Position and Orientation in Ad Hoc Networks

Dragos Niculescu, Badri Nath {dnicules, badri} @cs.rutgers.edu

Rutgers University

summary

- problem and motivation
- example
- basic idea
- AoA capable nodes
- algorithm outline
  - bearing propagation (DV)
  - error control
- simulation results
- conclusions

problem statement

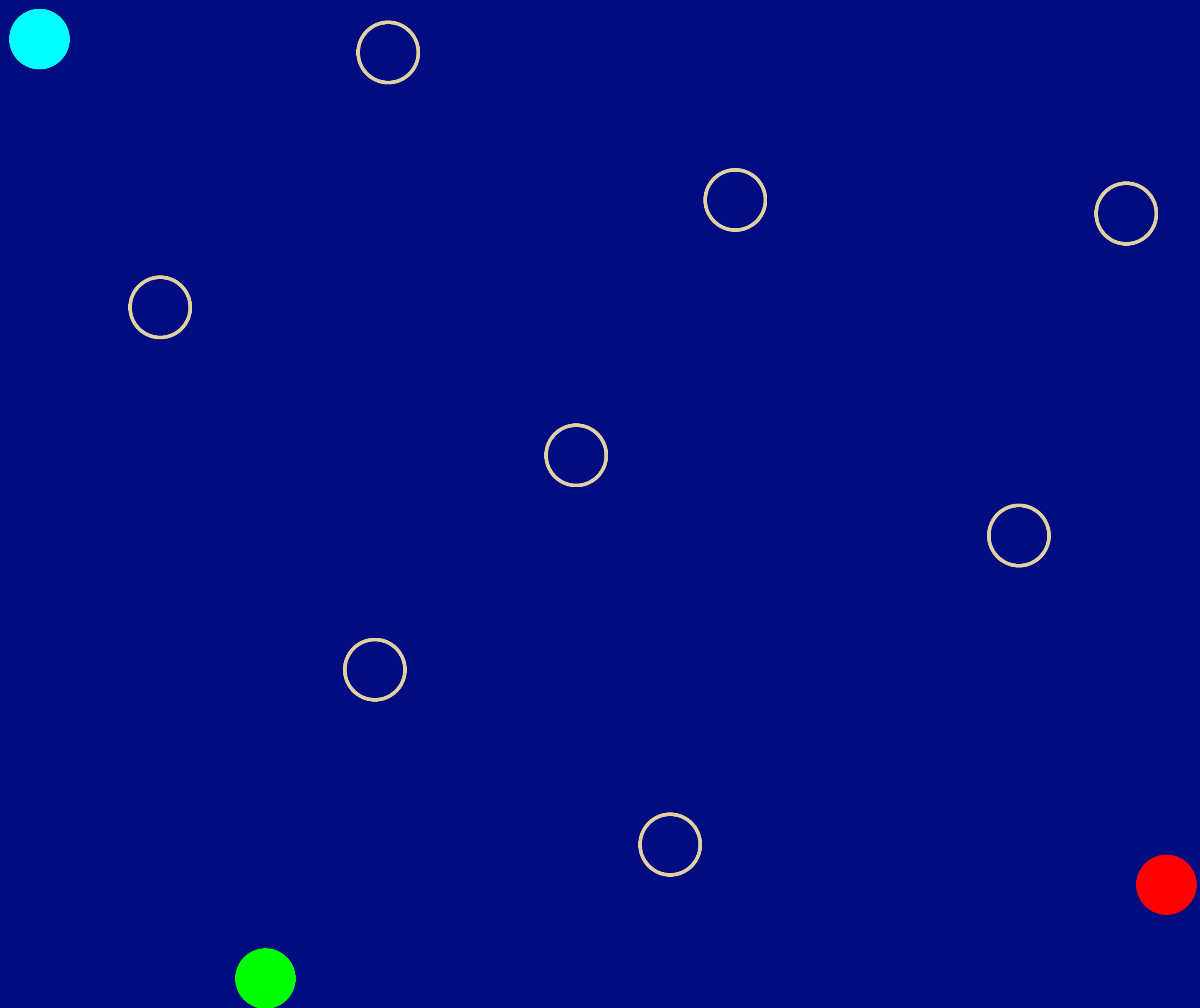
ad hoc deployed nodes should be able to know their

- location
  - global coordinates
  - low overhead for mobility
  - accuracy comparable with the node communication range
  - independent operation for disconnected regions
  - without additional infrastructure
- orientation
  - heading

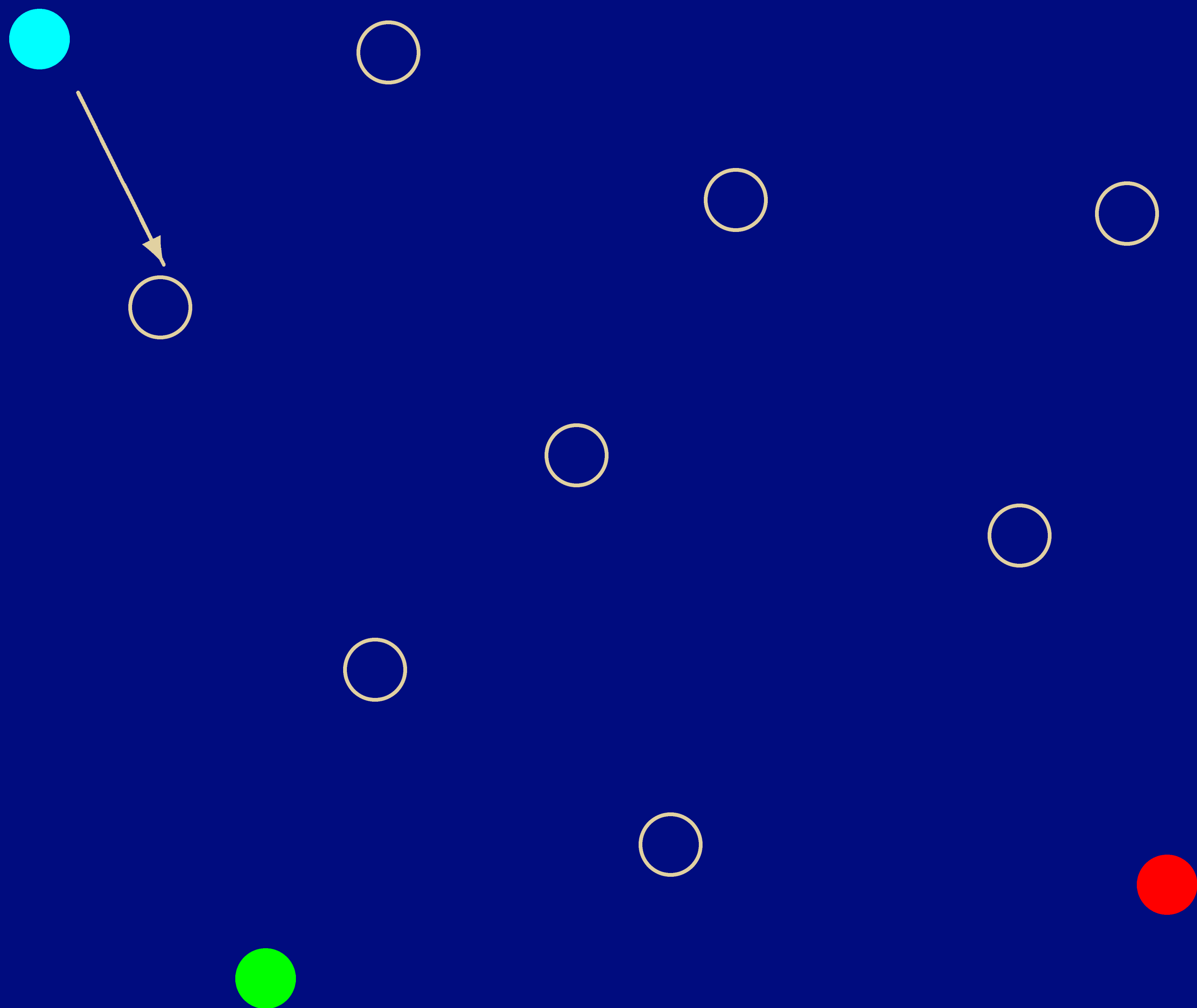
motivation

- a sensor reports a phenomenon and its:
  - position
    - place it on a map
    - routing with small or no routing tables
  - orientation
    - remote navigation
    - fine grained control – camera orientation
  - intensity
- possible solutions
  - GPS + digital compass in each node
    - compasses do not work well indoors
    - GPS needs line of sight

example



example



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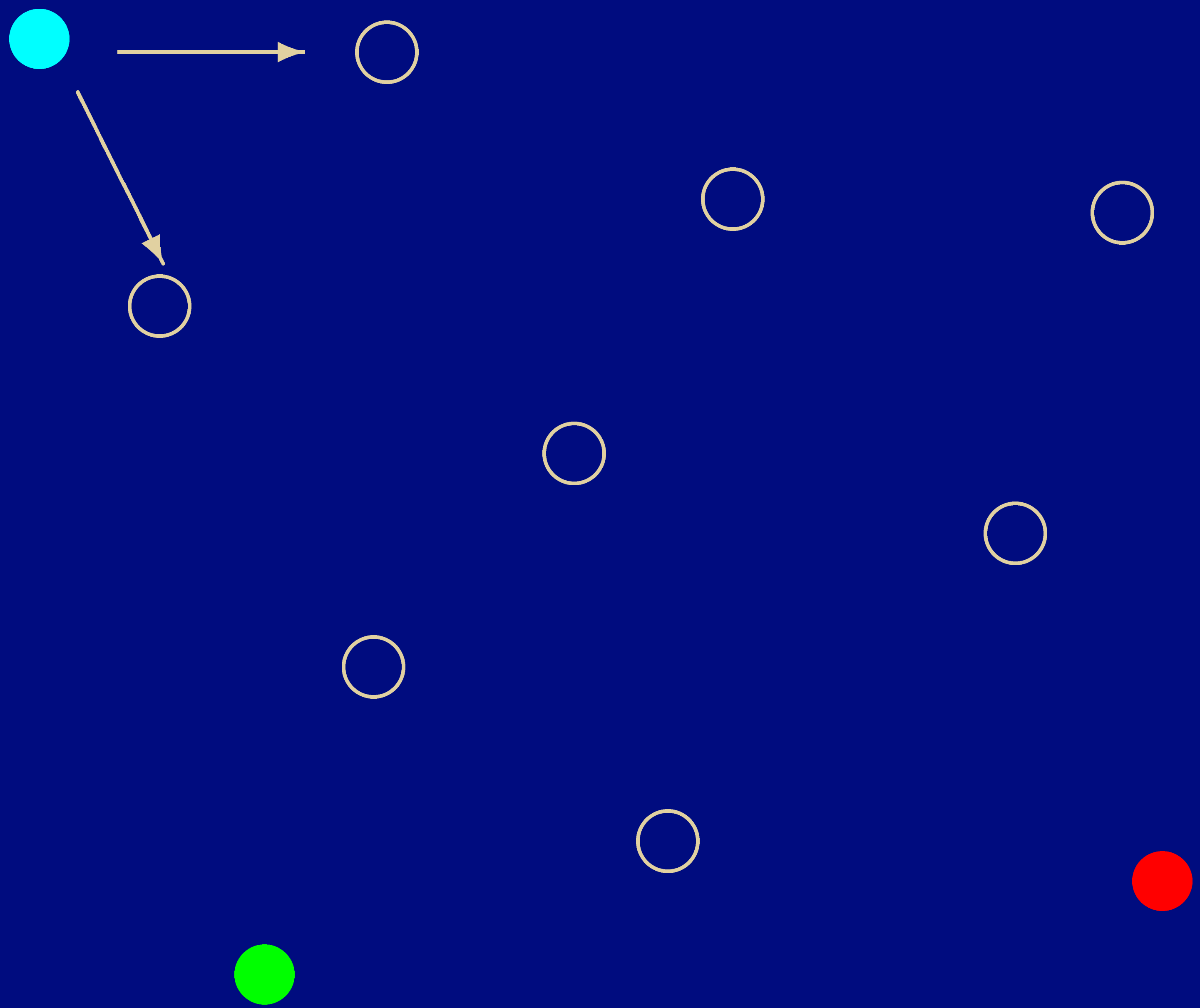

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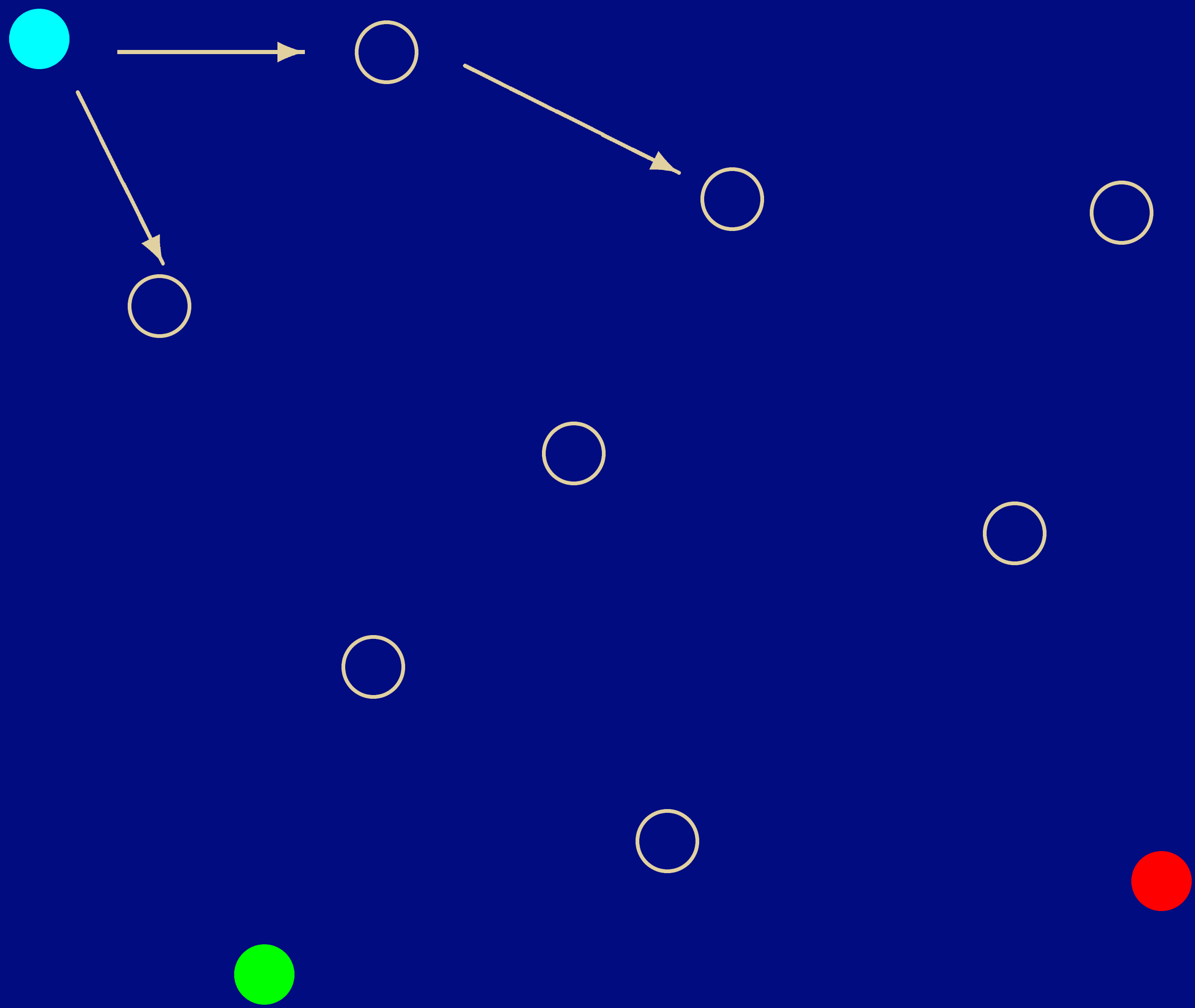

