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A Distributed Multi-Level Force-directed algorithm

MULTI-GILA

24th International Symposium On
Graph Drawing And Network Visualization,
September 19-21, Athens, Greece

Objective

Efficient graph drawing algorithm (graphs with more than 10M edges)

- Using emerging distributed computing platforms
- Running on inexpensive *PaaS* environments

Apache Giraph

- Runs on Hadoop
- *BSP* model
- *Think-Like-A-Vertex*

Think Like a Vertex

Iterative approach

```
for(Edge e in edges){
  Get s & t
  coordinates from e
  Compute their
  distance Δ
  Update s position
  using Δ and the
  force function
}
```

- A single entity knows the entire topology
- Hard to scale

TLAV approach

```
for(Vertex v in
neighbours){
   Get v coordinates
   Compute the
   distance Δ
   Update v position
   using Δ and the
   force function
}
```

- Whole topology is unknown
- Easier to scale

Distributed Design Challenges

- What does TLAV mean?
  - Vertex perspective
  - Messages exchange with neighbors
- Limitations
  - Vertices store a small amount of data
  - Light communication load (i.e. light messages)
  - Global variables are permitted, but expensive
- Infrastructure overhead

Related Work

Mueller et al., 2006

- Complex network infrastructure
  - Computing and rendering nodes
- Multi monitor visualization
- Tested on graph up to 8k nodes

Tikhonova and Ma, 2008

- 260,385 edges graph in 40 minutes
  - PSC's BigBen Cray XT3 cluster, 32 processors

Related Work

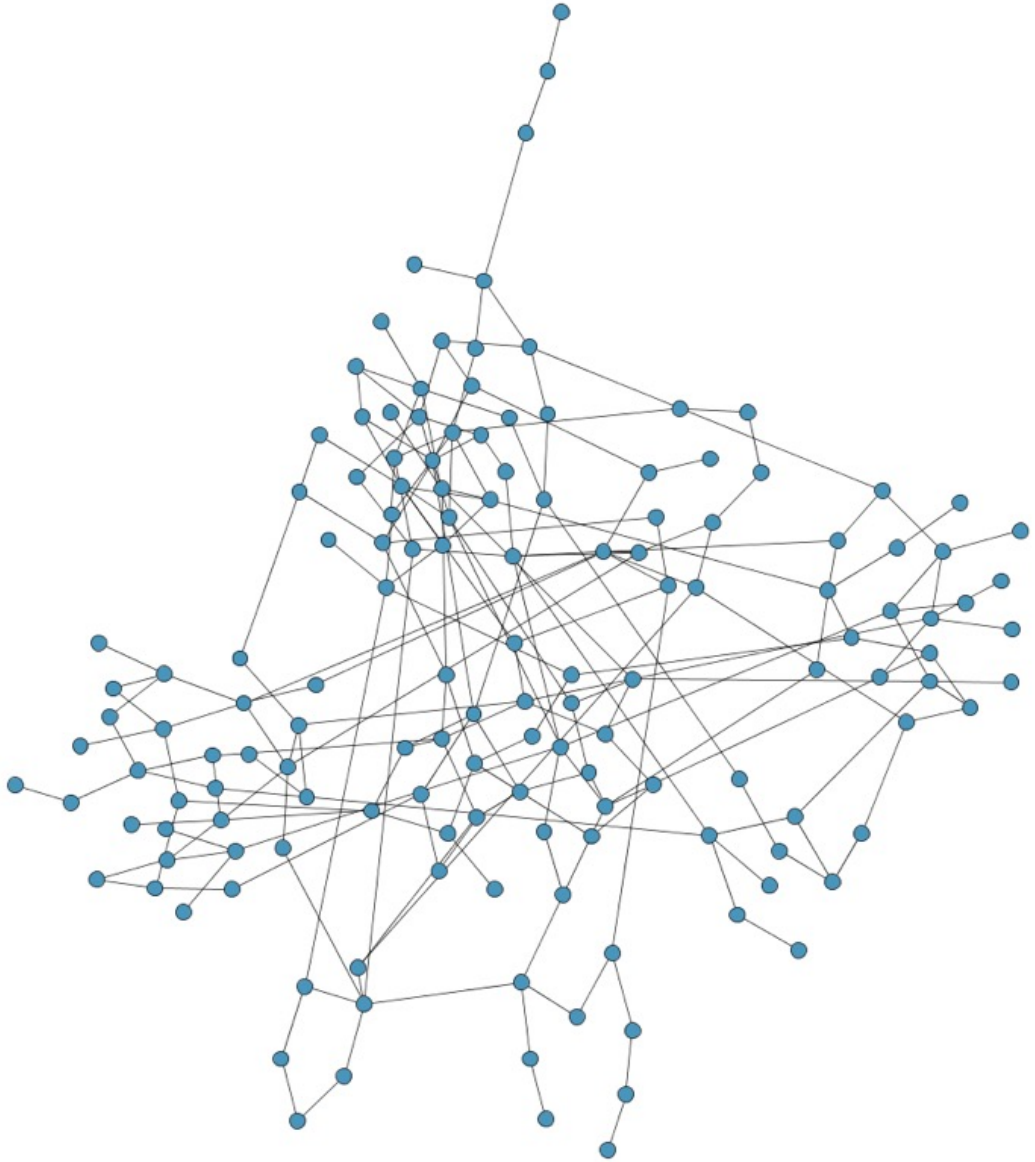
Hinge and Auber, 2015

- Force directed layout algorithm on GraphX
- Repulsive forces are approximated using centroids
- 8k vertices and 35k edges graph drawn in 5 hours
  - 16 machines, 24 cores and 48GB Ram each

Arleo et al., 2015

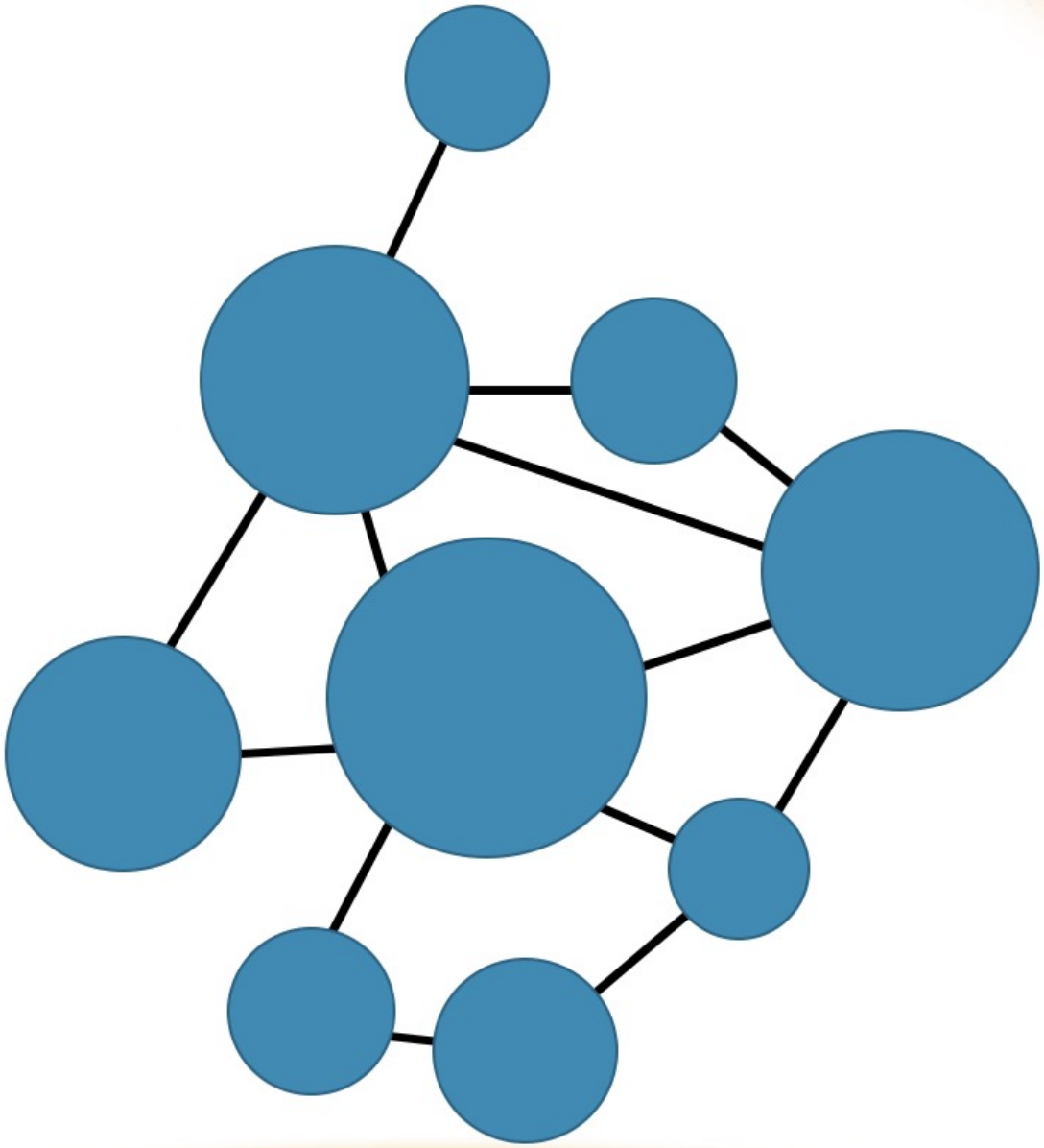
- "*Gila*" (former *Clint*)
- The first single-level FD layout algorithm on Giraph
- Performance was comparable to a centralized FD (Fruchterman-Reingold, 1991)
- 1.5M edges graph in less than an hour
  - 10 machines, 4 cores, 30GB Ram each

Multi-Level Layout



Coarsening

Multi-Level Layout



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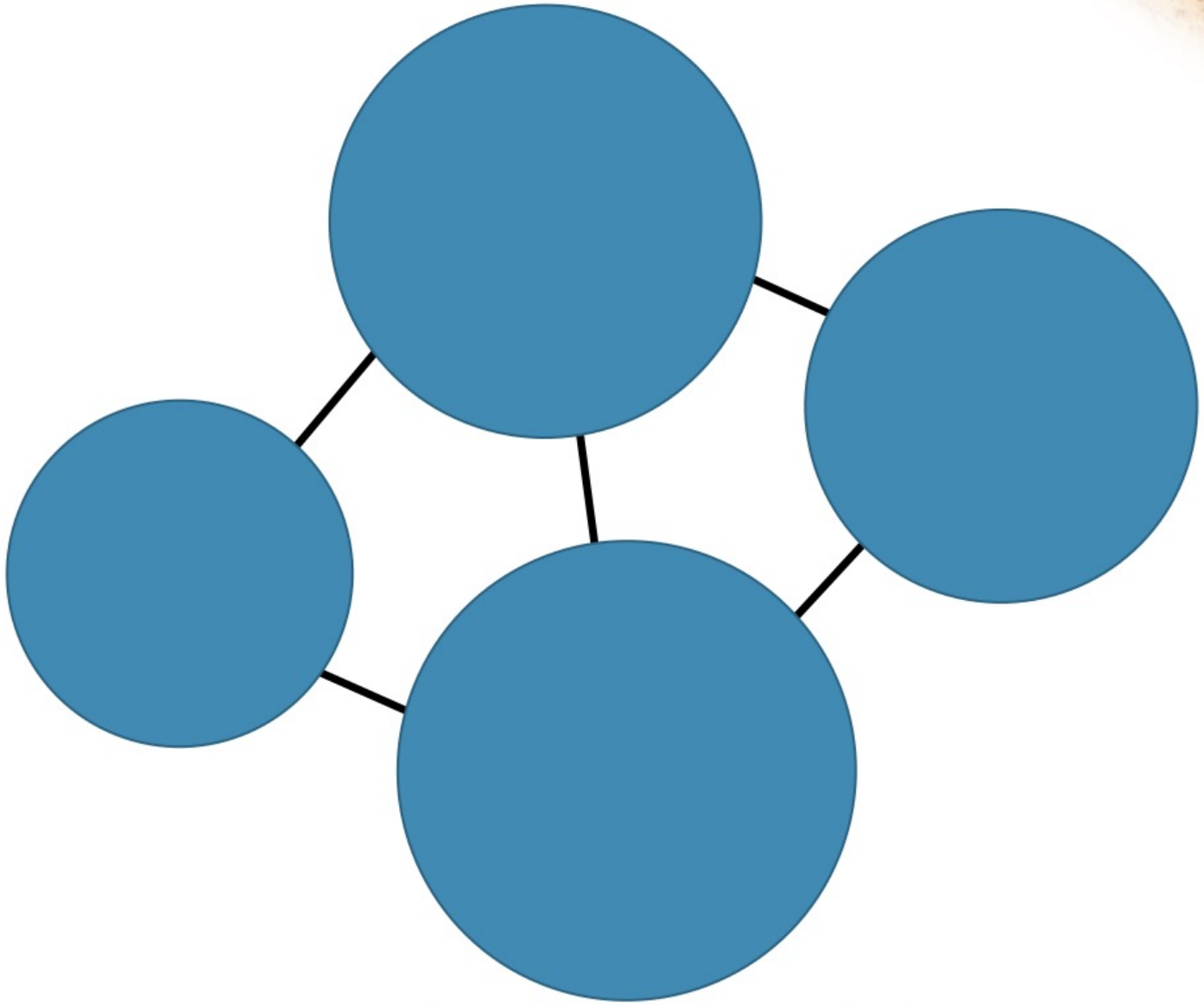

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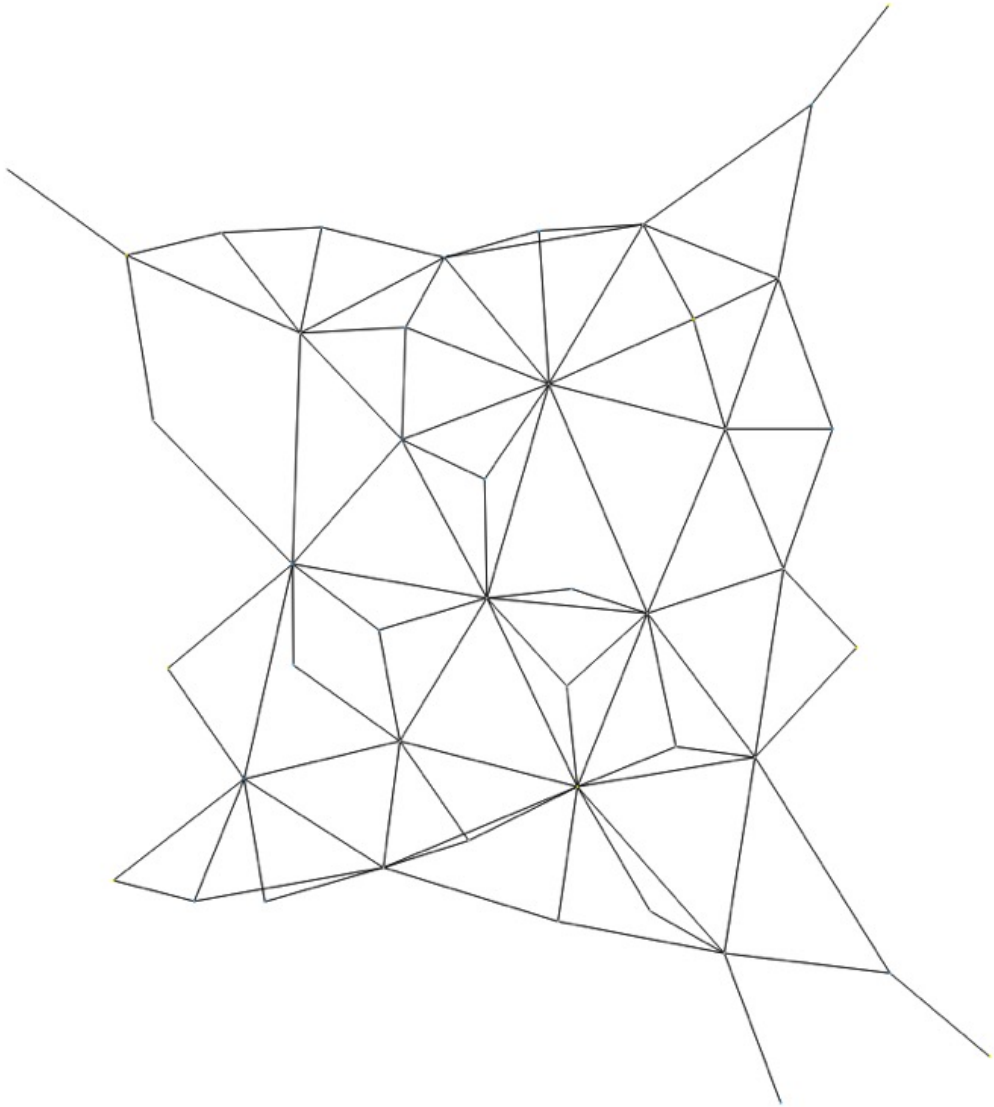

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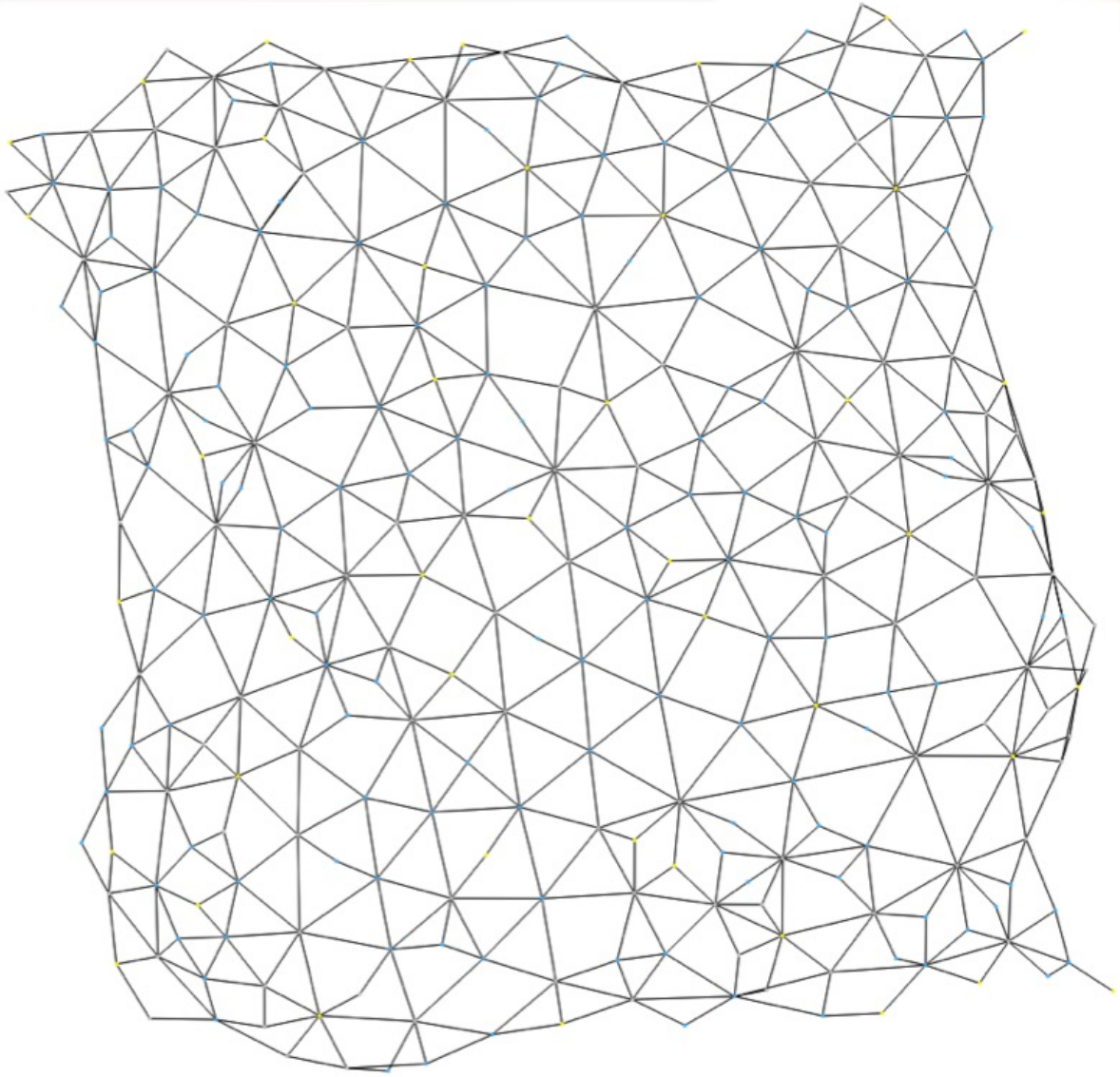

