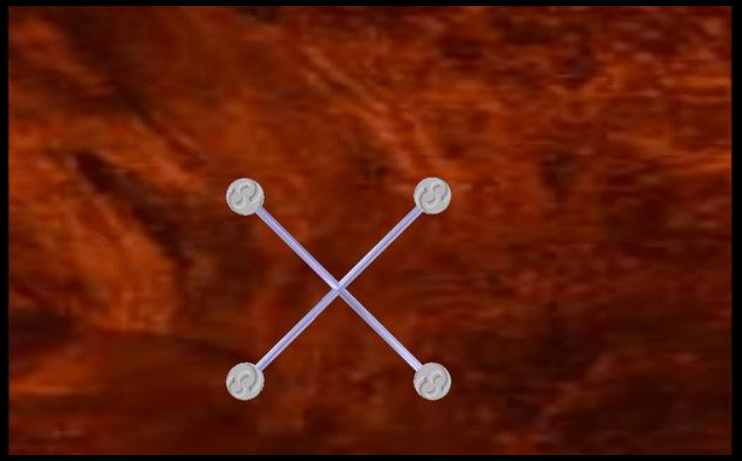
Planning and Navigation of Climbing Robots in Low-Gravity Environments



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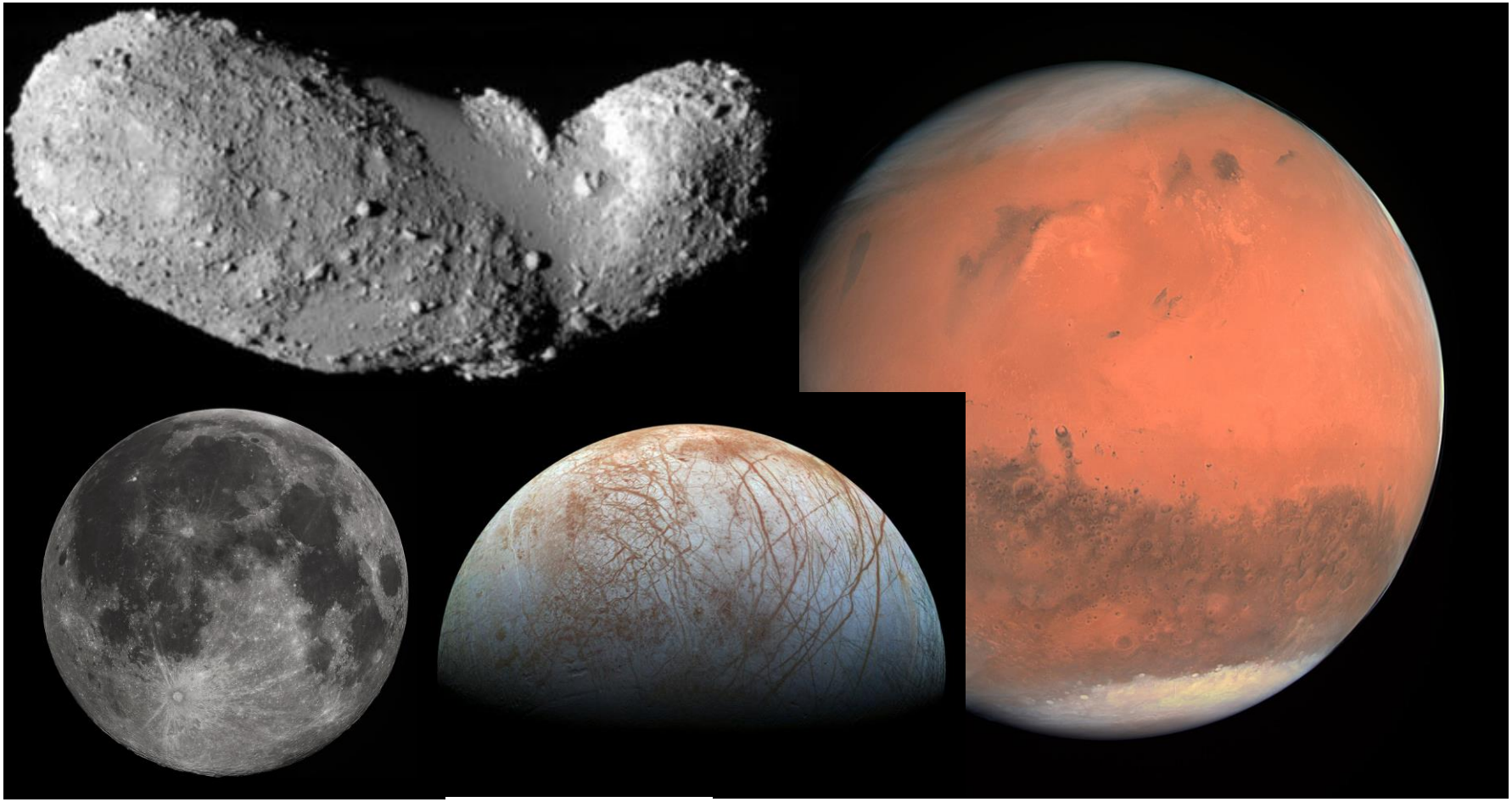
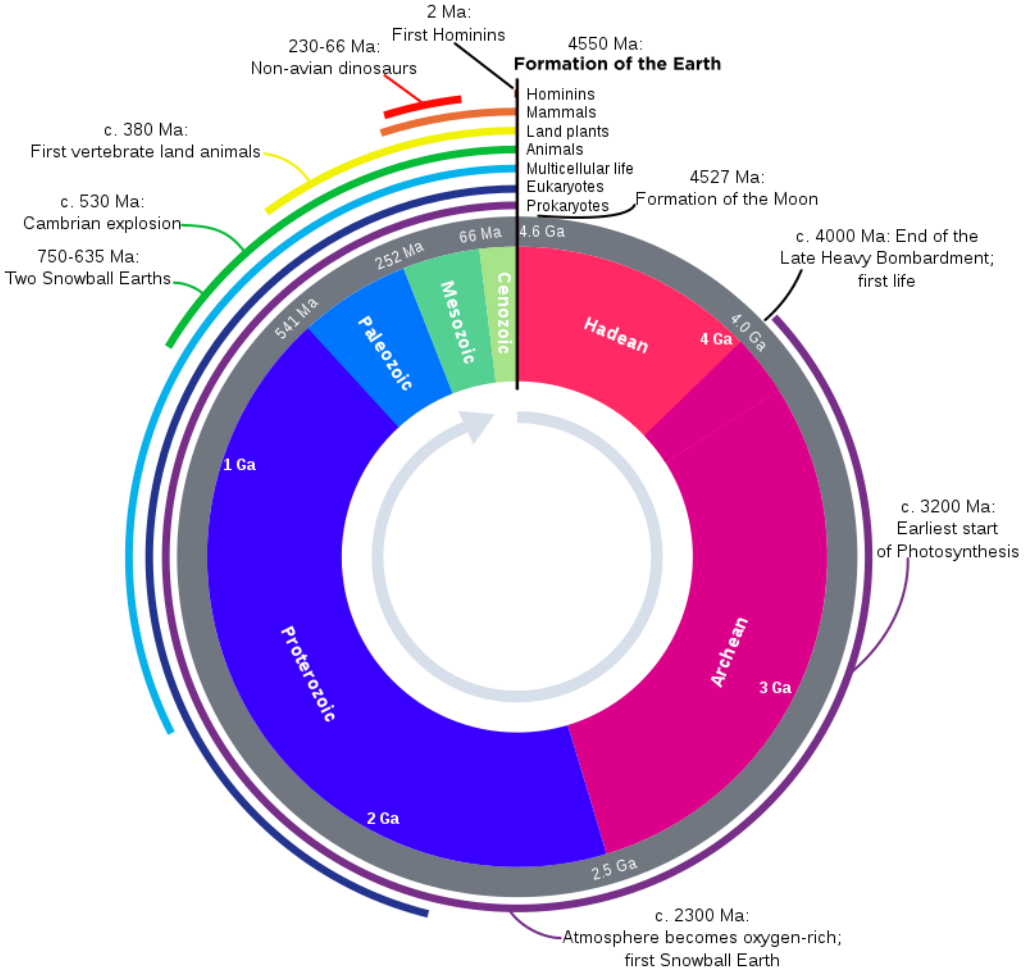
Low Gravity Environments



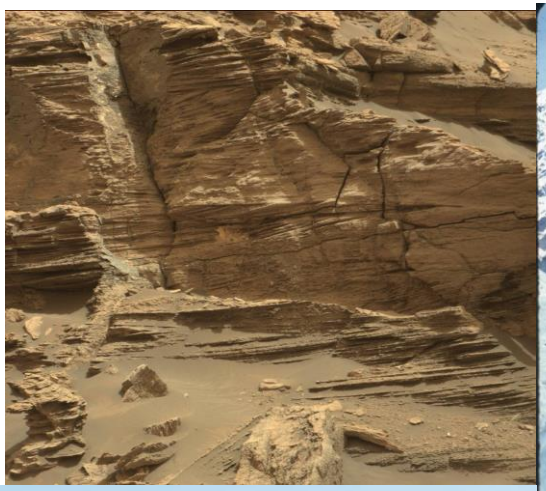
Planetary Science and Geology

- Strata form the basis for the geological history of Earth
- What if we could see these for other planets?