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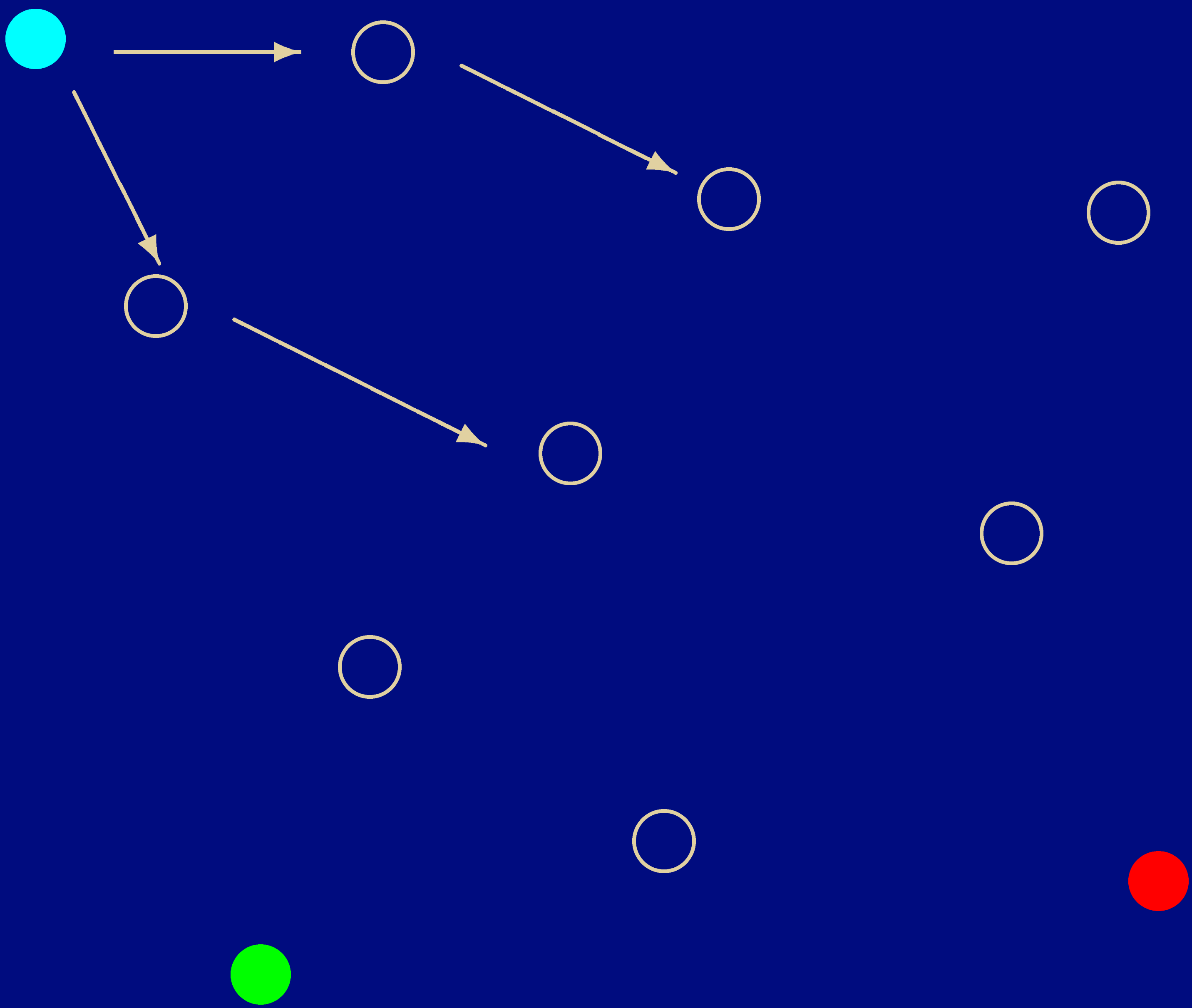

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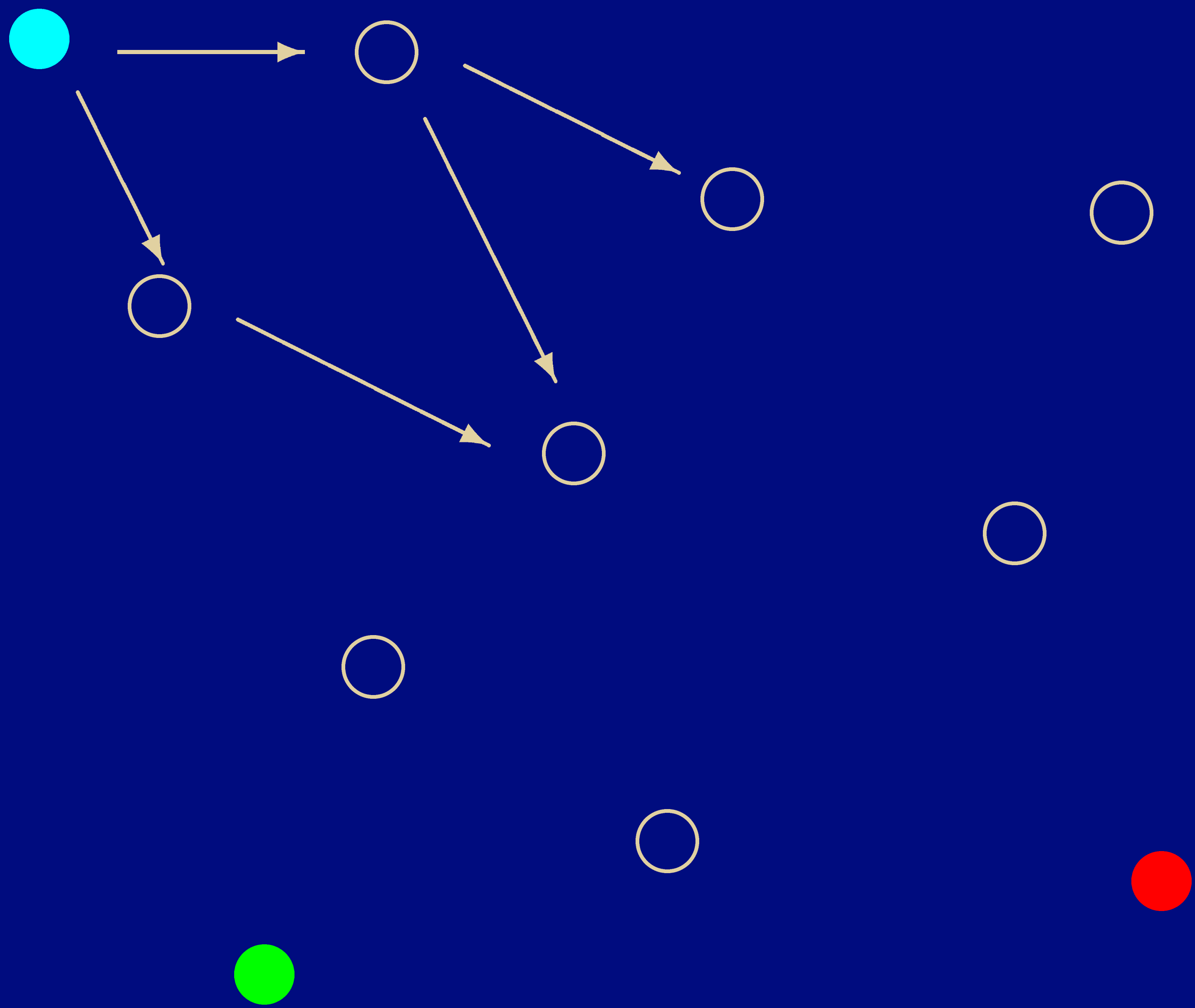

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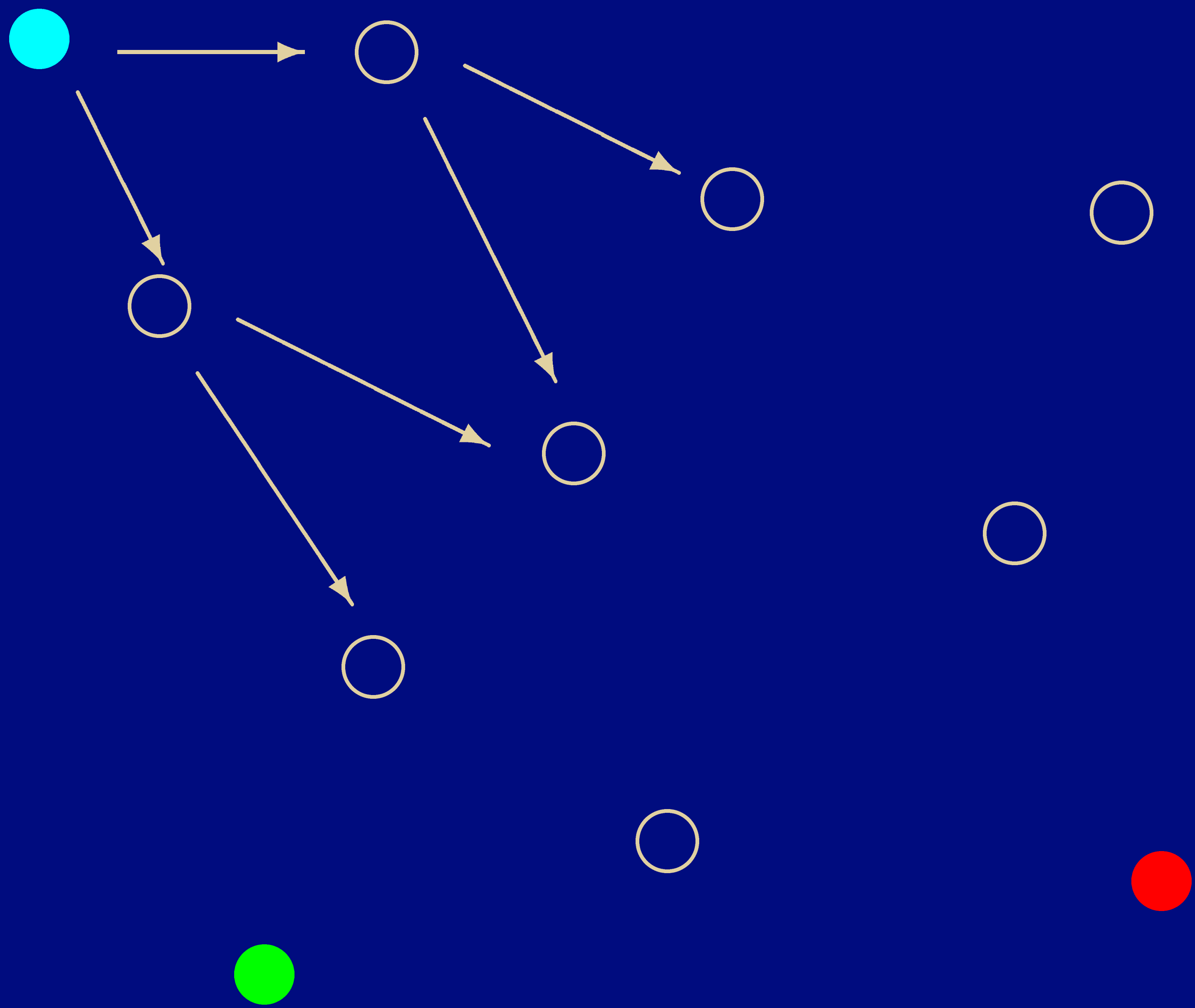

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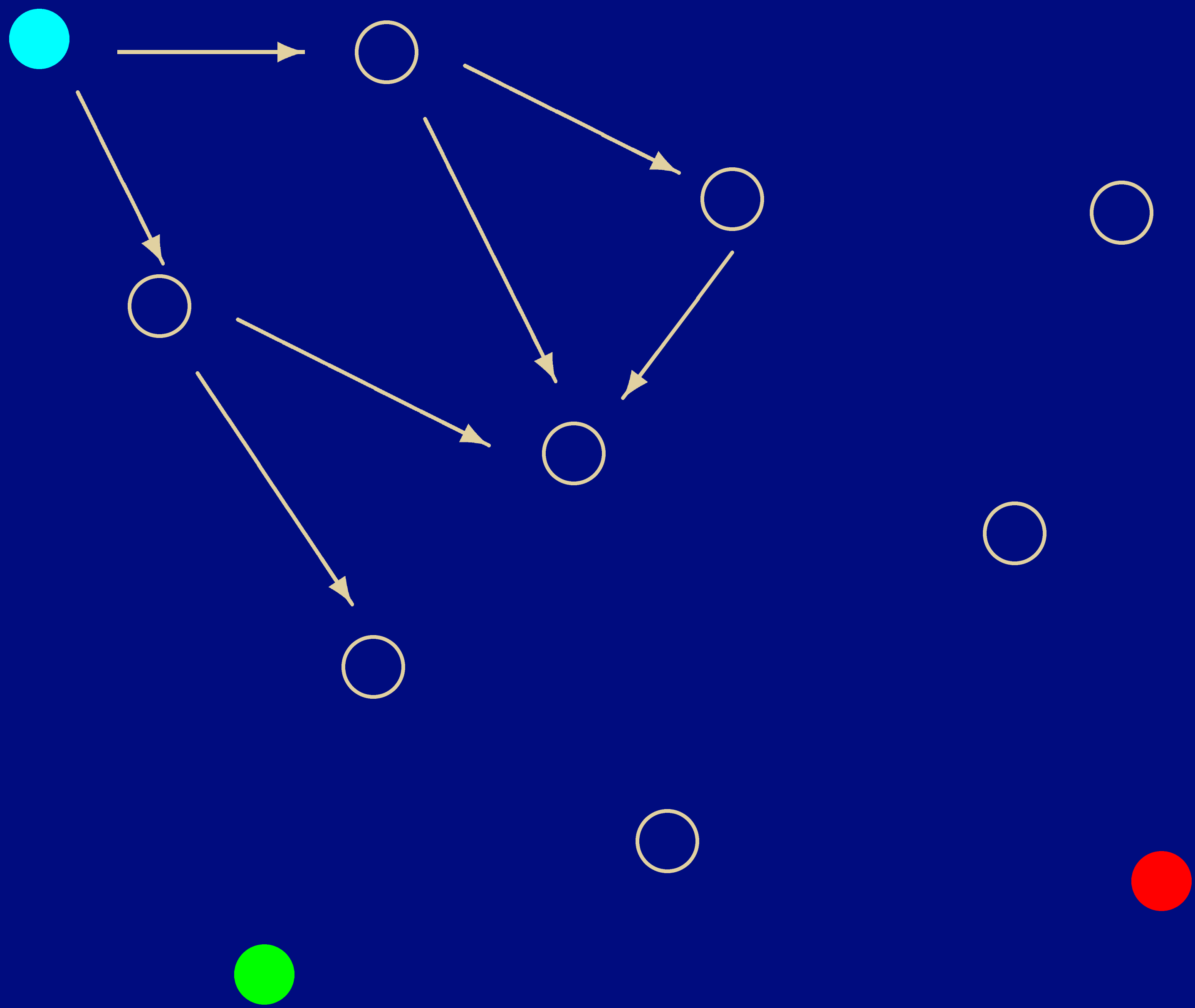

