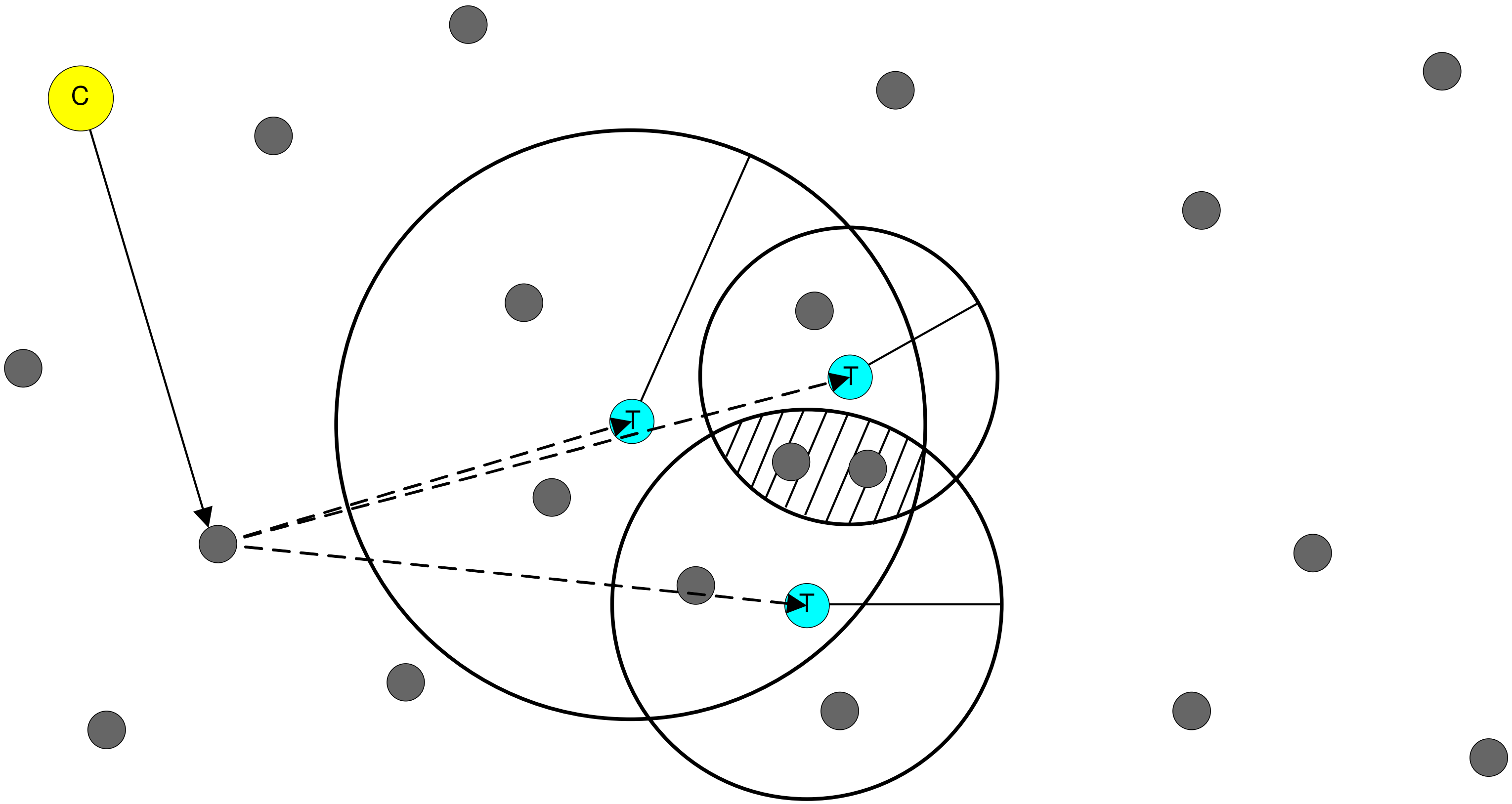
Multi-constraint System

- 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
- Re $s = \sum_{i=1}^{u} \max(0, d_i - range_i)^2$ metric s :
  - $s = 0$ 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

