Target Tracking, Aggregate Queries and Other Topics in Wireless Networks

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Wireless Devices

- Generate and consume data
- Have bounded energy
- Mobile

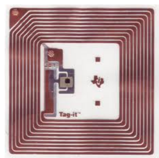




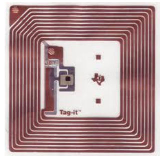
Challenges

- Efficient Communication
- Efficient Information Processing
- Distributed
- Adaptive, Privacy preserving



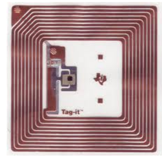




The idea: Use Locations



- Track and monitor
- Store and organise
- Query and use

Today



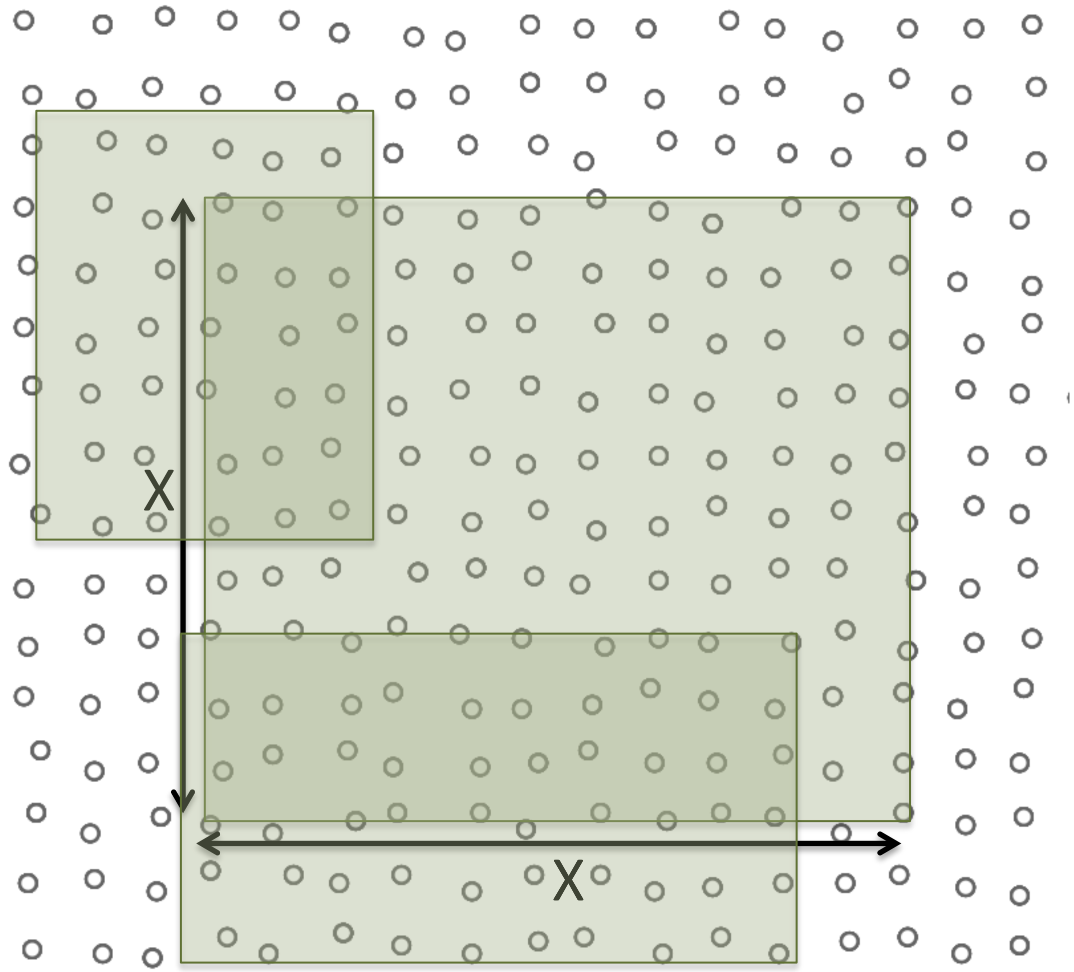

- Processing aggregate location information: Tracking collections of mobile objects

- Example of using locations for communication



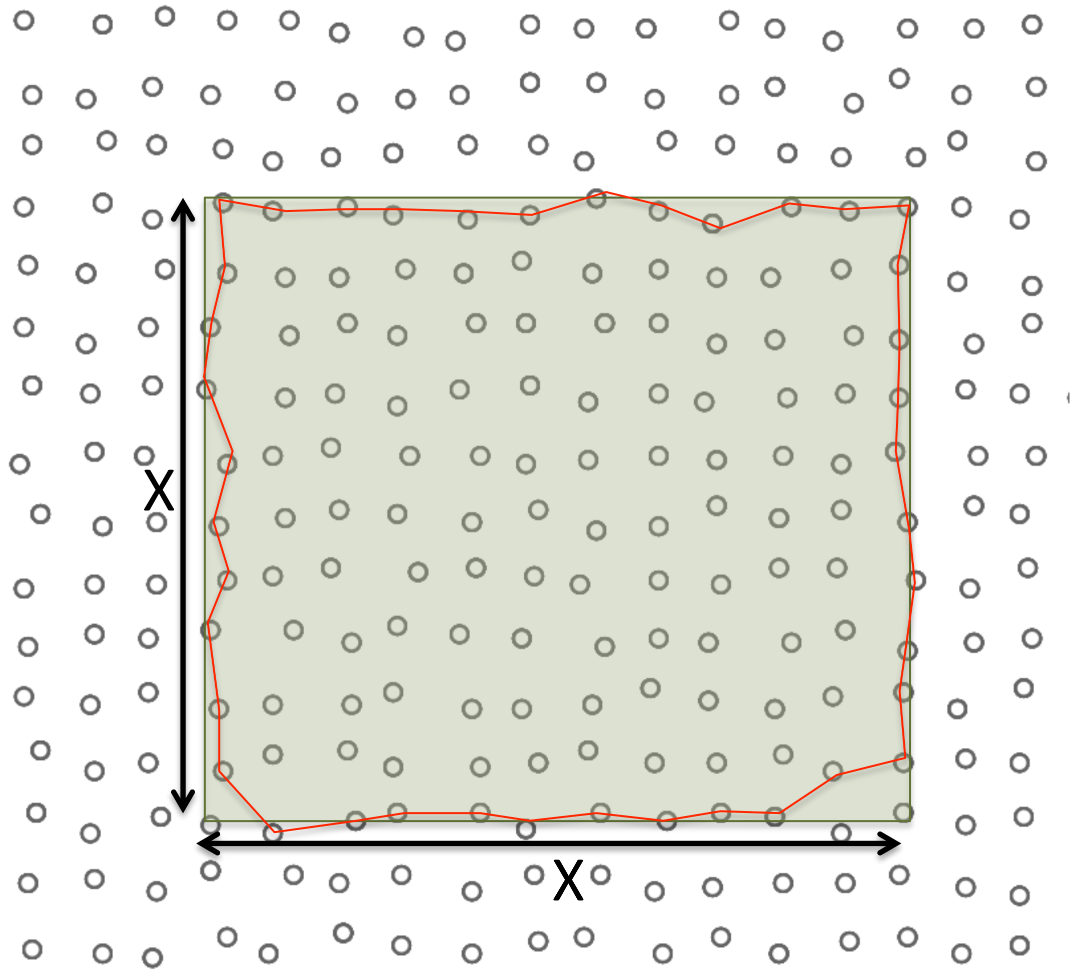
Part I: Tracking Mobile Objects

- How many objects are in X×X?
  - Traffic patterns, Information for network/power services, learning, adaptation etc..
- Ask all the static nodes in X×X
  - High cost : ≈X^2 nodes



Our Method: Find the answer from the perimeter!