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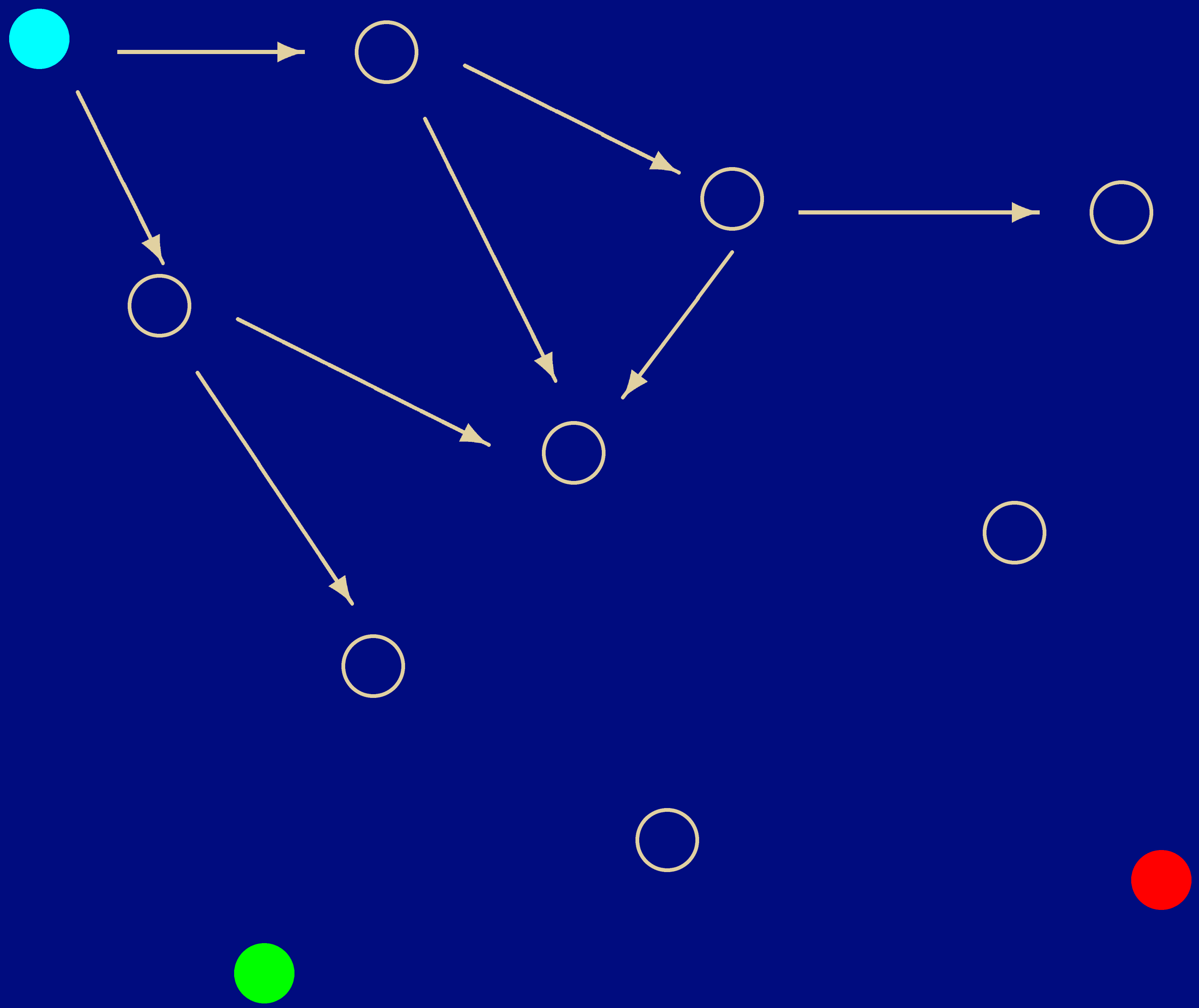

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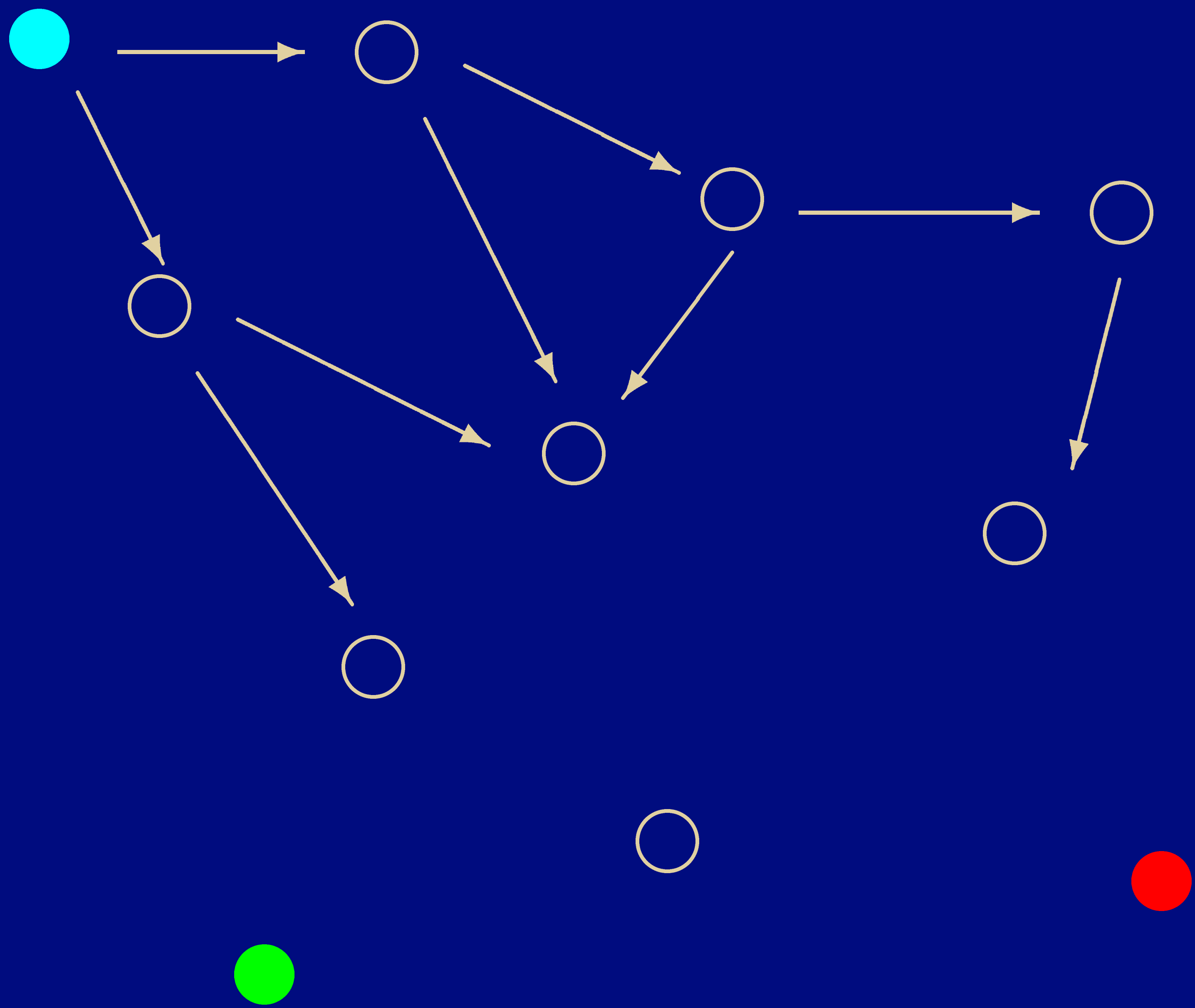
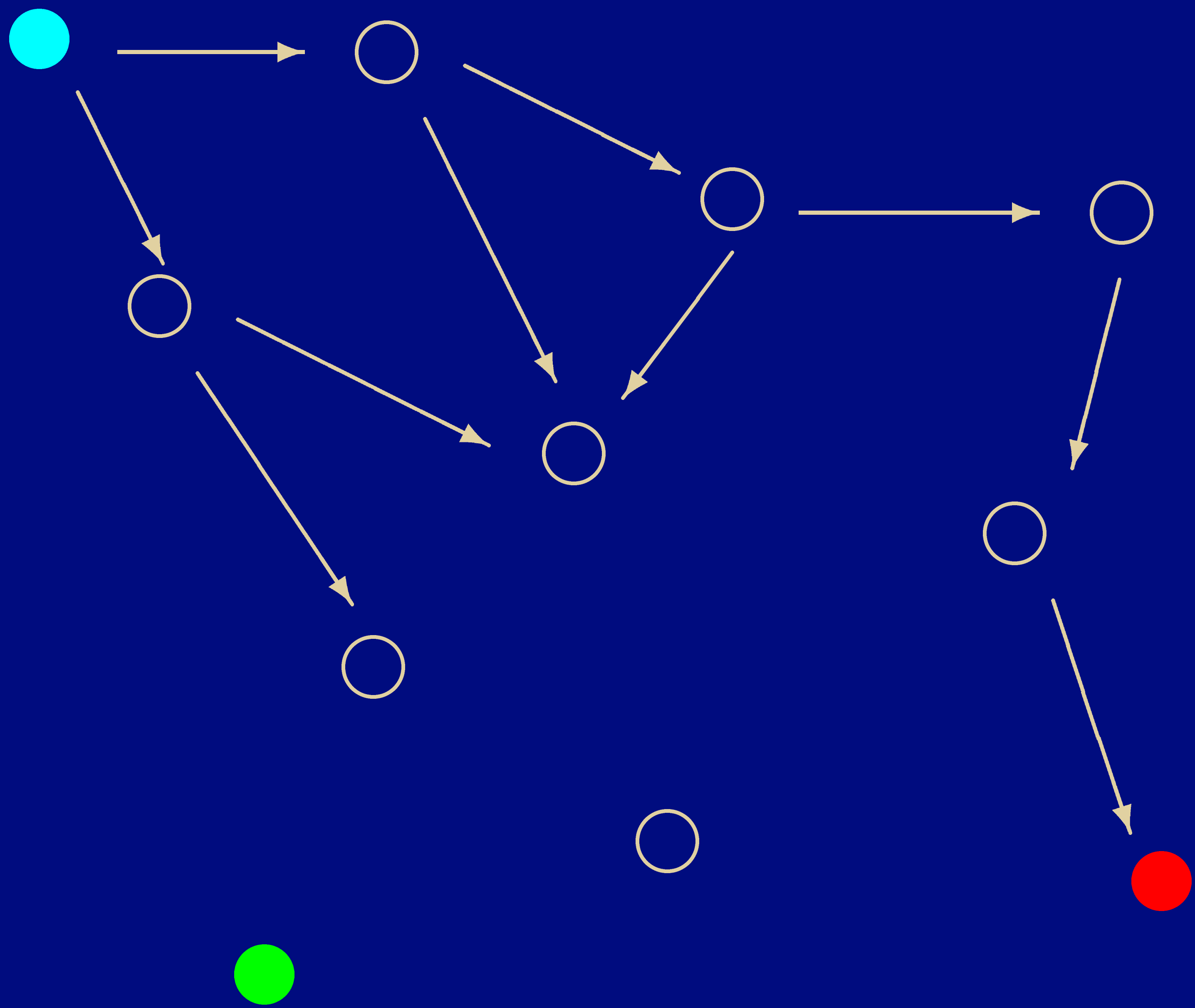


example



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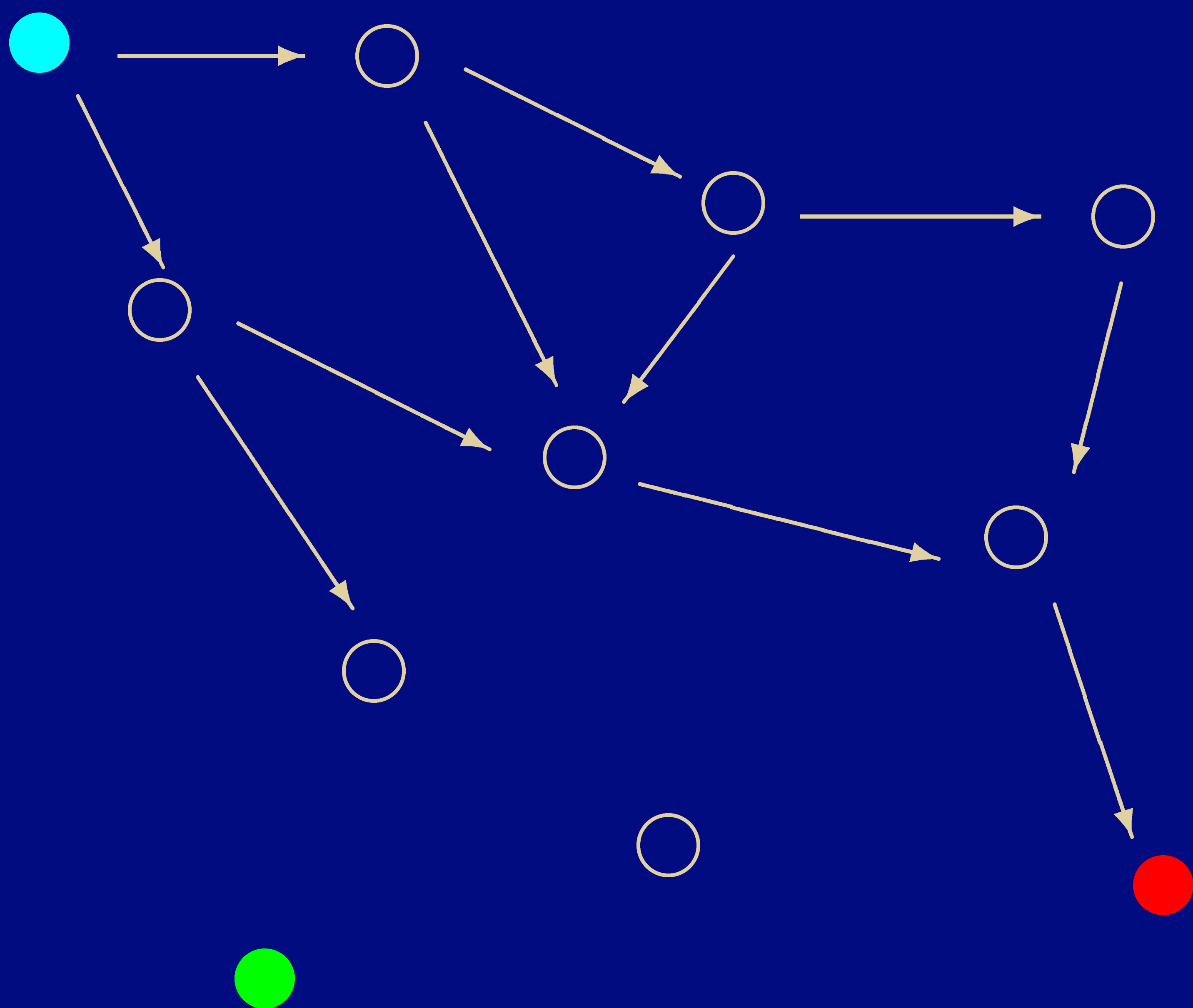