Science Targets

- Cliffs
- Crevasses
- Crater walls
- Caves

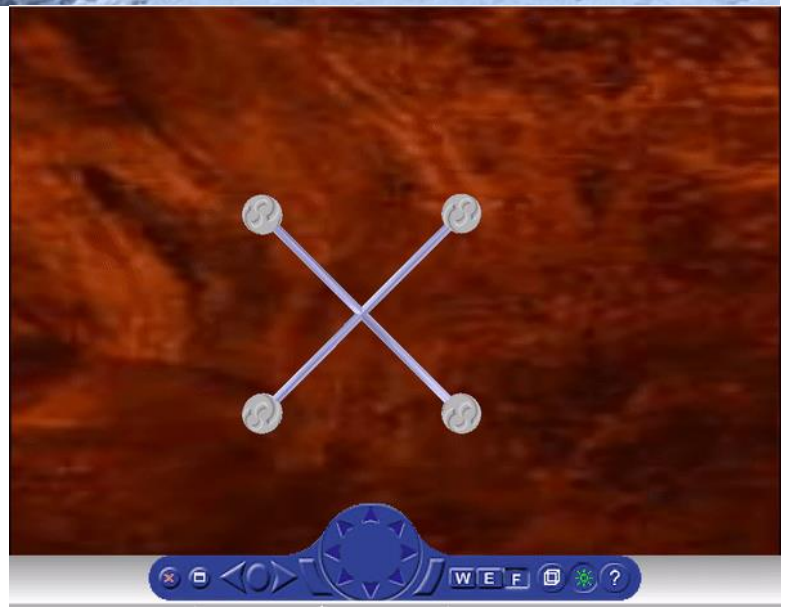


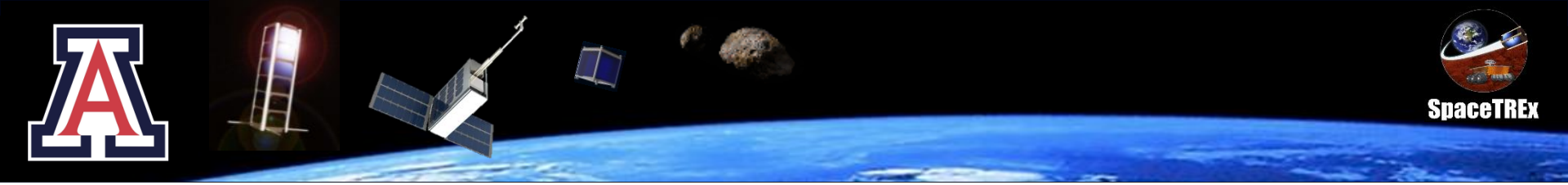
Related Work

- JPL
  - Axel
  - TRESSA
  - LEMUR-3

Alternate Means of Locomotion

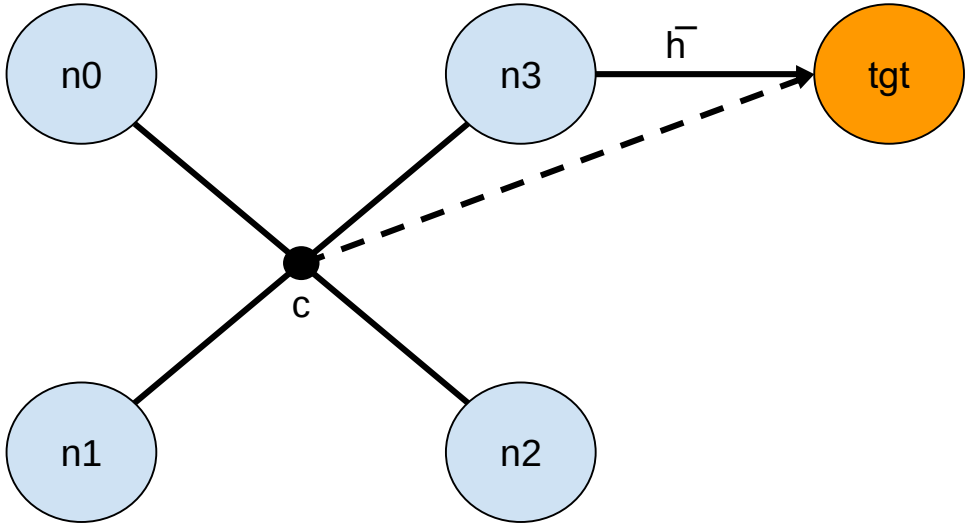
- What about glacial climbing?
- "Rope team" robots
  - Take turns moving
  - Hop using microthrusters
  - Cling using microspines

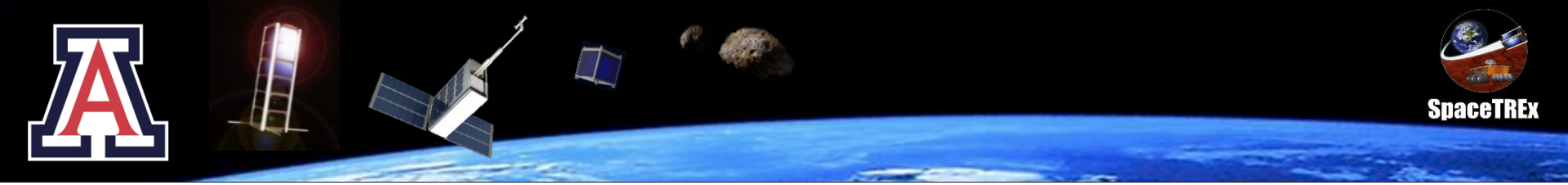




System of Autonomous Climbing Robots

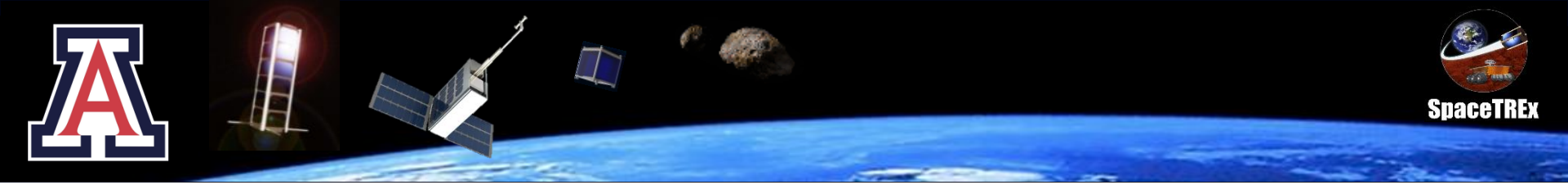
- Four linked hopping robots (nodes)
- Redundancy allows for node failures





Objective

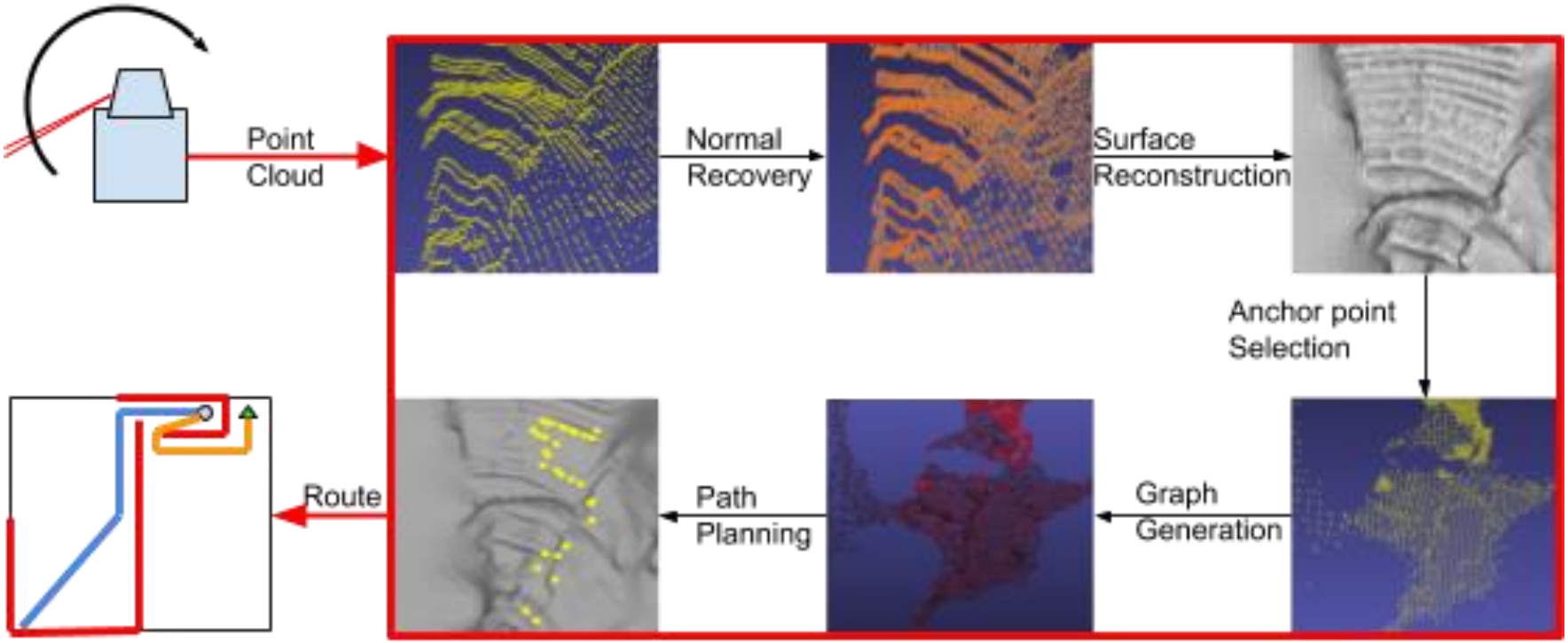
- Navigate a team of climbing robots from point A to point B autonomously?
  - Failure tolerant
  - Close to realtime



