Greedy Virtual Coordinates for Geographic Routing

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Background

- Geographic routing is a promising approach for wireless networks
  - Each node has an x-y coordinate
  - Stores little (constant) state per node
  - Easy to repair

Geographic Routing

- Try greedy forwarding
- Dead end
  - switch to guaranteed routing mode
  - either face or hull tree routing
- Whenever possible, switch back to greedy forwarding
  - because greedy forwarding gives good performance [Xing et al., 2004]

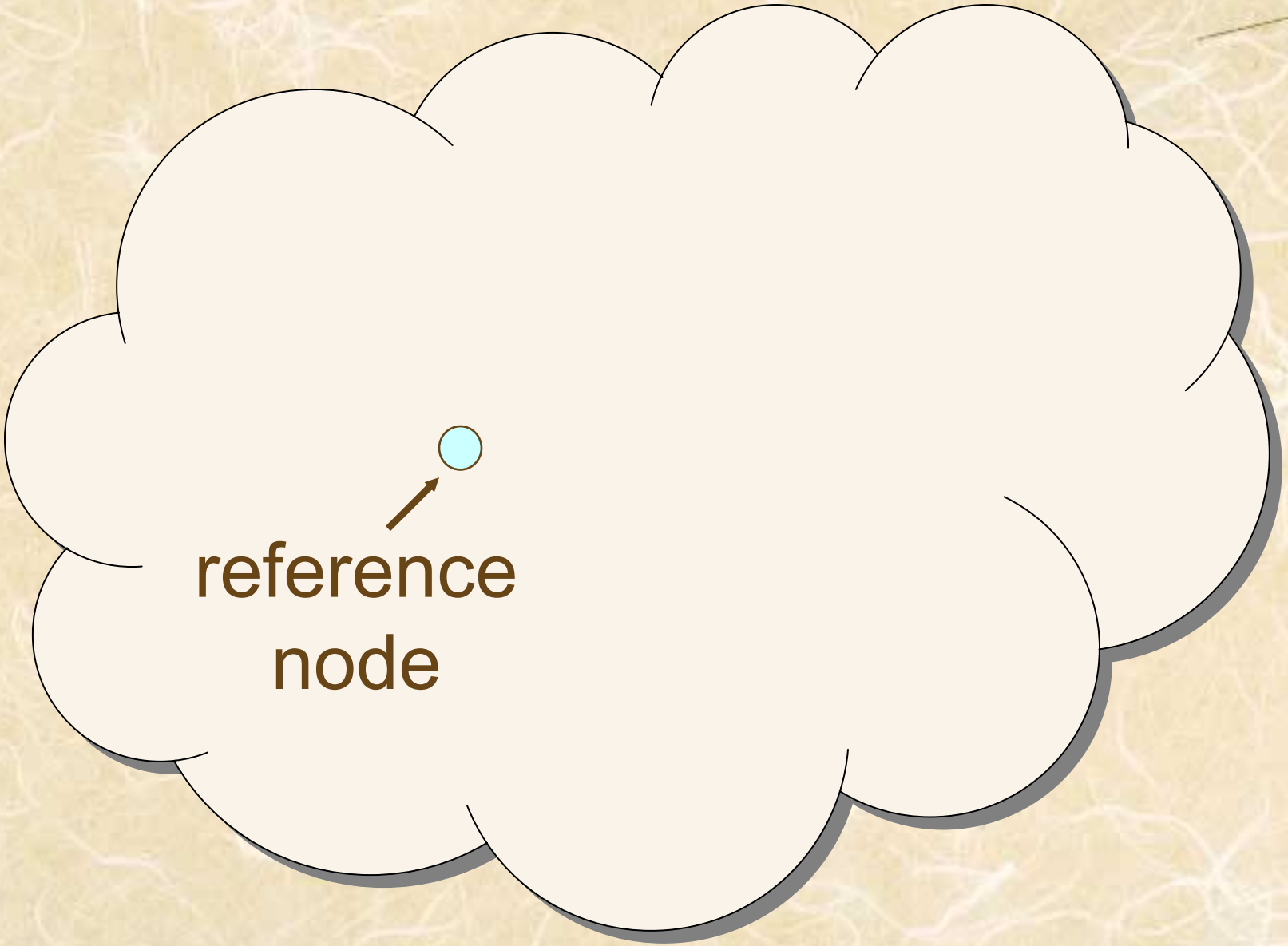
Case for Virtual Coordinates

- Not always feasible to have GPS for each node
- Virtual coordinates are sometimes better, e.g. sensornet on ship
- Physical locations are not required (Rao et al., 2003)
- Previous work: good for dense networks
- Know: greedy forwarding is efficient
- Challenge: *can we assign coordinates so that greedy forwarding always works?*

Greedy Embedding Spring Coordinates (GSpring)

- Start from initial coordinates
- Simulate physical spring system with repulsion forces
- Incrementally adjust nodes to make topology more convex
- Introduce damping and hysteresis to ensure system converges

Determining Initial Coordinates



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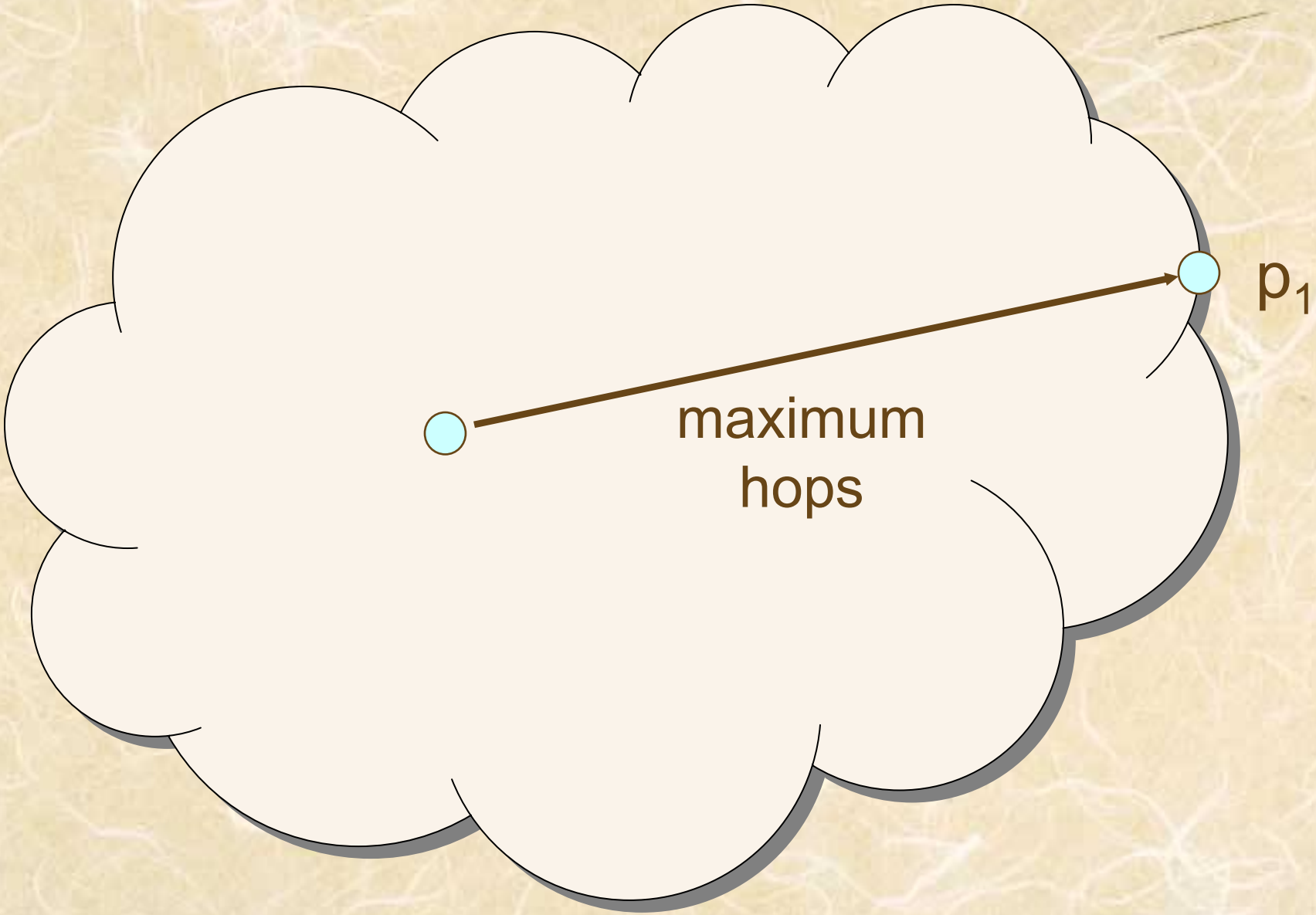