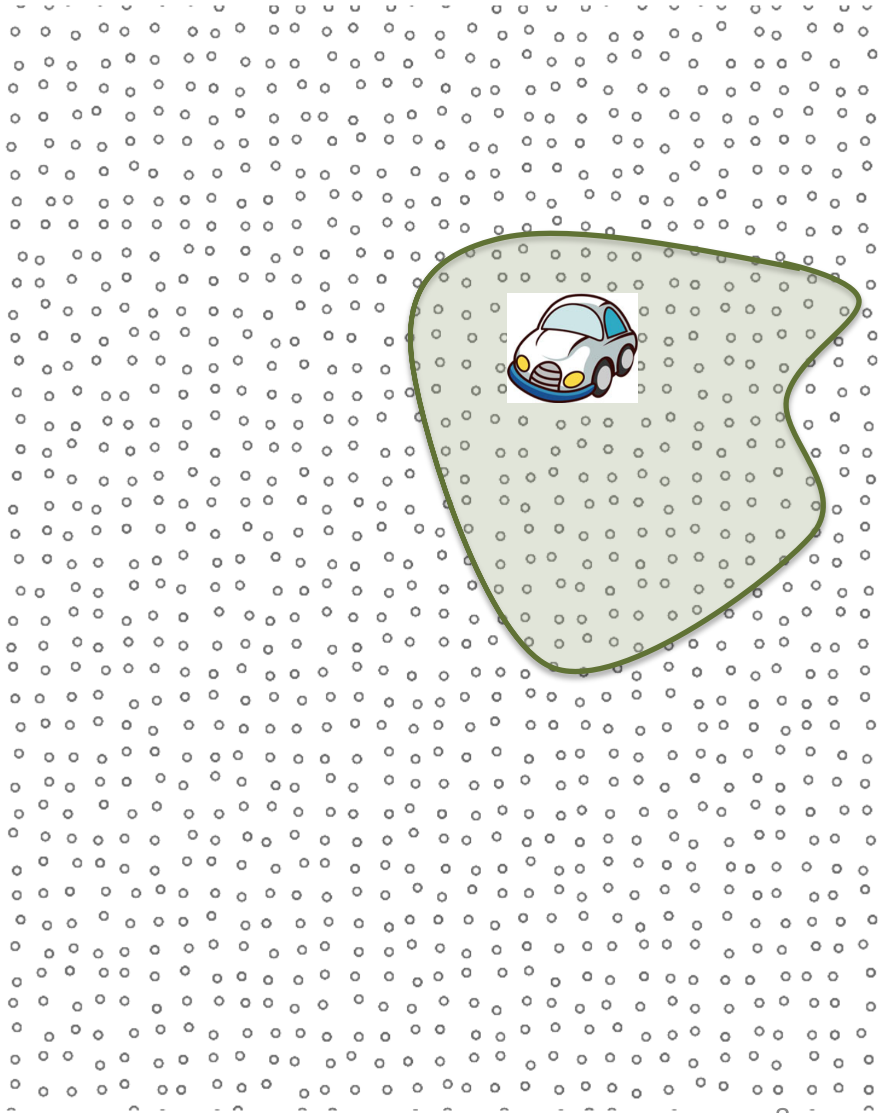
- Cost : O(X) nodes



[Sarkar, Gao, Mobicom ’10]
[TON ’13]

Properties

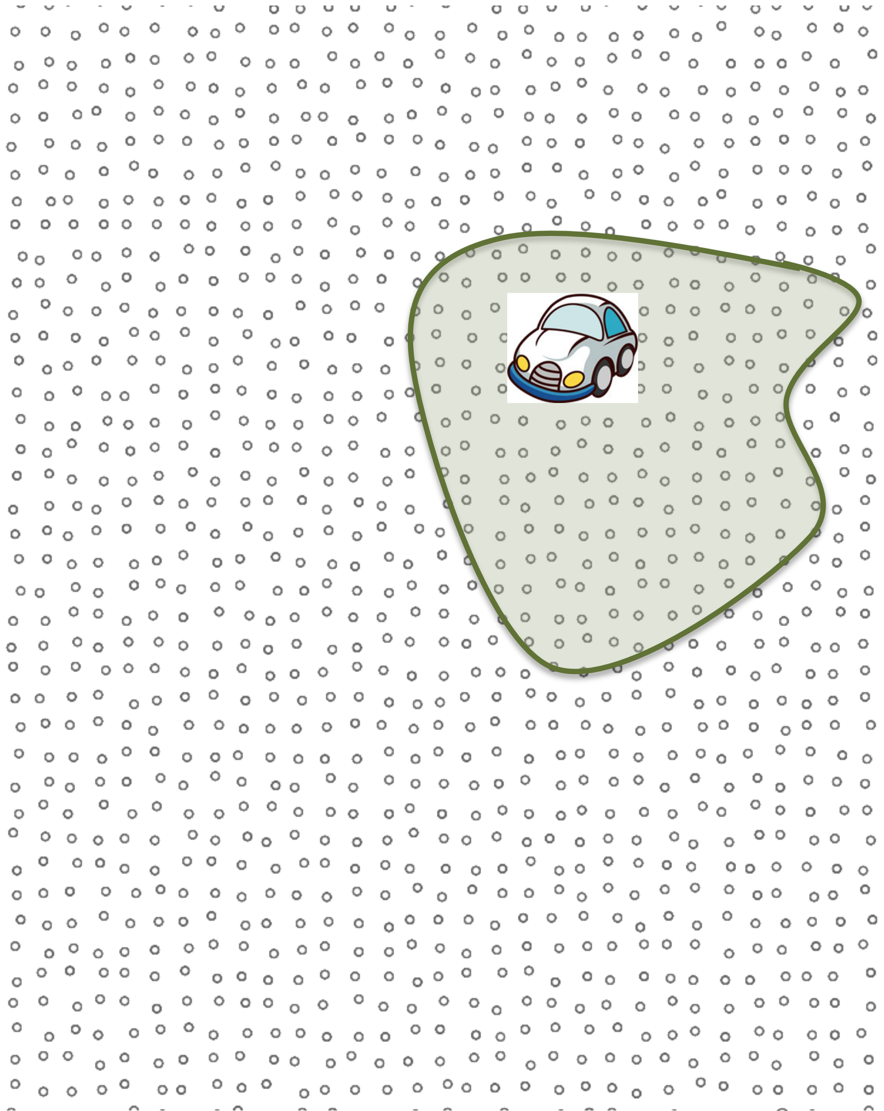
1. **Decentralized**
   – No reporting to server
   – Uses only local communications
2. **Robust to changes**
   – Node failures, link failures, mobility, detection errors, location errors..
3. **Preserves Privacy**
   – Does not need mobile device identification



Applications

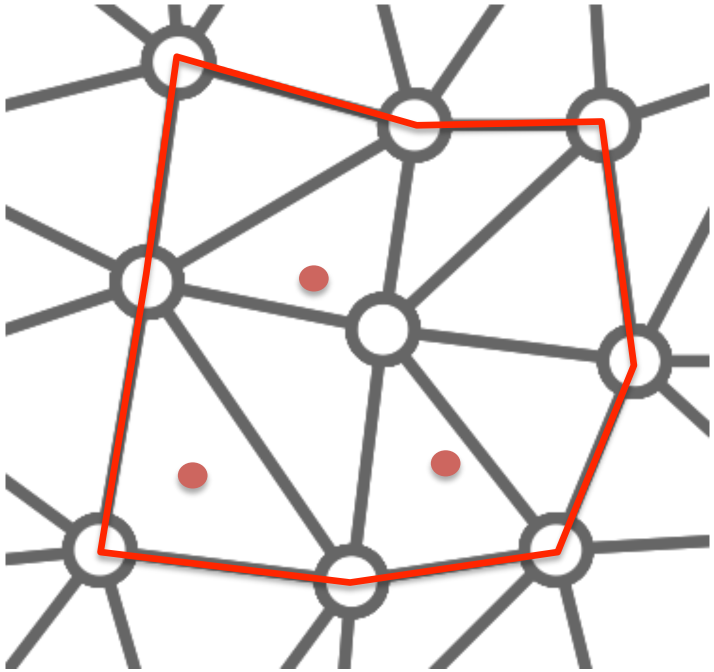
- **Range query:** Find number of objects in any region