Challenges

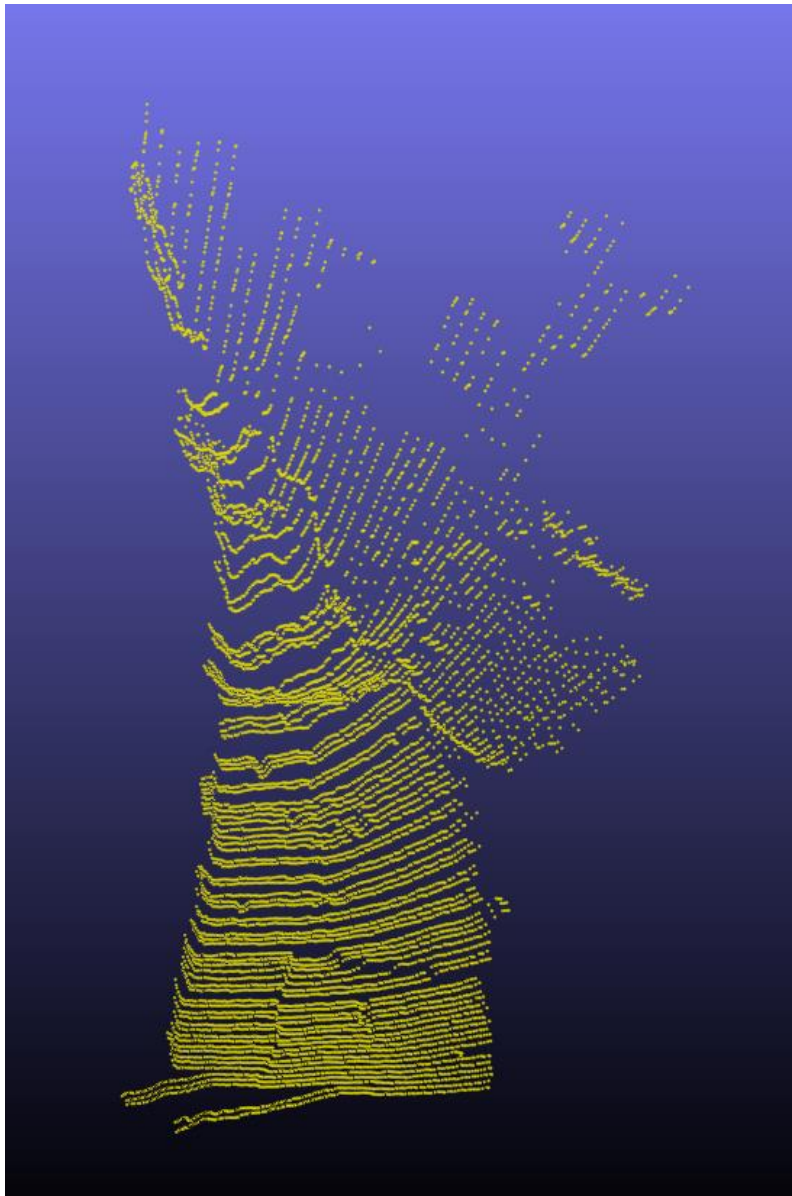
- Climbing is hard
- Unknown environment beforehand
- Reduced system awareness
- Much more research done on driving/flying/walking

Pipeline


Point
Cloud
Normal
Recovery
Surface
Reconstruction
Anchor point
Selection
Graph
Generation
Path
Planning
Route

