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Pathing in Age of Empires IV

Flow Fields and Steering Behaviors

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Lead Navigation Engineer
World's Edge

#GDC22

AGE OF EMPIRES IV

WORLD'S EDGE

relic ENTERTAINMENT

XBOX GAME STUDIOS

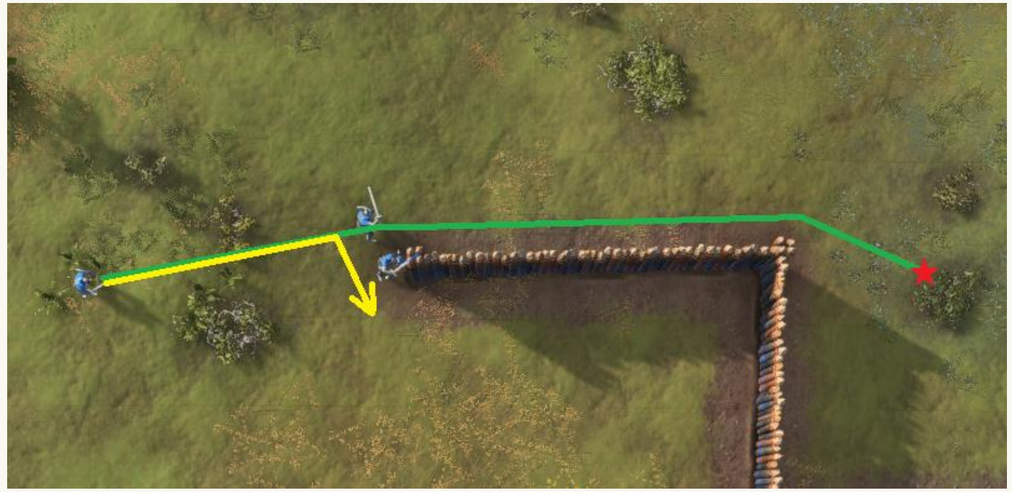
Motivation and Requirements

1600 Units	• Max 8 players with 200 units each.
1024 x 1024 Grid	• RNG terrain, mountains, trees, rivers.
Dynamic Environment	• Construction • Destruction • Deforestation
Formation Movement	• Units often move in cohesive formations.

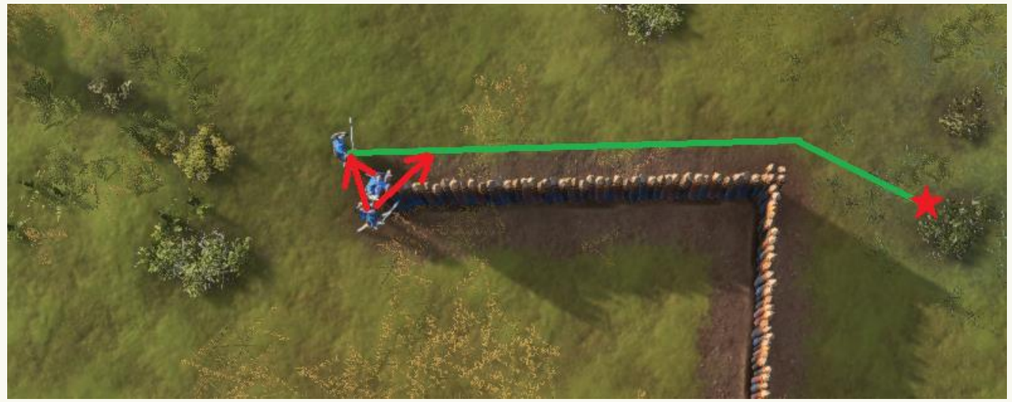
Problems with A*

Dynamic Obstacles

- Treat all the units as A* obstacles.
  - Recompute every frame.
  - Too expensive.
- Use obstacle avoidance steering.
  - No guarantee of a clear path back to the waypoint list.
  - May invalidate shortest path.



Avoid by following the yellow path.

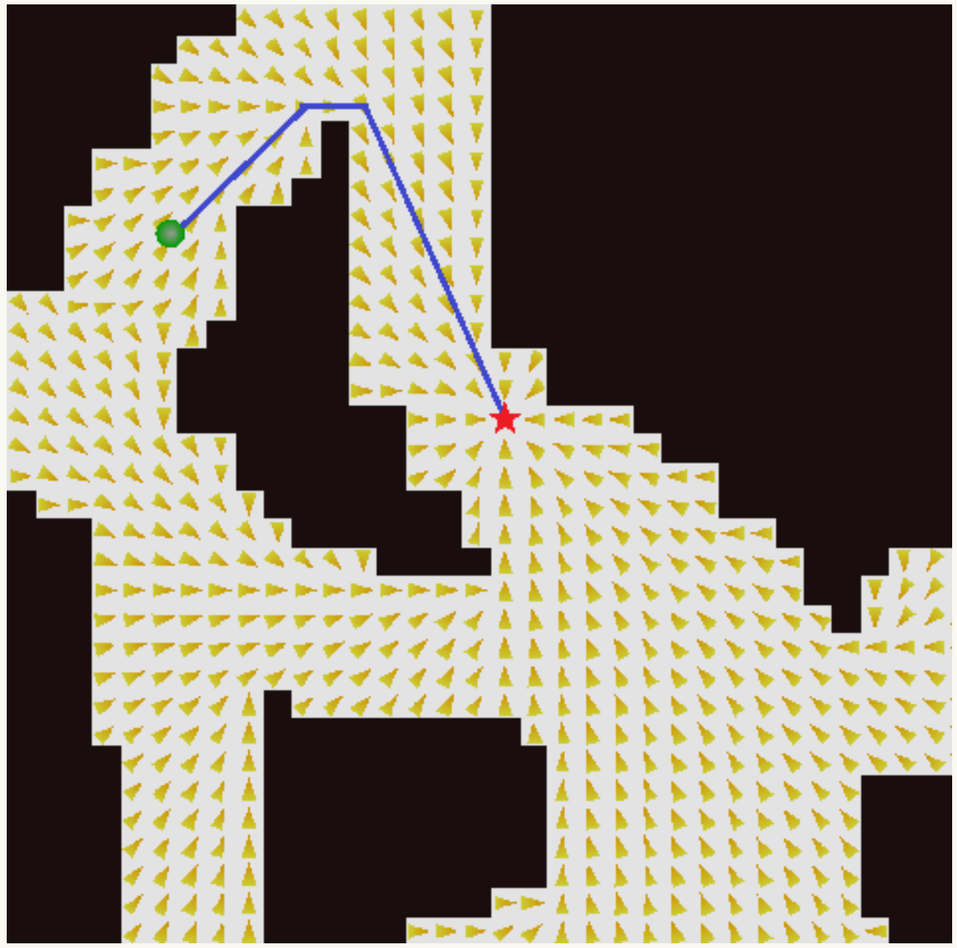


Unable to get back to the waypoint.

Flow Field

Distance Transform

Gradient



Game AI Pro Article by Elijah Emerson, Supreme Commander 2, Gas Powered Games
http://www.gameaipro.com/GameAIPro/GameAIPro_Chapter23_Crowd_Pathfinding_and_Steering_Using_Flow_Field_Tiles.pdf

Cost Field

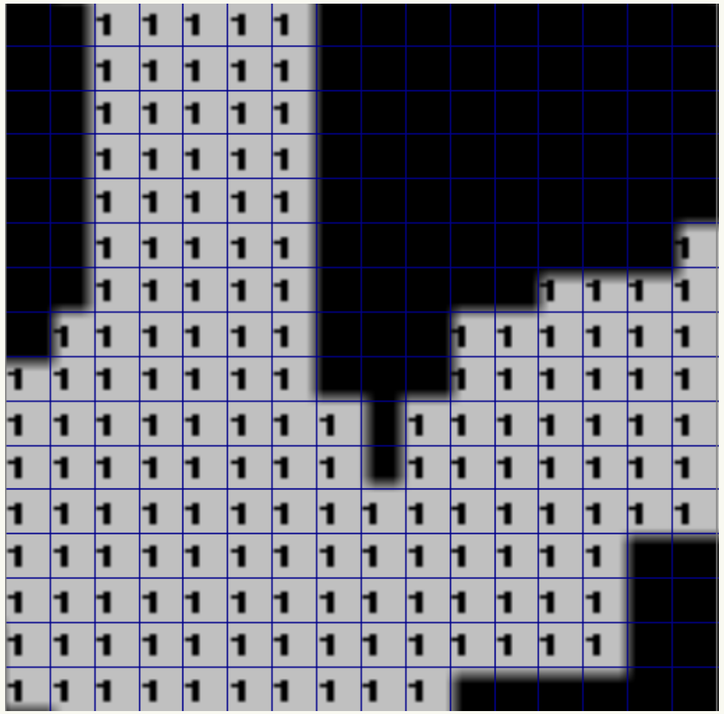
- Defines the cell traversal cost, can be non-uniform.

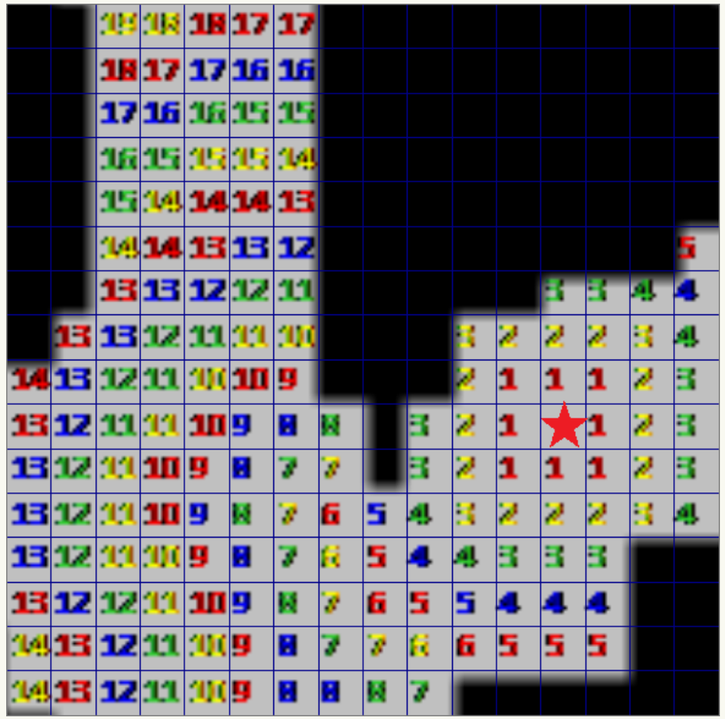
Integration Field

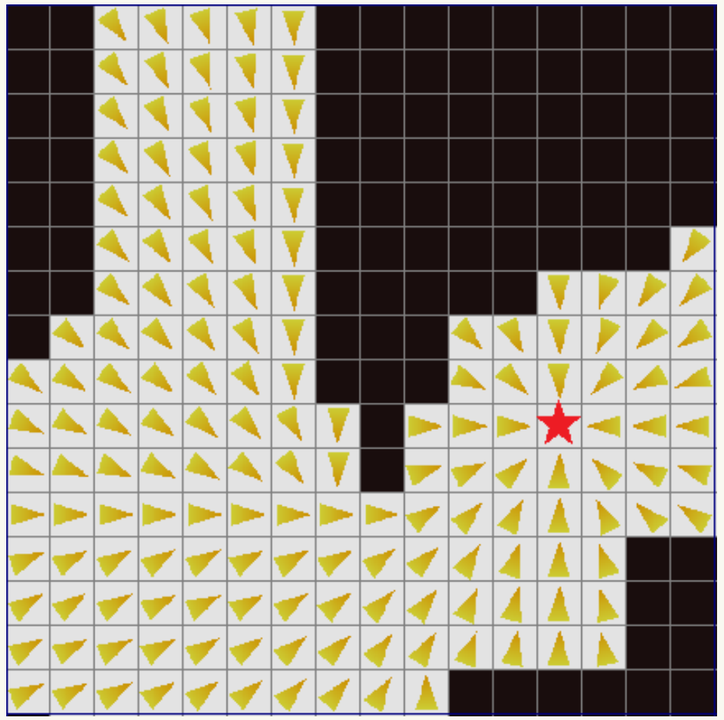
- Holds the distance transform results.

Flow Field

- Contains the flow directions.







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Fast Marching Method (FMM)

Problem: Direction Limitation

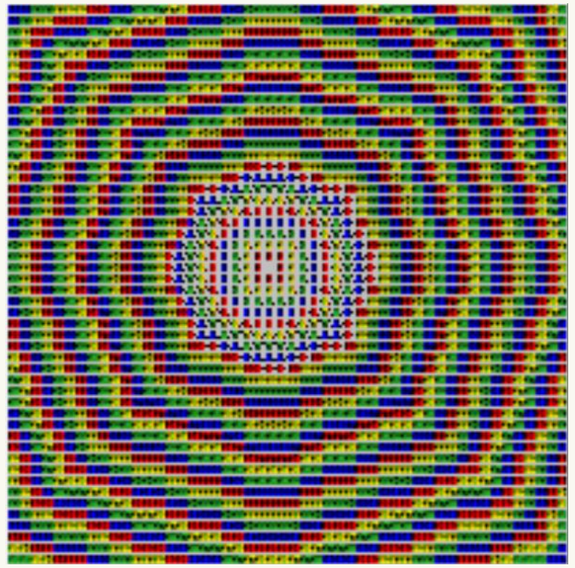
- Basic 8-neighbor Dijkstra Distance integration only gives 16 directions. **Causing unnecessary turns.**

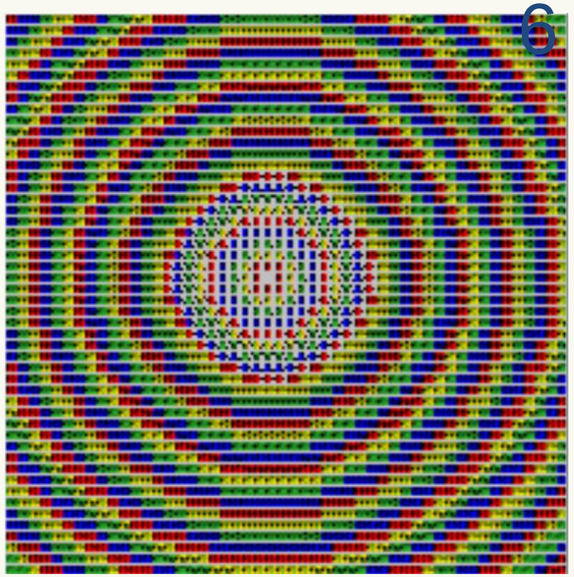
Solution: FMM Integration

- FMM provides a smoother gradient.