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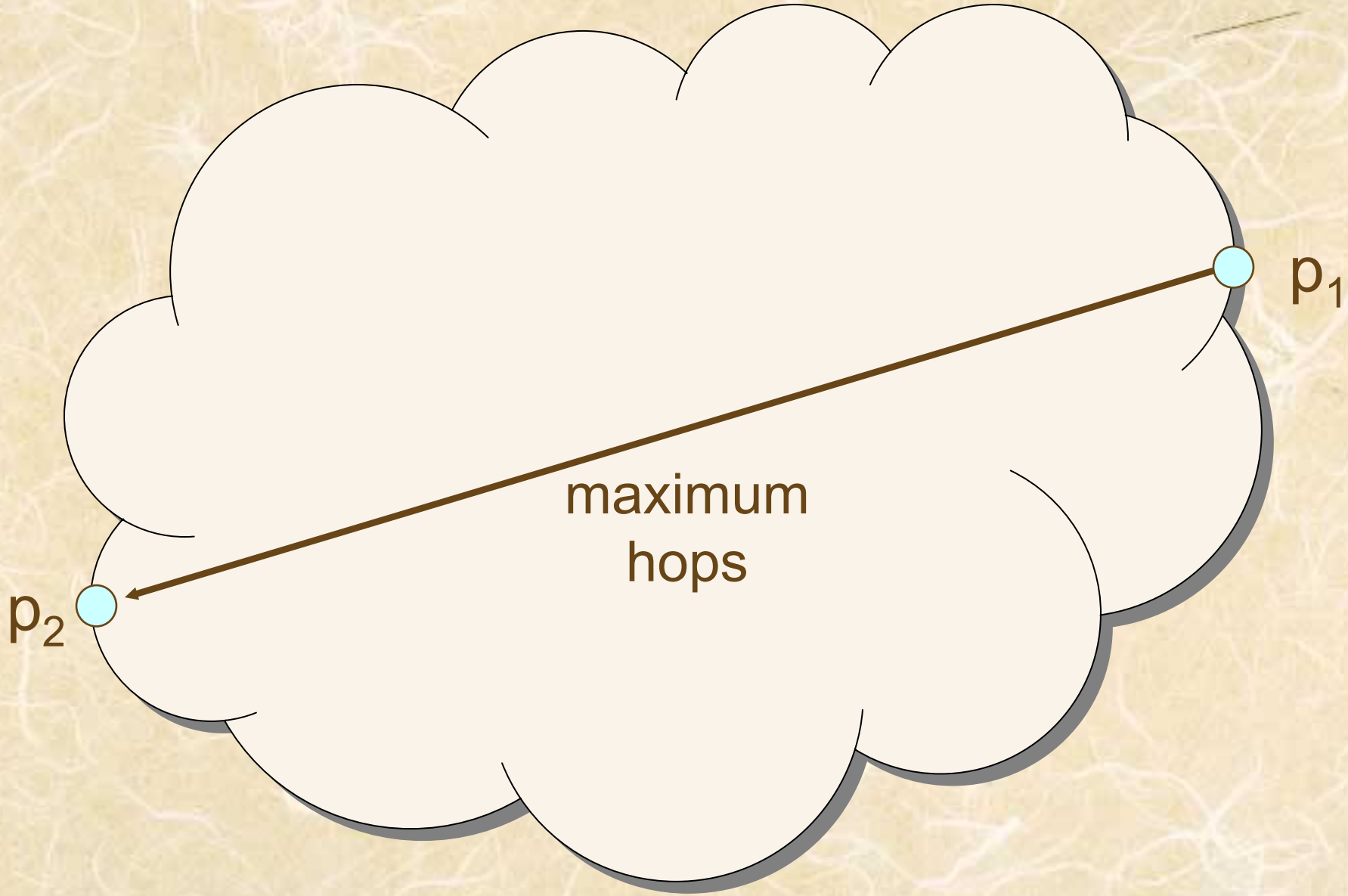

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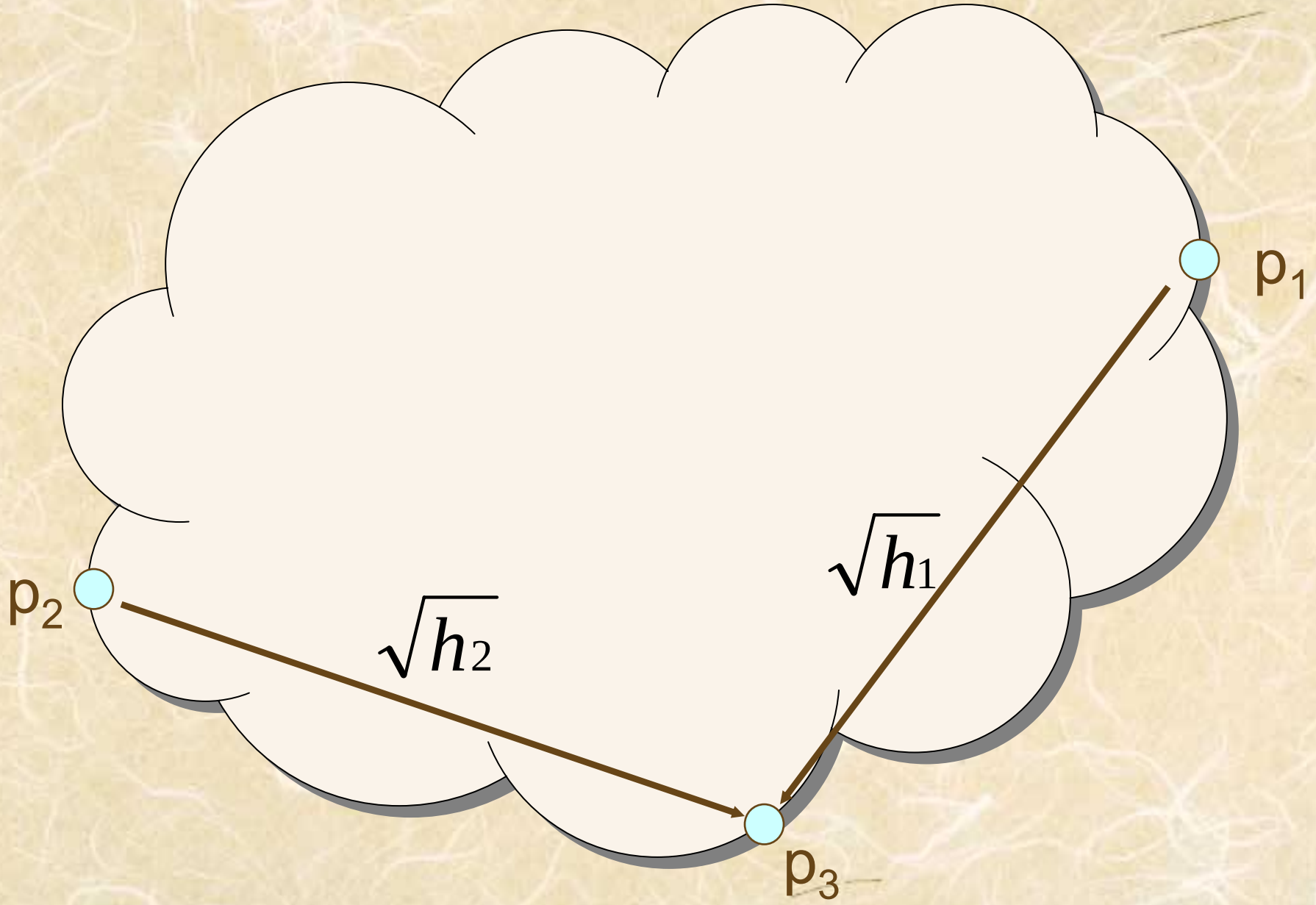

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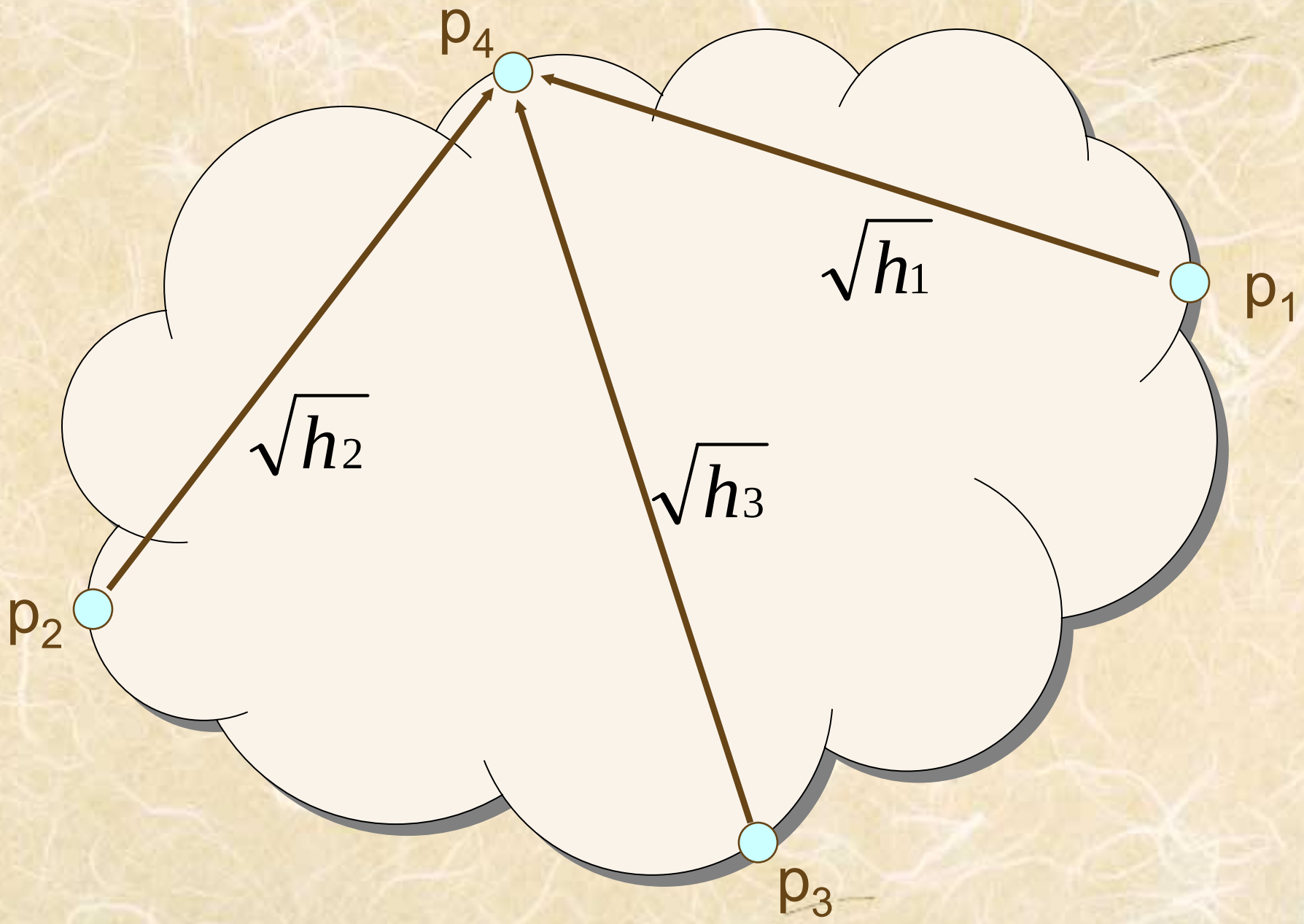