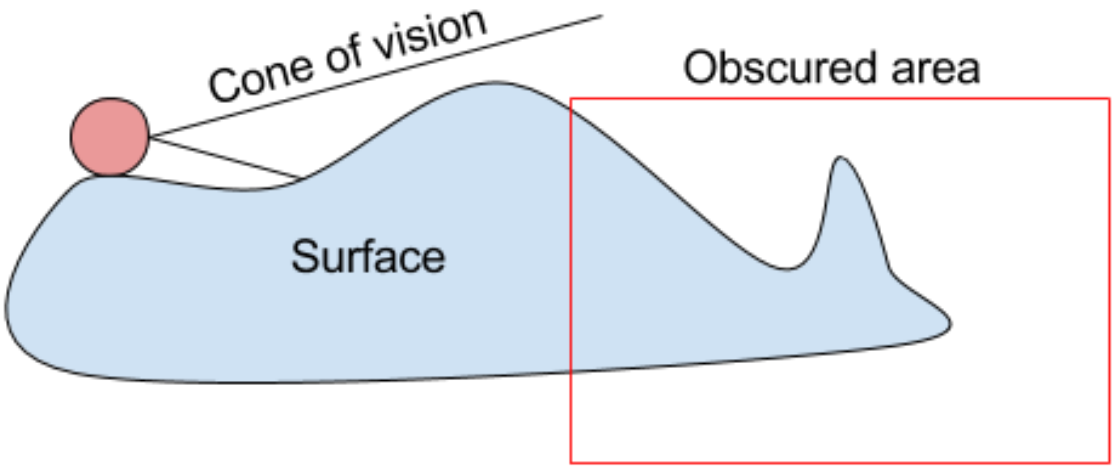
Step 1: Point Cloud Generation

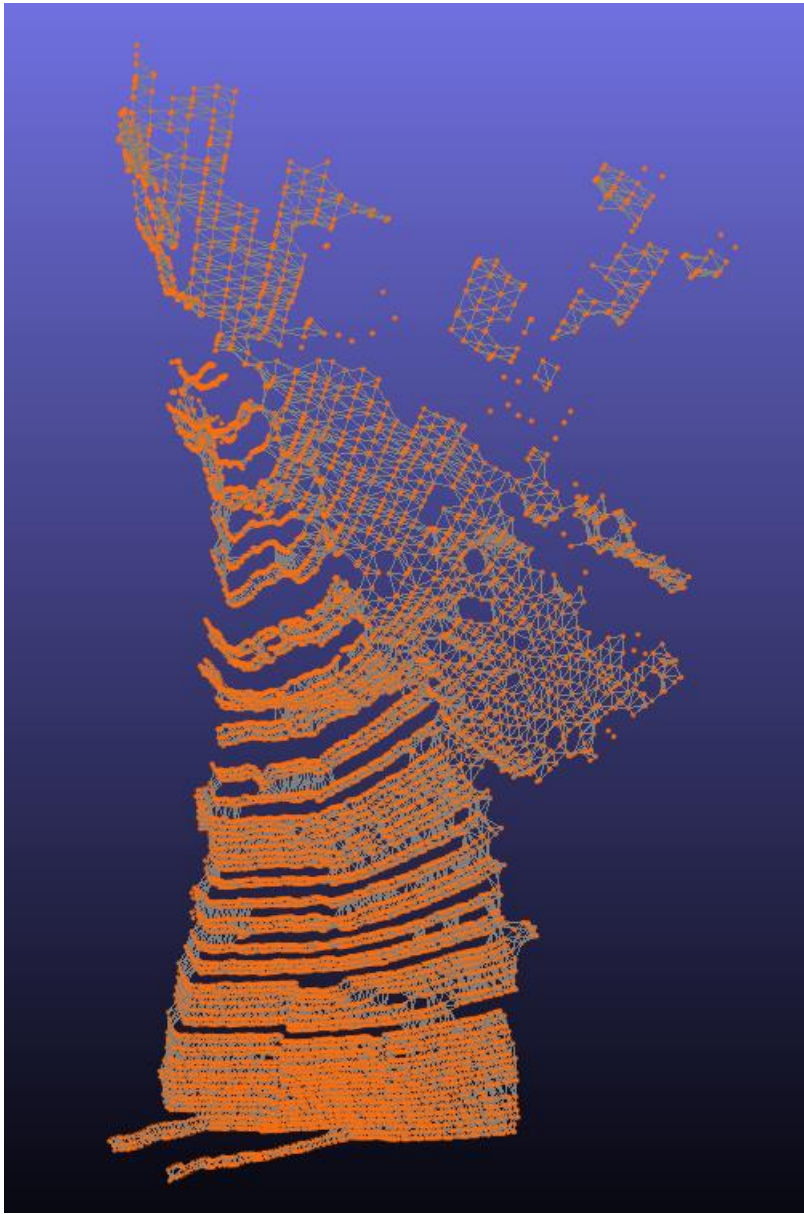
- Get LiDAR data



Step 2: Normal Vector Reconstruction

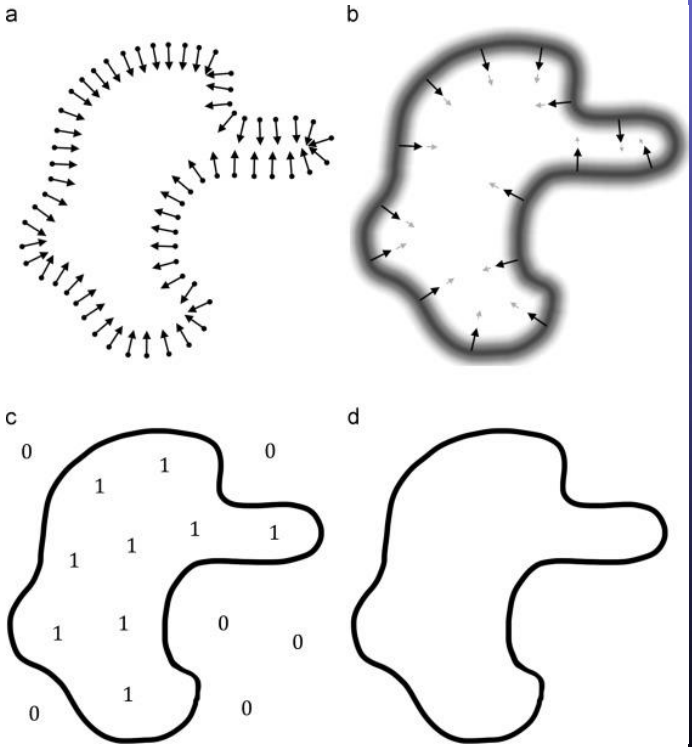
- Triangulation



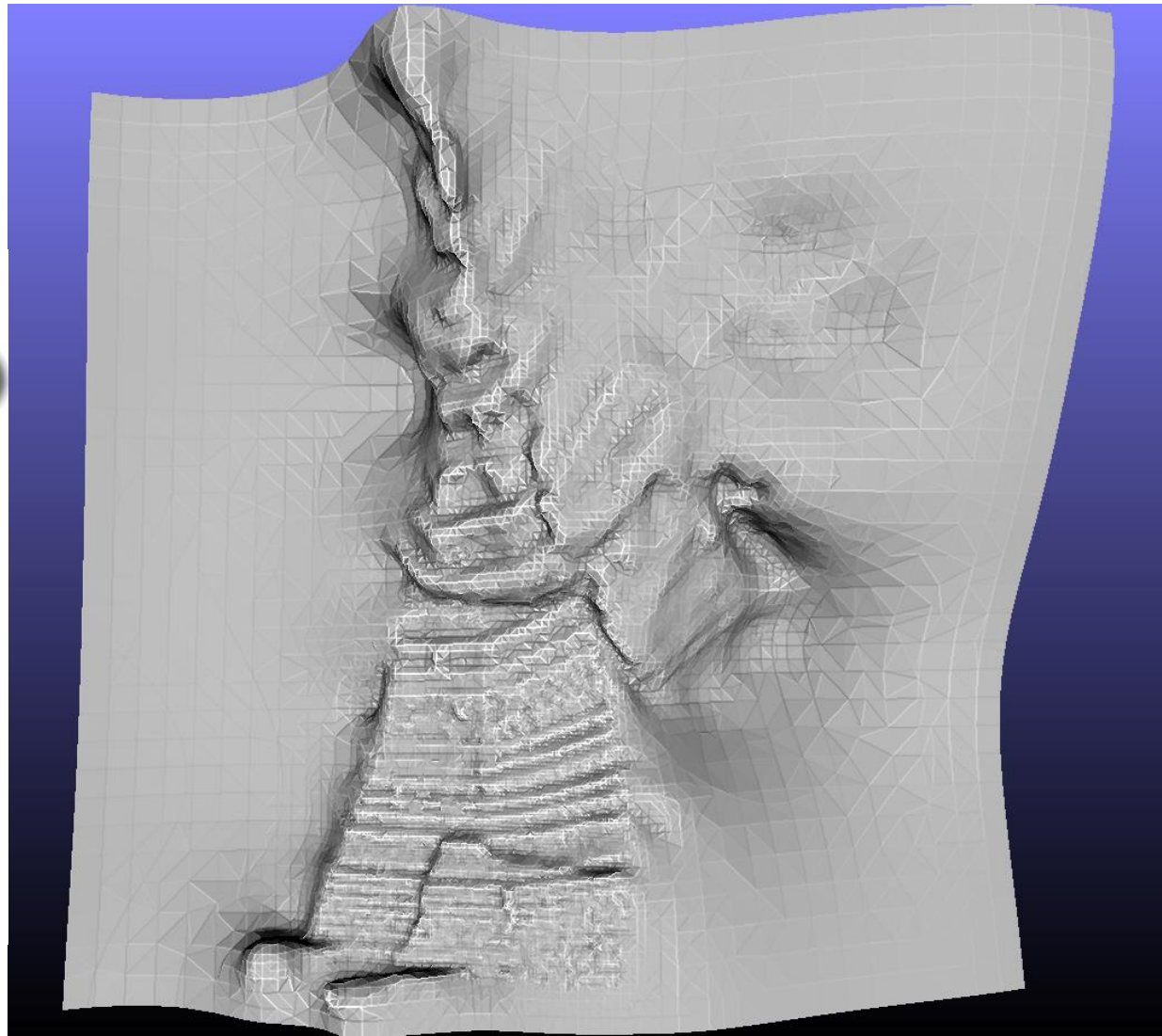


Step 3: Surface Reconstruction