- **Tracking :** Find me a nearby taxi



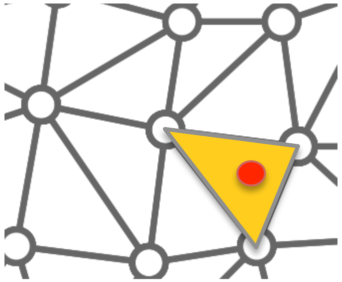
The Technique

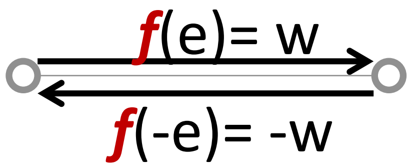
- Find a planar graph
  - [Sarkar et al, 09] [Gao, et al, 01] [Funke, Milosavljevic 07] [Zhang et. al, 08]
- Assign weights to edges of the graph
- Find count by adding weights along the boundary edges



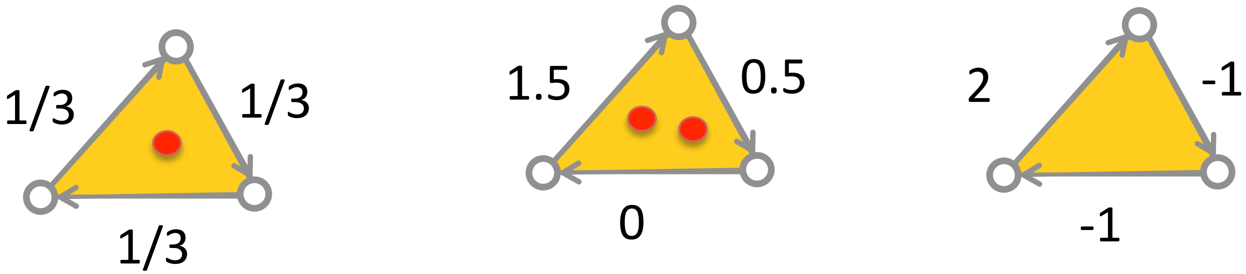
Edge Weights: Differential Form

- Assign "**directed**" weight ***f*** on edges:



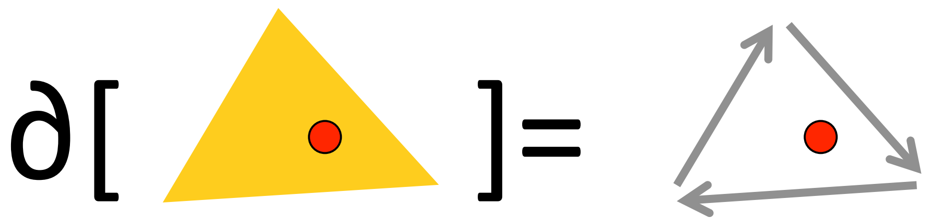


- Sum of weights **clockwise** gives the total weight of targets inside a face:

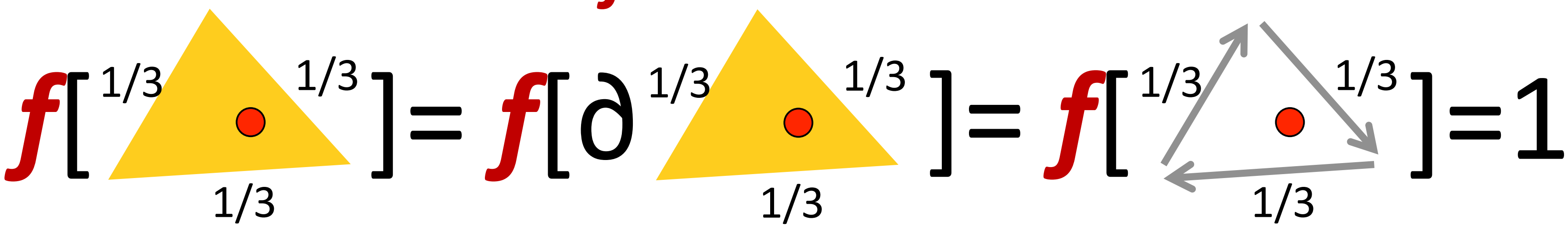


Boundary Operator

- A boundary operator acts on a face and gives the boundary edges in clockwise order.

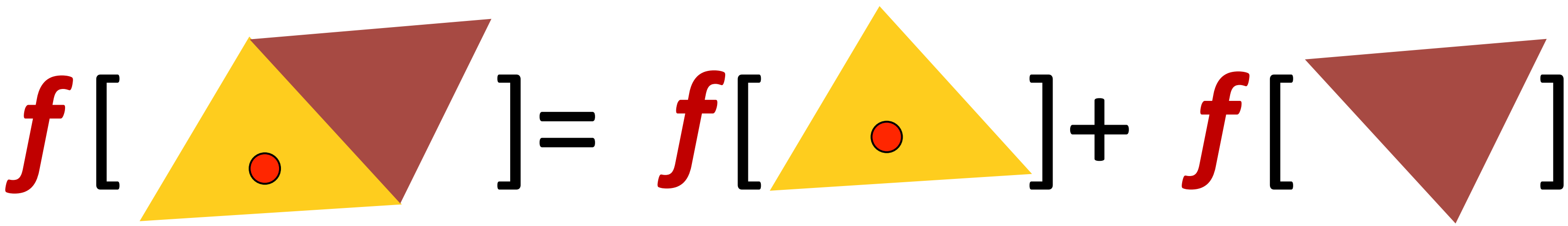


- Use ∂ to extend ***f*** to a face.



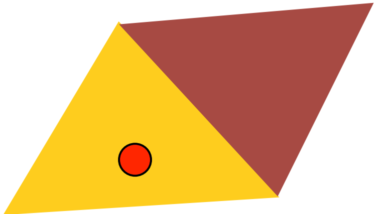
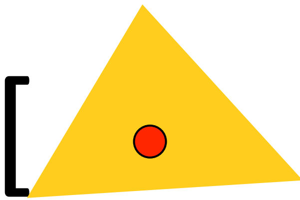
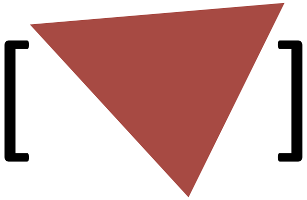
Function on Regions

- Function on a union of faces.



