Covering Space for In-Network Sensor Data Storage

Rik Sarkar*, Wei Zeng†, Jie Gao*, Xianfeng David Gu†

Department of Computer Science
Stony Brook University †

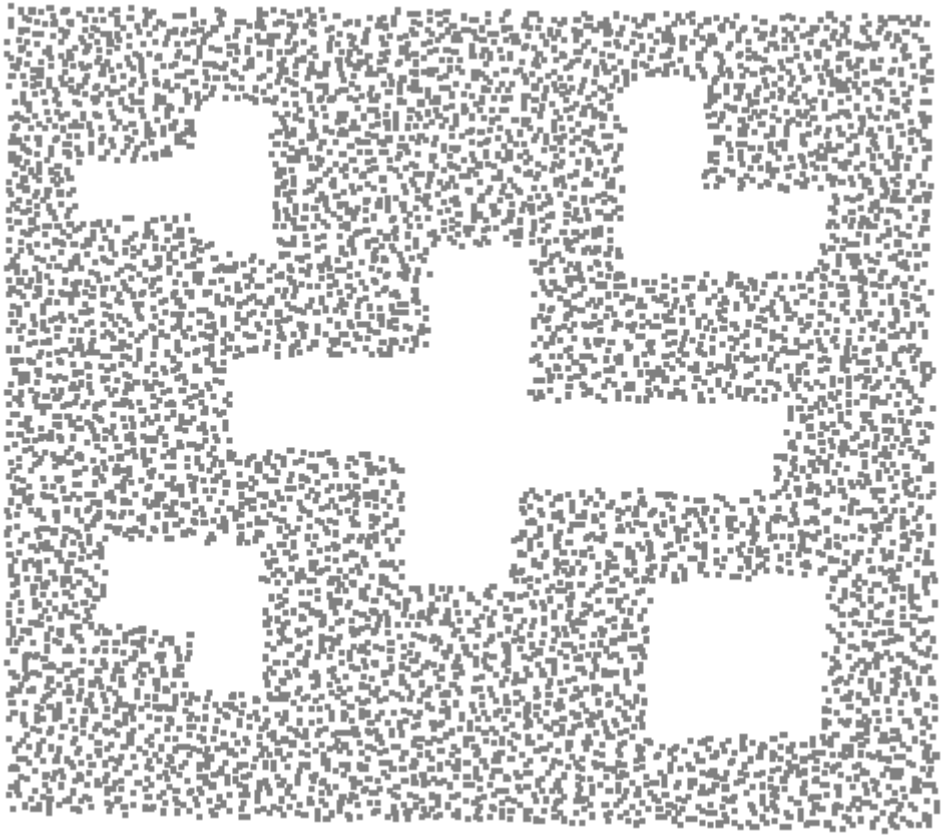
Department of Computer Science
Wayne State University *

by Sietse Au

In network data storage

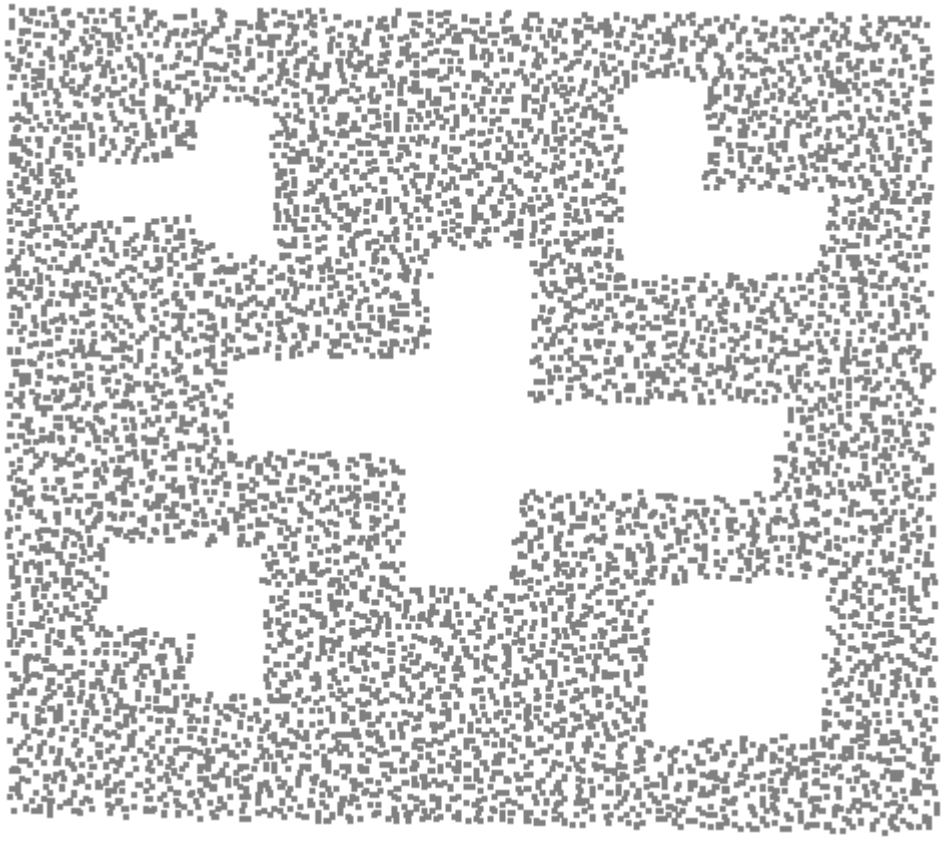
- Storing data in a network
  - Geographical Hash Tables
  - Double rulings
- Routing
  - Greedy routing
- Balance load throughout network

In network data storage



In network data storage

- Geographic Hash Table
  - Holes in network graph
  - Data accumulates at nodes around hole



Content

- Covering space
- Two mathematical transformations
  - Ricci flow
  - Möbius transform
- Applications of covering space & simulations
  - Network storage
  - Load balanced greedy routing

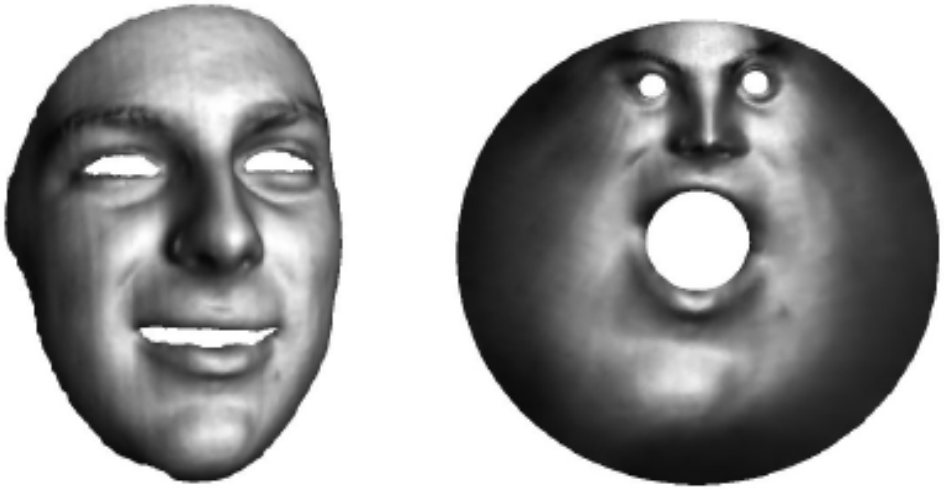
Covering space through Ricci Flow and Möbius transforms