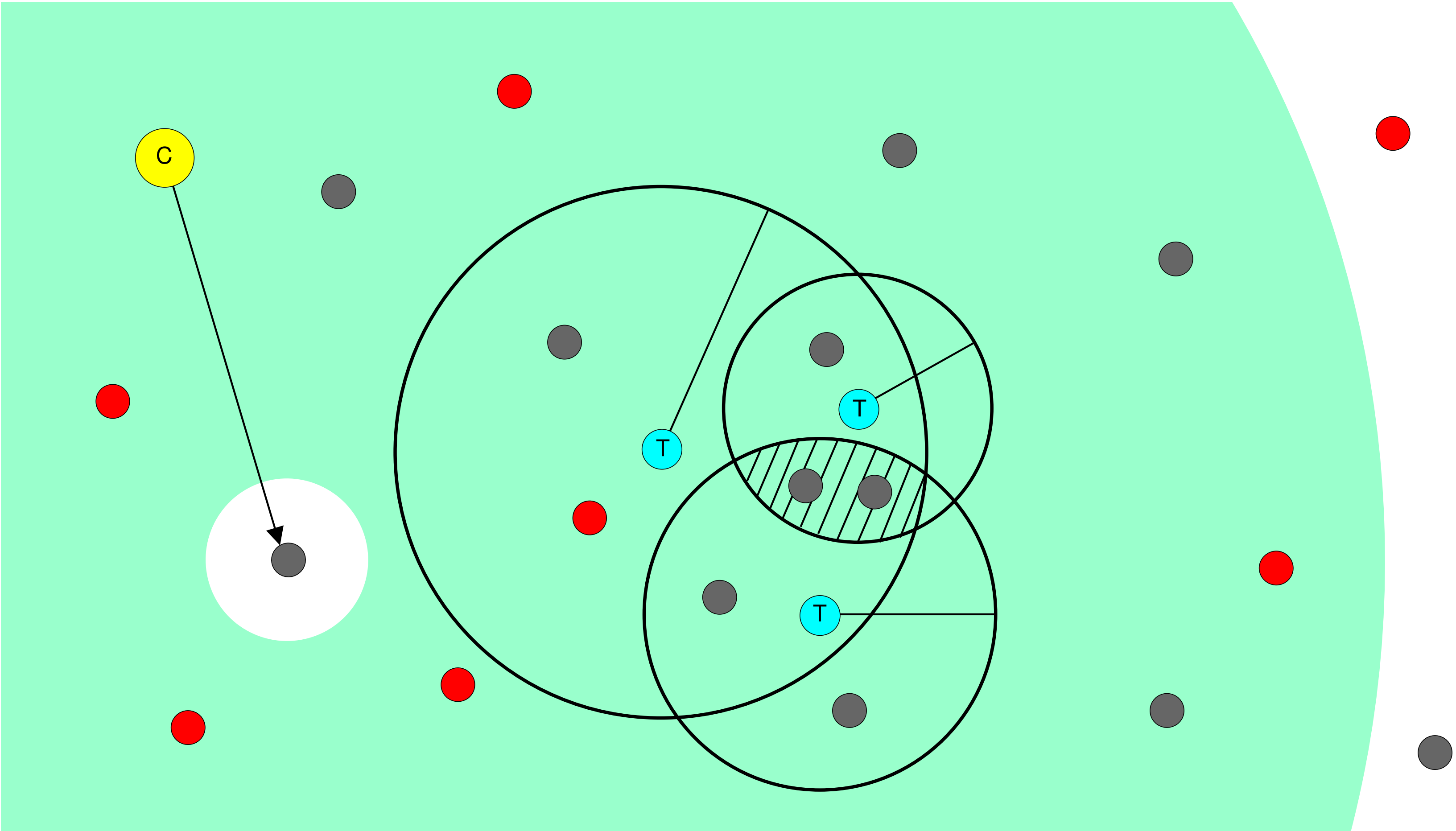
Multi-constraint System



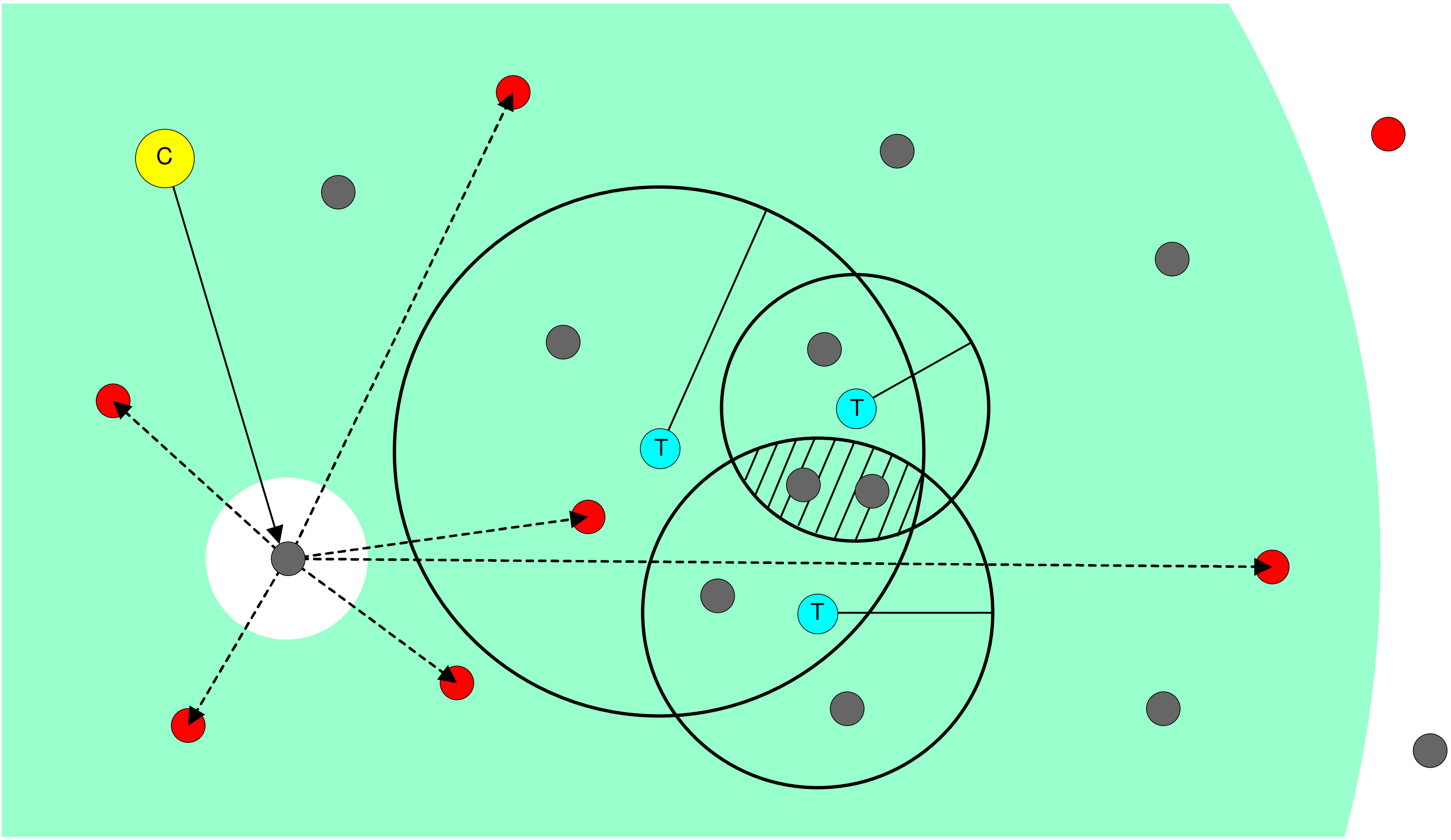
Multi-constraint System



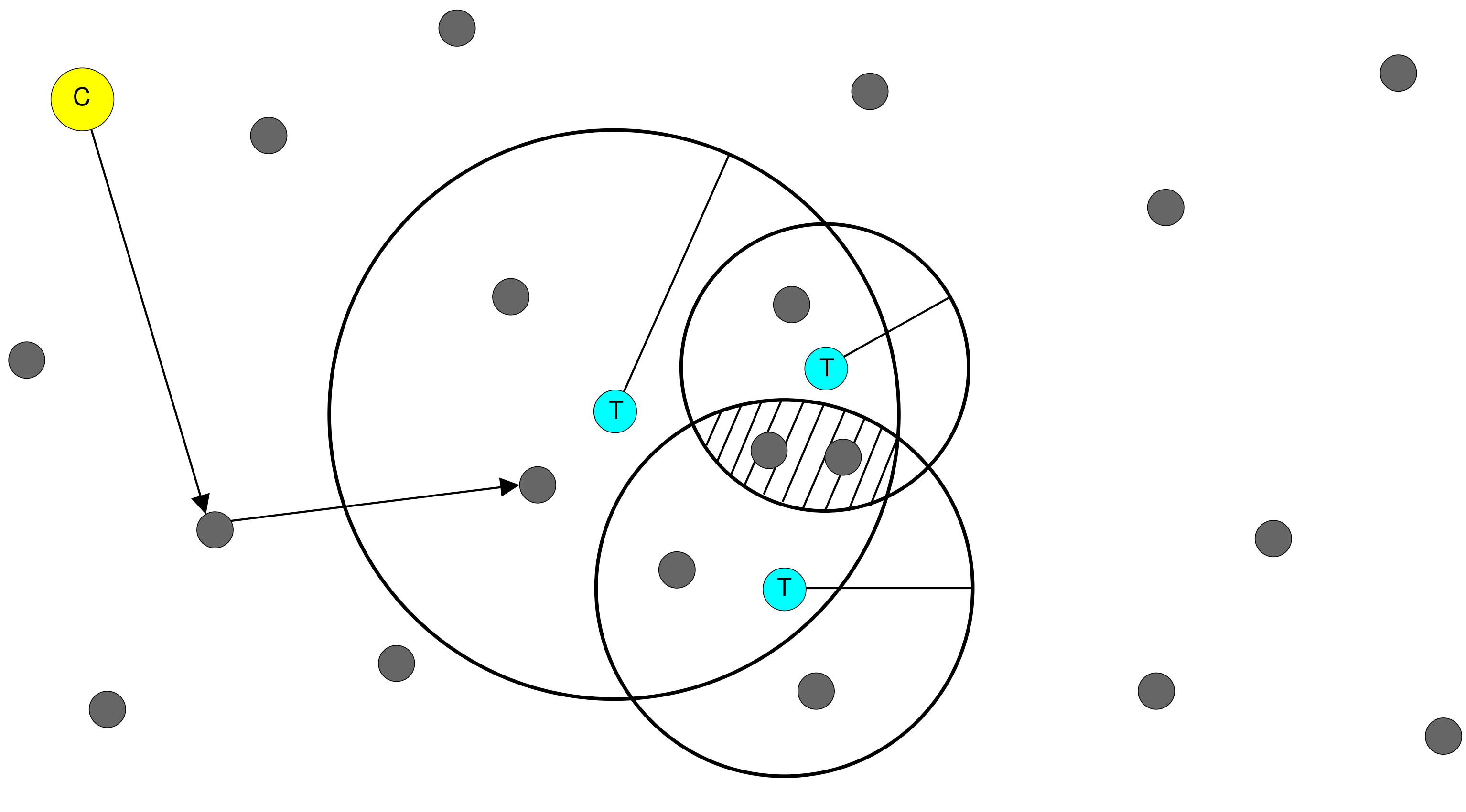
Multi-constraint System



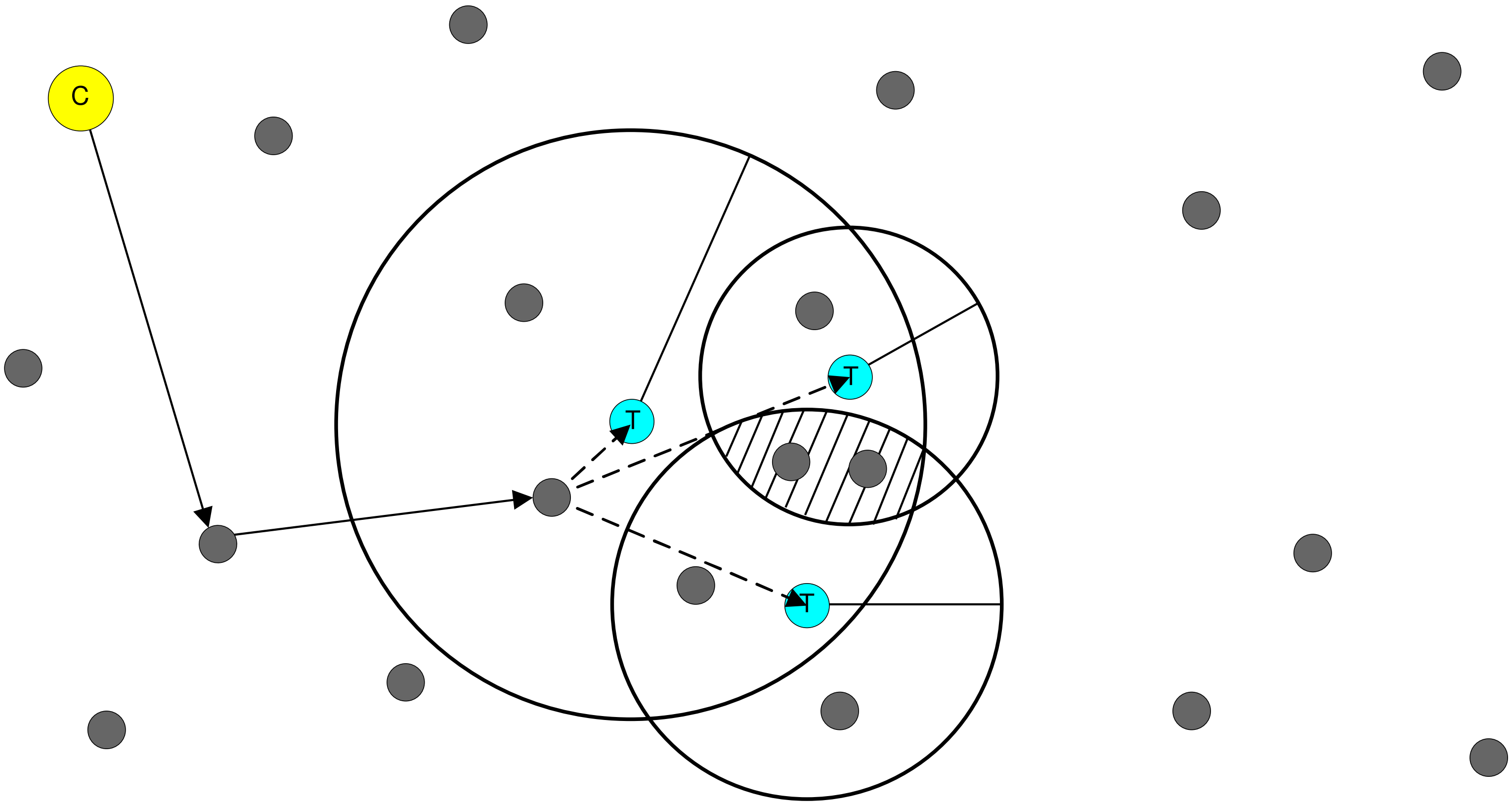
Multi-constraint System



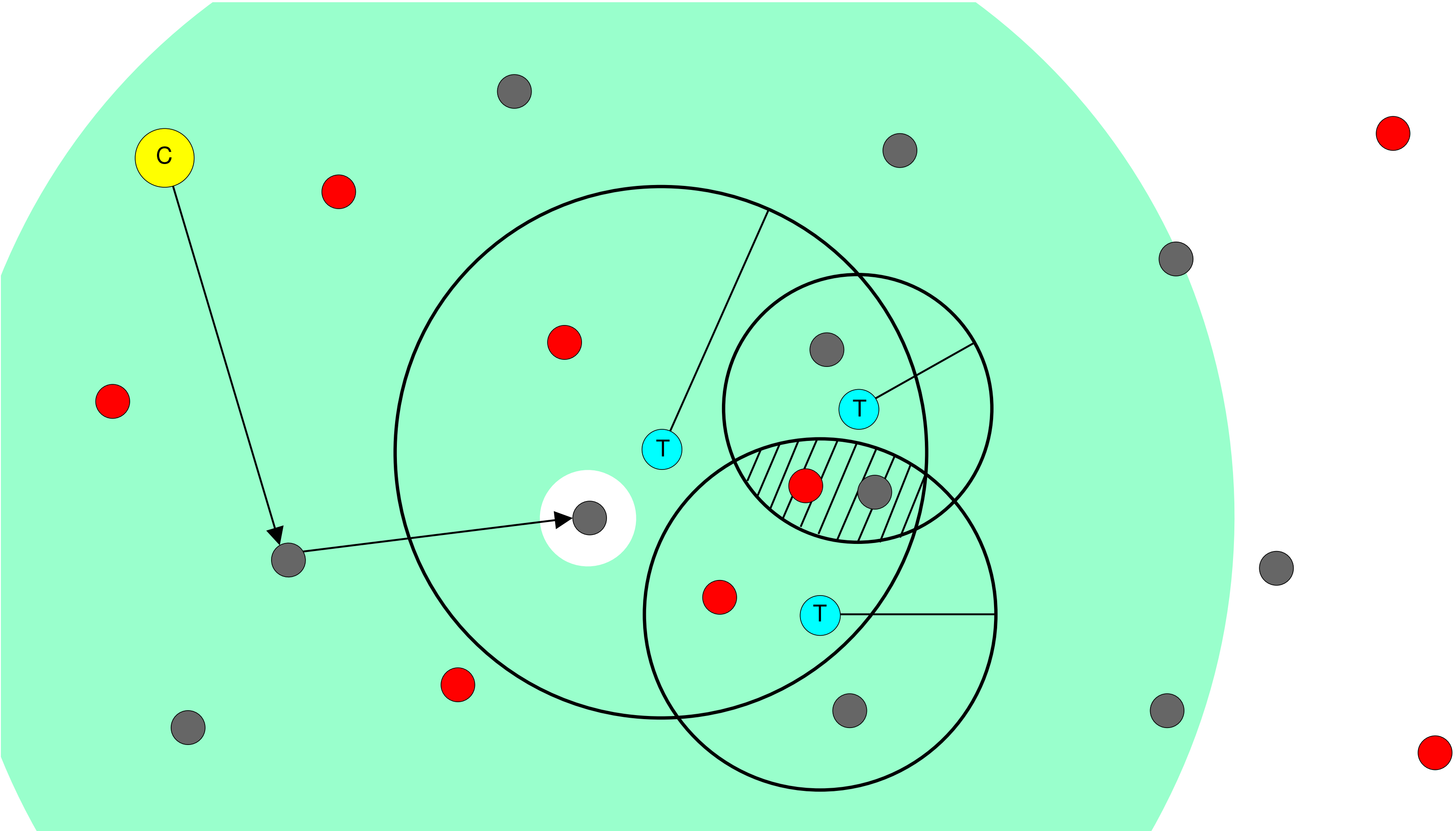
Multi-constraint System



Multi-constraint System