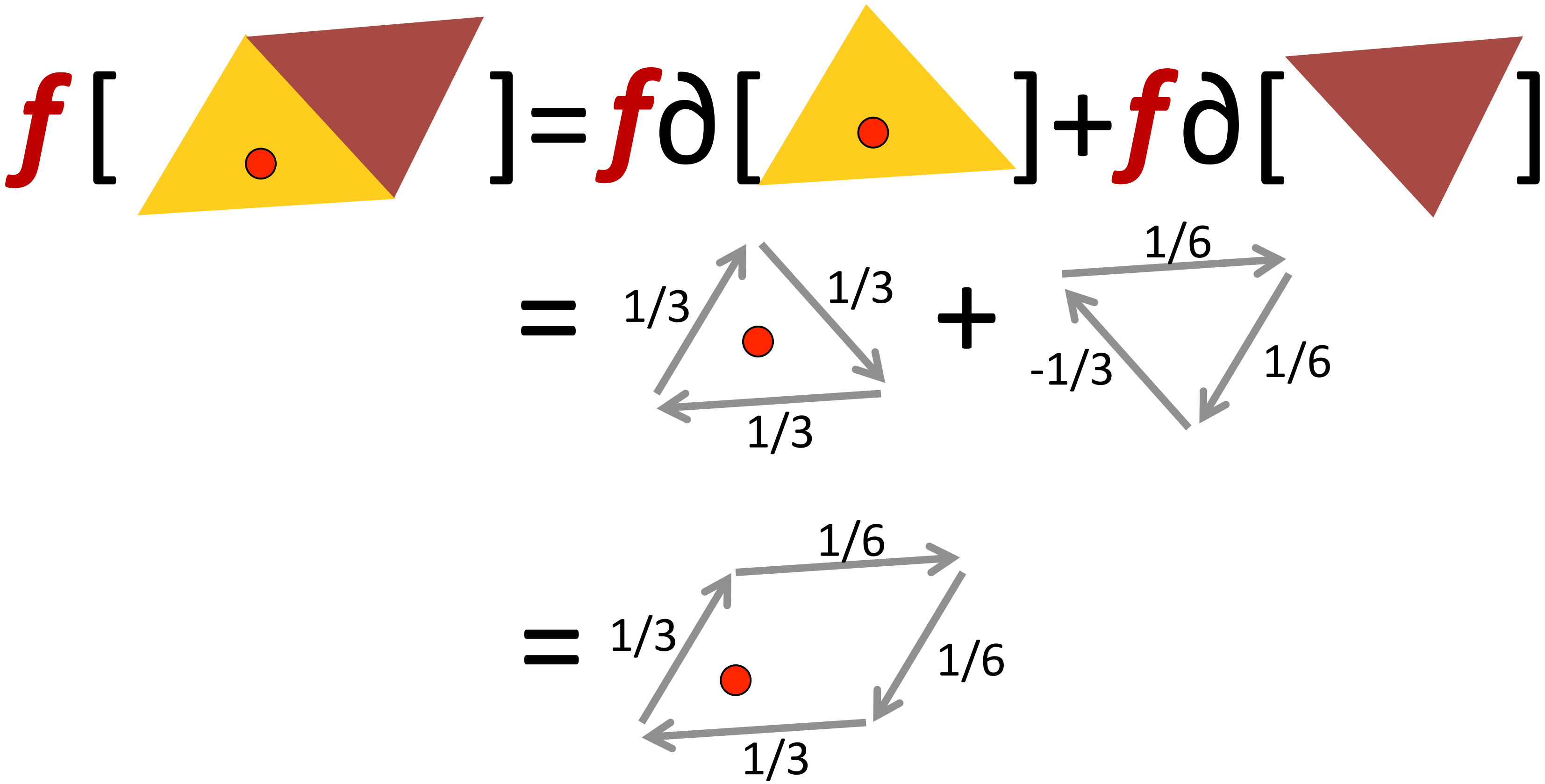
Function on Regions

- Function on a union of faces.

f [] = ***f***∂[] + ***f***∂[]

Function on Regions

- Function on a union of faces.

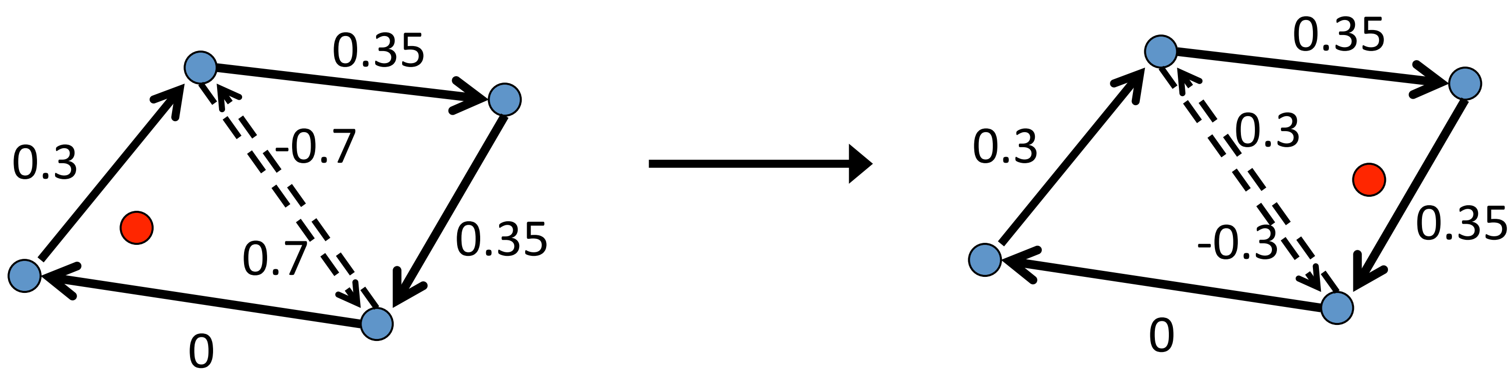


Differential Tracking Form for Range Queries

- Theorem: the total weights of targets inside a region **R** is the sum of edge weights of **∂R**.
  - In symbols: $\boldsymbol{f}$**(R) =** $\boldsymbol{f}$**(∂R)**
- Range query: walk along **∂R** in clockwise order and sum up edge weights.

Update Tracking Form When Targets Move

- If a target crosses an edge e, subtract target weight from ***f***(e).



Communication Cost

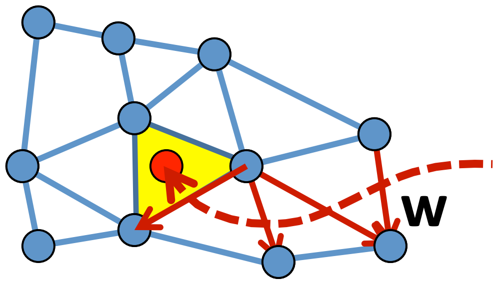
- Assuming static nodes have constant density.

- Update cost = # edges crossed
  = O(distance moved)

- Query cost = # edges on ∂R
  = O(perimeter of R)

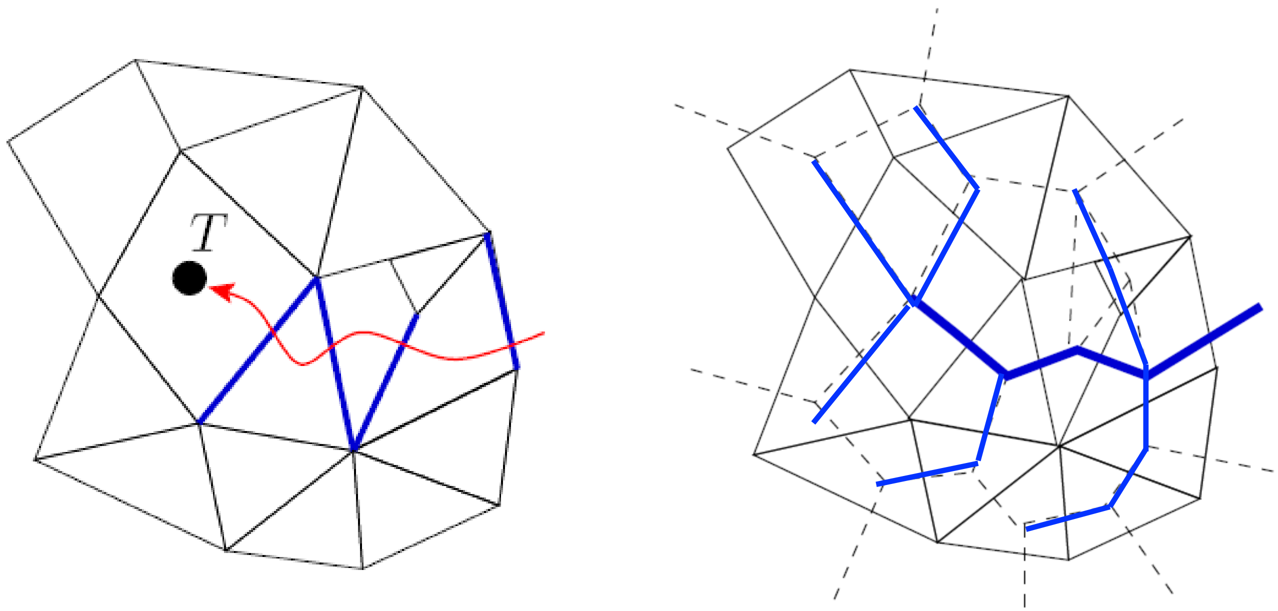
Initializing Tracking Form

- New targets coming into the network
  - Simply update ***f*** when a target comes in.
- For existing targets:
  - Imagine the target enters from the **outer face** along **any path**.



