

Lecture 18

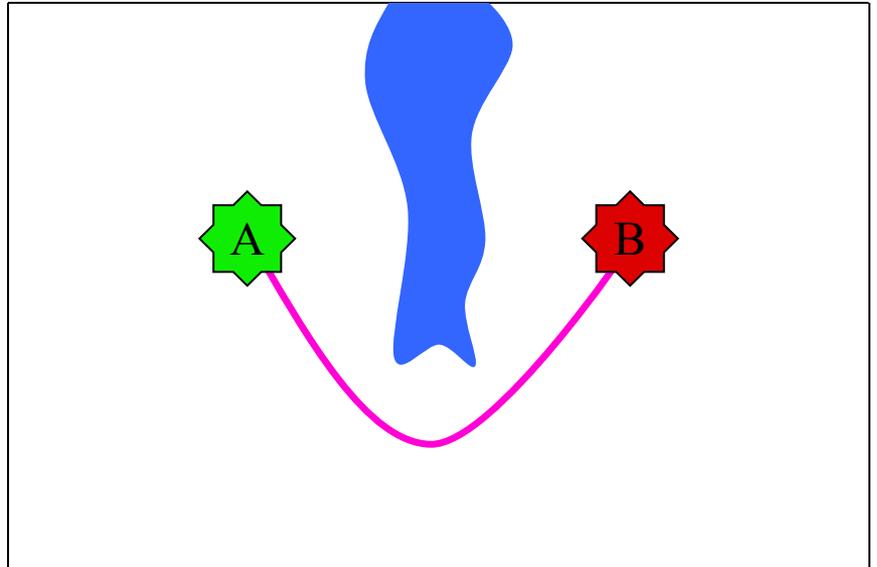
Pathfinding

Take Away for this Lecture

- What are the primary goals for pathfinding?
- Identify advantages/disadvantages of A*
 - In what situations does A* fail (or look bad)?
 - What can we do to fix these problems?
- Why combine steering and A*?
 - Is this combination always appropriate?
- What do commercial games use?

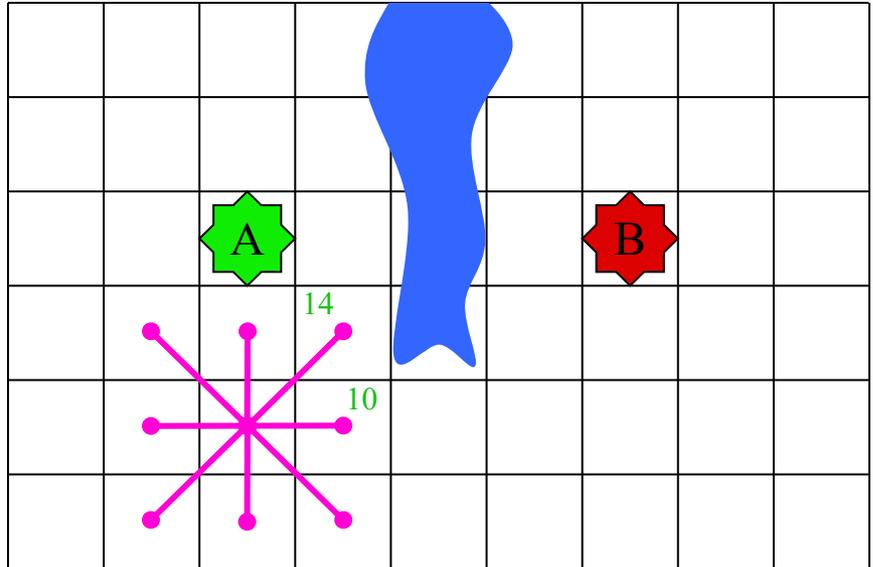
Pathfinding

- You are given
 - Starting location A
 - Goal location B
- Want **valid** path A to B
 - Avoid “impassible” terrain
 - Eschew hidden knowledge
- Want **natural** path A to B
 - Reasonably short path
 - Avoid unnecessary turns
 - Avoid threats in the way



Abstraction: Grid & Graph

- Break world into grid
 - Roughly size of NPCs
 - Terrain is all-or-nothing
 - Majority terrain of square
 - Terrain covering “center”
- Gives us a weighted graph
 - Nodes are grid centers
 - Each node has 8 neighbors
 - Weight = distance/terrain
- **Search for shortest path**



- Real distance not required
 - 14:10 ratio for diagonals
 - Allows us to use integers

Breadth-First Search (Lab 2)

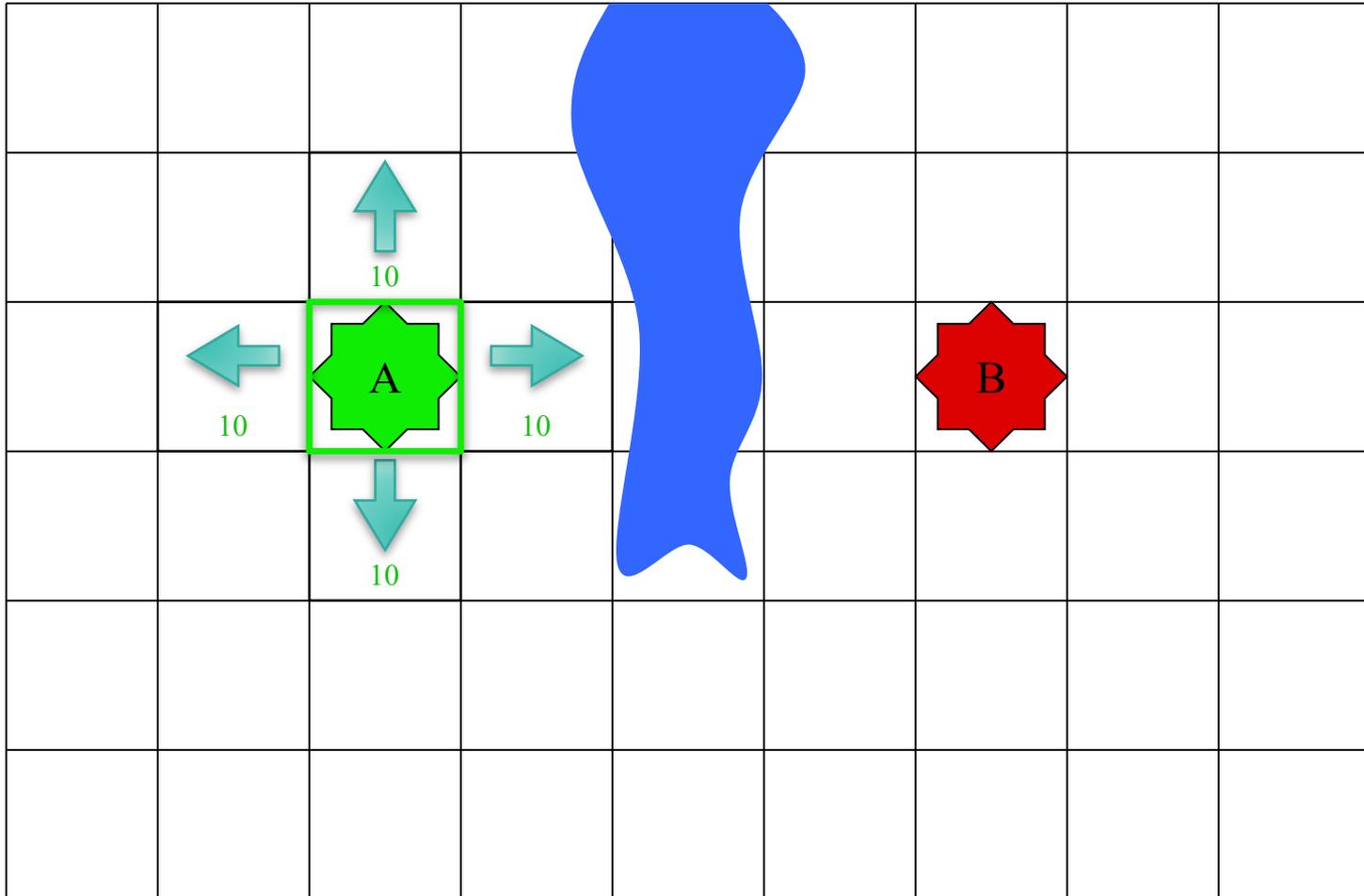
Intuition

- **Search maintains**
 - Current node, initially **start**
 - List of nodes to visit
- **Basic Steps**
 - Have we reached the **goal**?
 - Add neighbors to *end* of list
 - Work from *first* node in list
 - Process “first-in first-out”