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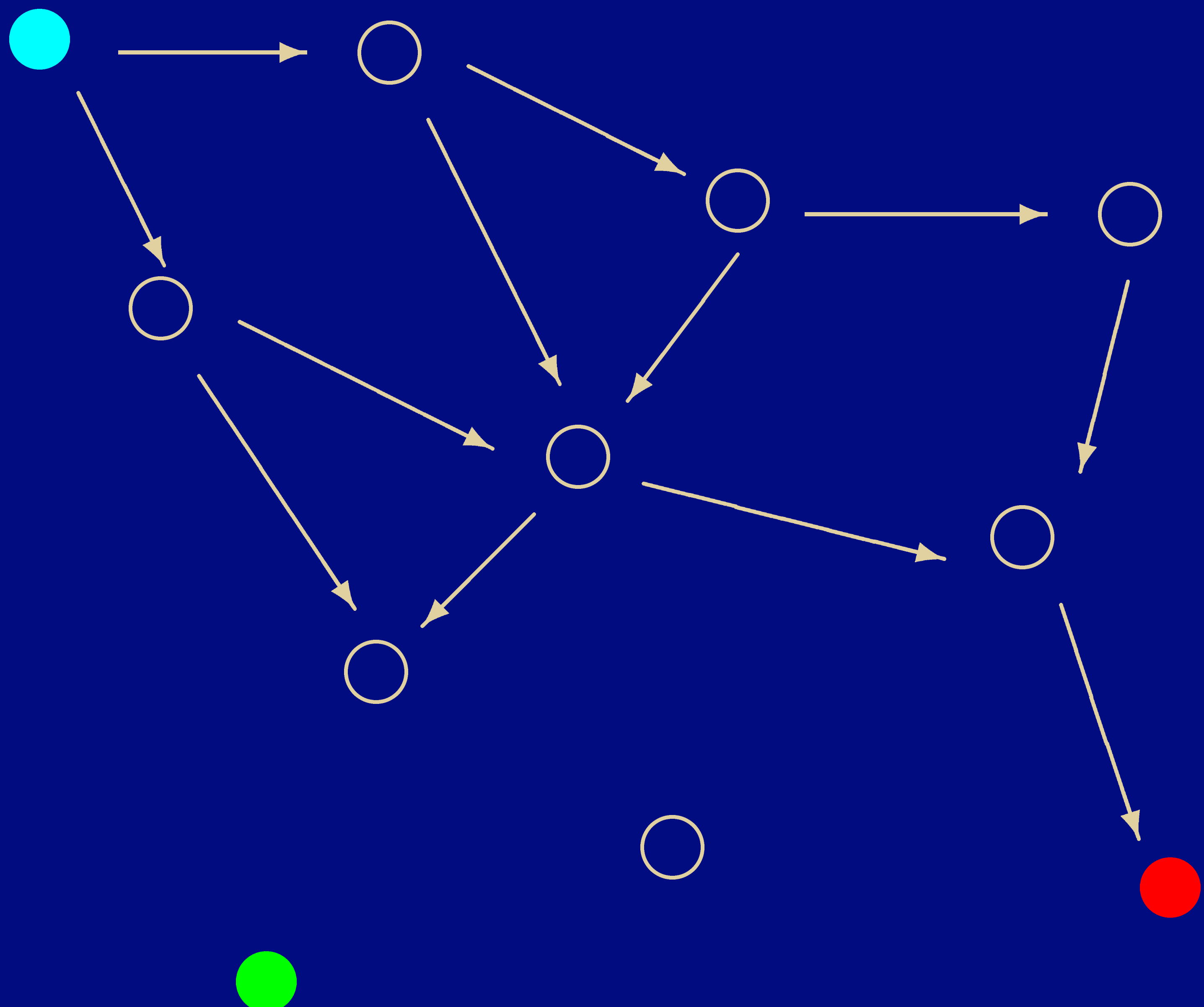

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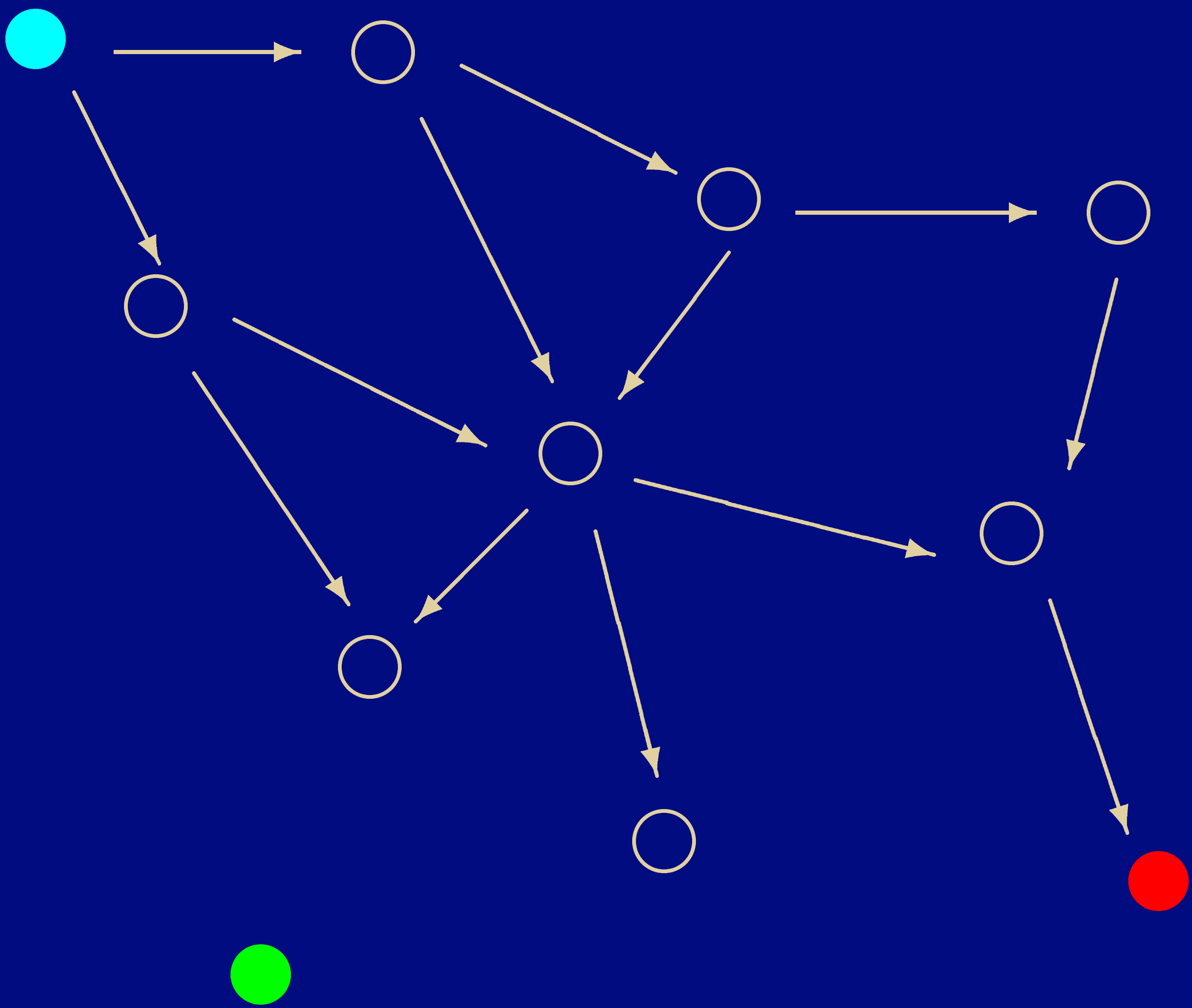
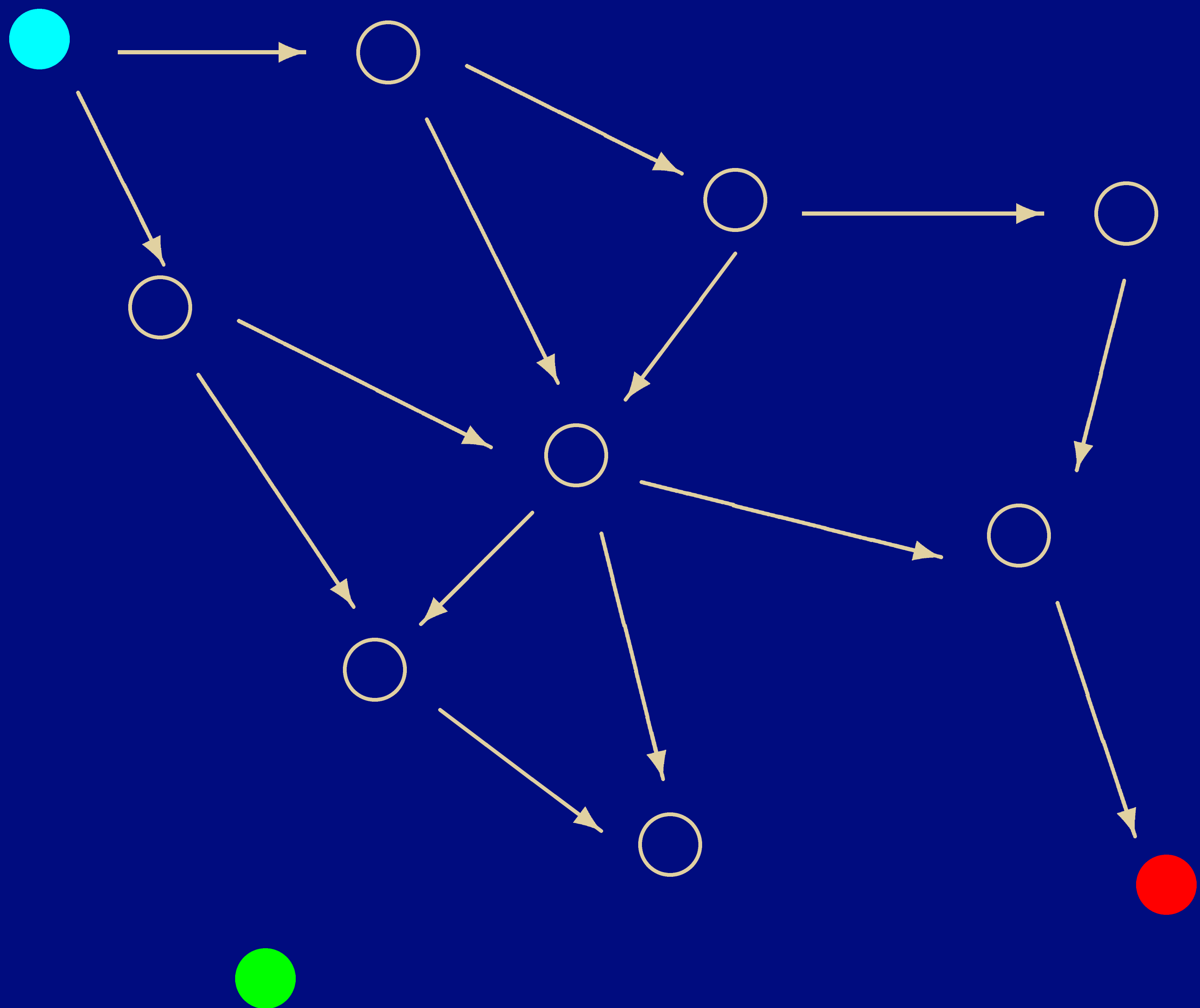


example



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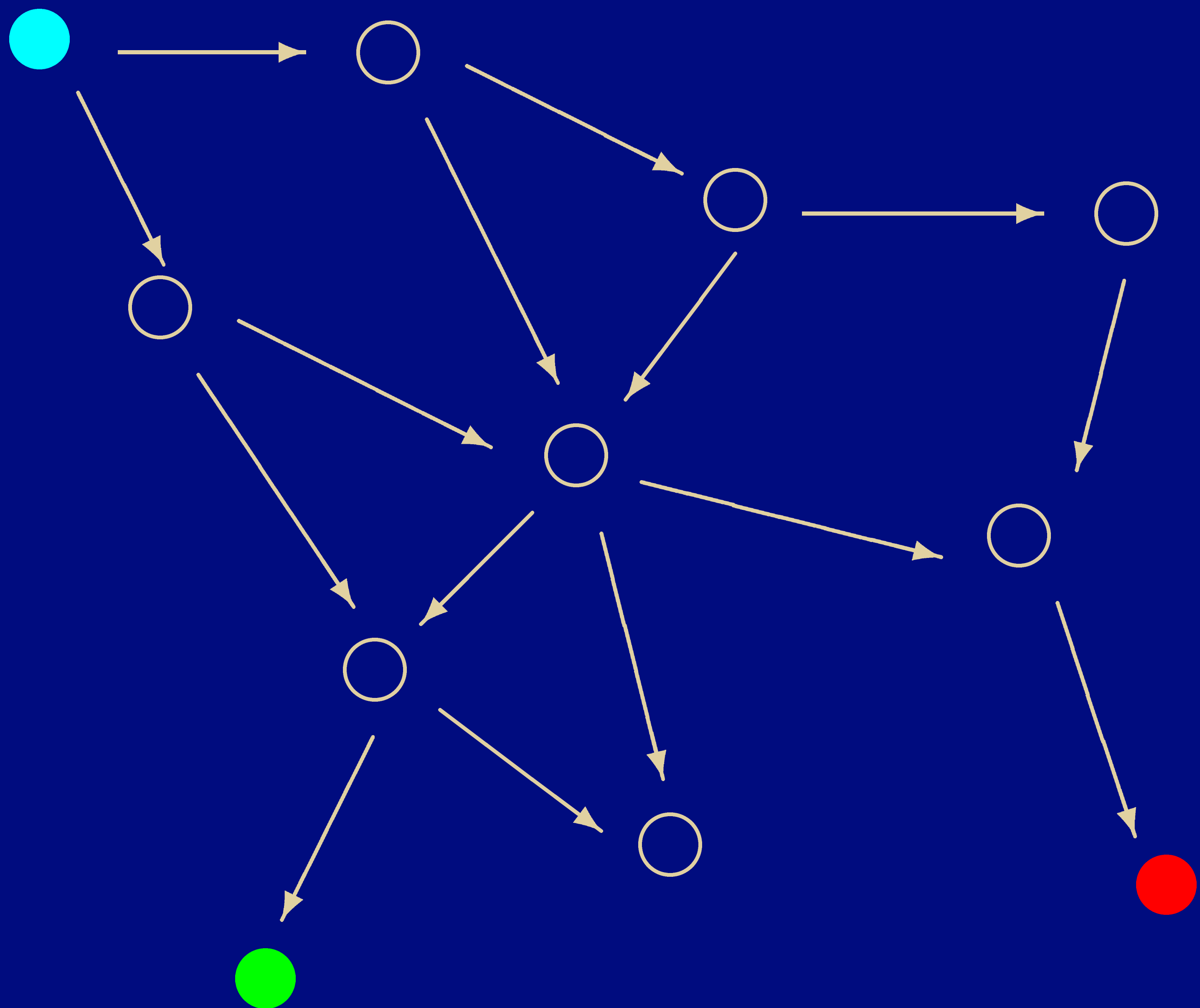