Storing the gradient

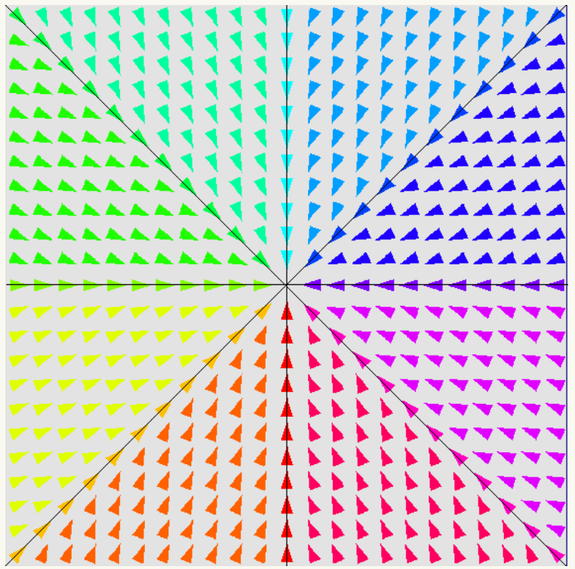
- An 8-bit array stores 256 possible directions.

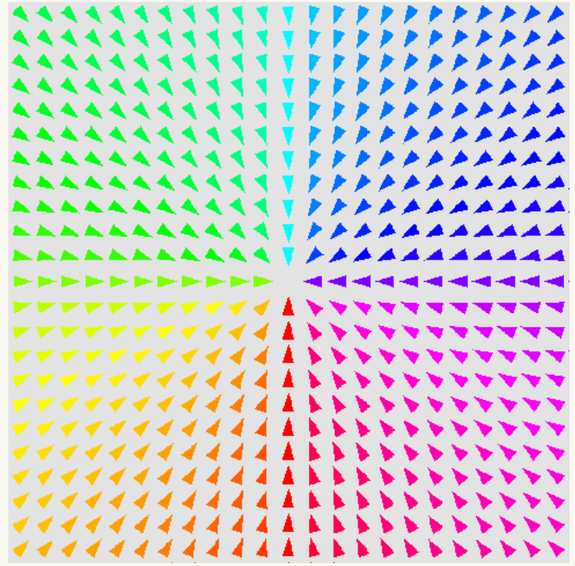




Dijkstra

FMM



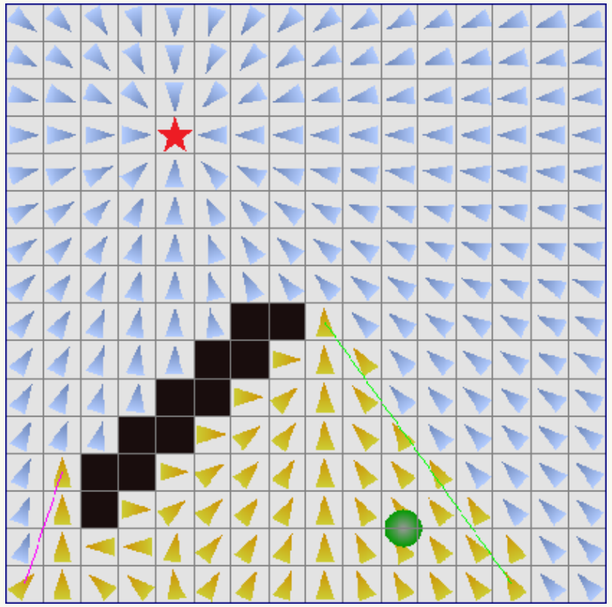


Dijkstra and Fast Marching Algorithms
http://www.numerical-tours.com/matlab/fastmarching_0_implementing/

Line-of-Sight (LOS) Integration

Faster and more accurate than FMM

LOS



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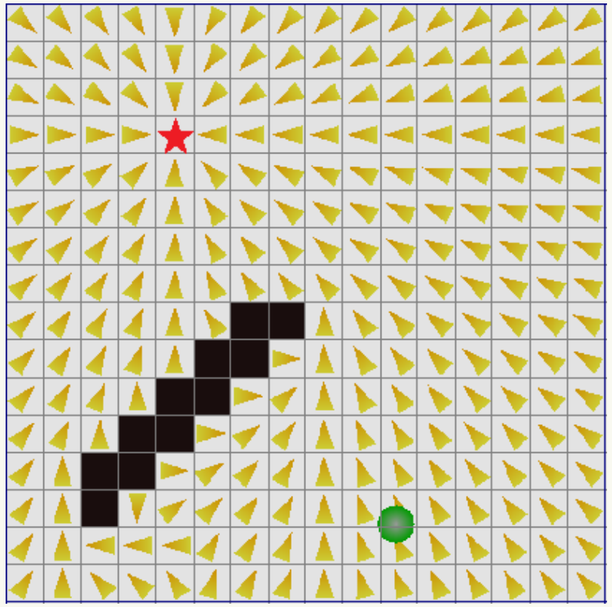
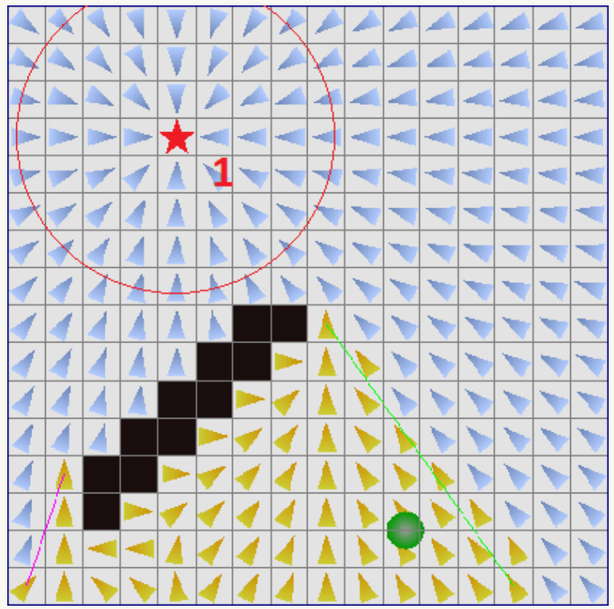


Line-of-Sight (LOS) Integration

Faster and more accurate than FMM

1)Breadth-First-Search (BFS) to iterate through the visible area.

LOS



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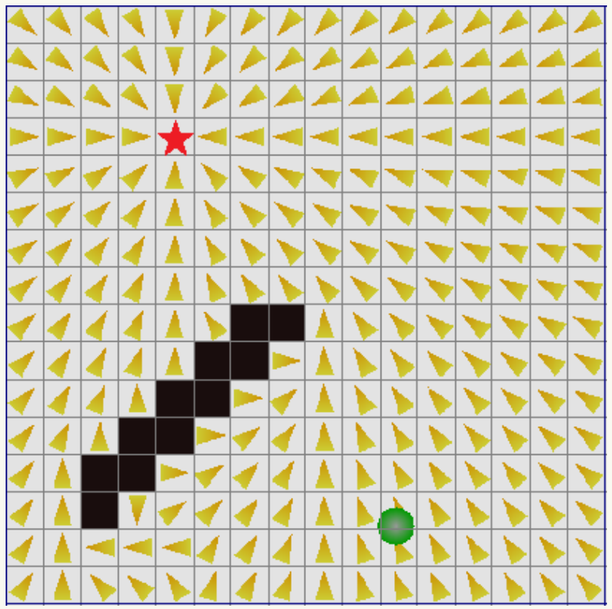

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2)Detect Impasse corners and draw "shadow lines" from the goal to the corner, extending to the edge of the tile.

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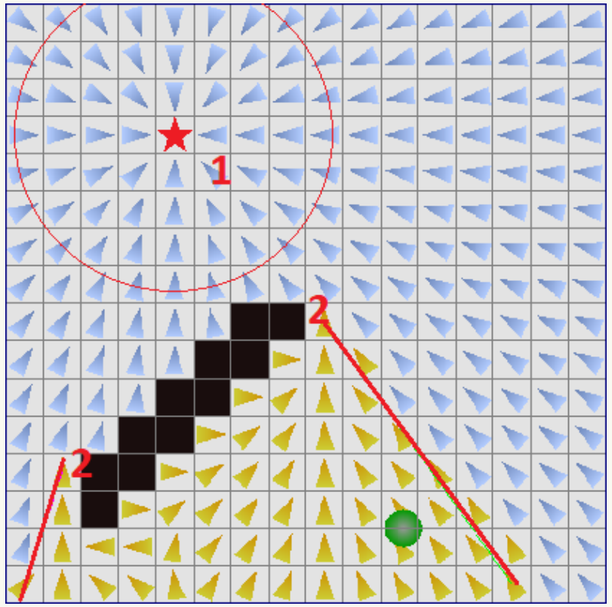

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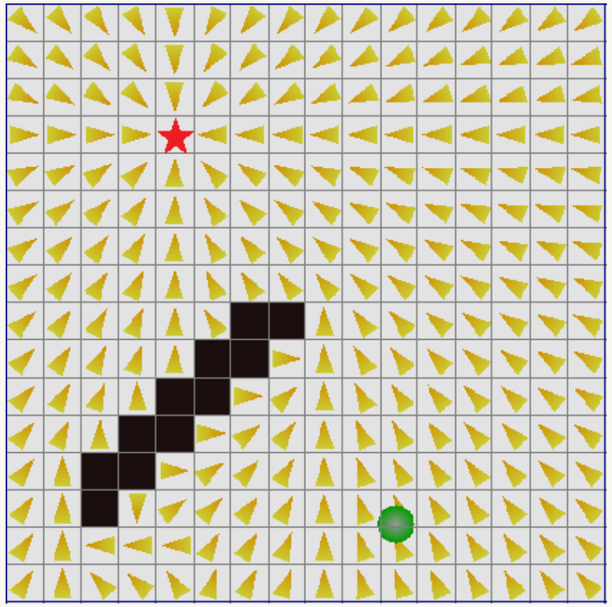

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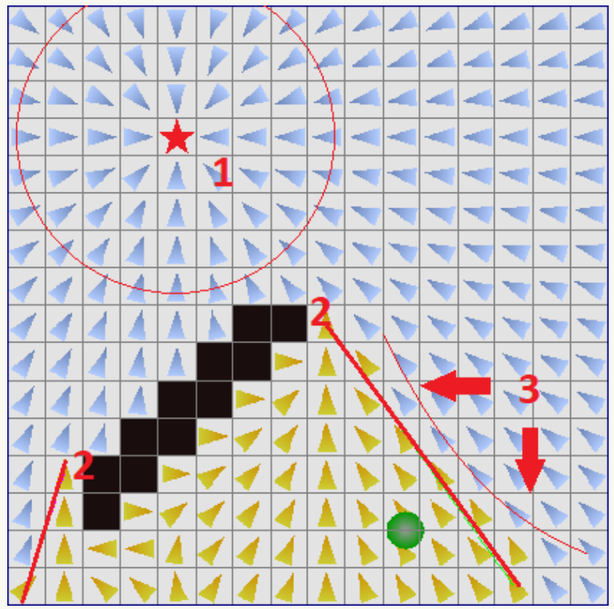

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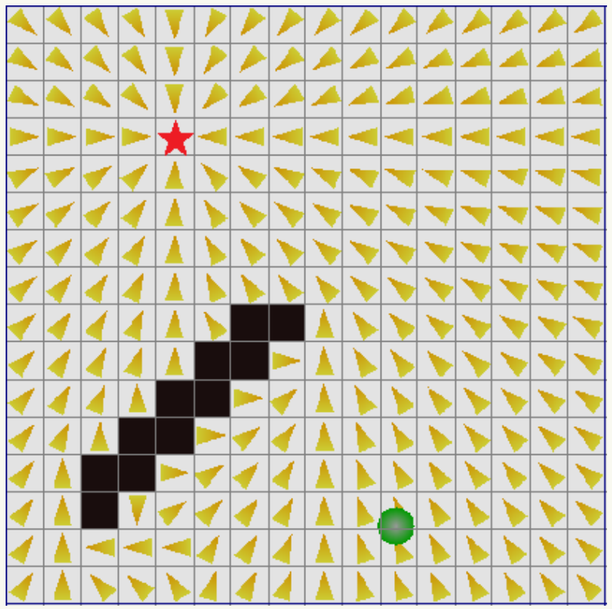

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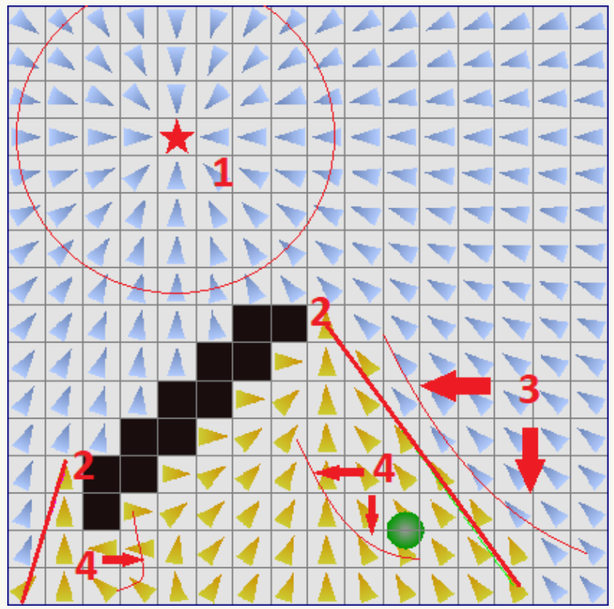
2) Detect Impasse corners and draw “shadow lines” from the goal to the corner, extending to the edge of the tile.
3) Line-of-Sight integration terminates at the shadow lines.
4) **Starting at the shadow lines, use FMM integration for shaded area.**

LOS



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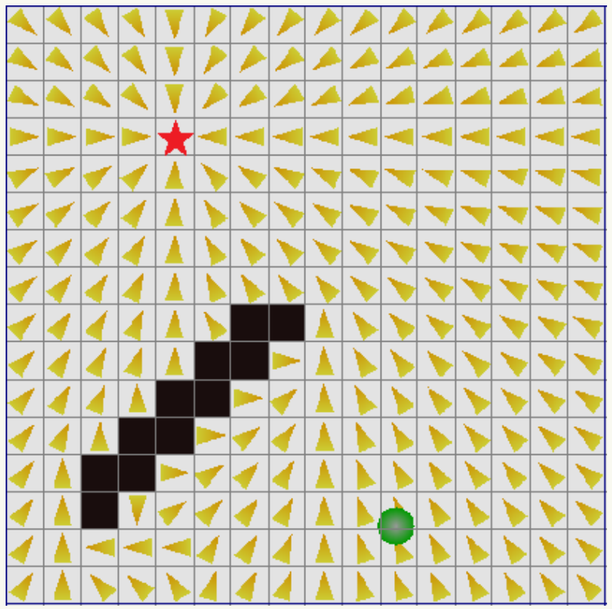