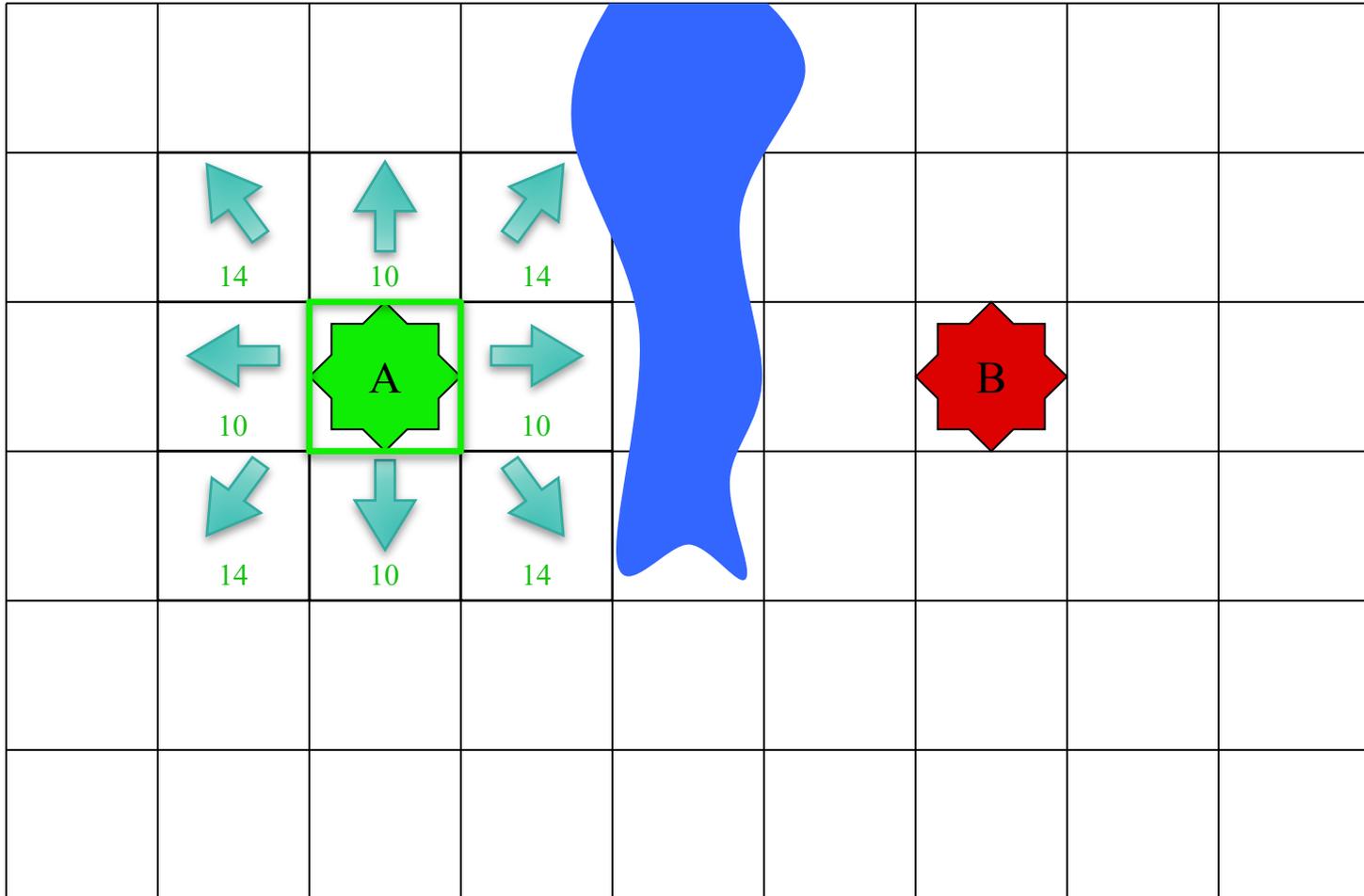
Algorithm

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n = start; L = { };  
while (n not goal) {  
    add n to visited;  
    N(n) = unvisited neighbors  
    foreach (m ∈ N(n)) {  
        add m to end of L;  
    }  
    n = removeFirst(L);  
}  
return path to goal;
```

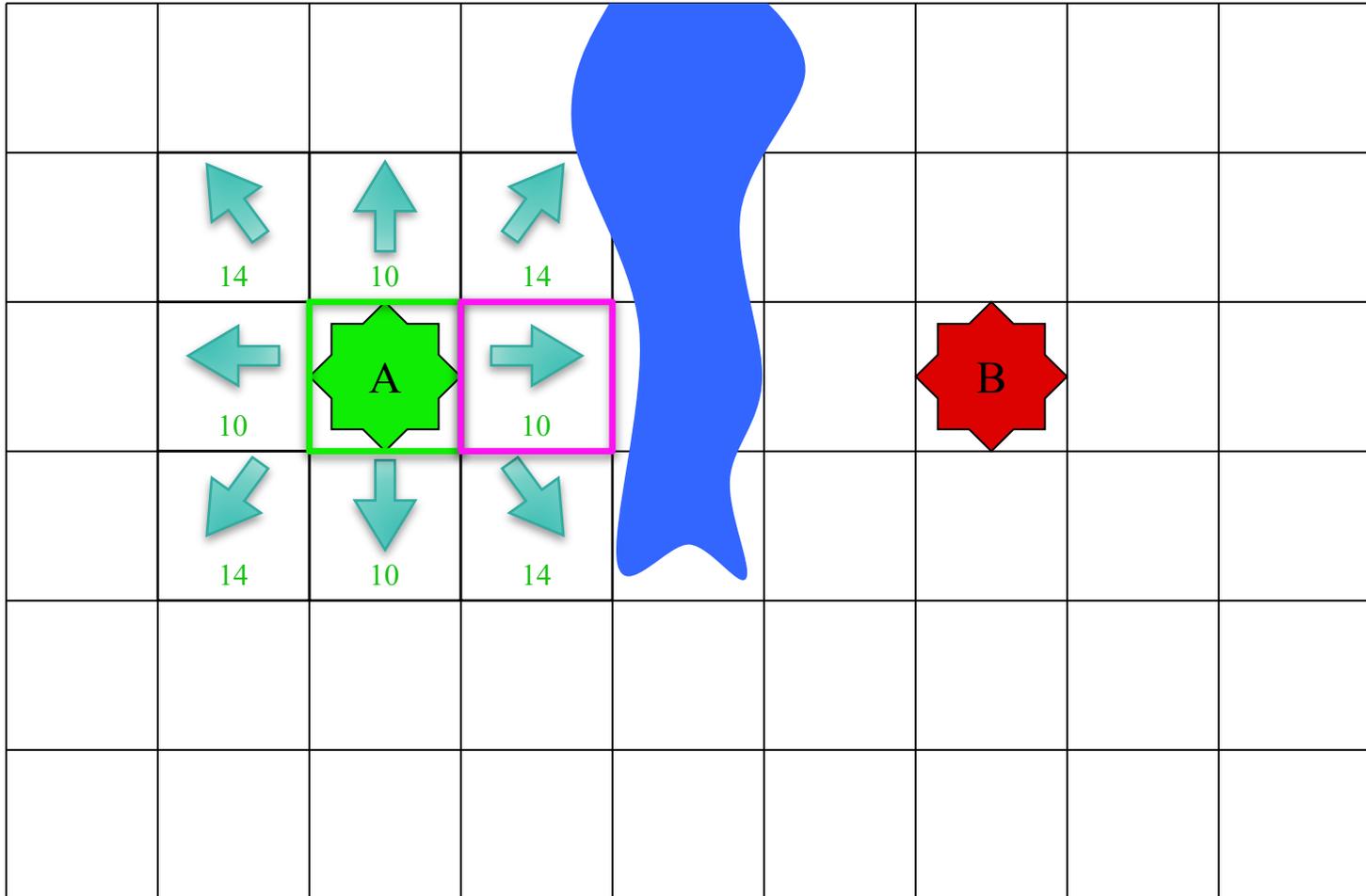
Pathfinding: Breadth-First



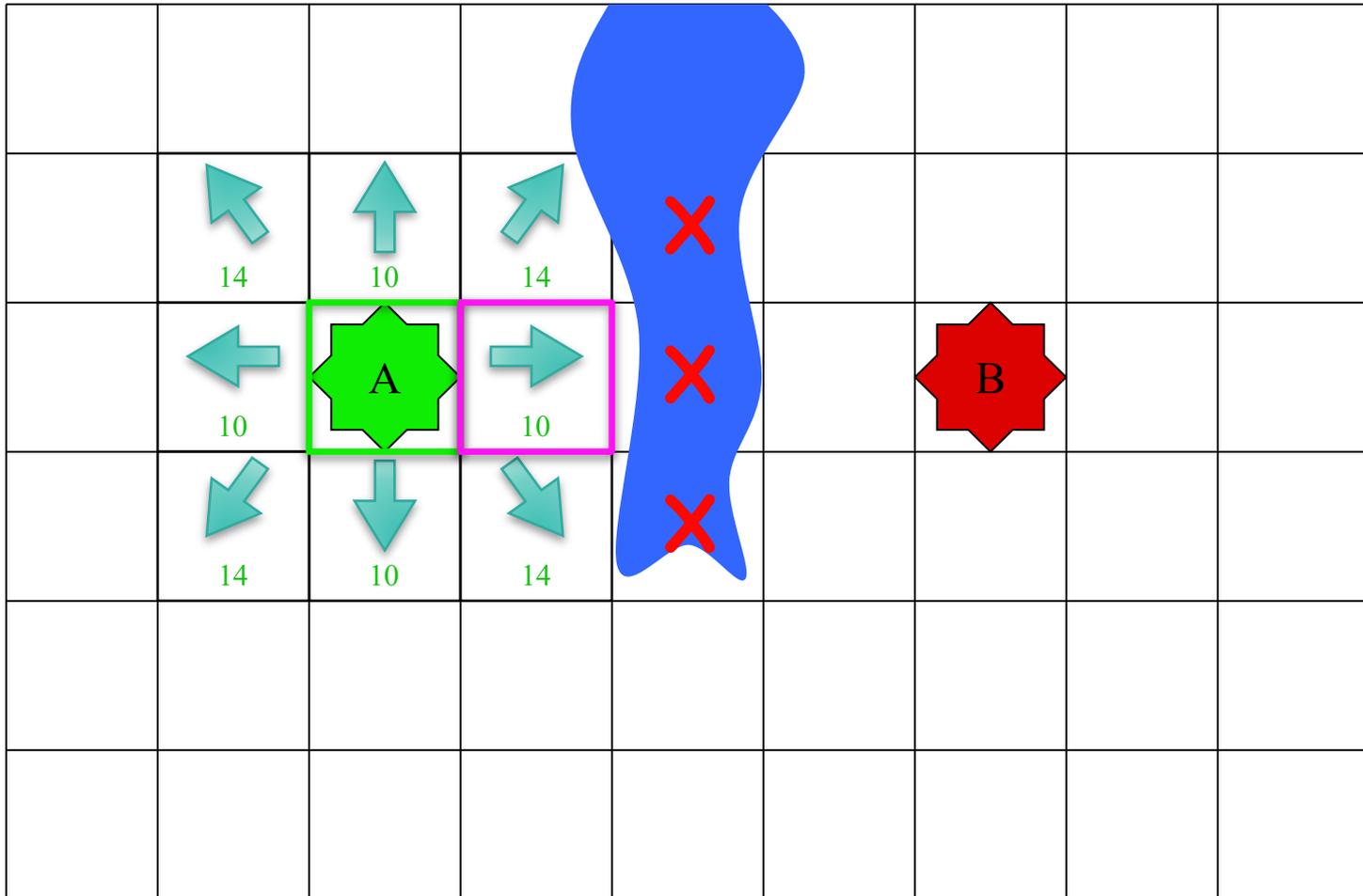
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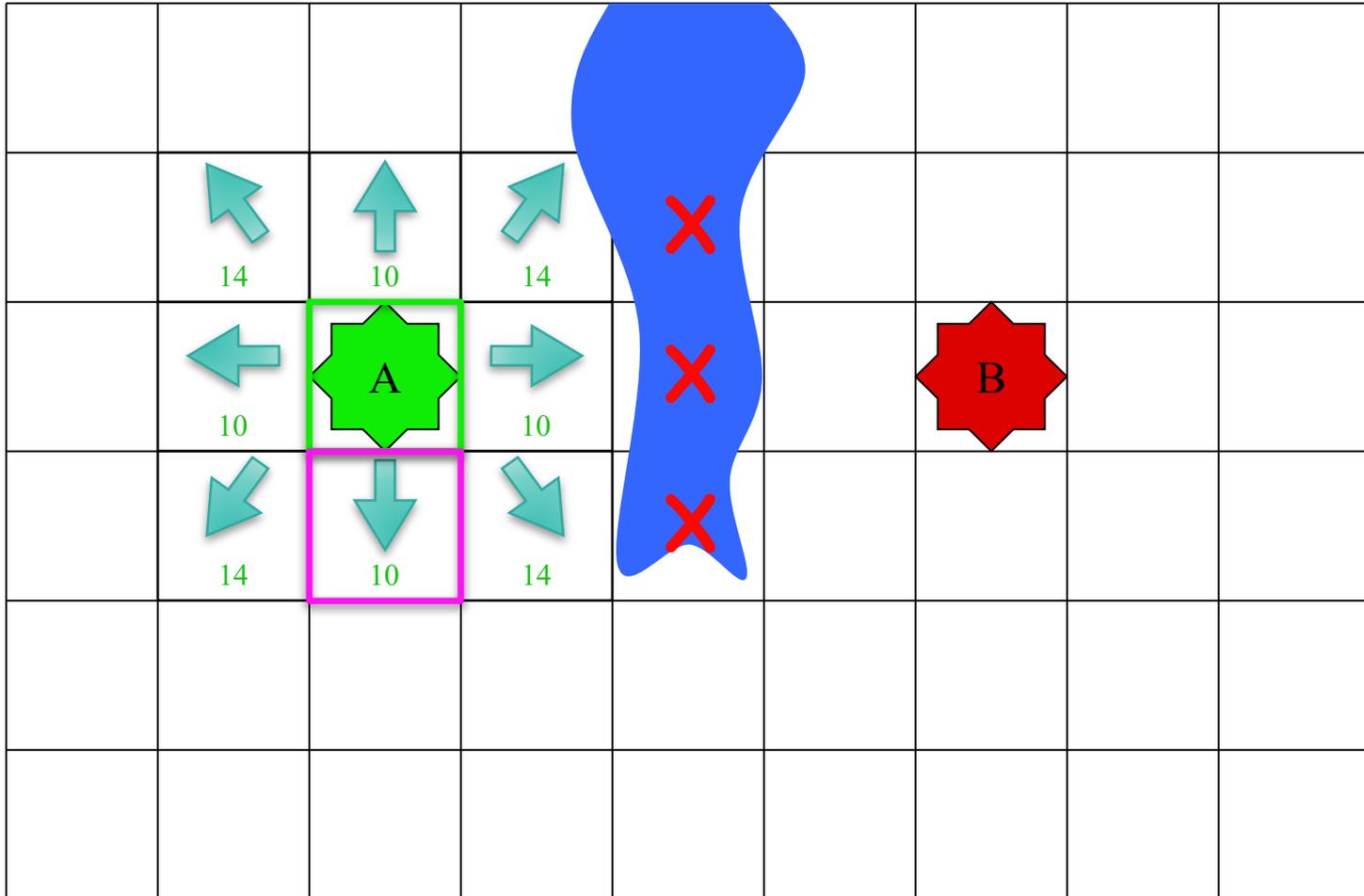
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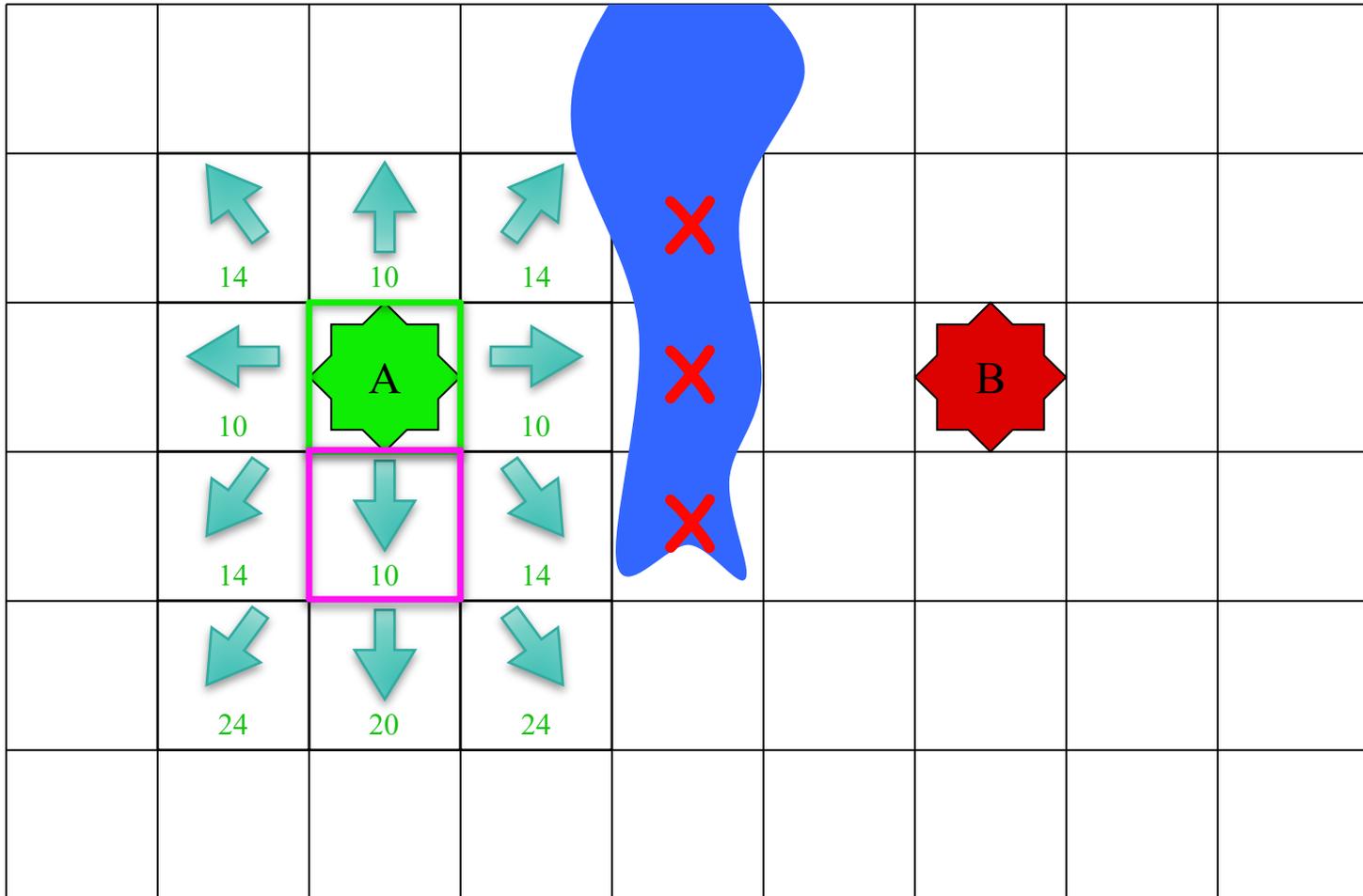