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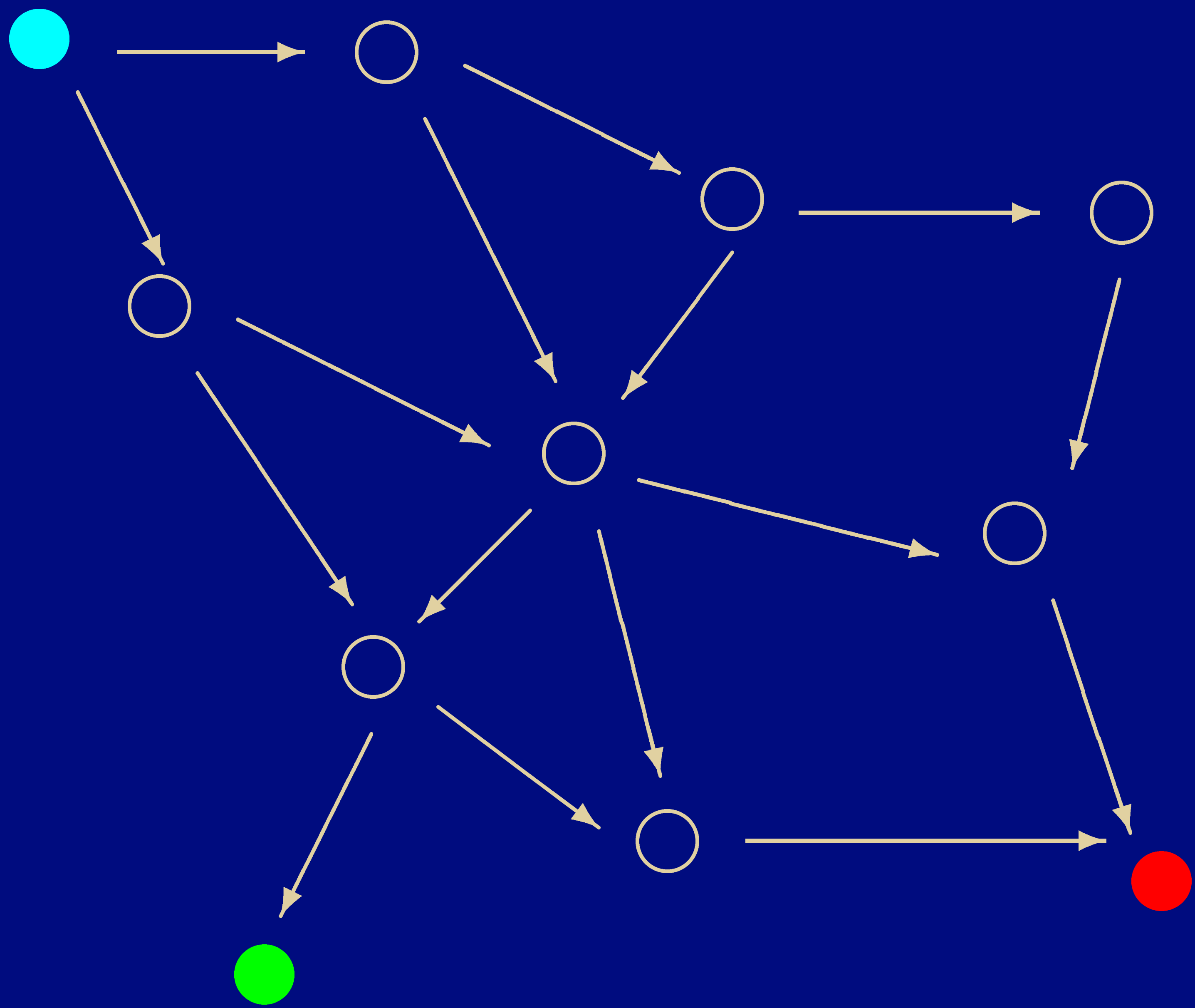

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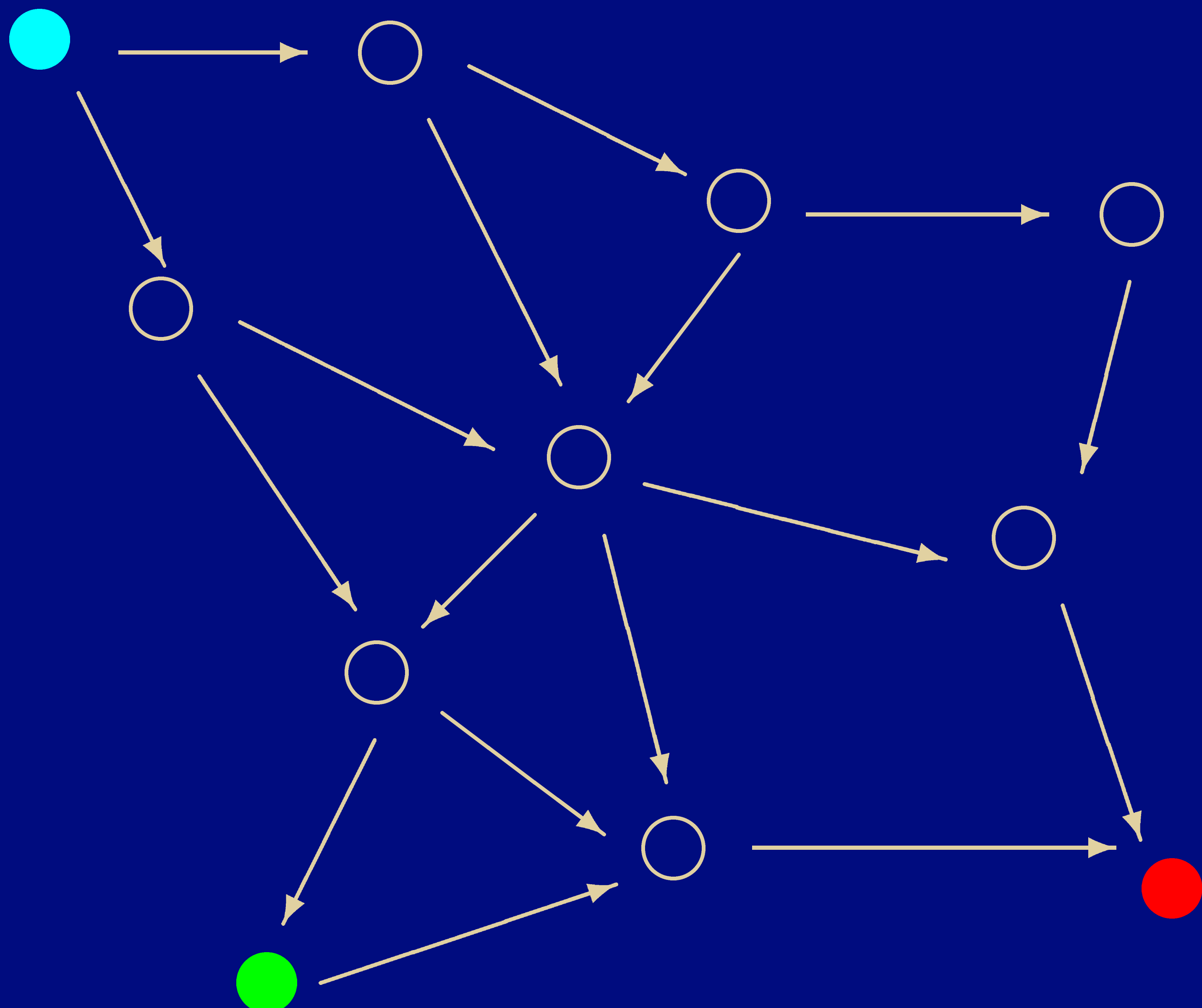
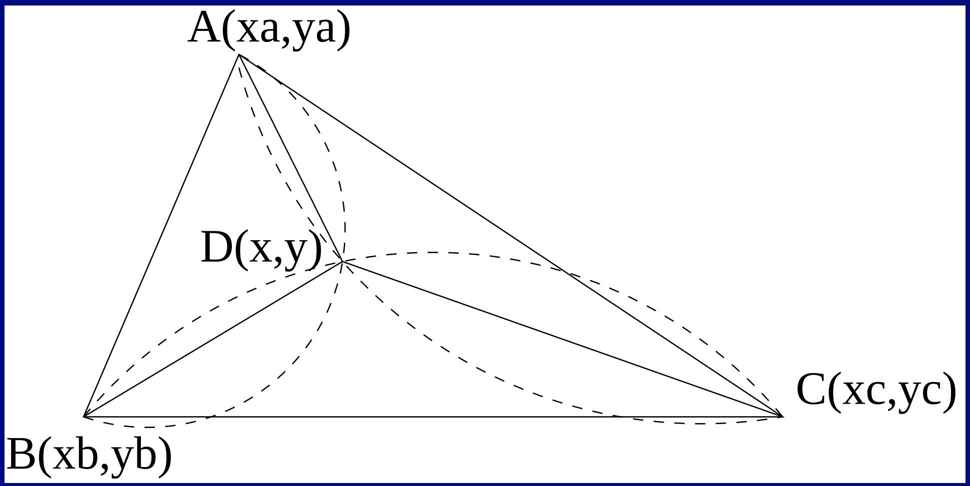


terminology and assumptions

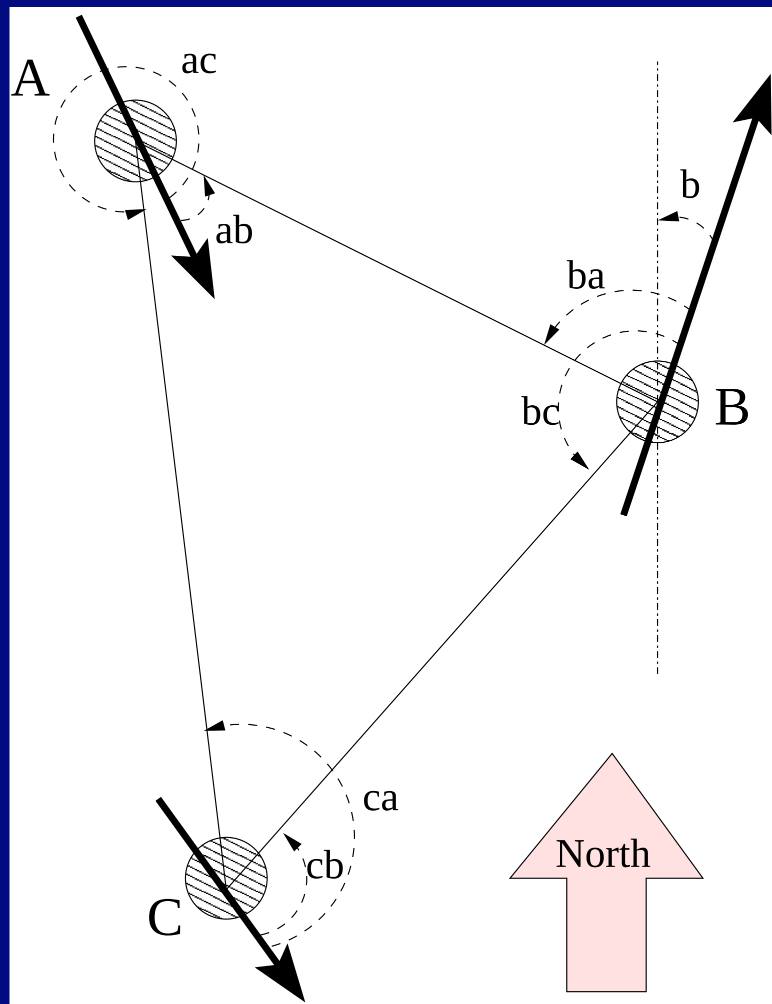
- terminology
  - landmark - a node which knows its own position
  - range - distance to an objective
  - bearing - angle between one's facing direction and some objective
  - heading, orientation - absolute bearing, or angle to north
- assumptions
  - nodes are deployed randomly $\rightarrow$ connected graph
  - a fixed fraction of nodes are landmarks
  - nodes have a limited radio radio range

basic idea

- Given
  - (imprecise) bearings to at least three landmarks , $\widehat{ADB}$, $\widehat{BDC}$, $\widehat{CDA}$
  - the positions of the landmarks (x_i, y_i), $i = A, B, C$
- a node may infer its own position (x, y)
- and its orientation/heading, once (x, y) and (x_A, y_A) are known