- Virtual coordinates

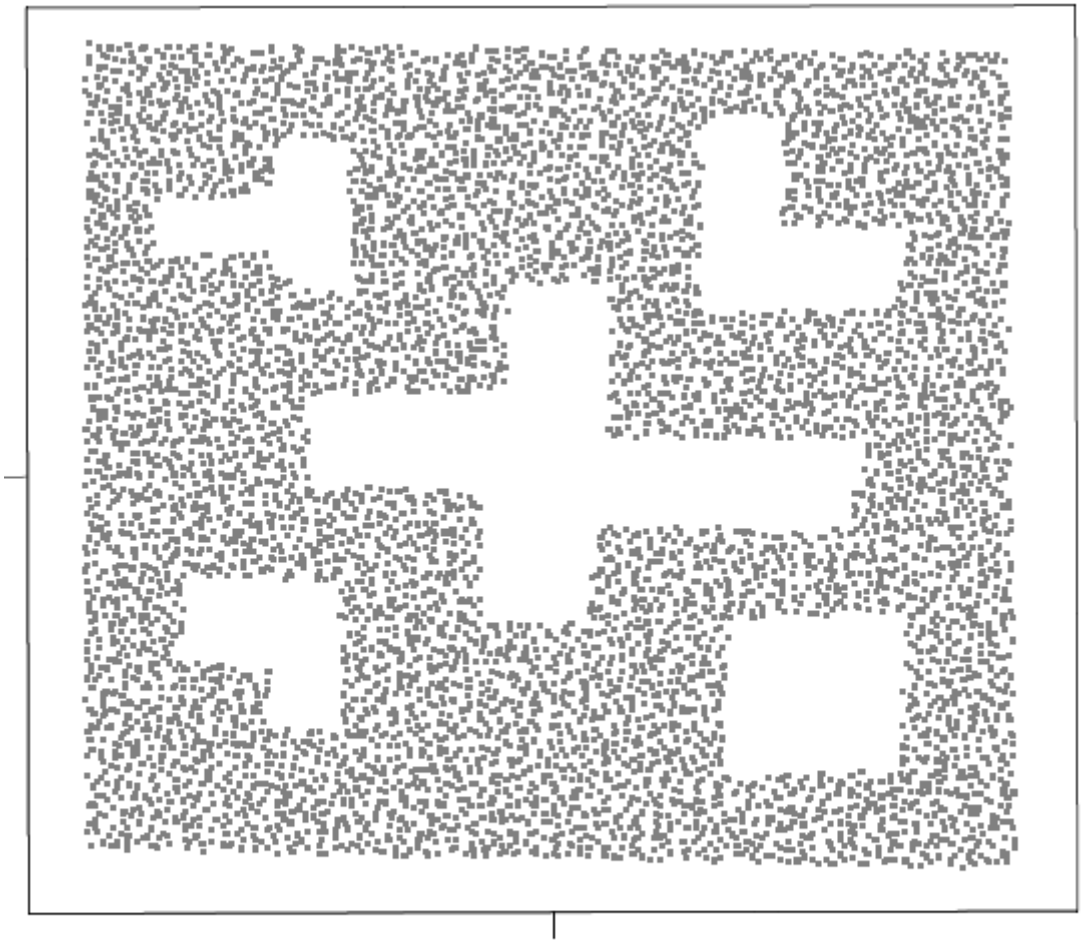
- Ricci Flow
  - Create a unit disk with circular boundaries
- Möbius transform
  - Reflecting the unit disk inside circular boundaries