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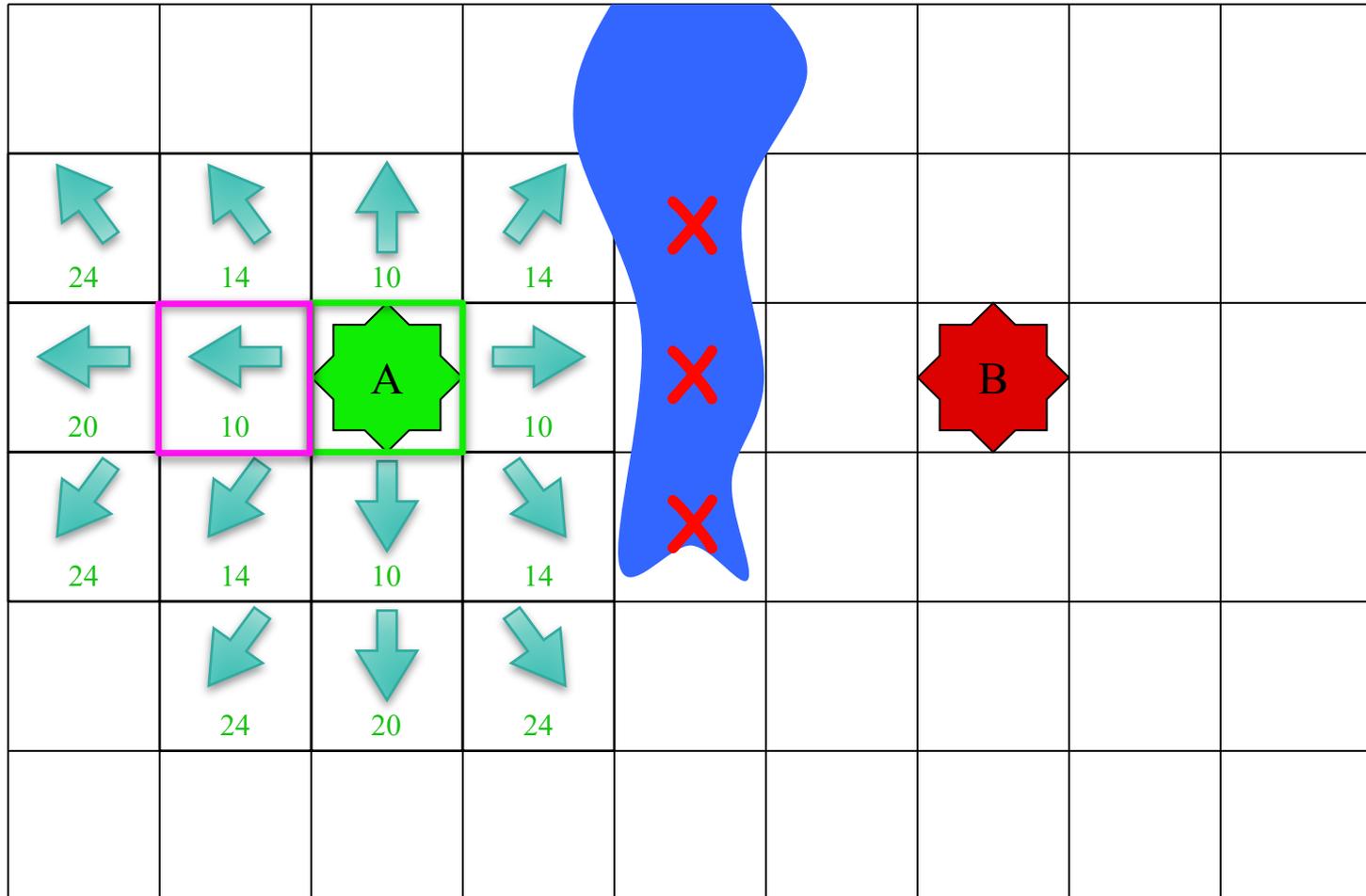
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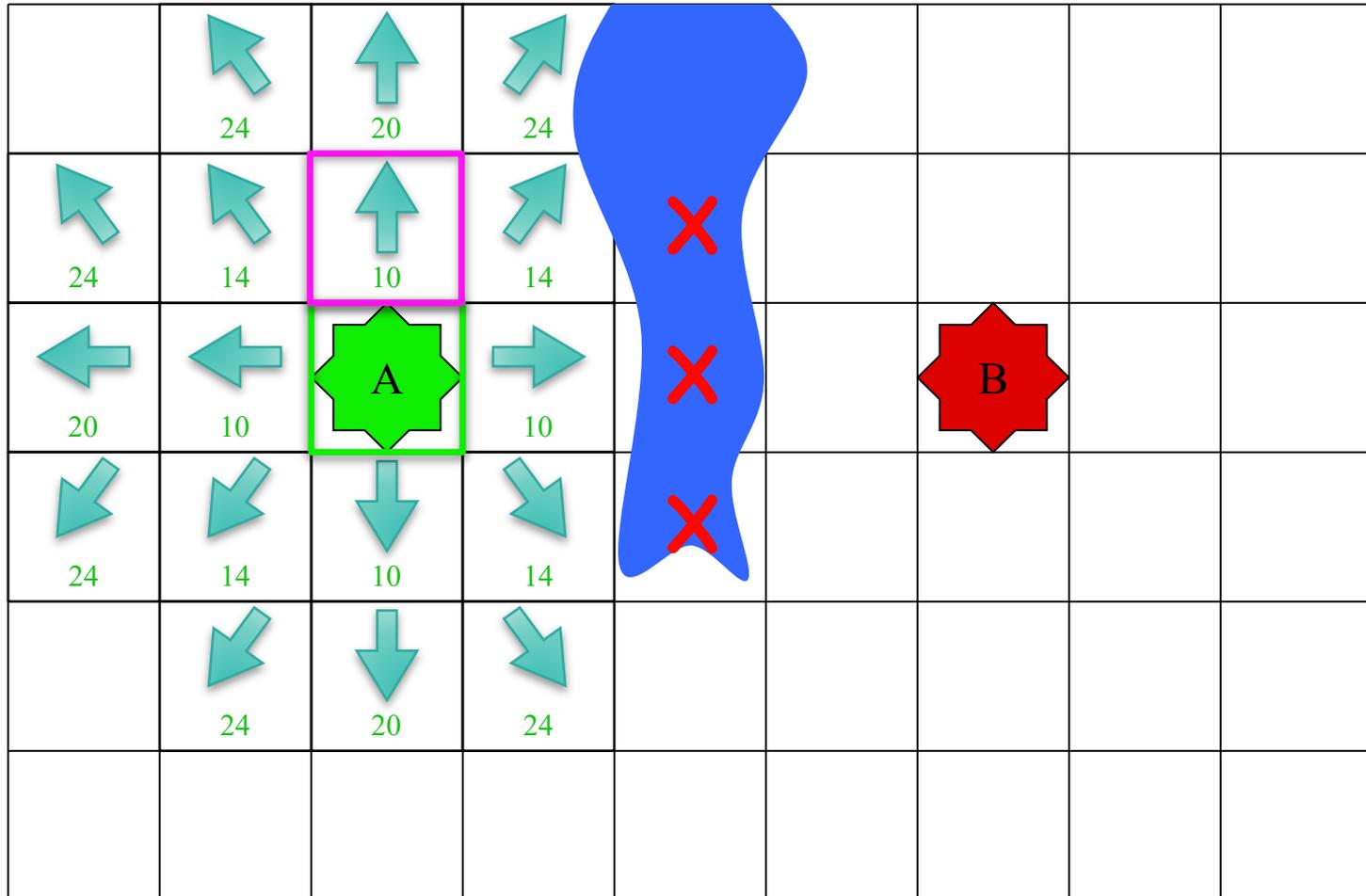
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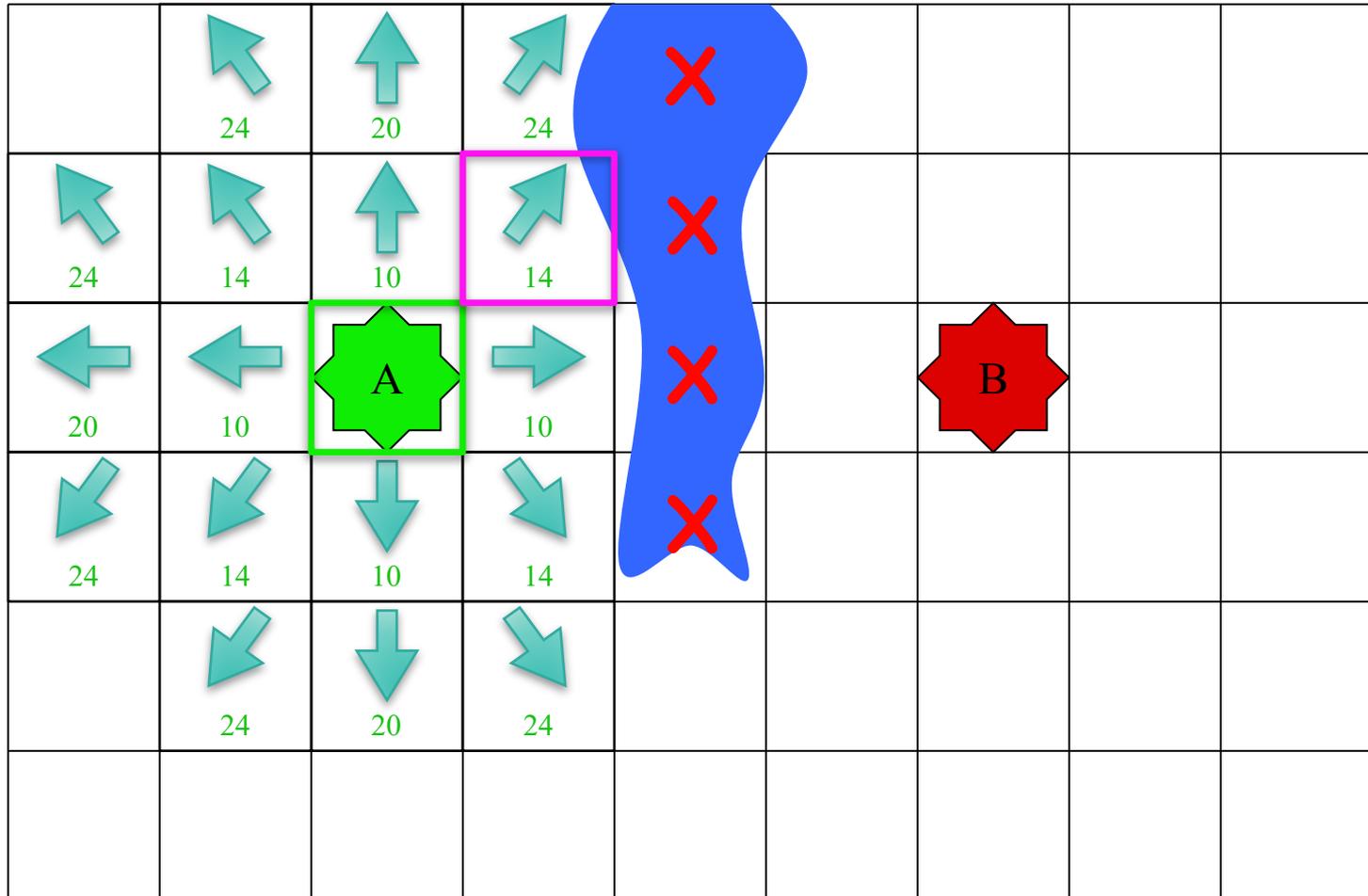
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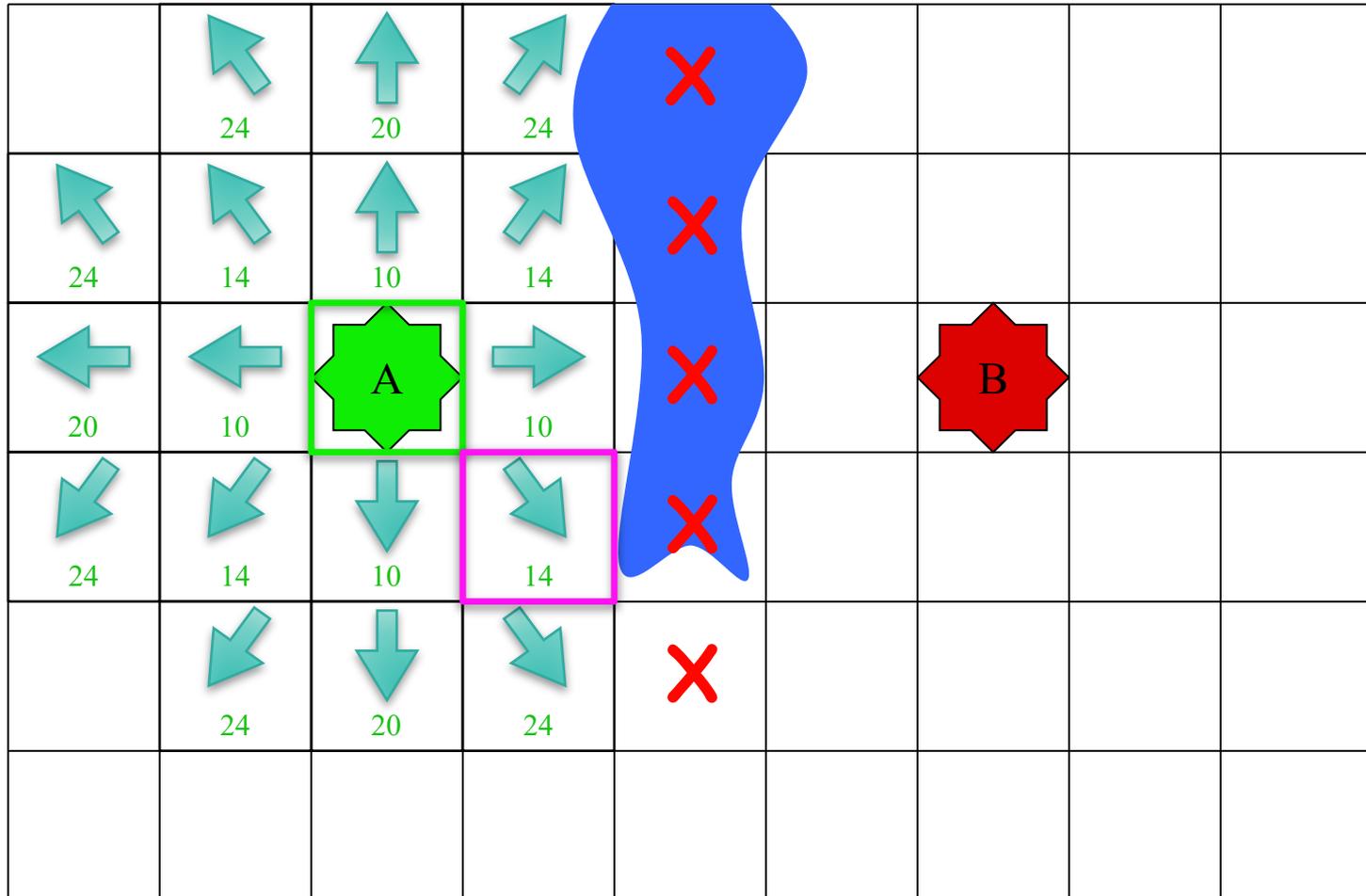
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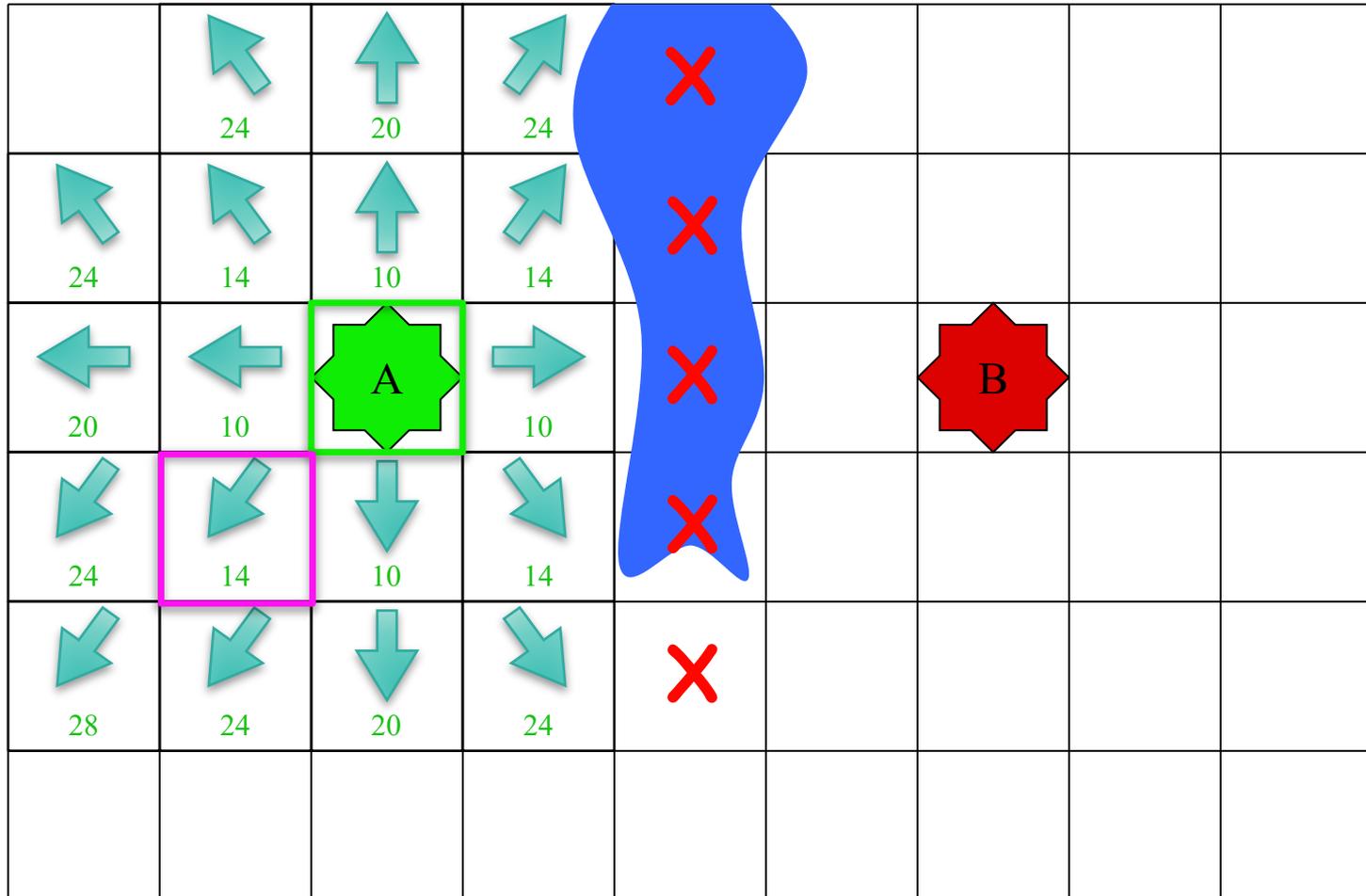
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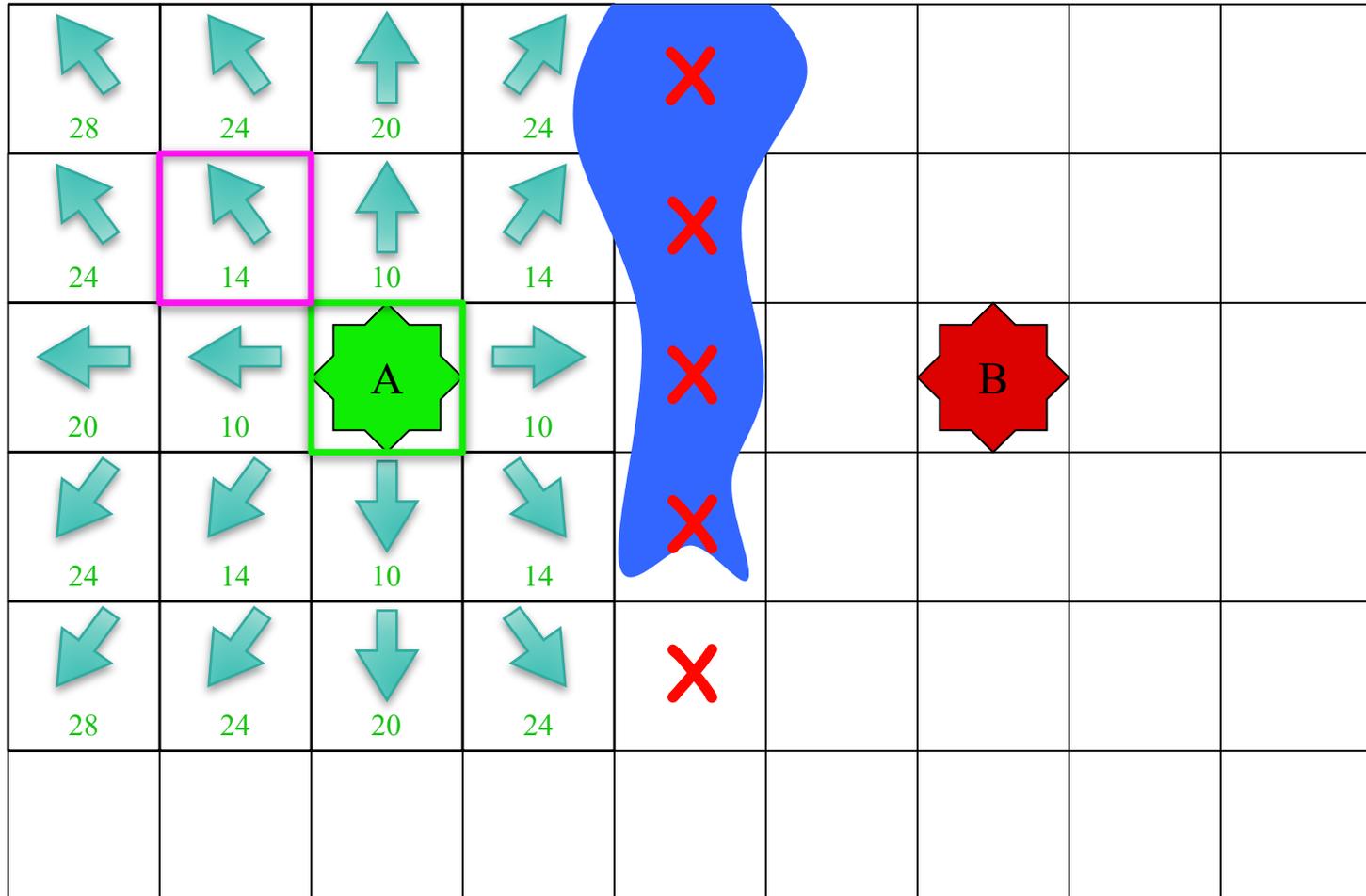