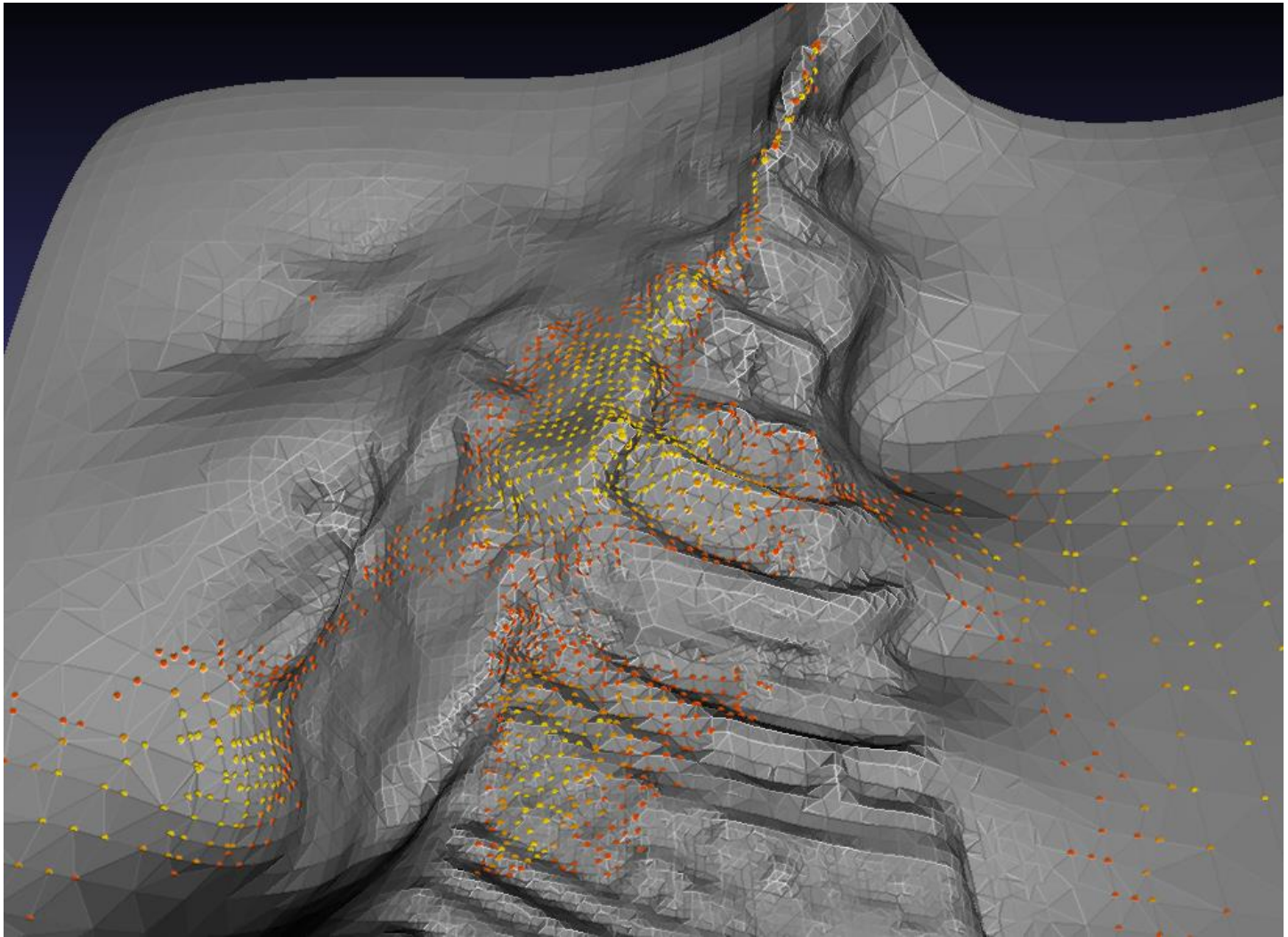
- No gaps



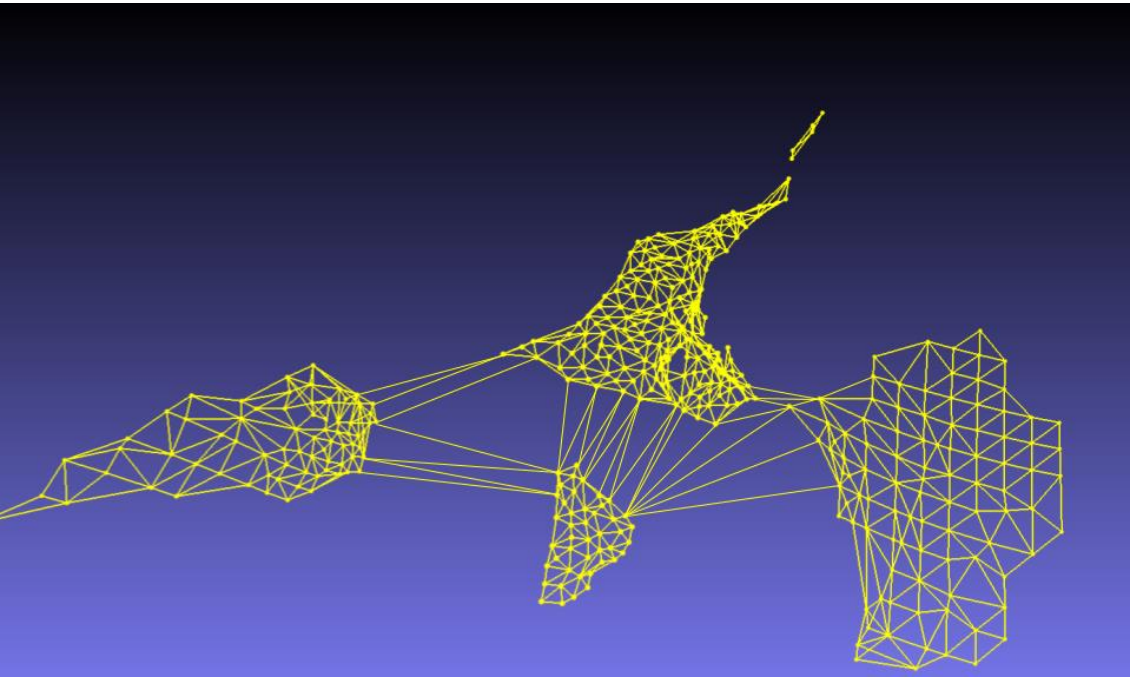
Src: Lai et al



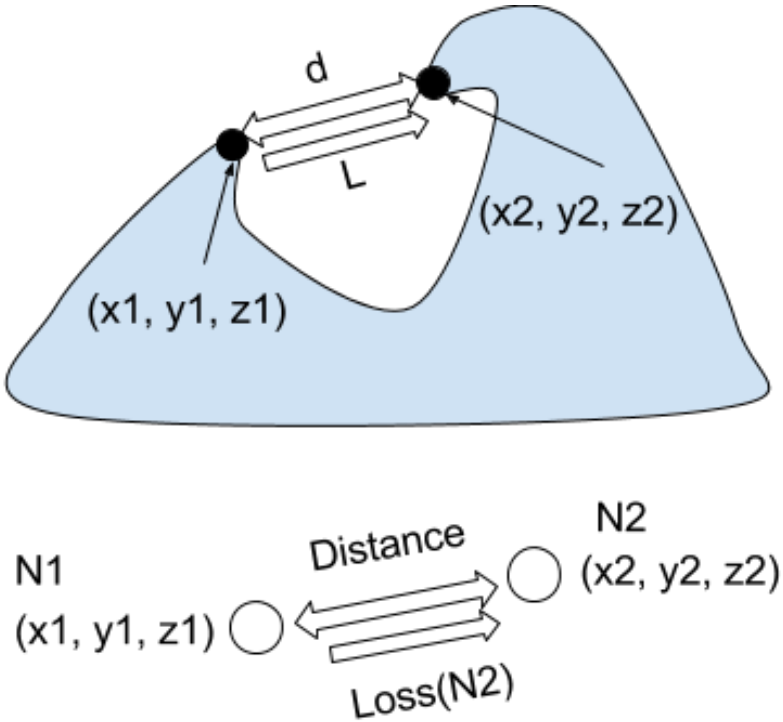
Step 4: Anchor Point Selection



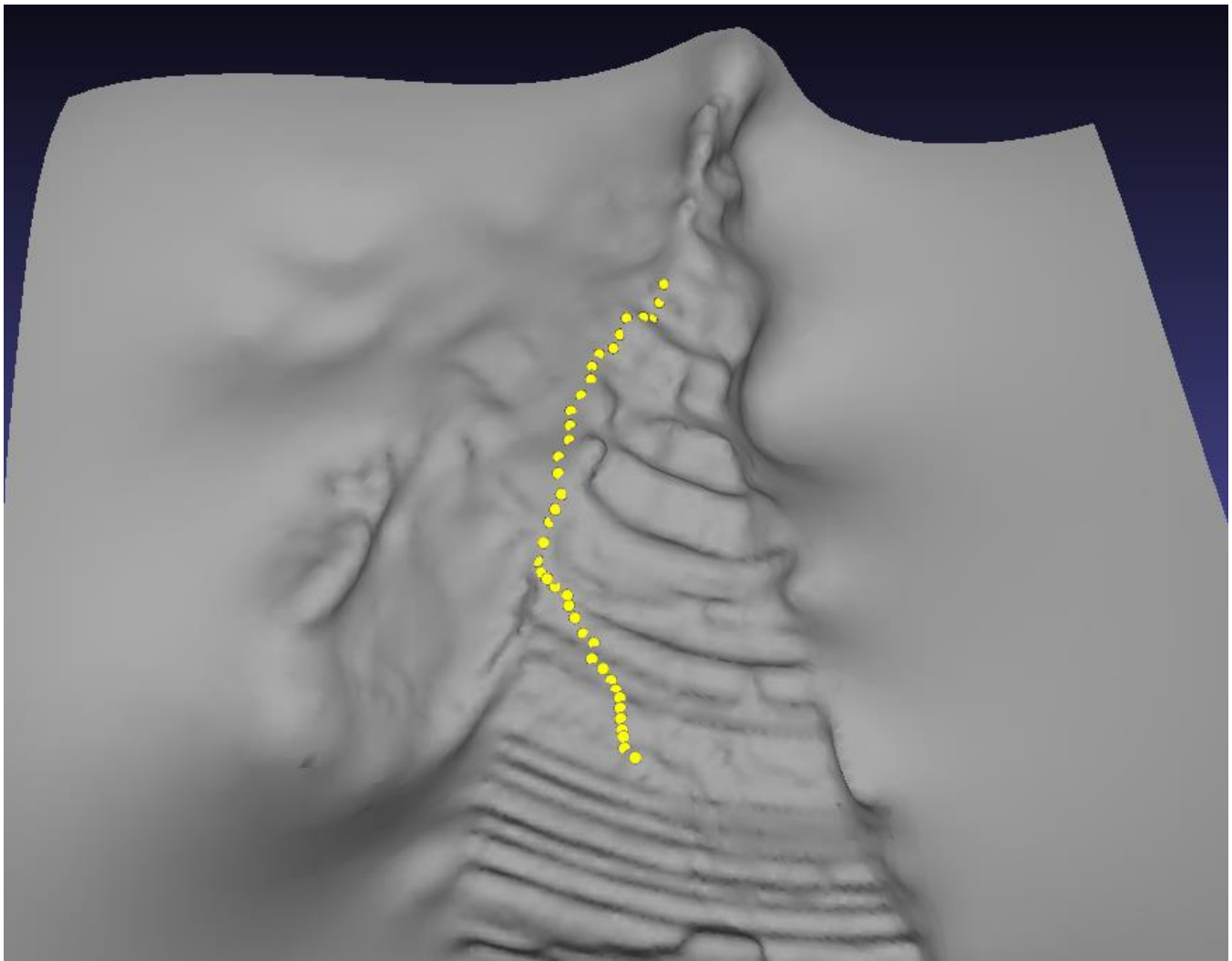
Step 5: Graph Generation

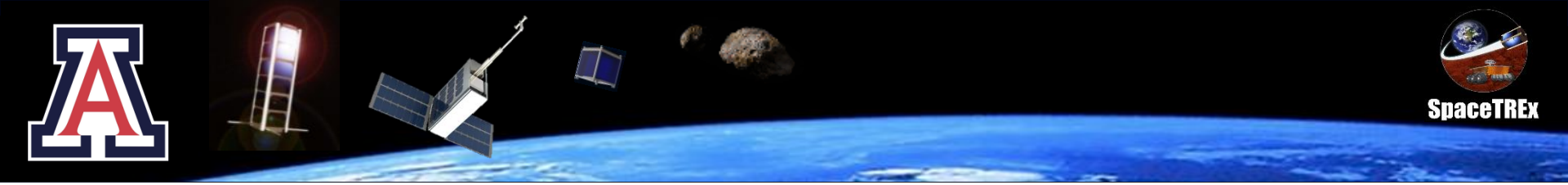