Ricci Flow

- Assume that this works
- Transformation with a predefined curvature

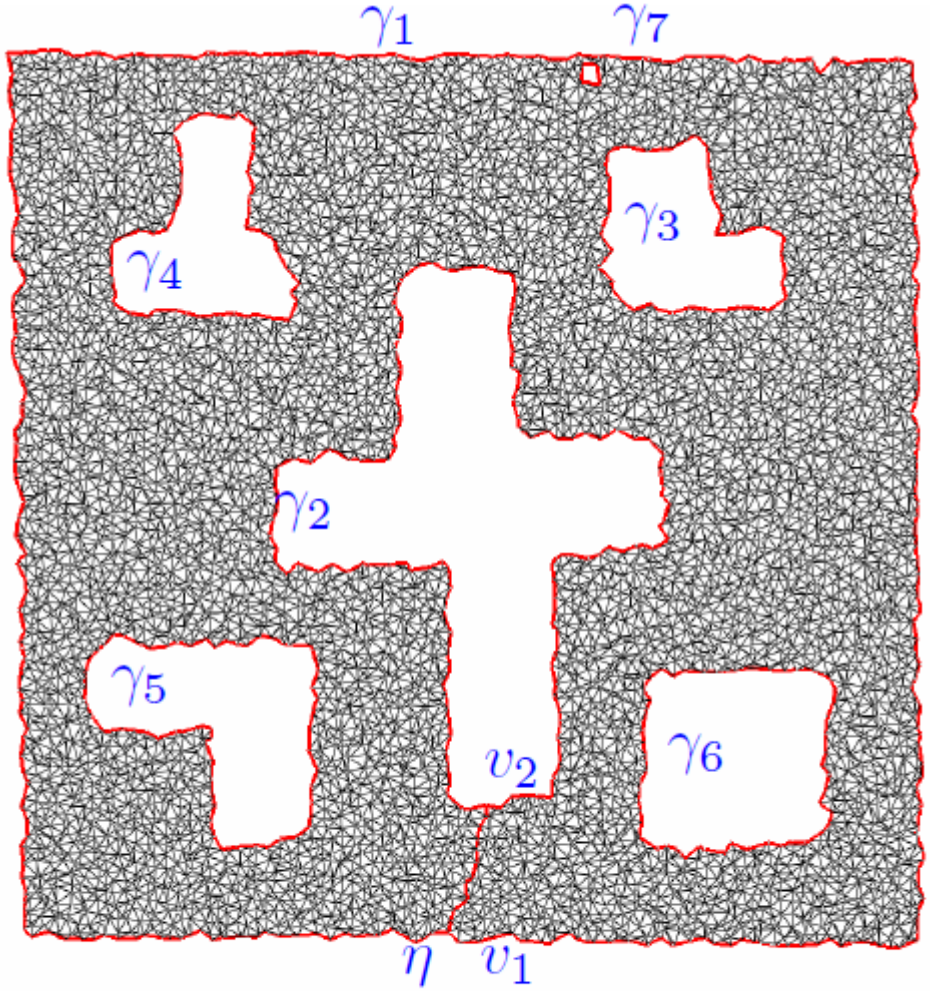


Ricci Flow



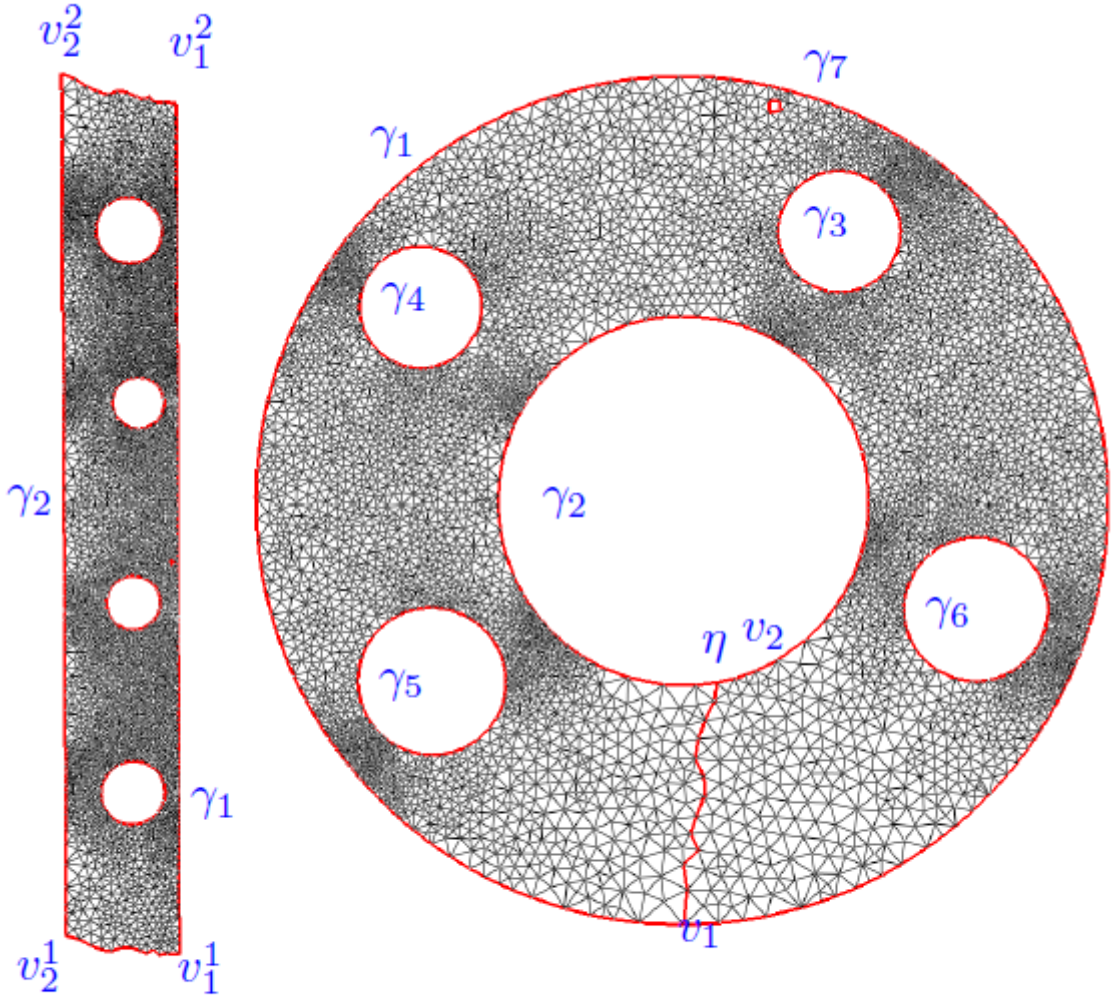
(a) Nodes

Ricci Flow



(b) Triangulation

Ricci Flow

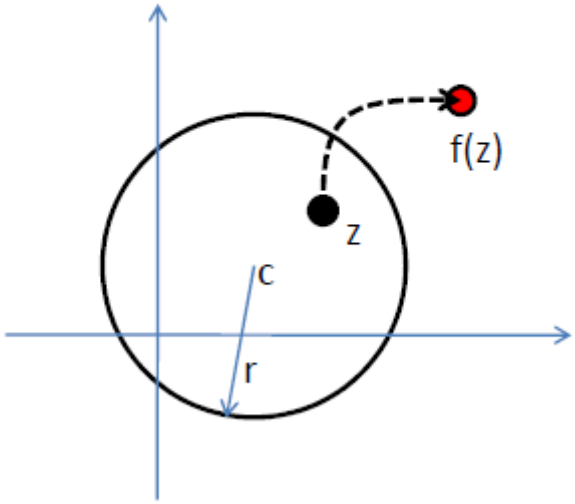


(c) Virtual Coordinates

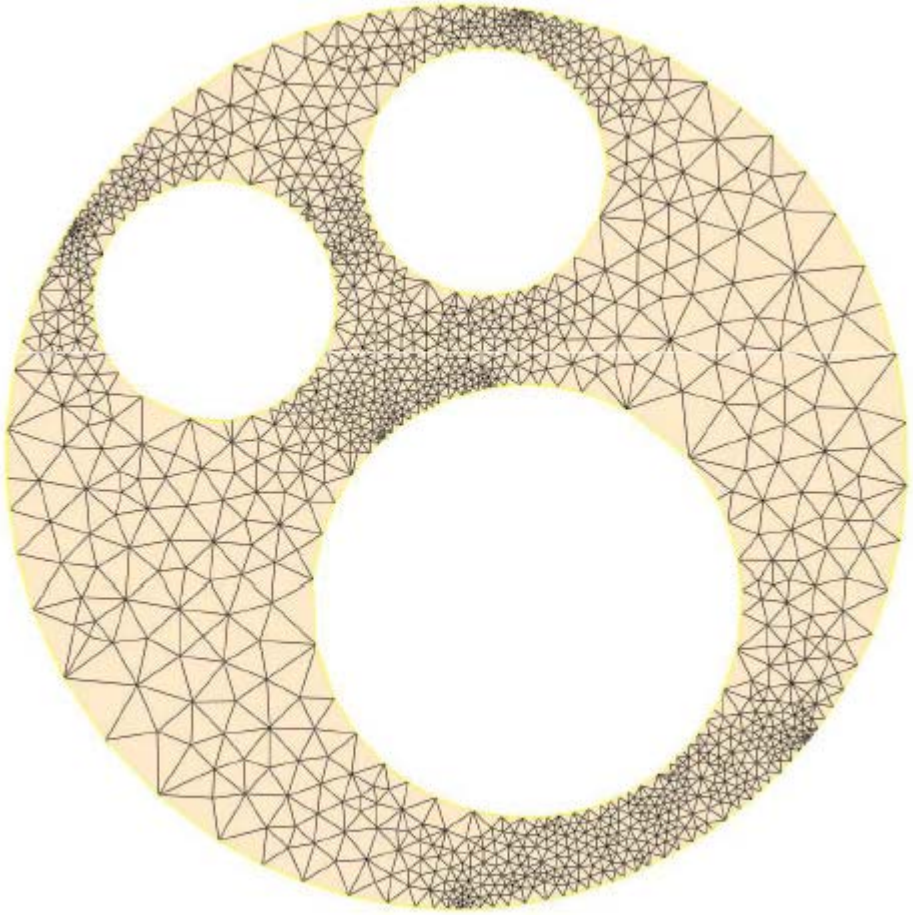
Reflections using Möbius transform

- Circular reflection
- Maps points inside a circle with center c and radius r to points outside of the circle.