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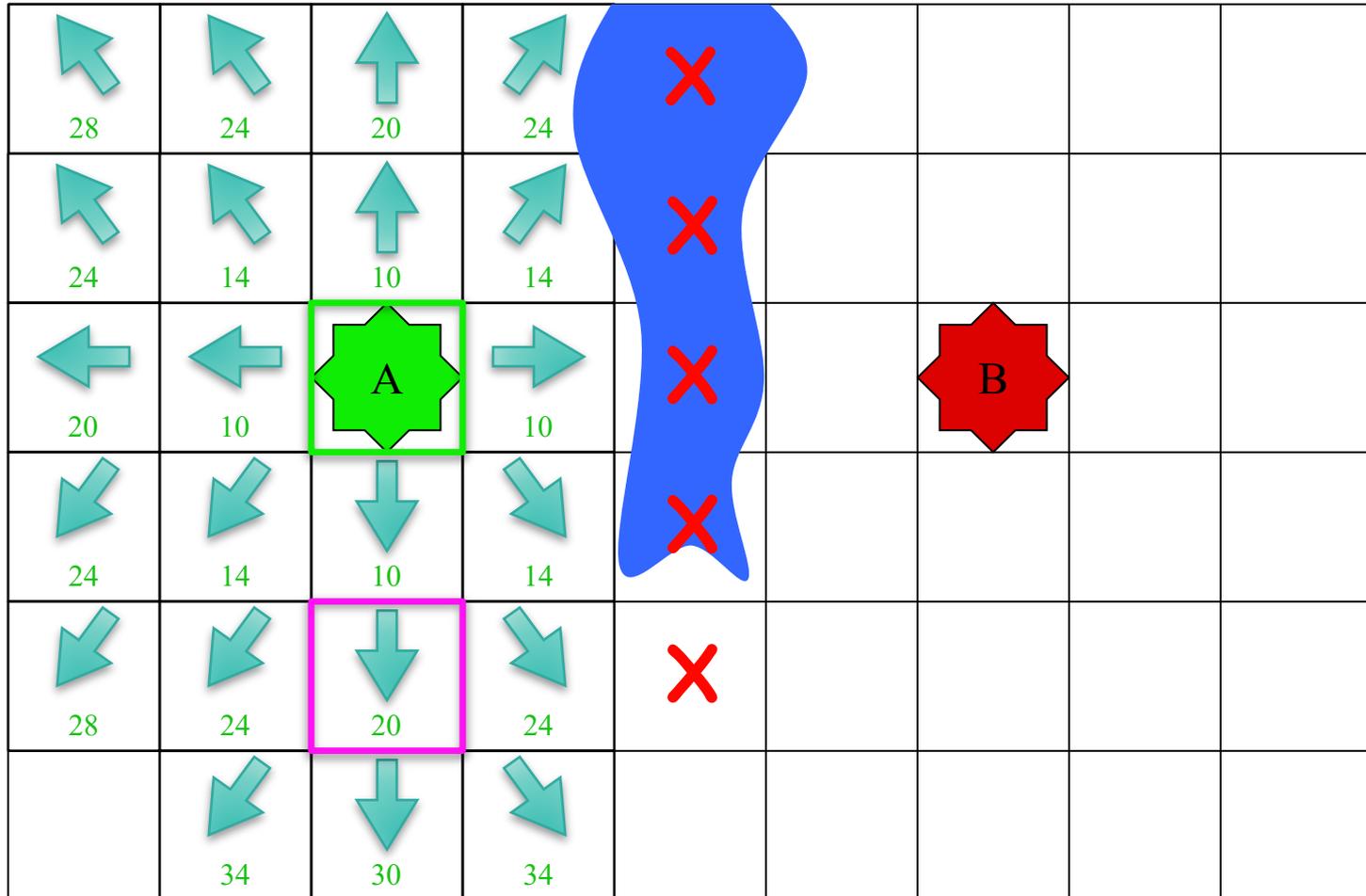
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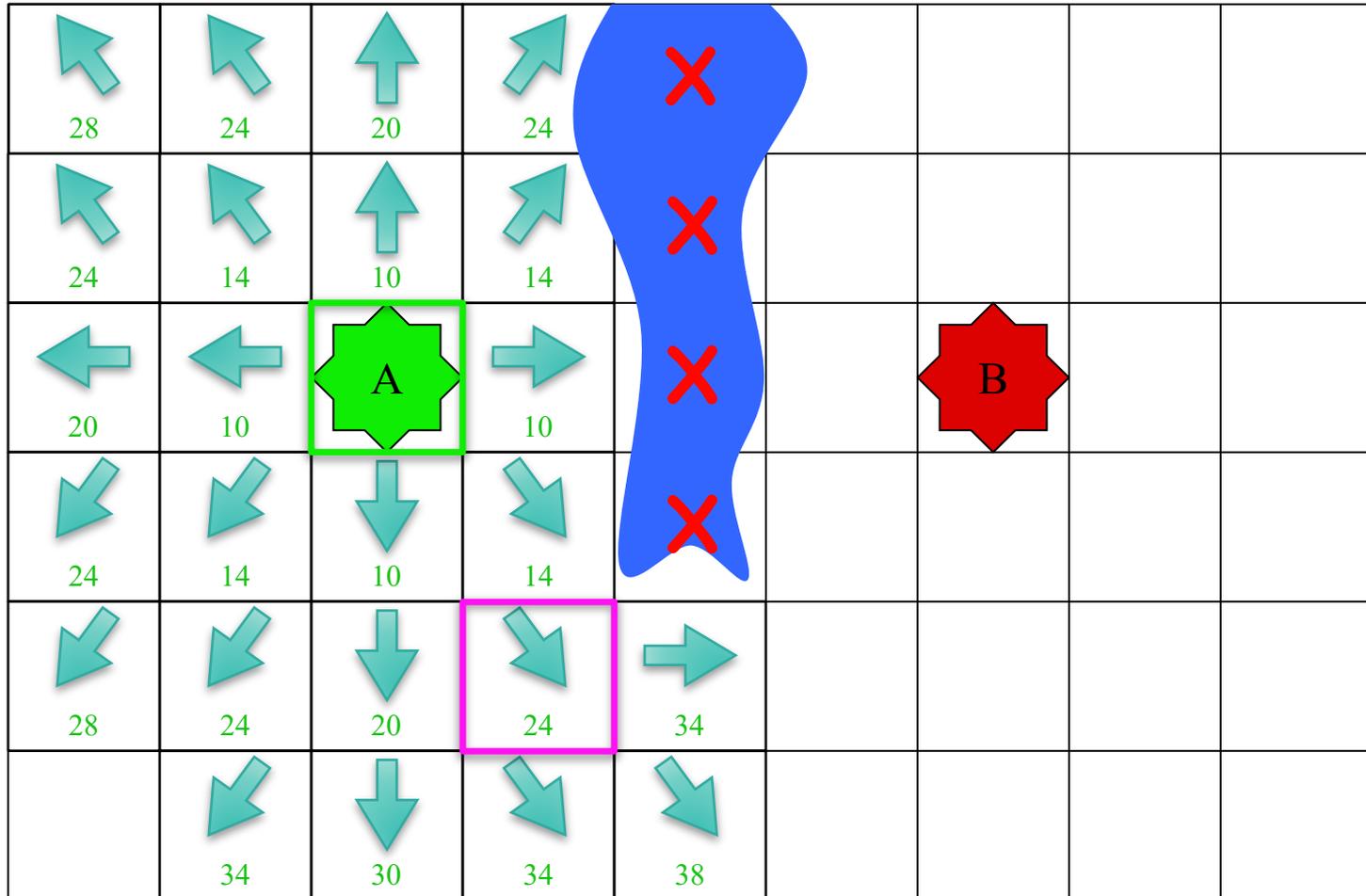
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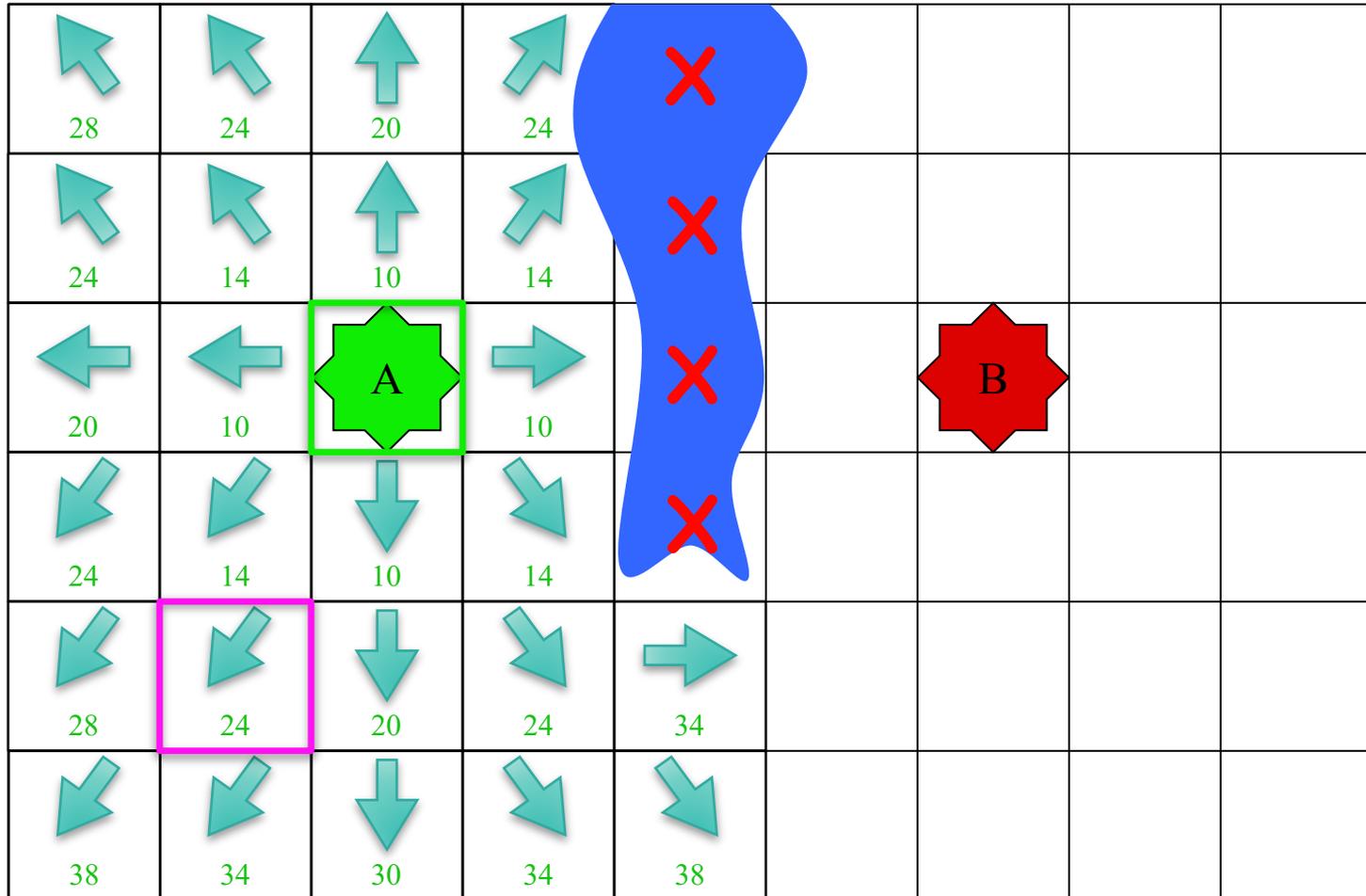
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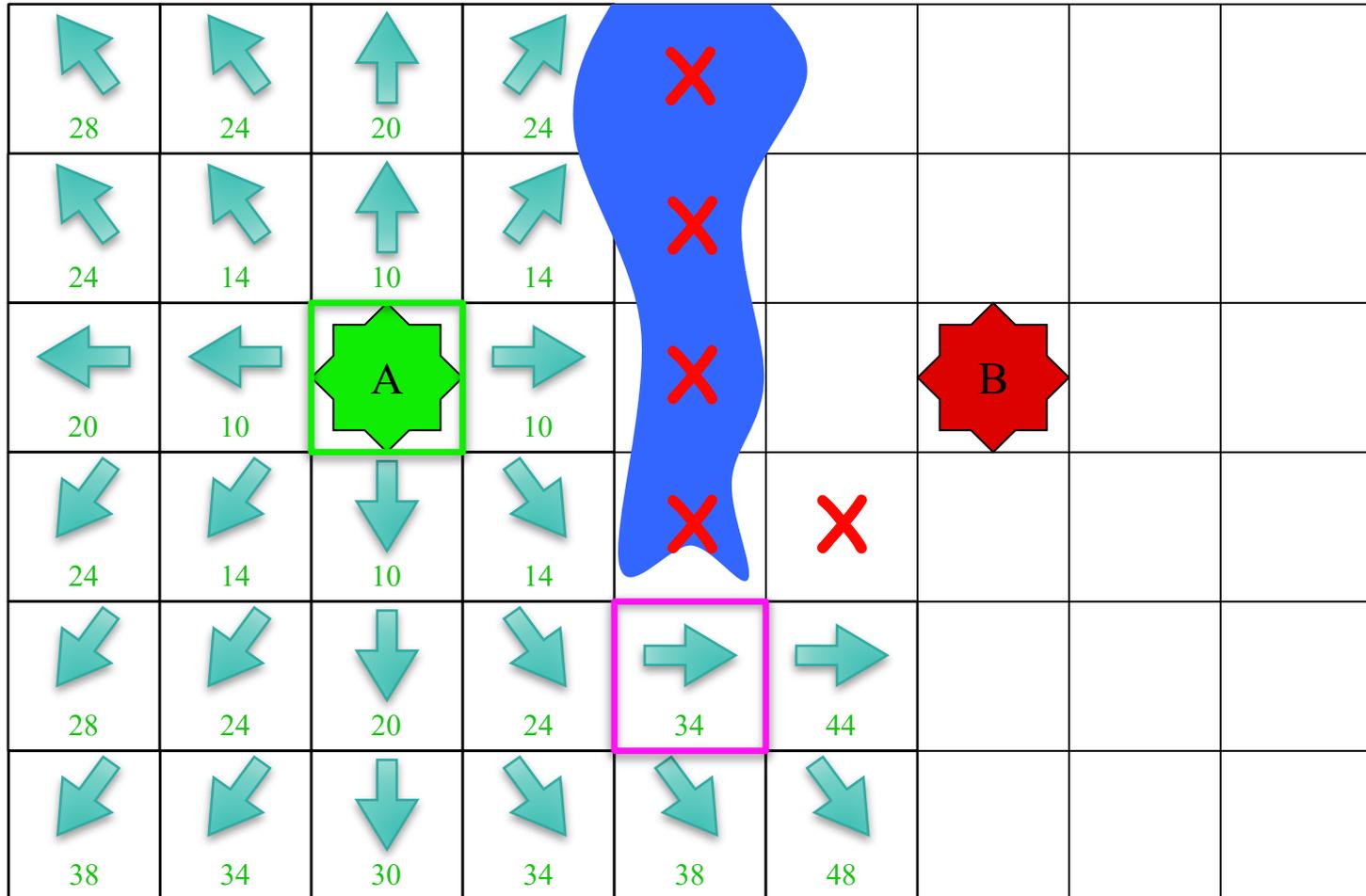
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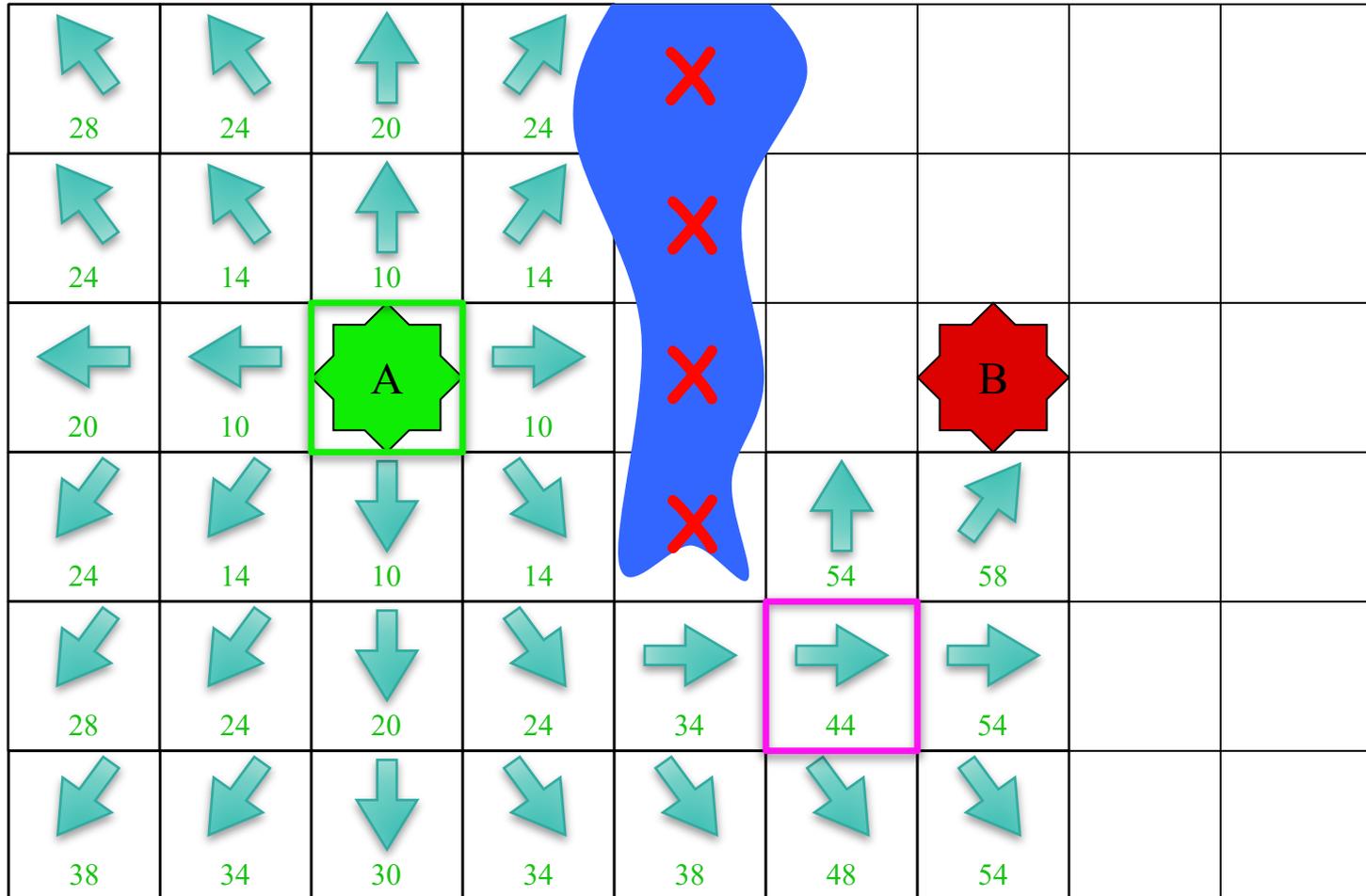
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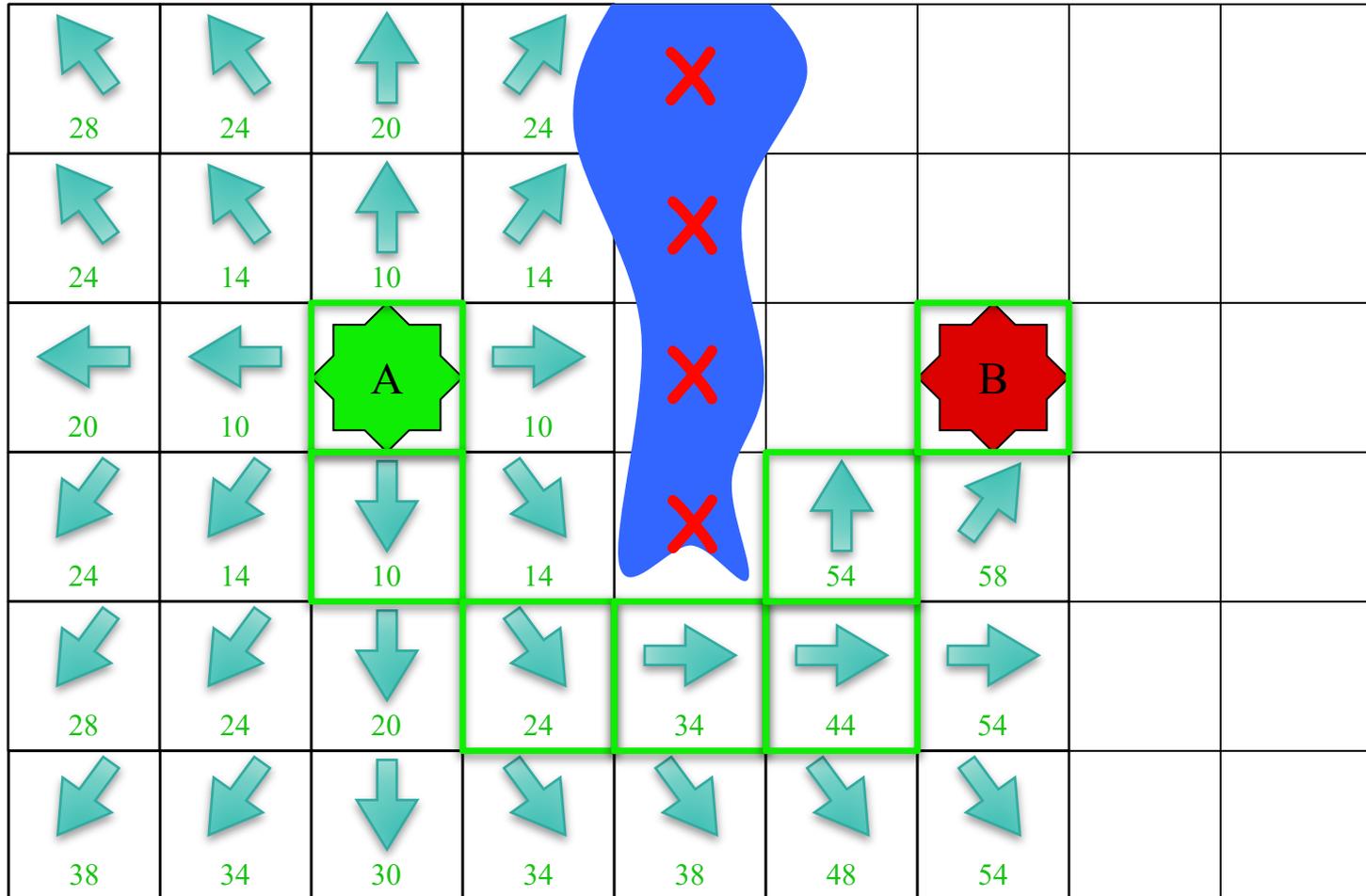
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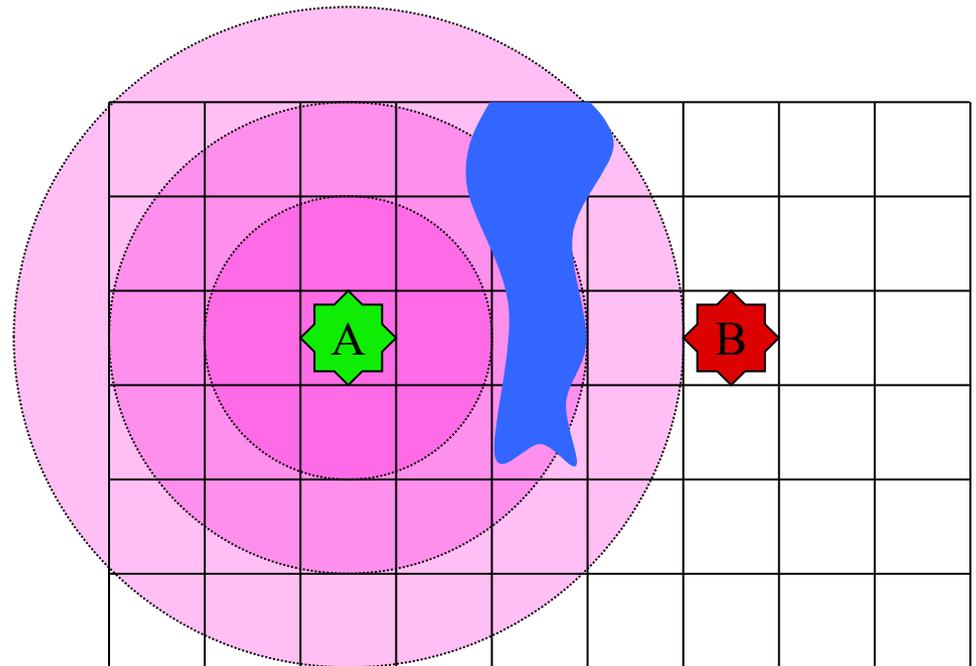


Pathfinding: Breadth-First



Breadth-First is Slow!

- Searches too many grids
 - Grids far away from goal
 - Works “radially outward”
- What is the problem?
 - Using **graph** algorithms
 - No spatial knowledge
- **Idea:** Spatial+Graph
 - Measure distance normally
 - Pick neighbor close to goal



Heuristic Search

Intuition

- Modified version of BFS
 - Have a list of candidates
 - Always pick *best* candidate
- Need f , **heuristic** function
 - Used to pick next step
 - Avoids stupid choices
- Regularly **update** f
 - Recompute on all neighbors
 - Reassign value if smaller

Algorithm