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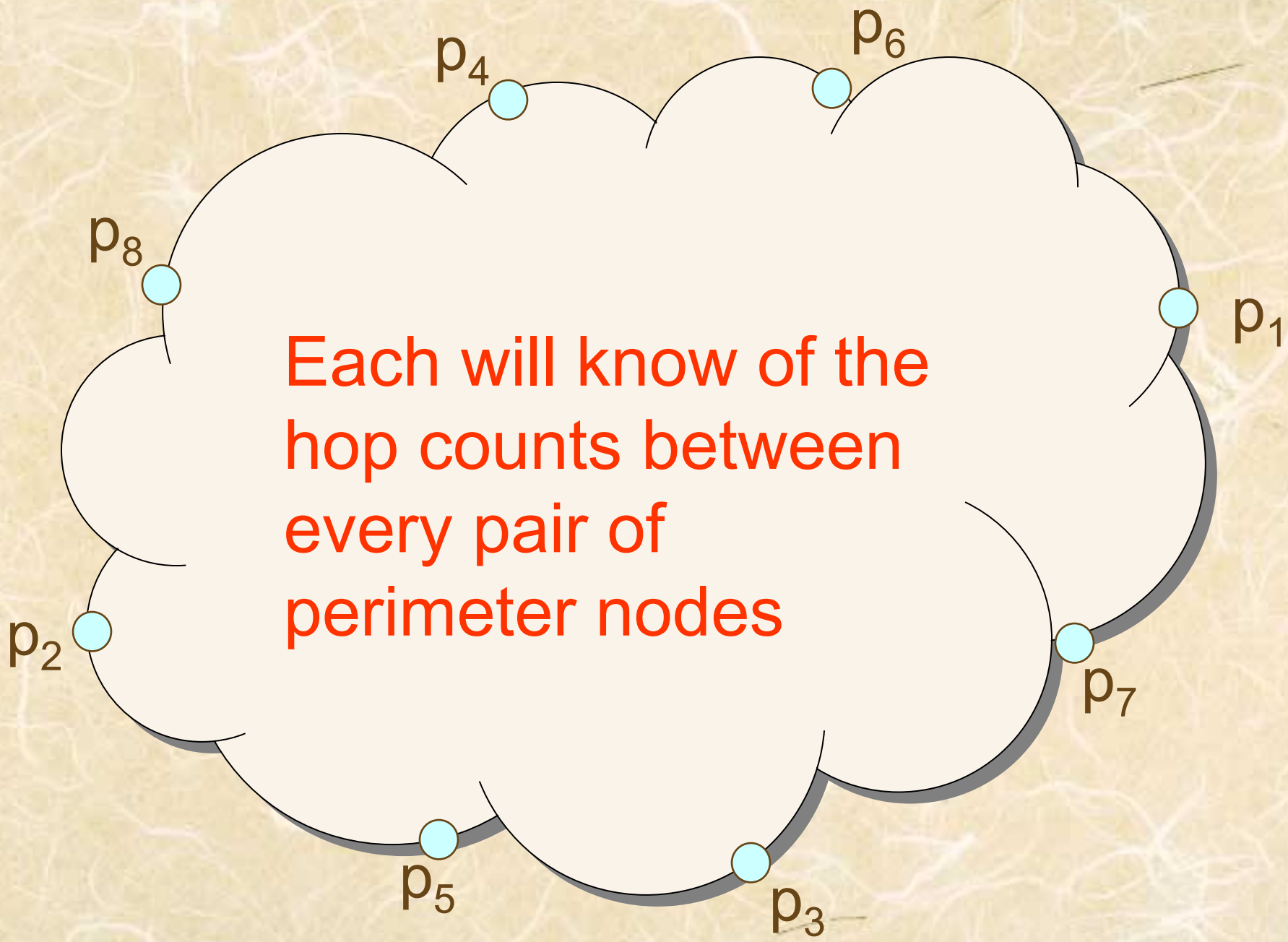
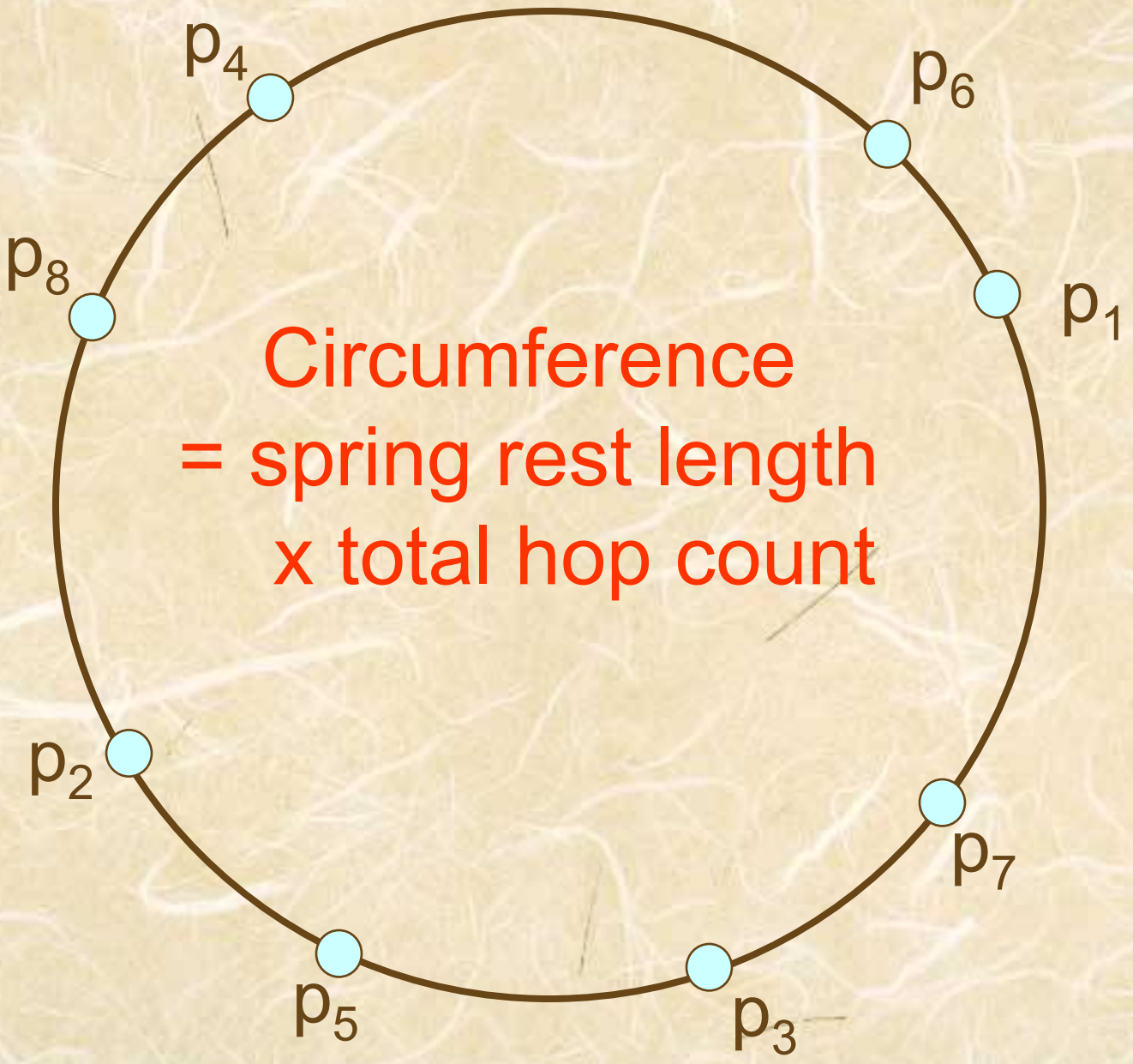
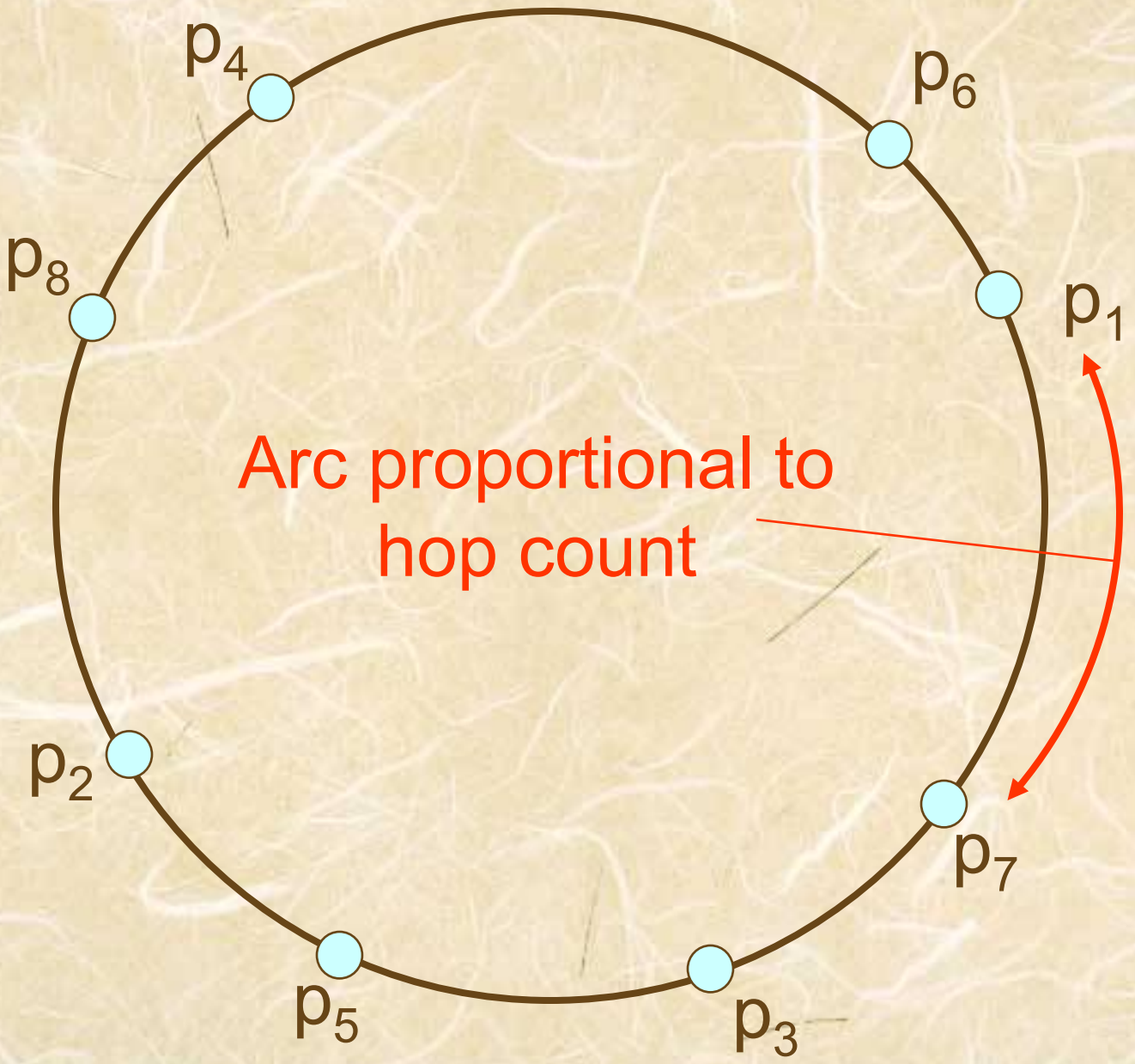


Projection onto Circle



Projection onto Circle



Determining Initial Coordinates

- After perimeter nodes determined
  - matrix of hop counts between them
- Determine cyclical ordering of nodes
- Project nodes onto a circle
- Interpolate for the nodes in between
- Some nodes can wait

Key idea: stretch network toplogy out in the virtual space like a trampoline!