Initializing Tracking Form

- Take a spanning tree of the dual.
- Imagine each target has moved along the path from the outer face
- The weight on each dual edge is assigned to the corresponding primal edge
- Total communication cost for initialization =O(n)

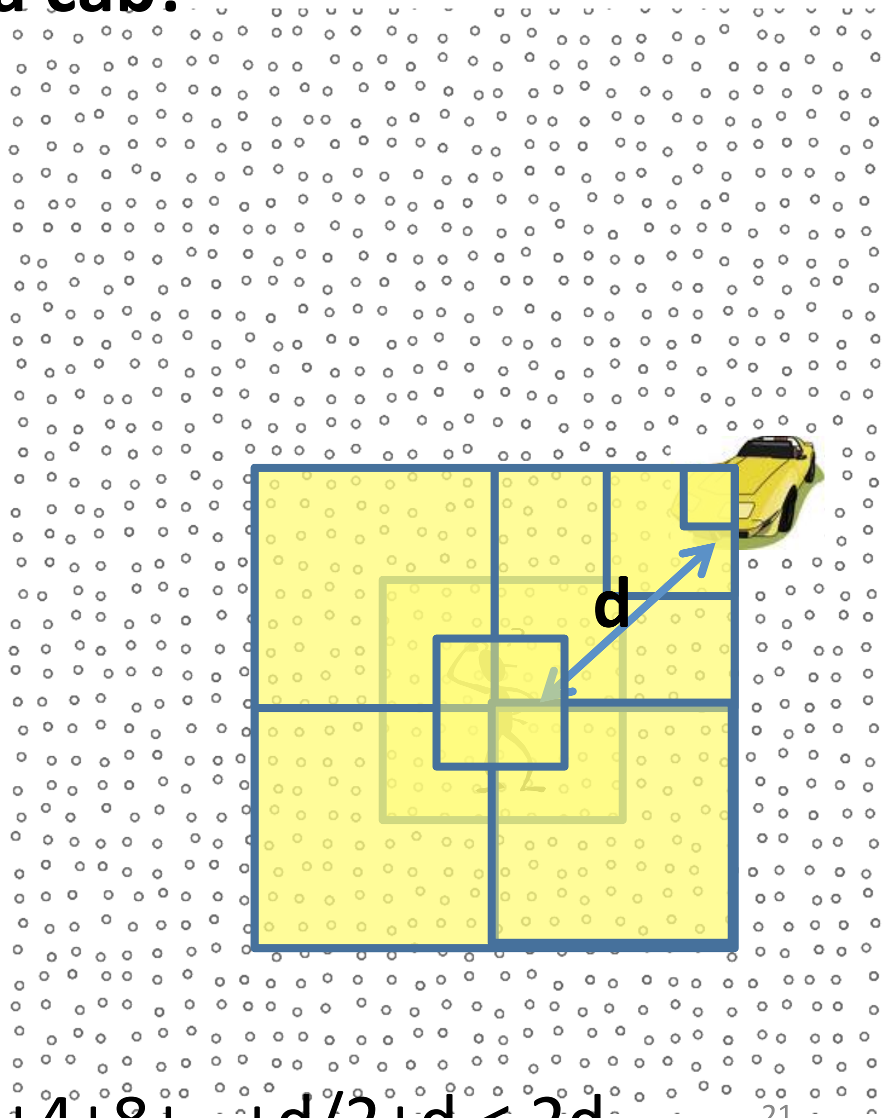


Using Range Queries for Target Tracking

Find me a cab!

1. **Exponentially expand the range**
   - Stops when the range contains a cab
2. **Recurse & refine**

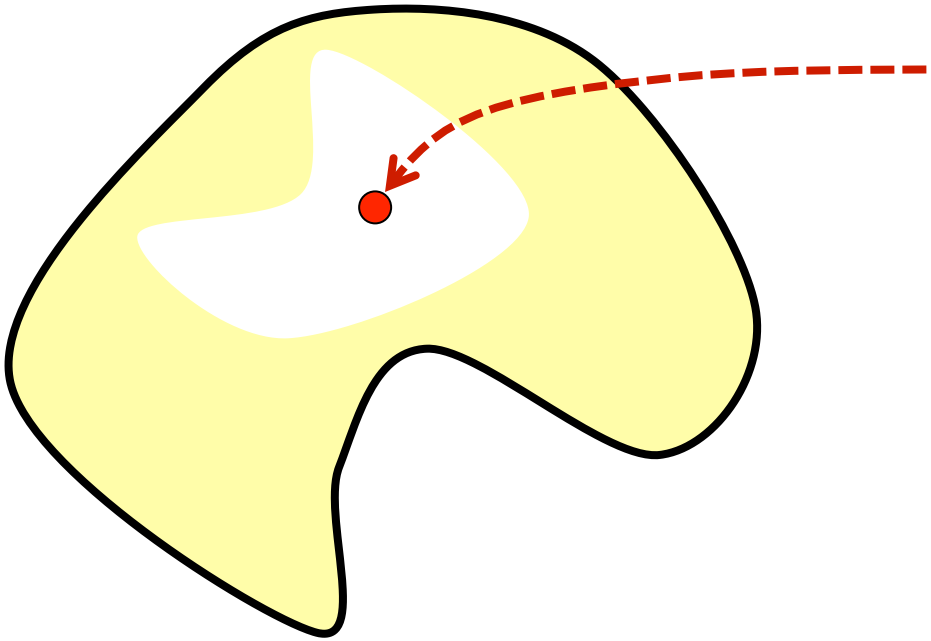
- Total cost =O(d)
- Distance sensitive queries



1+2+4+8+…+d/2+d < 2d

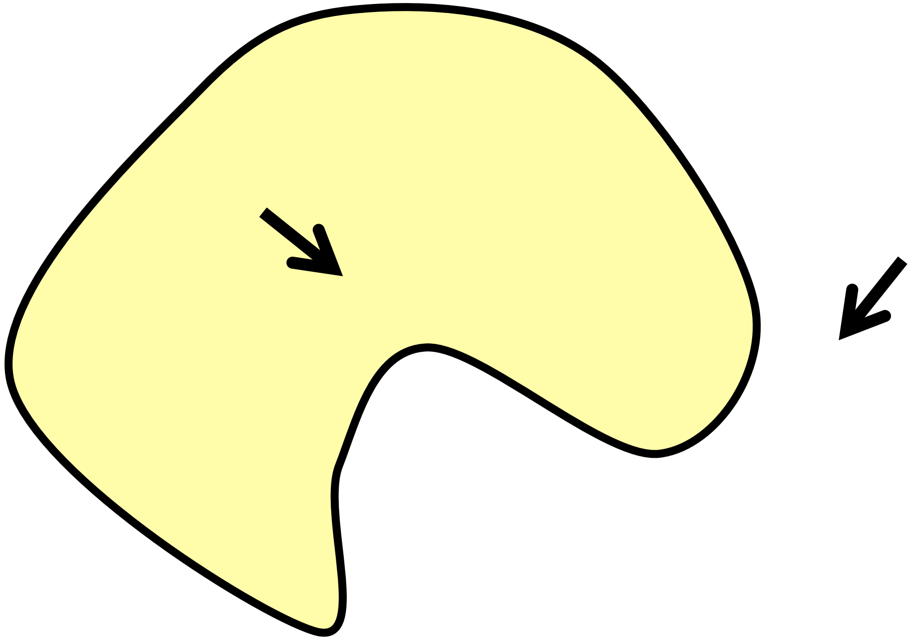
Robustness to Coverage Holes

- A target can be lost in the hole but range query still returns correct results!



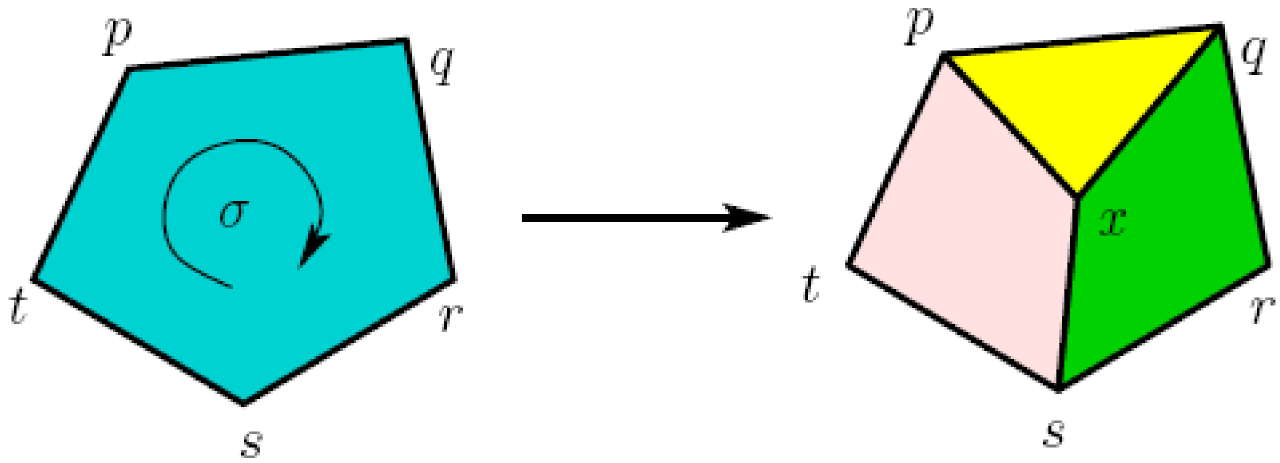
Robustness to Link or Node Failures

- A link failure or node failure in the interior or exterior of R does not affect the query result.