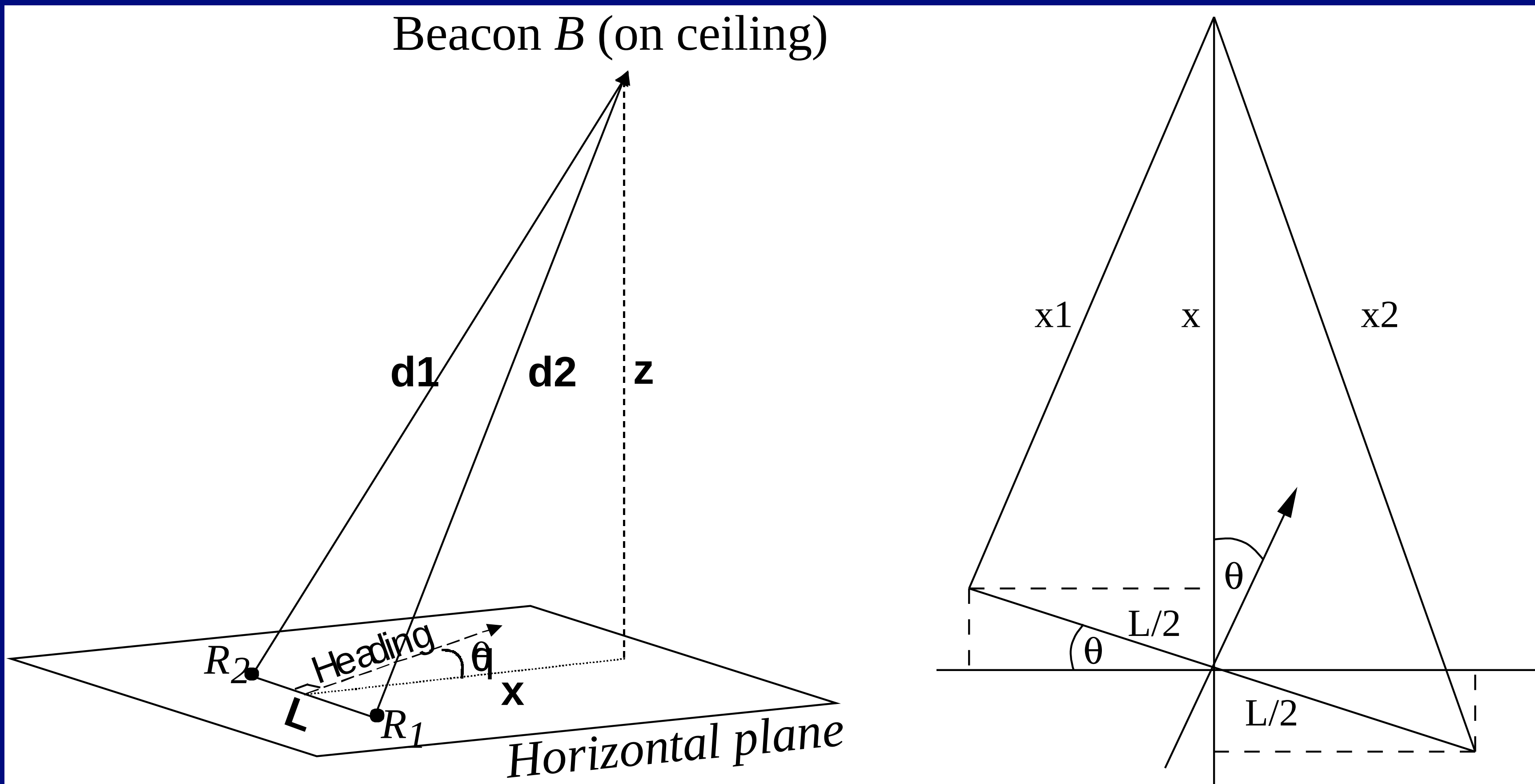
angle of arrival capability - example



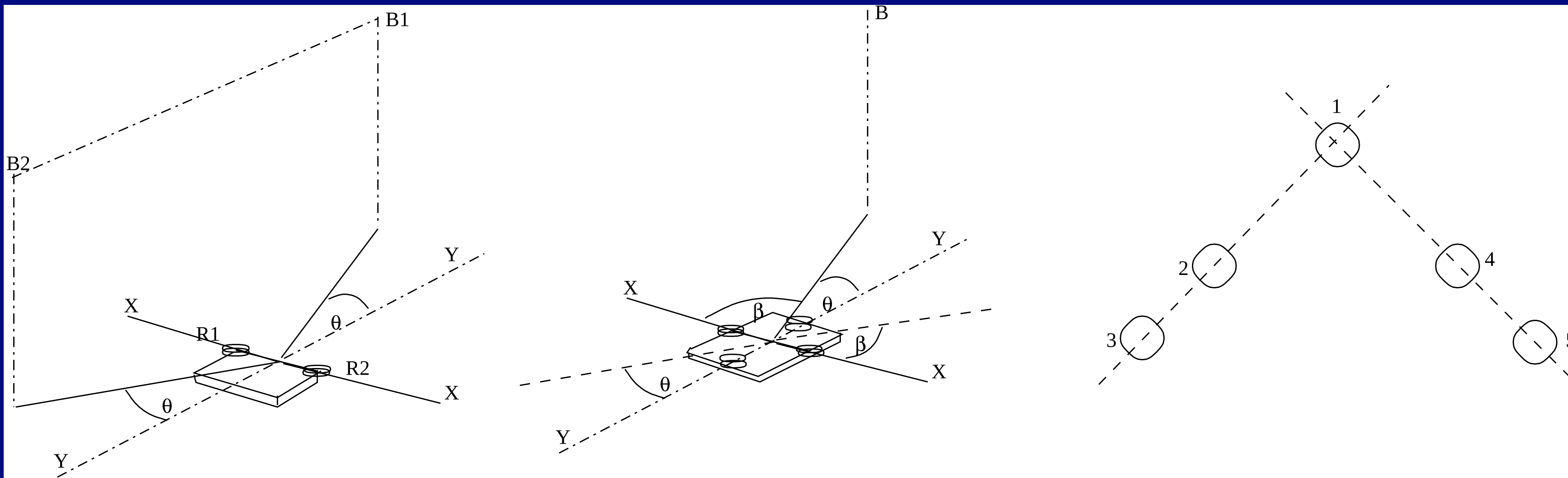
angle of arrival capable nodes

- **Cricket** compass - MIT (Hari Balakrishnan, Mobicom 2001)
  - uses 5 ultrasound receivers
    - 0.8cm each
    - a few centimeters across
  - TDoA (time difference of arrival)
  - ±10% accuracy for angles < 40 degrees
- **Medusa** node - UCLA (Mani Srivastava, Mobicom 2001)
- antenna arrays

“Cricket” compass - basic principle

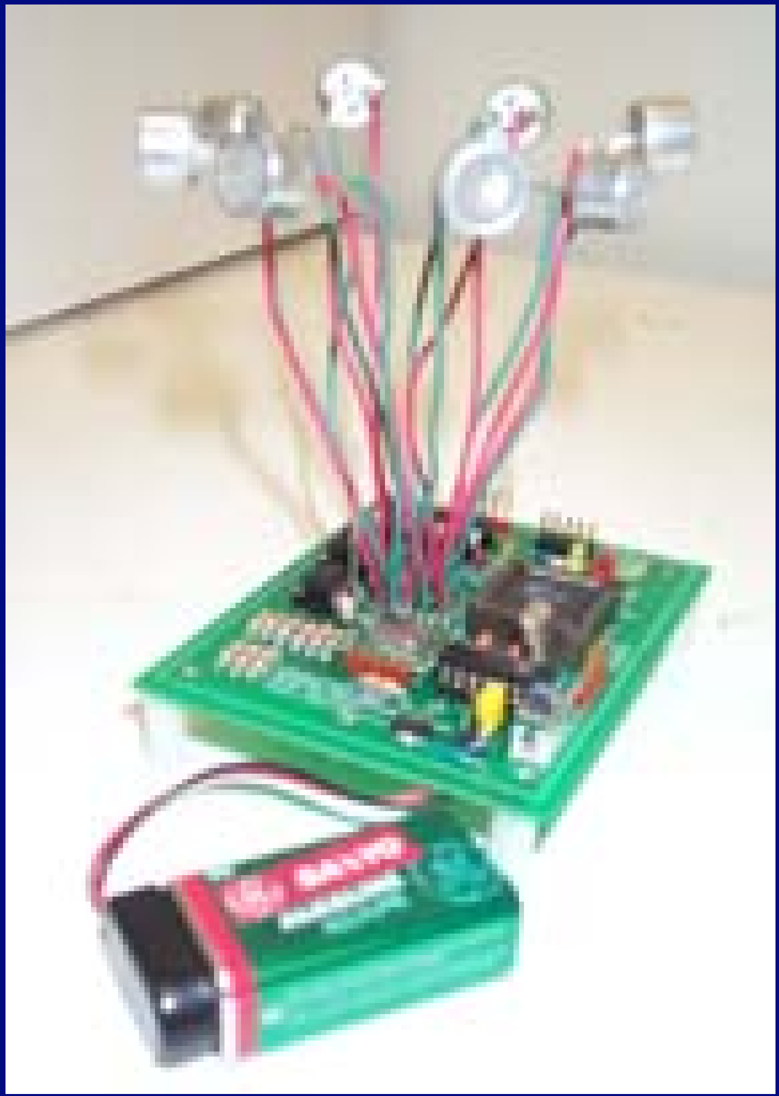


“Cricket” compass - disambiguation



- based on measuring ranges
  - front - back ambiguity
- range differentials are measured using phase difference
  - wavelength $\sim L \rightarrow$ range ambiguity

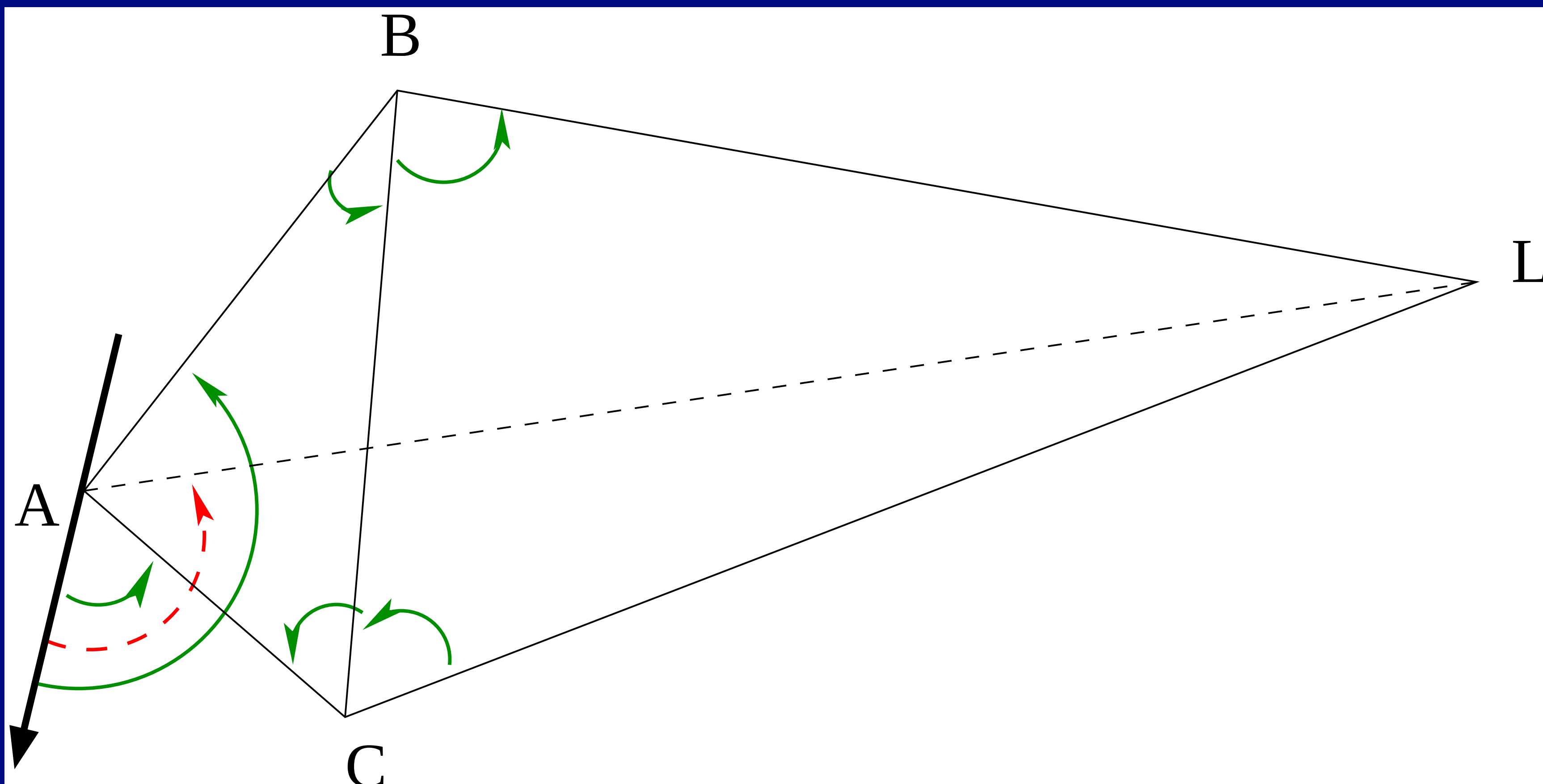
“Medusa” node



algorithm outline

- a few nodes (landmarks) know their position
- all nodes have the AoA capability $\rightarrow$ find bearings to immediate neighbors
- regular nodes infer bearings to at least three landmarks
  - non-colinear
  - non-cocircular (with the node itself)
- like in DV, bearings to landmarks are propagated hop by hop
- each landmark is treated independently at each node

bearing propagation (DV)



- green angles are known → find bearing to *L* (red angle)

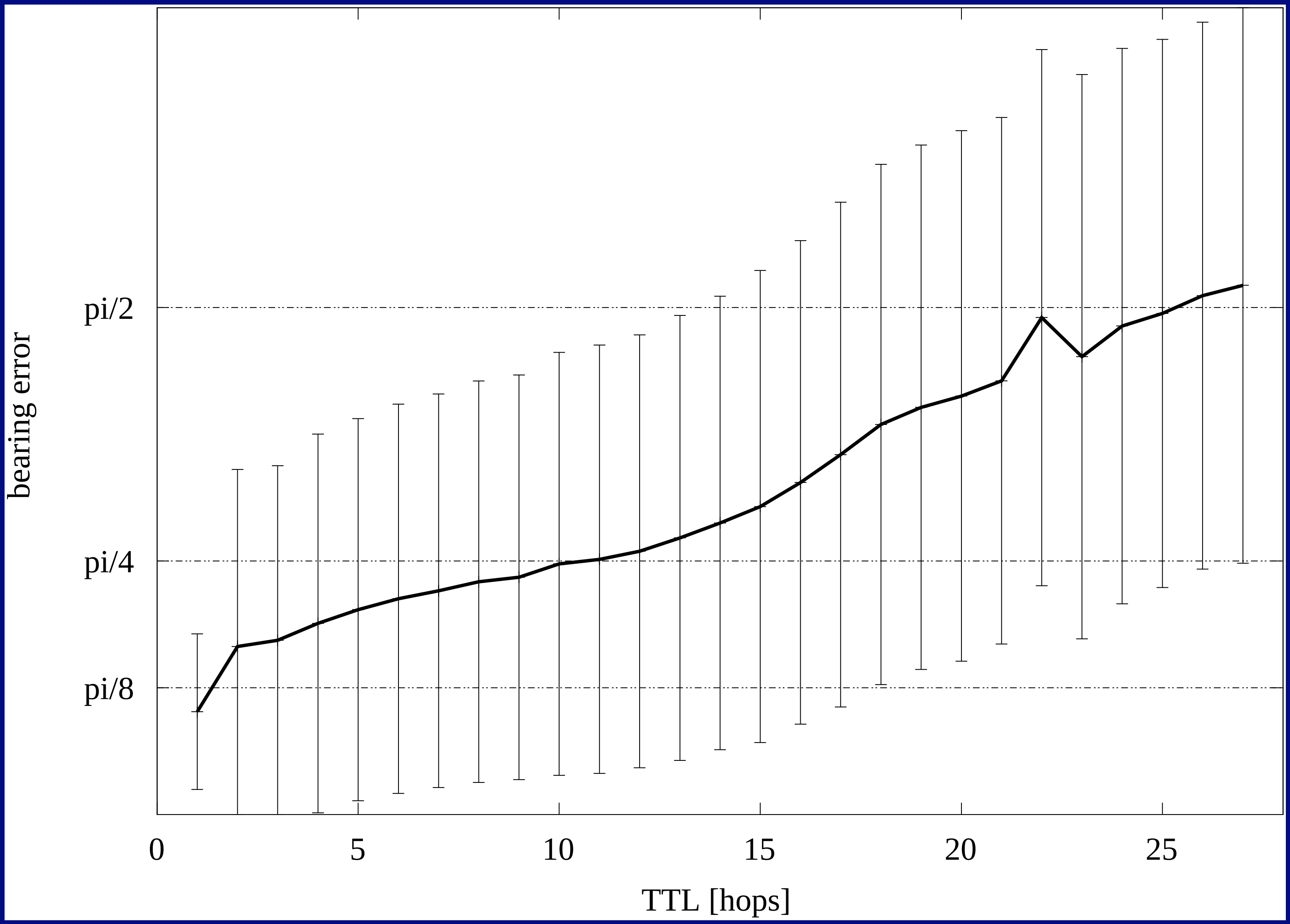
position computation

- each node obtains a table $\{X_i, Y_i, dir_i\}$ - coordinates and bearings to landmarks
- several ways to solve:
  - solve a nonlinear system to intersect the n circles
  - $\binom{n}{2}$ pairs of landmarks, find distances to centres $\rightarrow$ GPS problem
  - $\binom{n}{3}$ triplets of landmarks, find $\binom{n}{3}$ estimates $\rightarrow$ centroid
  - there are $O(n)$ algorithms providing the same accuracy
- absolute position + bearing to known point = heading(absolute orientation)