Spring Relaxation Update Rule

- Spring force:

$$F_{ij} = \kappa \times (l_{ij} - |\, x_i - x_j \,|) \times u(x_i - x_j)$$

(Hooke's Law)

- Net force:

$$F_i = \sum_{j \neq i} F_{ij}$$

- Update rule:

$$x_i = x_i + \frac{\min(|\, F_i \,|, \alpha_t)}{|\, F_i \,|} F_i$$

Greedy Embedding

Graph where given any two distinct nodes *s* and *t*, there is a neighbor of *s* that is closer to *t* than *s*.

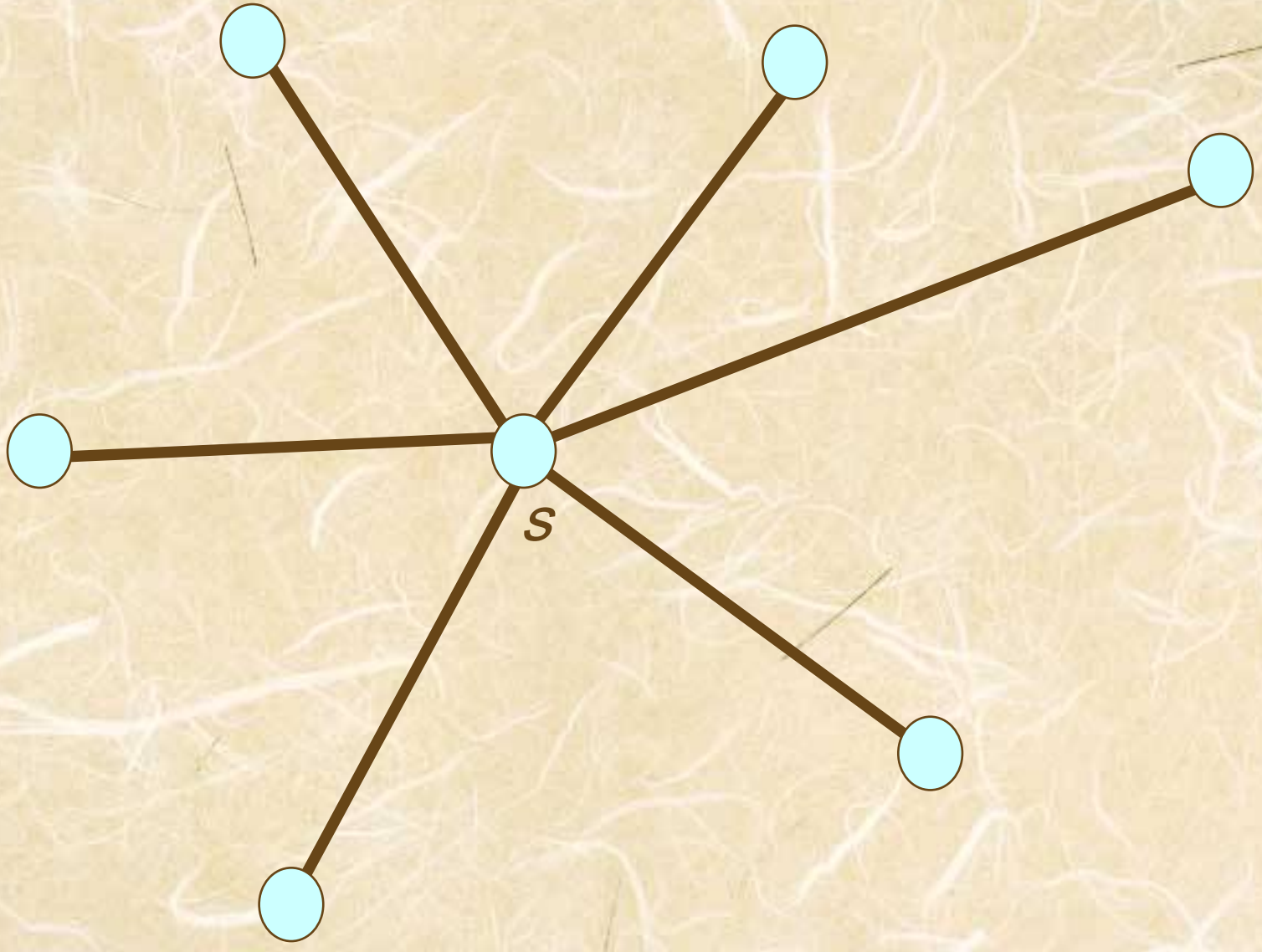
- Greedy forwarding works between any pair of nodes

- Here's a thought:

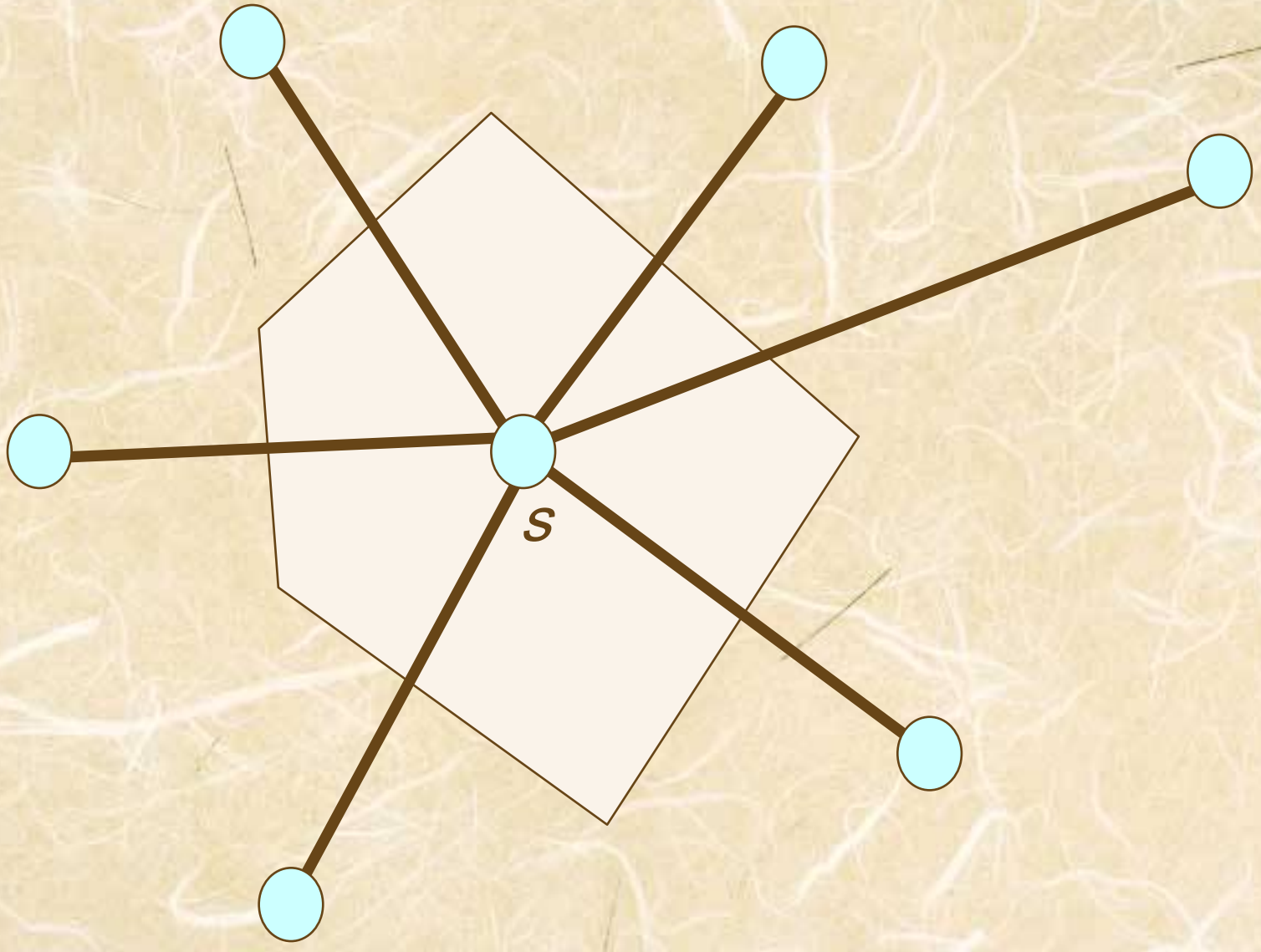
If we pick virtual coordinates such that resulting graph is a greedy embedding, we can achieve good routing performance