Robustness to Node Insertion

- Node insertion: refine the current face and give proper weights to the new edges.
- The weight of existing edges are not affected.



Tracking with Mobile Sensors

- Sensors can move.
  - Maintain the planar graph.
    e.g., [Karp Kung 2001] [Gao, et al, 01]
  - When a sensor crosses an edge, Insert it into new face

Privacy

- We do not need node ids
- Only detect when ‘someone’ crosses edge

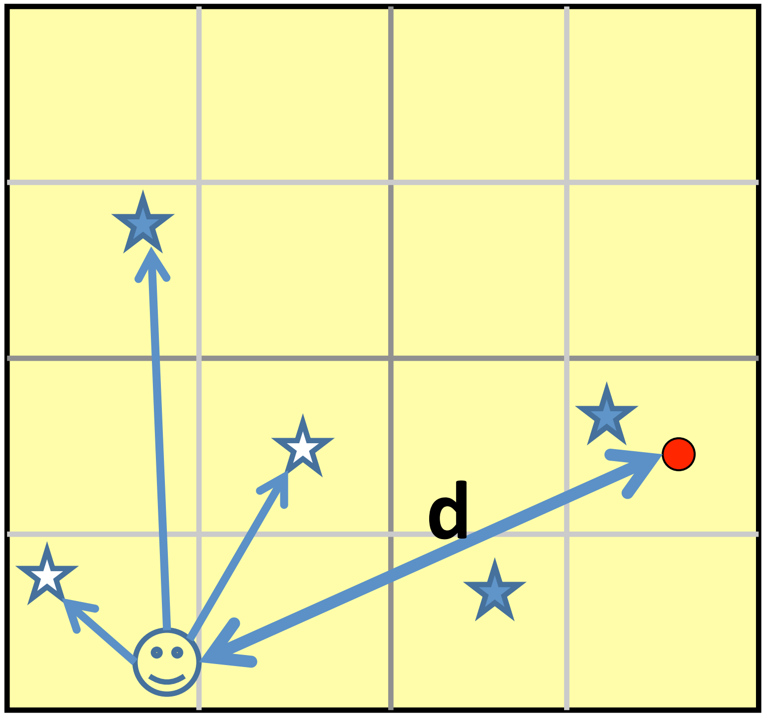
- Do not follow the movements of individuals

Range Query of Continuous Data Fields

- Sensors monitor a temperature field.
- Treat each sensor reading as a target with certain weight.
- Apply the same scheme.

Comparison with Location Services

- LLS [Abraham etal 2004]
  - Used to find individual mobile targets
  - Use a hierarchy of location servers



Location is stored at the server for the square containing the mobile device at each level.

Query goes to the location server at each square containing the query node.

Query cost : O(d)

Differential Forms v.s. LLS

Designed for aggregates
And range query

Designed for
finding individuals

- Range query cost

  Differential forms << LLS
- Query individual targets

  Differential forms ≈ 2 · LLS

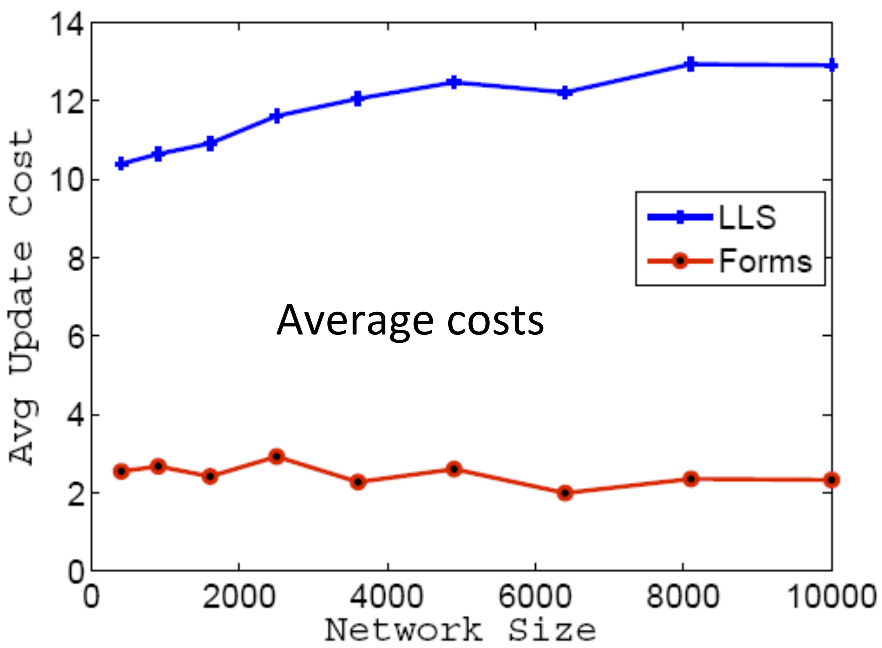
- Update cost

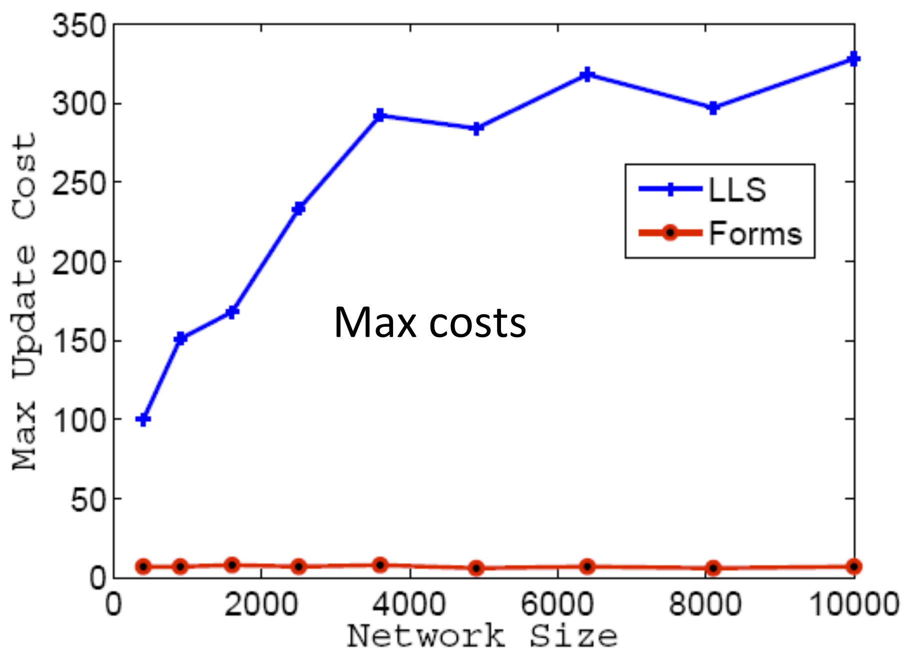
  Differential forms << LLS

  O(d) v.s. O(d log d)