```
n = start; L = { };  
while (n not goal) {  
  add n to visited;  
  N(n) = unvisited neighbors  
  foreach (m ∈ N(n)) {  
    add m to L;  
    update f(m);  
  }  
  pick n ∈ L with f least;  
}  
return path to goal;
```

Heuristic Search

Intuition

- Modified version of BFS
 - Have a list of nodes
 - Always pick the least f
- Need f , **heuristic**
 - Used to pick the next node
 - Avoids stupid paths
- Regularly **update** f
 - Recompute on all neighbors
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Algorithm

```
n = start; L = { };
while (n != goal) {
    L = L ∪ N(n);
    visited neighbors
    n ∈ N(n) {
        f = g + h;
    }
    pick n ∈ L with f least;
}
return path to goal;
```

Examples:

- *Dijkstra's Algorithm*

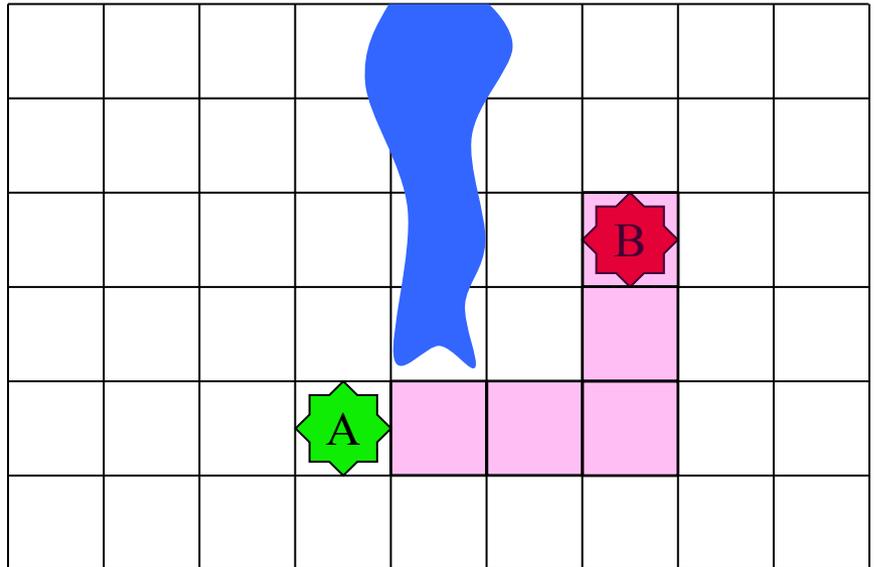
$f = \text{dist. from source}$

- *Greedy Algorithm*

$f = \text{estimated dist. to goal}$

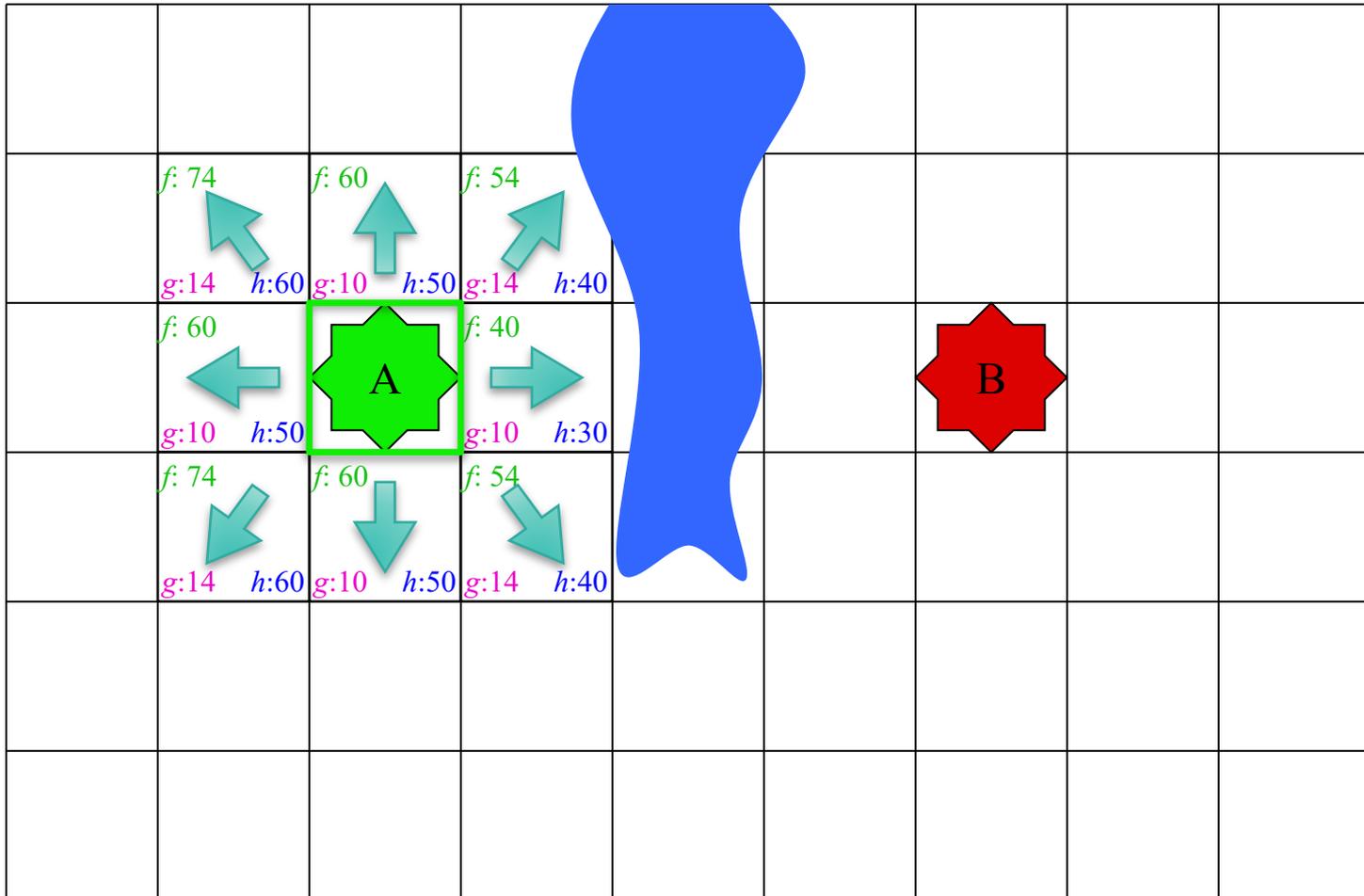
A* Algorithm

- **Idea:** Dijkstra + Greedy
 - g : distance on **current path**
 - An “exact calculation”
 - Distance along graph
 - h : estimated dist. to **goal**
 - *Spatial* distance
 - Ignores all obstacles
 - Final heuristic $f = g + h$
- Many variations for h
 - Regular distance
 - “Manhattan Metric”

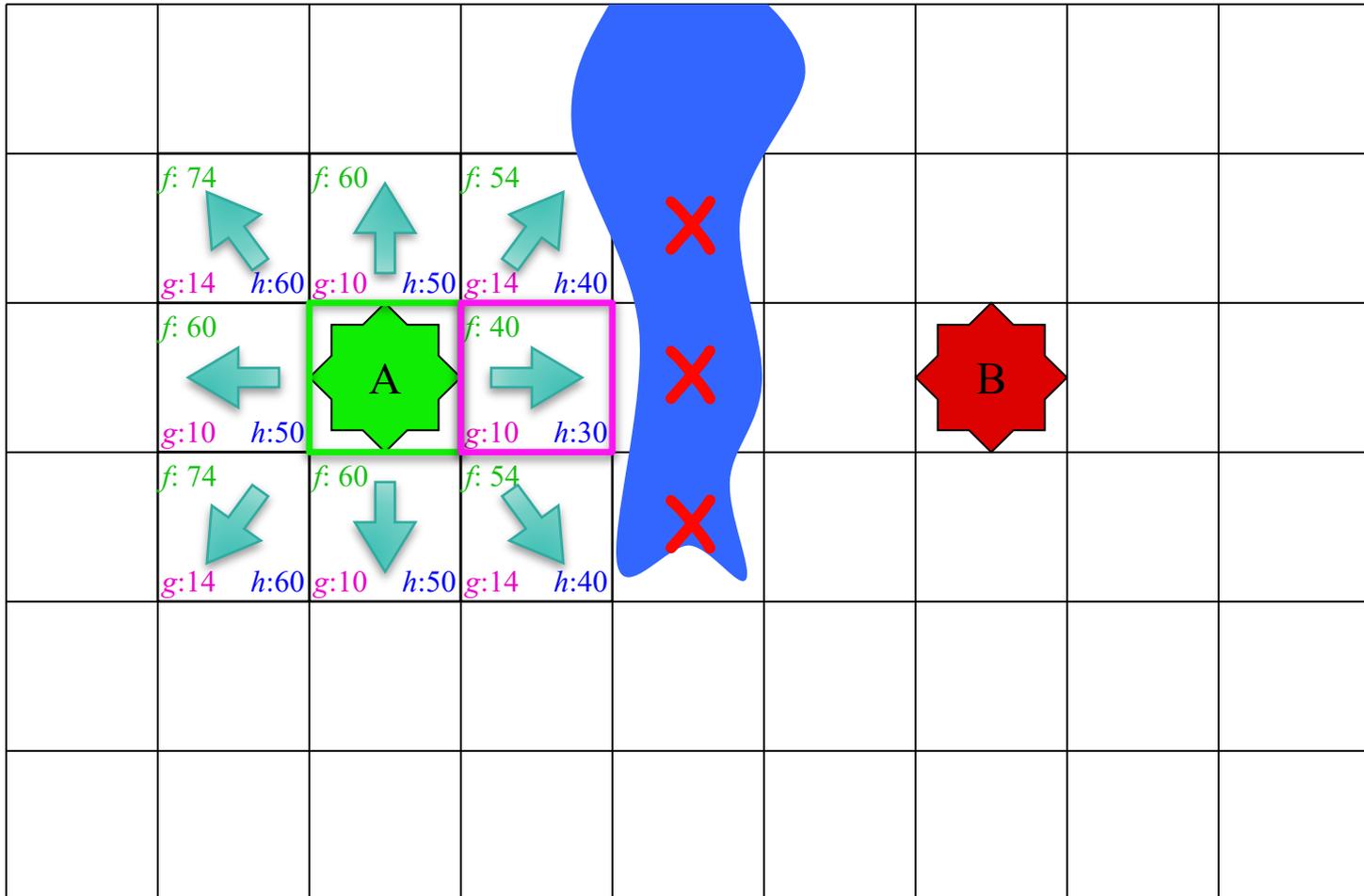


Manhattan distance = $30 + 20 = 50$

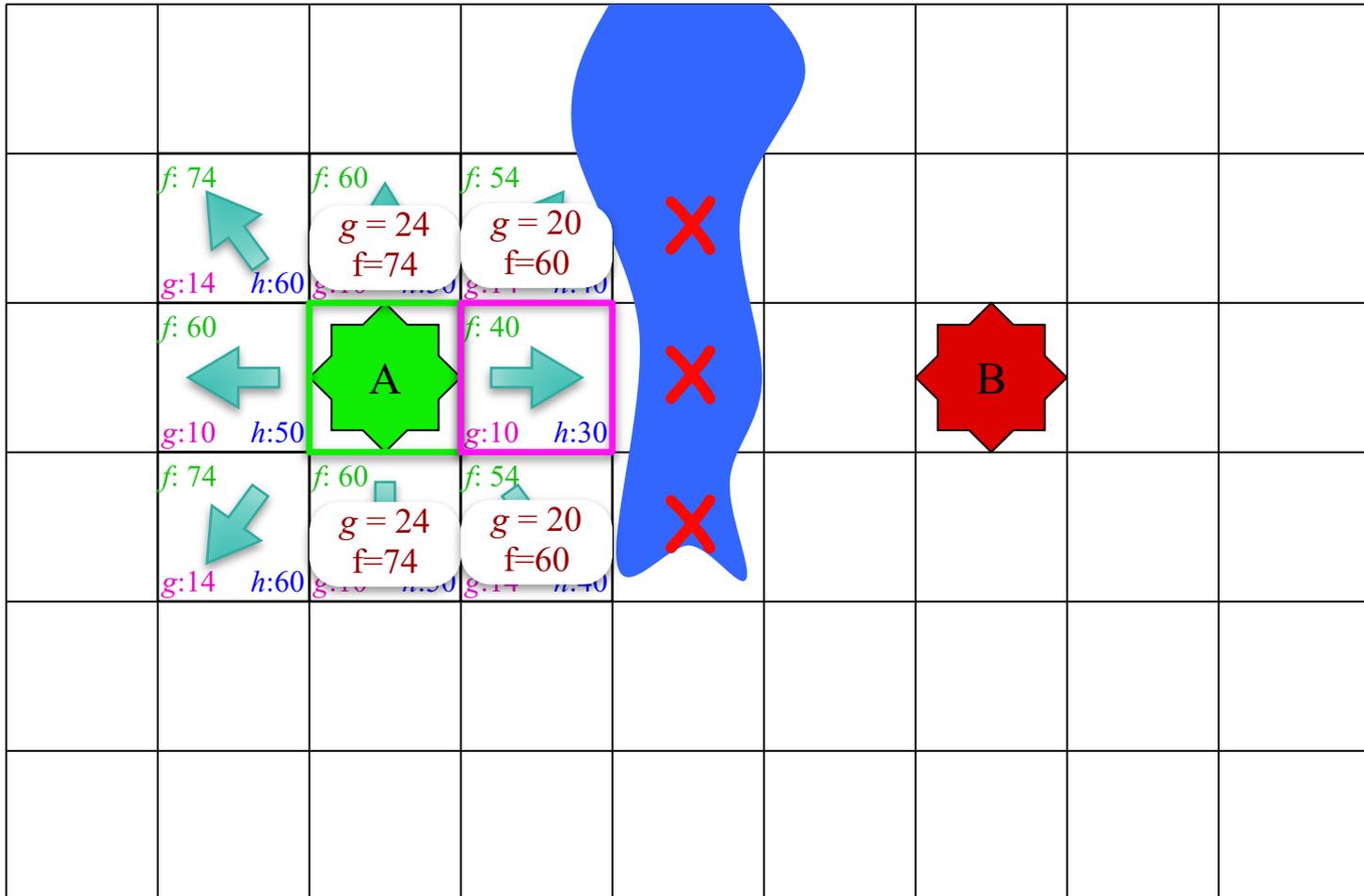