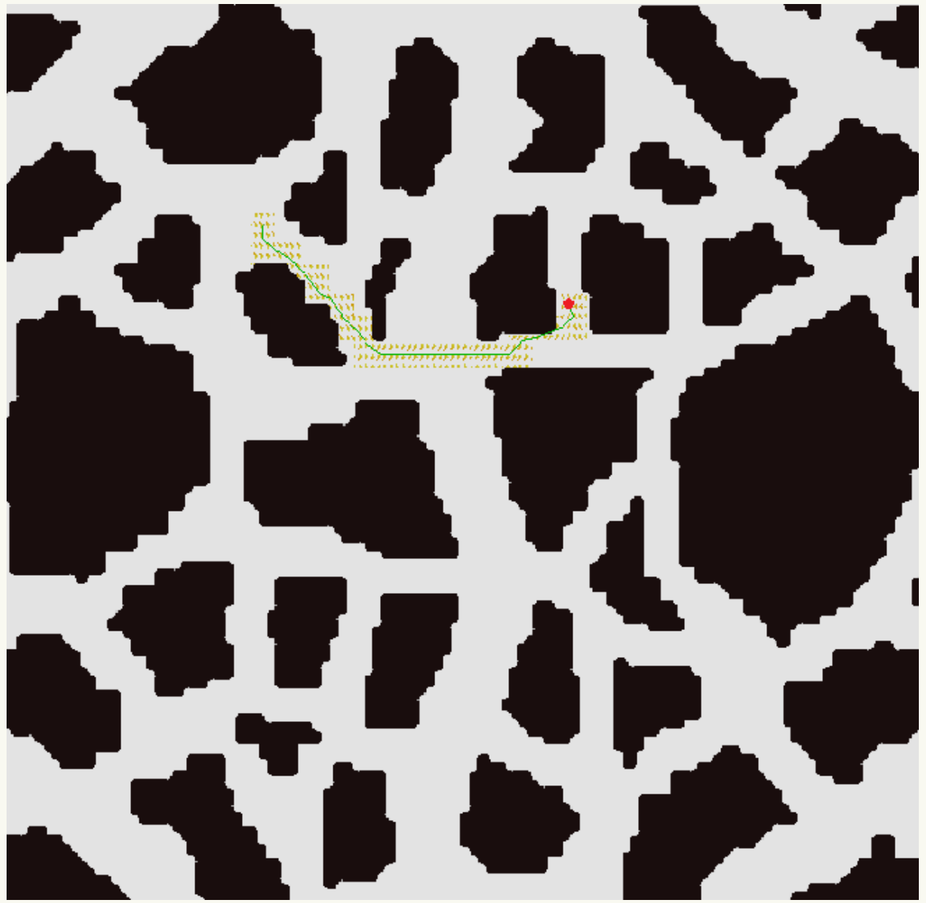
Limiting The Flow Area

High Computation Cost

- 1024x1024 is a lot of nodes to integrate.

Unnecessary Information

- Only need flow on the way to the destination.



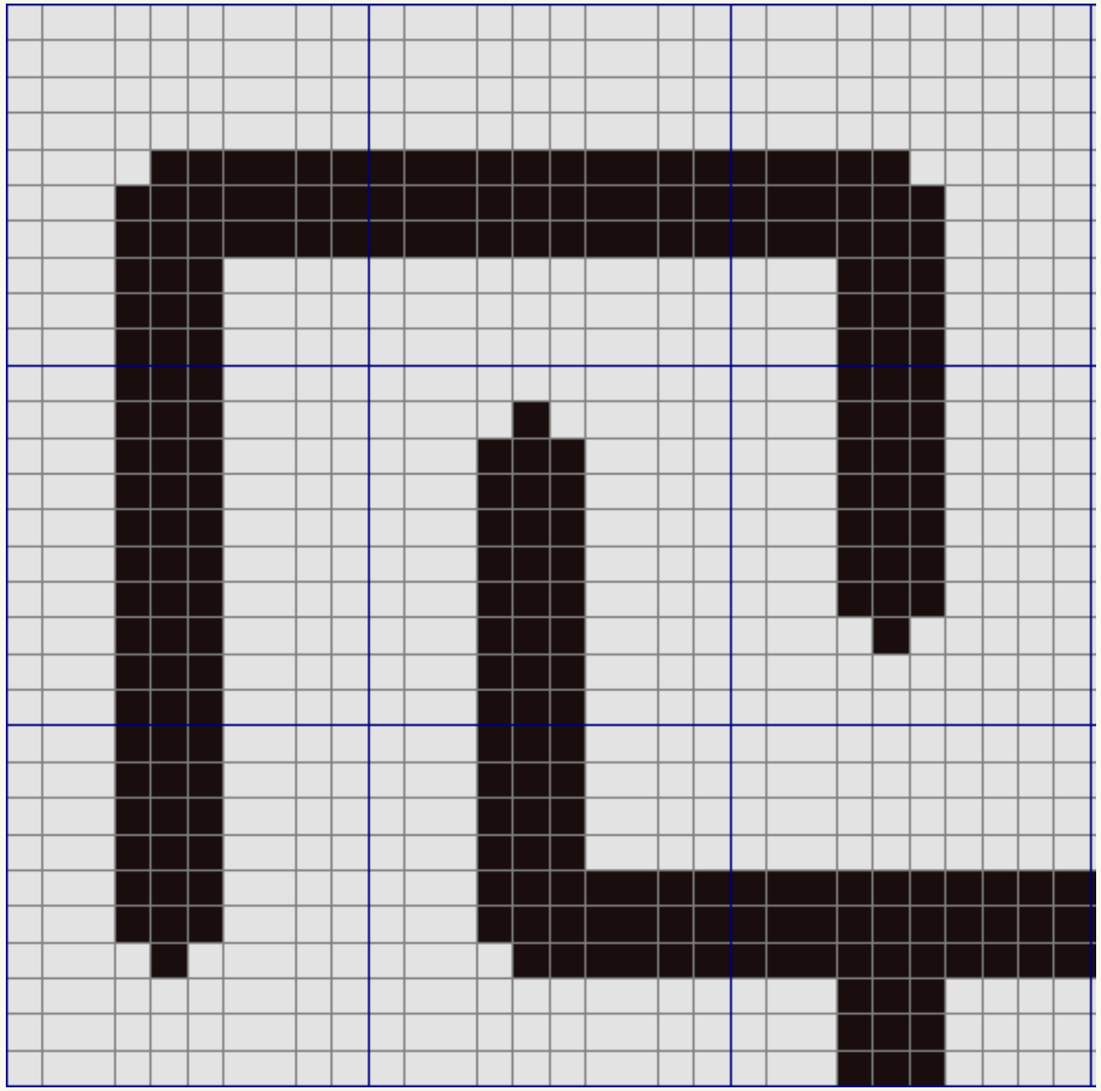
Portal Graph

Borrowing the idea from **Hierarchical Path-Finding A***, we generate an abstract graph over the grid.

>> Divide the grid into tiles

Detect portals at each edge that connects two tiles together

Determine connectivity and cost between the portals within a tile using flood fill



HPA* (Hierarchical Path-Finding A*)
https://webdocs.cs.ualberta.ca/~mmueller/ps/hpastar.pdf

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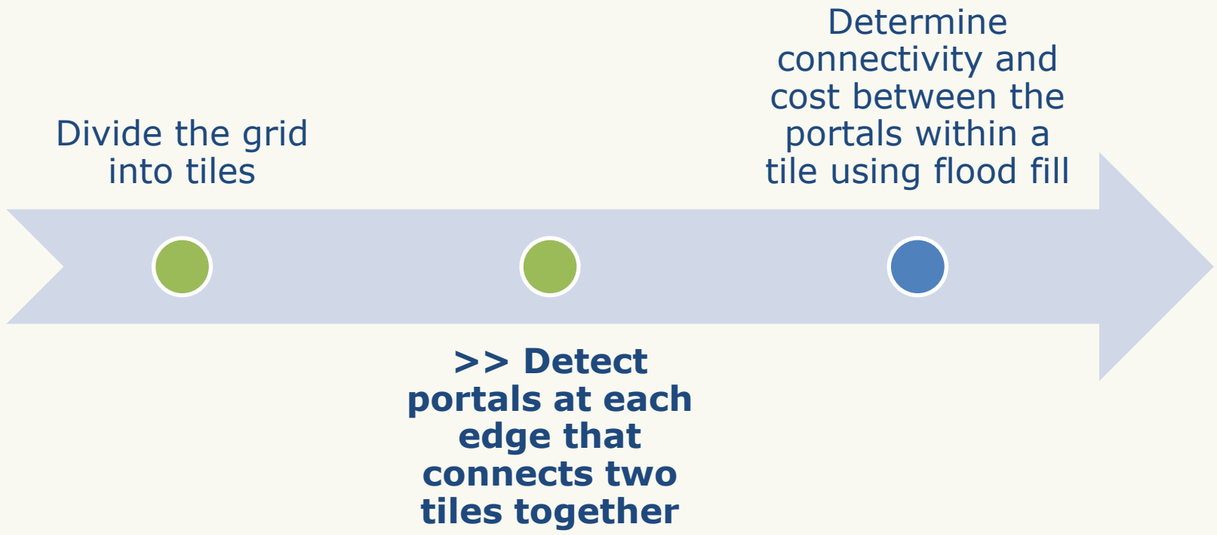