Update Costs

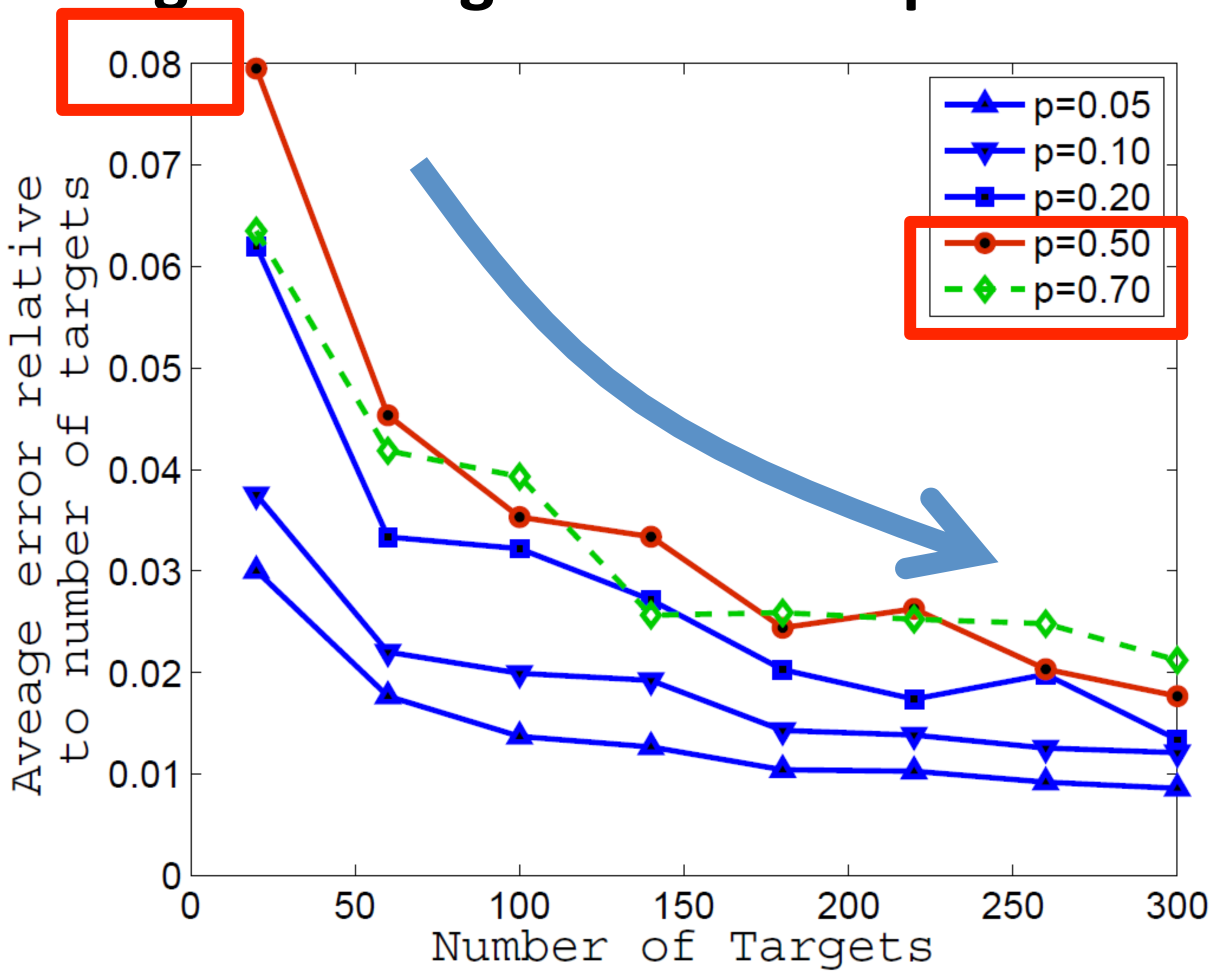
- The target moves one unit randomly per time unit --- discrete Brownian motion.
- LLS higher avg cost, some moves are expensive.





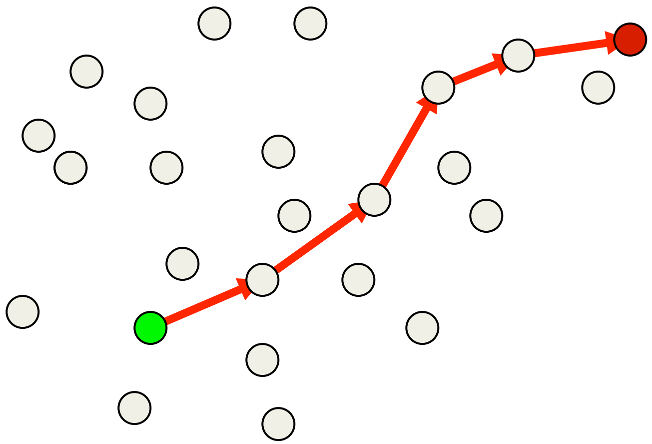
Robustness to Crossing Errors

Each edge crossing missed with probability p



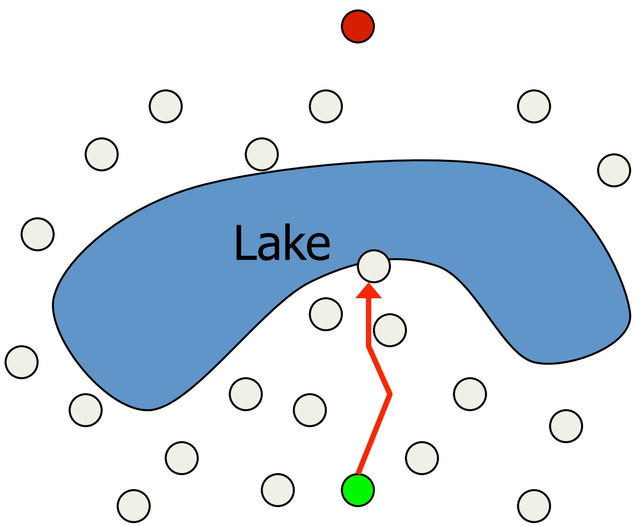
Part II: Greedy Routing

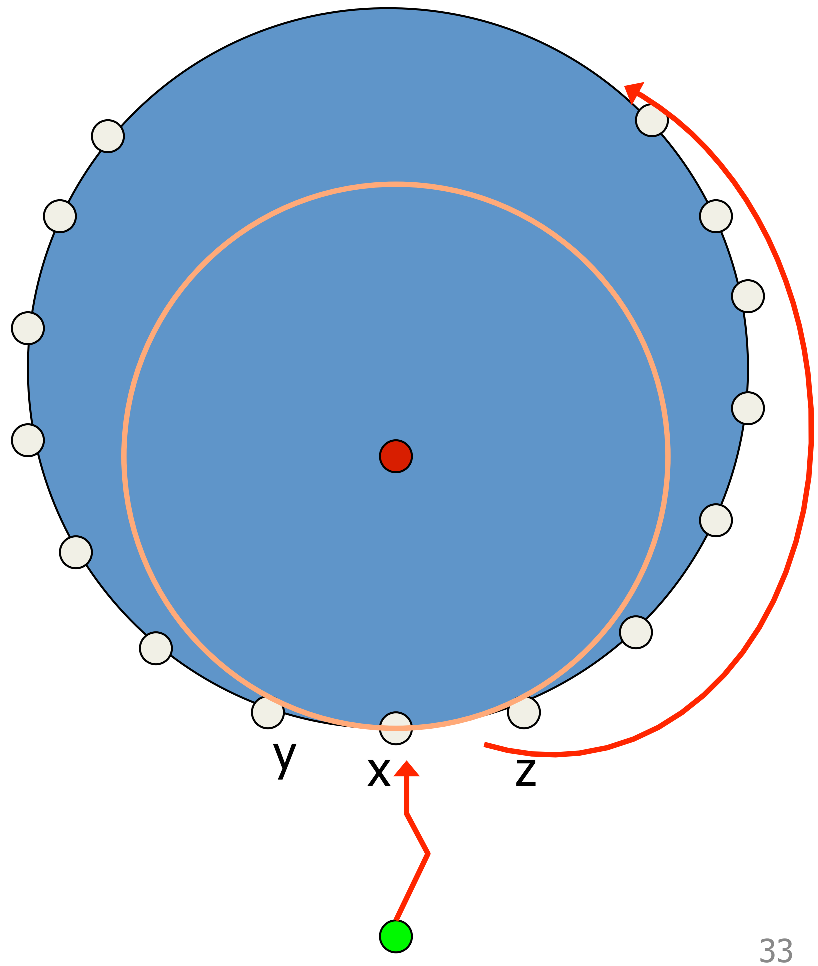
- Assign coordinates to nodes
- Message moves to neighbor closest to destination
- Simple, compact, scalable