Multi-constraint System



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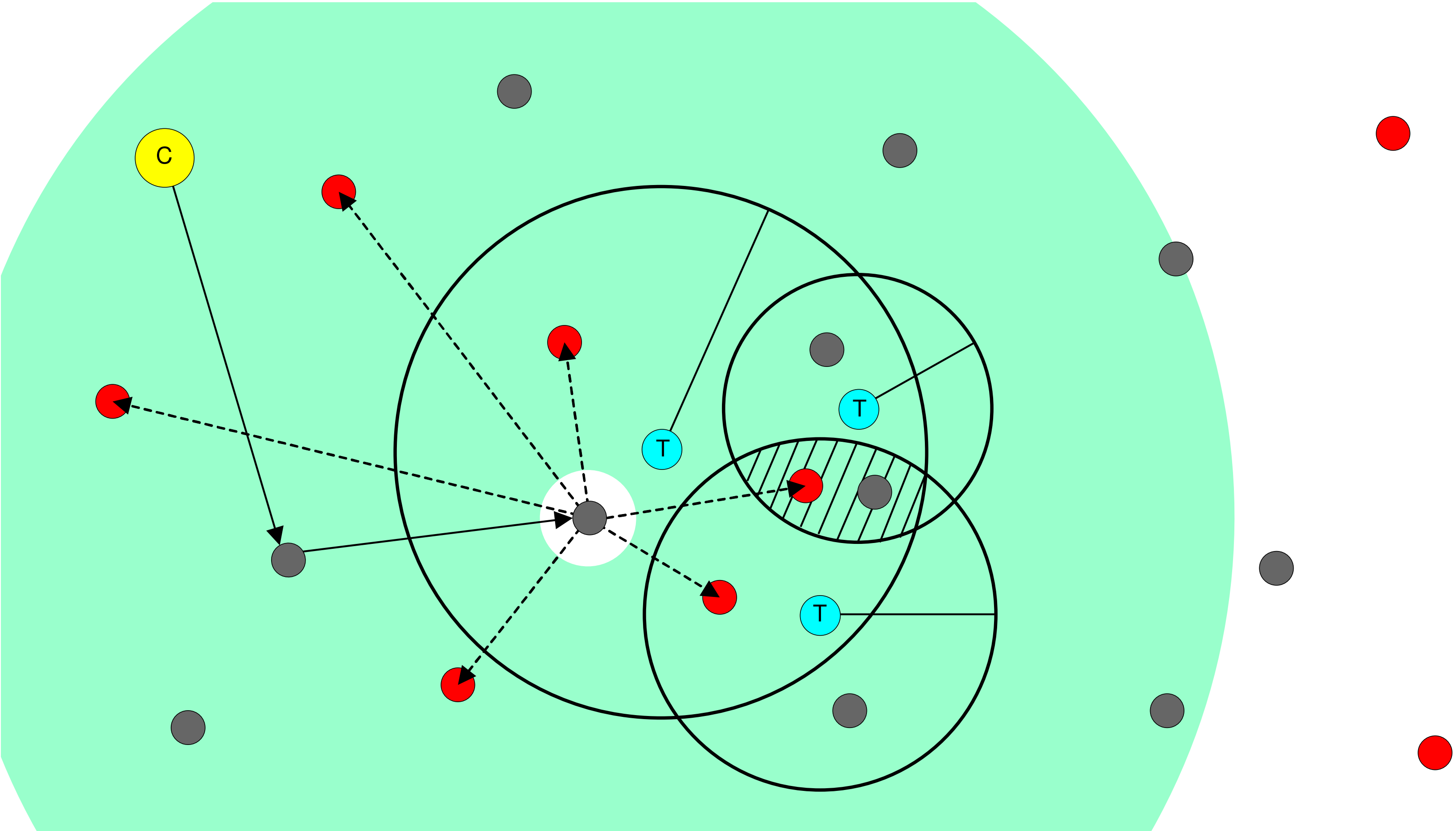
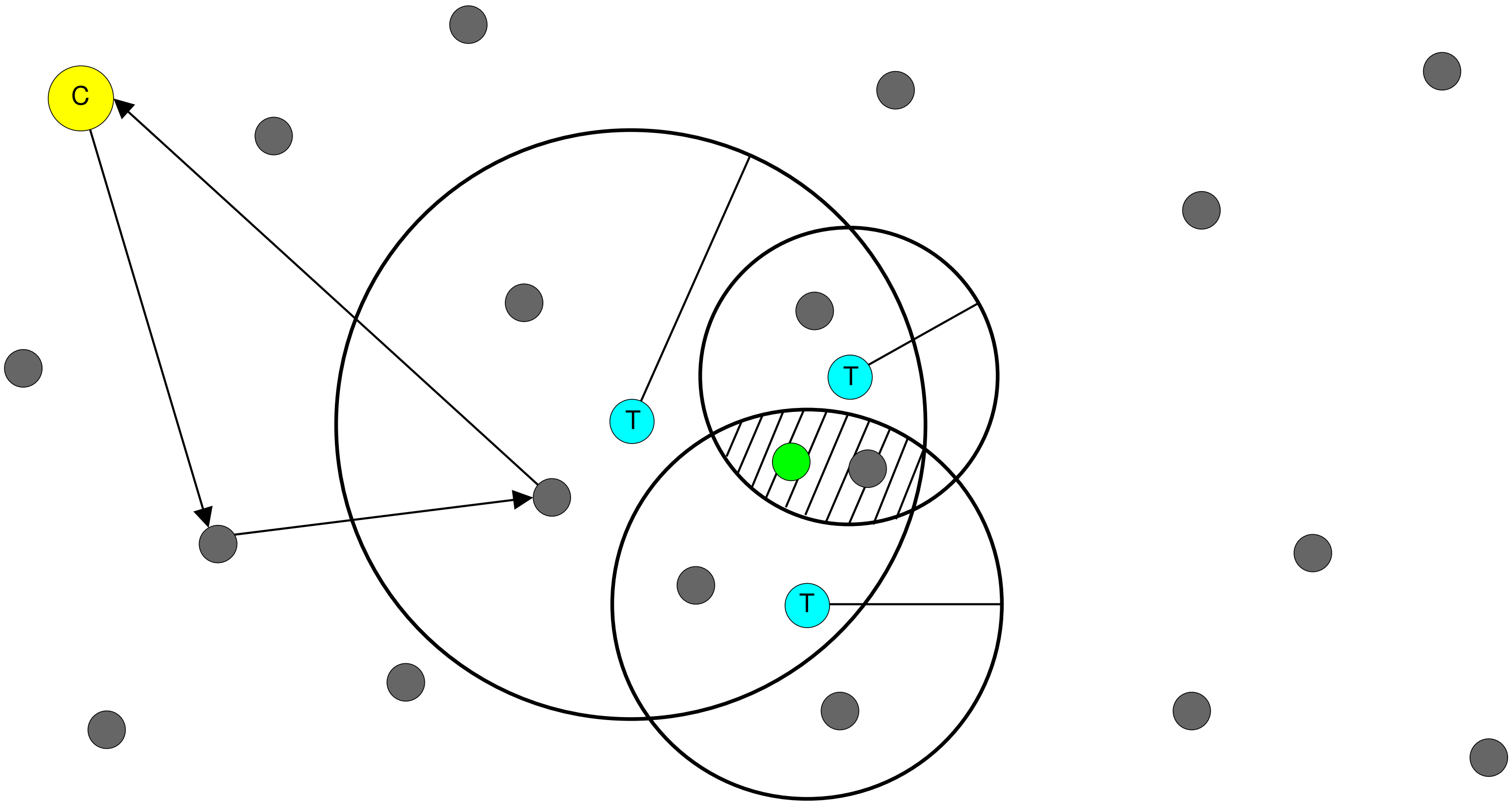


Multi-constraint System



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

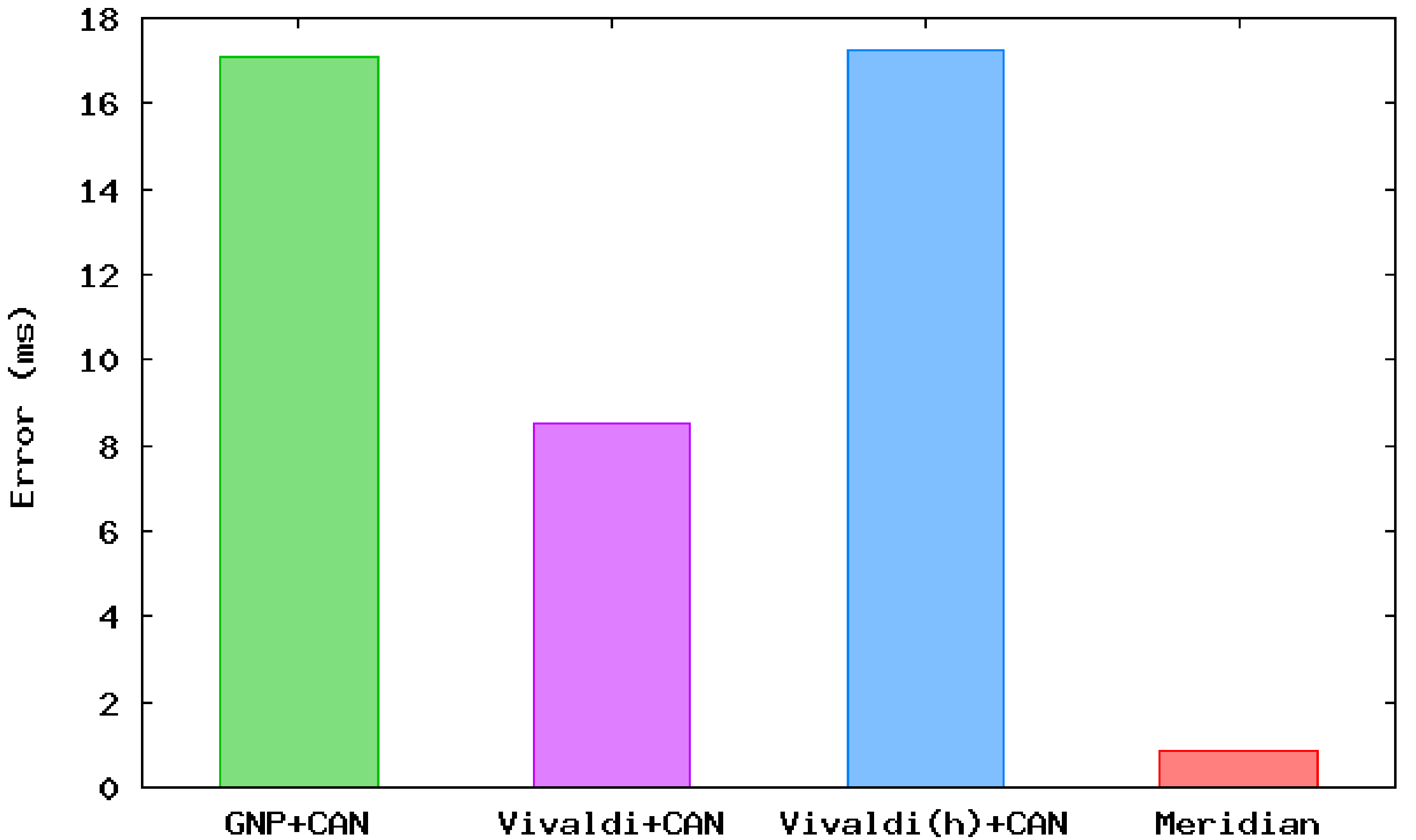
- Tight resource limits on:
  - Execution time of query
  - Number of hops
  - Amount of memory allocated