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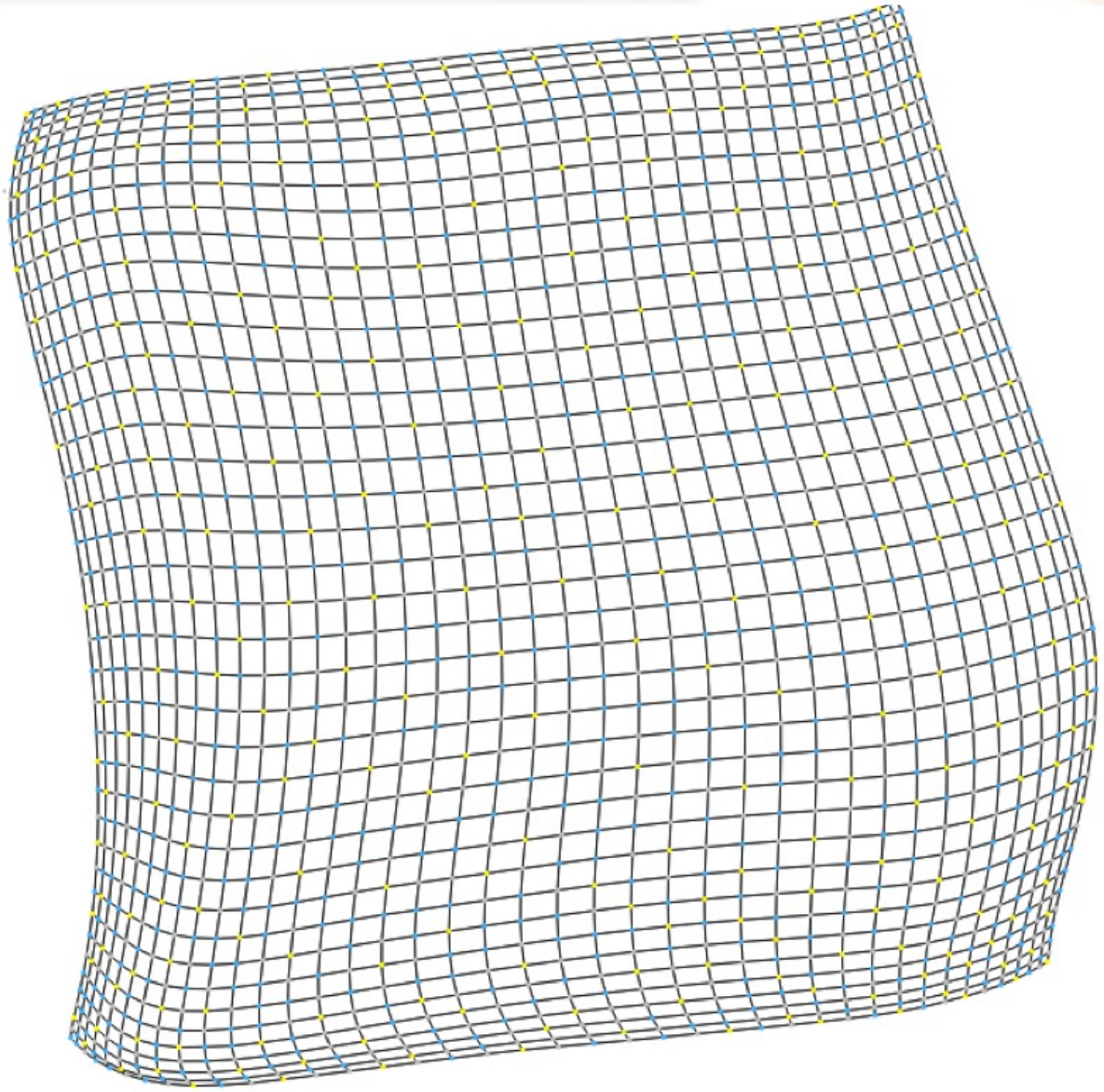


Placement & Layout

Our Contribution

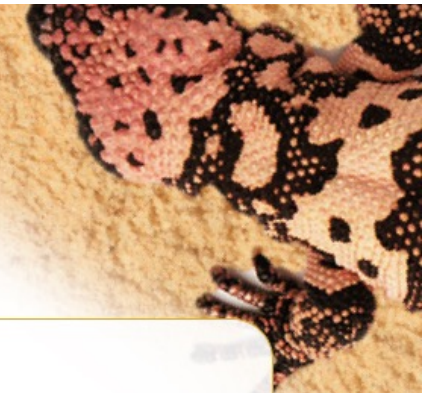
- First distributed multi-level force-directed layout algorithm
  - Implemented on *Giraph*
  - Single level layout provided by GILA
- Experimental evaluation
  - Small regular graphs
  - Medium sized graphs (up to 1.5M edges)
  - Large graphs (up to ~11M edges)

Algorithm Overview

Key-Ideas

- Coarse hierarchy generation inspired by FM^3 (Hachul-Junger, 2004)
  - Distributed Merger
  - Distributed Placer
  - Designed to have a low impact on total running time
- Dynamic single-level layout tuning
  - Coarse levels will have more accurate drawings
  - Allows us to scale to bigger graphs

Multi-Gila Pipeline



Pre-process

- Pruning
- Partitioning
- Component Discovery

Multi-Level layout

- Distributed Solar Merger
- Distributed Solar Placer
- Gila (single level layout)

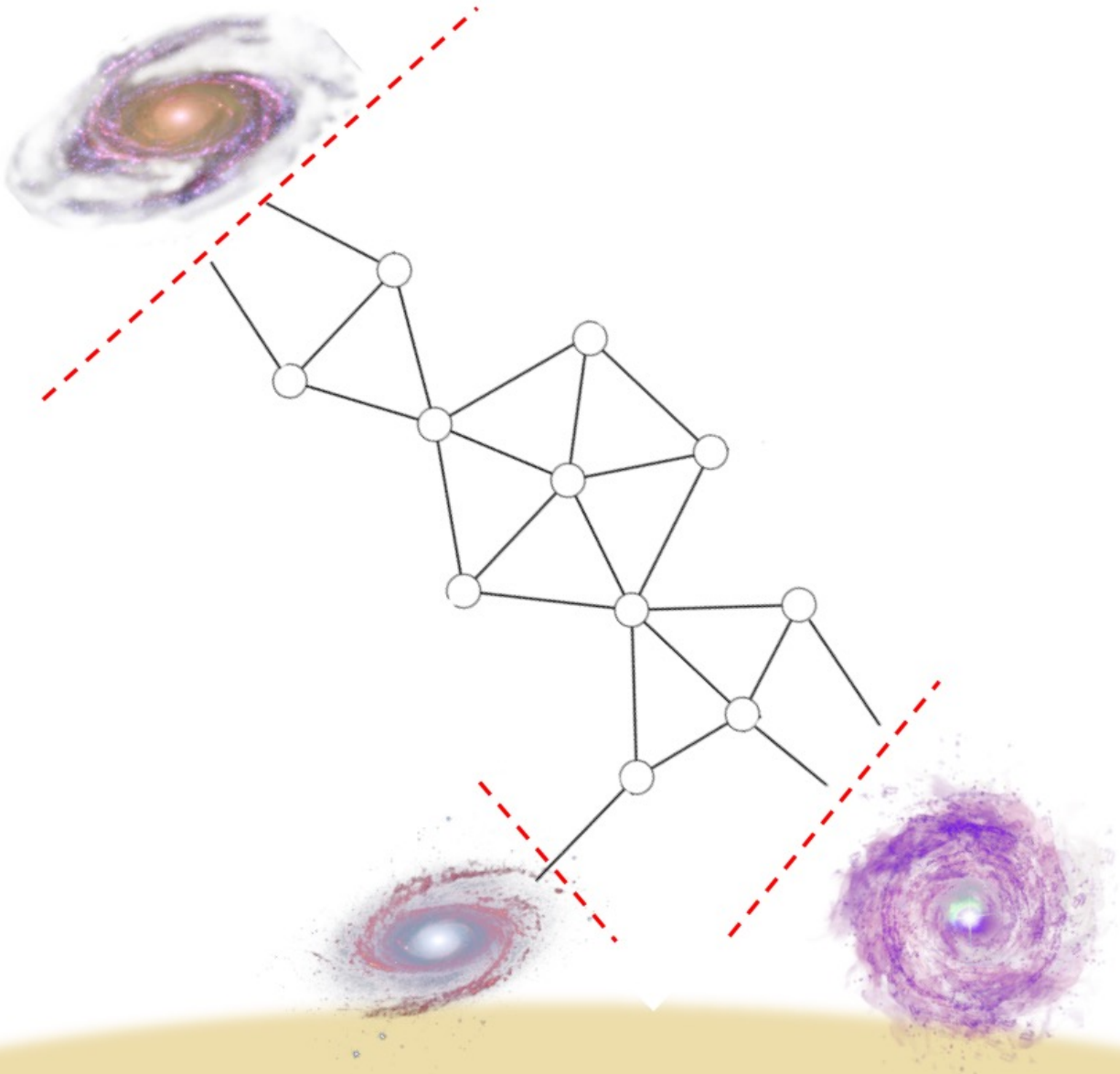
Post-Process

- Graph reconstruction
- Connected components arrangement

Coarsening Phase

- Partitioning of the input graph into subgraphs
- These subgraphs are called *Galaxies*:
  - There is a single *Sun*
  - *Sun's* neighbors are called *Planets*
  - If any, *Planets'* neighbors are called *Moons*
  - Max GTD between any two of its nodes: 4
- *Galaxies* are collapsed onto their sun

FM³ Solar Merger (FSM)



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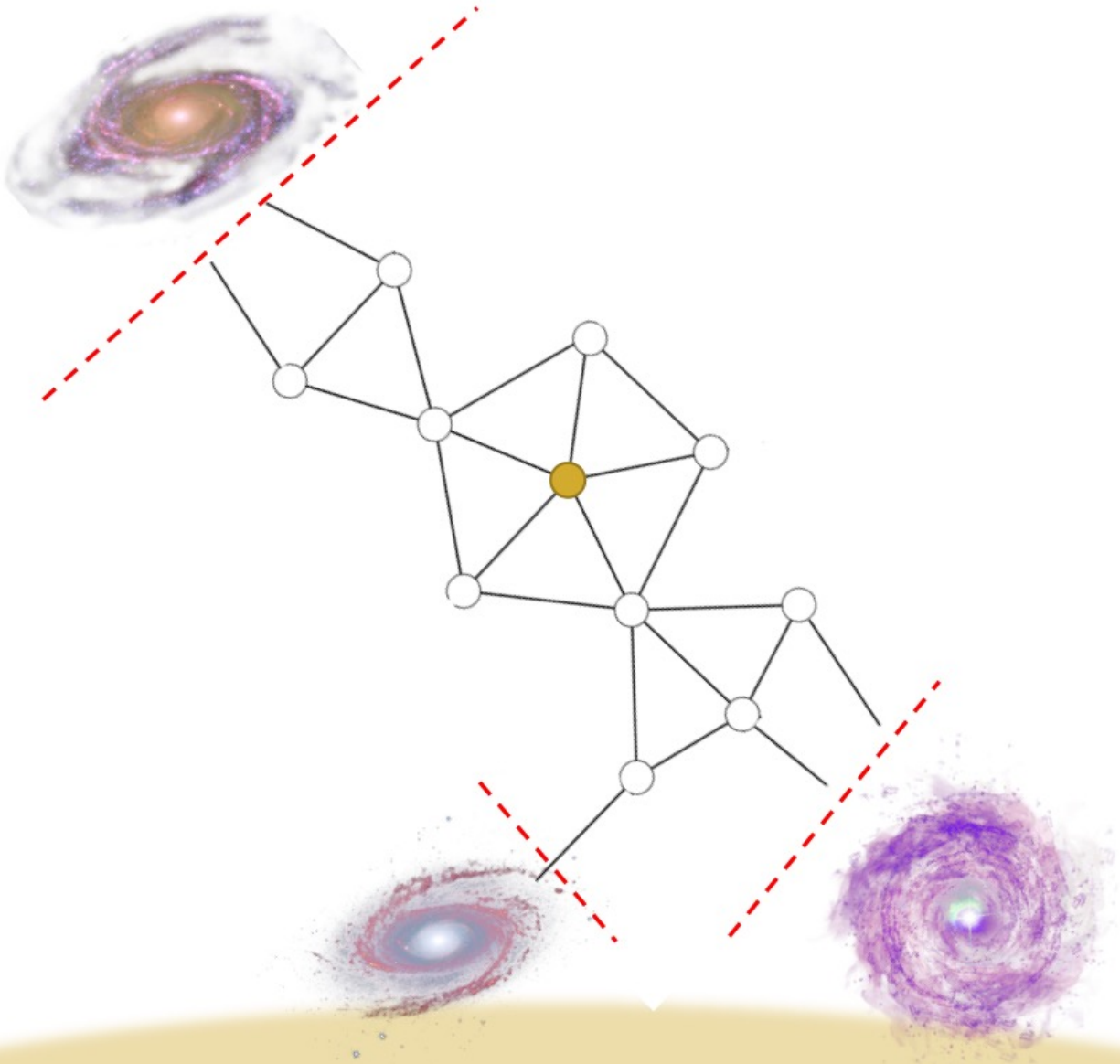

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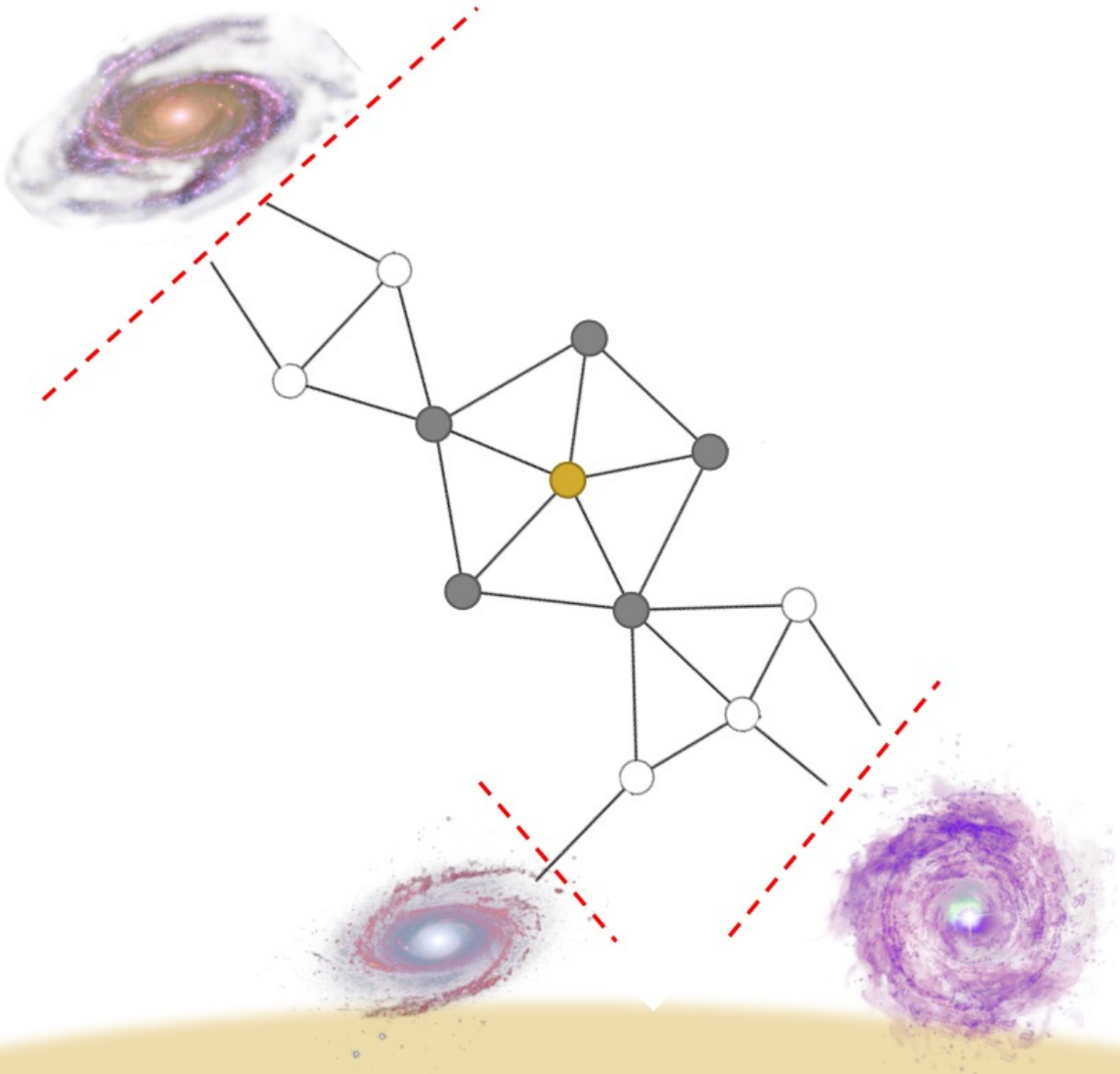

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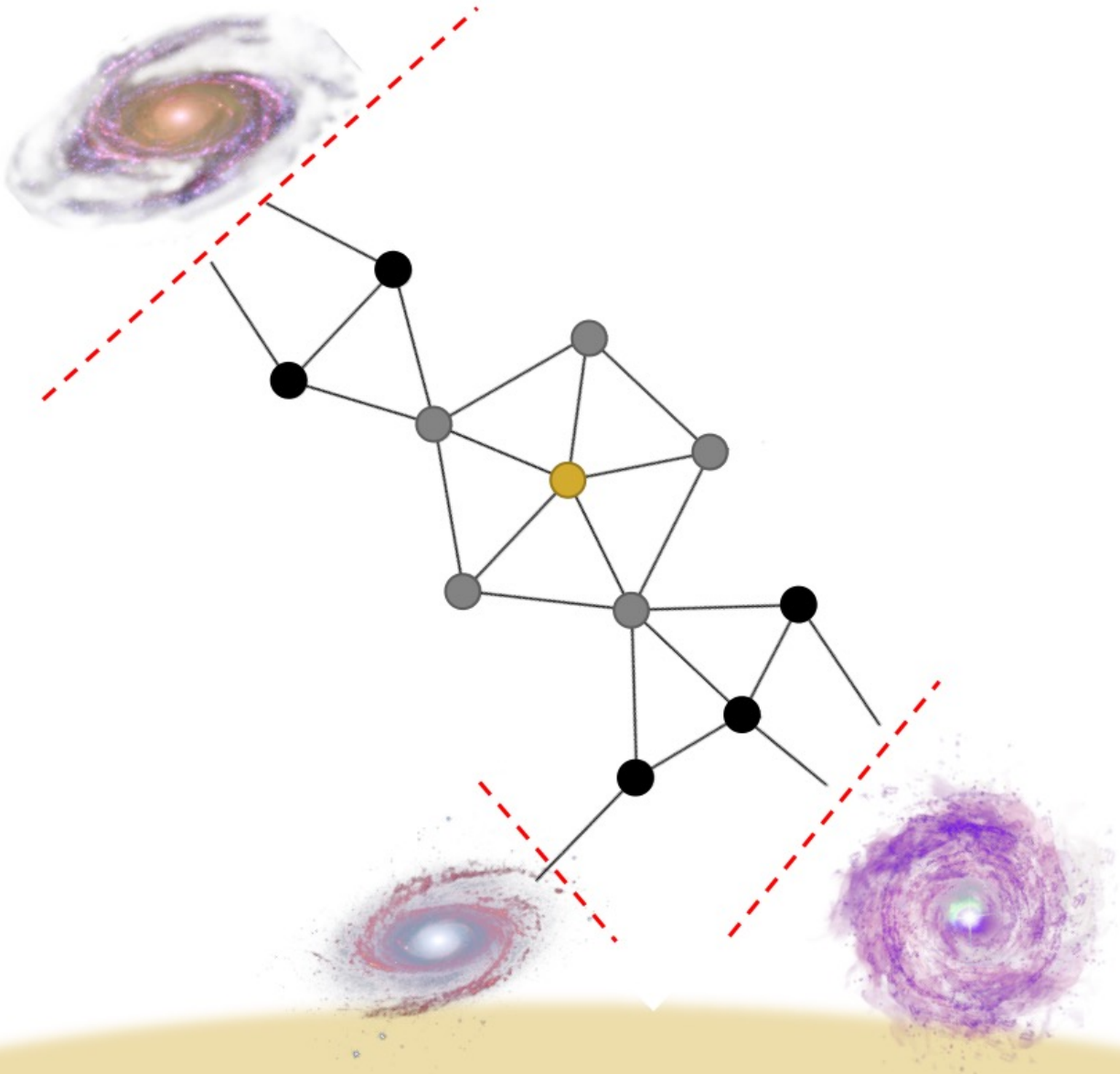