error control

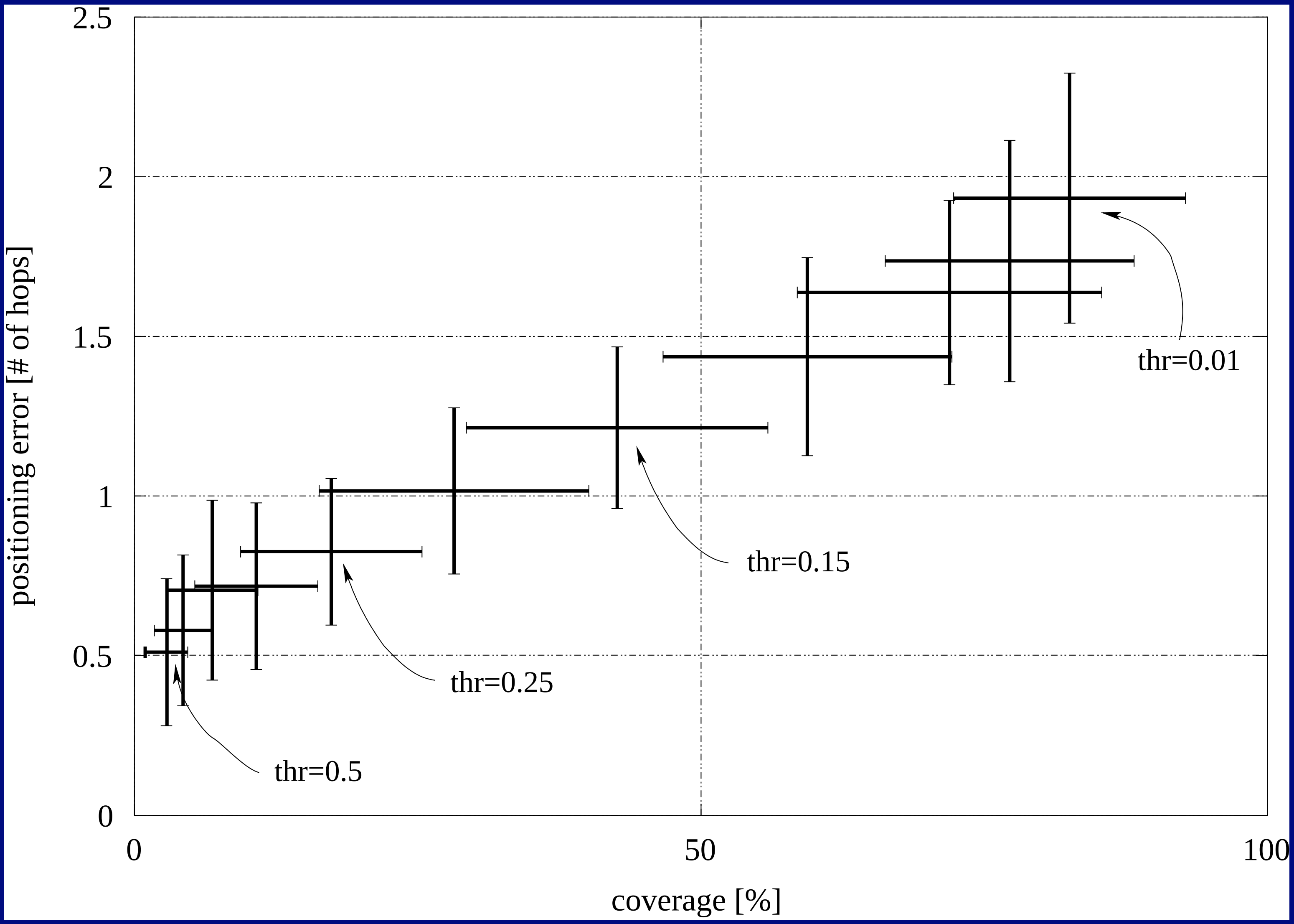
- lightweight methods → CPU, memory, communication
- the propagation scheme compounds errors
  - limit the travel distance of packets (TTL)
- small angle error → large distance error
  - avoid angles below a threshold
- large errors are clustered
  - prune position estimations that are far off the centroid
- these three methods together reduce the errors by half

error control - propagation



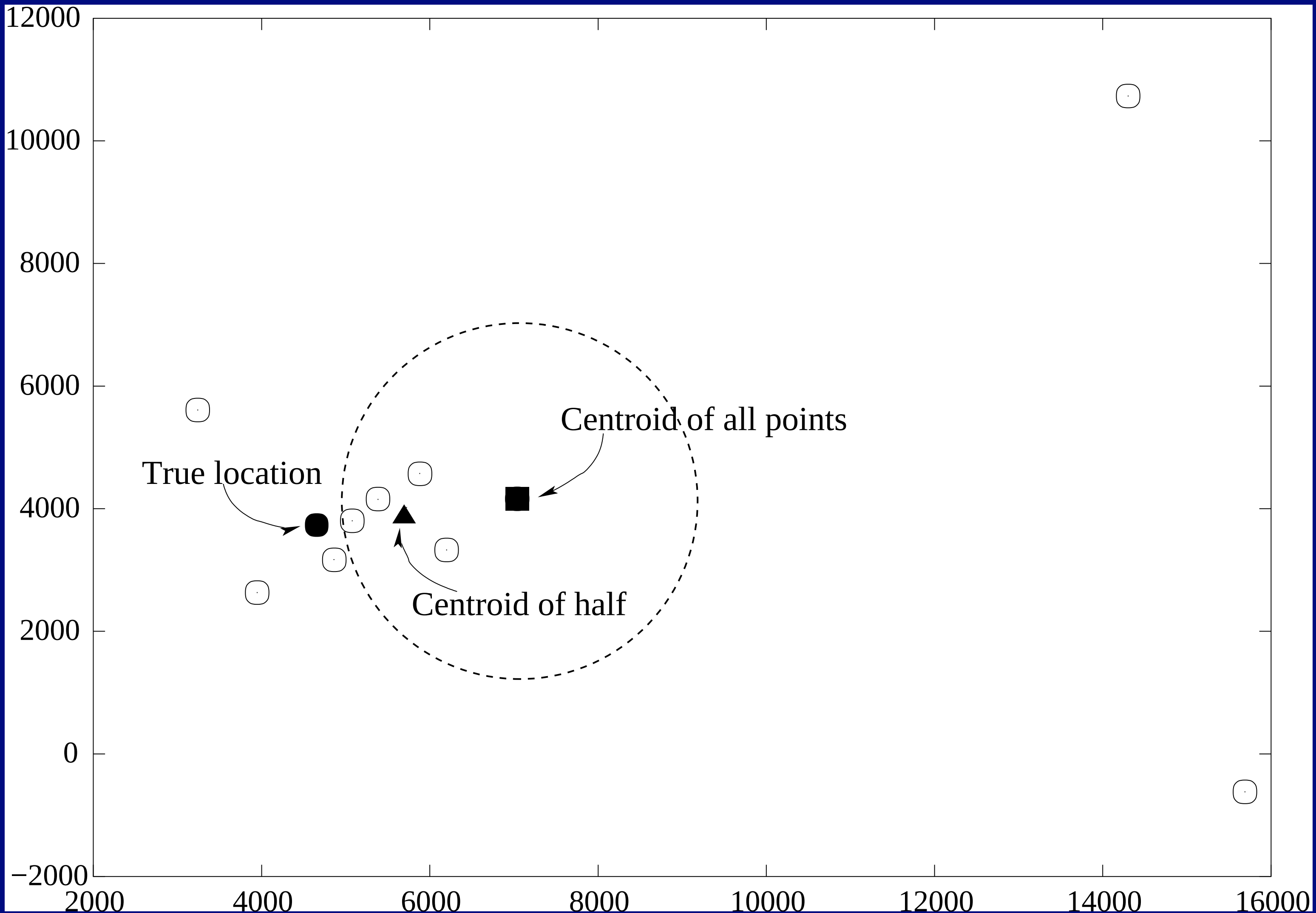
gps=0.05 err=0.4 eps=0.05 nodes=200

error control - small angles



gps=0.2 err=0.4 eps=0.10 ttl=6 nodes=200

error control - remove outliers

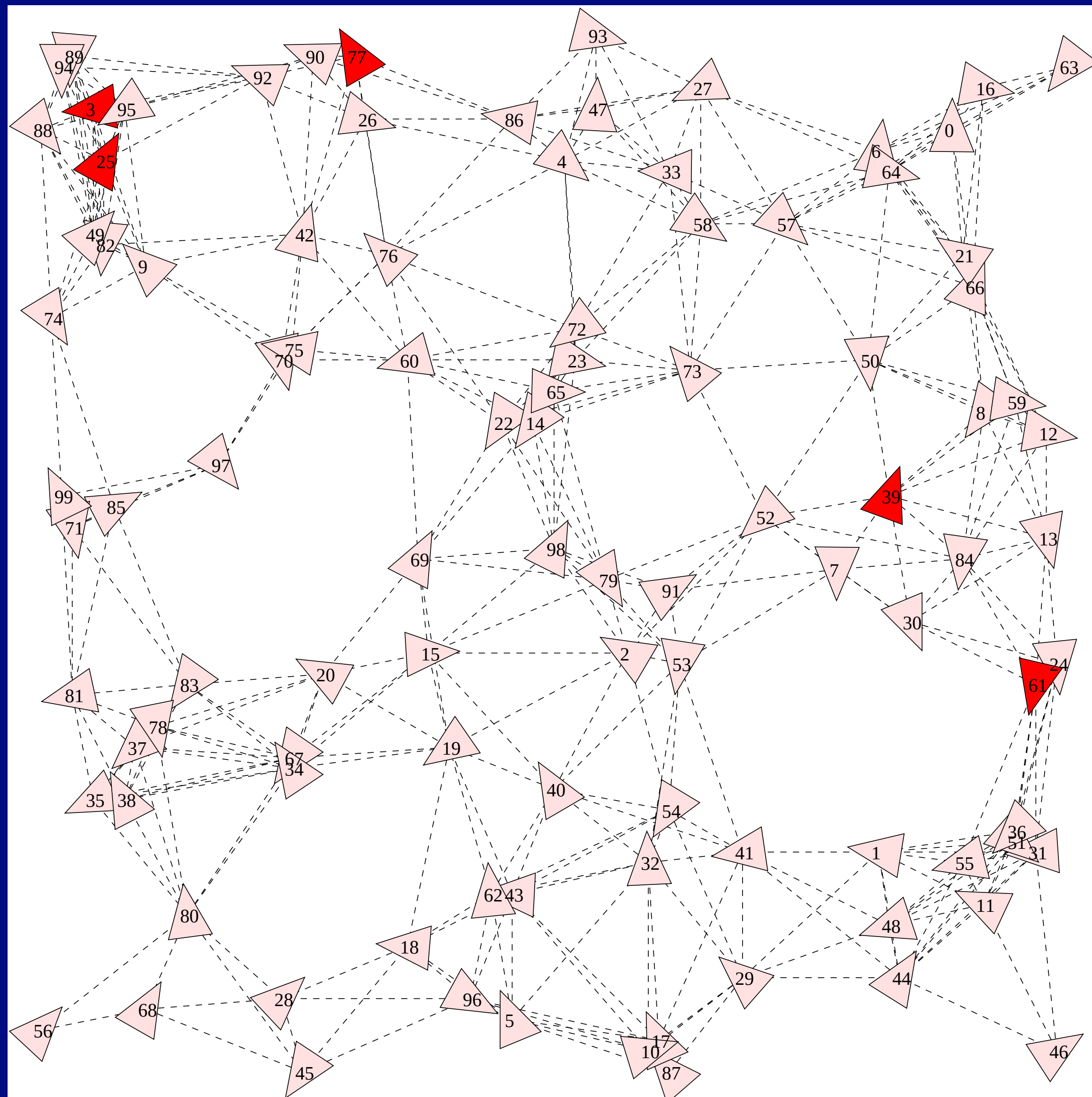


hopsize=2000

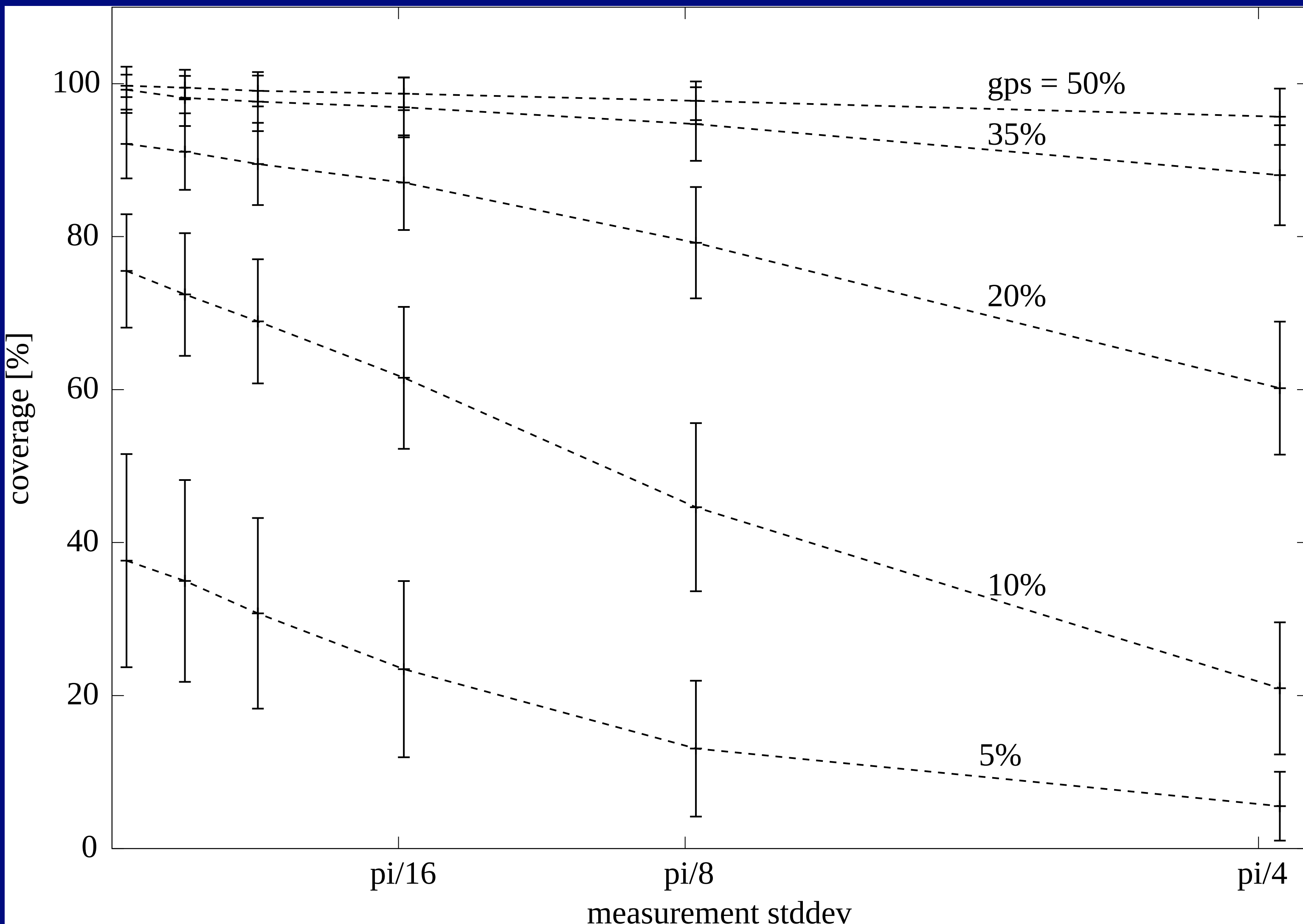
simulation

- random topology 100 nodes
  - isotropic [1]
  - AoA errors
    - white Gaussian noise
    - with a 95% probability, the measured angle is within $\pm 2\,stddev$ of mean
- performance metrics
  - coverage - how many nodes get a position/heading
  - absolute position error - in number of hops
  - bearing error - with respect to landmarks
  - heading error - absolute orientation