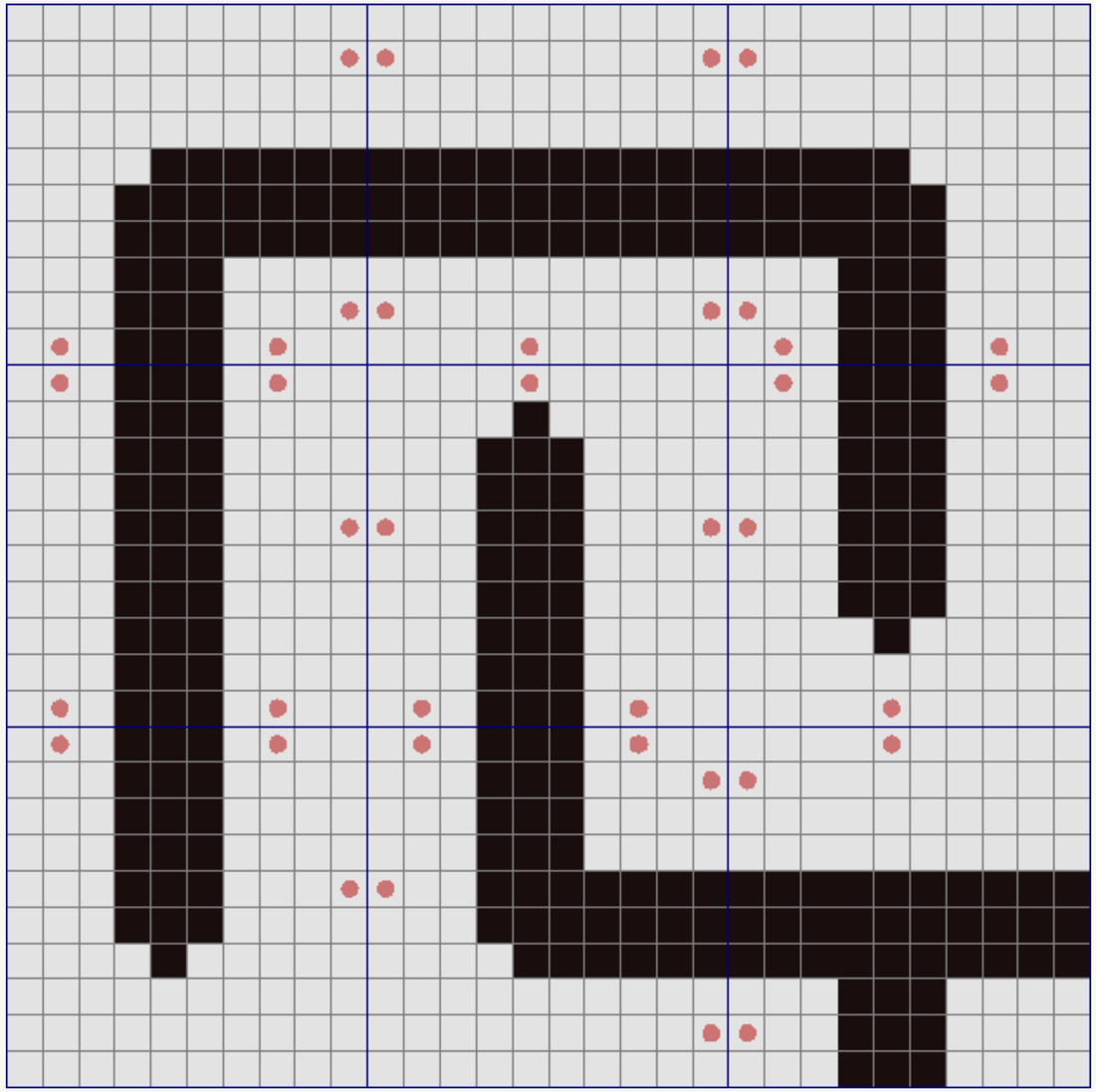

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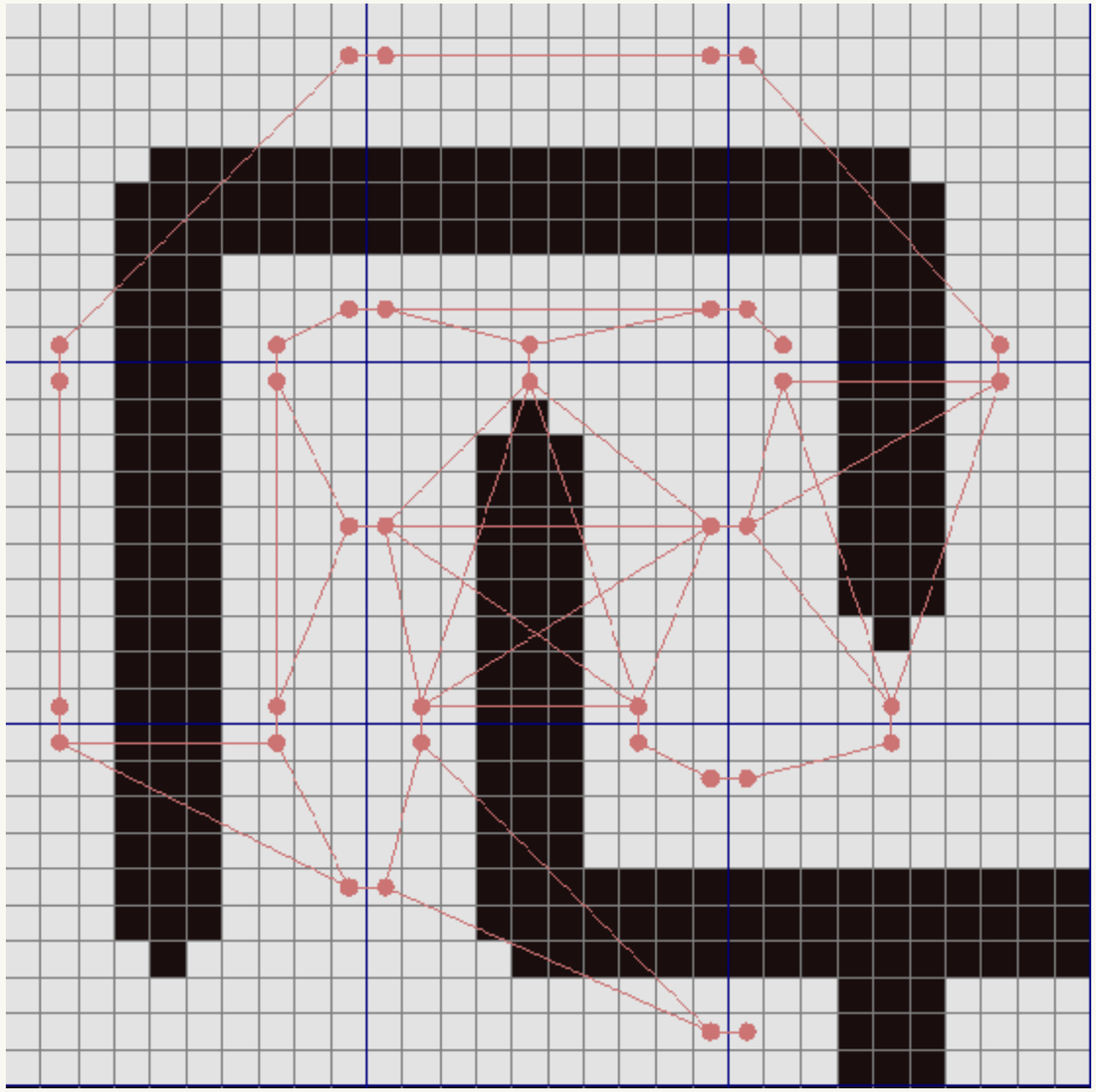

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The red lines only indicate the connectivity of the nodes, not the traversal path.

Flow Path

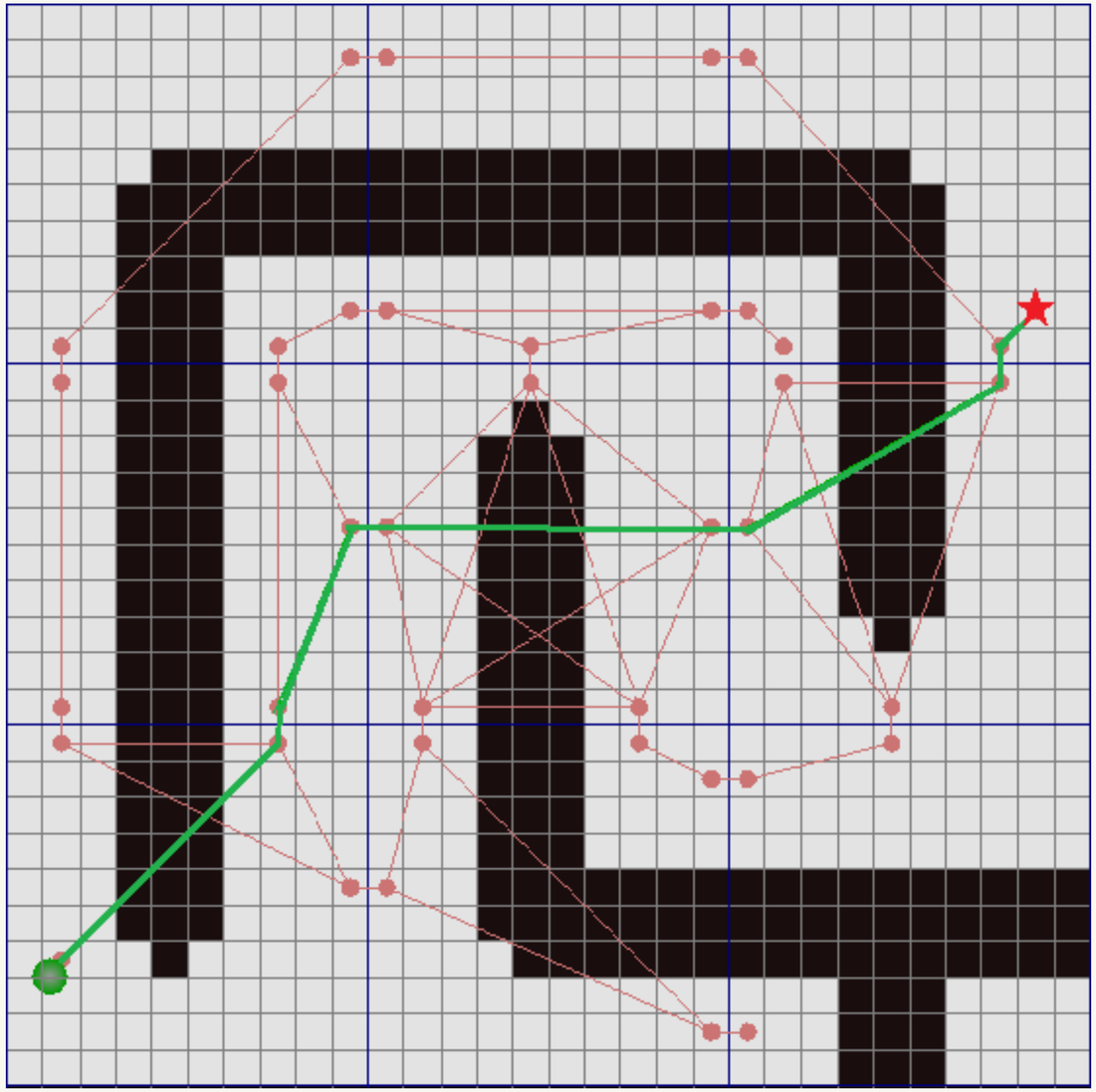
Generate Flows over the Flow Path

>> Get an A* Path on the Portal Graph

Generate flow only for the tiles traversed by the A*

- Carry the flow through the connecting portals to each tile

Follow the flow to reach the goal



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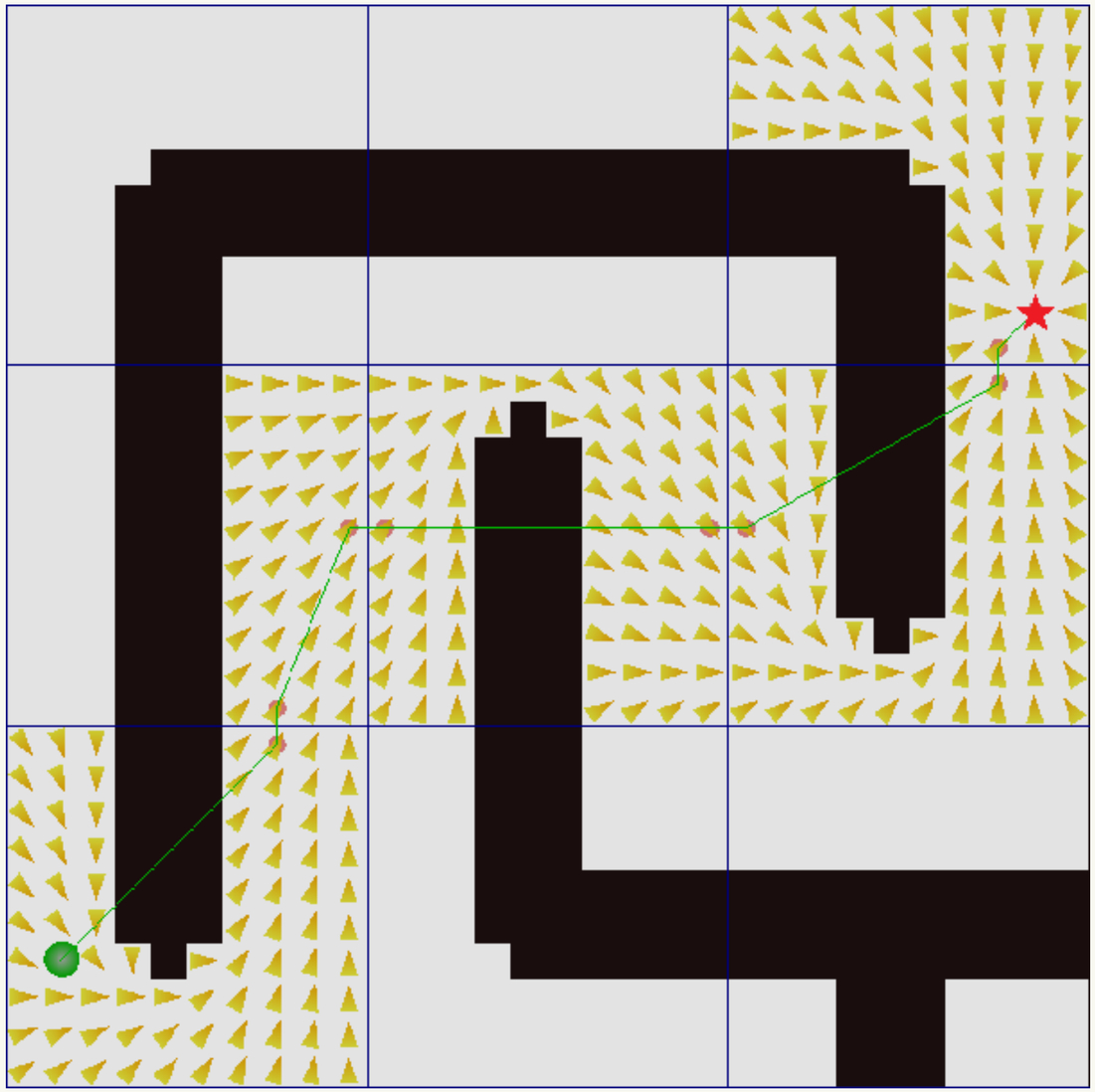

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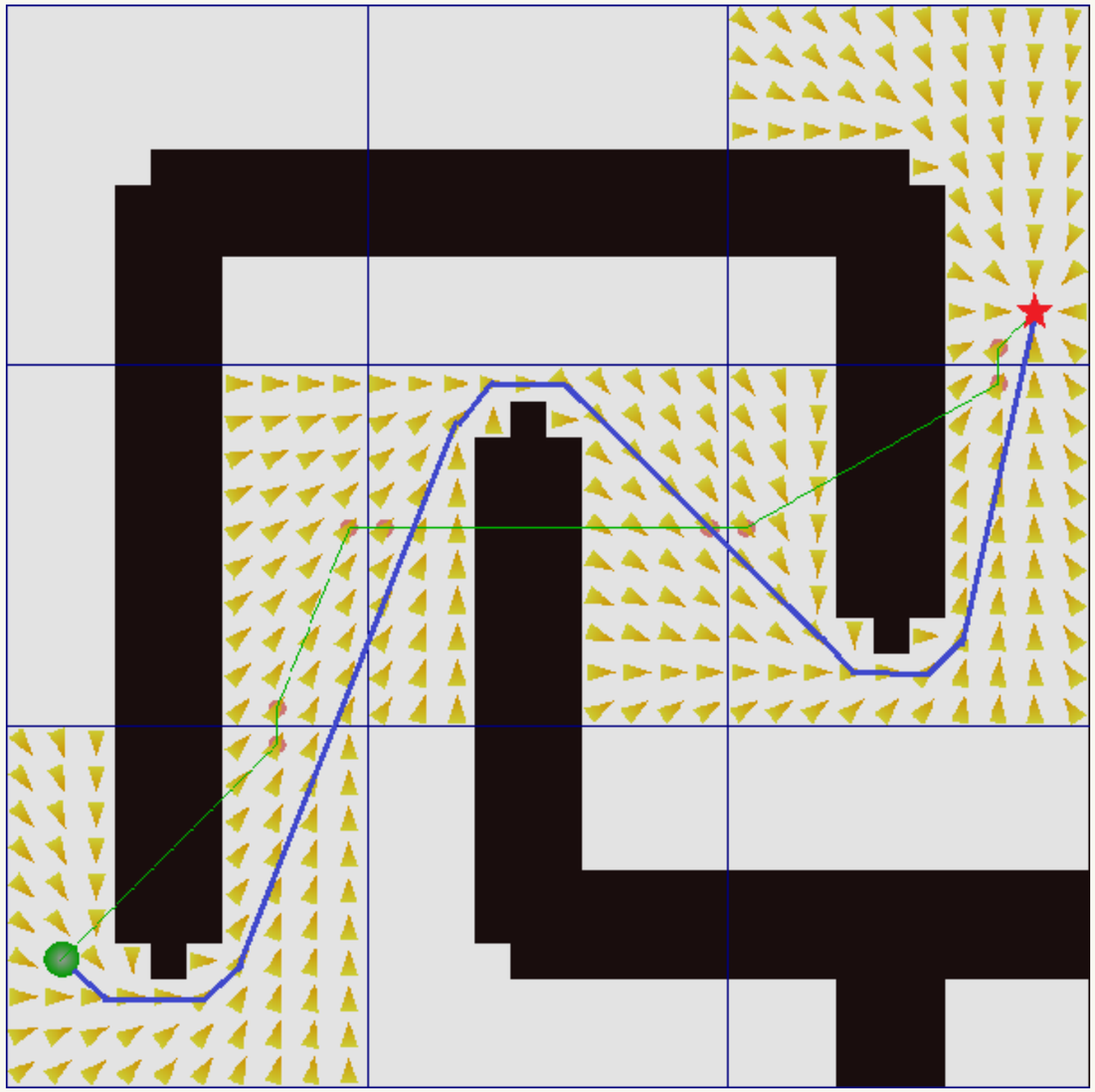
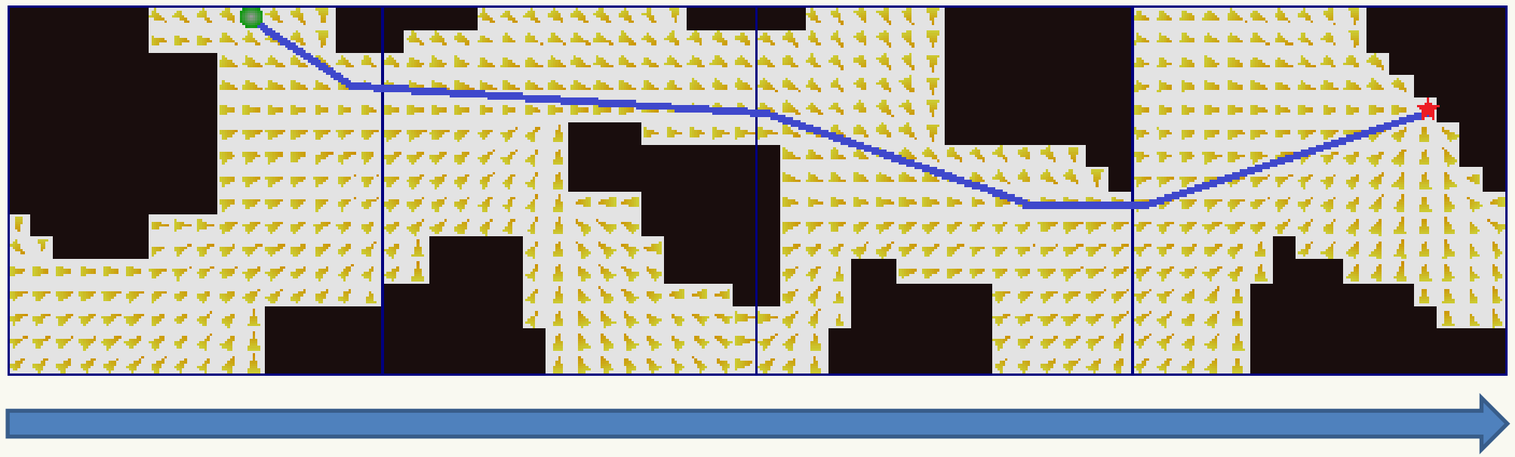