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

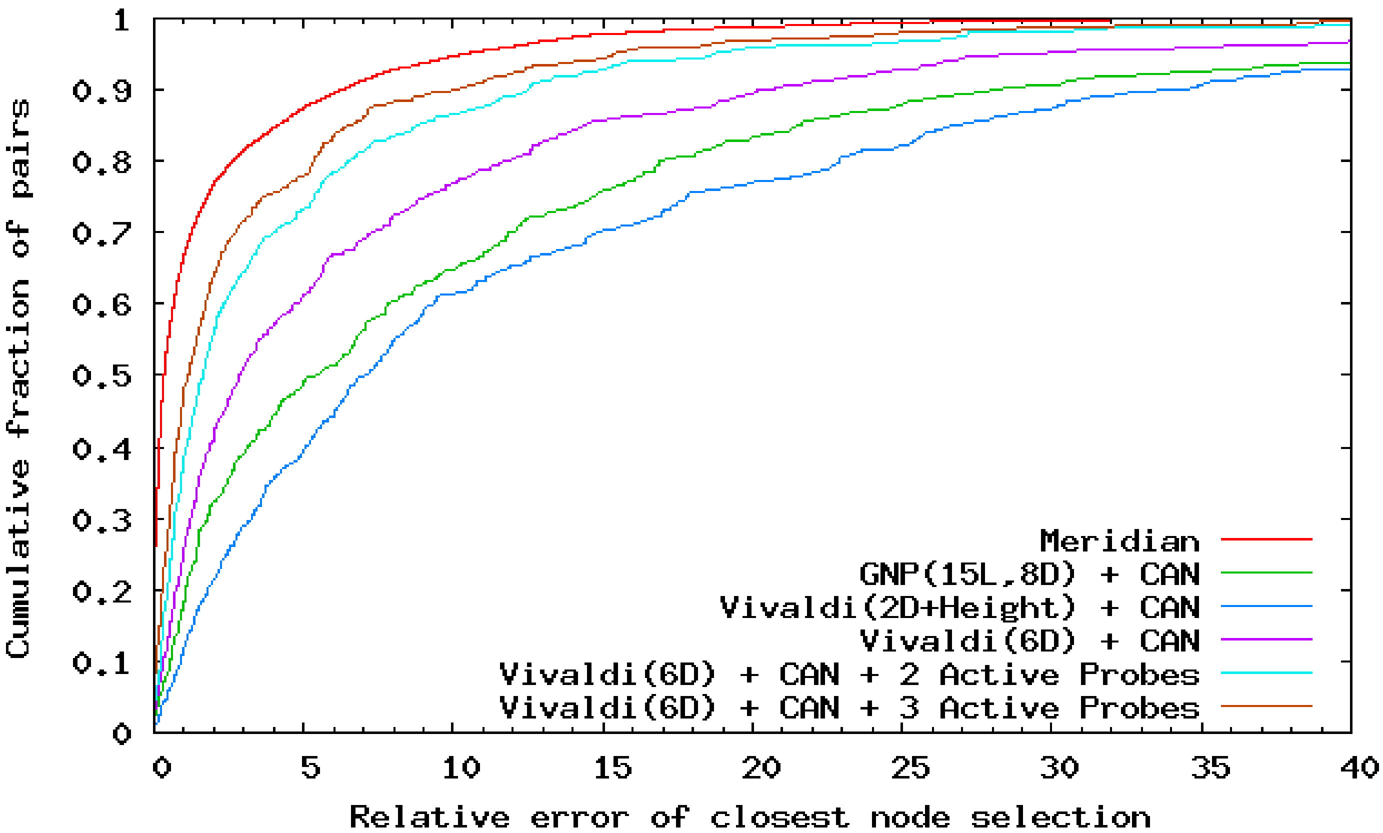
Evaluation: Closest Node Discovery

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



Evaluation: Closest Node Discovery

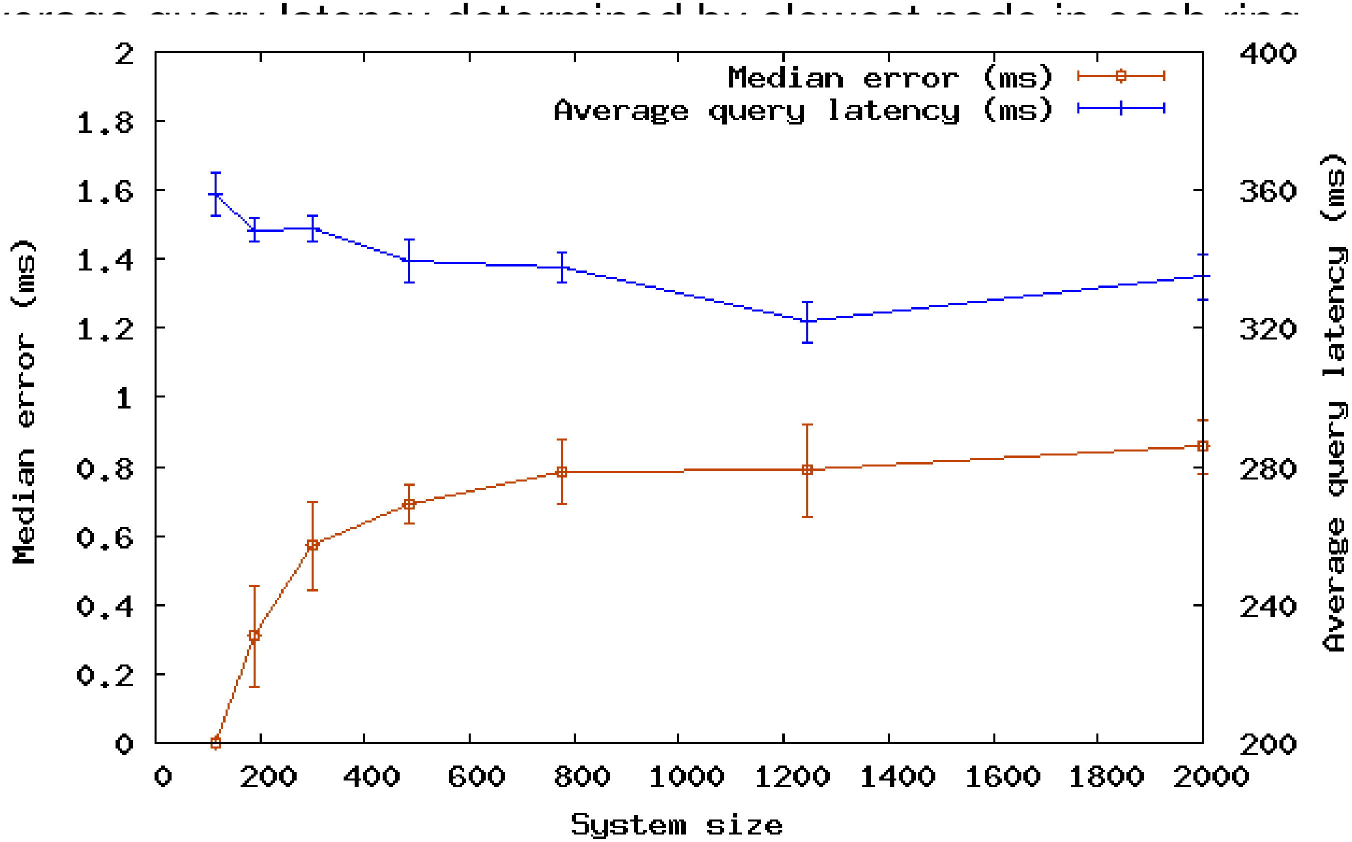
CDF of relative error shows Meridian is more accurate for both typical nodes and fringe nodes



Evaluation: Closest Node Discovery

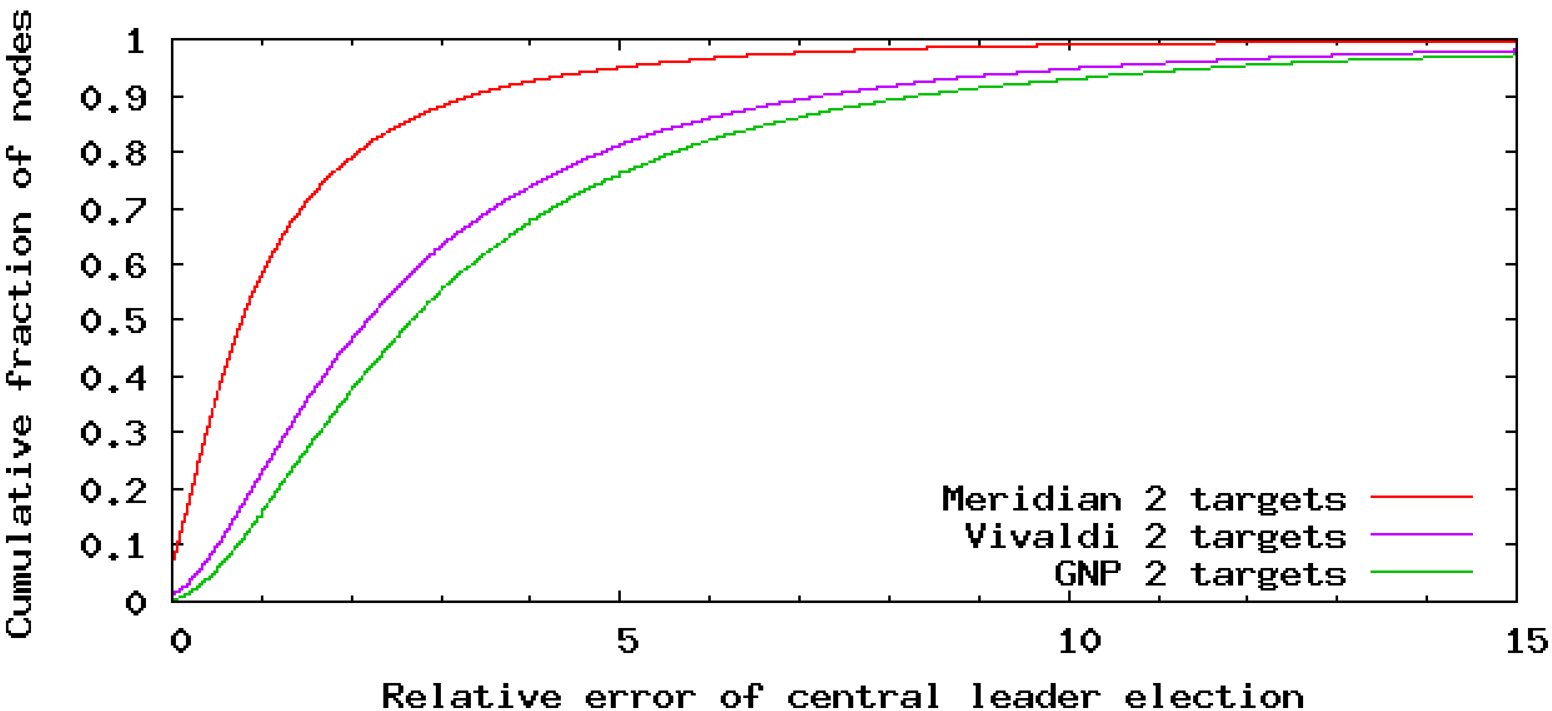
With k = $\lfloor \log_{1.6} N \rfloor$, error and query latency remain constant as N increases

Average query latency determined by slowest node in each ring



Evaluation: Central Leader Election

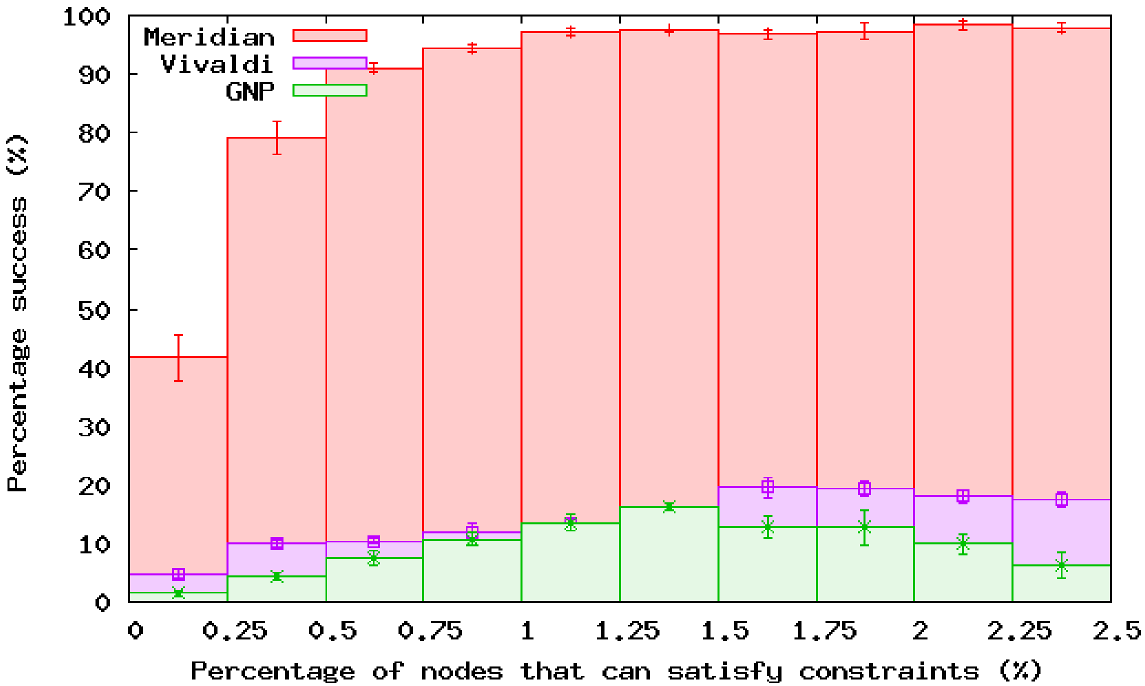
Meridian incurs significantly less relative error



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:

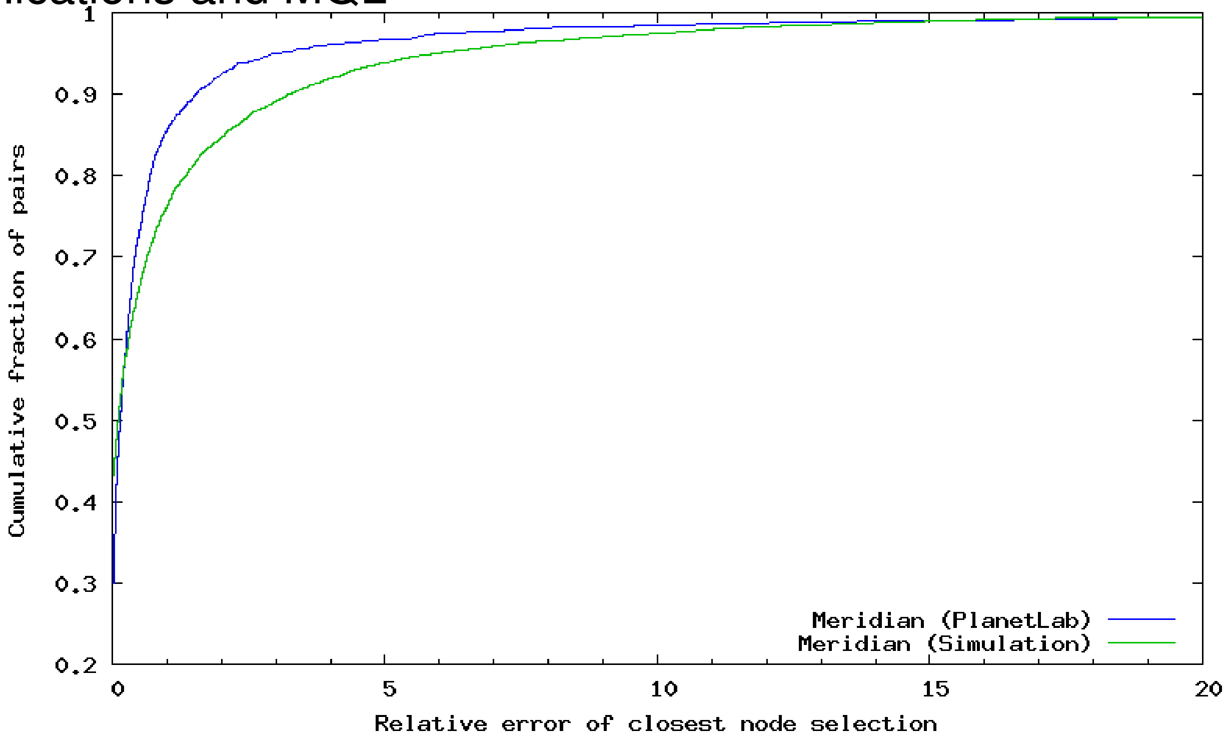
2 Constraints		3 Constraints		4 Constraints	
Meridian: 91%	VC: 35%	Meridian: 90%	VC: 19%	Meridian: 91%	VC: 11%