[1] the network has the same properties (density, radio range) in all directions

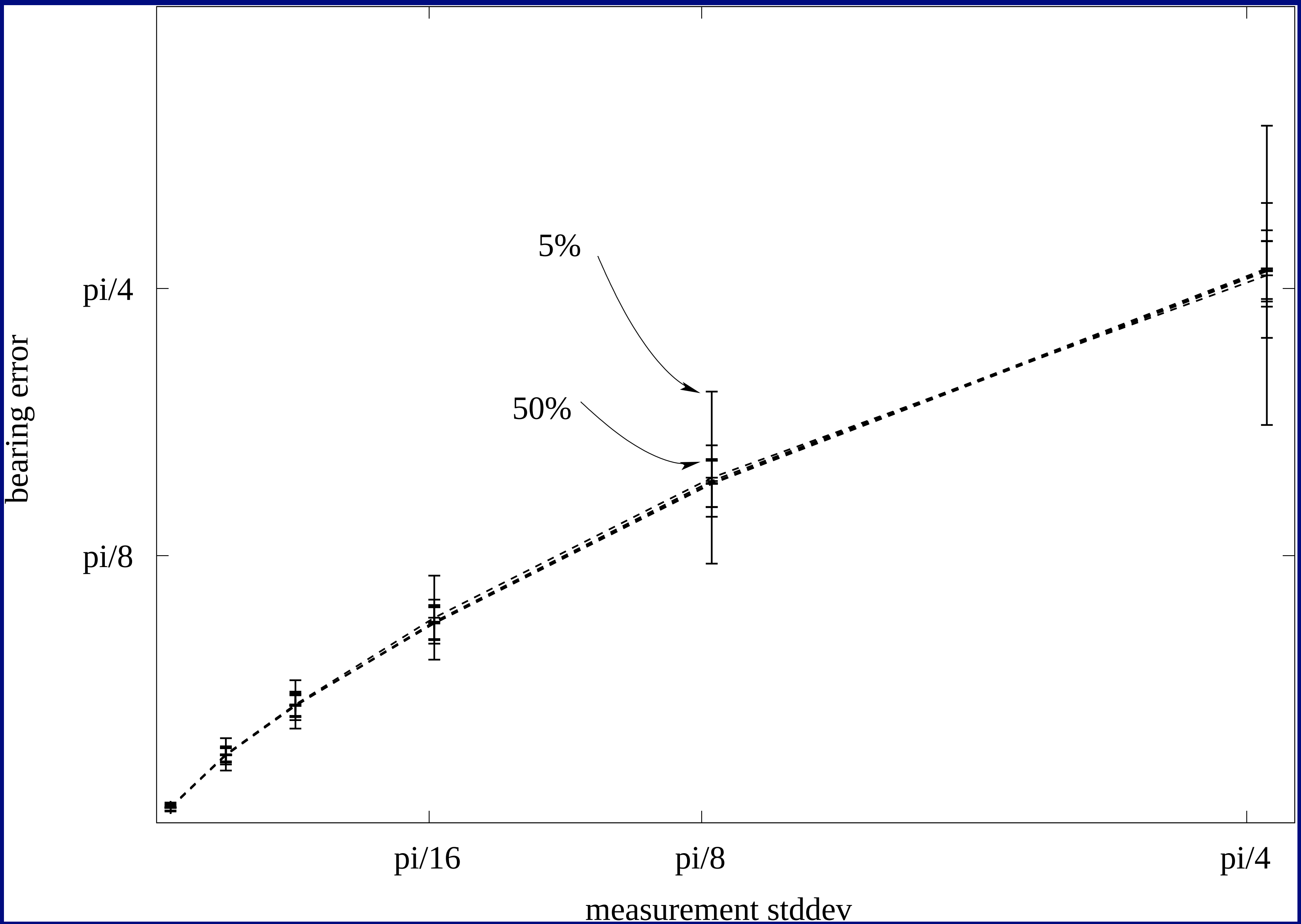

89 94 90 77 92 93 27 63 16
3 95 26 86 47 0 88 6 25 4 33 64 58 57
49 82 42 9 76 21 66 74 72 75 70 60 23 73 50 65 59 8 22 14 12
97 99 85 39 71 52 13 98 69 84 79 7 91 30
15 2 53 24 61 83 20 81 78 37 19 67 34 40 54 35 38
36 51 31 41 1 32 55 62 43 11 80 48 18 29 44
28 96 68 5 56 17 10 46 45 87

coverage

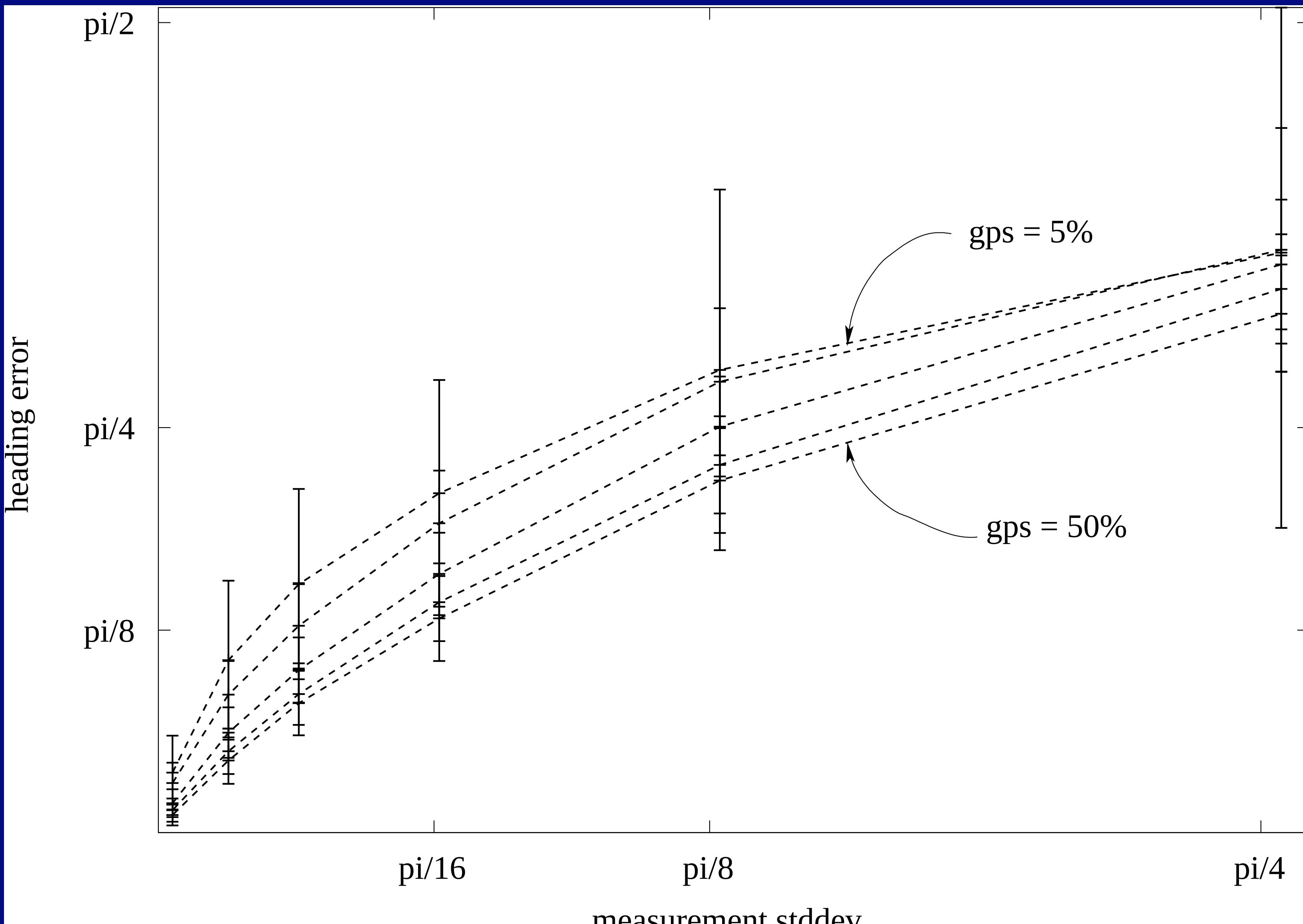


coverage [%]
0
20
40
60
80
100
pi/16
pi/8
pi/4
measurement stddev
gps = 50%
35%
20%
10%
5%

bearing error

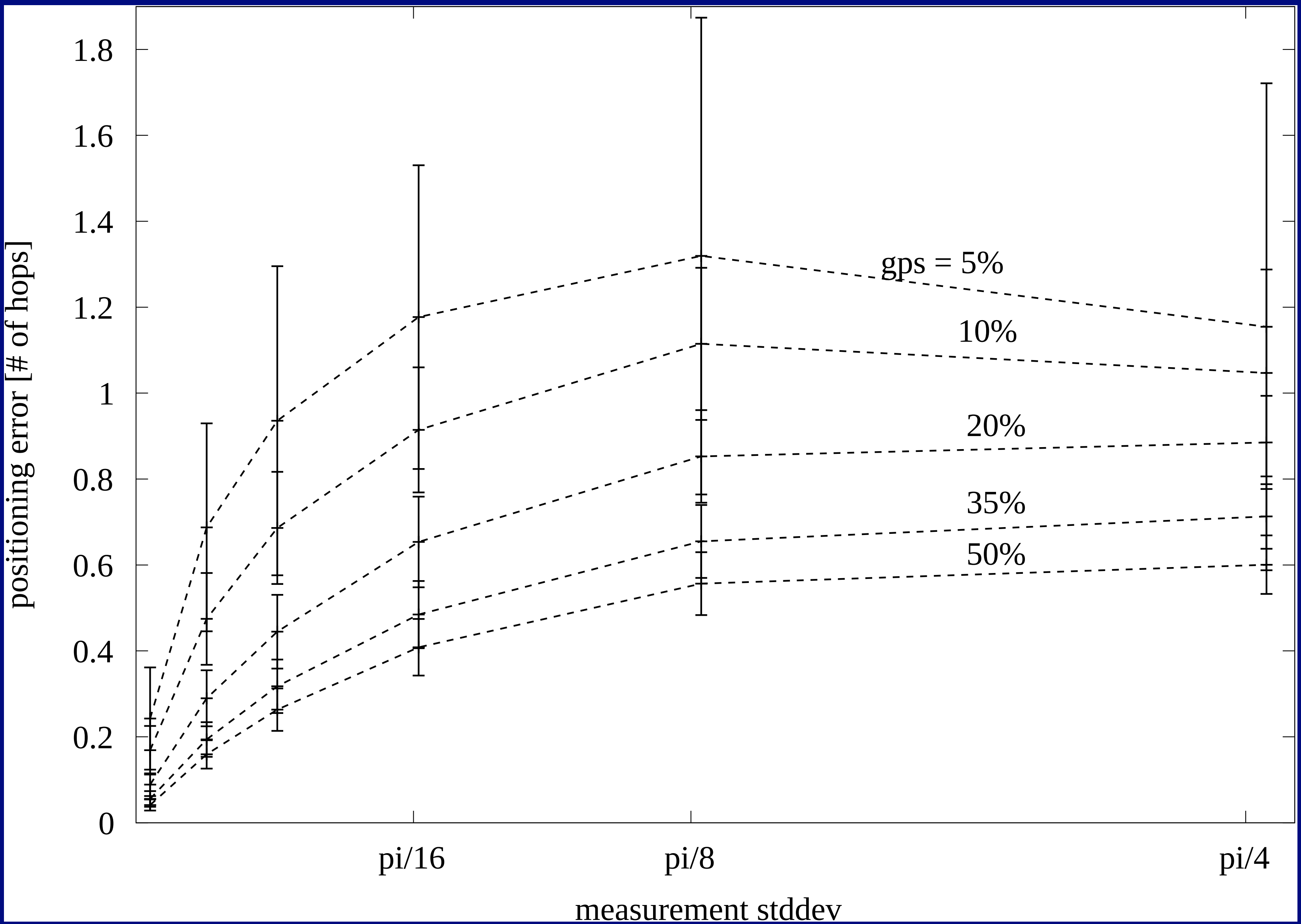


heading error



- Heading error = double of the bearing error

location error



simulation summary

- error reduction - simple methods
- error - coverage tradeoff
- heading error is about double the heading error
- nodes inside the convex hull of acquired landmarks get better estimates
- # of landmarks is more critical for position than for orientation

future work

multimodal estimation

- can AoA and signal strength be used together?

node mobility

- a moving landmark
  - is a new landmark
  - one flying landmark could be enough for the entire static network
- mobile nodes are supported by static nodes

conclusions

- APOS (Ad Hoc Positioning and Orientation System)
  - provides position and orientation for randomly deployed nodes
  - needs AoA capability in all nodes, but no signal strength
  - distributed, no infrastructure
  - uses a DV based scheme to propagate landmark bearings
  - positioning accuracy $\rightarrow$ one hop away from the true location
  - orientation accuracy $\rightarrow$ double the measuring accuracy