The Perfect Flow: Accurate, But…

The Perfect Flow can be generated from the destination to the starting position.

High Computation Cost	• This is costly for paths that are 20, 30 tiles long.
Unnecessary Information	• Units don’t always follow the path to the end due changes on the battlefield.
Not Cache Friendly	• It’s unlikely the identical path will be requested again.



The Perfect Flow

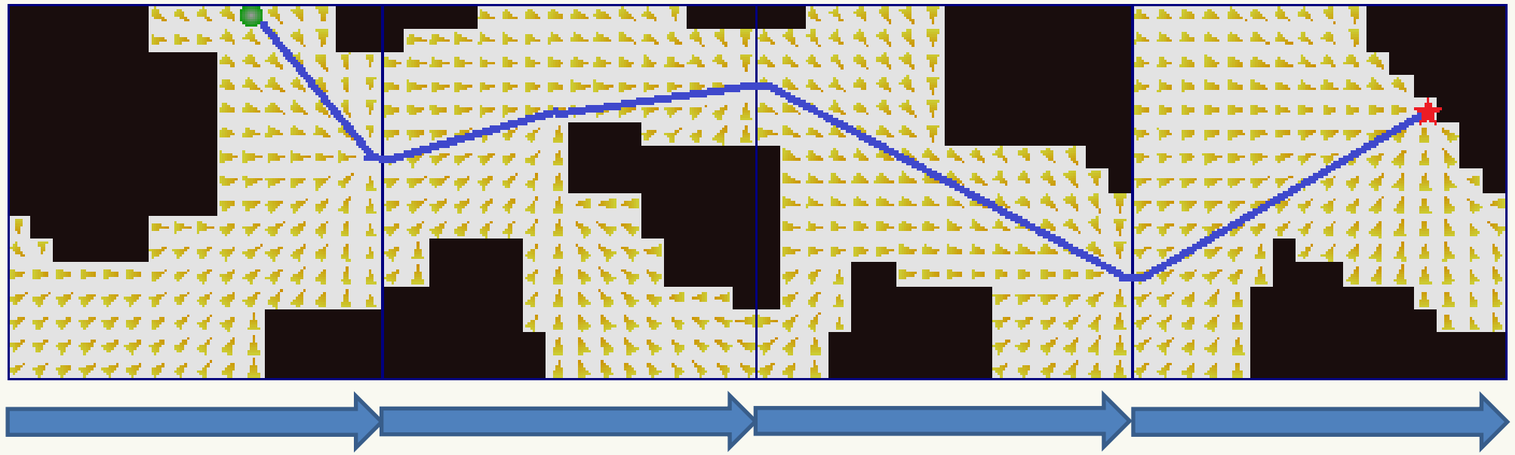
Single Tile Flow

We can generate a **single tile** at a time as the unit moves onto new tiles.

Minimum Cost
- This gives the unit something usable much sooner.

Cache Friendly
- Enables each tile to be cached individually and be reused as building blocks for different paths.

Poor Accuracy
- The integrity of the flow suffers since each tile is generated only from the connecting portal.



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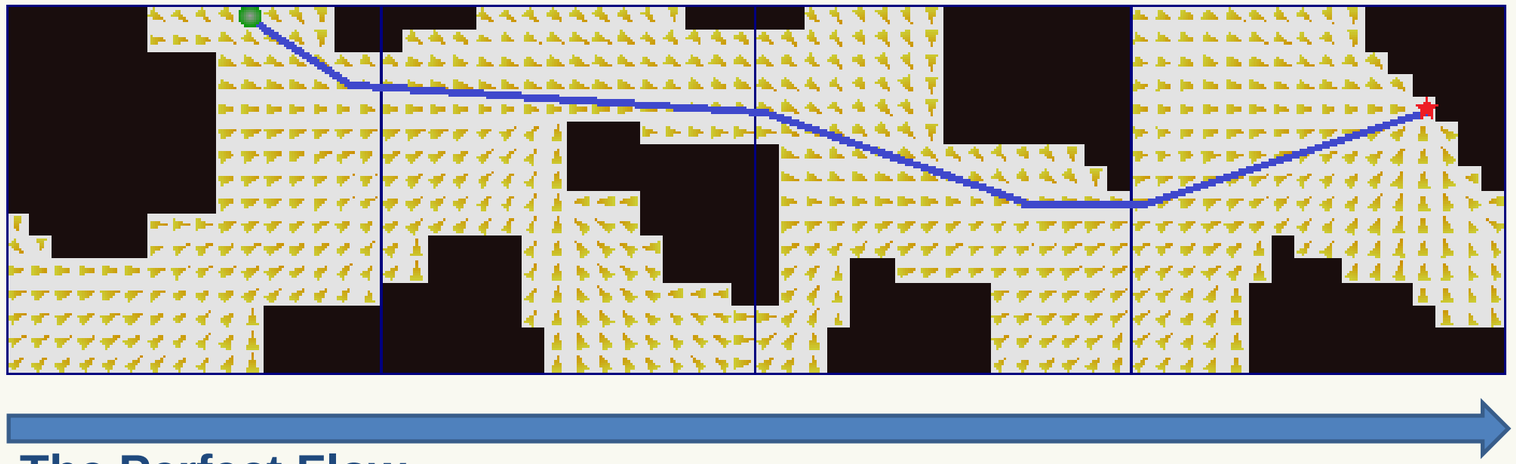


The Perfect Flow

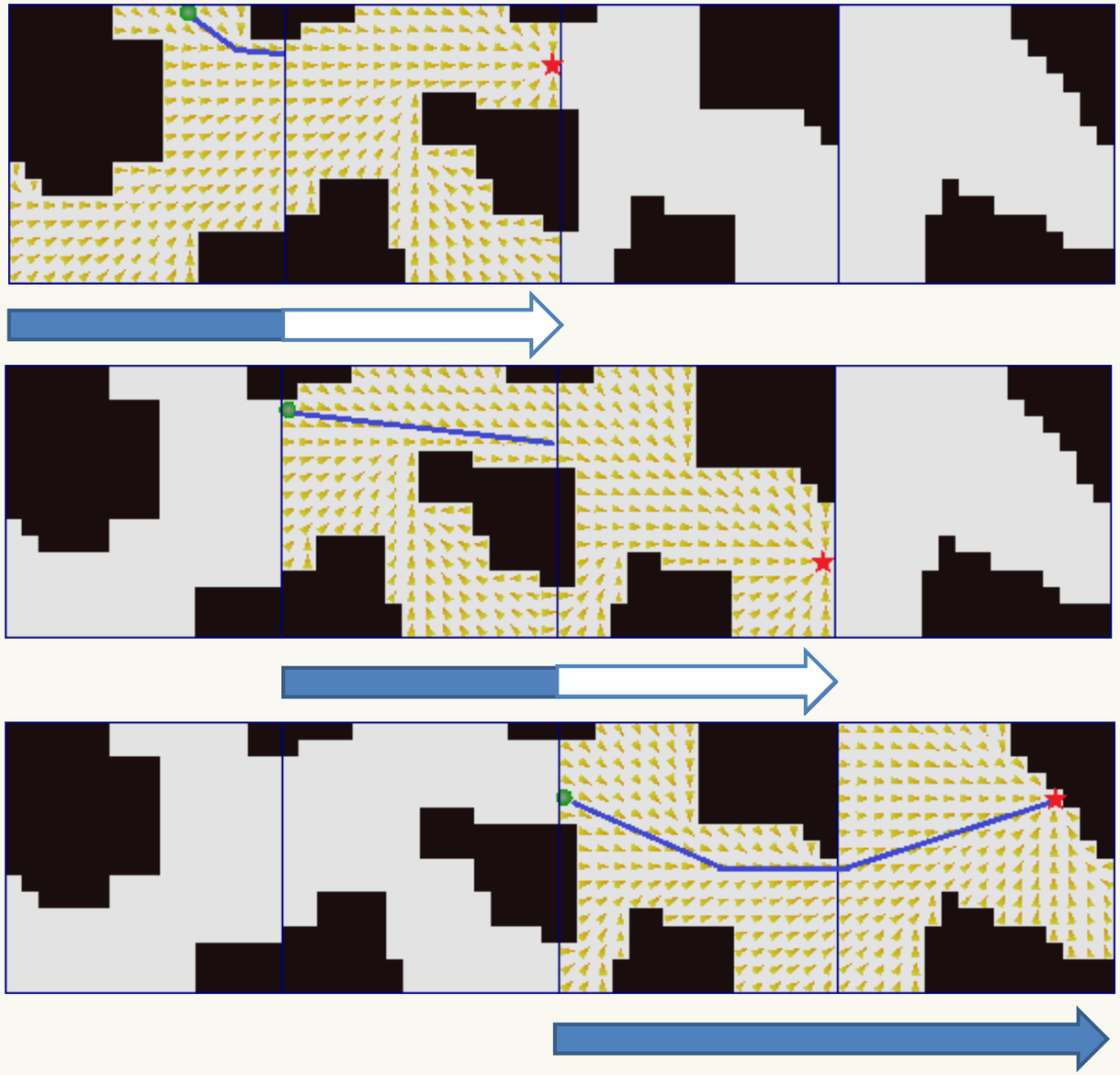
Segmented Flow

Generate Further Upstream

- Improves the quality and accuracy of the flow.

Overlapping Segments

- Overlap the parent tile with new segments, so we don’t run into the same issue as the single tile flow.



Overlapping Segmented Flow

Near Optimal Proximation

- The **overlapping segments** closely approximates the perfect flow.

Minimize Cost

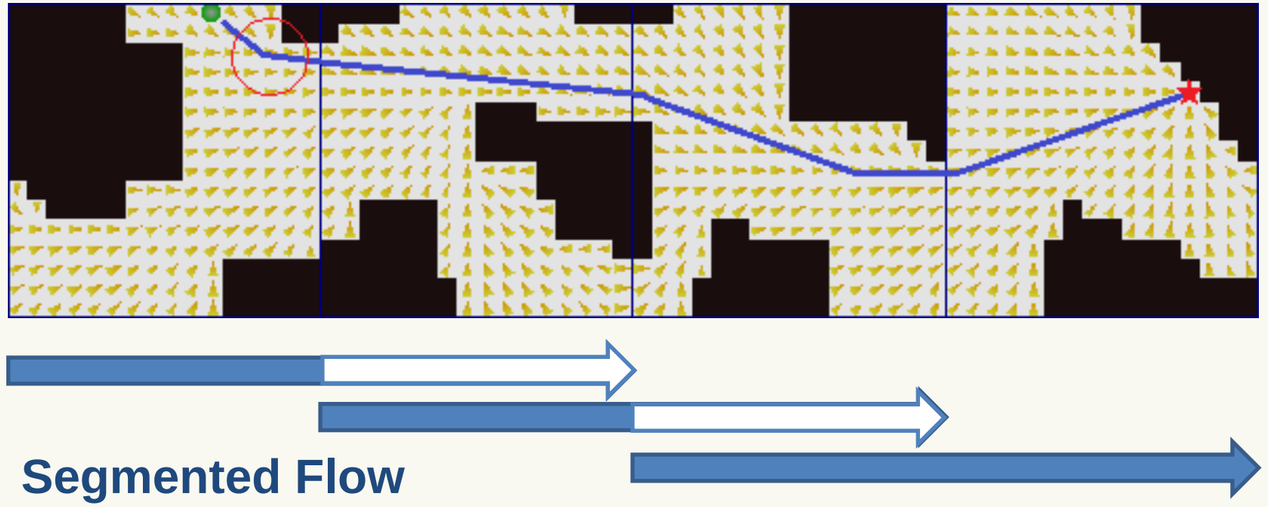
- Short segments ensure minimal impact to the simulation cost.

Compute As Needed

- Generate the new segments as the unit moves.

Cache Friendly

- Segments can be cached and reused as building blocks.