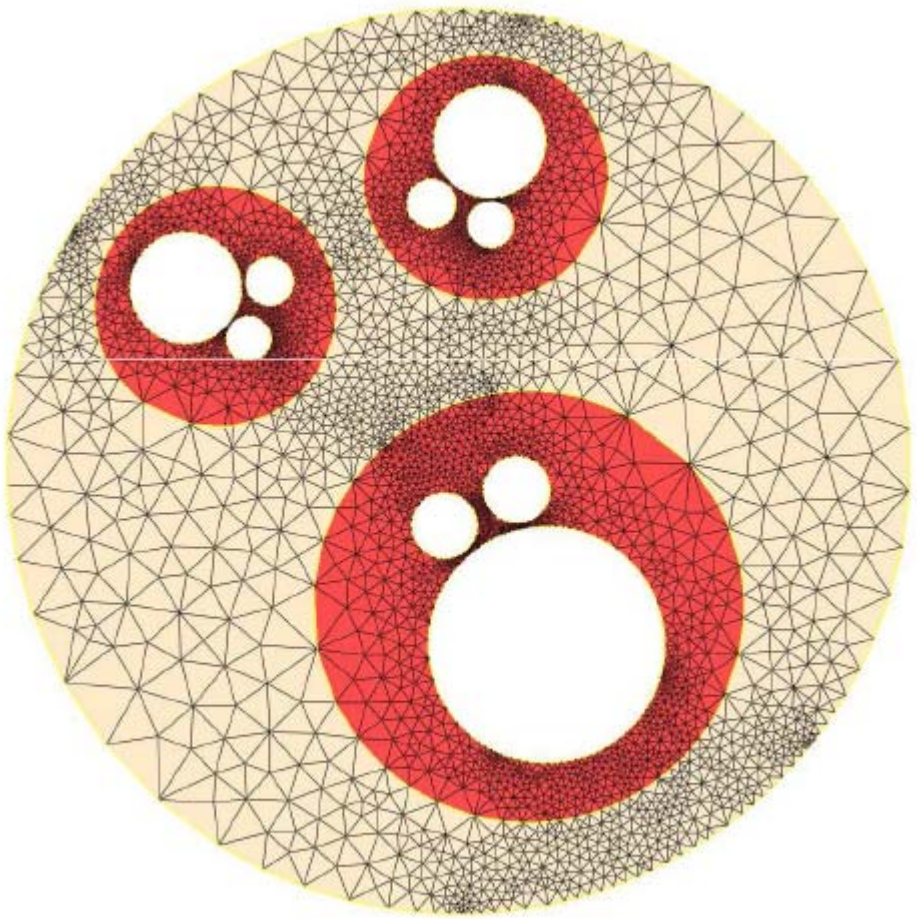
$$f(z) - c = \frac{r^2}{z - \overline{c}}$$