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

Meridian Summary

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

Octant

Determining the physical location of Internet nodes in the real world

(*Combining Sextant with Meridian...*)

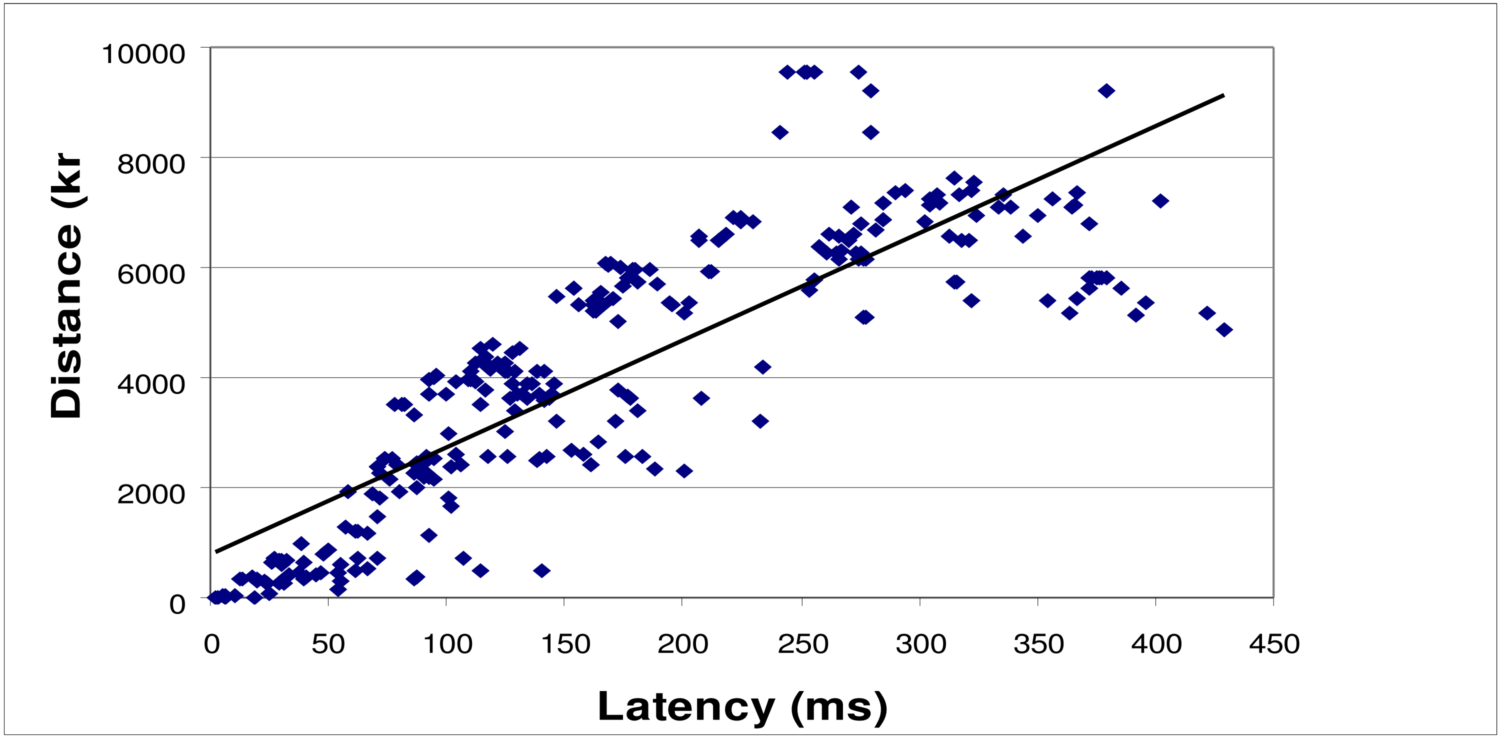
Octant

- Often need to determine the physical location of a machine on the Internet
  - Provide customized services
  - Trace user activity
  - Perform monitoring and locate attackers
- Need to map from IP Address to geographic location
  - IP to Zip Code: Static, Course-grained, Inaccurate
- Need a dynamic, accurate way of finding physical location of machines
  - Must work even if host is behind NAT, firewall or in a VPN

Octant Approach

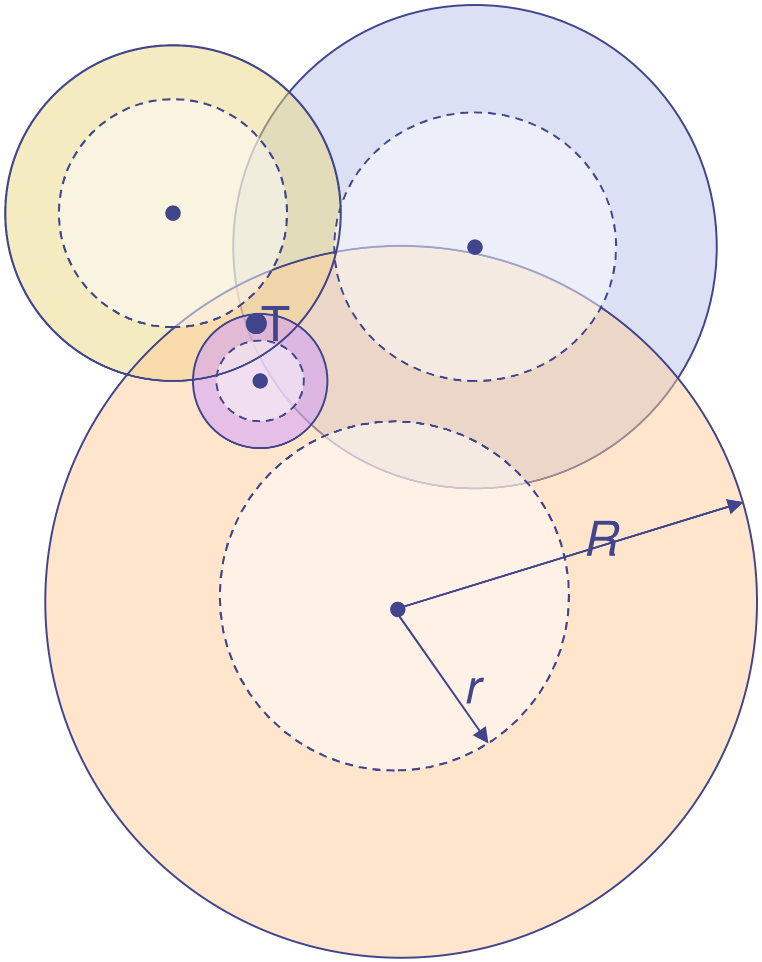
- Find general dependency between network latency and physical distance
- Set up a system of constraints based on latency measurements to known landmark nodes
  - Aggressively extract constraints
  - Use both positive and negative information
- Solve the system geometrically, yielding the set of physical areas on the globe where a target may be located

Latency-Distance Relationship



Internet latencies correlated with distance

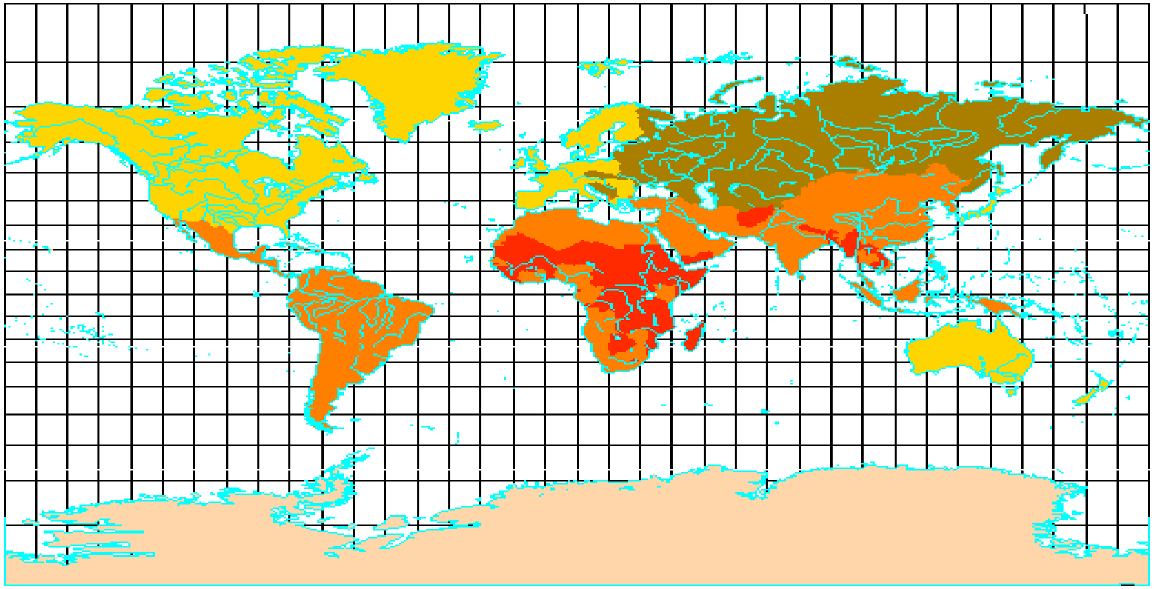
Positive and Negative Information



A latency probe establishes the minimum and maximum distances between a target T and chosen landmarks

Geometric intersection yields target location

Cylindrical Equidistant Projection



- Use Bézier curves to bound the areas in which a node can appear
- Map curves onto projected 2D globe

Summary

Octant is a dynamic and accurate Internet host localization service

Achieves high fidelity by using both positive and negative information

Can be used to determine the physical location of any node without user input

Network Positioning for Wide-Area and Wireless Networks

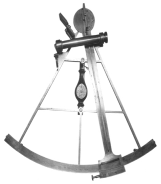
Emin Gün Sirer

Department of Computer Science
Cornell University

Localization is Critical

- Locality information is the building block for novel services in wired and wireless networks
  - Critical to find out where in the physical world nodes (and other items of interest) are
    - Locality-aware content, computing, routing, service discovery, event tracking in sensor networks, ...
  - Critical to select servers based on the position of target nodes
    - Find closest server, find centrally located node, find node within latency bounds

Sextant



Determining the location of nodes and events in wireless (ad hoc, sensor) networks

Localization in Wireless Networks

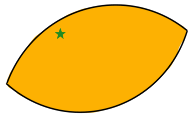
- Infrastructure-based hardware (GPS) is the traditional solution
  - Expensive
  - Power-hungry
  - Does not work indoors, without infrastructure

- How well can we do with intelligent software and cheap, ubiquitous hardware?