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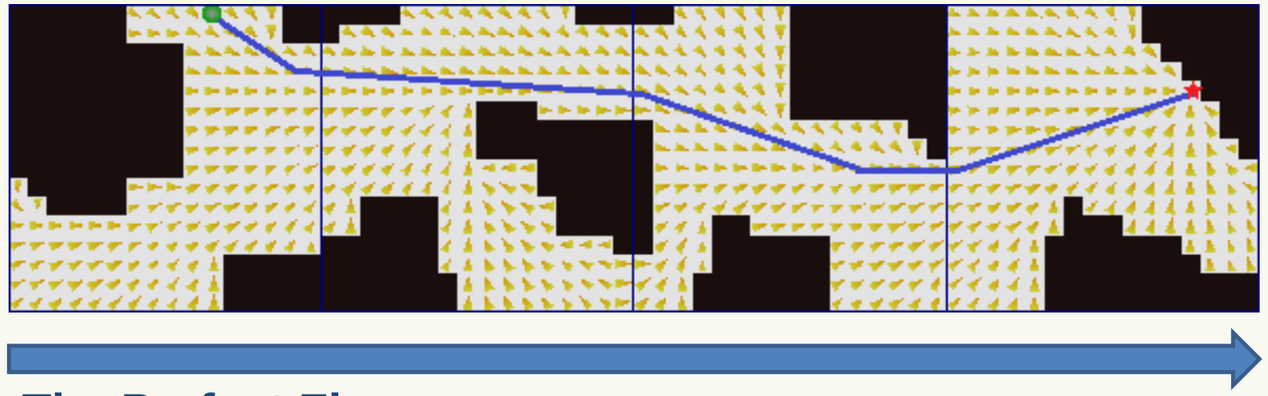
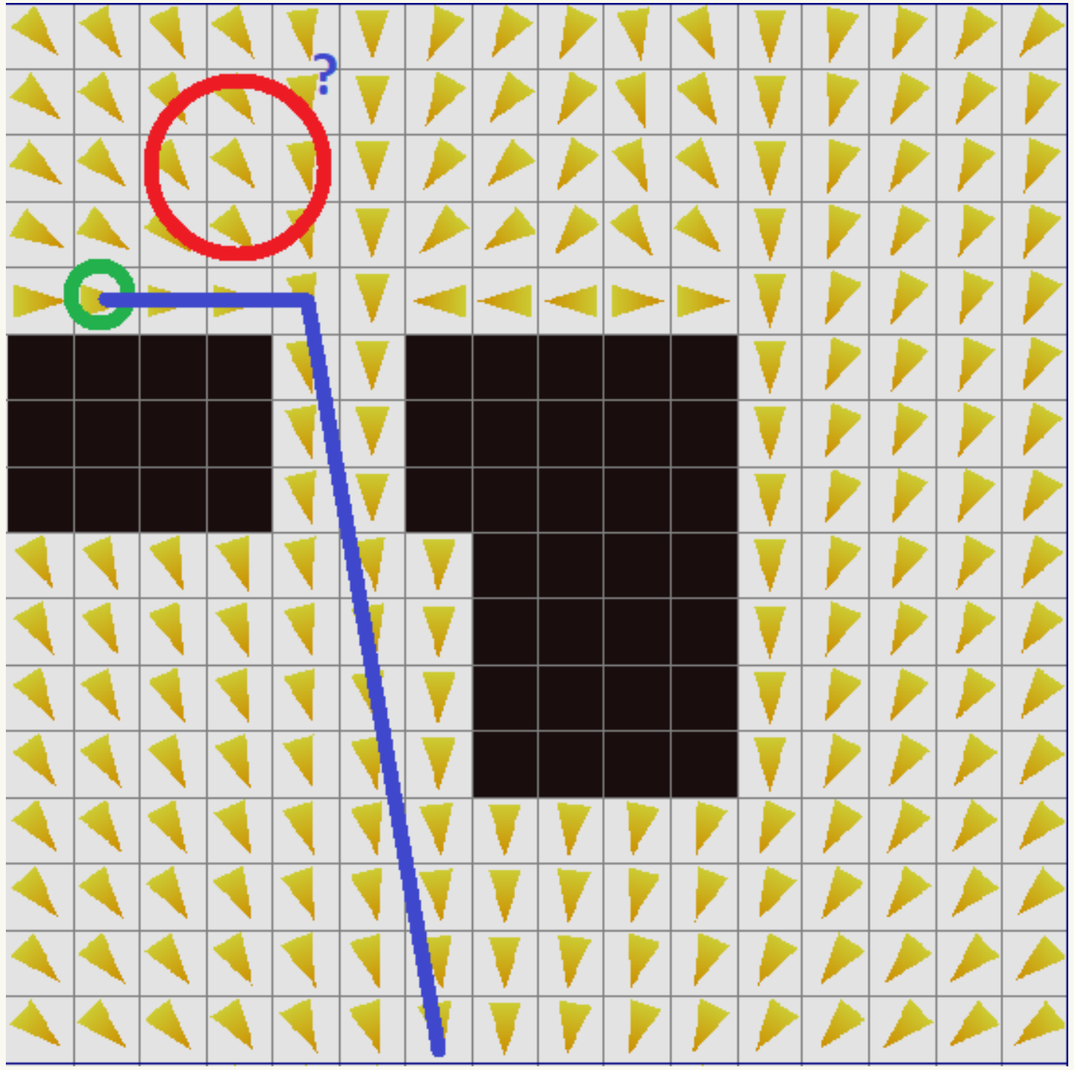


The Perfect Flow

Extended Flow

Problem: Group of mixed size or traversal restrictions.



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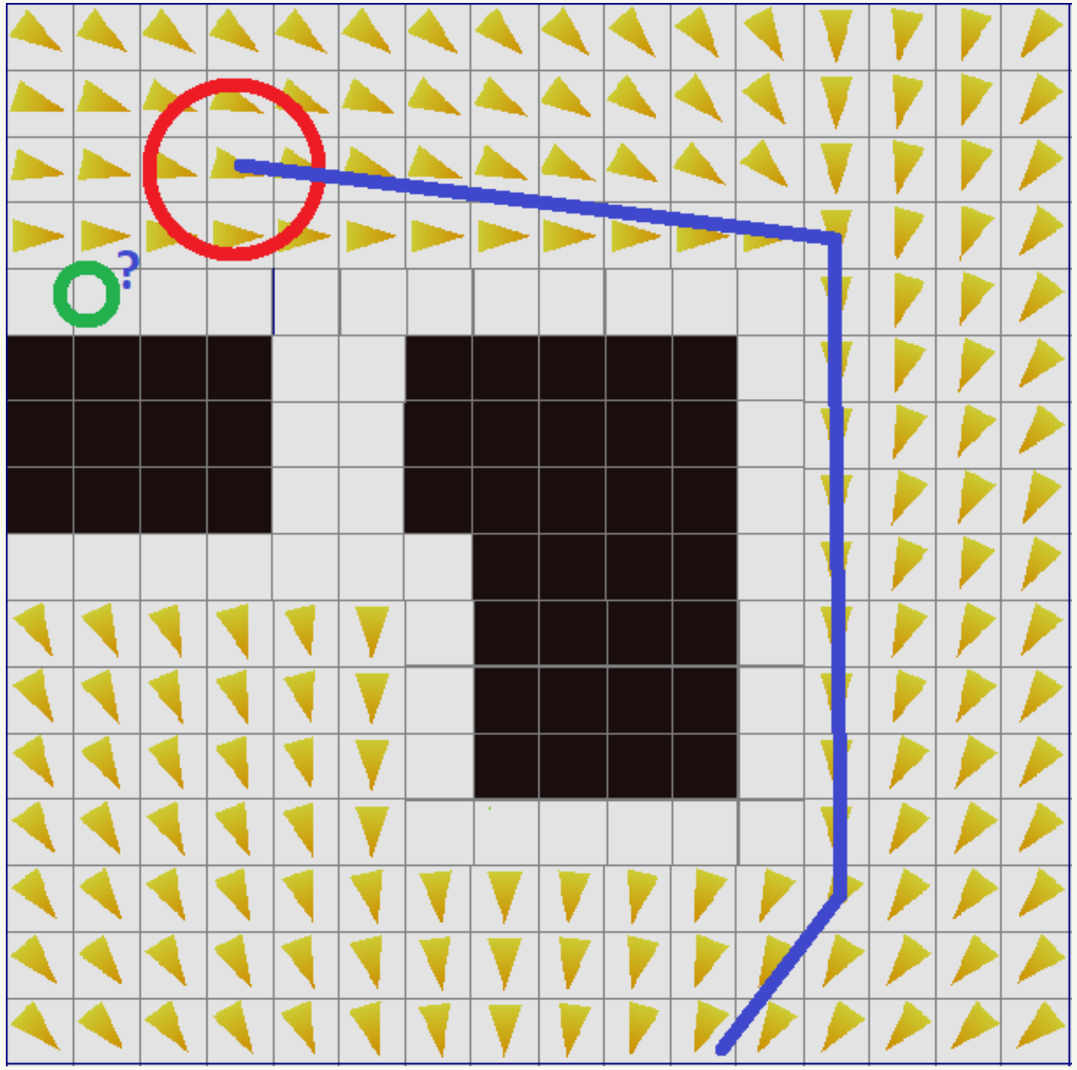

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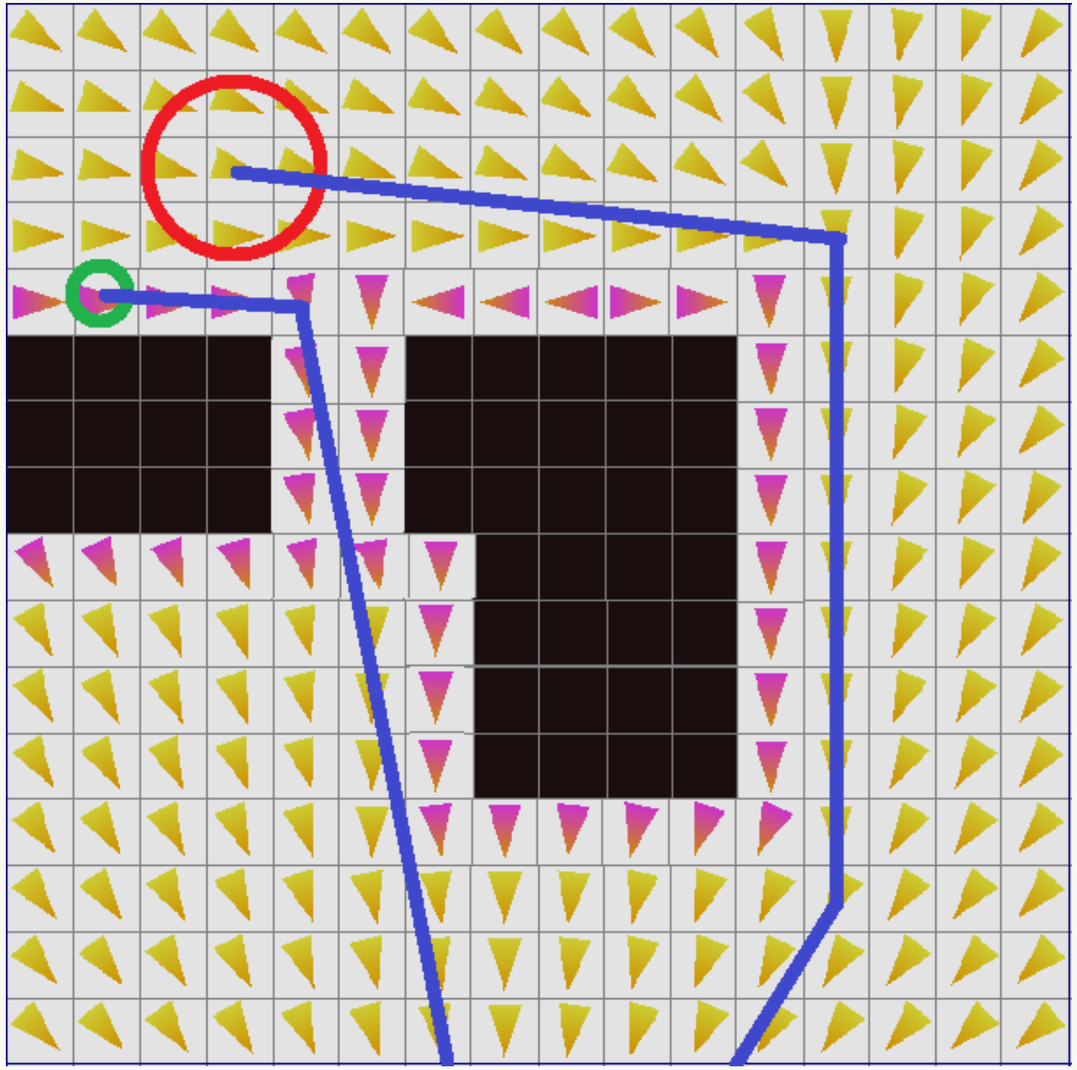

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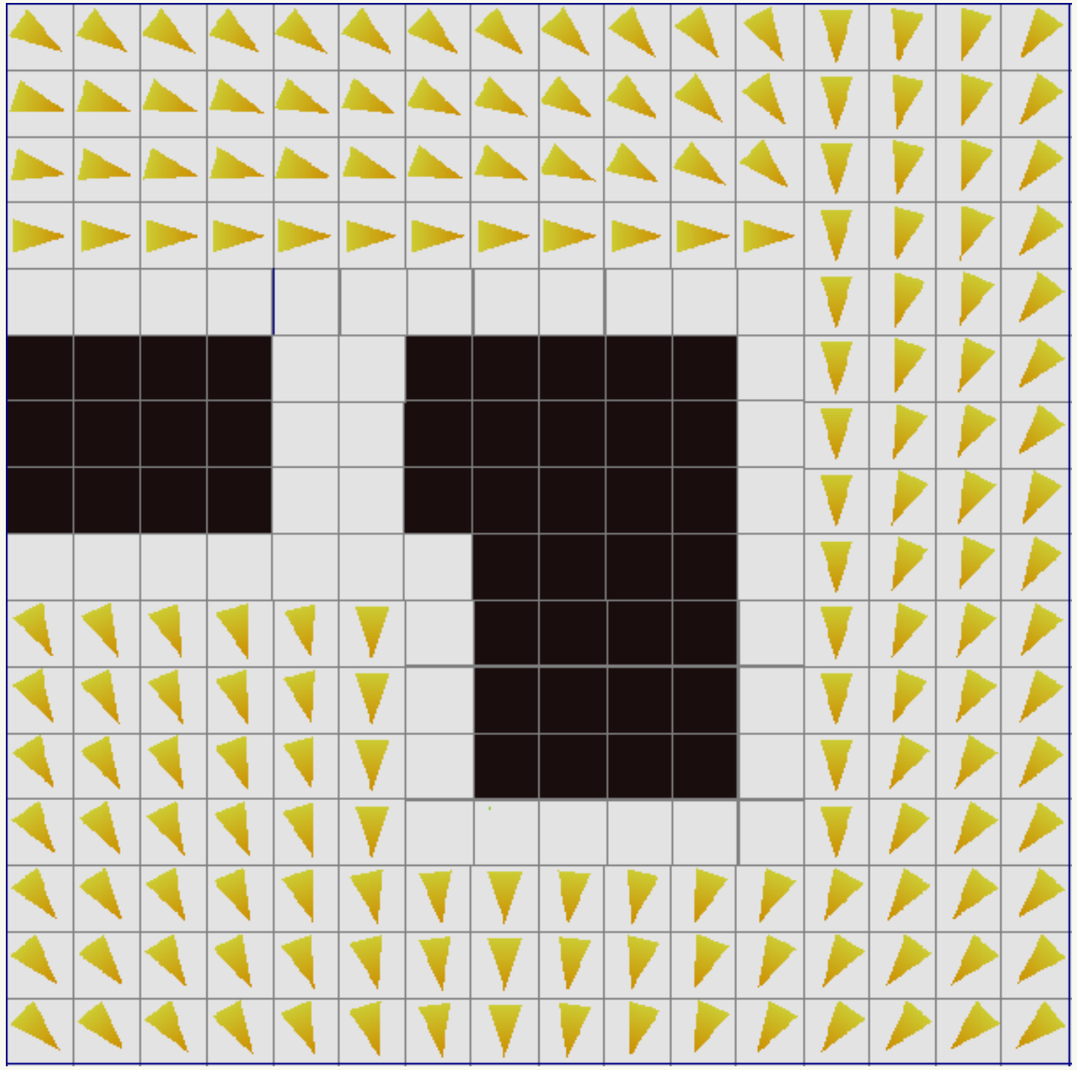
Solution: Extend the flow from the most restricted type.