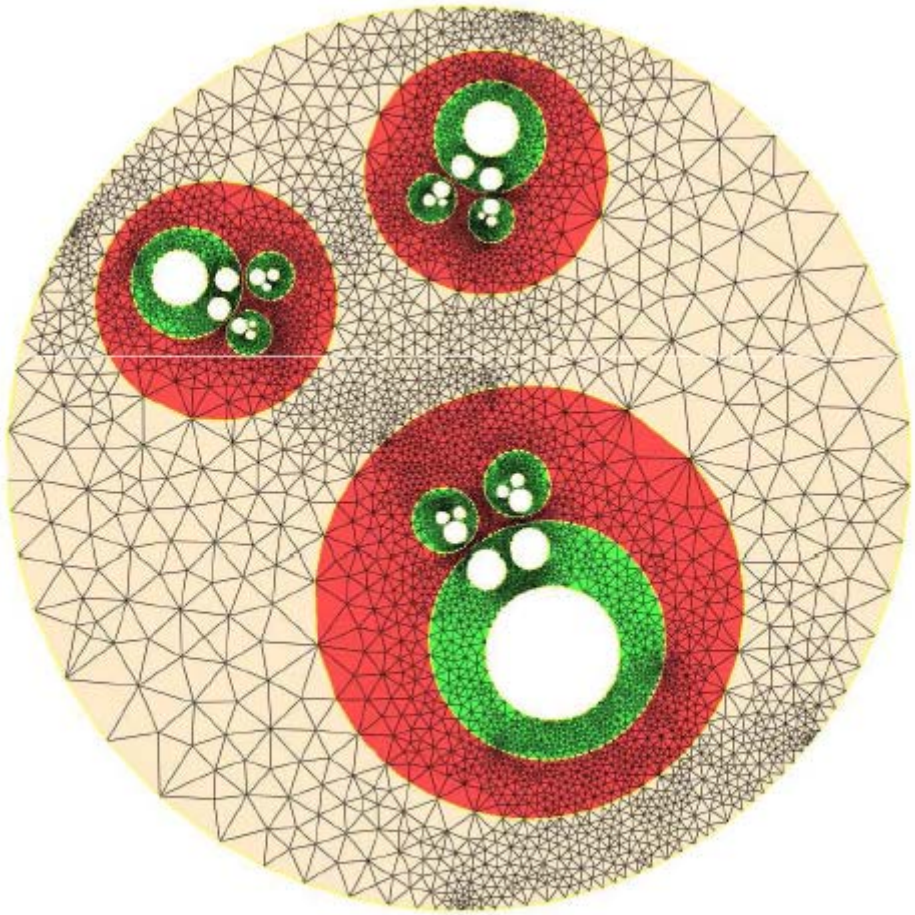
Reflections using Möbius transform



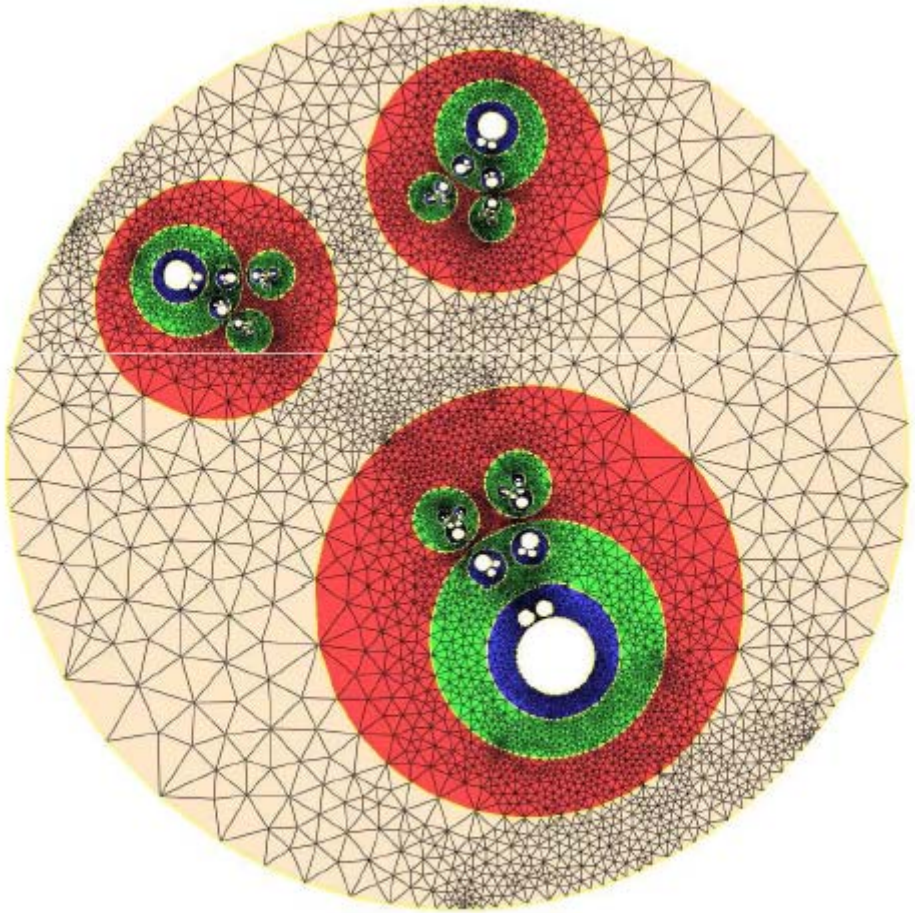
Reflections using Möbius transform



Reflections using Möbius transform



Reflections using Möbius transform

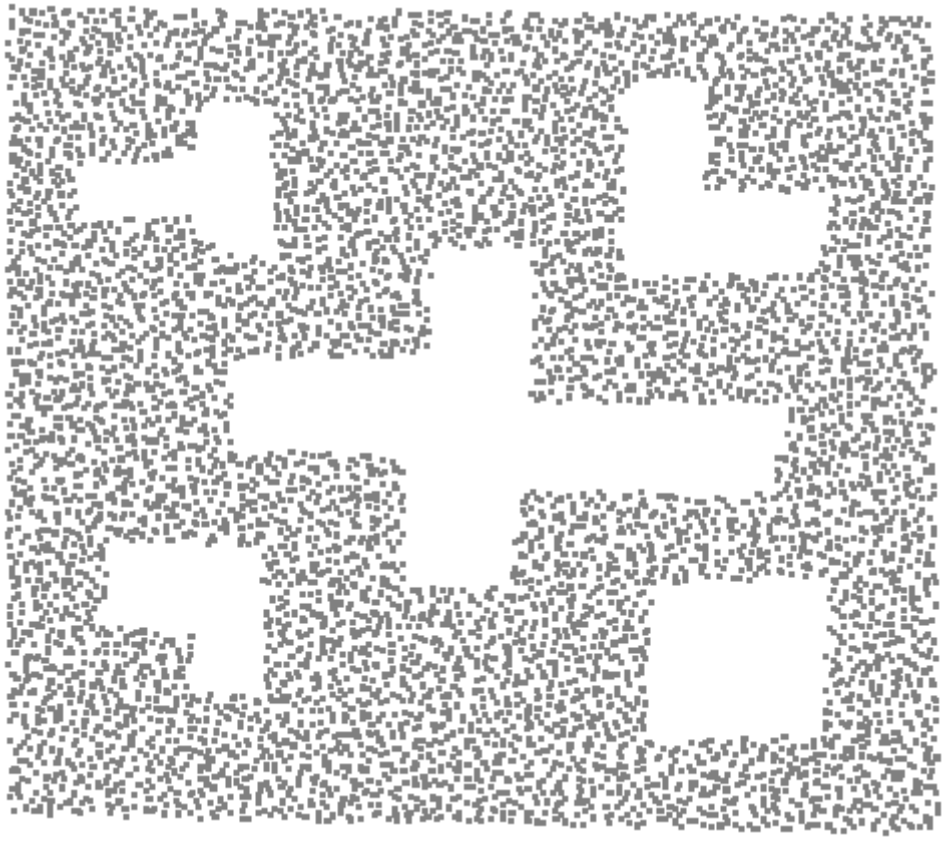


Applications

- Geographical Hash Tables
- Double Rulings
- Load balanced greedy routing

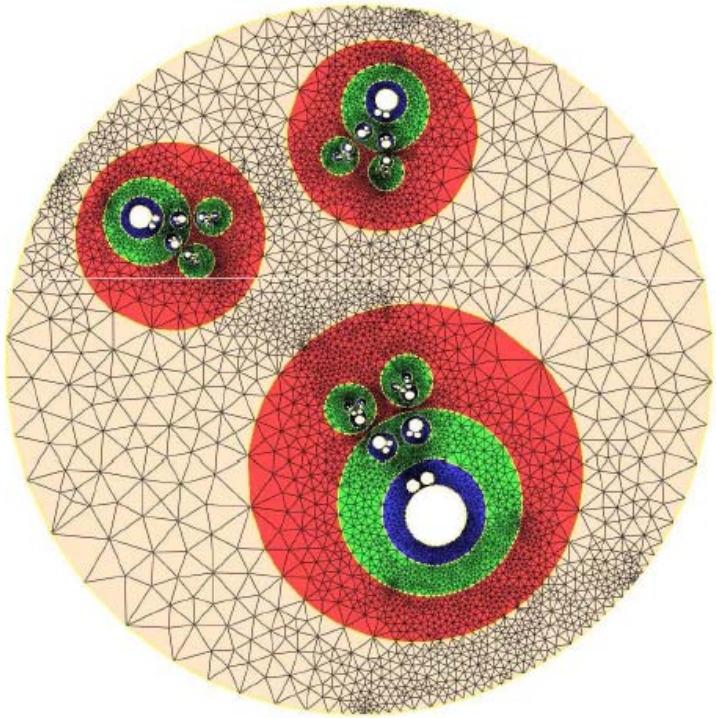
Geographical hash tables

- Maps a value to a geographica location
  - Holes are a pain
  - Nodes die faster due to increased load

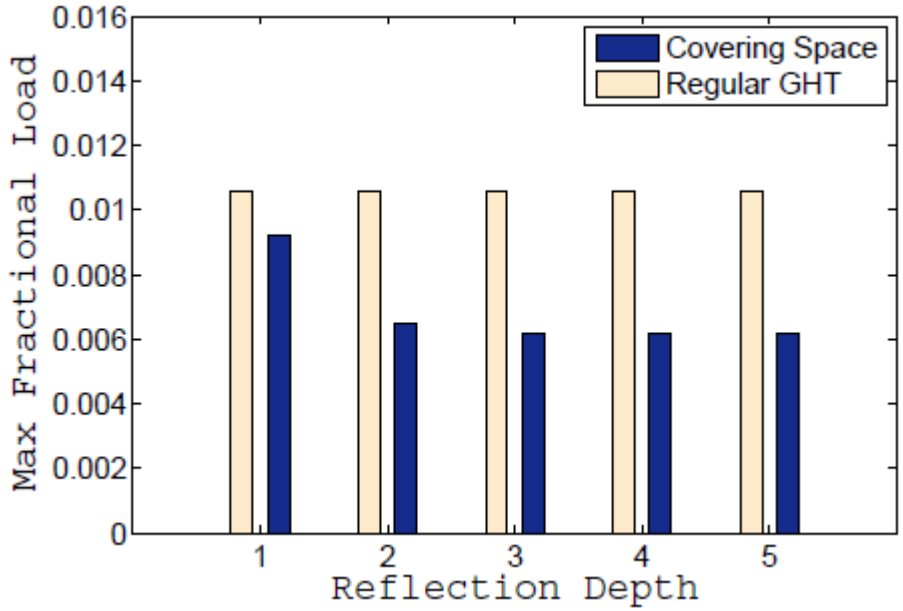


Geographical hash tables

- Balancing the load with a covering space
- Locations in holes are mapped to elsewhere