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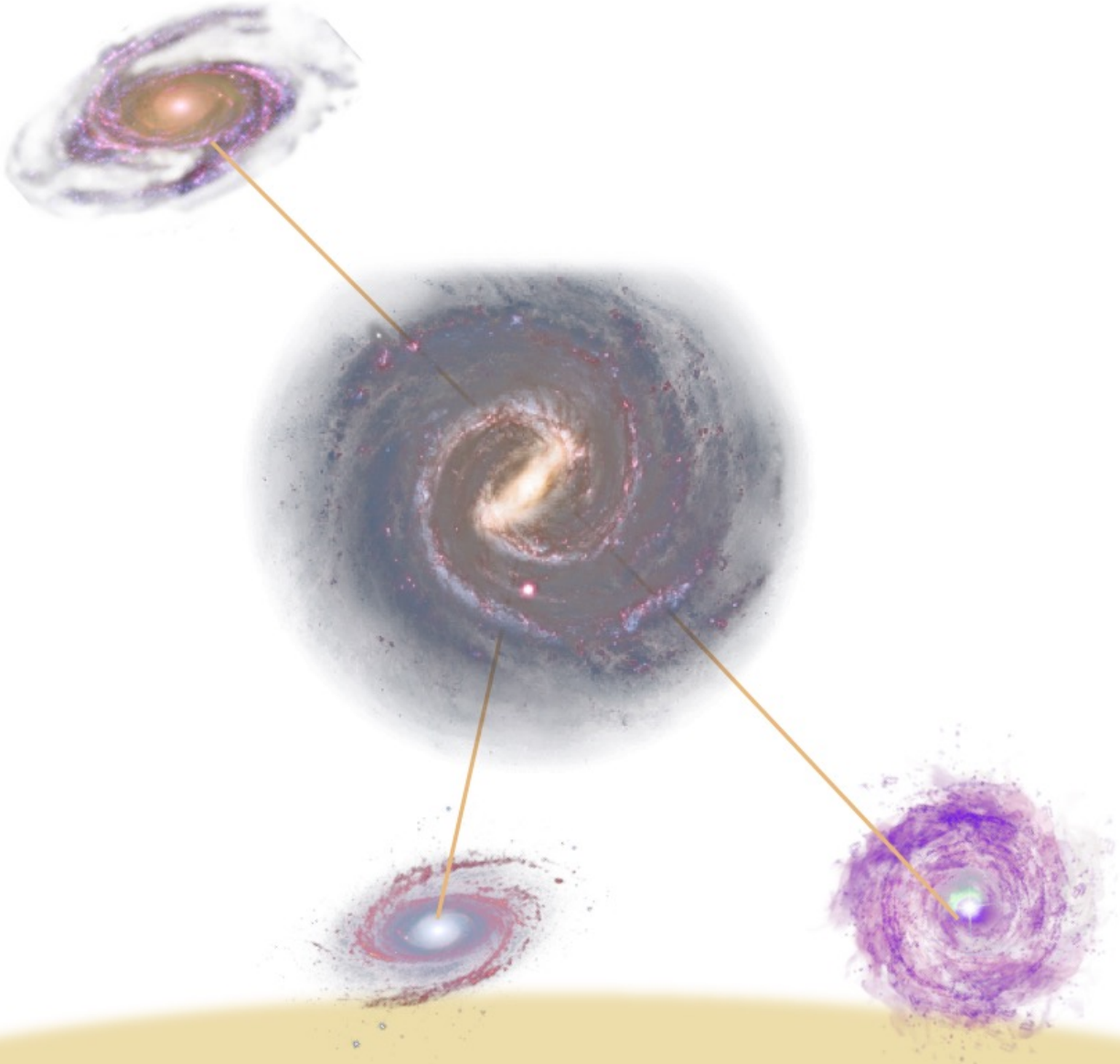
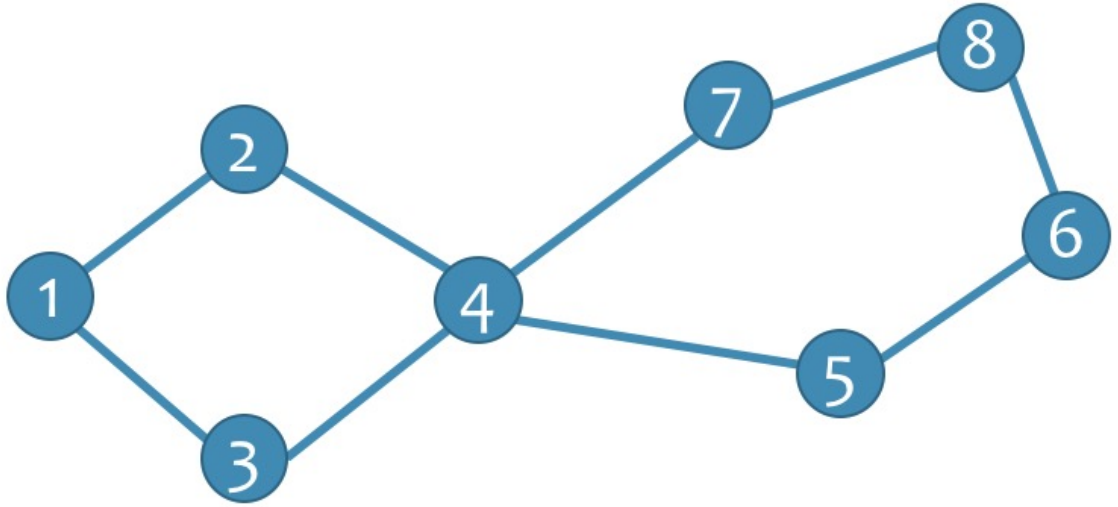


Challenges

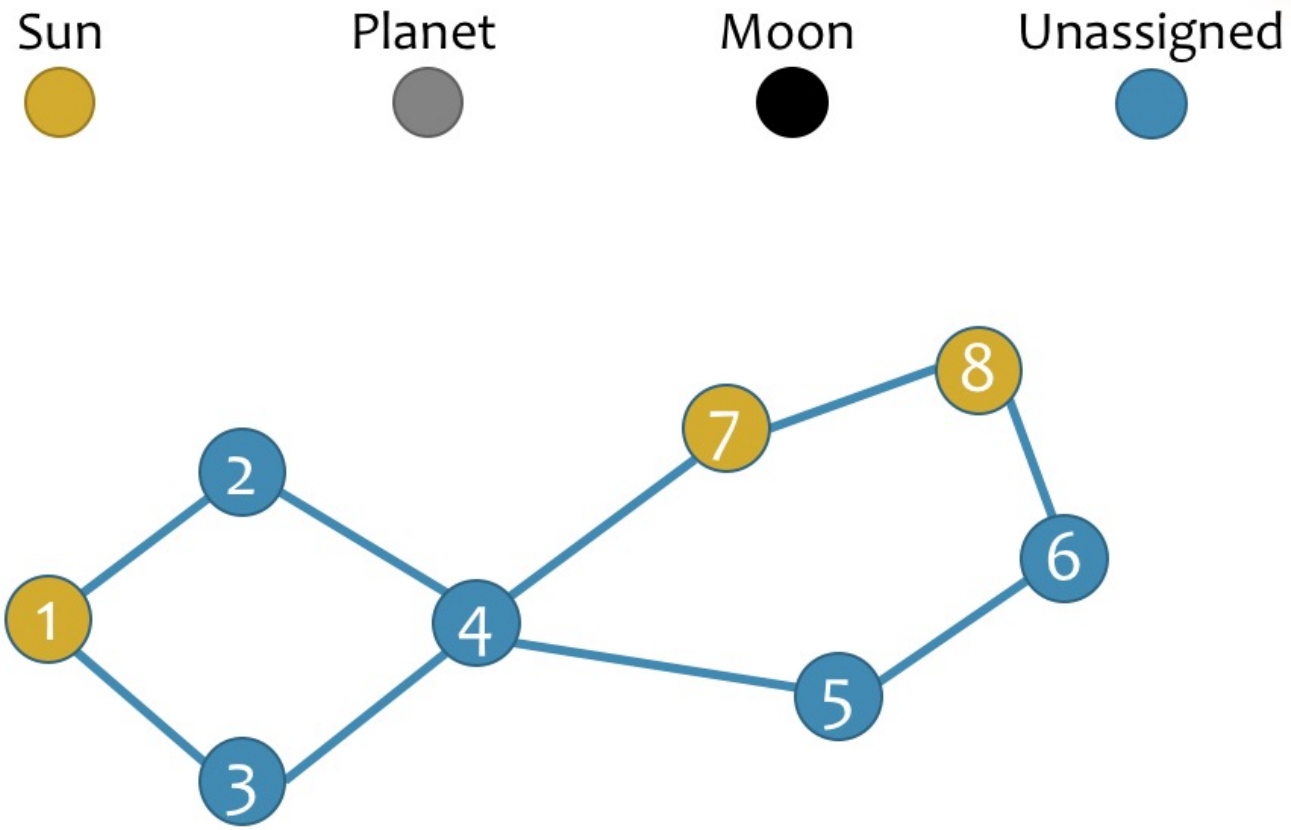
- No knowledge of the entire graph topology
- Path information must be preserved
- One-vertex pickup not feasible
- It is necessary a network discovery protocol
  - Network exploration using messages

Distributed Solar Merger (DSM)



Sun Generation

Distributed Solar Merger (DSM)



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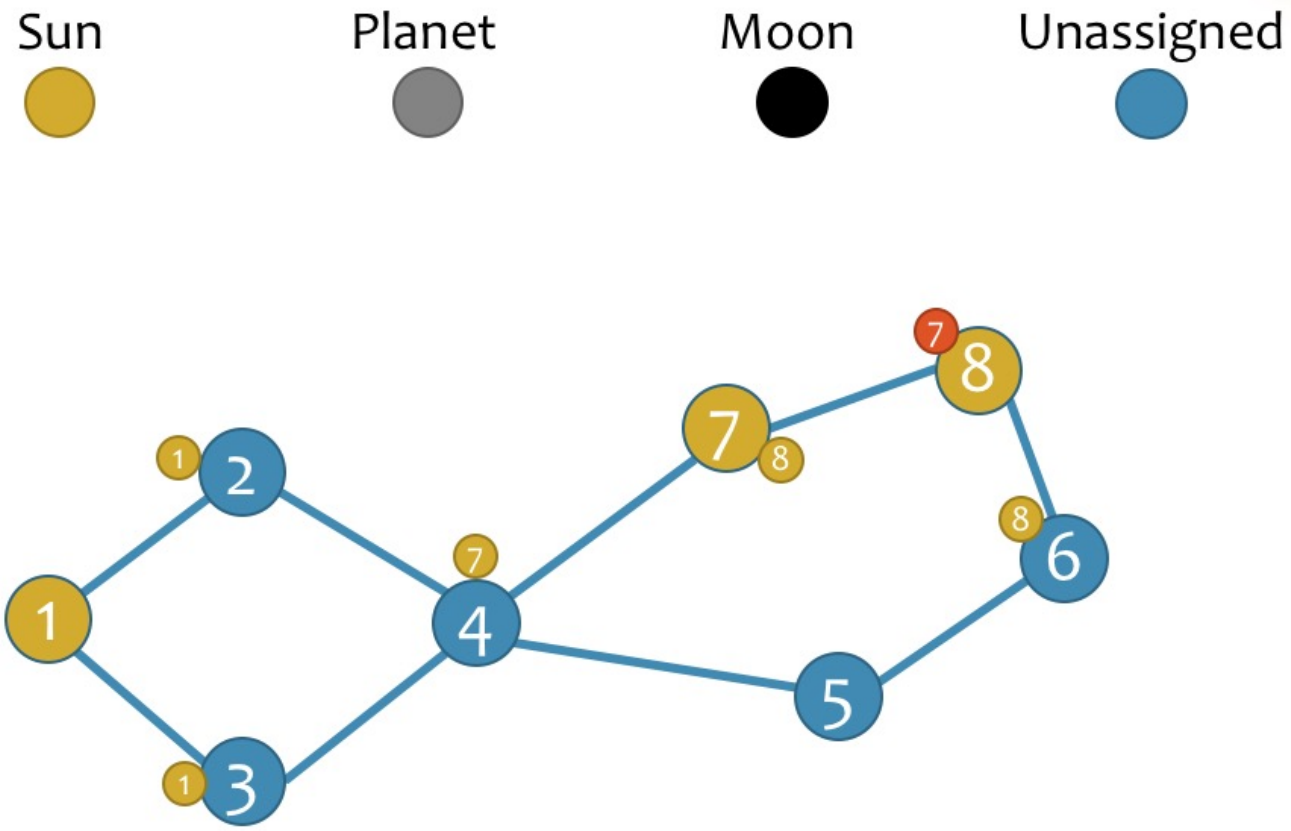
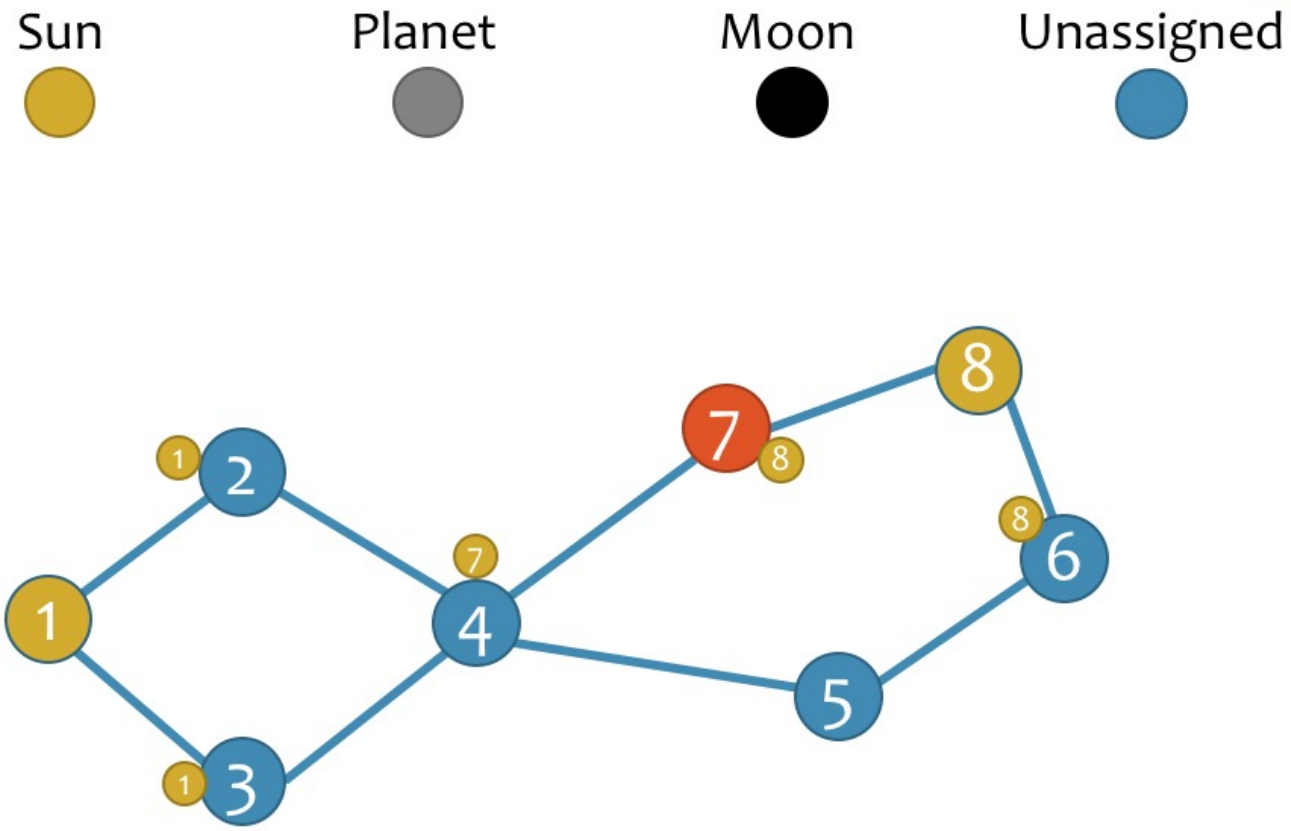


Correction procedure

Distributed Solar Merger (DSM)



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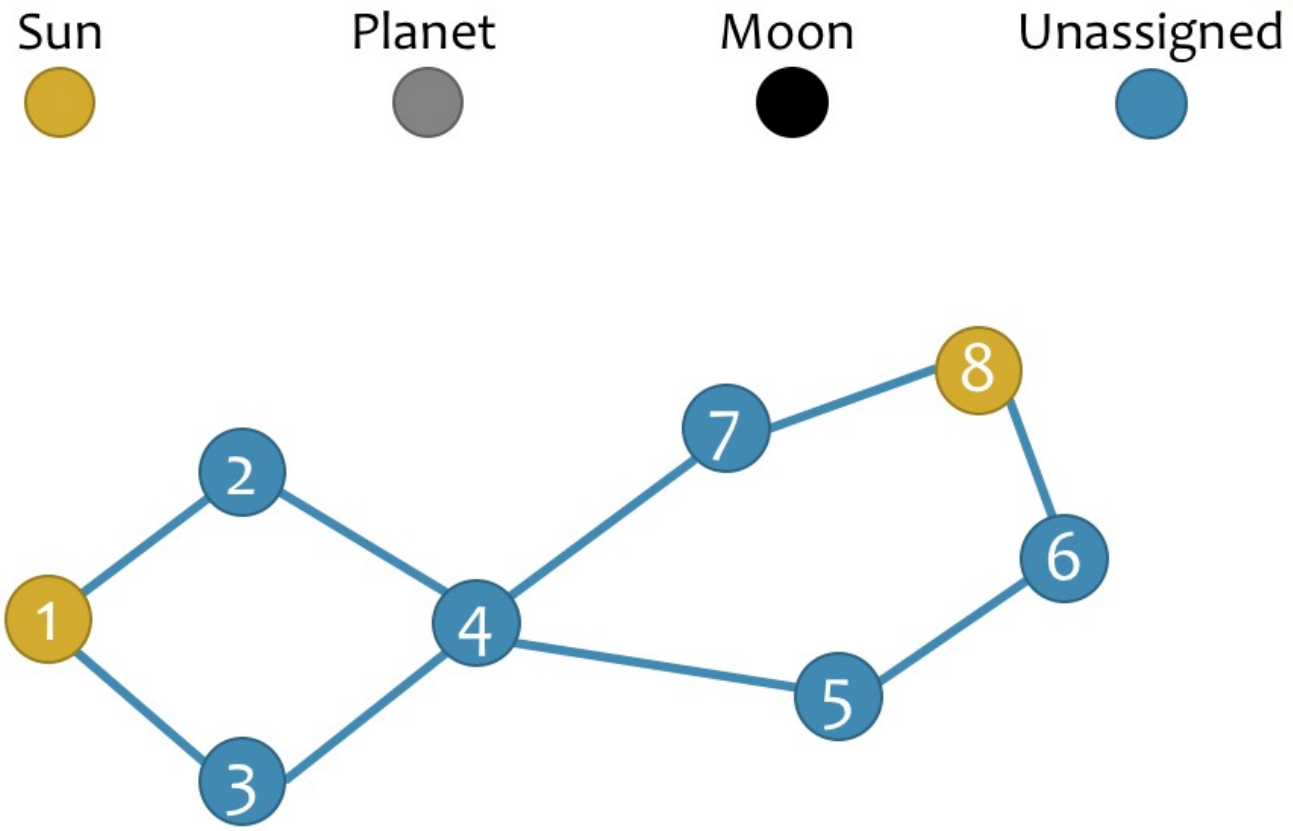