HOW? ☺

Region of Ownership



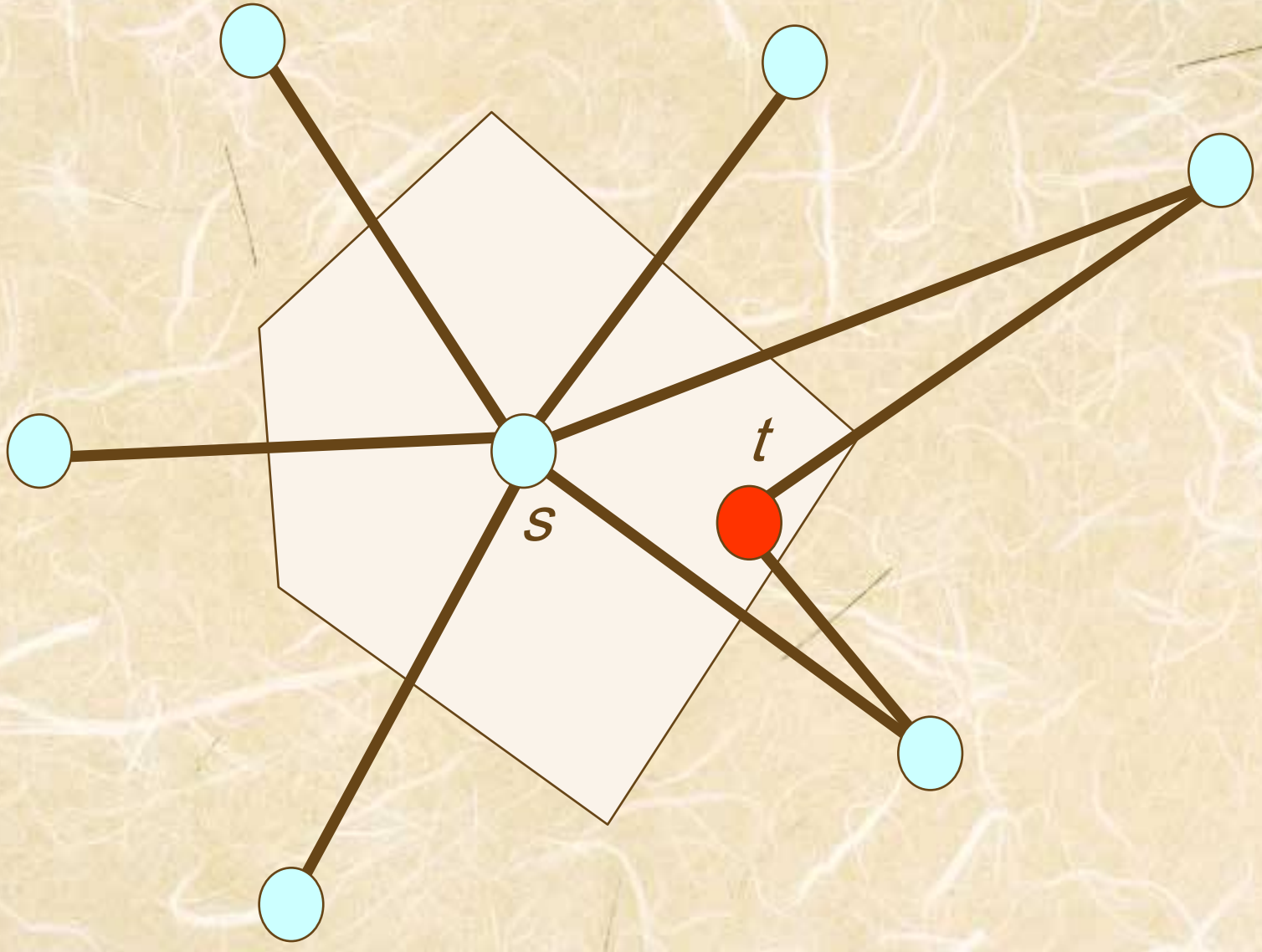
Region of Ownership



Theorem

An embedding of a Euclidean graph is greedy if and only if the region of ownership of every vertex does not contain any other vertices of the graph.

Greedy Embedding Adjustment



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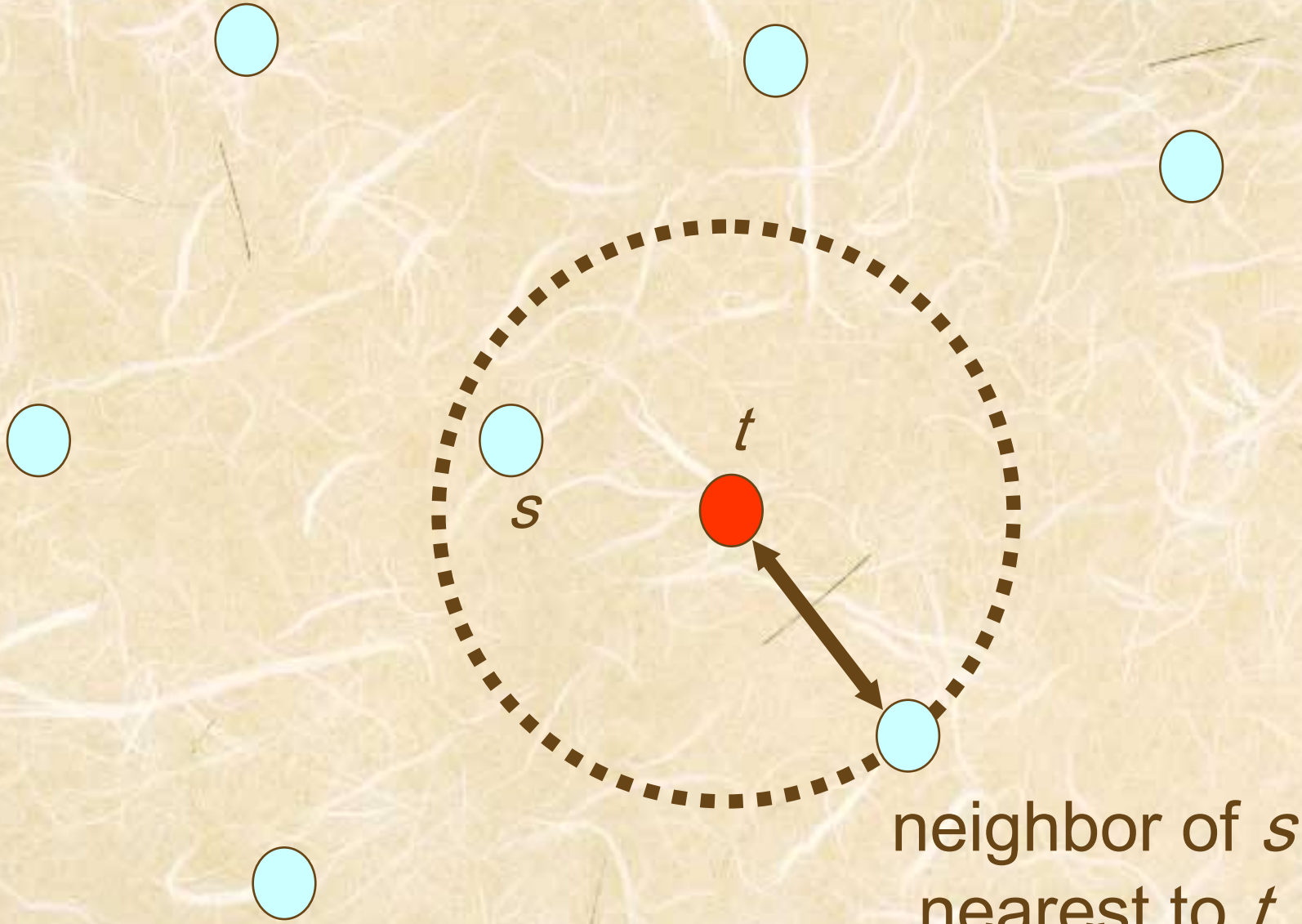

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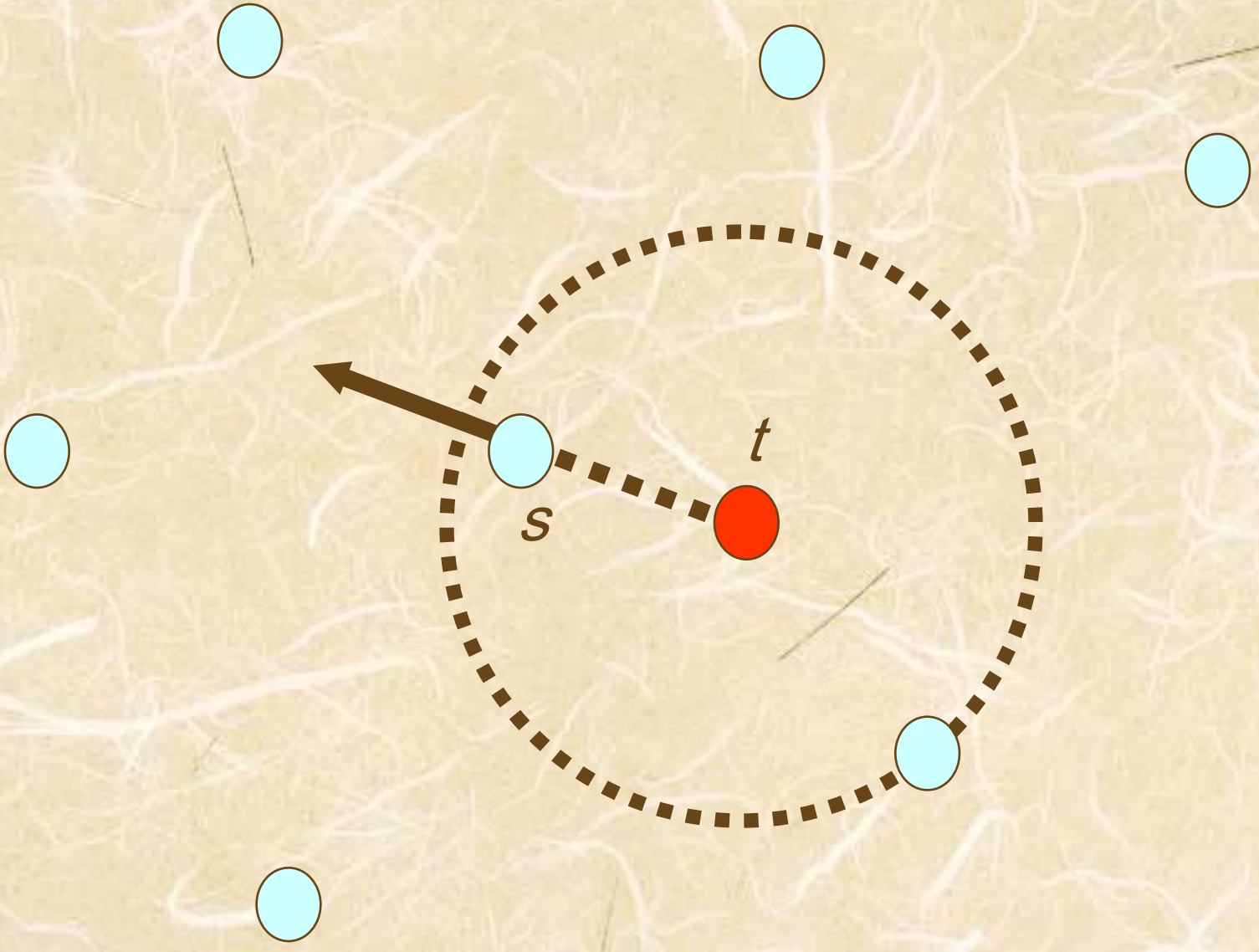