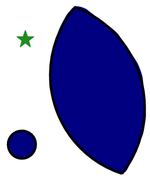
Sextant Approach

- Treat localization as a constraint-satisfaction problem
  - Extract constraints aggressively from the network
  - Disseminate them transitively
  - Solve in a distributed manner

Sextant Properties



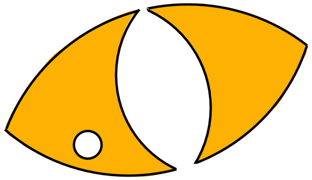
Positive Constraint



Negative Constraint

- Accurate
  - Negative as well as positive information
  - Explicit representation
- Practical
  - Constraint extraction
  - Deployed on Mica-2 motes, PDAs and laptops

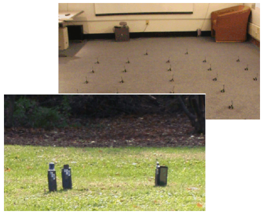
Sextant Properties



- Need not be convex
- May have holes
- May have disconnected components

- Accurate
  - Negative as well as positive information
  - Explicit representation
- Practical
  - Constraint extraction
  - Deployed on Mica-2 motes, PDAs and laptops

Sextant Properties



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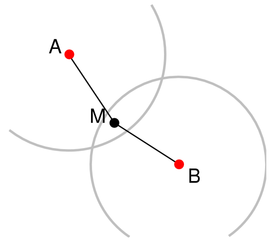
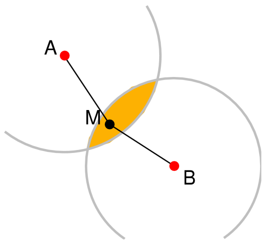
Node Localization



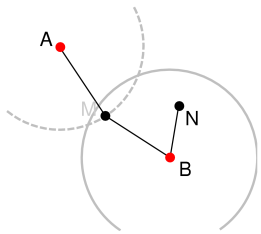
Positive information

Node Localization



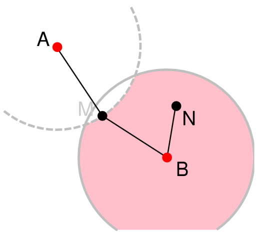
Intersection of Positive information

Node Localization



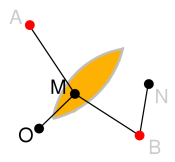
Negative information

Node Localization



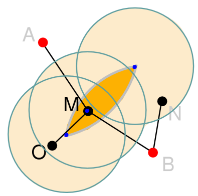
Positive information

Node Localization



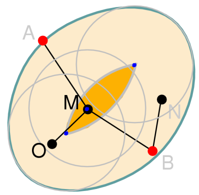
Transitive dissemination of positive information

Node Localization



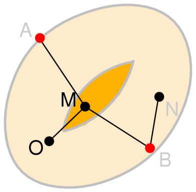
Transitive dissemination of positive information

Node Localization



Transitive dissemination of positive information

Node Localization



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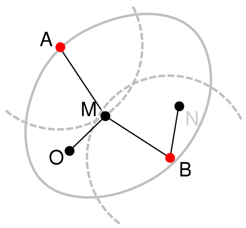
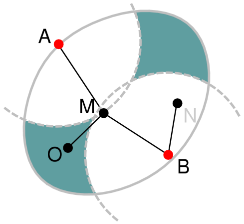


Combining negative and positive information

Node Localization



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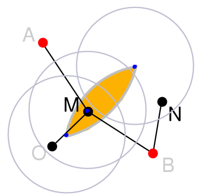

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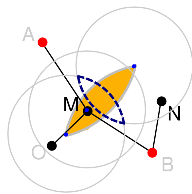

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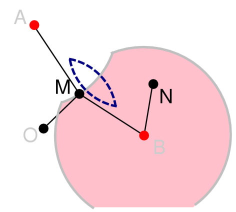

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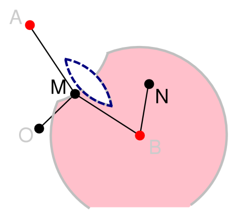
Node Localization



Refining position estimates

Sextant Approach

Location estimate: $ß_x$

Set of positive constraints: Γ_x

Set of negative constraints: Θ_x

$$ß_x = \bigcap (p \in \Gamma_x) \setminus \bigcup (n \in \Theta_x)$$

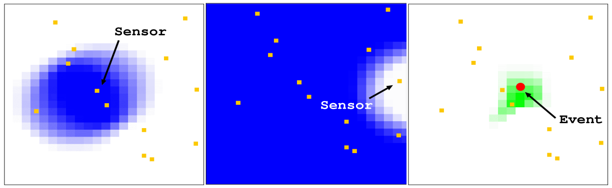
Sextant Areas

- Represent areas explicitly
  - Use Bezier curves to bound bezier regions
  - Four control points define a curve
  - Union and intersection are implemented efficiently
- Not a point estimate!
  - Ideally, applications should take the bezier region as input
  - Can generate point estimate from bezier regions

Localizing Events

- Hot area in sensor networks
- The Sextant approach provides a comprehensive, unified framework
- Differences from node localization
  - Constraints from sensors, not wireless radios
  - Boolean connected/not connected to sensed/not sensed
  - Annotate resulting areas with probabilities

Event localization

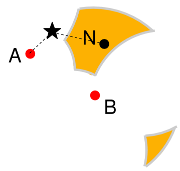


- Decompose space into a grid, propagate probabilities
- Calculate normalized Bayesian probabilities

Event Localization

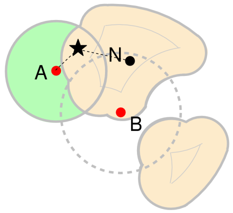
Start with initial Sextant node regions

Event Localization



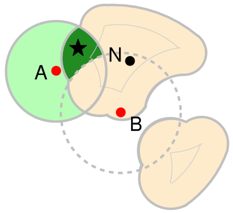
An event occurs

Event Localization



Sextant is used for event localization

Event Localization



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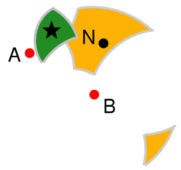


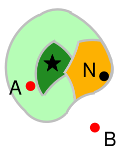
Event localized

Event Localization

Title:sextant
Creator:Tgif-4.1.43-Q
CreationDate:Sun M

Event used for node localization!

Event Localization



Event used to refine node location!

Event Localization

Event detection helps refine node positions!

Meridian

Selecting nodes based on location

(without knowing their actual location in the real world)

Network Location Service

Select nodes based on a set of network properties

Underlying abstract problems

Real-world problems:

Real-world problems	Underlying abstract problems
Locate closest game server	**Finding closest node to target**
Distribute web-crawling to nearby hosts	
Perform efficient application level multicast	**Finding the closest node to the center of a set of targets**
Satisfy a Service Level Agreement	
Provide inter-node latency bounds for clusters	**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:

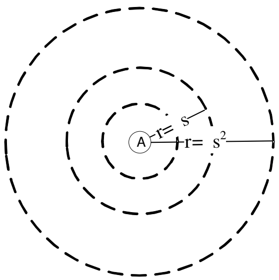
- Solve network location problems in O(log D) hops

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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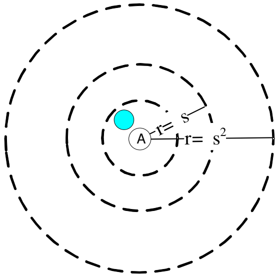

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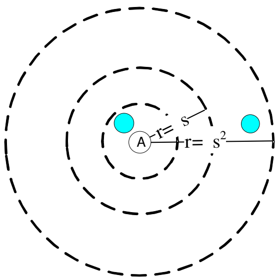
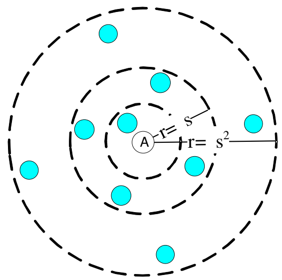


Multi-resolution Rings

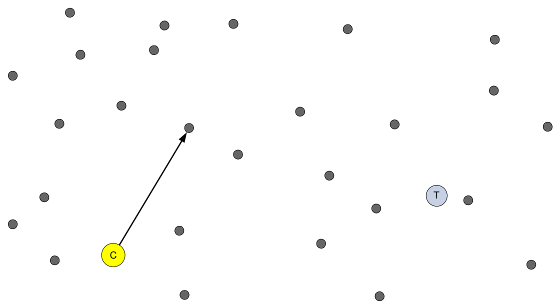
- Organize peers into small fixed number of concentric rings
- Radii of rings grow outwards exponentially
  - Logarithmic # of peers per ring
  - Favors nearby neighbors
  - Retains a sufficient number of pointers to remote regions
- Gossip protocol used for peer discovery



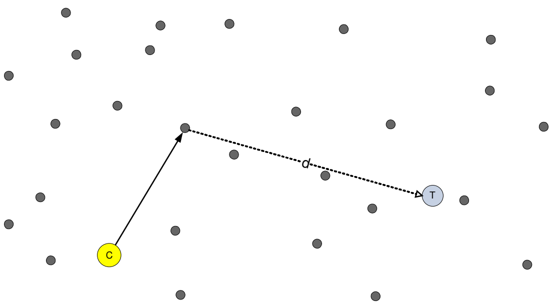
Closest Node Discovery

- 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

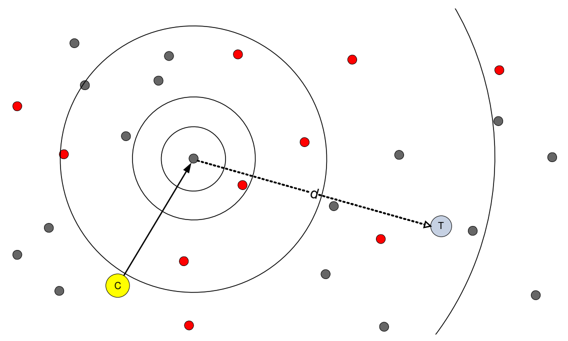
Closest Node Discovery



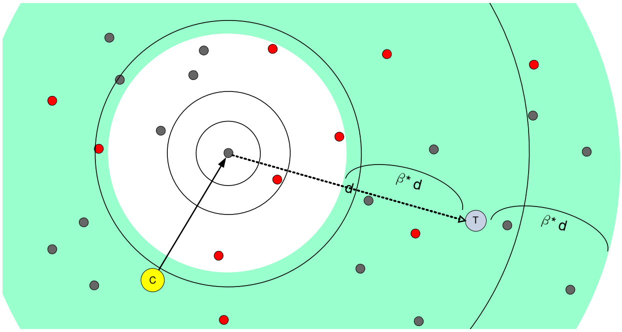
Closest Node Discovery



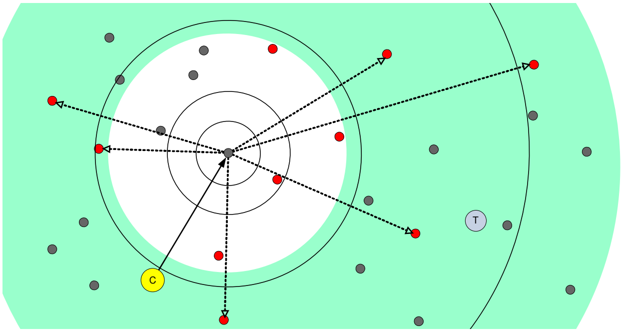
Closest Node Discovery



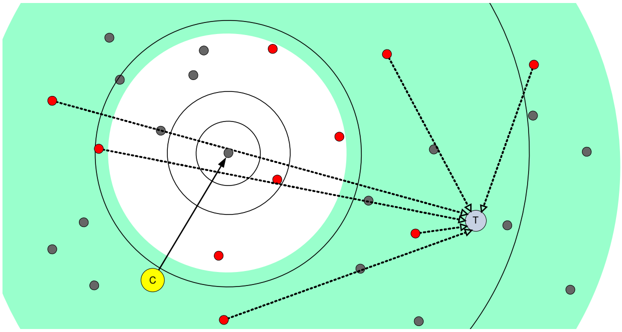
Closest Node Discovery



Closest Node Discovery



Closest Node Discovery



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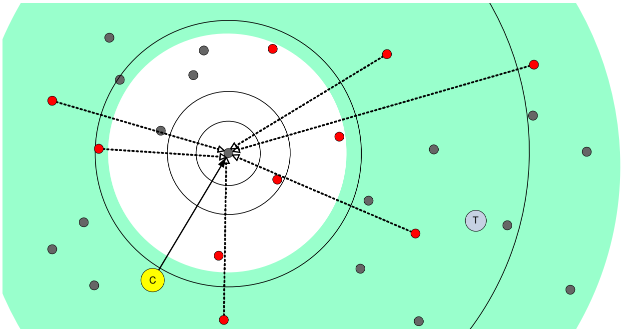
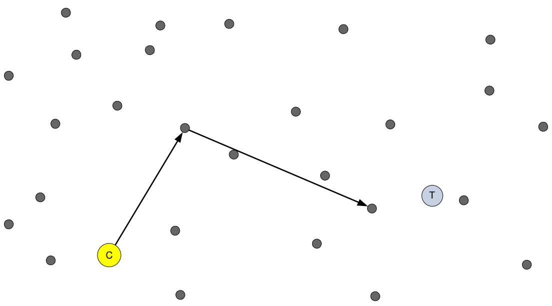
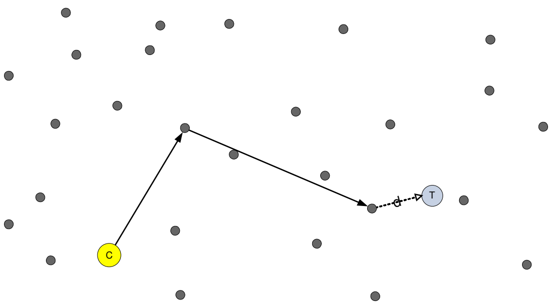