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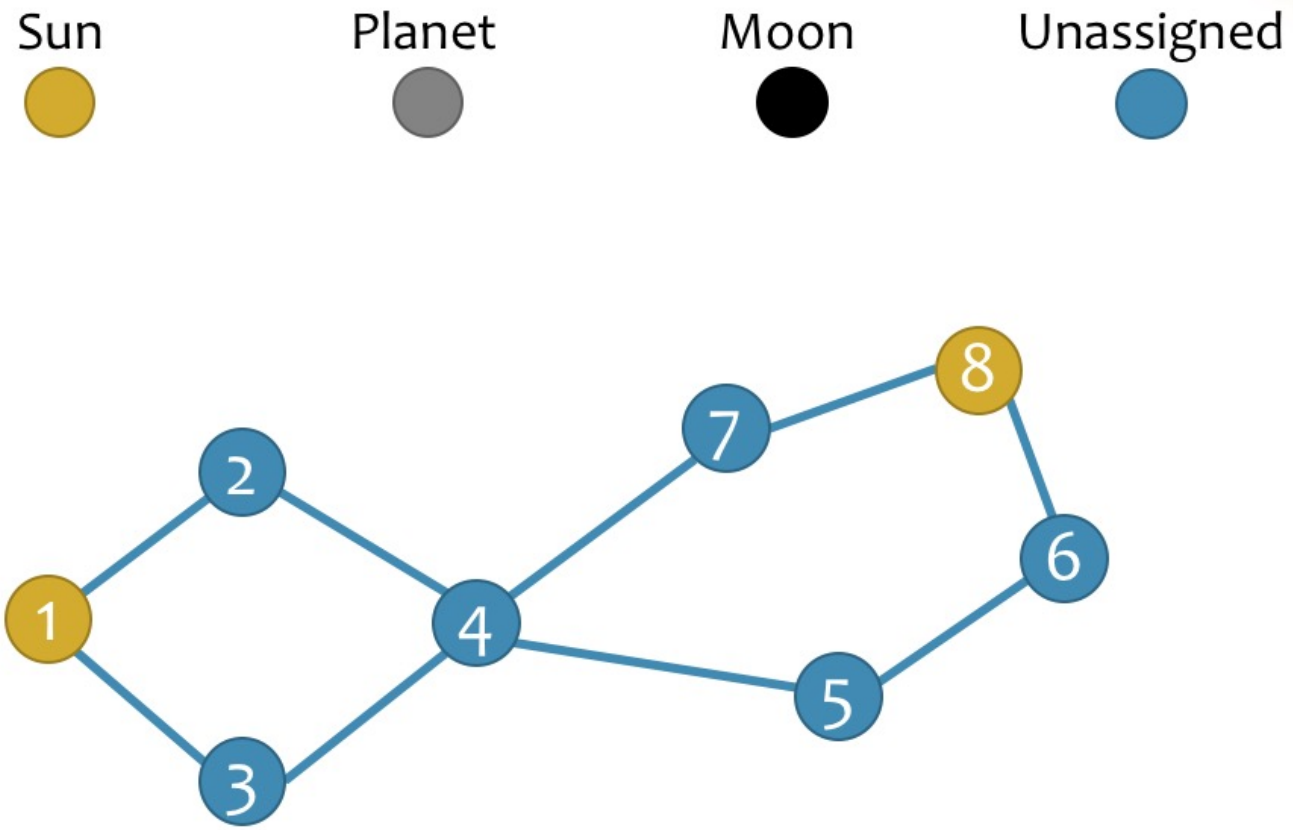
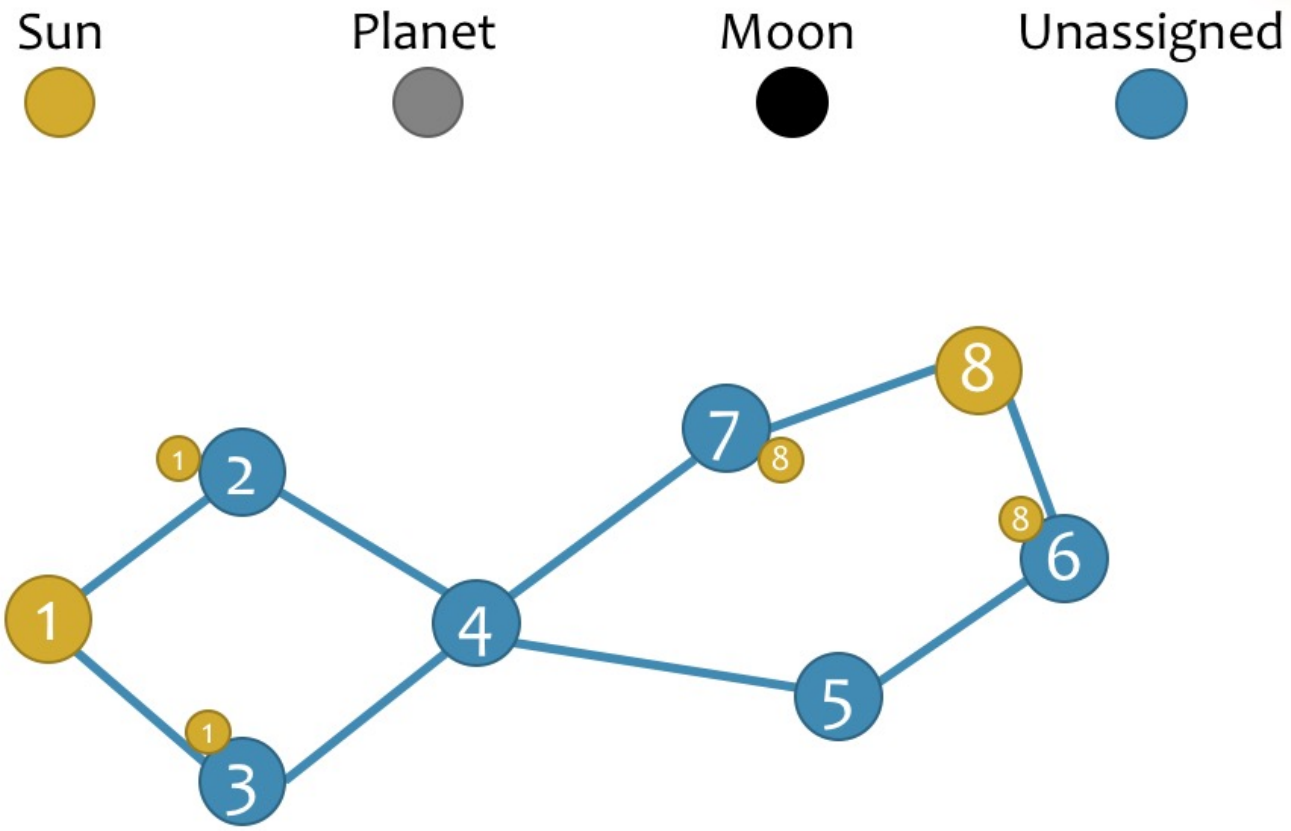


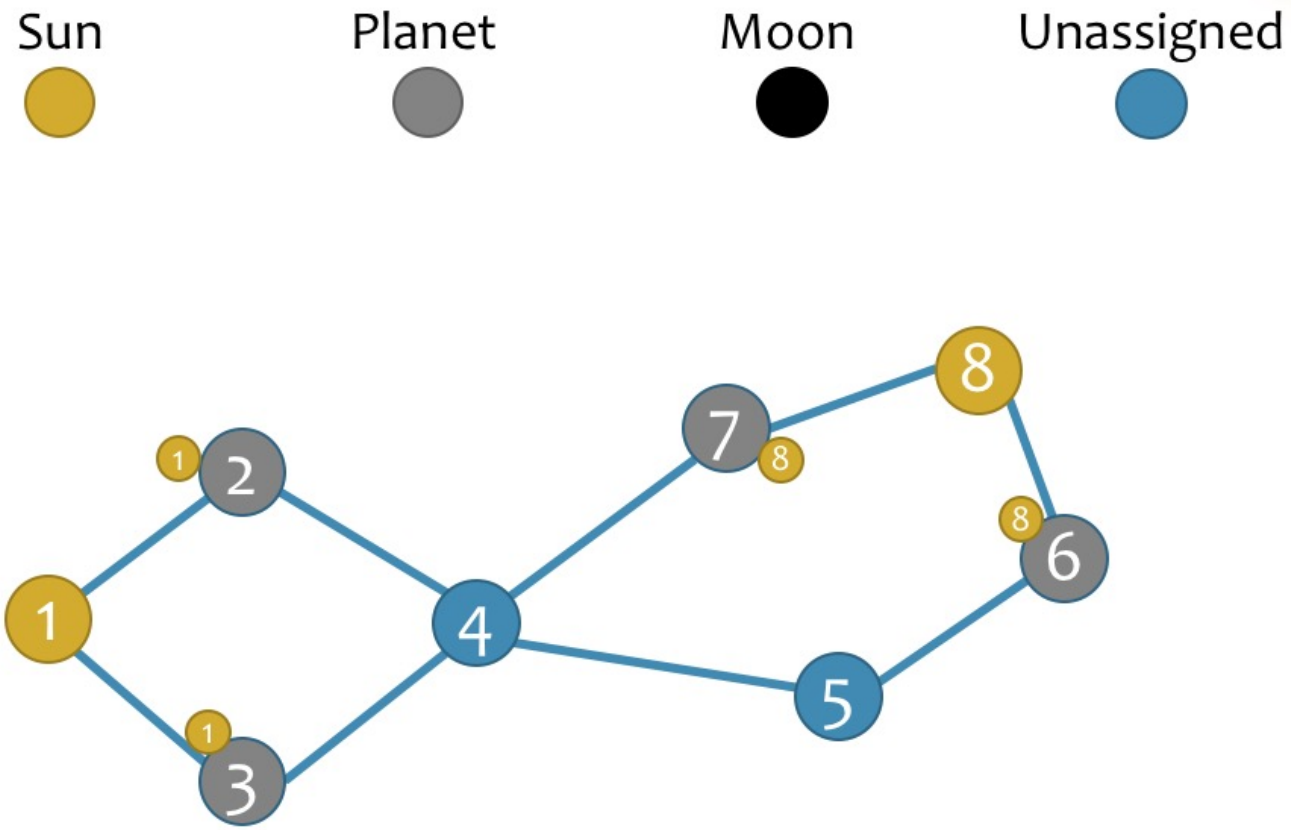
Sun Offer

Distributed Solar Merger (DSM)



Planet Response

Distributed Solar Merger (DSM)



Planet Response

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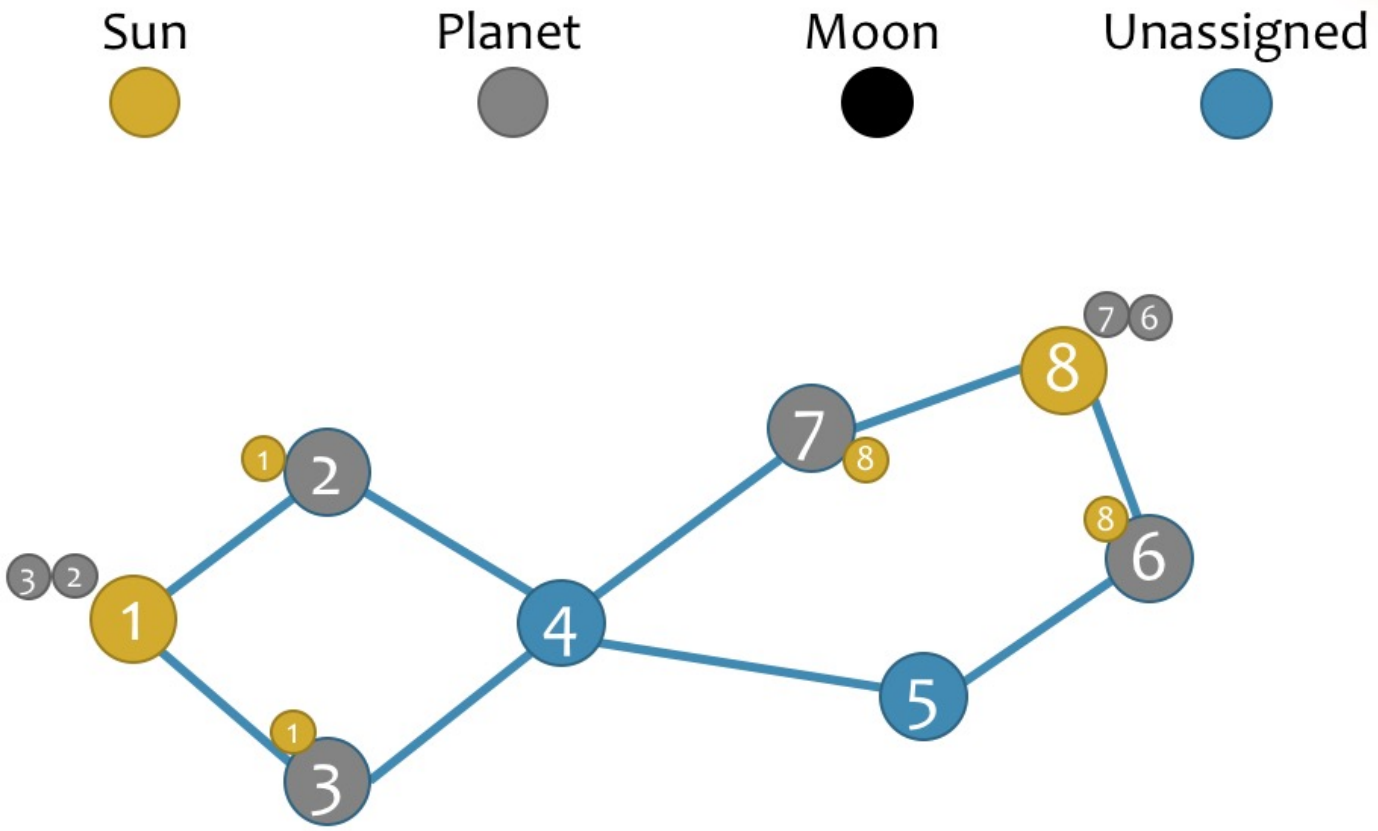
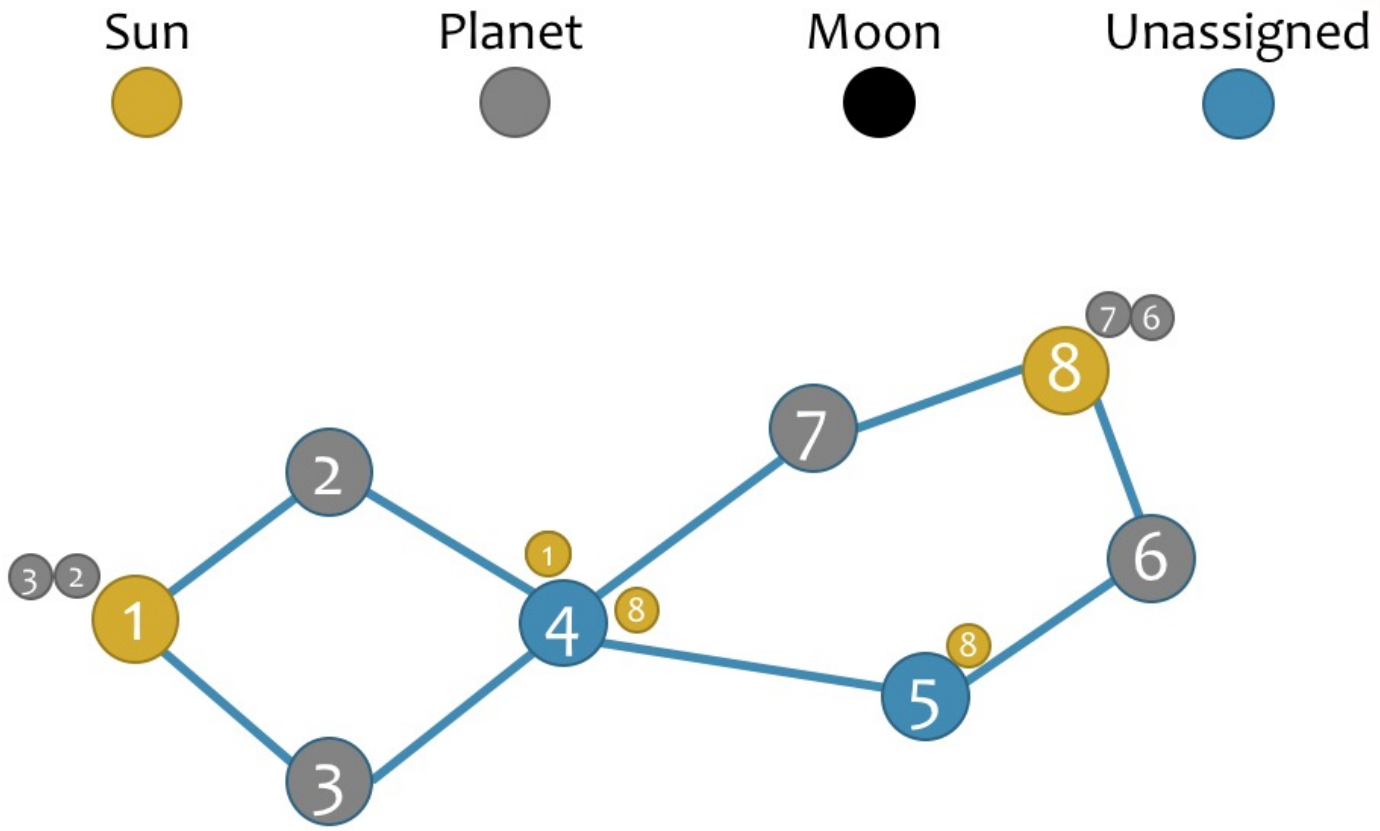


Regime Merger

Distributed Solar Merger (DSM)



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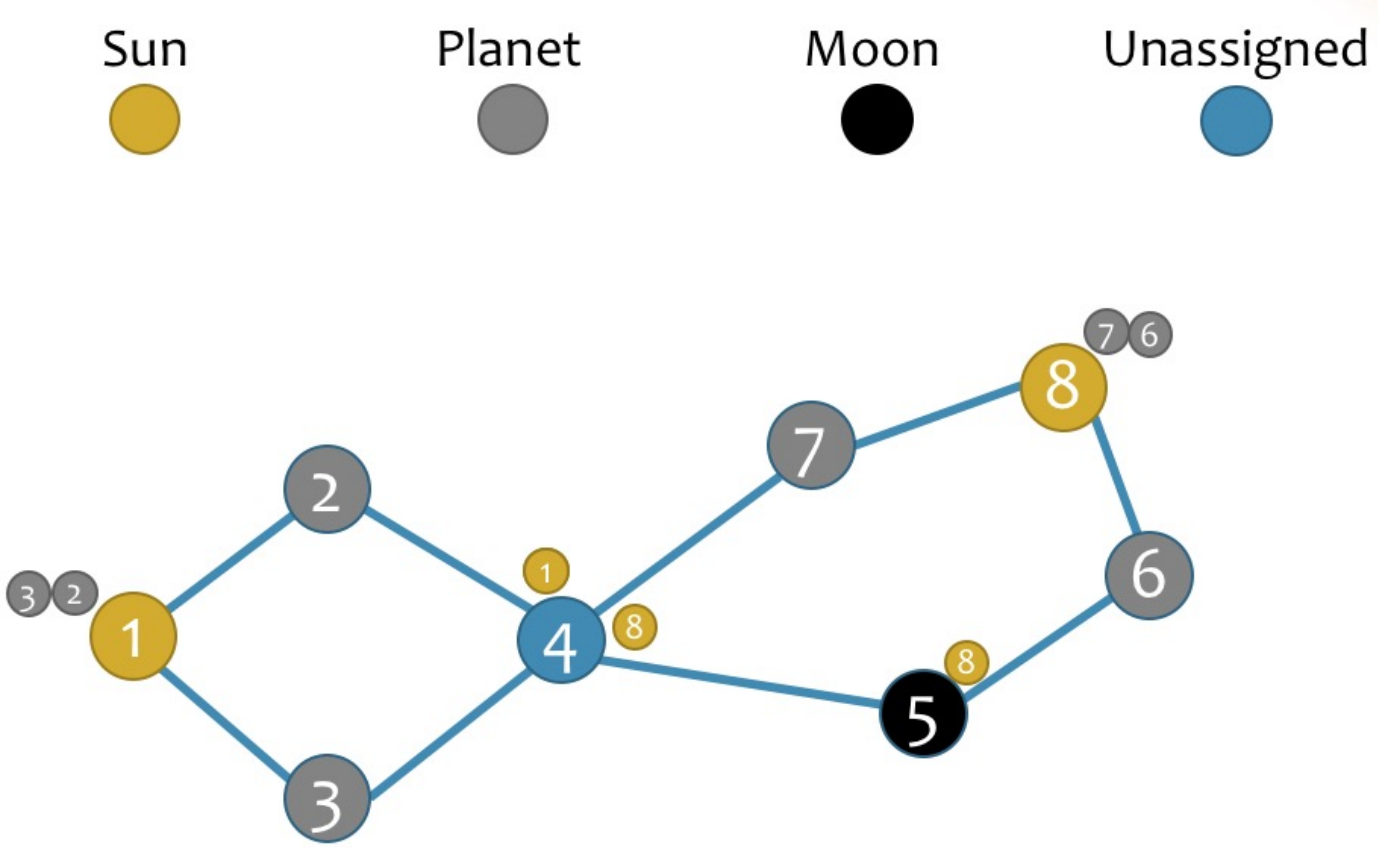

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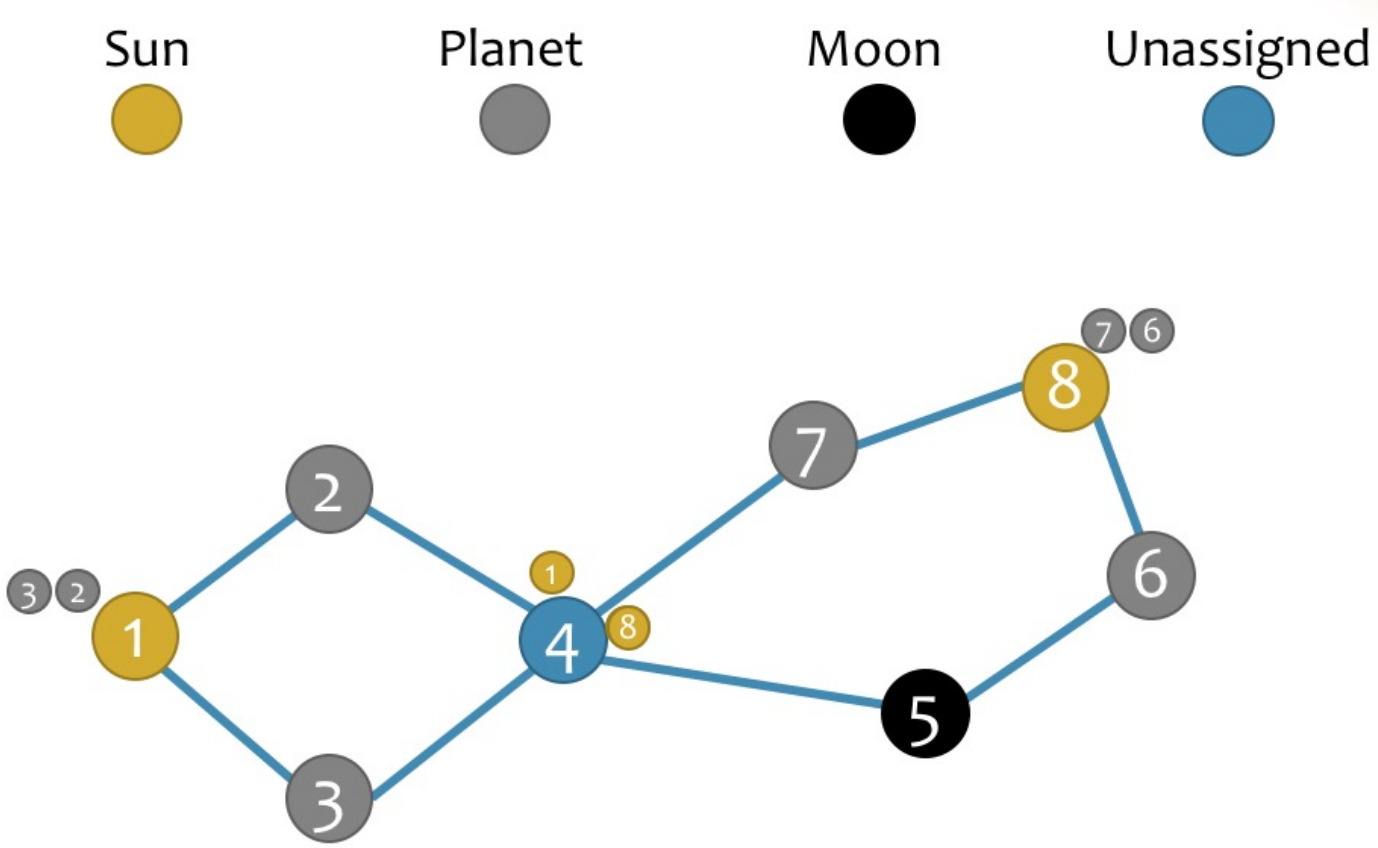