Note: Simple visualization, not all edges shown



Step 6: Path Planning

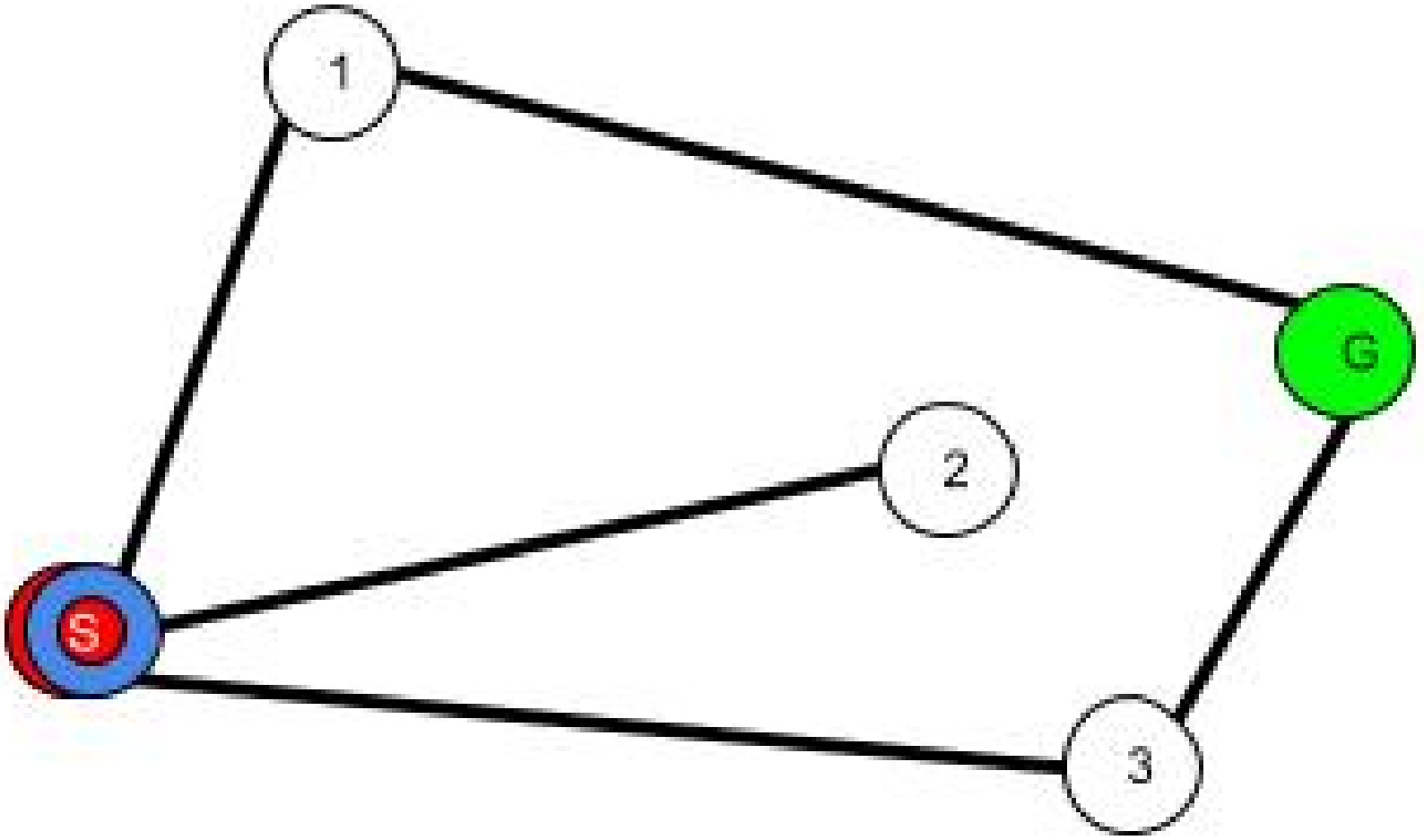


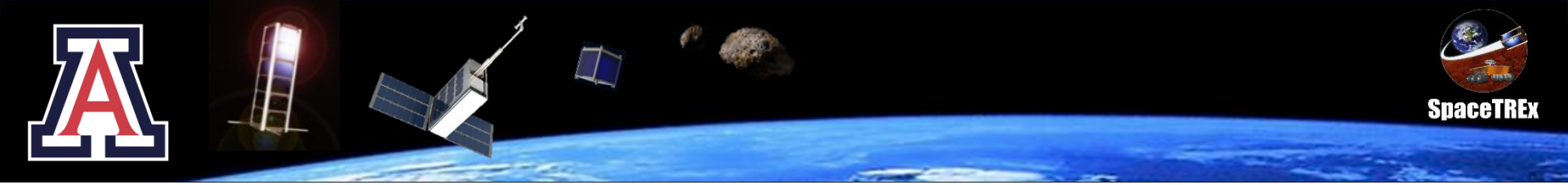


A* Refresher

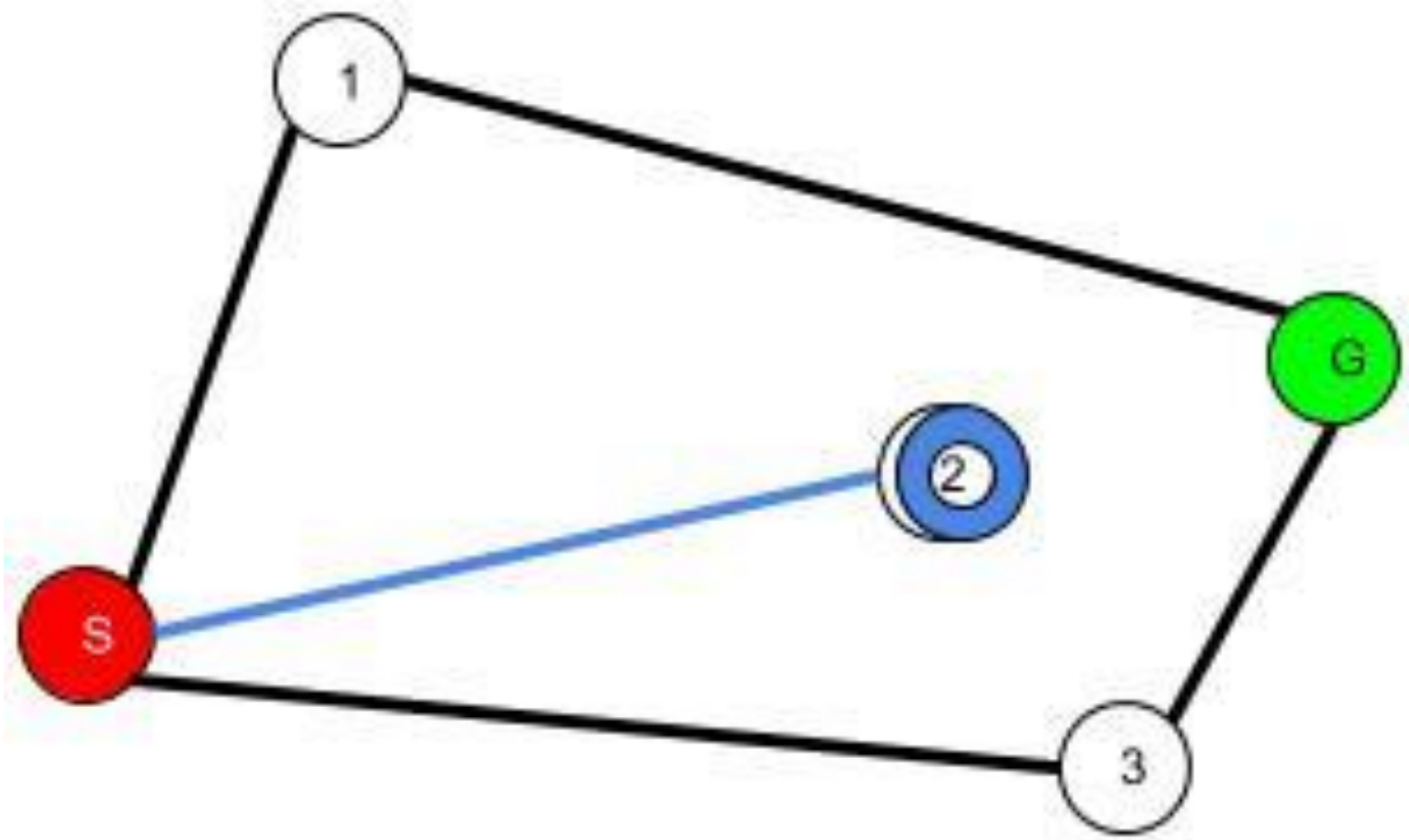
- Defacto path planning algorithm
- Optimal path between two vertices in Euclidean space