Greedy routing may get stuck

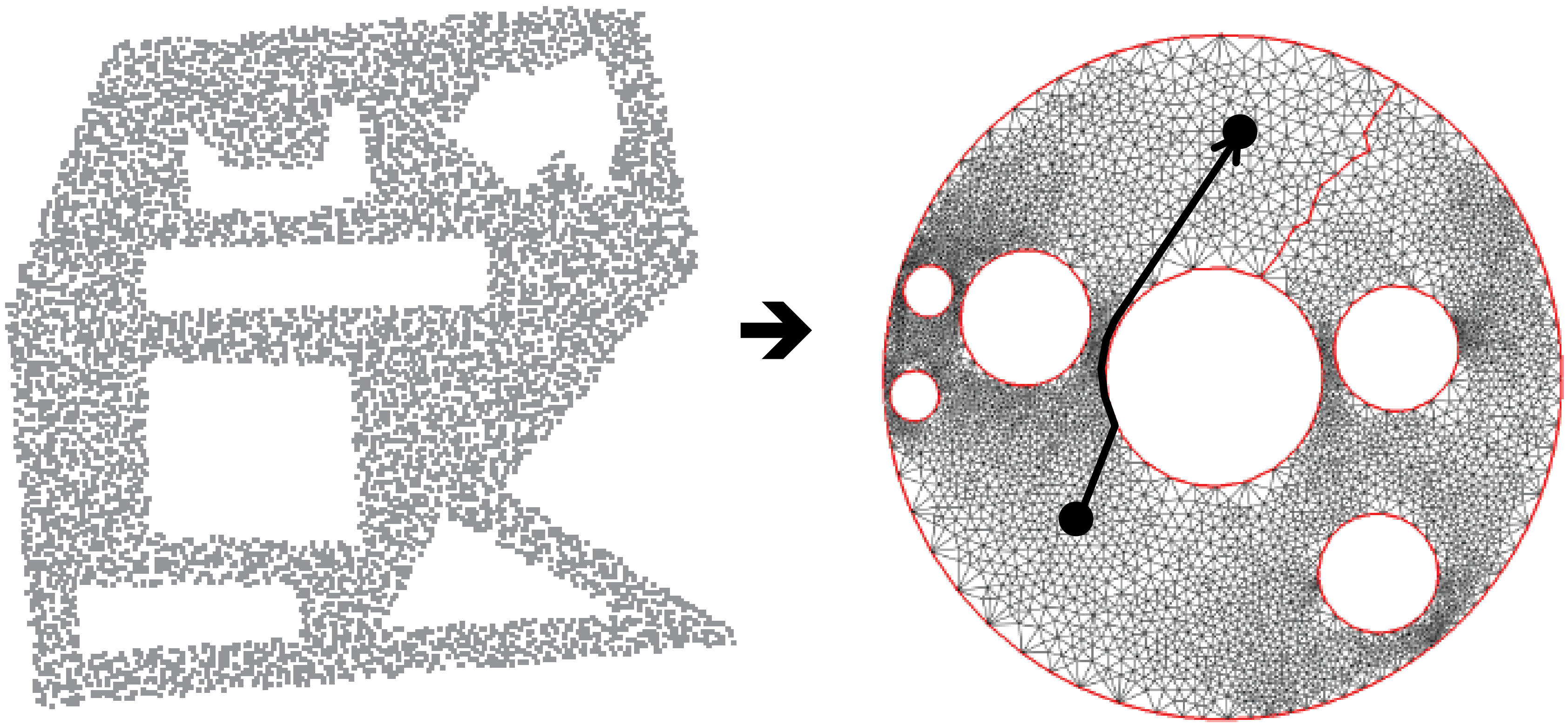
- “Holes” in network





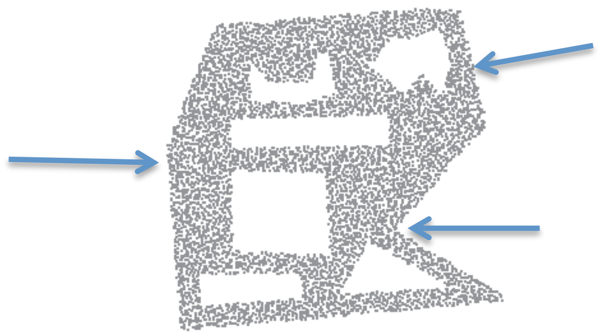
Make all holes circular

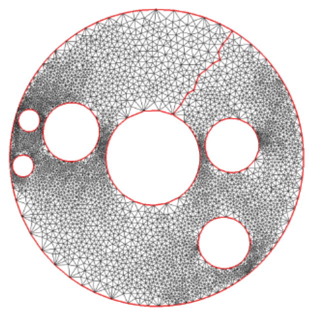
- Virtual Coordinates
- Greedy routing does not get stuck at holes.



Network Simplification by Curvature Flow

- Different parts have different curvatures

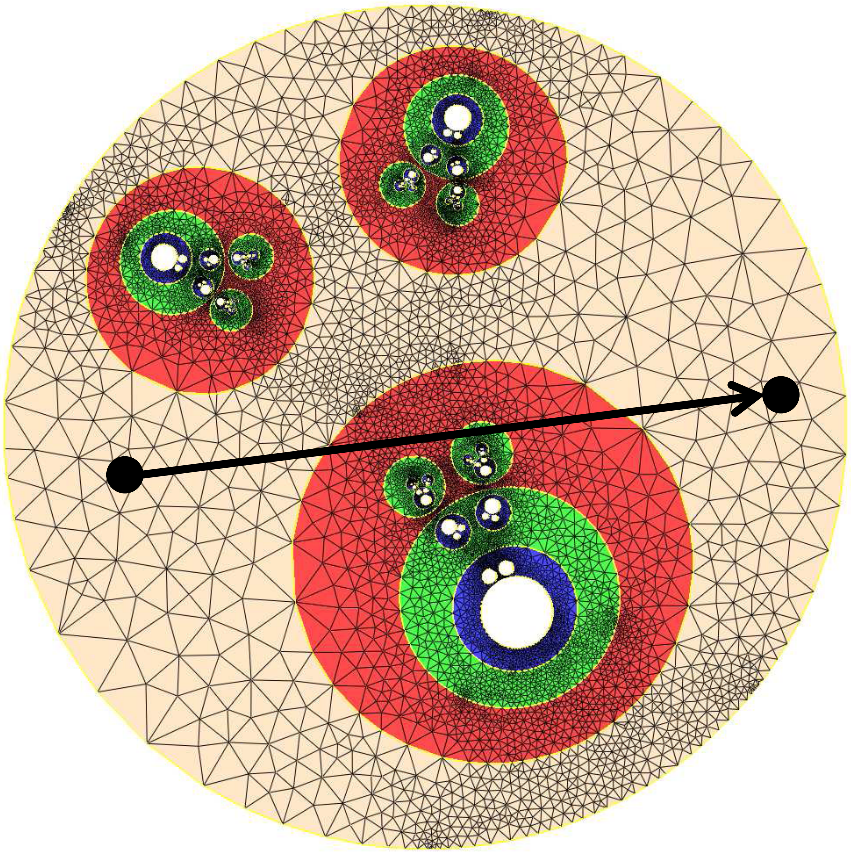




- Let curvatures diffuse to desired values
- Get a simple shape
  - Routing Works
  - Easy to describe network
  - Easy to apply location based algorithms

Use covering space, tile up the domain

- Greedy routes cut through the holes and do not overload boundary.



Other Topics

- **Contour Tracking, Queries**
- **Gossip, Diffusion**
- **Security, Surveillance, Wormholes**
- **Data Storage and retrieval**
- **Social/Complex Networks**

Summary

Use locations, computational geometry.

- Information processing
- Mobility management
- Communication

Thank you!