Greedy Embedding Update Rule

- Repulsion force:

$$R_{ik} = \delta \times u(x_i - x_k)$$

- Net force:

Spring forces

Repulsion forces

$$F_i = \sum_{j \neq i} F_{ij} + \frac{\min(|\sum_{k \neq i} R_{ik}|, R_{max})}{|\sum_{k \neq i} R_{ik}|} \sum_{k \neq i} R_{ik}$$

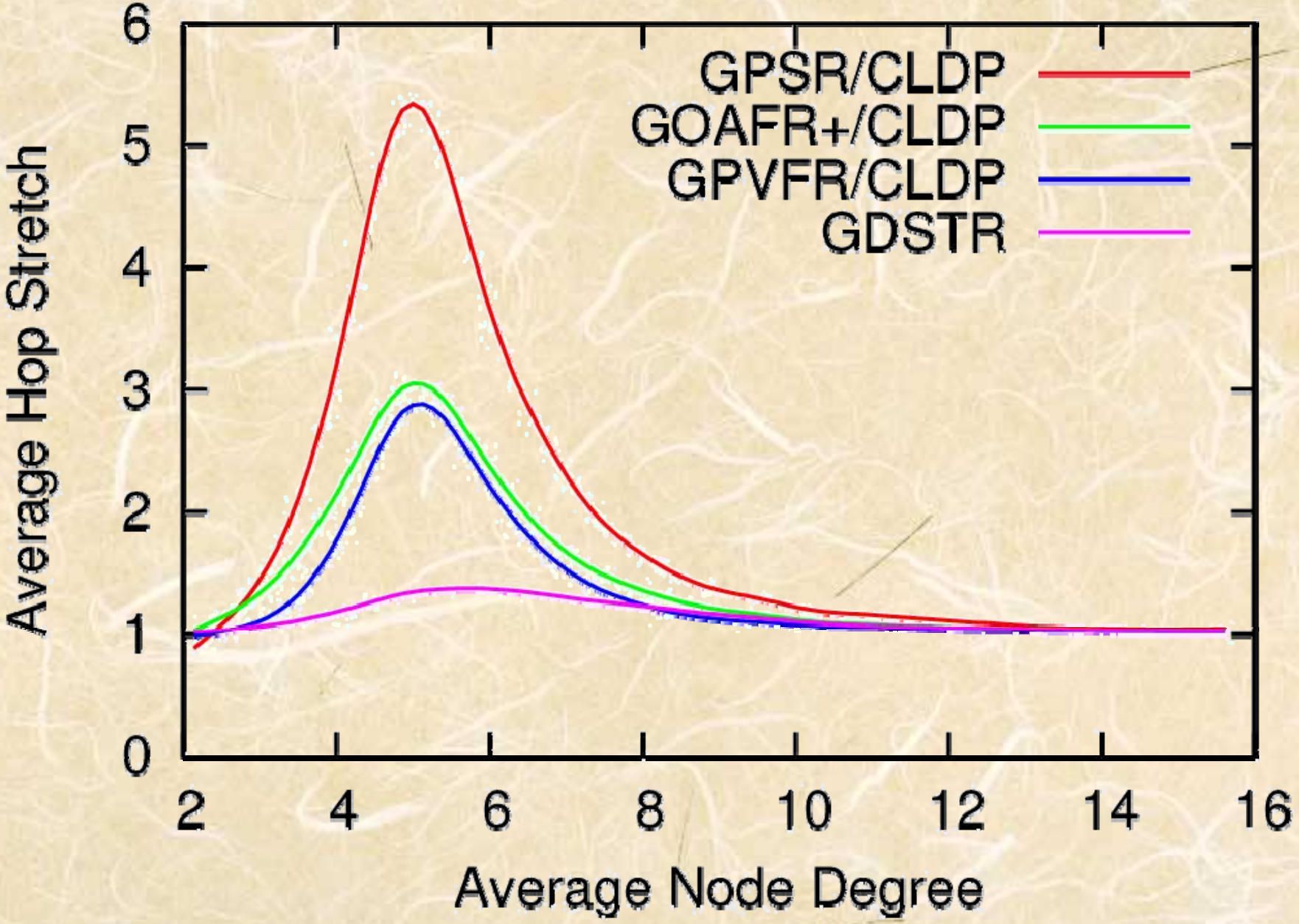
Greedy Embedding Spring Coordinates (GSpring)

- Once a node has stabilized, use geocast to determine nodes in region of ownership
- Use damping and hysteresis to ensure system converges

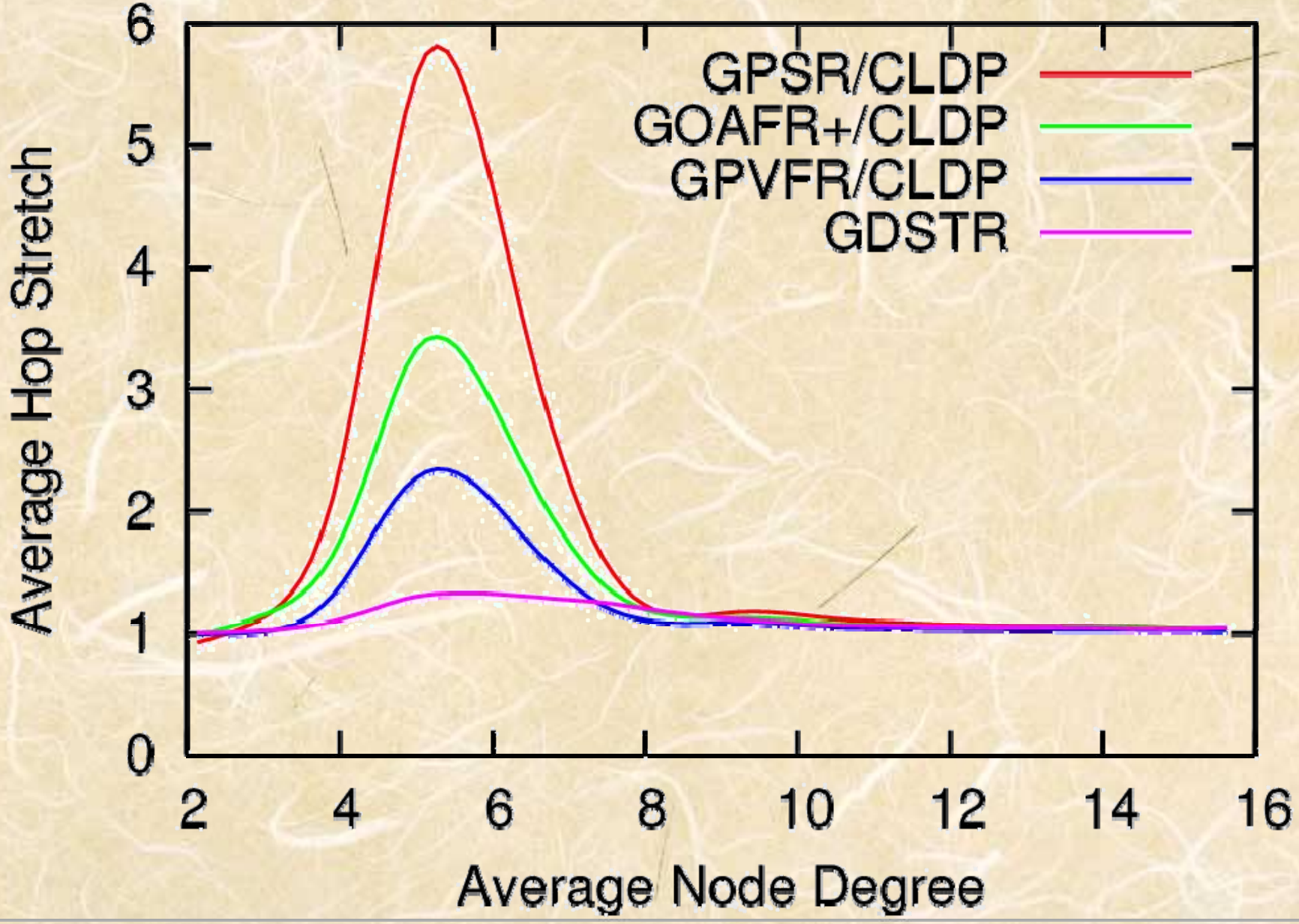
Performance

- Measured Hop Stretch
- Topologies
  - range of network densities (average node degree)
  - larger networks up to 2,000 nodes
    - low/high density
    - obstacles

Actual Physical Coordinates



GSpring Coordinates

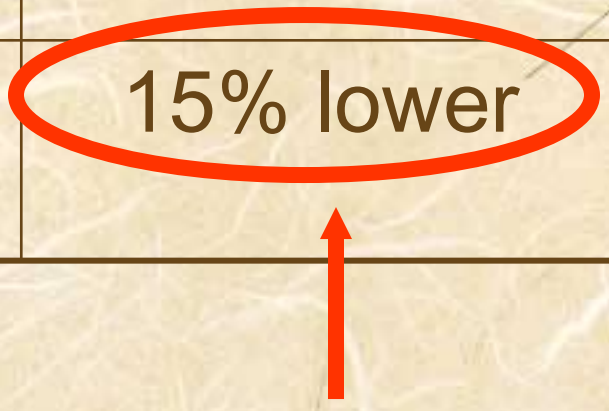


Performance

- Routing algorithm: GDSTR
- Compare with
  - actual coordinates
  - NoGeo (Rao et al., 2003)
- Measured costs:
  - iterations required
  - geocast messages