- The yellow arrows are generated for the larger unit that takes up 3 cells.



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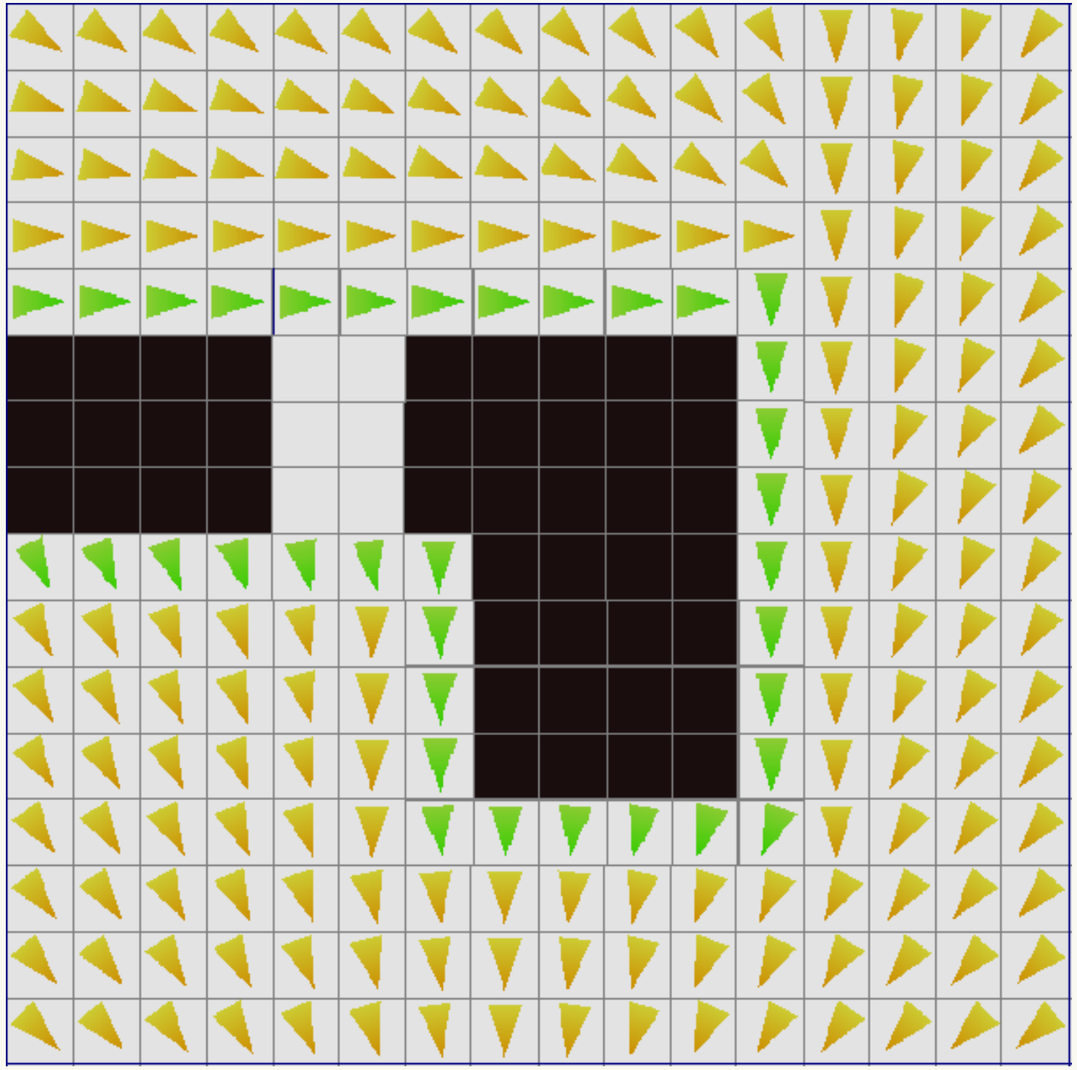

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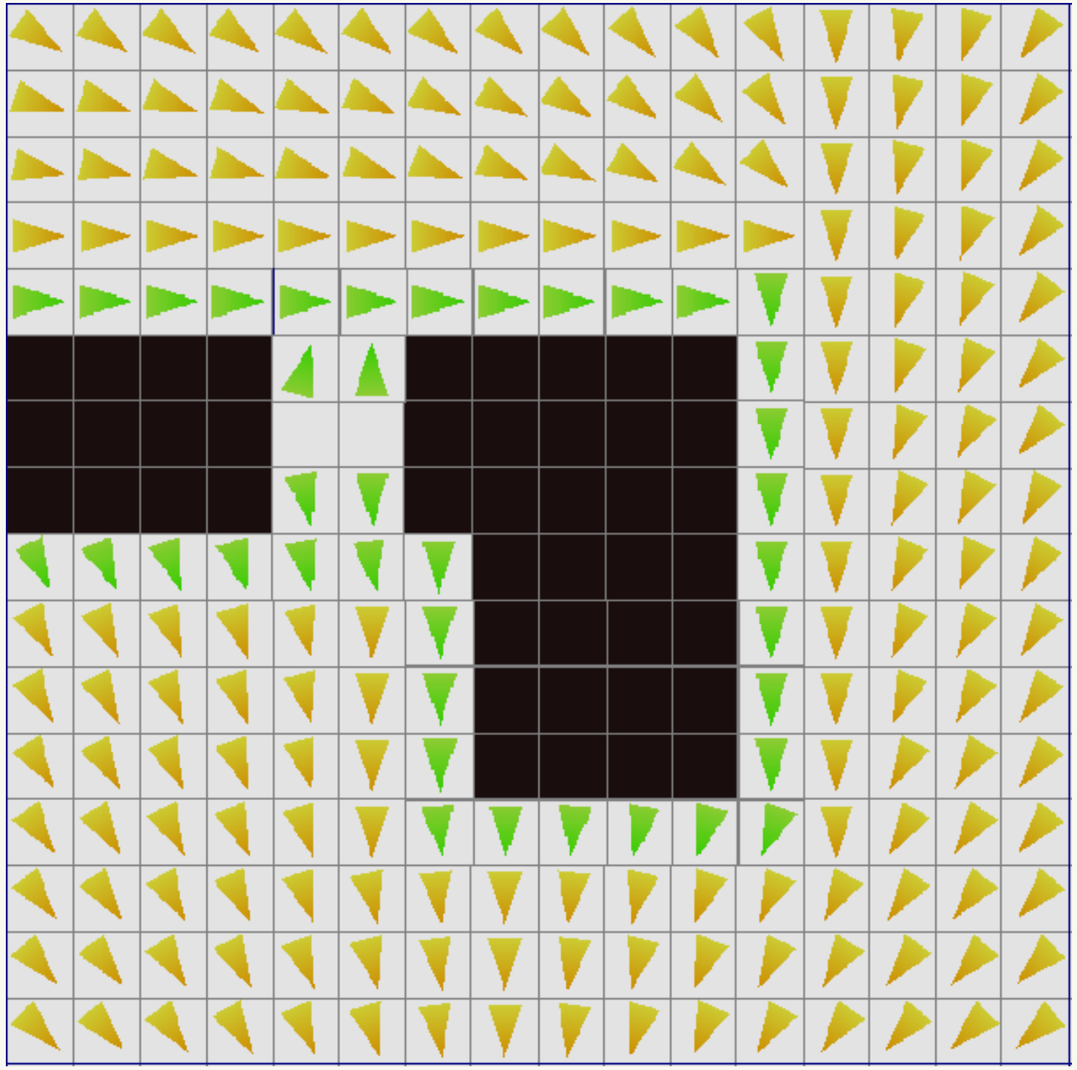

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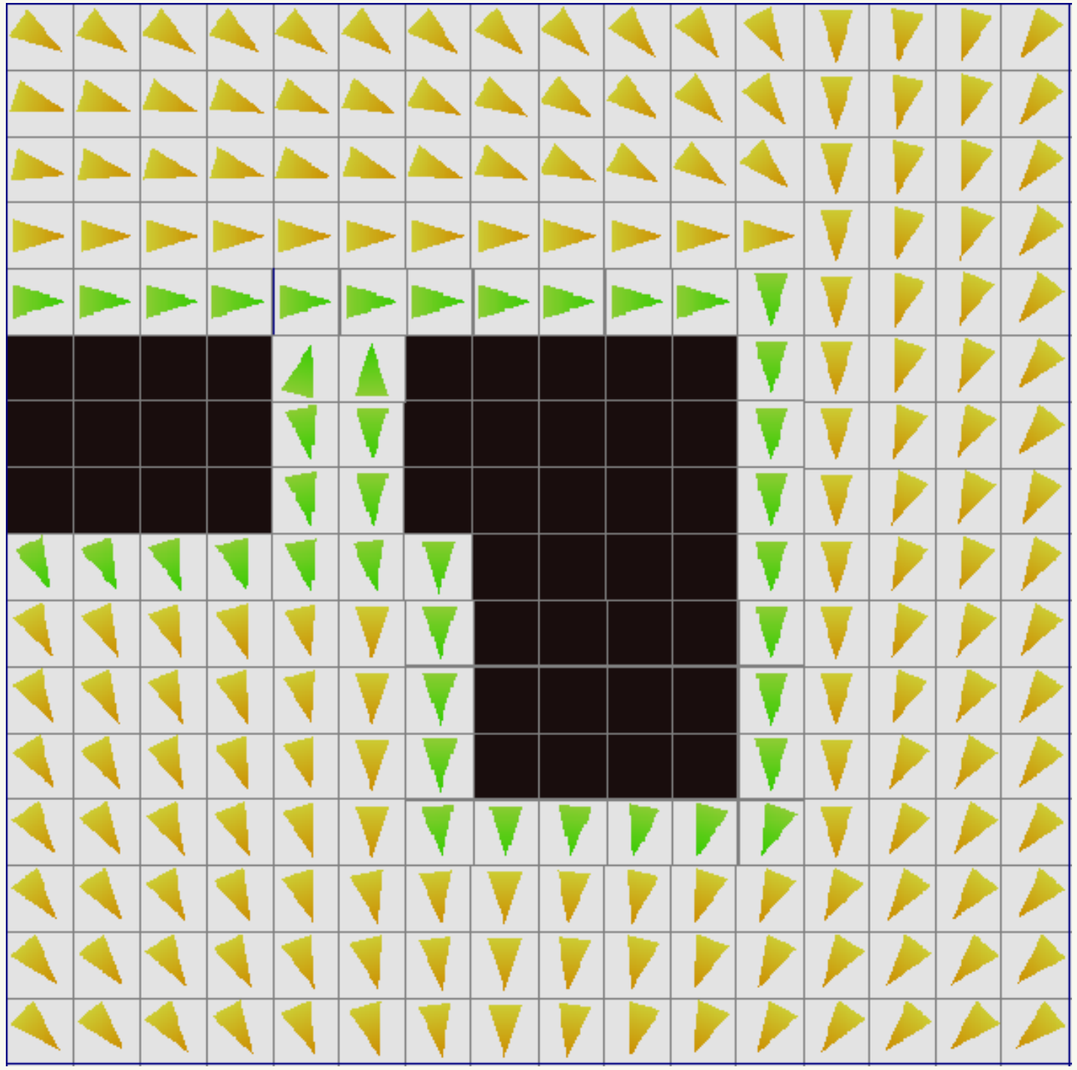