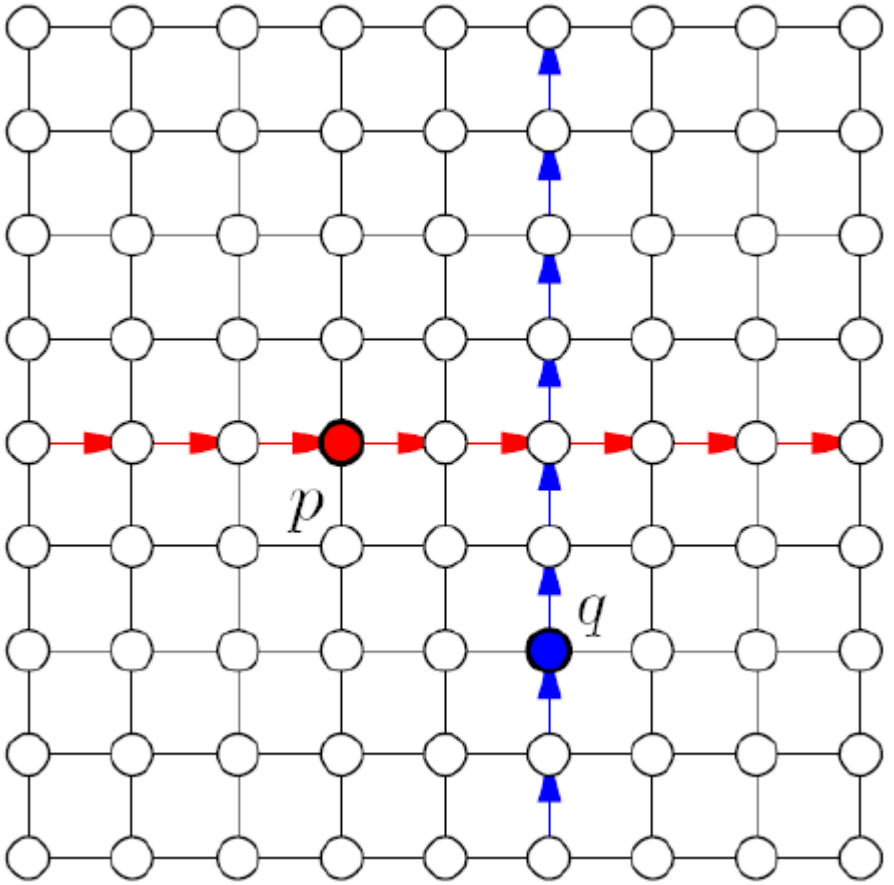
Geographical hash tables simulation result



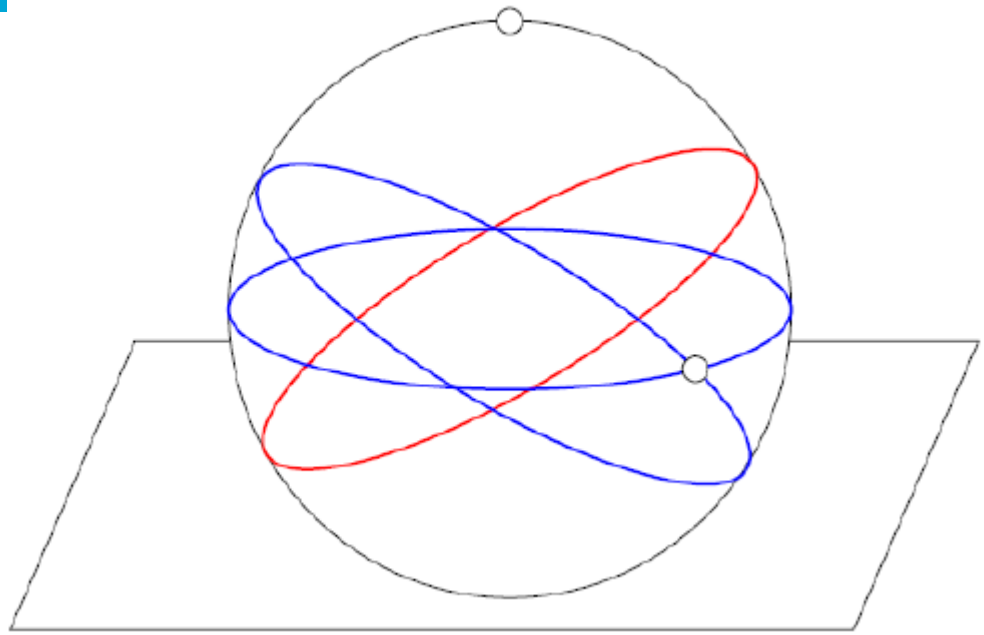
Maximum fractional load converges to a constant factor