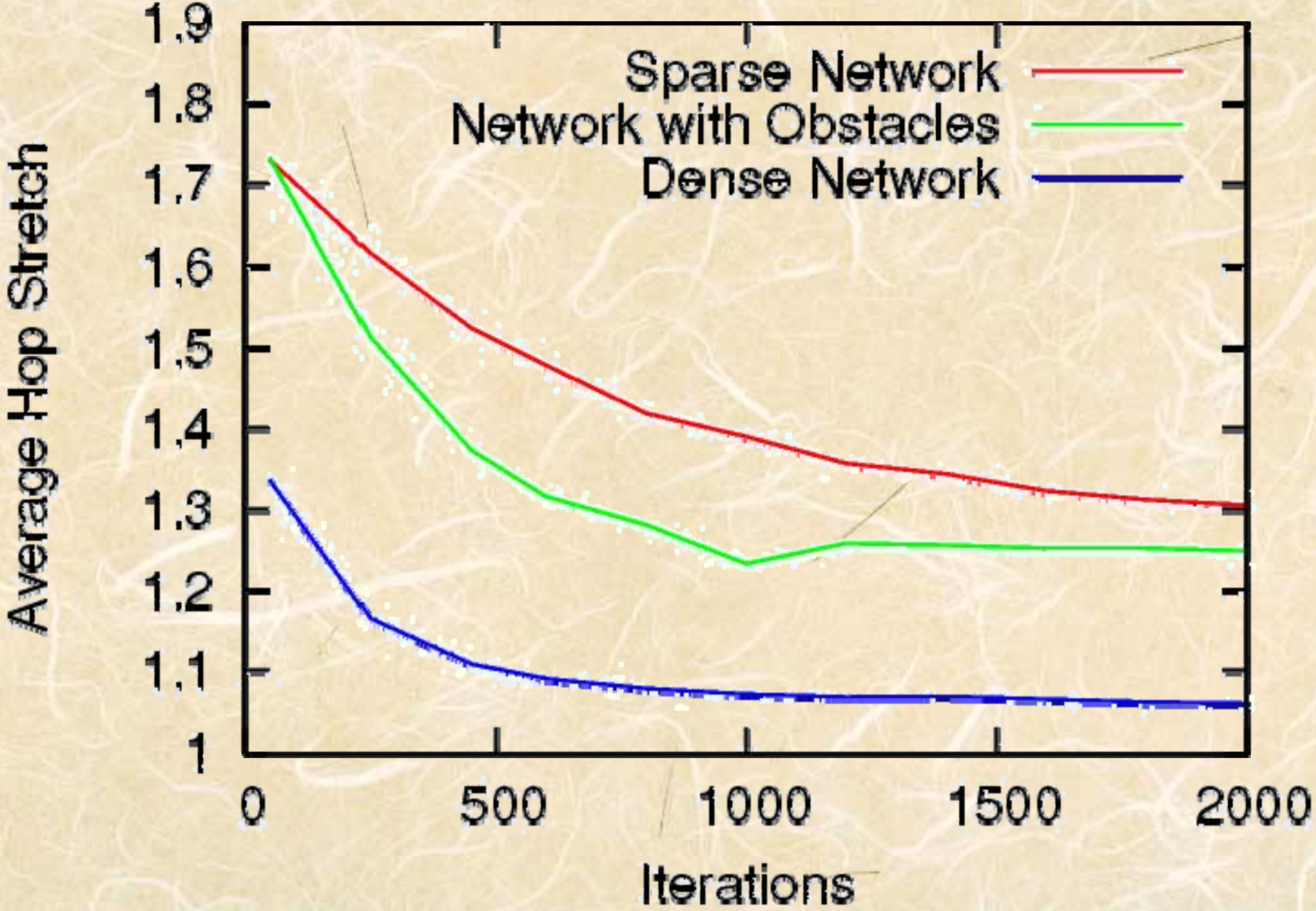
Performance: Hop Stretch

Network Type	Physical coordinates	NoGeo
Sparse UDG	Same	30% lower
Dense UDG	Same	50% lower
Obstacle	15% lower	50% lower

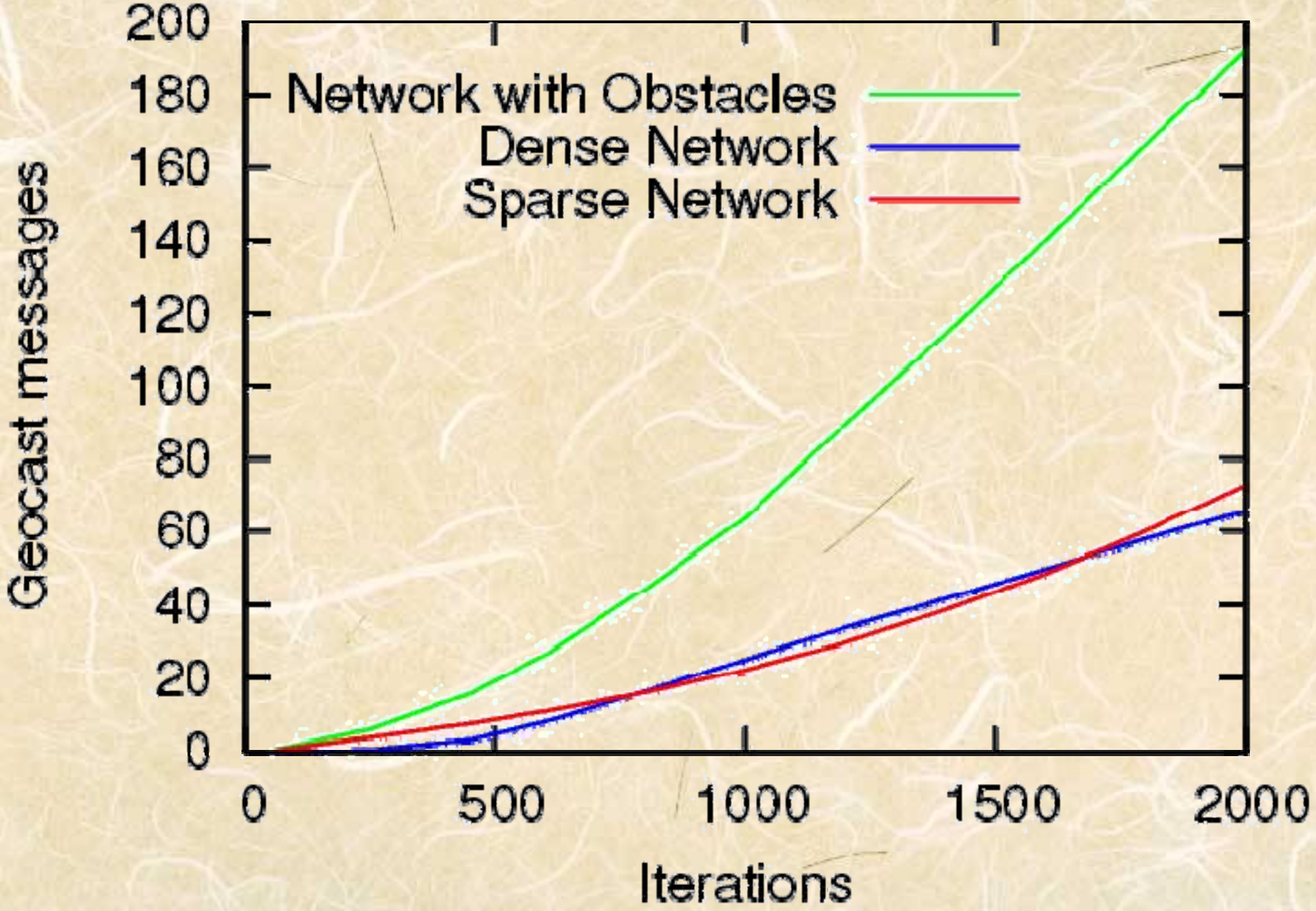


Can do better than actual coordinates!

Performance over Time



Messaging Costs



Summary

- Two key ideas:
  - Initial coordinates: stretch network out like a trampoline
  - To make topology more complex: need to move nodes out of each others “regions of ownership”