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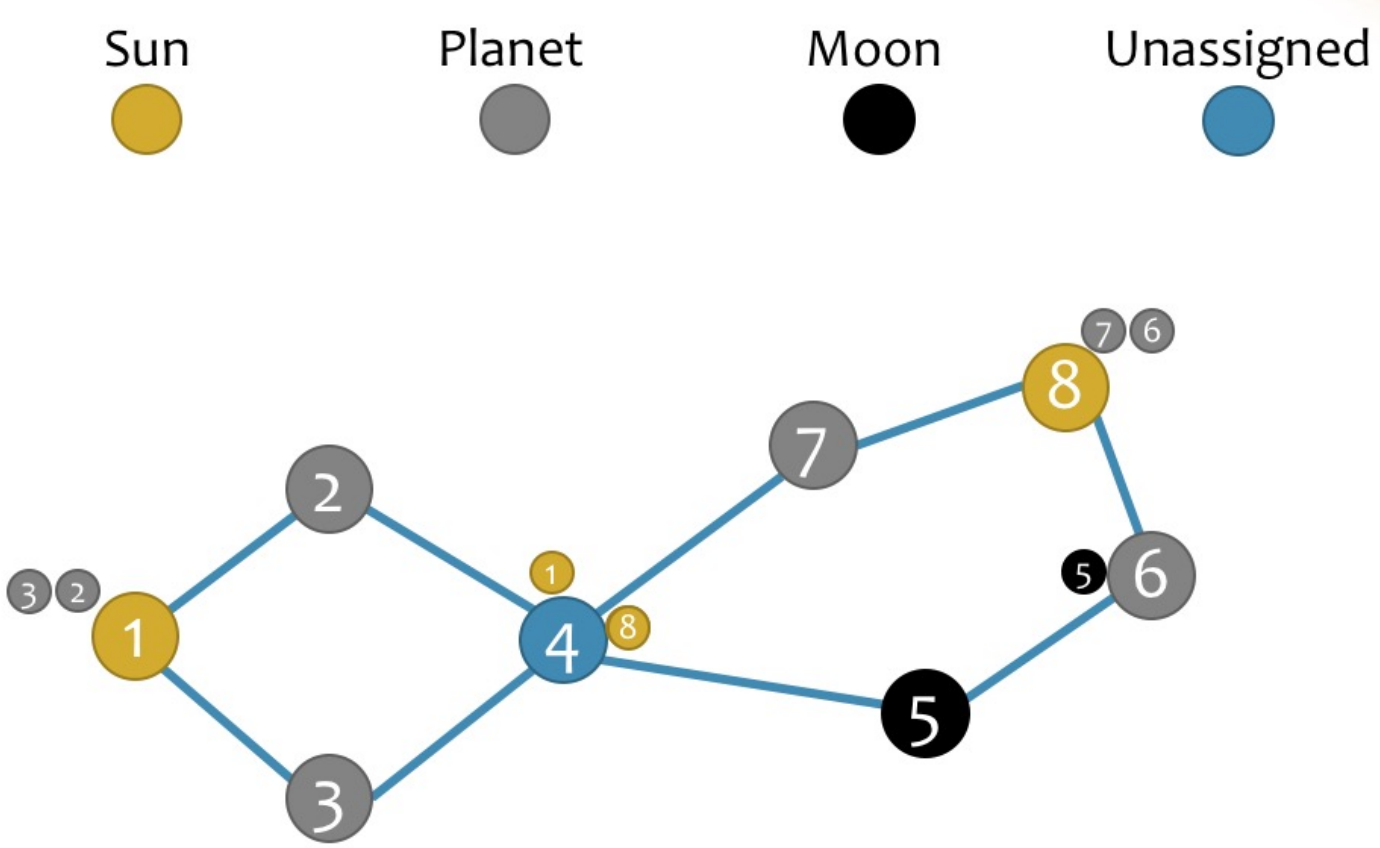

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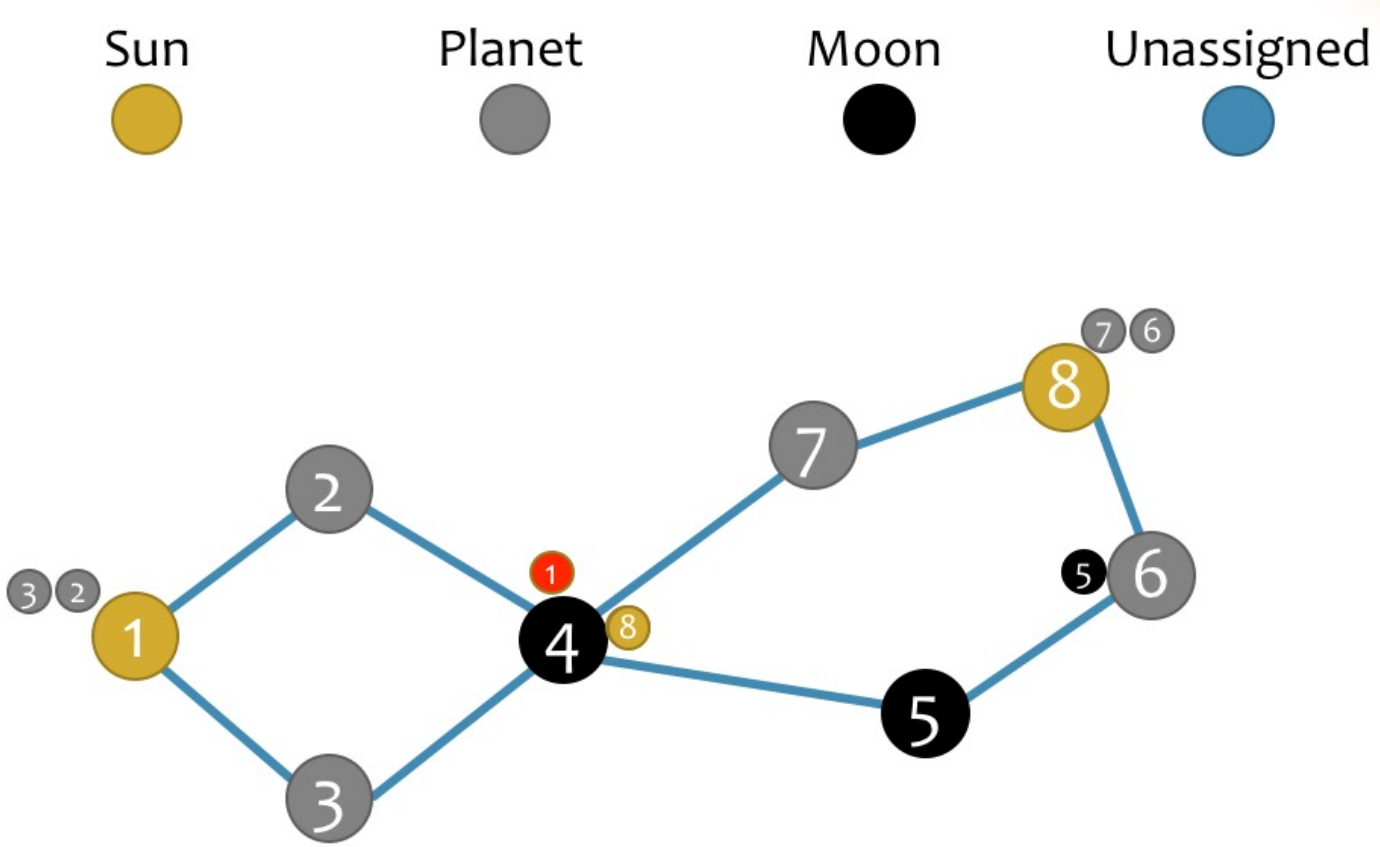

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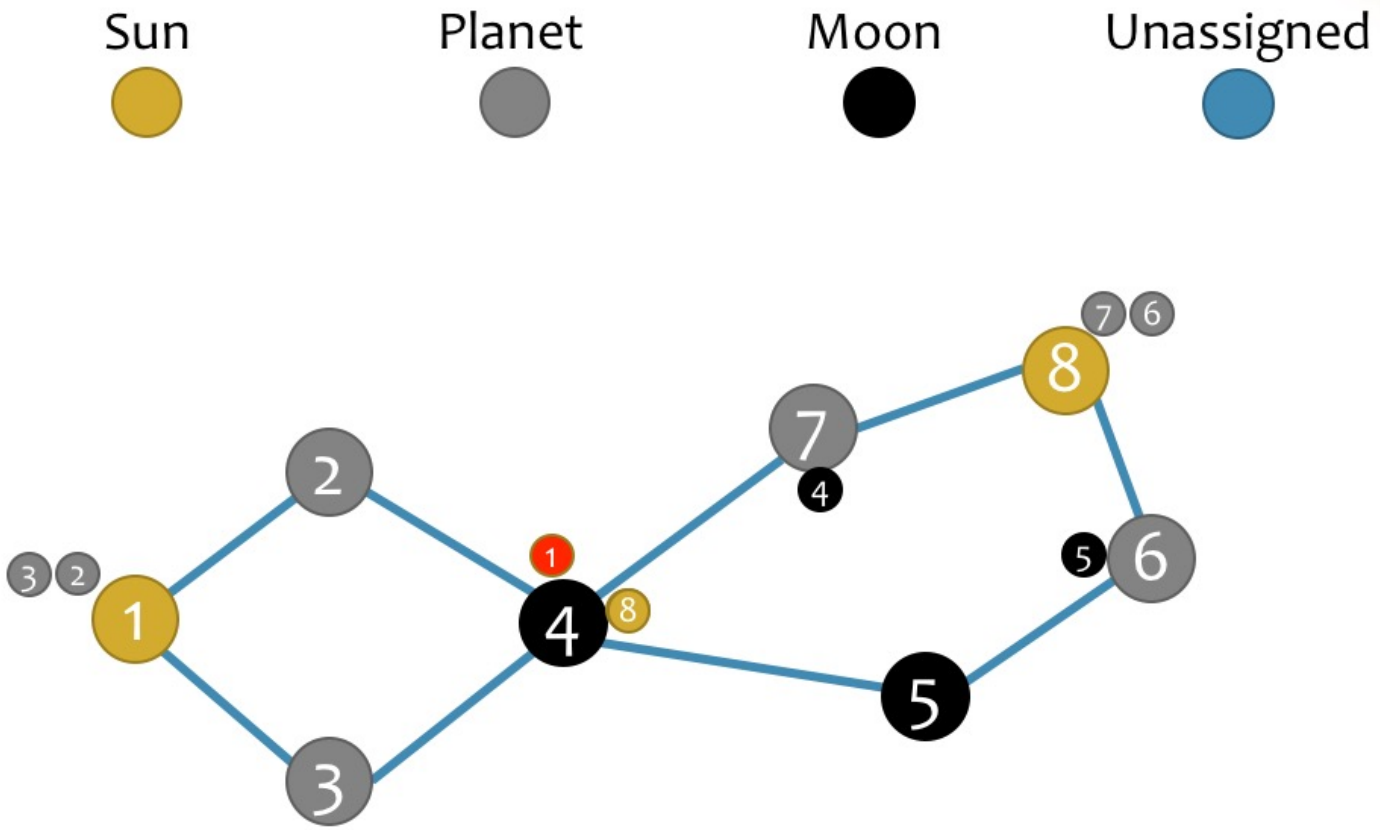

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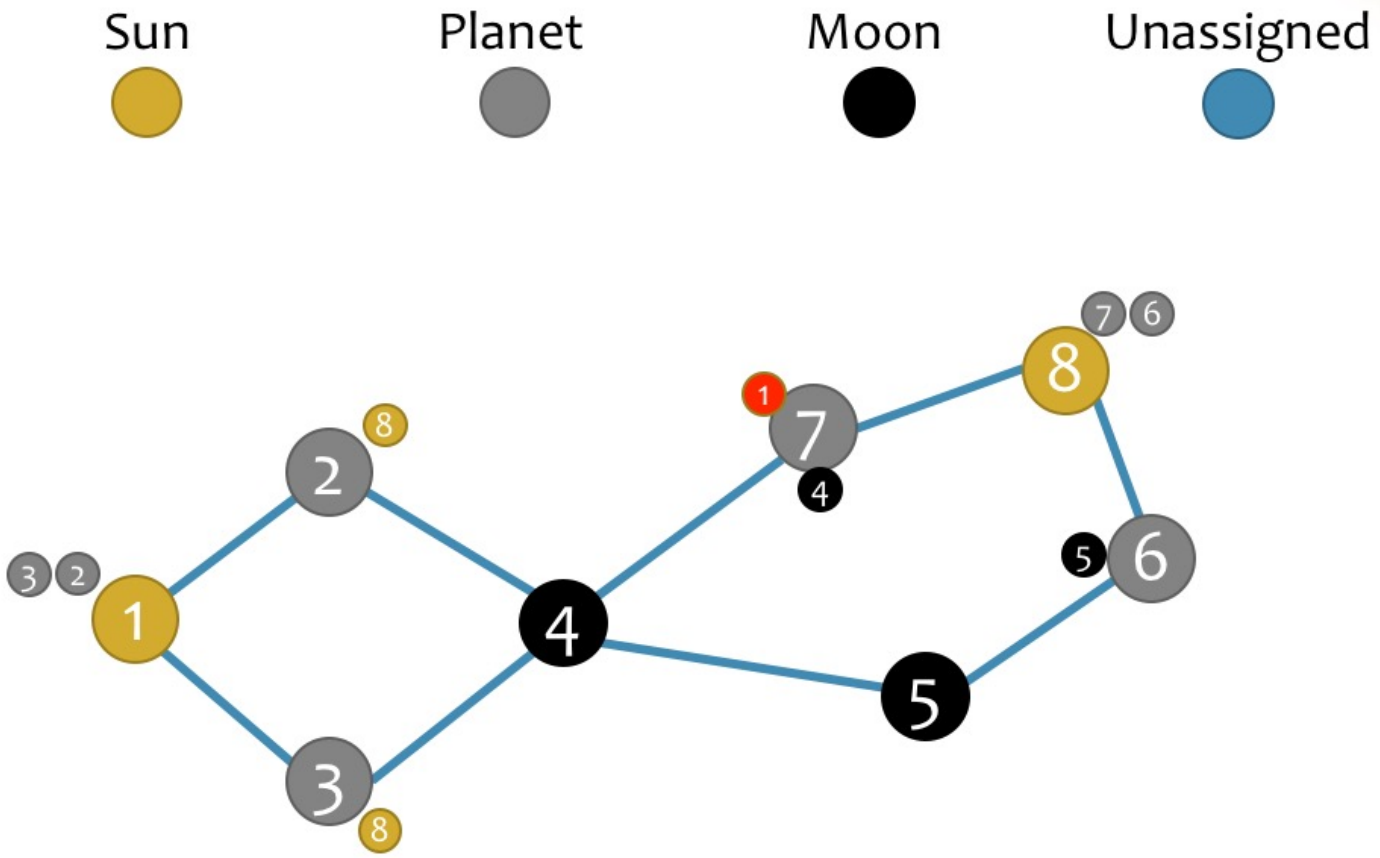
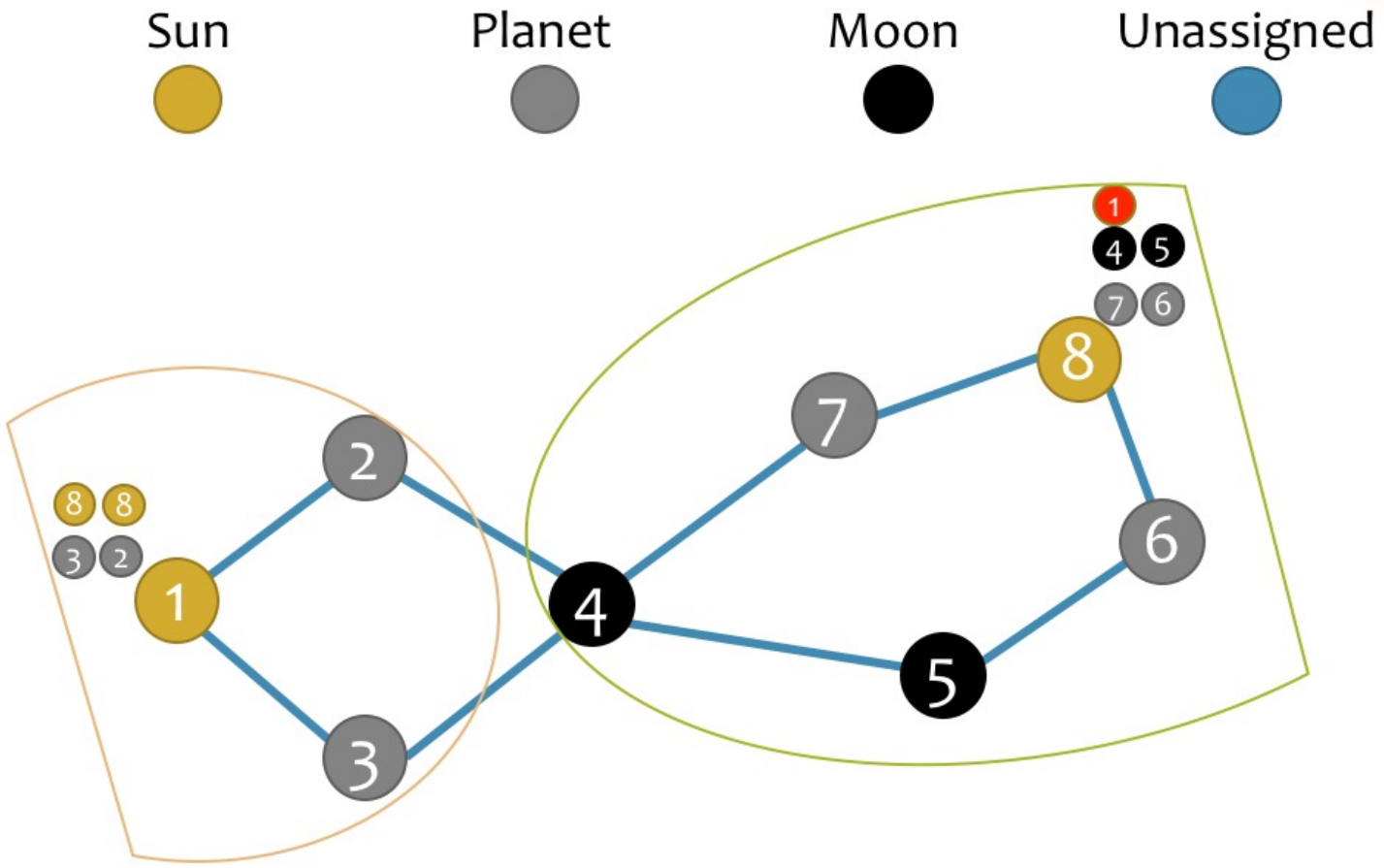


Message Delivery

Distributed Solar Merger (DSM)



Distributed Solar Merger (DSM)