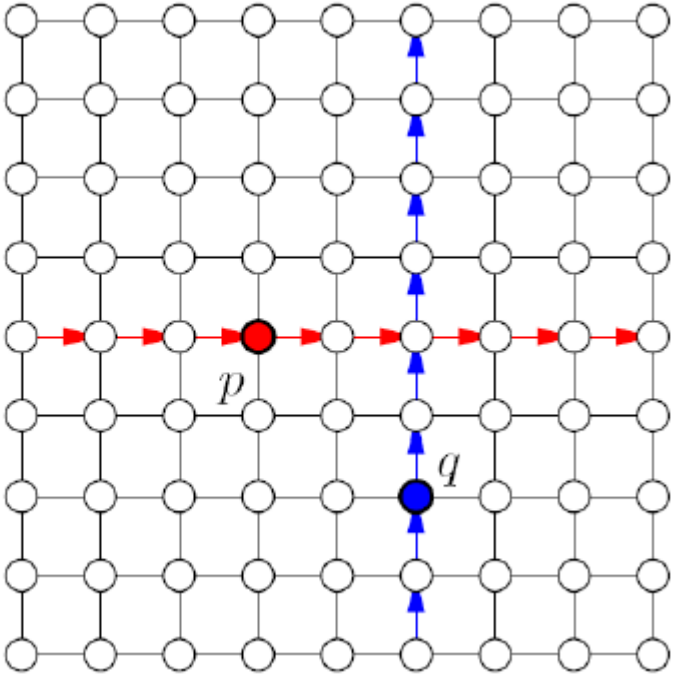
Double ruling

- Consumer
- Producer

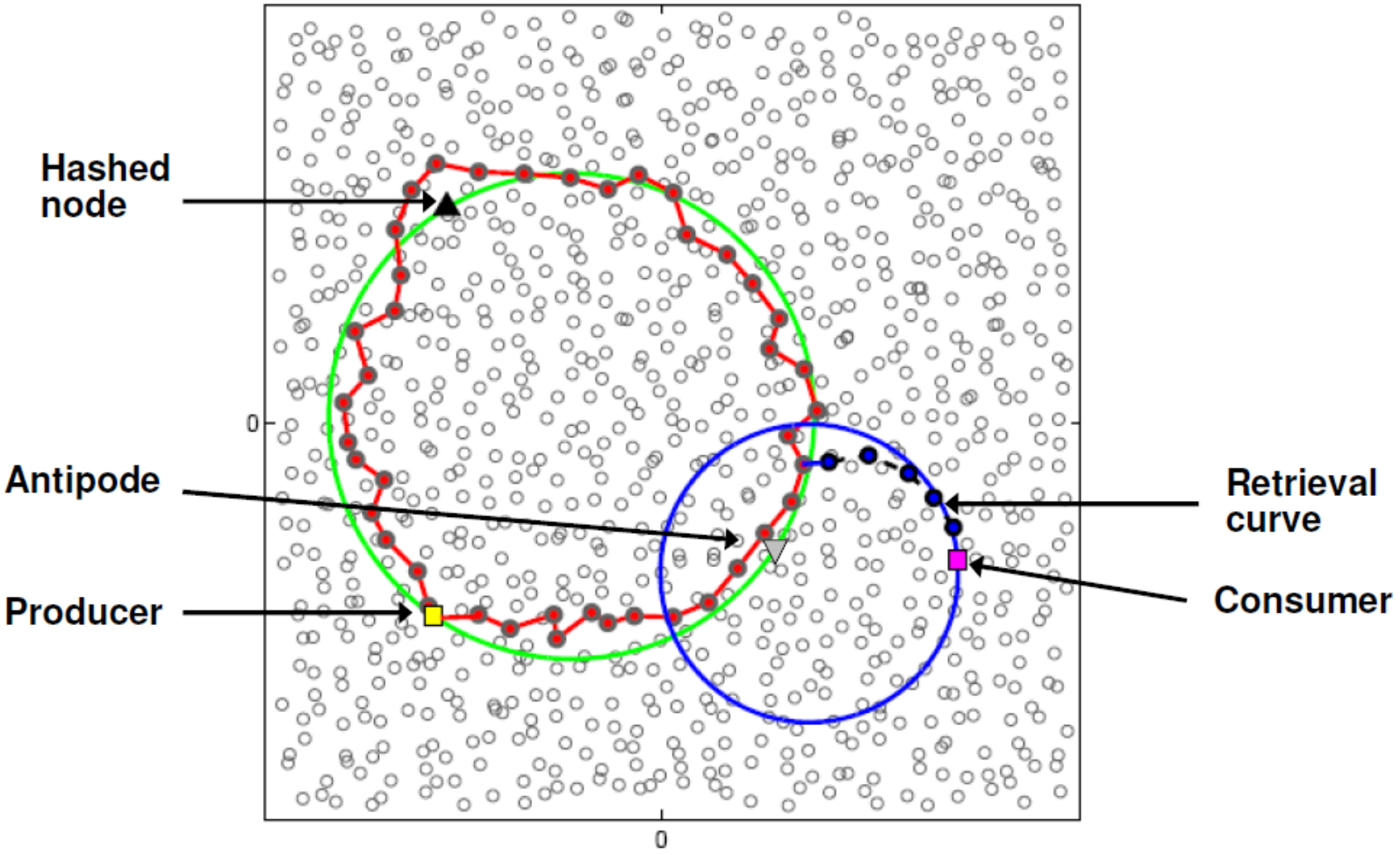


Double ruling in covering space

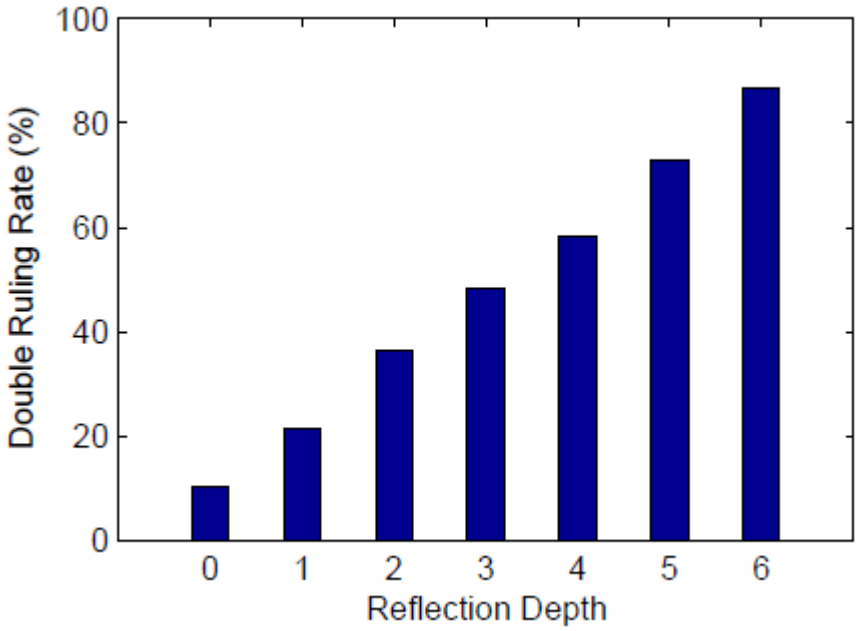




Double ruling in covering space

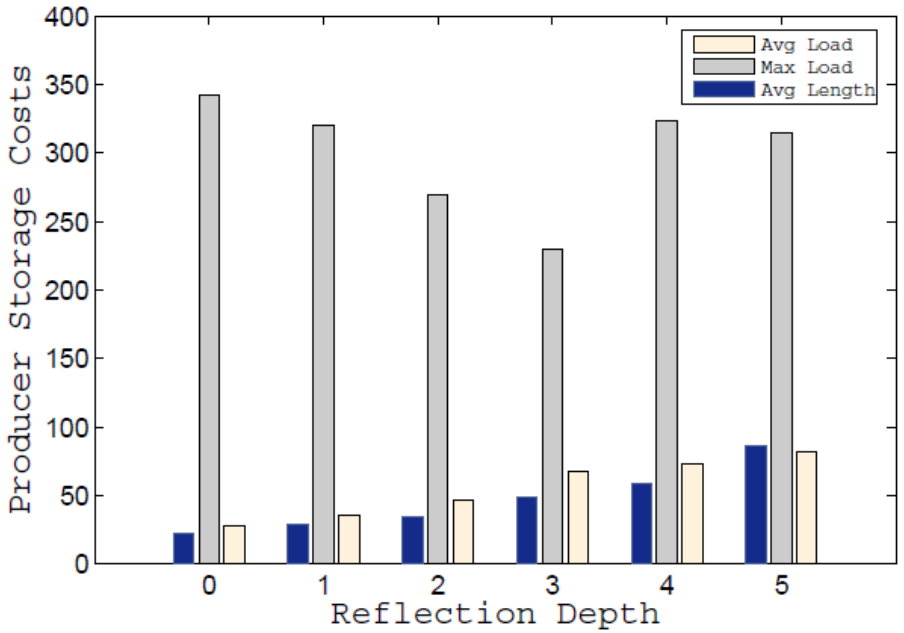


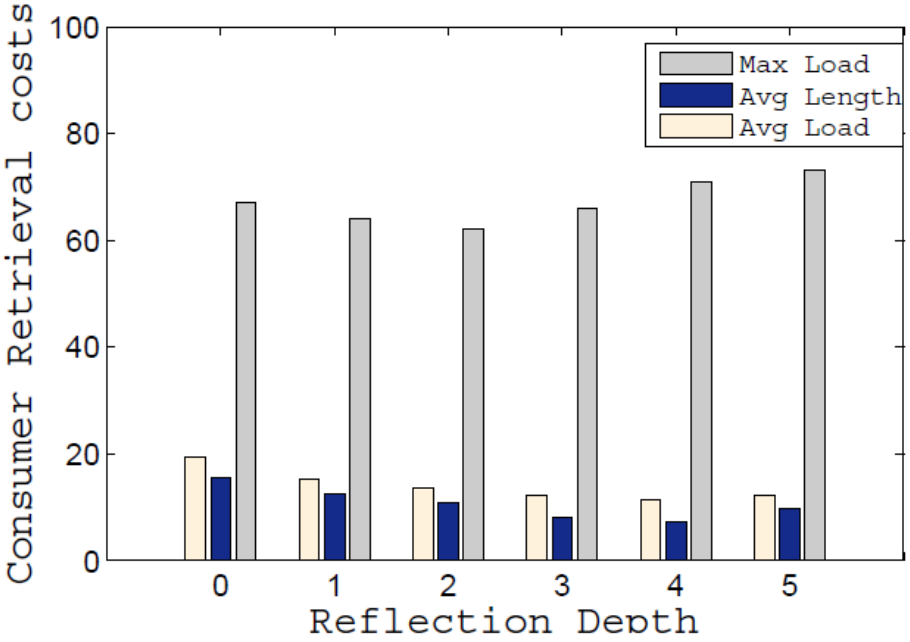
Double ruling simulation results



Higher double ruling rate by increasing reflection depth

Double ruling simulation results

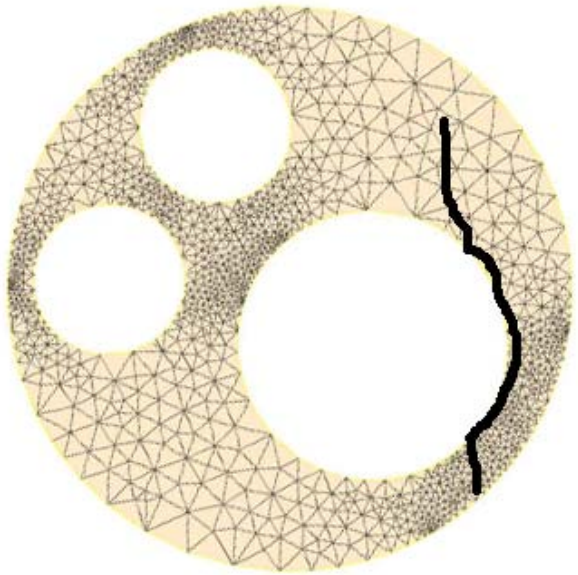




Storage production cost is high, but retrieval costs are low

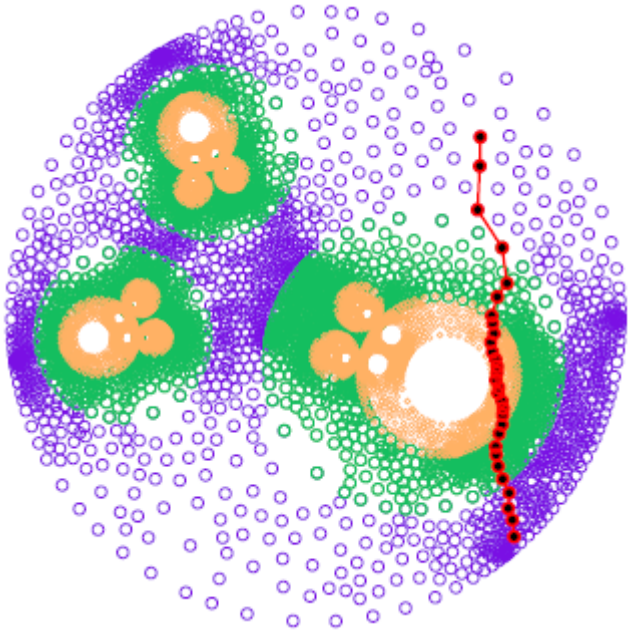
Load balanced greedy routing

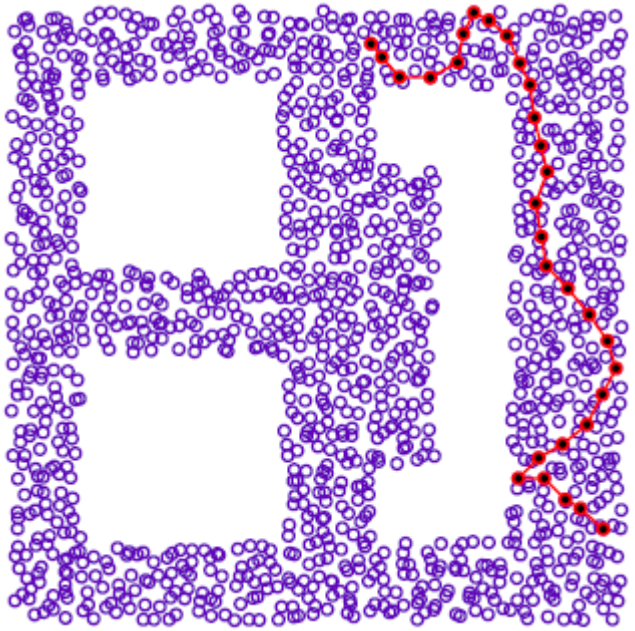
- Greedy routing shortest distance