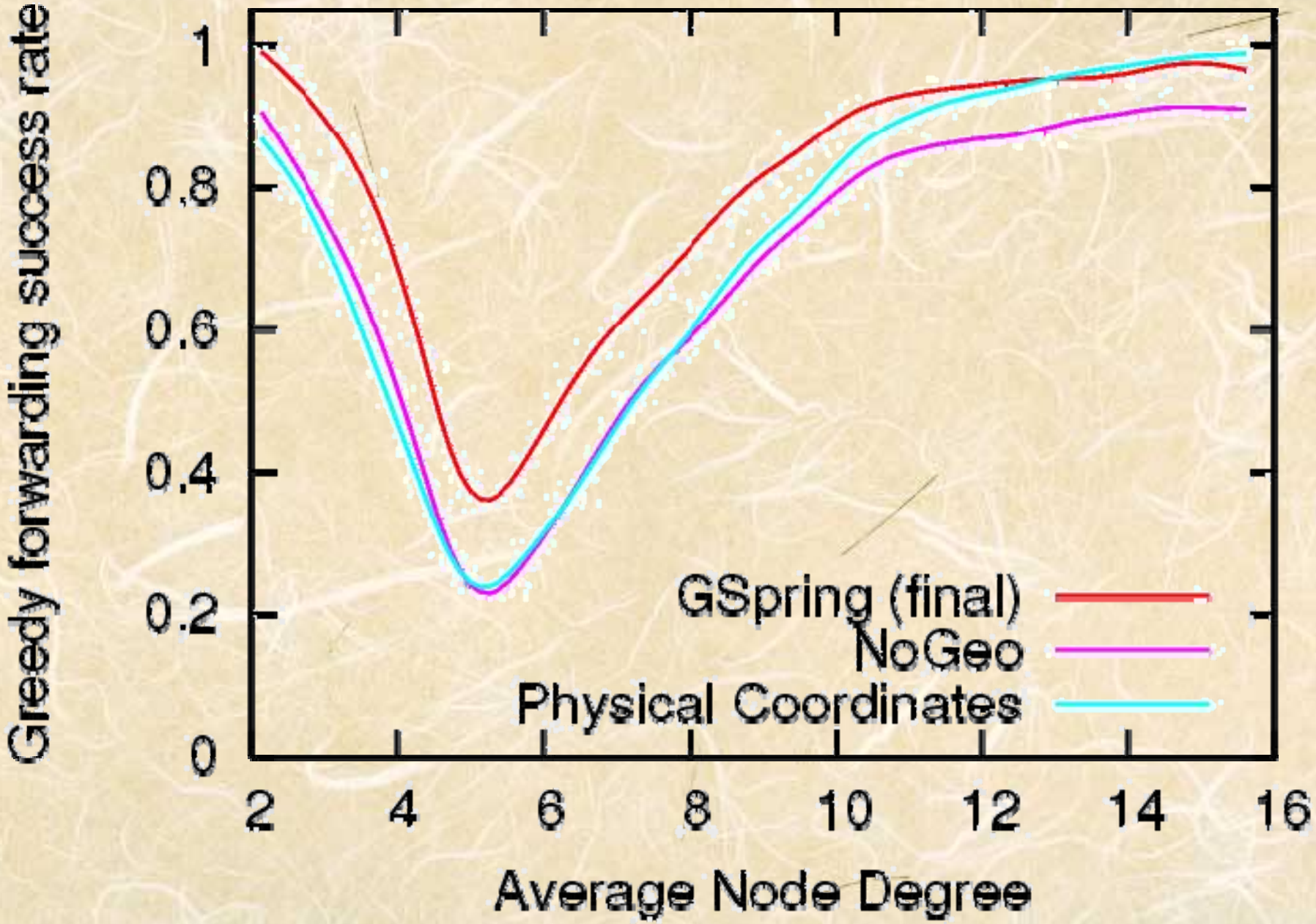
Future Work

- Evaluate GSpring in a real wireless deployment
- Study theoretical properties
- Region of Ownership generalizable to higher dimensions
  - Can we do achieve greedy embeddings more easily?

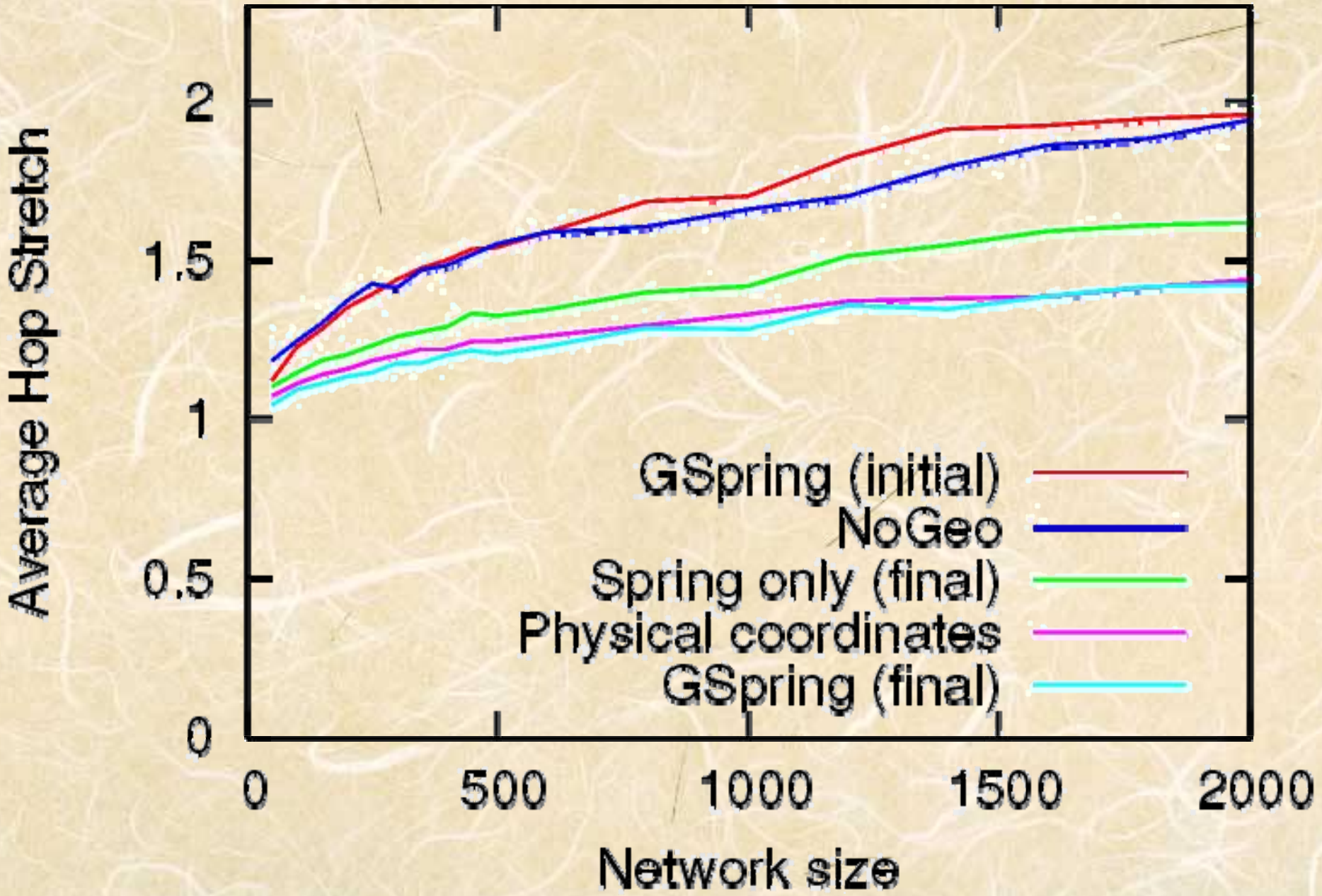
Conclusion

- Hard to find greedy embedding with local, distributed algorithm
  - more greedy improves routing performance
- Good for networks with obstacles
  - converts concave voids into convex ones
- “Embedding routing table into coordinate system”

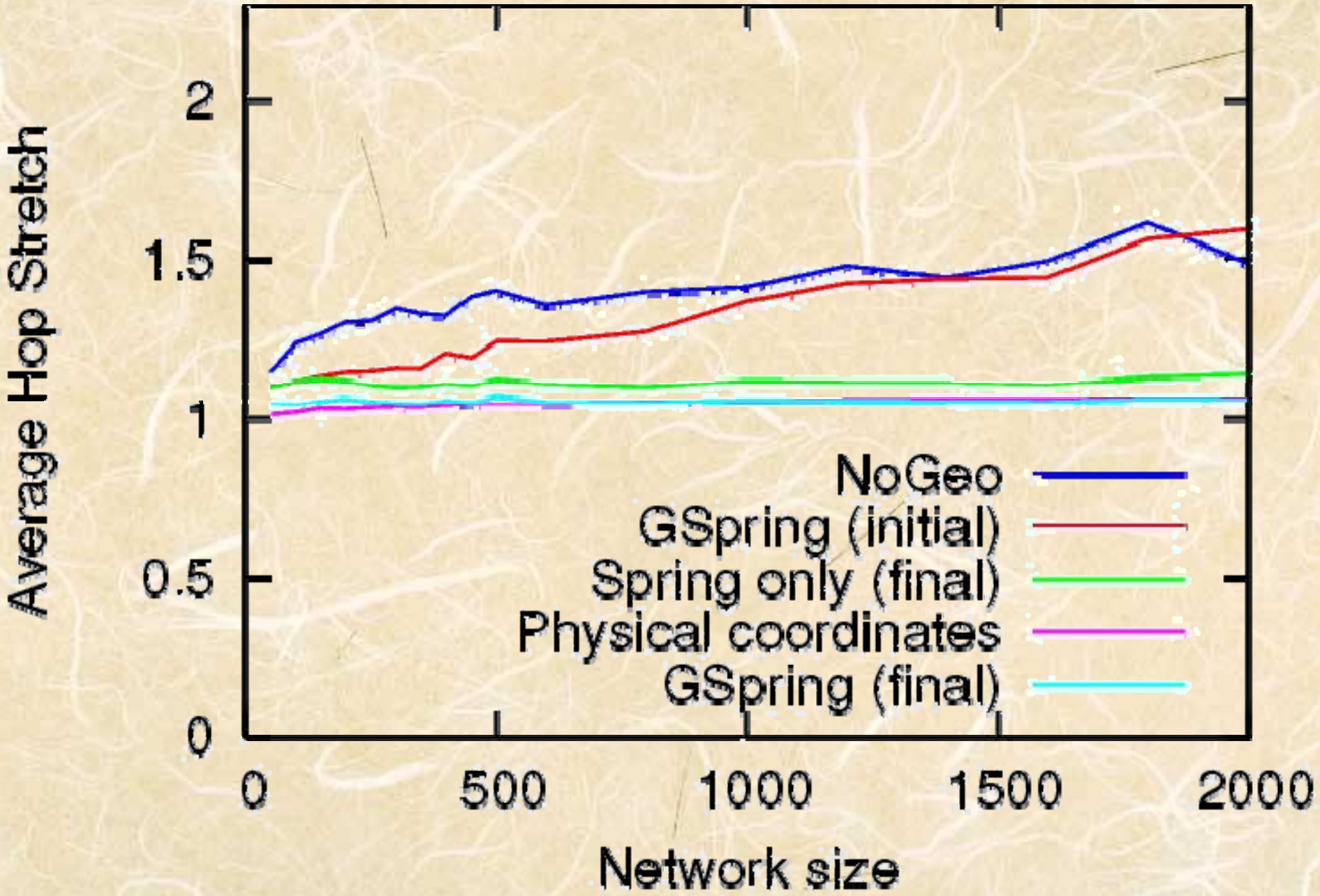
Greedy Forwarding Success



Sparse UDG Networks



Dense UDG Networks



Networks with Obstacles