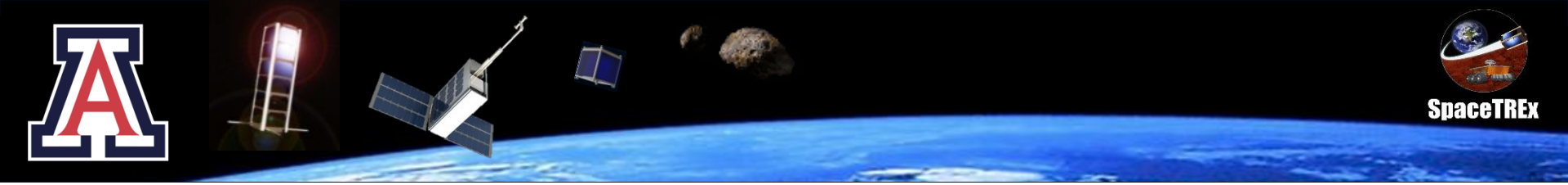
A* Refresher





A* Refresher





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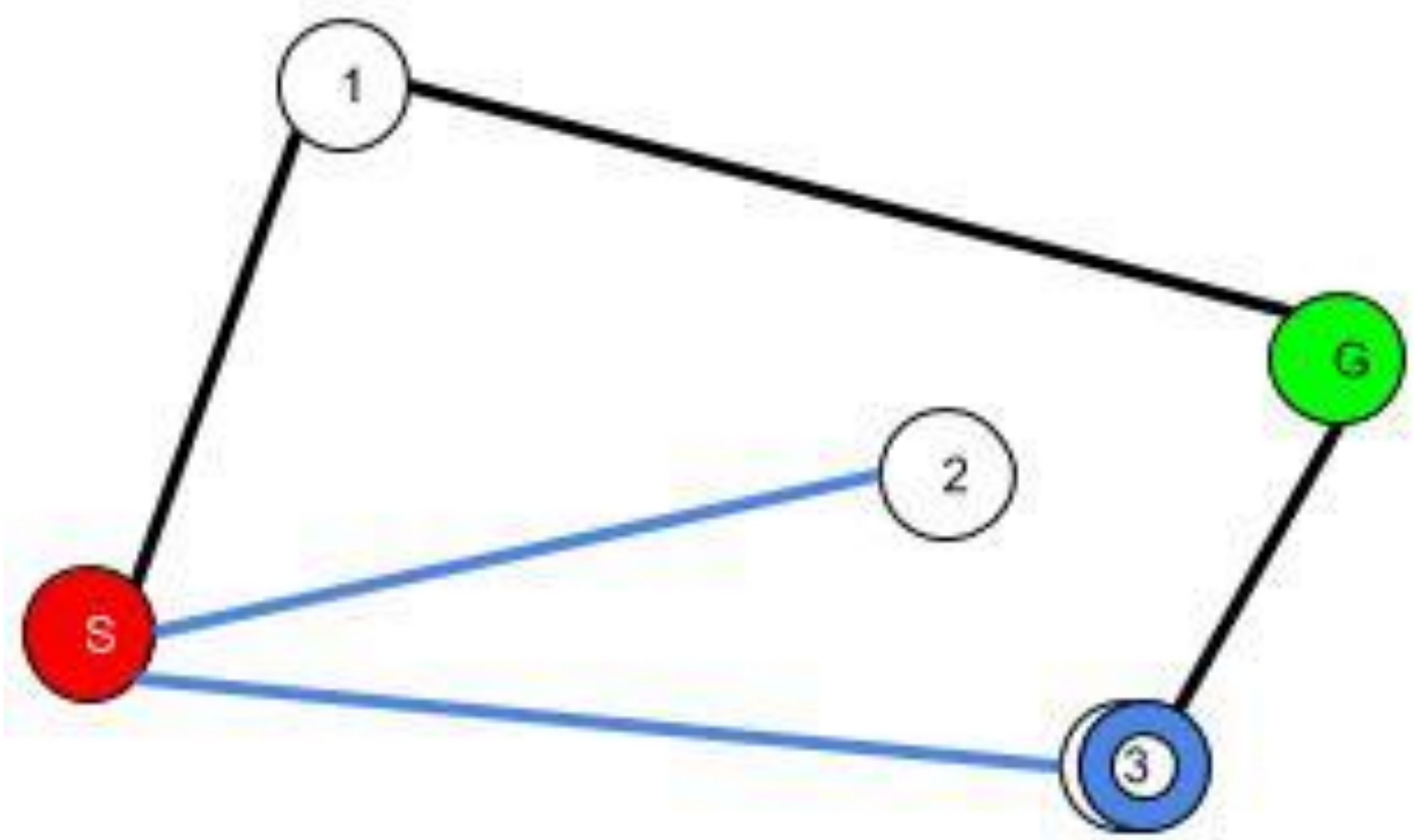
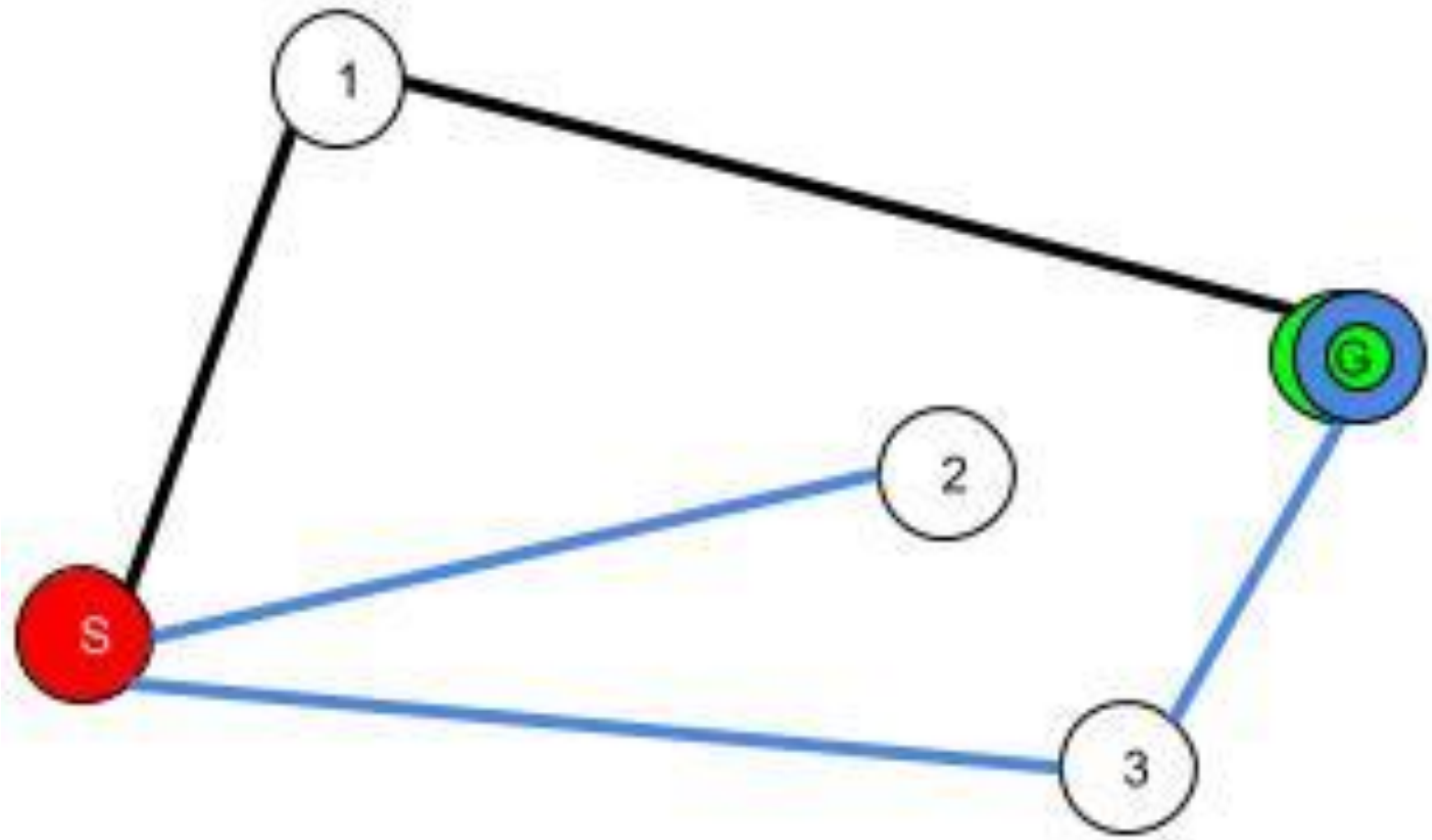
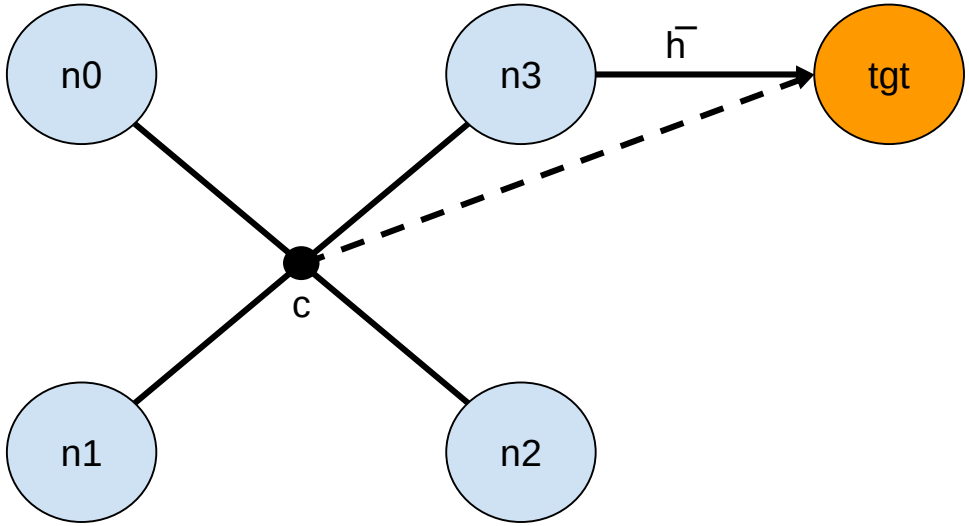


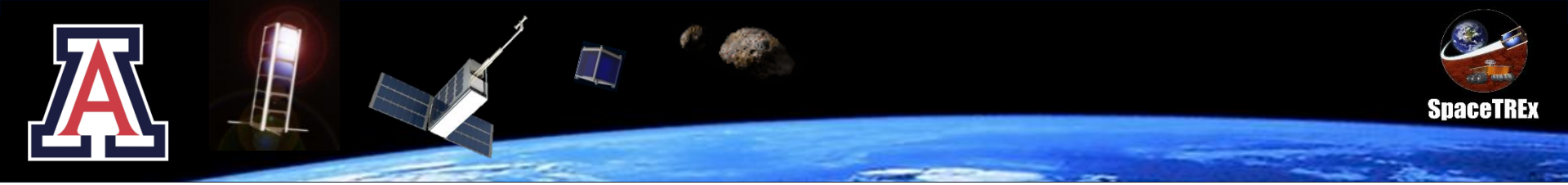
A* Refresher



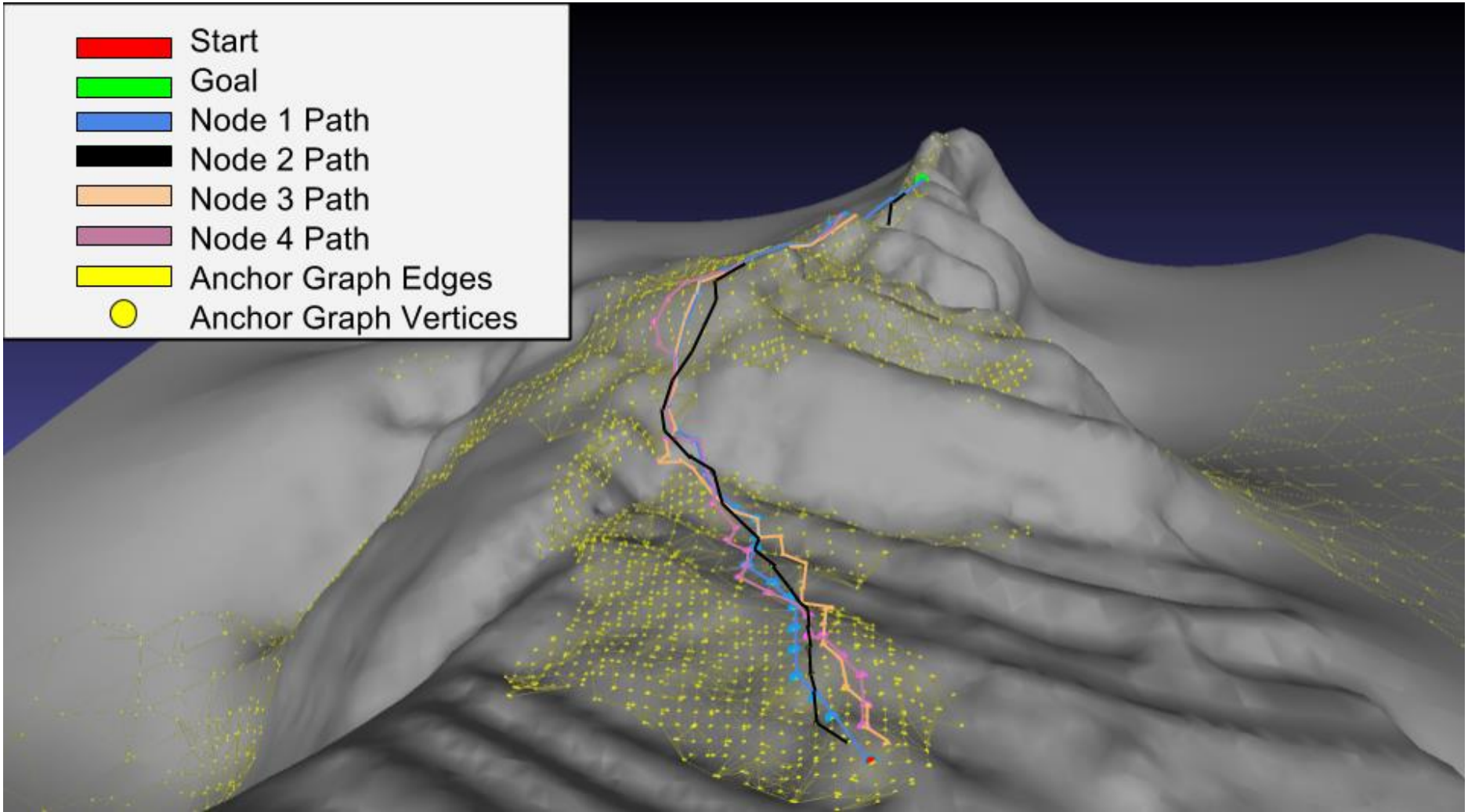
Bounded-Leg A*

- Remove
  - Long edges
  - Edges that exceed the tether
  - Vertices that are occupied by other nodes
- Run A*