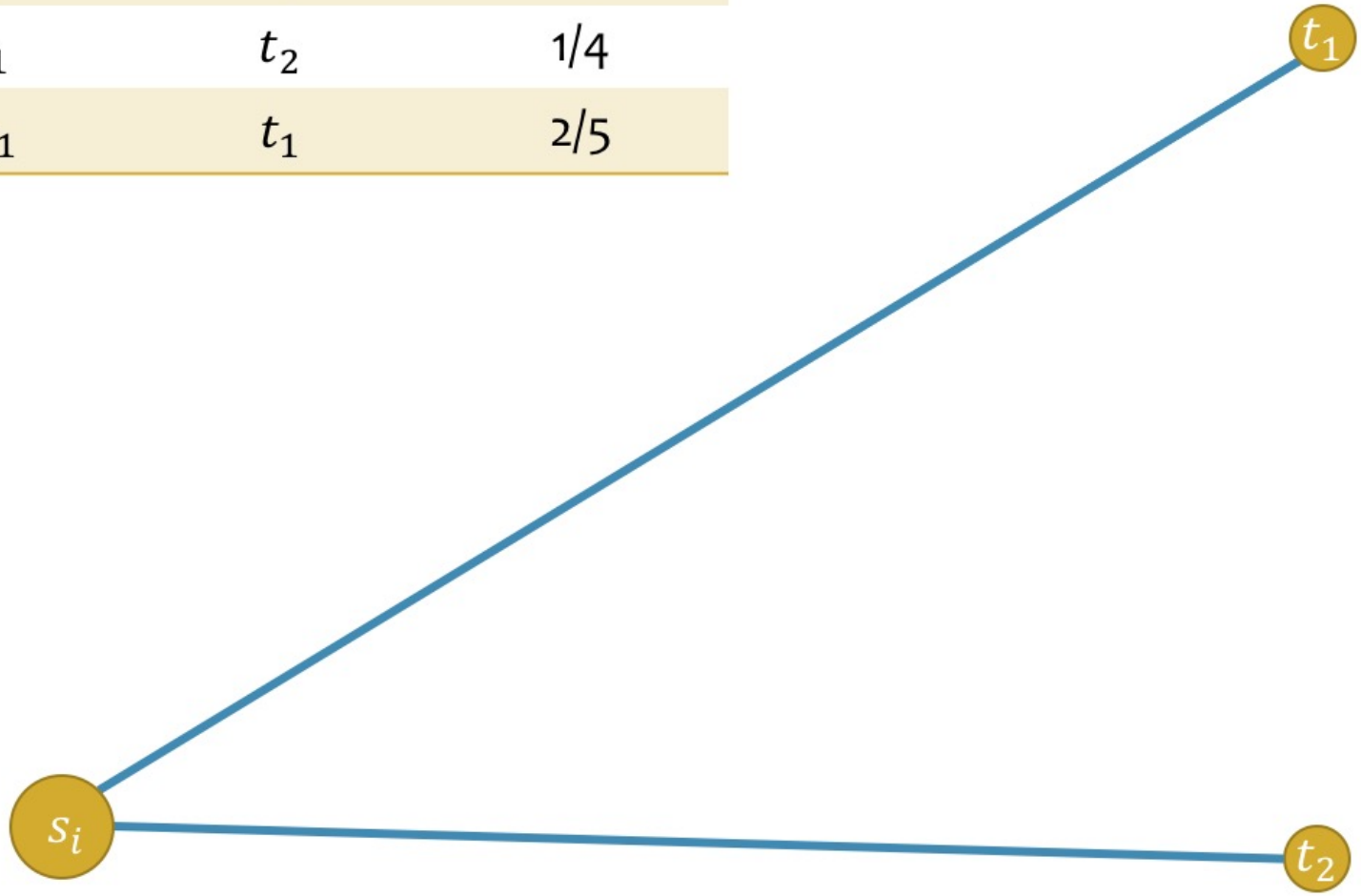
- Process repeated until 100% coverage is achieved
- All paths are found using sun offers
  - Conflict resolutions allow neighbor discovery
- The new level (vertex and edges) is created
- Control passes to the new level

Distributed Solar Placer (DSP)

- For each of its planets/moons it knows:
  - On which path they are
  - Where they are on the path
    - A path between two suns is at most of length 5
- Each sun knows the coordinates of its neighbors

Distributed Solar Placer (DSP)

Planets/M.	Path	Position
p_1	t_1	1/5
p_1	t_2	1/4
m_1	t_1	2/5



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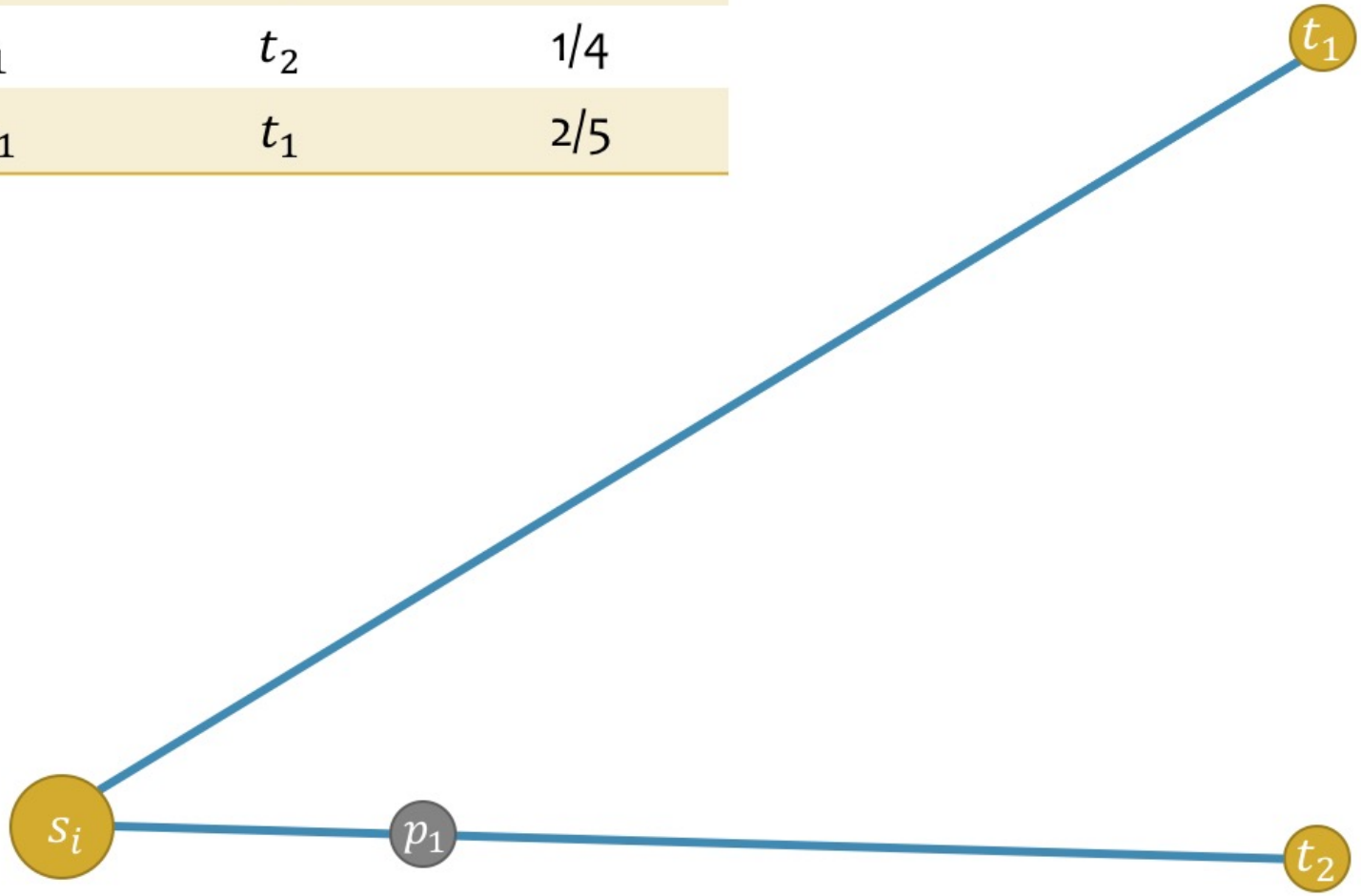

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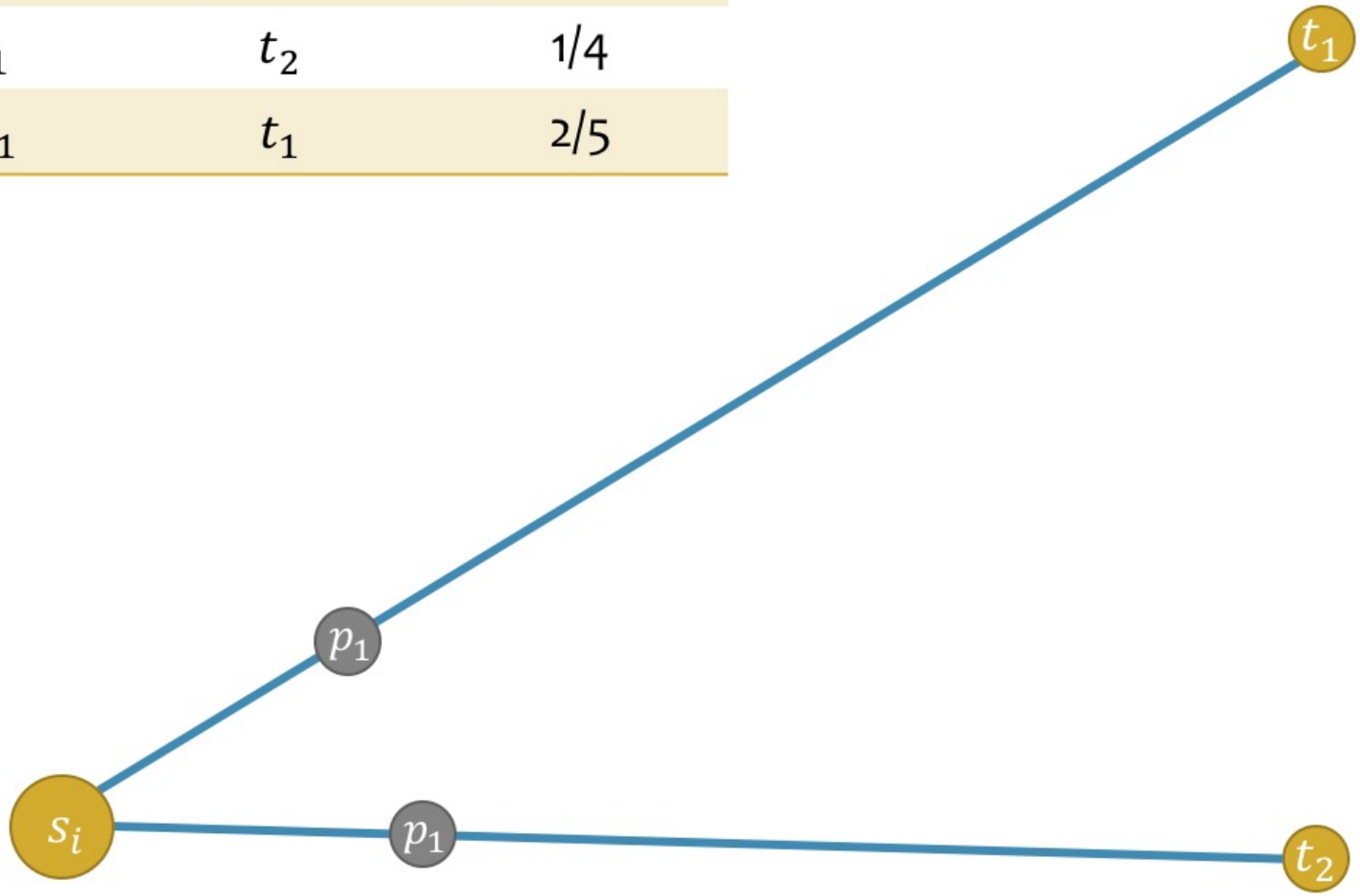

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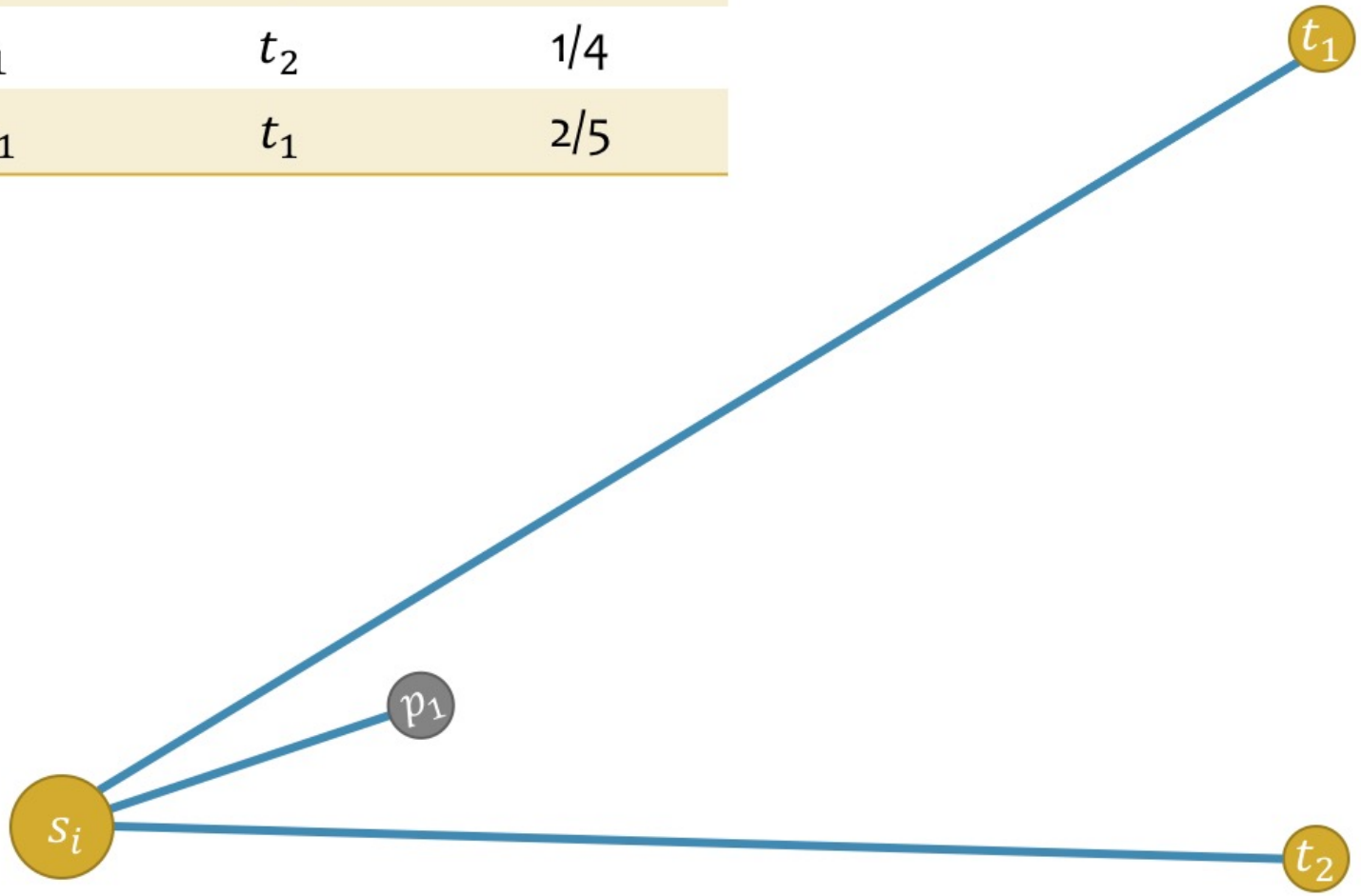

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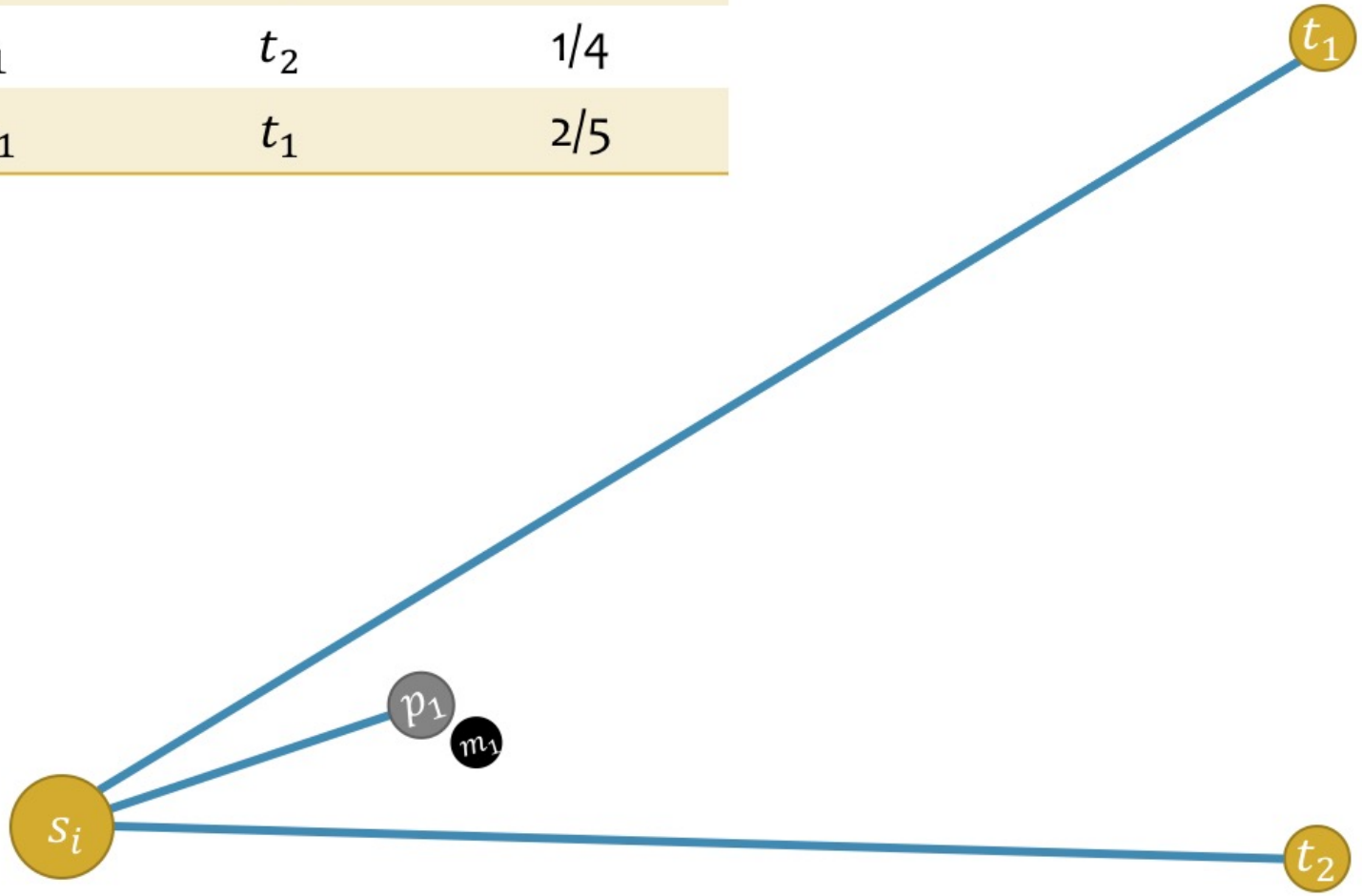

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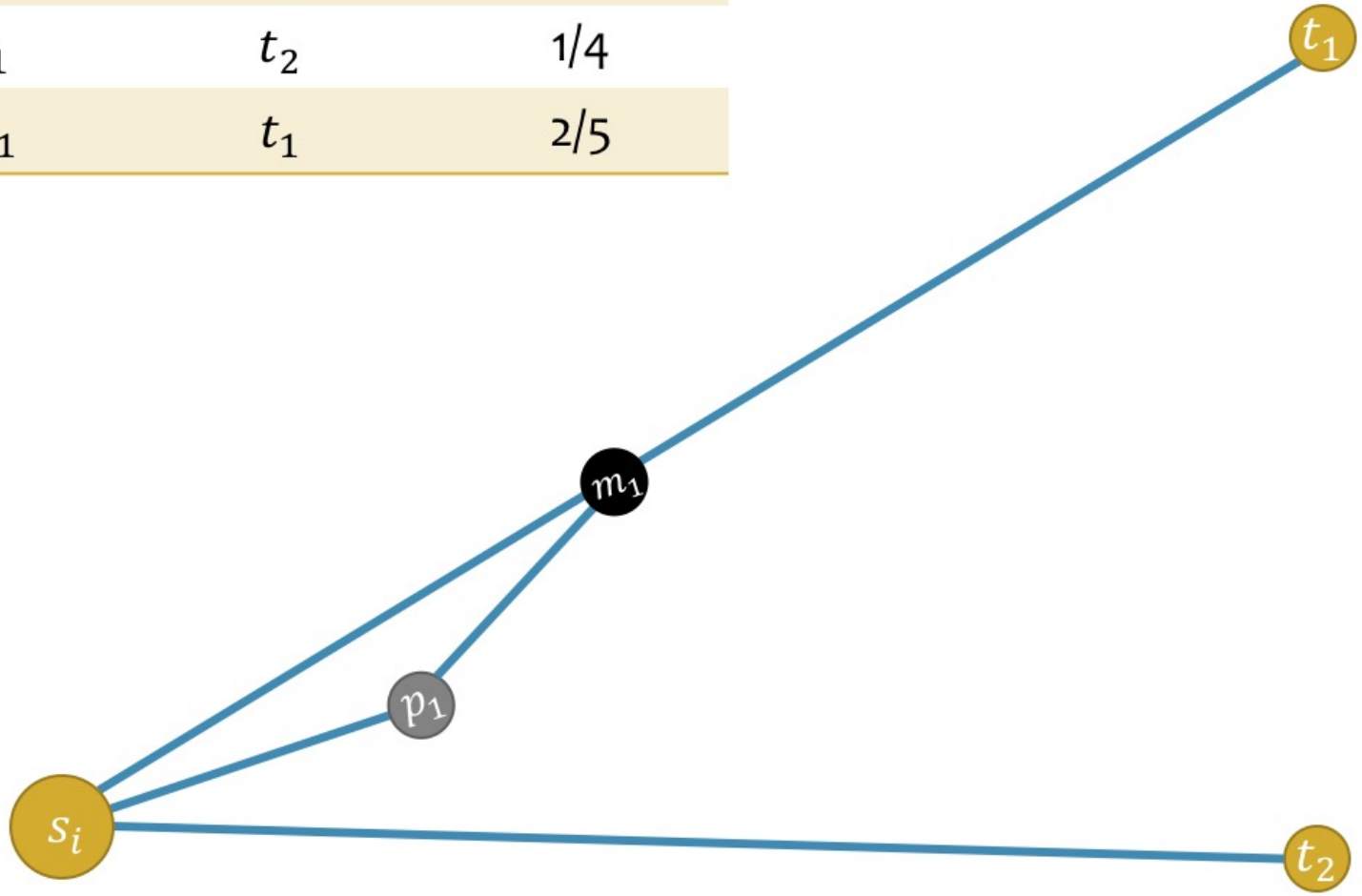