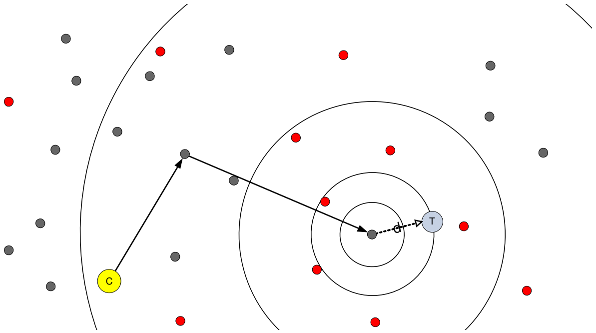
Closest Node Discovery



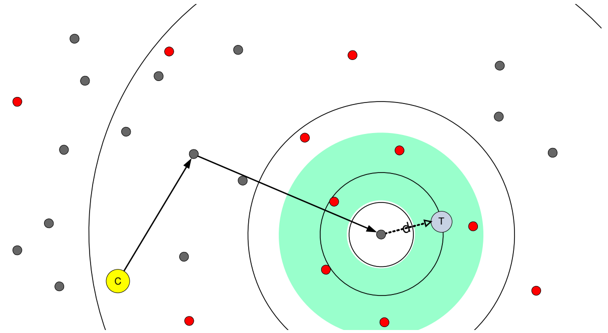
Closest Node Discovery



Closest Node Discovery



Closest Node Discovery



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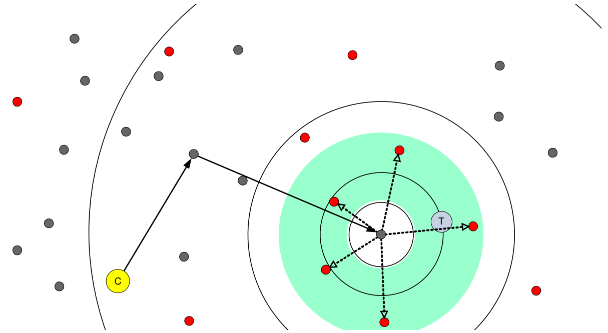

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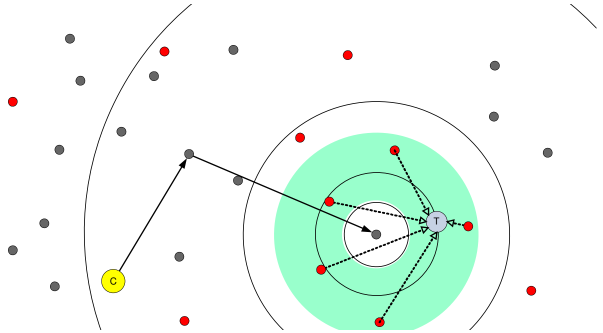

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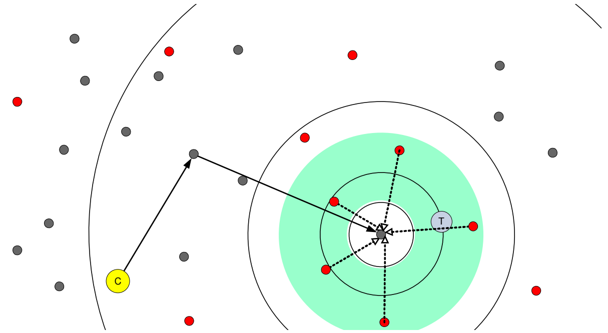

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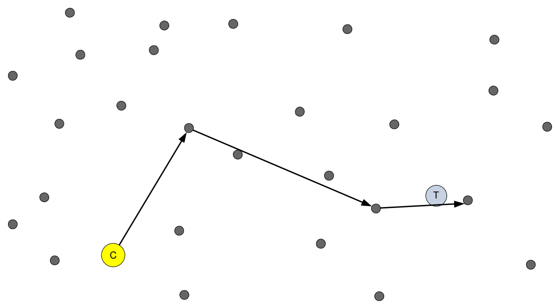

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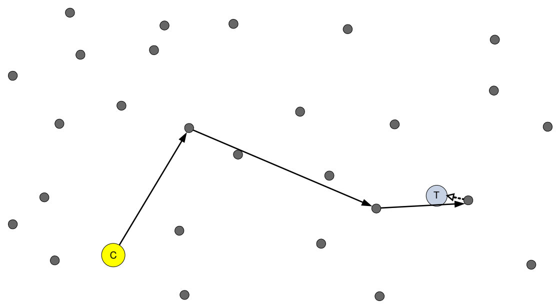

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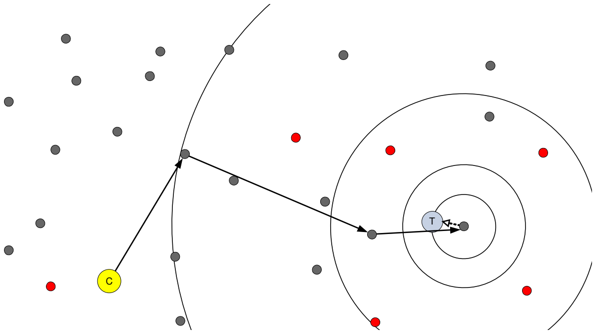
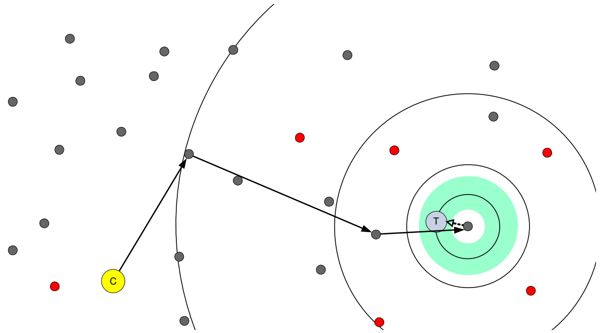
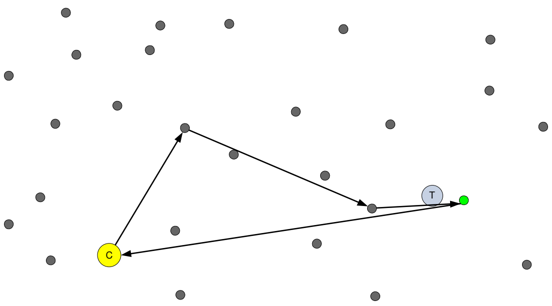


Closest Node Discovery



Closest Node Discovery



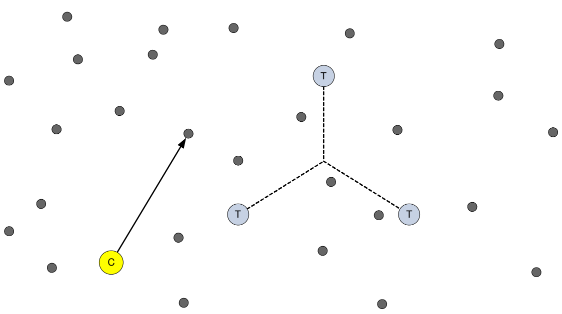
Meridian Theoretical Analysis

- 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

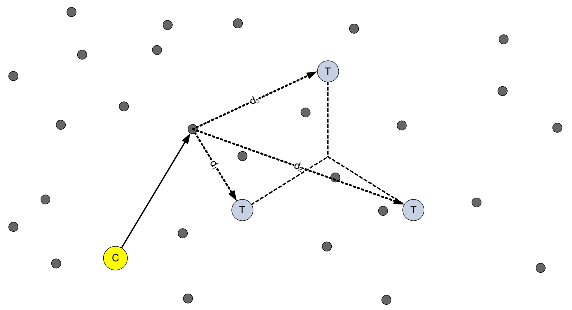
Central Leader Election

- 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

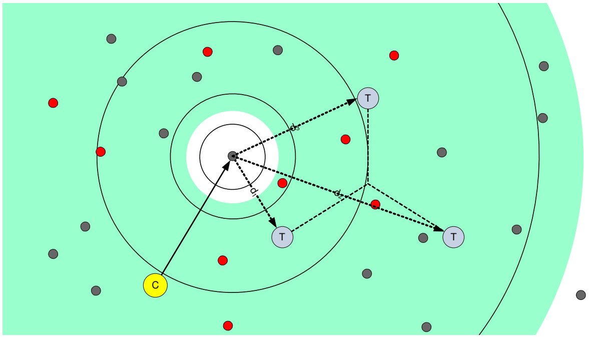
Central Leader Election



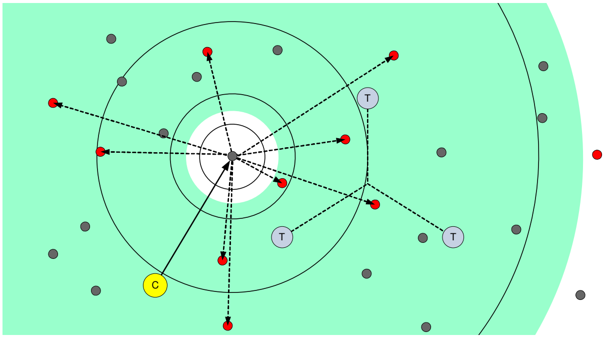
Central Leader Election



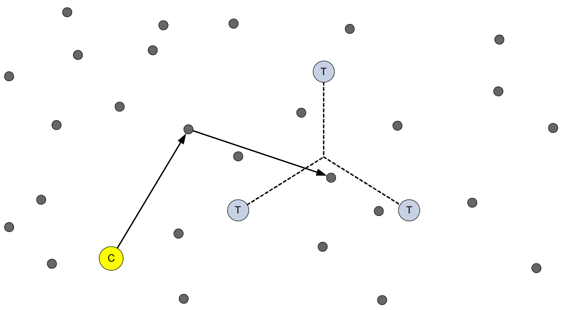
Central Leader Election



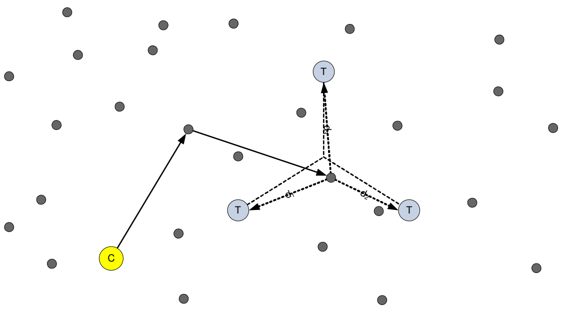
Central Leader Election



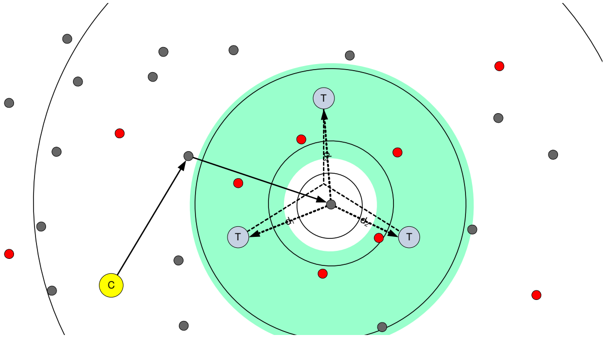
Central Leader Election



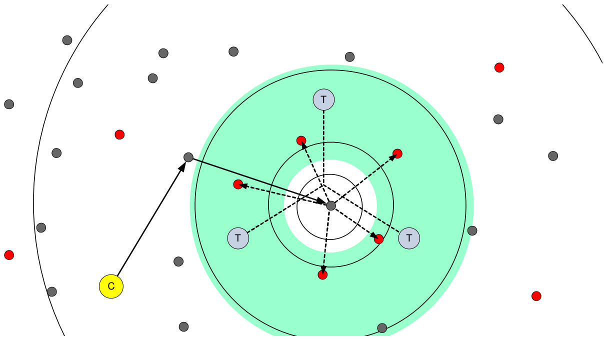
Central Leader Election



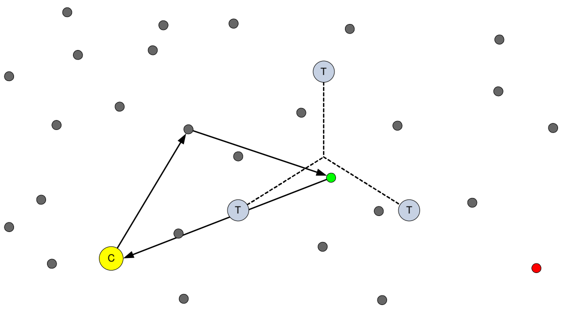
Central Leader Election



Central Leader Election



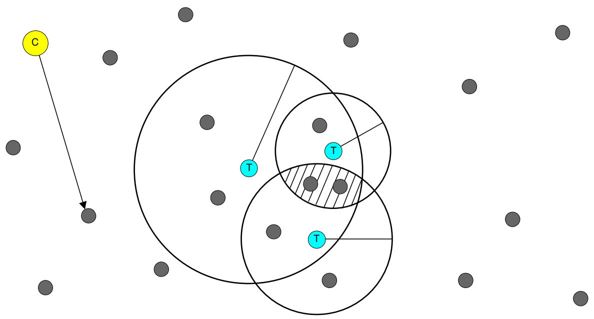
Central Leader Election



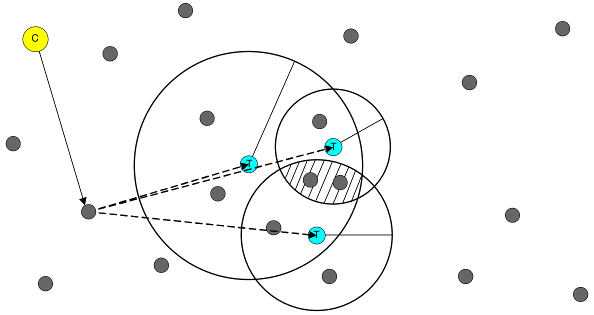
Multi-constraint System

- 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
- Re $s = \sum_{i=1}^{u} \max(0, d_i - range_i)^2$ metric s :
  - 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