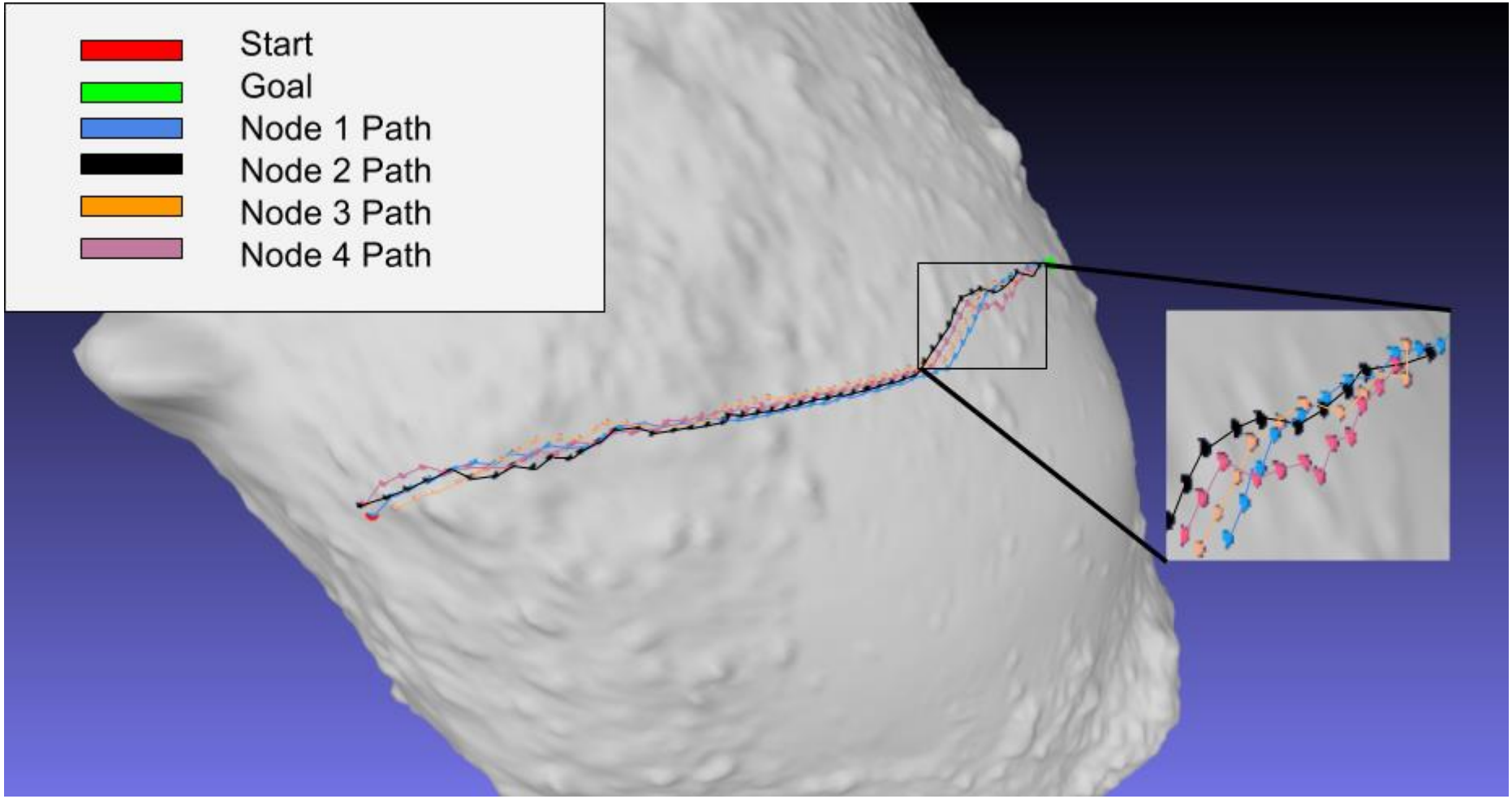



SpaceTREx

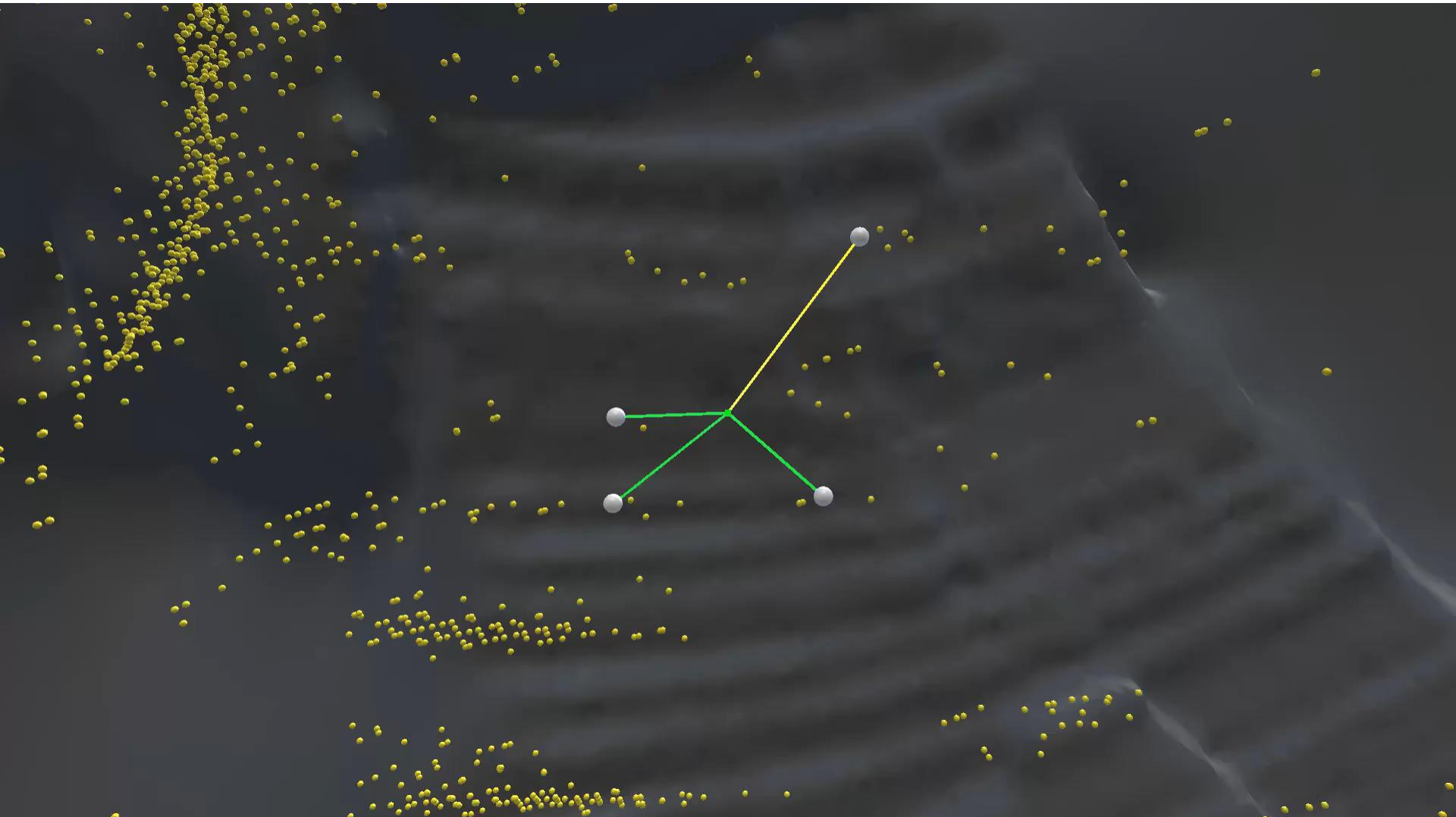
Results


Start
Goal
Node 1 Path
Node 2 Path
Node 3 Path
Node 4 Path
Anchor Graph Edges
Anchor Graph Vertices

Results



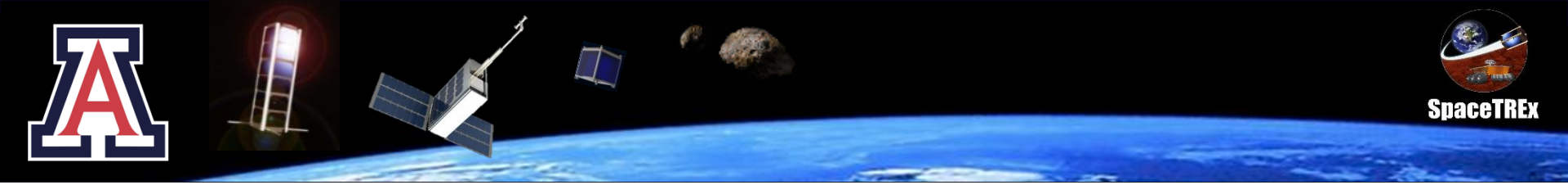
Results



Analysis/Emergent Behavior

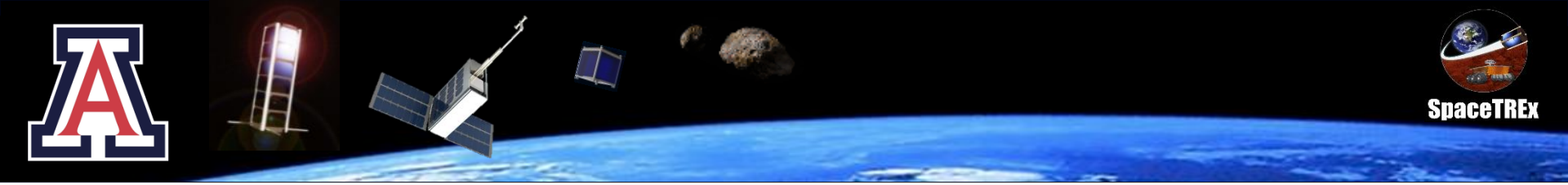
- Longer tethers led to single-file climbing

- Shorter tethers led to parallel climbing



Future Work

- Fine tuning anchor point selection
  - Optical granulometry
- Hardware testing



Questions?