- Hugs boundary of the hole
- Accumulation of routing paths through nodes at hole boundaries



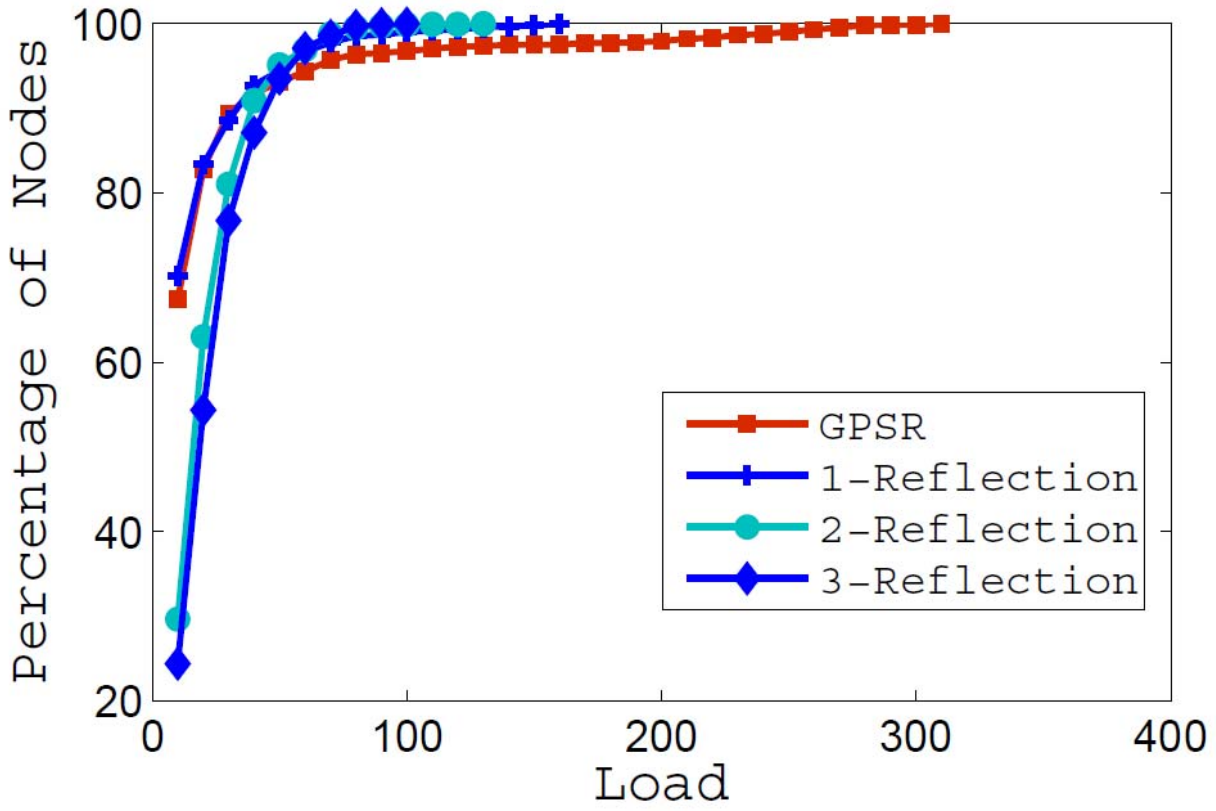
Load balanced greedy routing

- Routing path in covering space





Load balanced greedy routing simulation results



Load is more balanced, less nodes have a very high load

Conclusion use of covering space

- Geographical Hash Tables
  - Load is balanced throughout the network
- Double ruling
  - Double ruling rate is increased by each reflection
  - Cost for storage of data is high
  - Cost for retrieval is relatively low
- Load balanced routing
  - Reflection helps distributing the load
  - Paths can get long when path goes through reflections

Questions