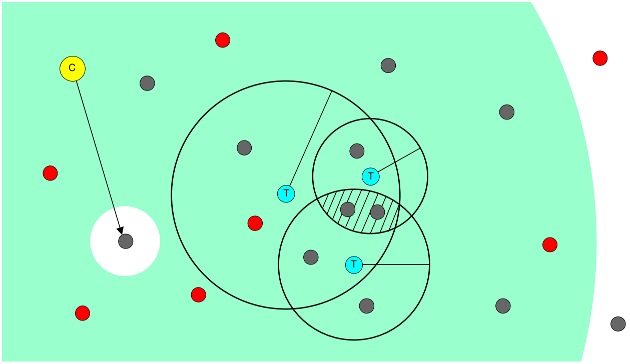
Multi-constraint System



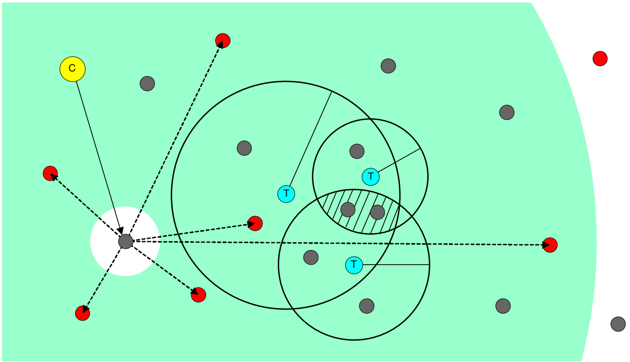
Multi-constraint System



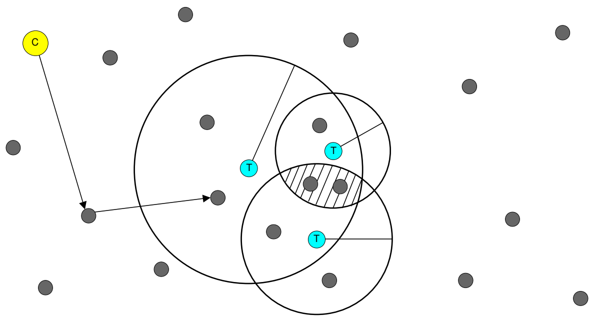
Multi-constraint System



Multi-constraint System



Multi-constraint System



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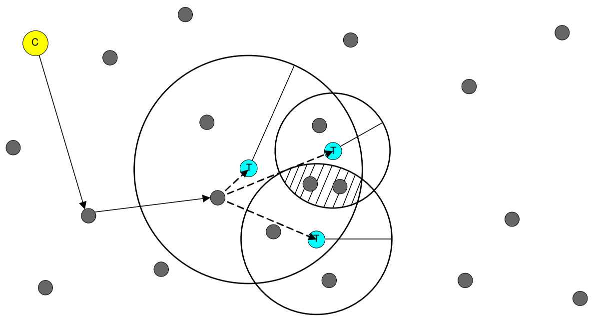
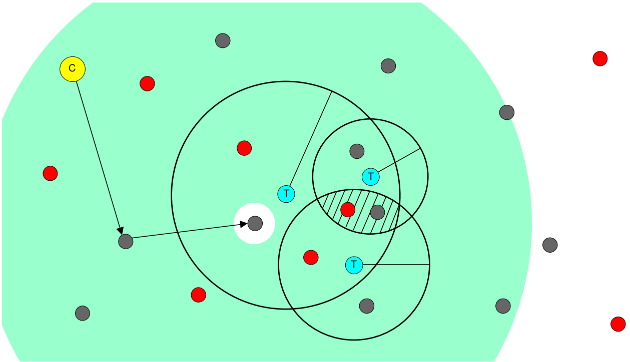
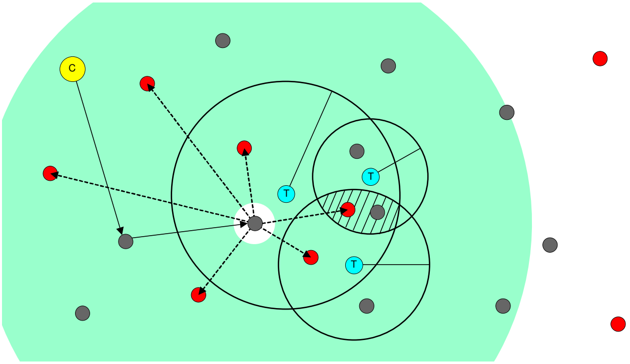


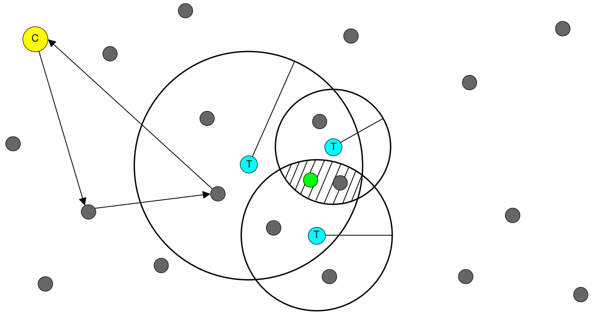
Multi-constraint System



Multi-constraint System



Multi-constraint System



Meridian Query Language

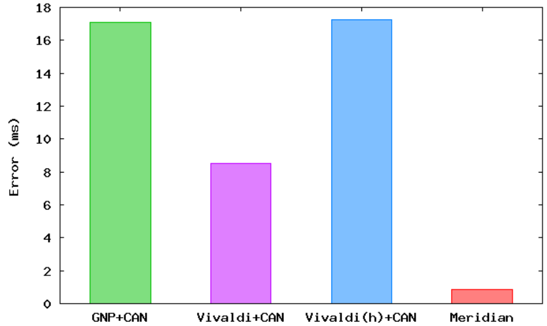
- Variant of C/Python
  - Safe, polymorphic, and dynamically-typed
  - Includes an extensive set of library functions
- Allows users to:
  - Access multi-resolution rings
  - Issue latency probes
  - Forward queries to peers
- Tight resource limits on:
  - Execution time of query
  - Number of hops
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

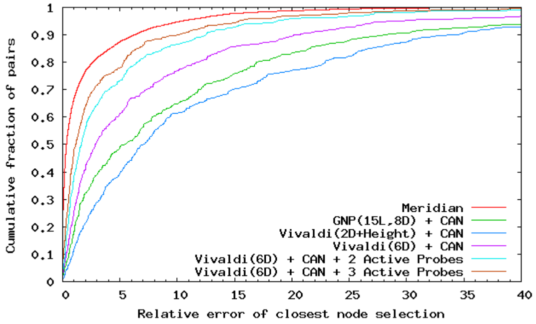
Evaluation: Closest Node Discovery

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



Evaluation: Closest Node Discovery

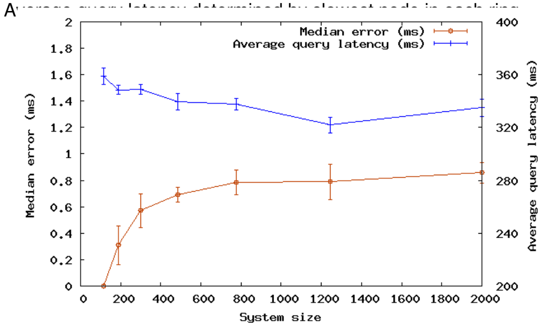
CDF of relative error shows Meridian is more accurate for both typical nodes and fringe nodes



Evaluation: Closest Node Discovery

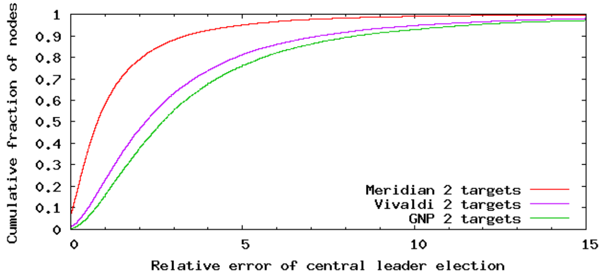
With k = ⌊$\log_{1.6}$ N⌋, error and query latency remain constant as N increases

A



Evaluation: Central Leader Election

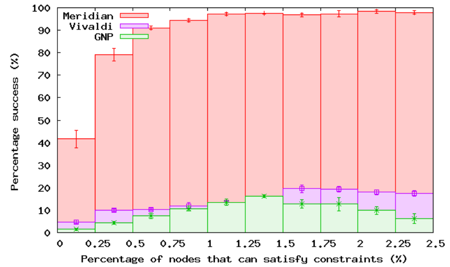
Meridian incurs significantly less relative error



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:

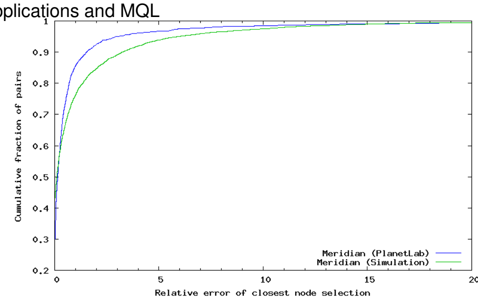
2 Constraints		3 Constraints		4 Constraints	
Meridian: 91%	VC: 35%	Meridian: 90%	VC: 19%	Meridian: 91%	VC: 11%



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

Meridian Summary

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

Octant

Determining the physical location of Internet nodes in the real world

(*Combining Sextant with Meridian...*)

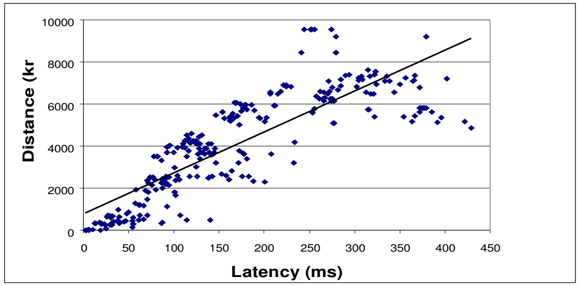
Octant

- Often need to determine the physical location of a machine on the Internet
  - Provide customized services
  - Trace user activity
  - Perform monitoring and locate attackers
- Need to map from IP Address to geographic location
  - IP to Zip Code: Static, Course-grained, Inaccurate
- Need a dynamic, accurate way of finding physical location of machines
  - Must work even if host is behind NAT, firewall or in a VPN

Octant Approach

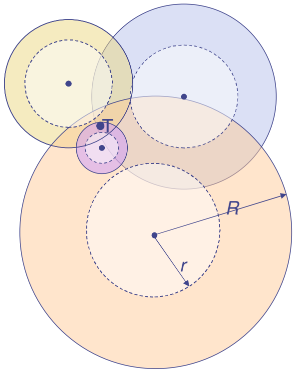
- Find general dependency between network latency and physical distance
- Set up a system of constraints based on latency measurements to known landmark nodes
  - Aggressively extract constraints
  - Use both positive and negative information
- Solve the system geometrically, yielding the set of physical areas on the globe where a target may be located

Latency-Distance Relationship



Internet latencies correlated with distance

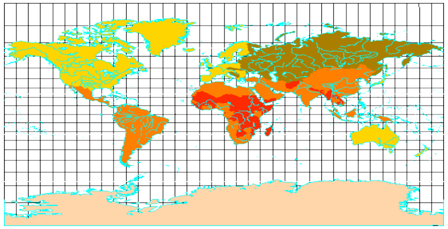
Positive and Negative Information



A latency probe establishes the minimum and maximum distances between a target T and chosen landmarks

Geometric intersection yields target location

Cylindrical Equidistant Projection



- Use Bézier curves to bound the areas in which a node can appear
- Map curves onto projected 2D globe

Summary

Octant is a dynamic and accurate Internet host localization service

Achieves high fidelity by using both positive and negative information

Can be used to determine the physical location of any node without user input