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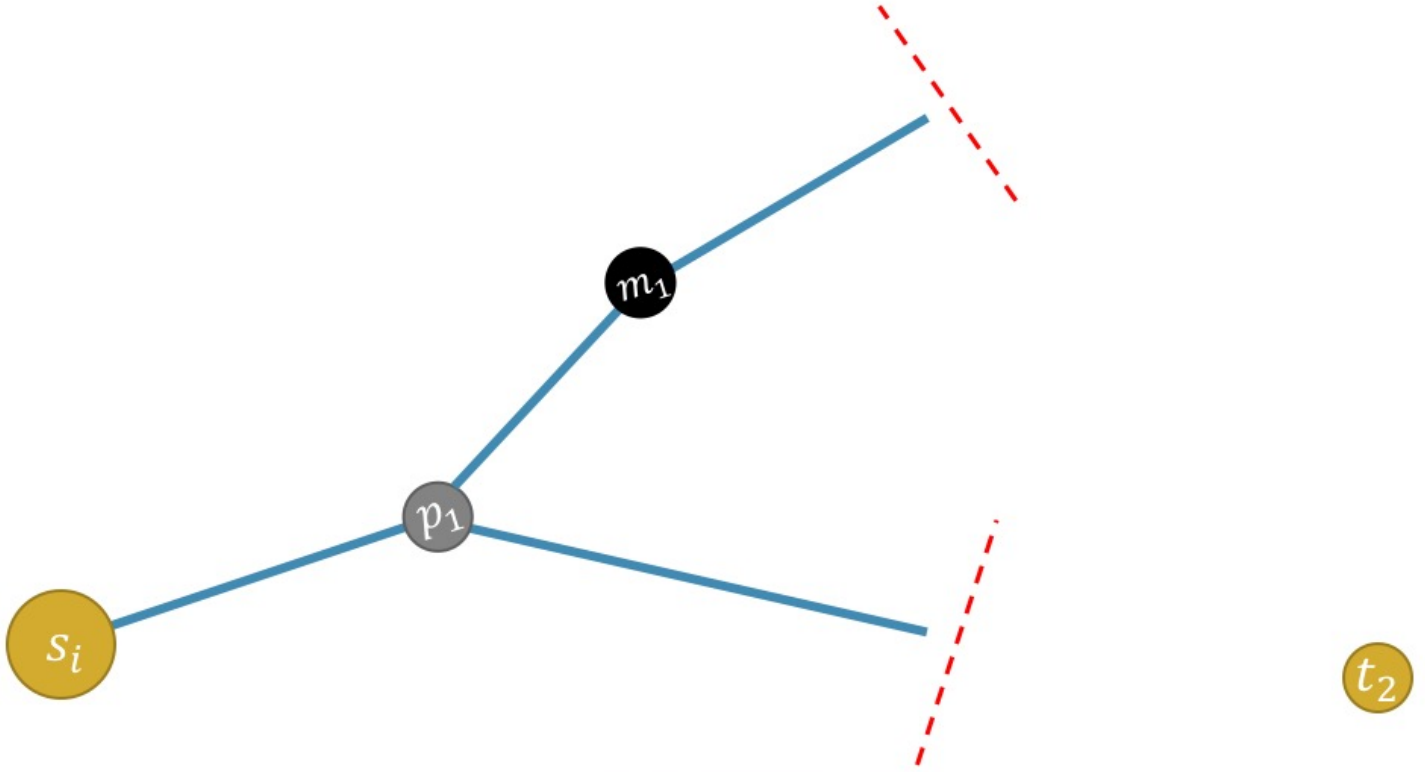


Gila – Single Level Layout

- Based on FR algorithm
- Repulsive forces computed by means of a controlled flooding scheme
  - Spatial decomposition techniques unfeasible
  - GTD as an approximation of geometric distance
- Layout process takes several iterations
  - Each iteration is split in two phases

Gila – Single Level Layout

Seeding

Vertices broadcast their coordinates

Propagation

Forces computation

Messages broadcast

N° of times a message is propagated depends on its *time to live (k)*

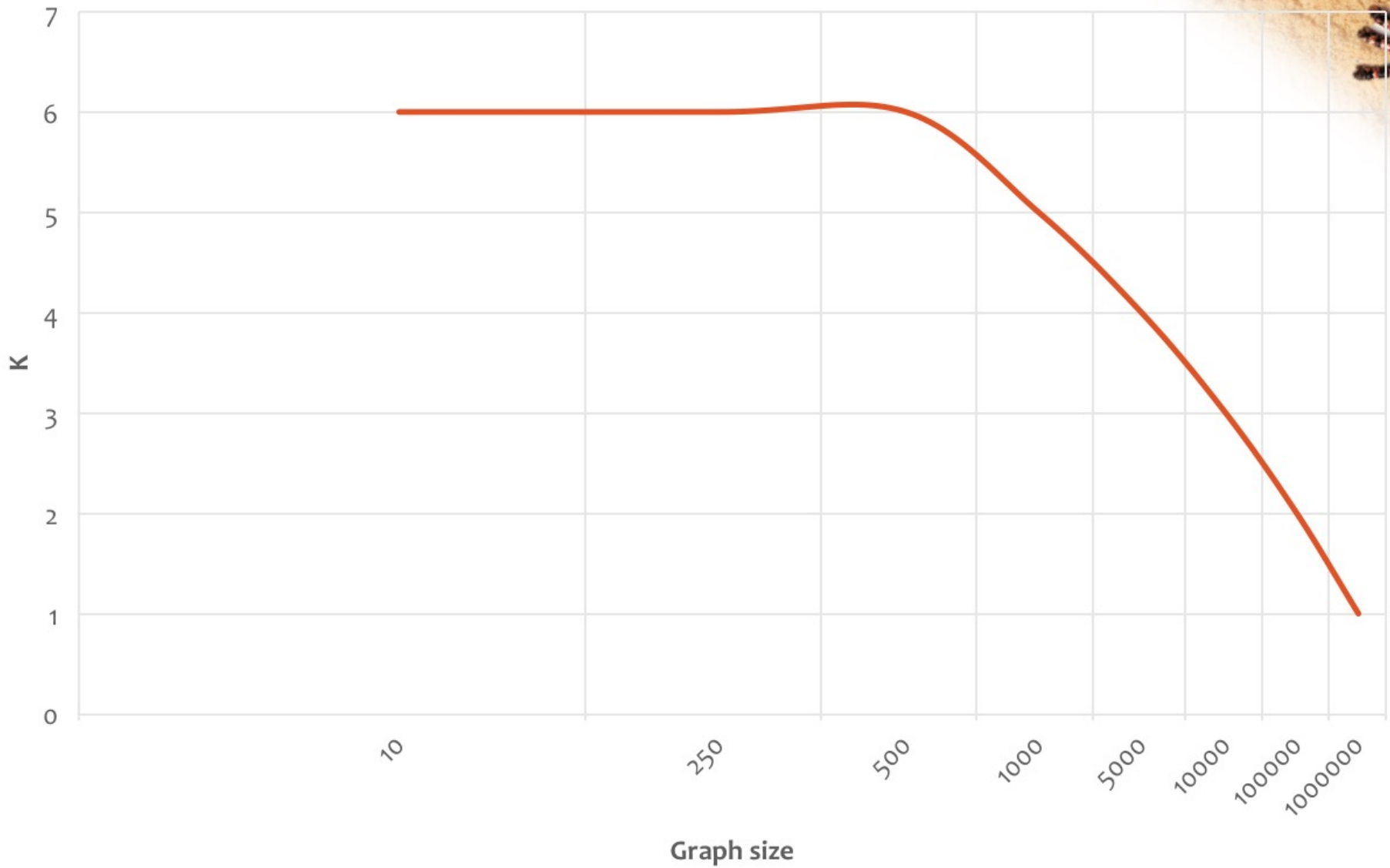
Gila – Single Level Layout

- Overall # of messages: $O(m^k)$
- *A lot* of traffic (and potential overhead)
- Messages are expensive…
- … but a bigger *k* implies better quality

Choose *k*

as a tradeoff between quality and cost

Dynamic *Gila* tuning



Experimental results

Test Suite

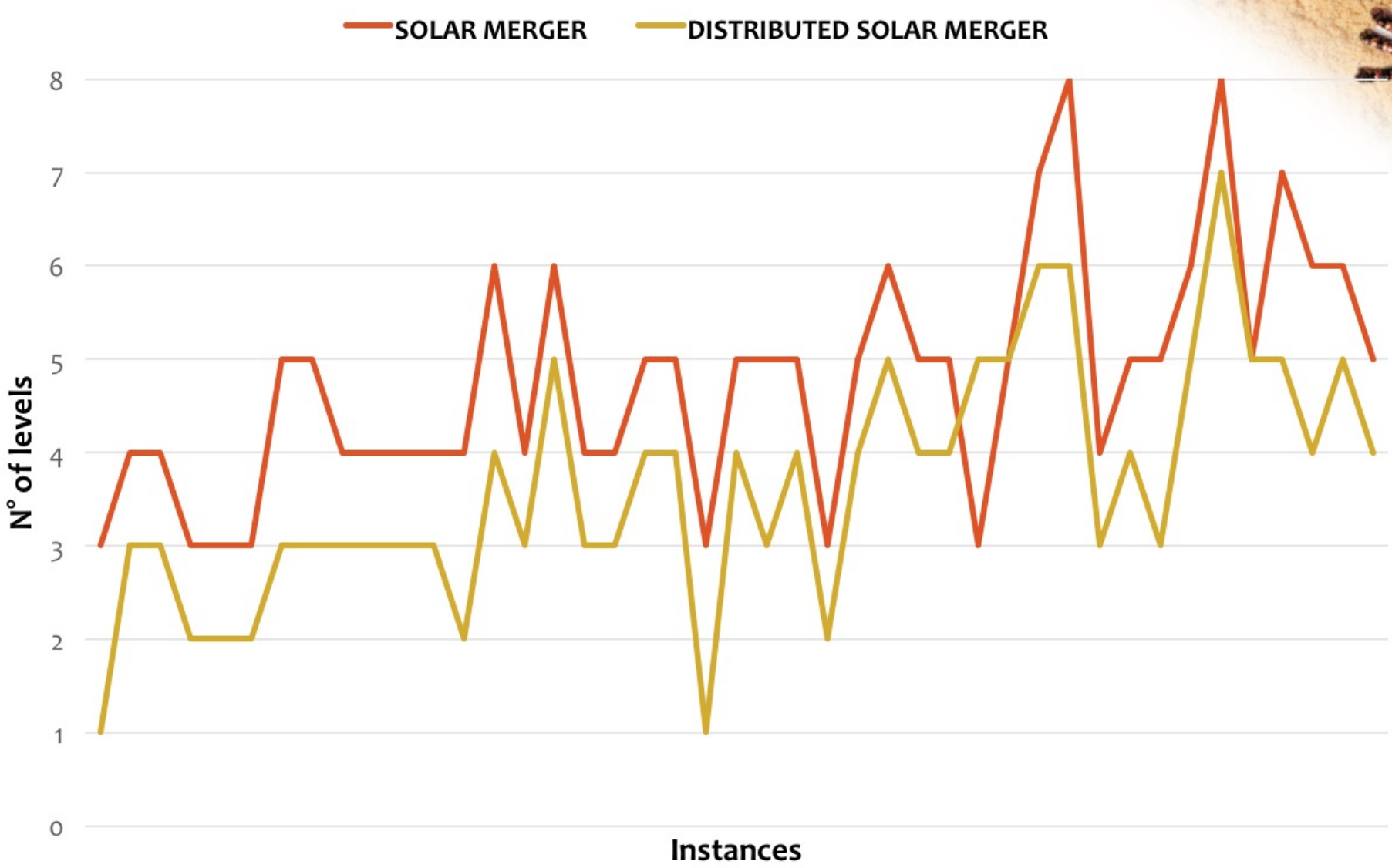
- 43 Small, synthetic graphs
  - *Bartel et al., 2011*
- 5 Medium sized graphs
  - Up to 1.5M edges
- 3 Large graphs
  - Up to ~10M edges

Experimental Environment

- Small, synthetic graphs
  - Single machine pseudo-cluster, MacBook laptop
- Medium sized graphs
  - AWS cluster, 5-15 r3.xlarge instances
- Large graphs
  - AWS cluster, 20-30 r3.xlarge instances