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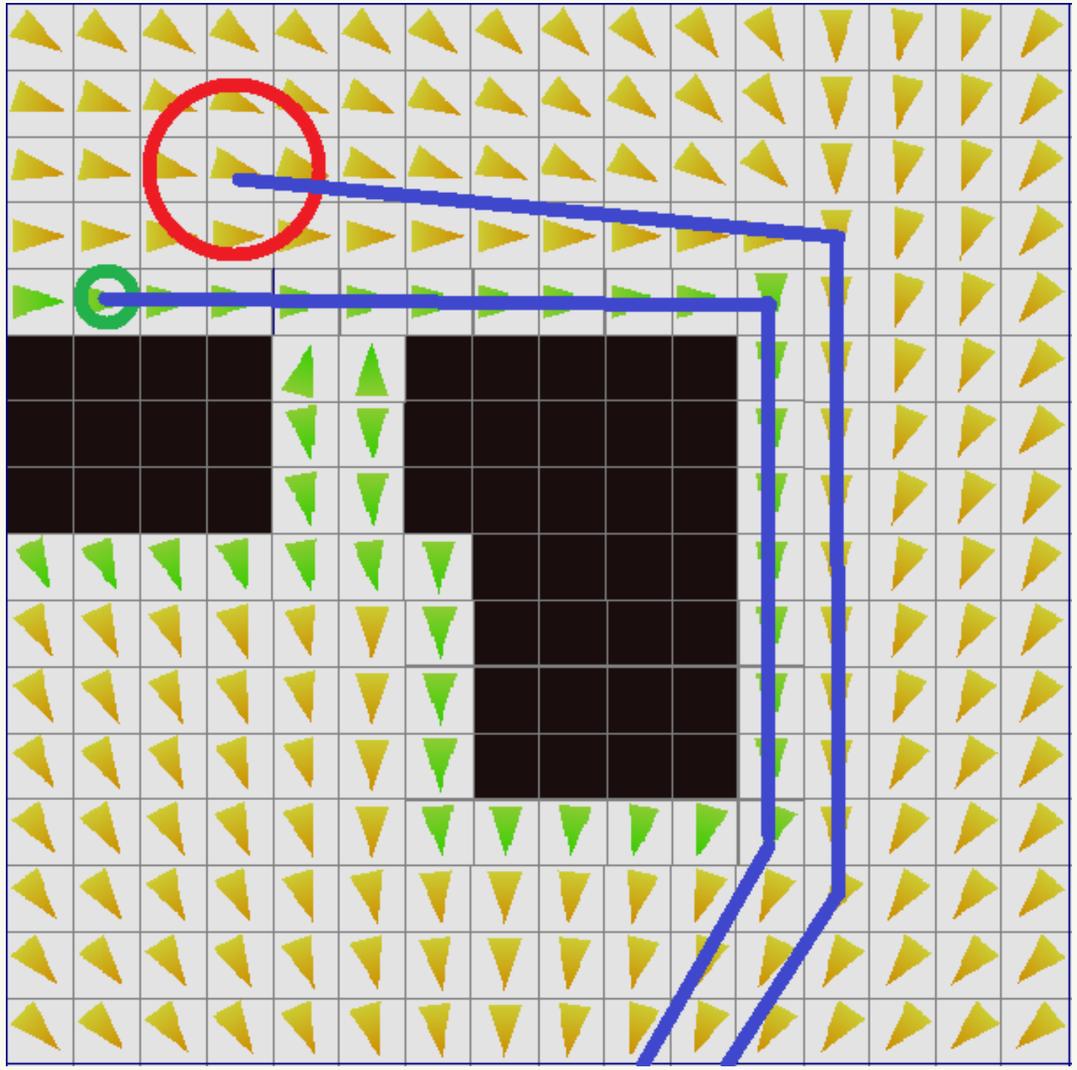


Merged Graph

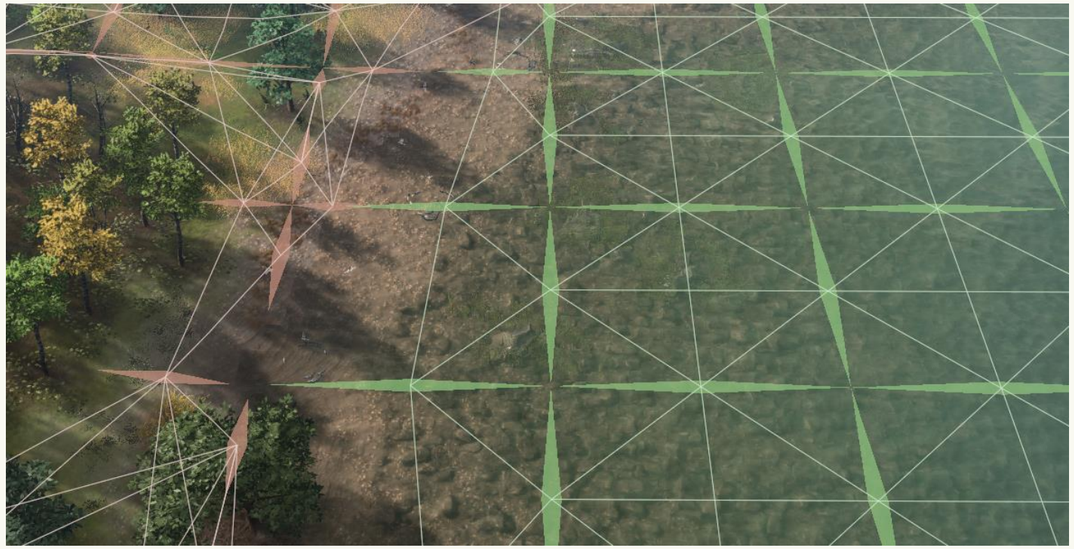
Consolidate pathfinding requests between land units and water transports.

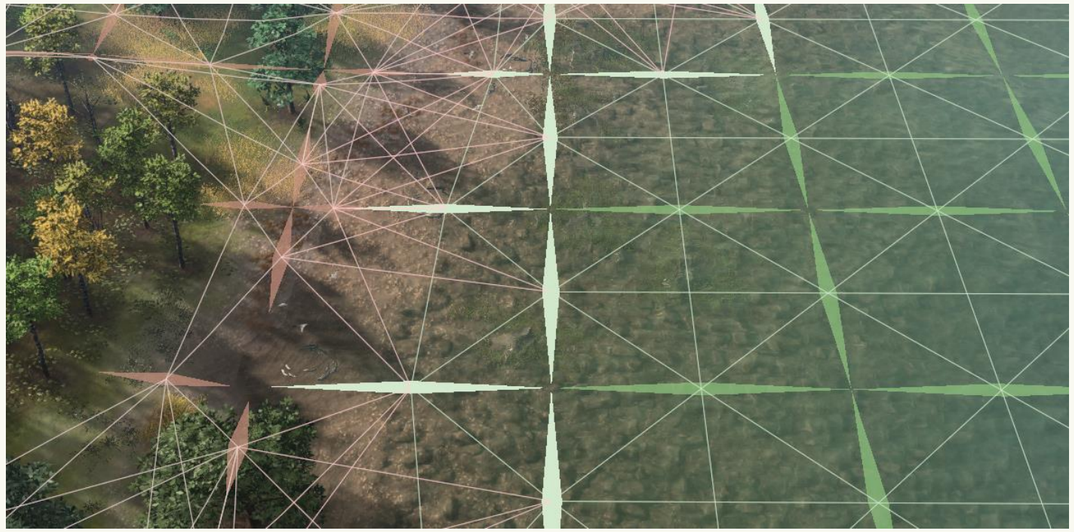
Create the Merged Graph

- Markup the grid cells of the landing area.
- Stitch together the graphs at the landing area.

Use the Merged Graph

- Single A* call from land to water.
- Navigate both units toward landing area.





Flow Field with Formation

Generate Flow Path

- A **virtual formation leader** requests and follows a flow path.

Formation Steering

- **Units follow the formation spots** generated around the leader.
- **Units follow the flow** when no line-of-sight to formation spot.

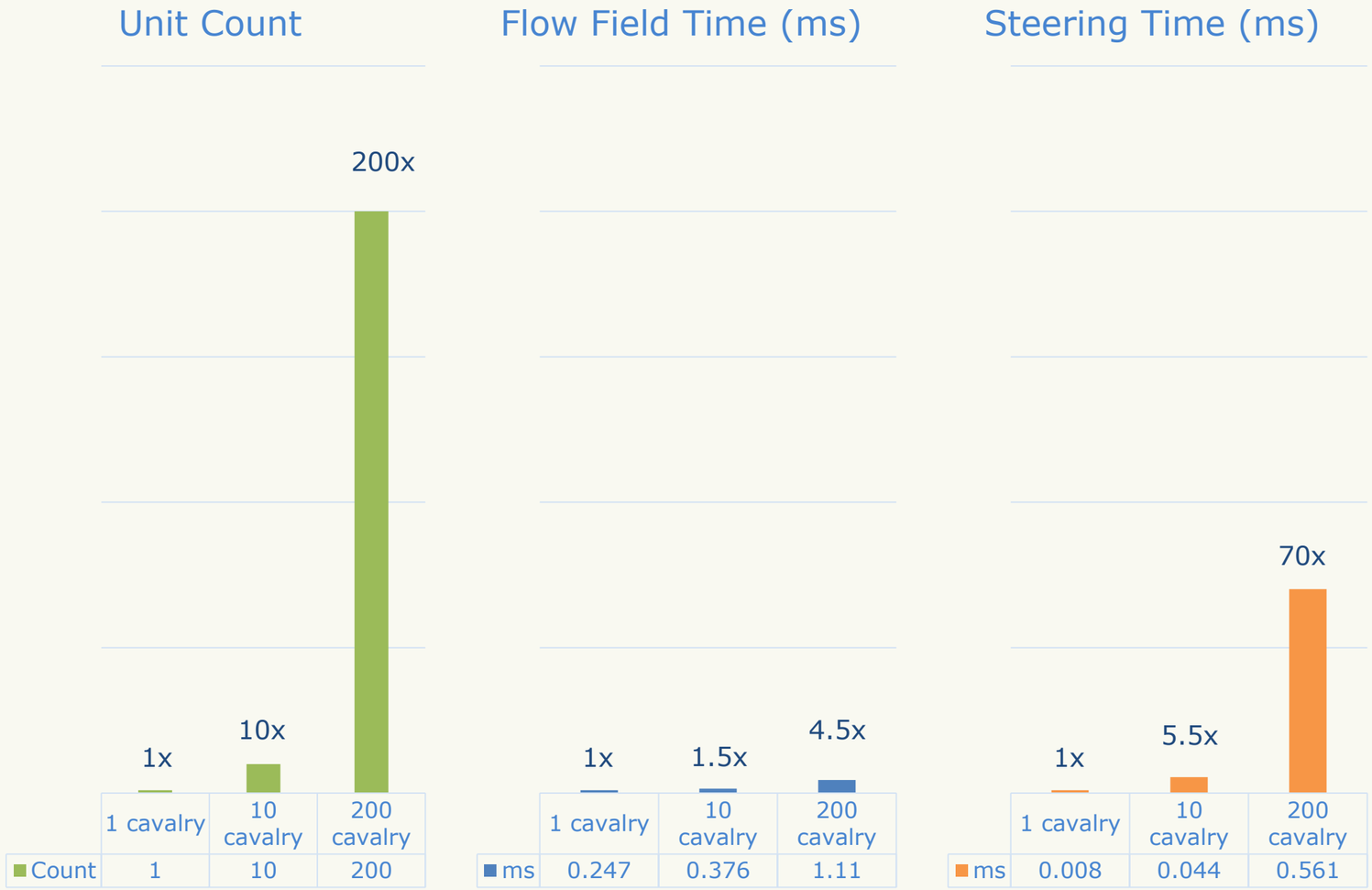
Expanding Flow Path

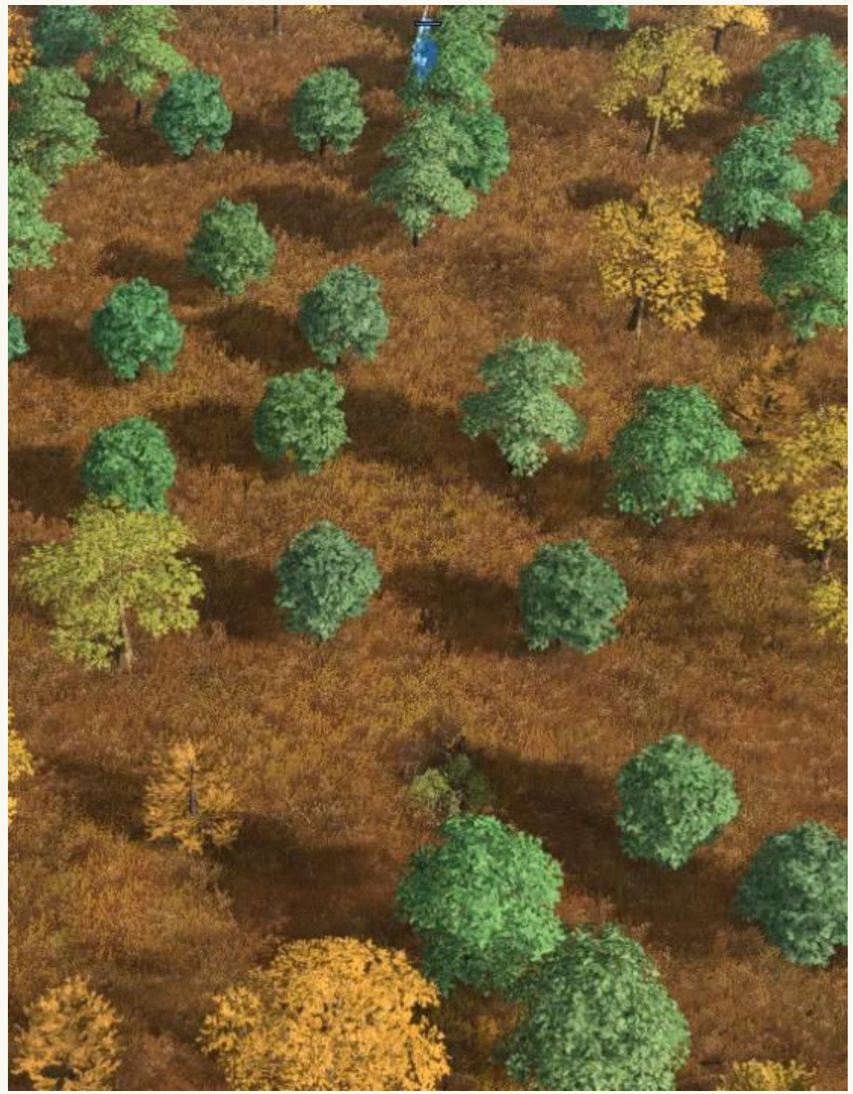
- **Expand addition leaf nodes** from the flow path to fully cover all the units.

Avoidance and Obstacle Steering

- Avoid Moving Units
- Avoid Immobile Units
- Avoid Small Static Obstacles
- Group Cohesion

Performance Analysis





Flow Fields Summary

Pros

- Supports steering due to spatial path information.
- Can be shared by all units going the same general direction.

Cons

- Extra cost if the path is only used by a single unit.
- Extra cost recompute cost when terrain changes

Thank You

AGE OF EMPIRES IV

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Thursday, March 24 | 2:00pm - 2:30pm

- **THE MAW: SAFELY MULTITHREADING THE DETERMINISTIC GAMEPLAY OF 'AGE OF EMPIRES IV'**
- **Speaker: Joel Pritchett** (Microsoft)

Thursday, March 24 | 4:00pm - 5:00pm

- **GIVE YOUR PLAYERS A SEAT AT THE TABLE: FEEDBACK FUNDAMENTALS**
- **Speakers: Emma Bridle** (World's Edge, Xbox Game Studios), **Savannah Harrison** (World's Edge, Xbox Game Studios)