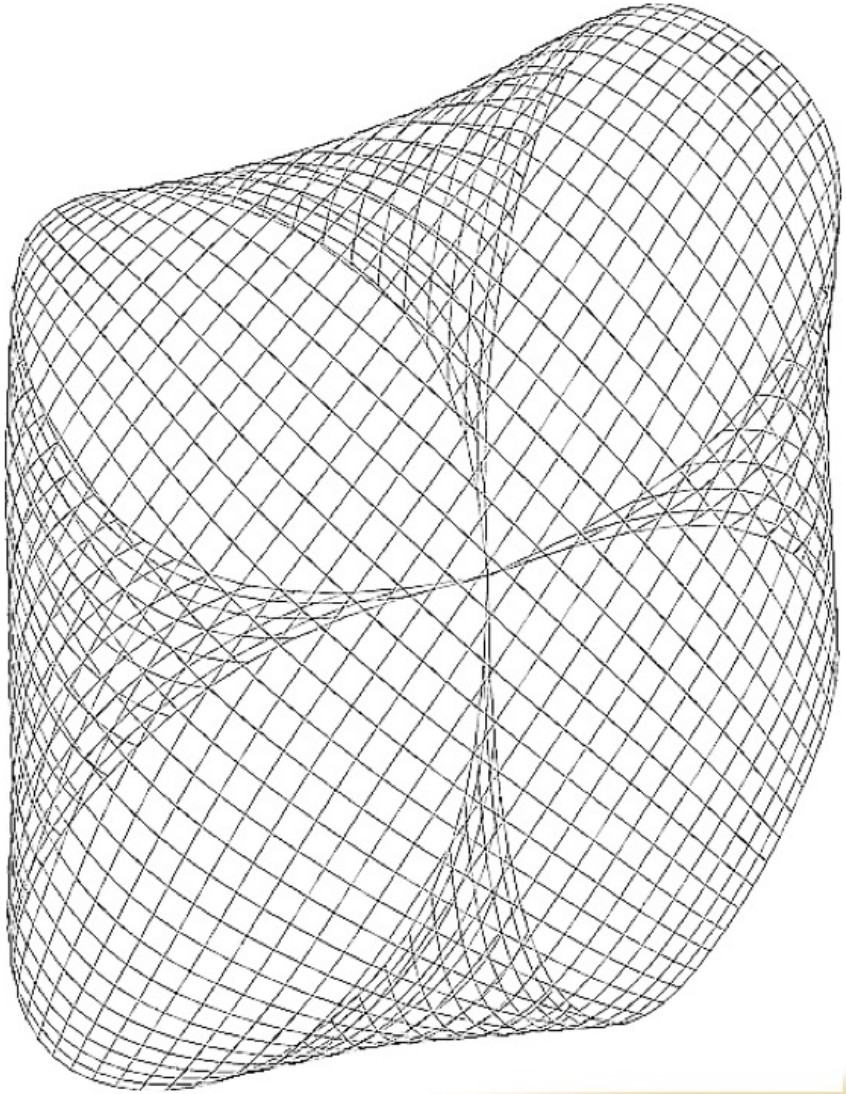
4 cores,
30GB Ram

Number of Levels

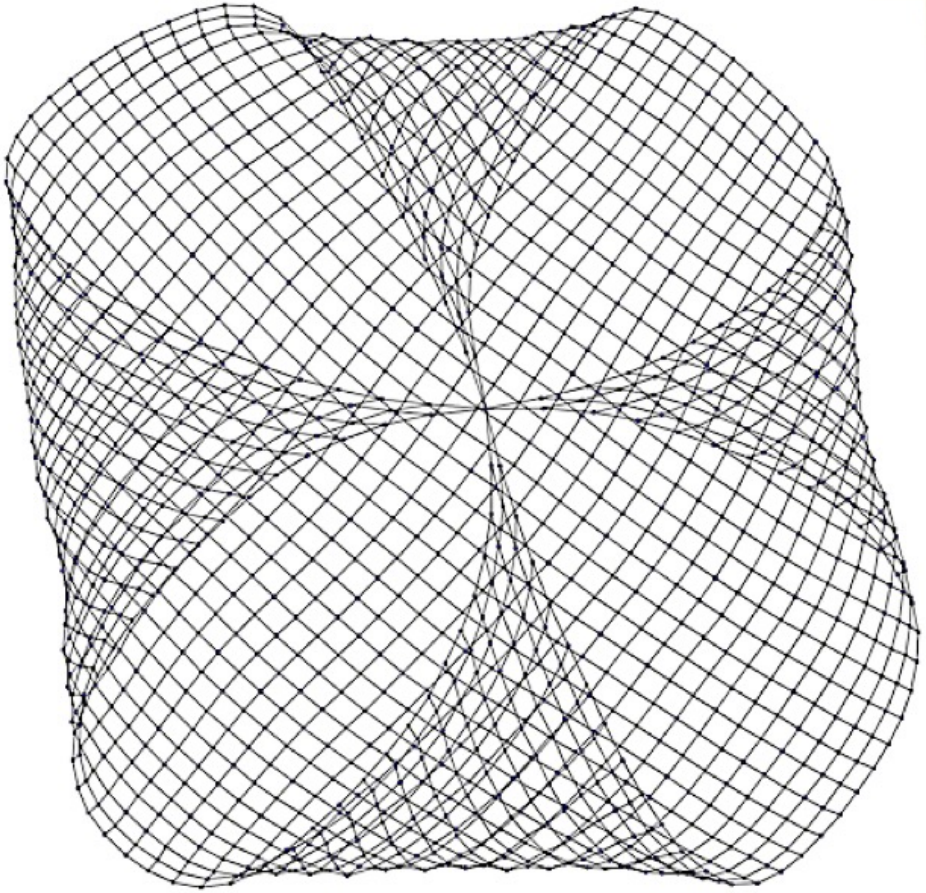


Grid 40x40 Double Folded

Multi-Gila

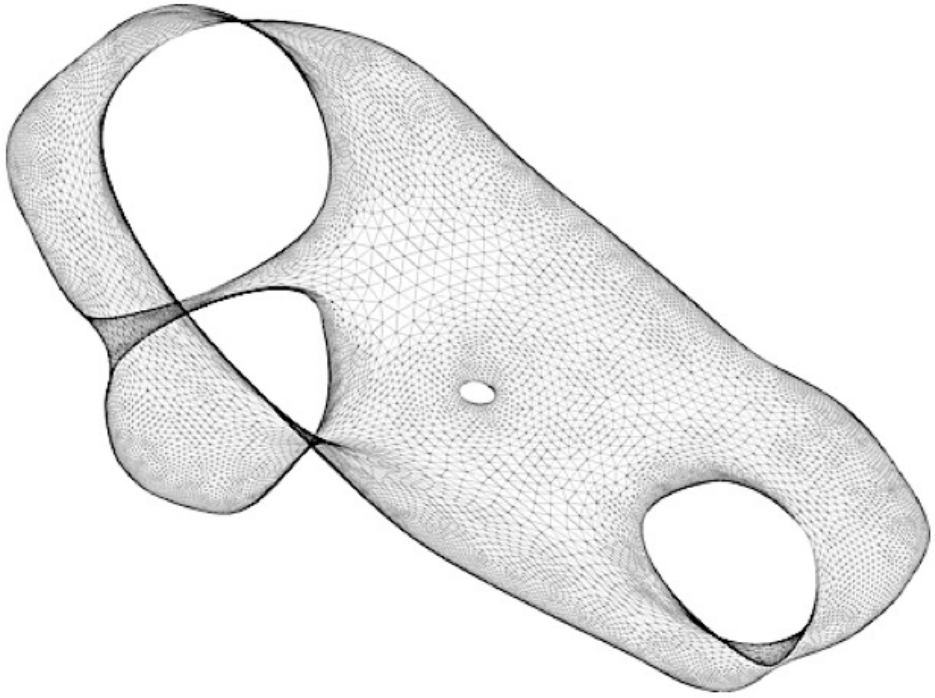


FM³



"4elt" Mesh

Multi-Gila



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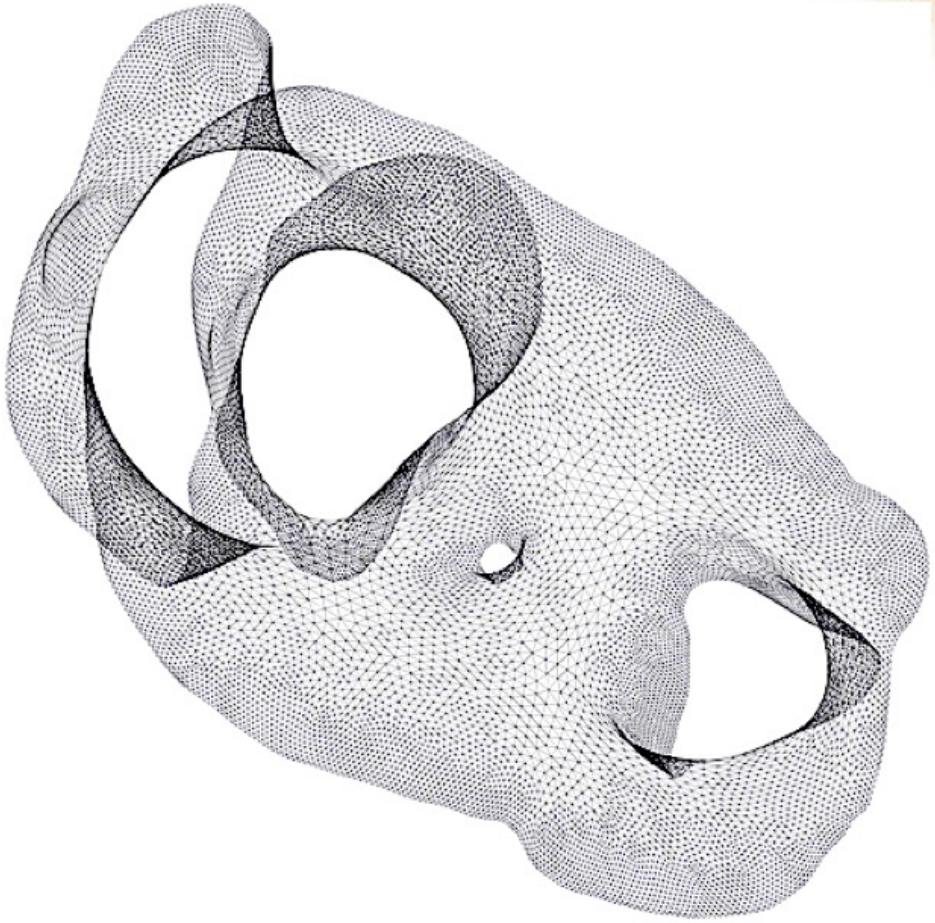
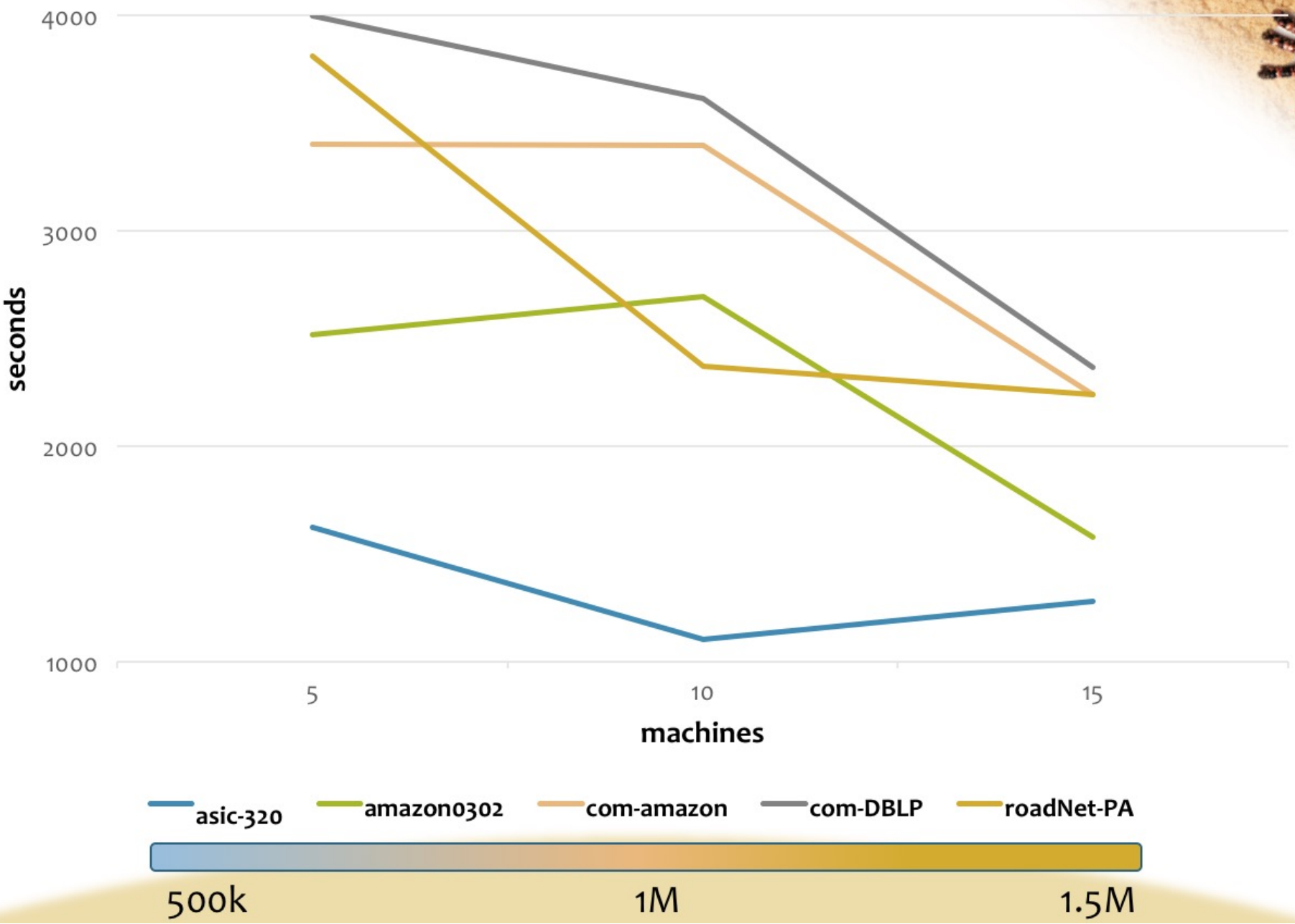
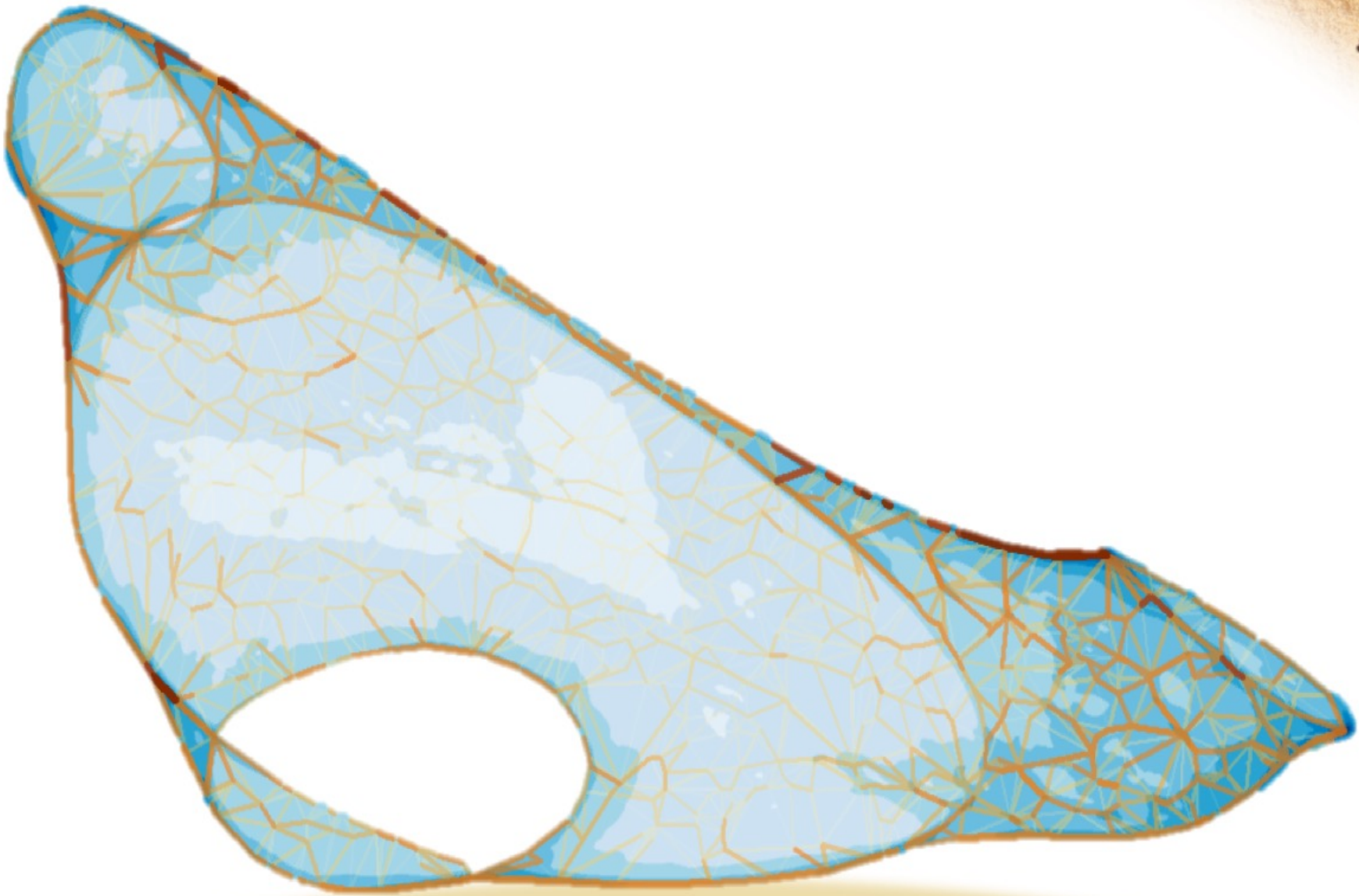


Medium-Sized Graphs Scalability



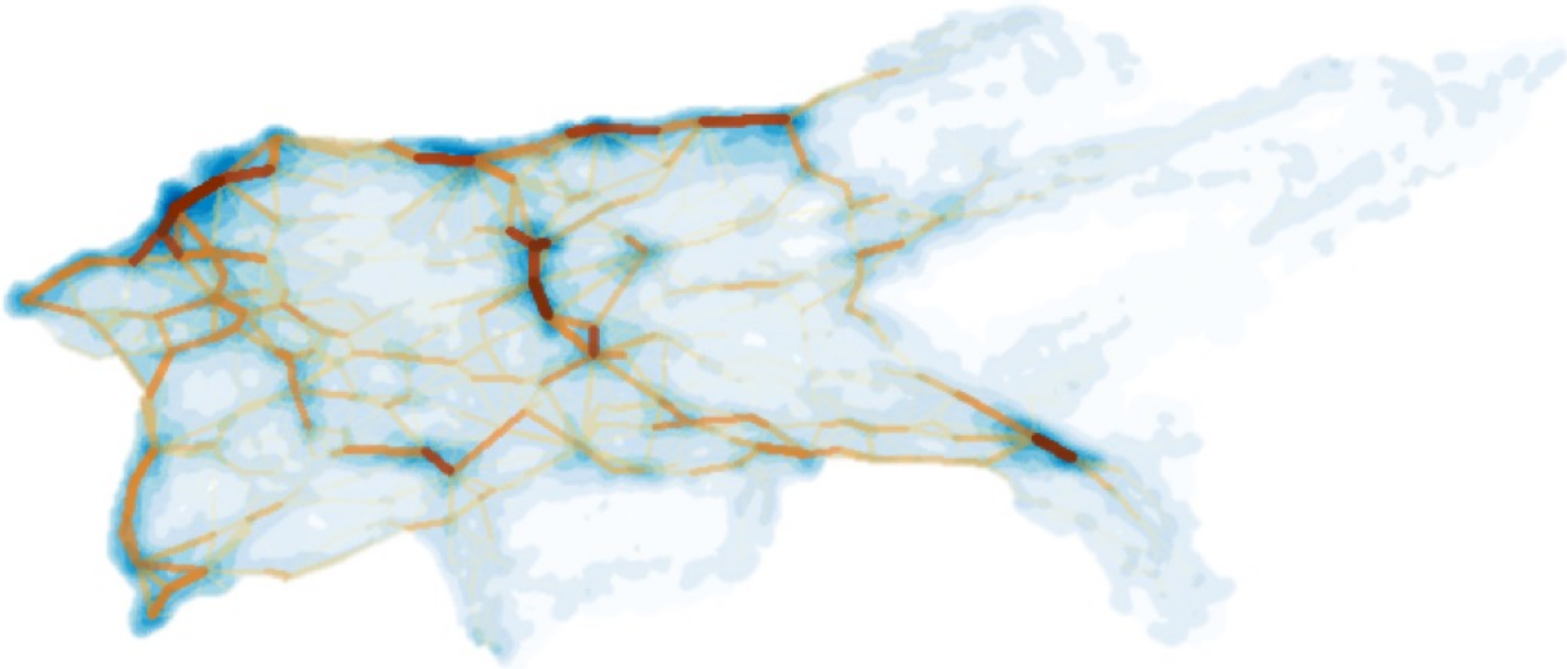
Applications: *Multi-Gila* and *Lago* ❖

❖ Brandes et al., 2012



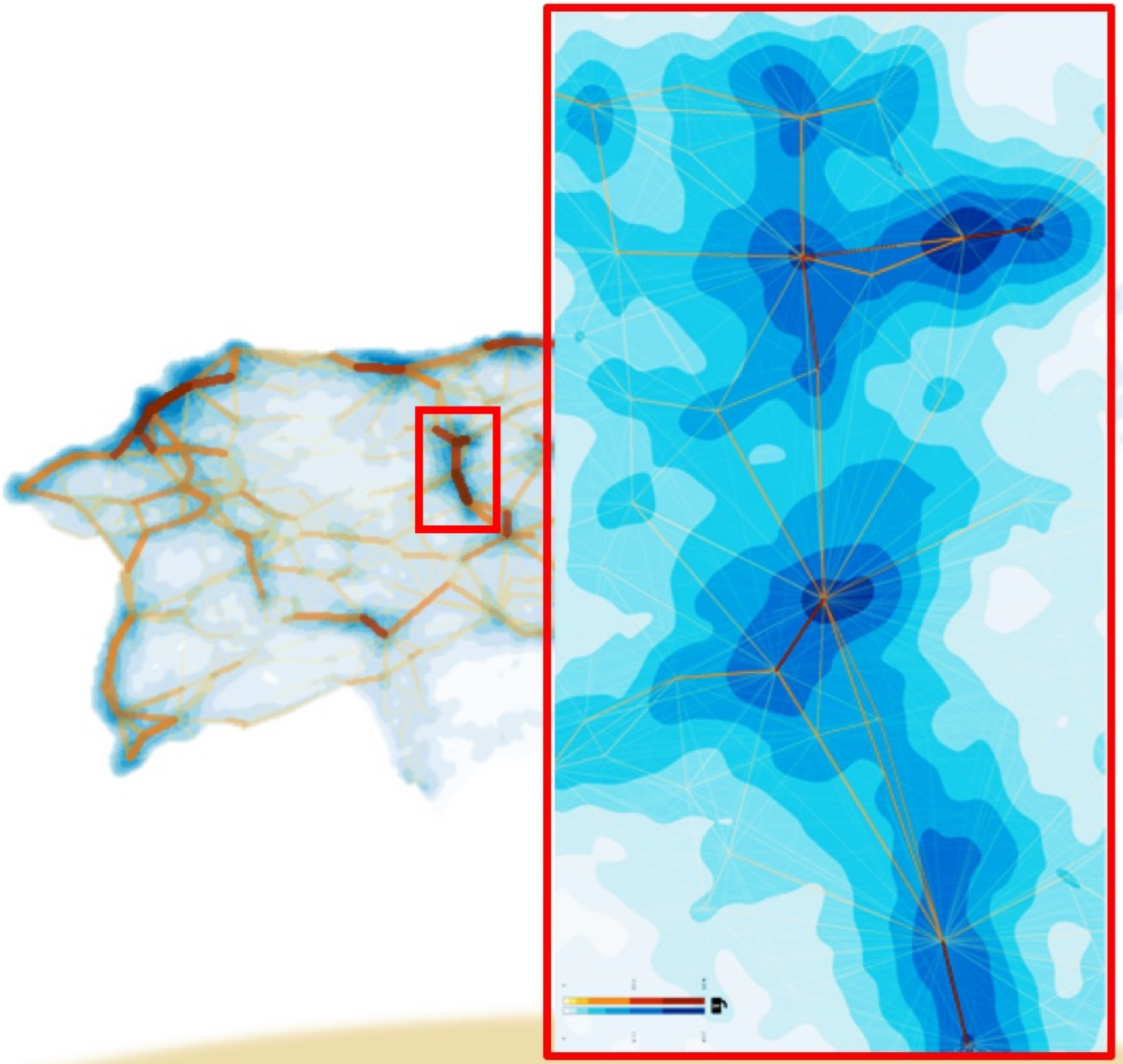
Hugetric-00020, 7M vertices, 11M edges

Applications: *Multi-Gila* and *Lago*



Asic-320, 121k vertices, 515k edges

Applications: *Multi-Gila* and *Lago*



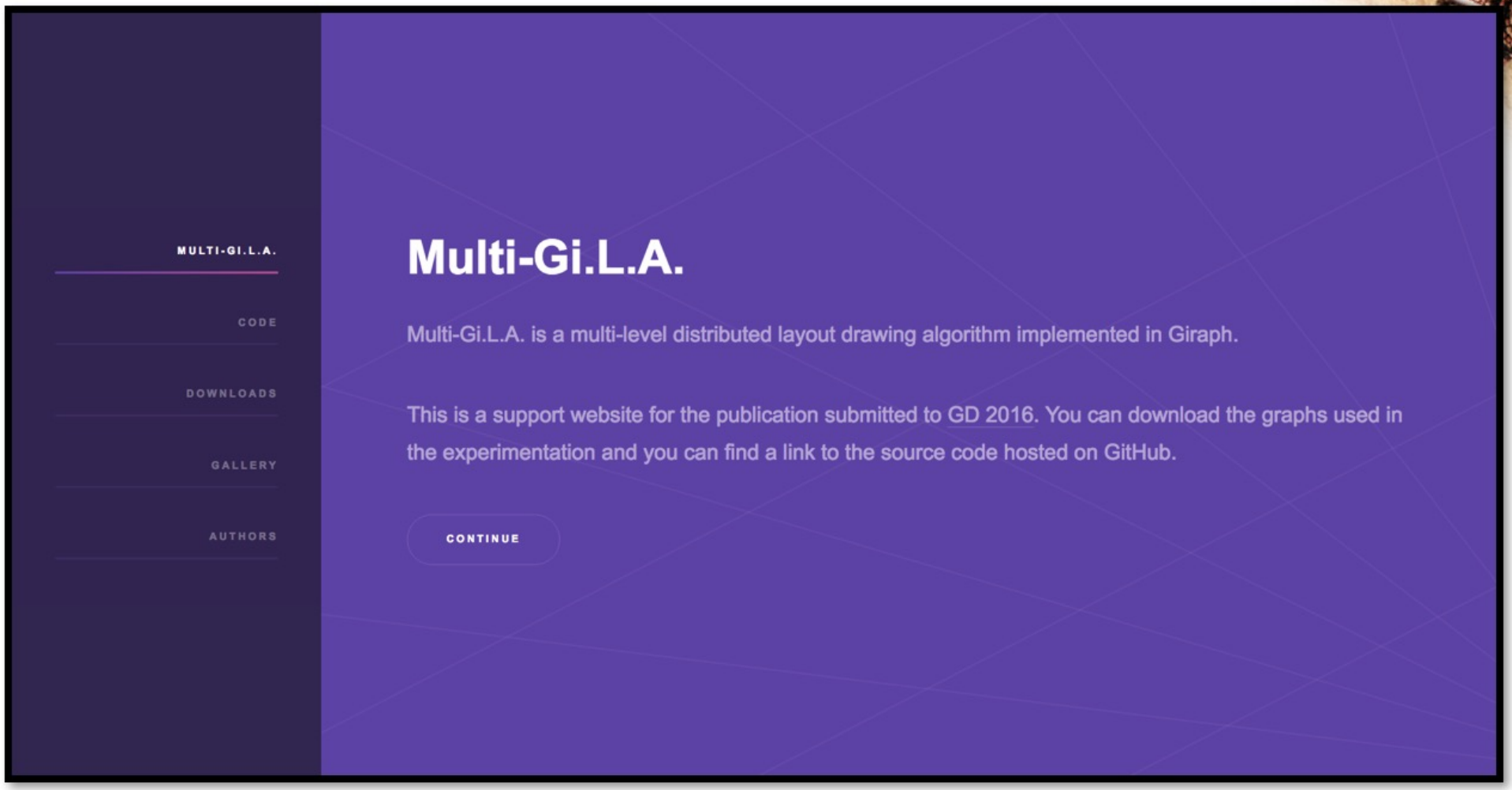
Asic-320, 121k vertices, 515k edges

Conclusions & Future Work

- Multi-Gila: the first distributed multilevel FD
  - Quality of drawings comparable to FM^3
  - Exhibits high scalability with large graphs
- Future work
  - New repulsive forces approximation techniques
  - New coarsening techniques

THANK YOU

Multi-Gila Website



http://multigila.graphdrawing.cloud