Pathfinding: A* Algorithm



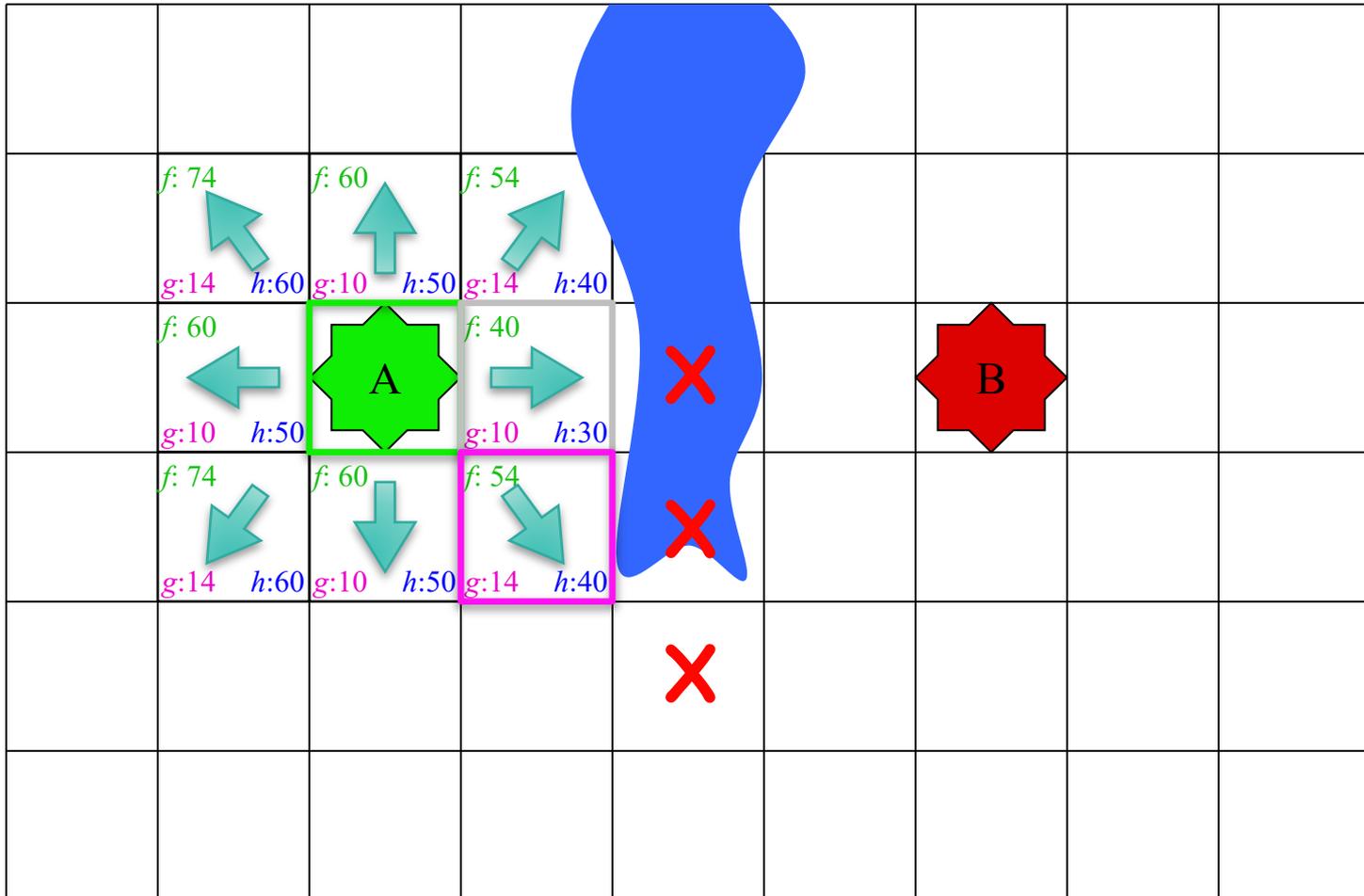
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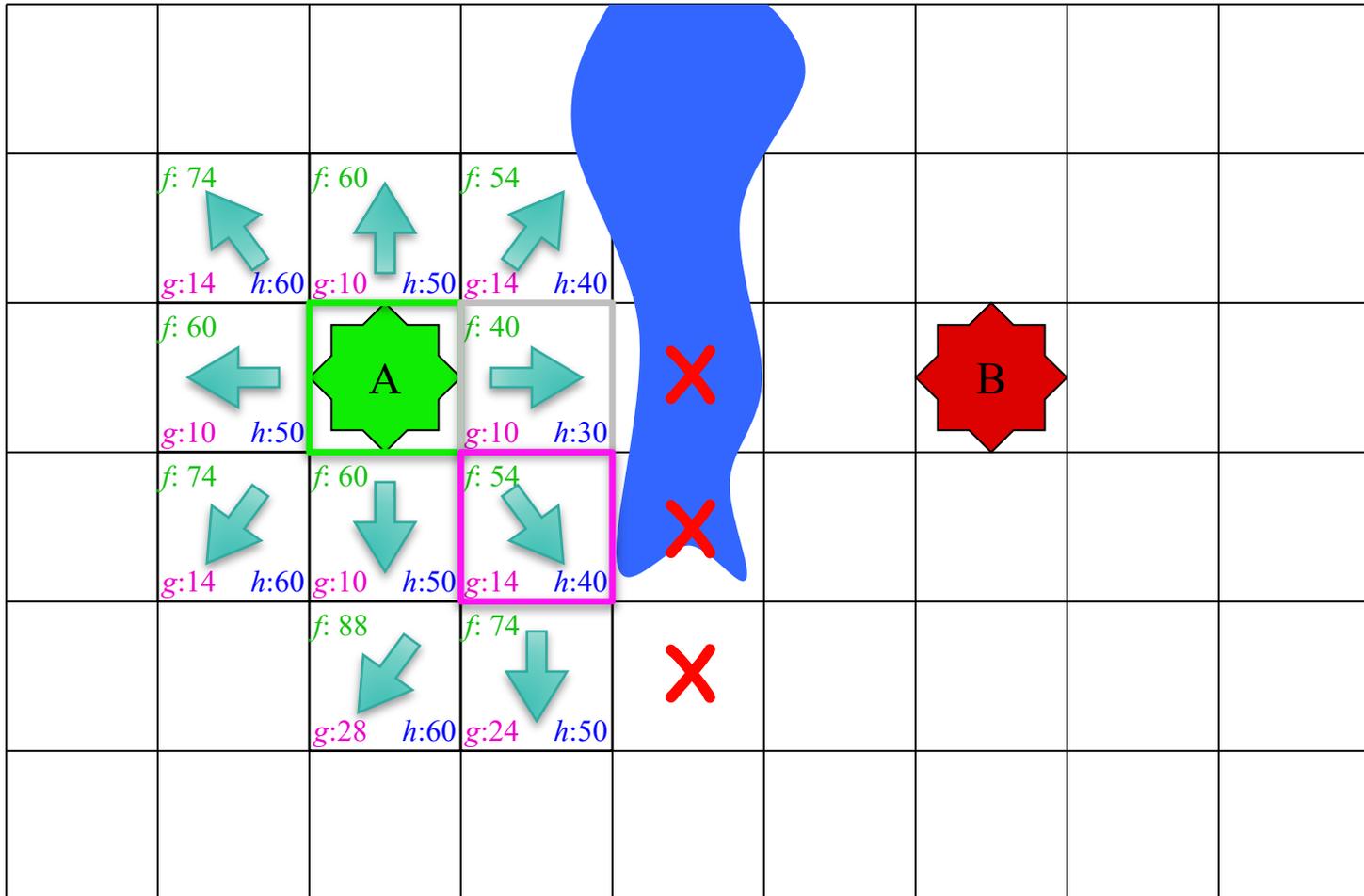
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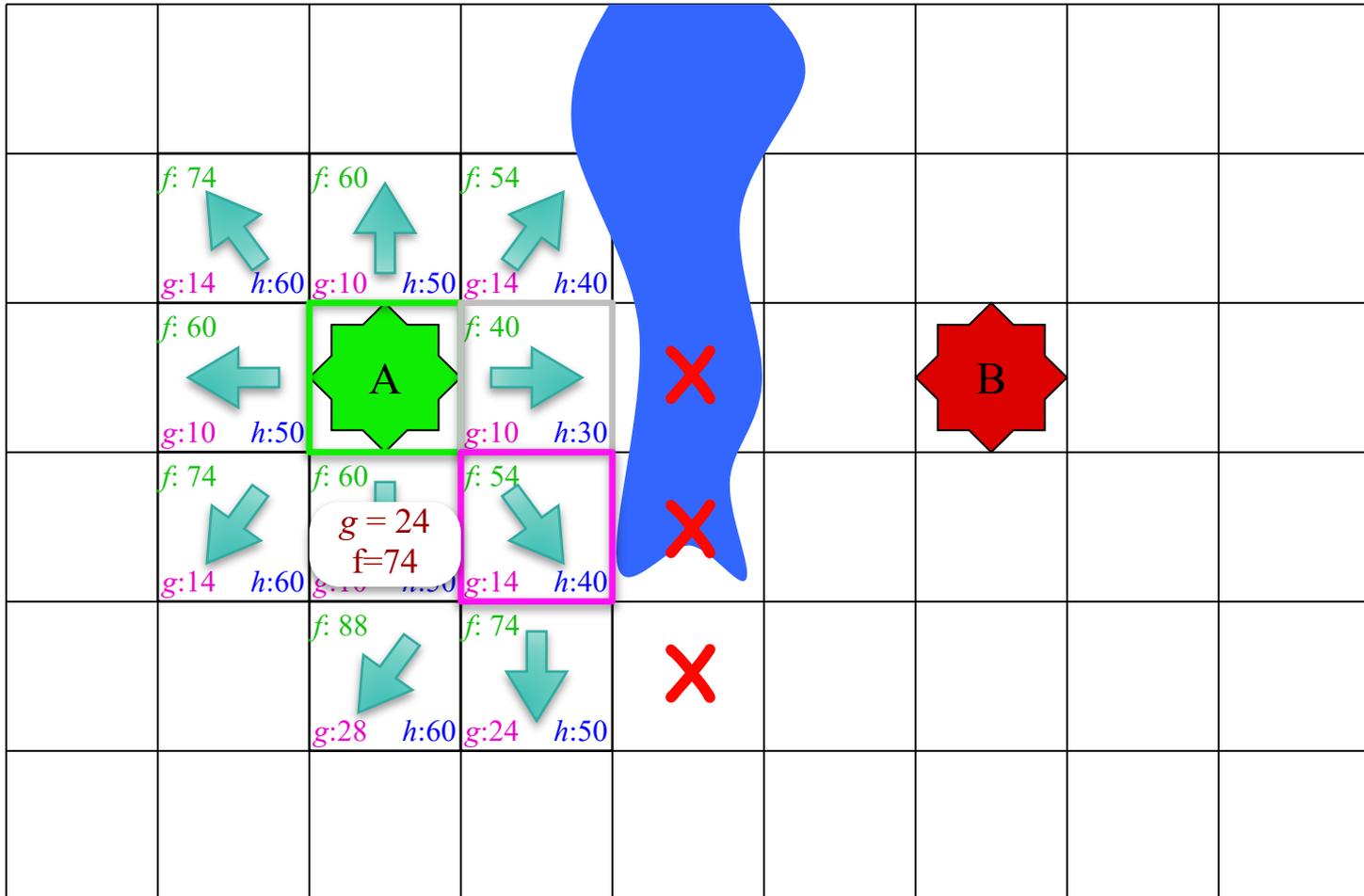
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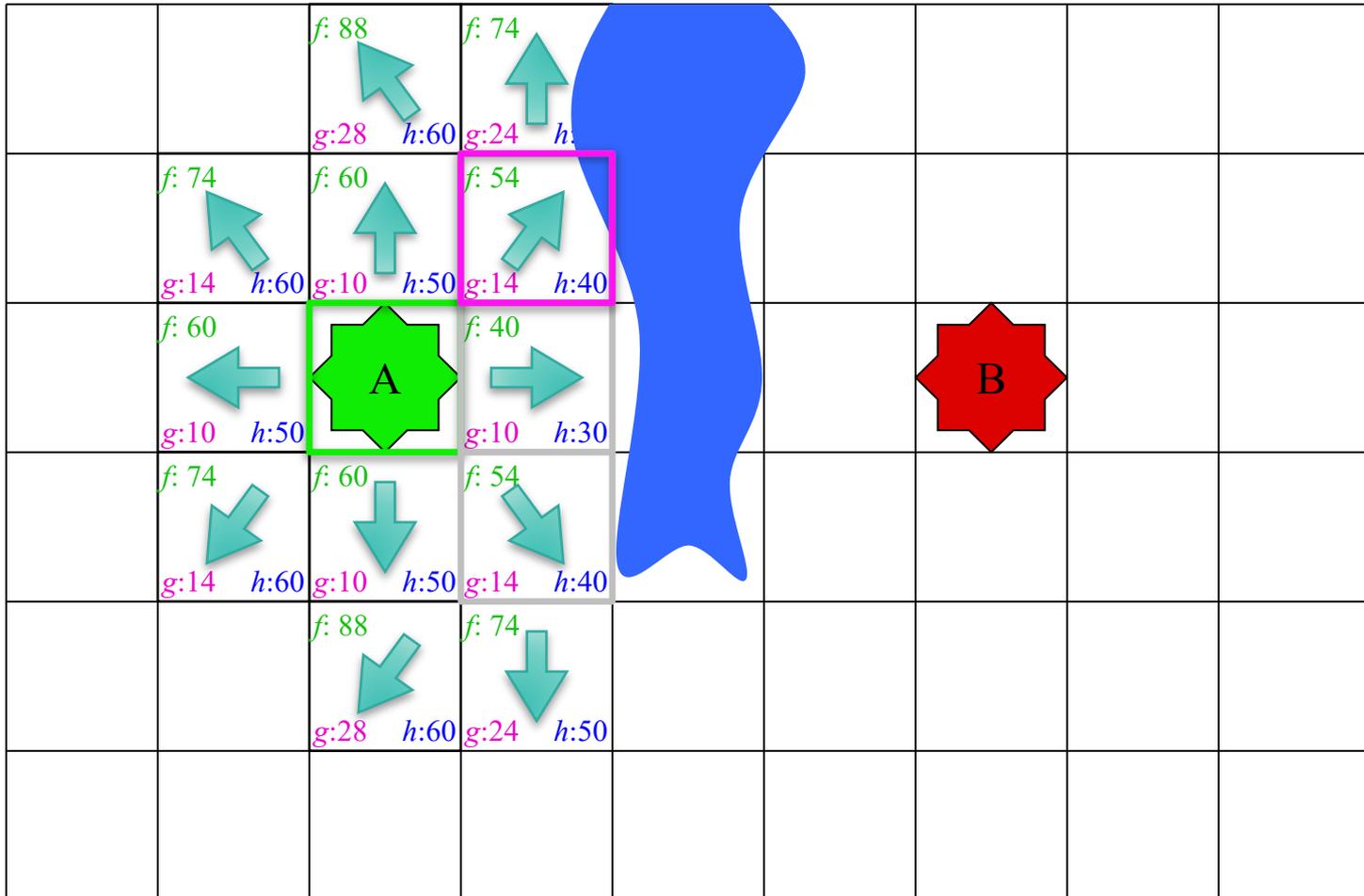
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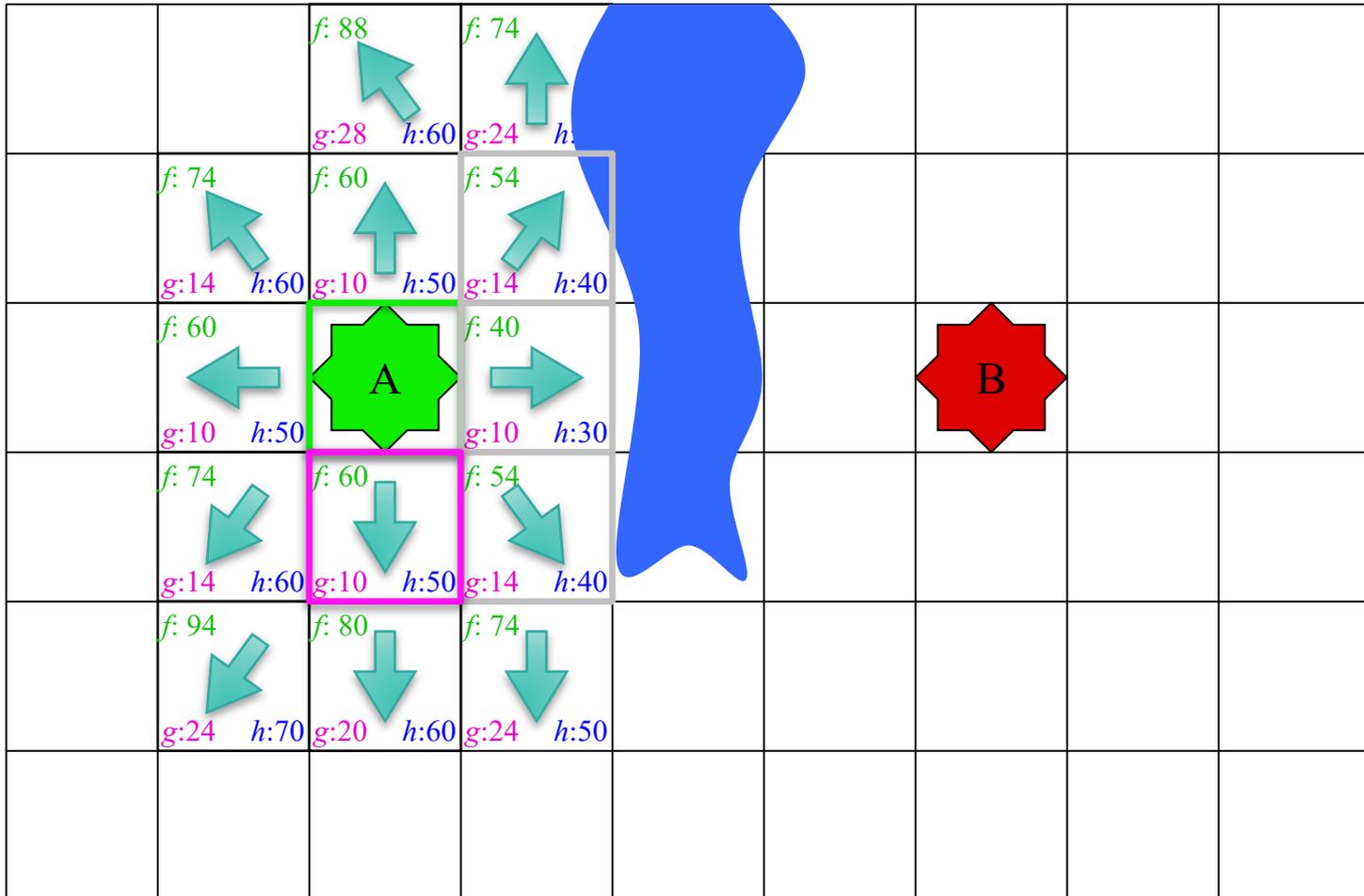
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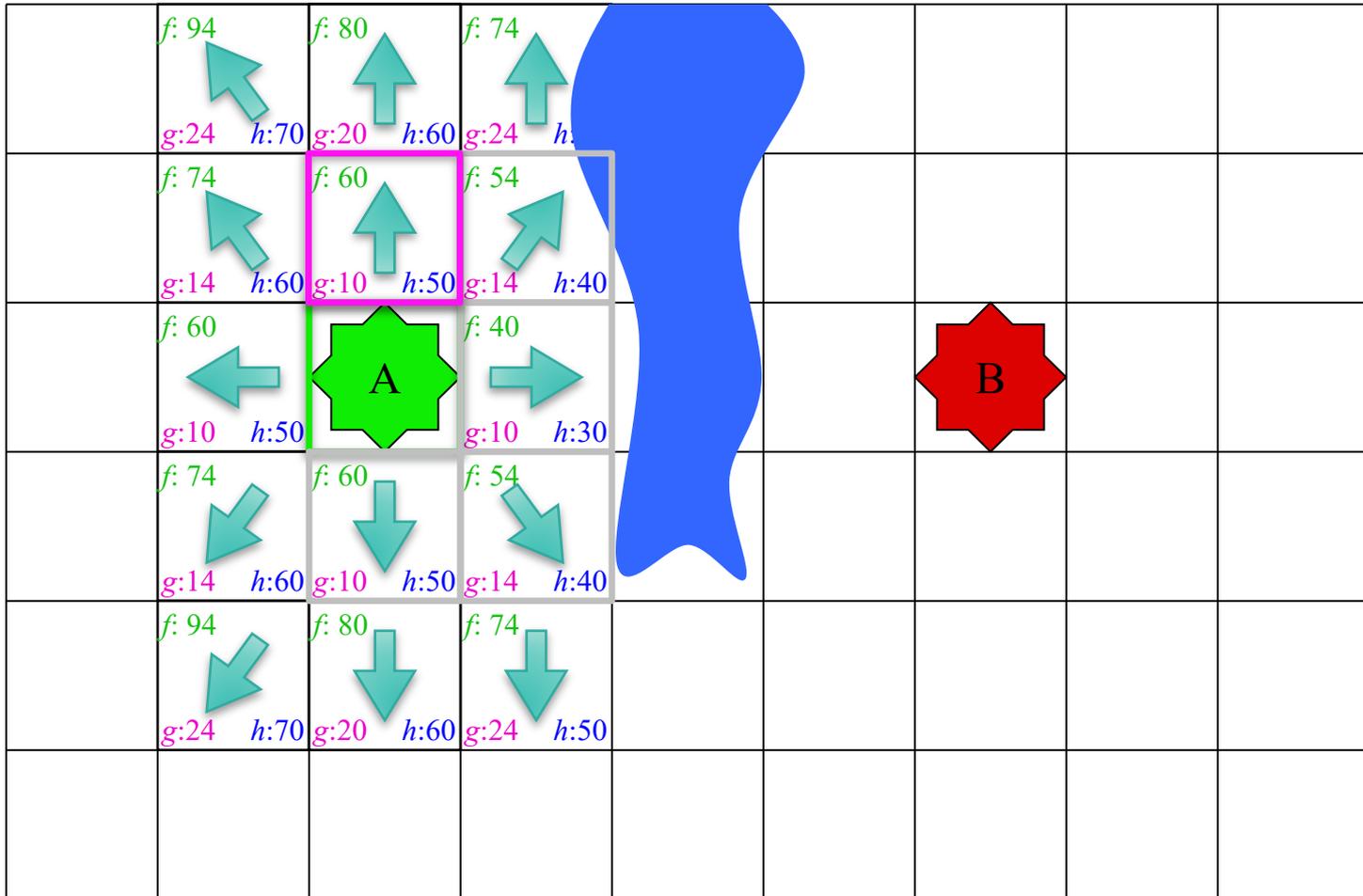
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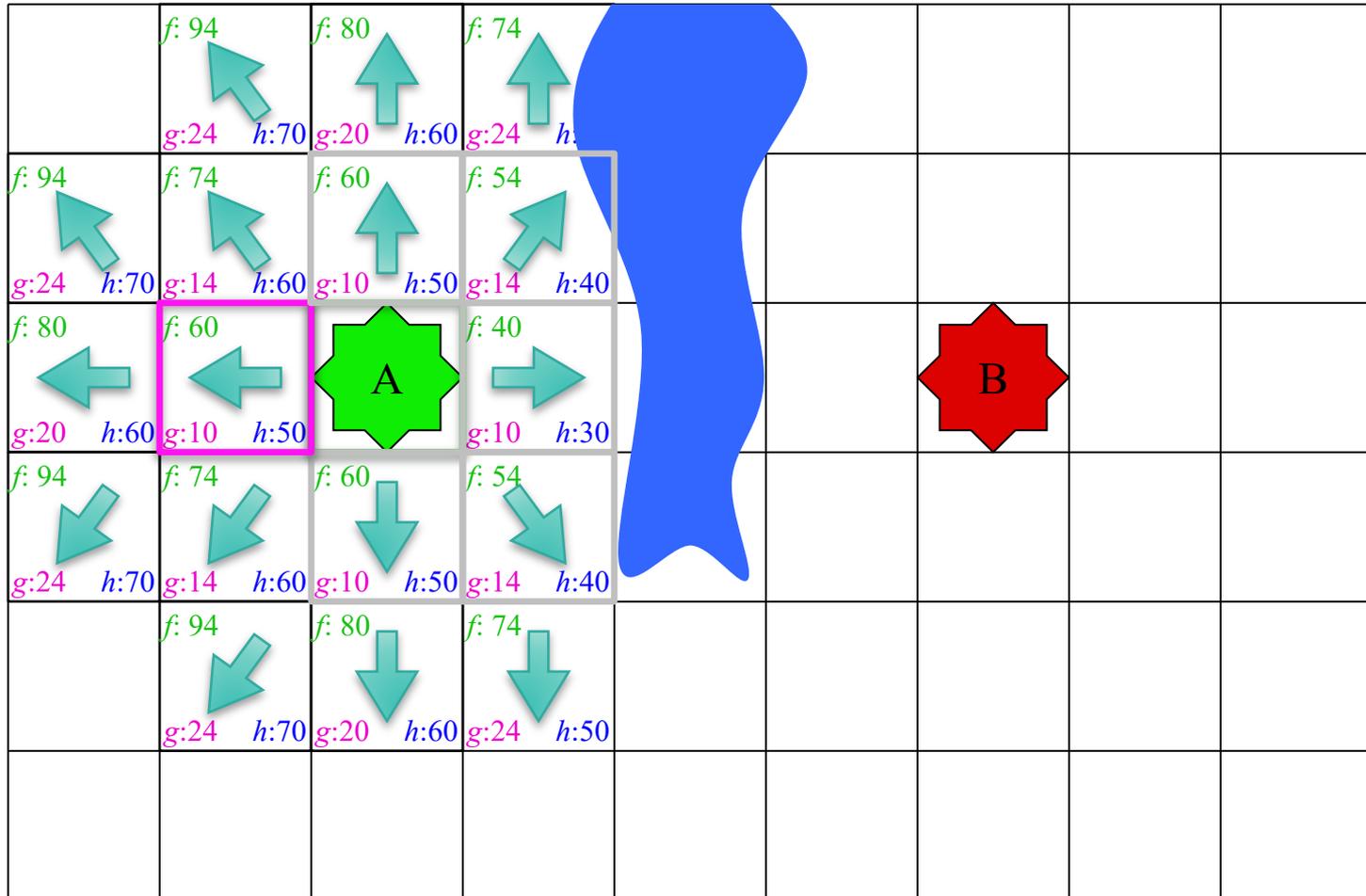
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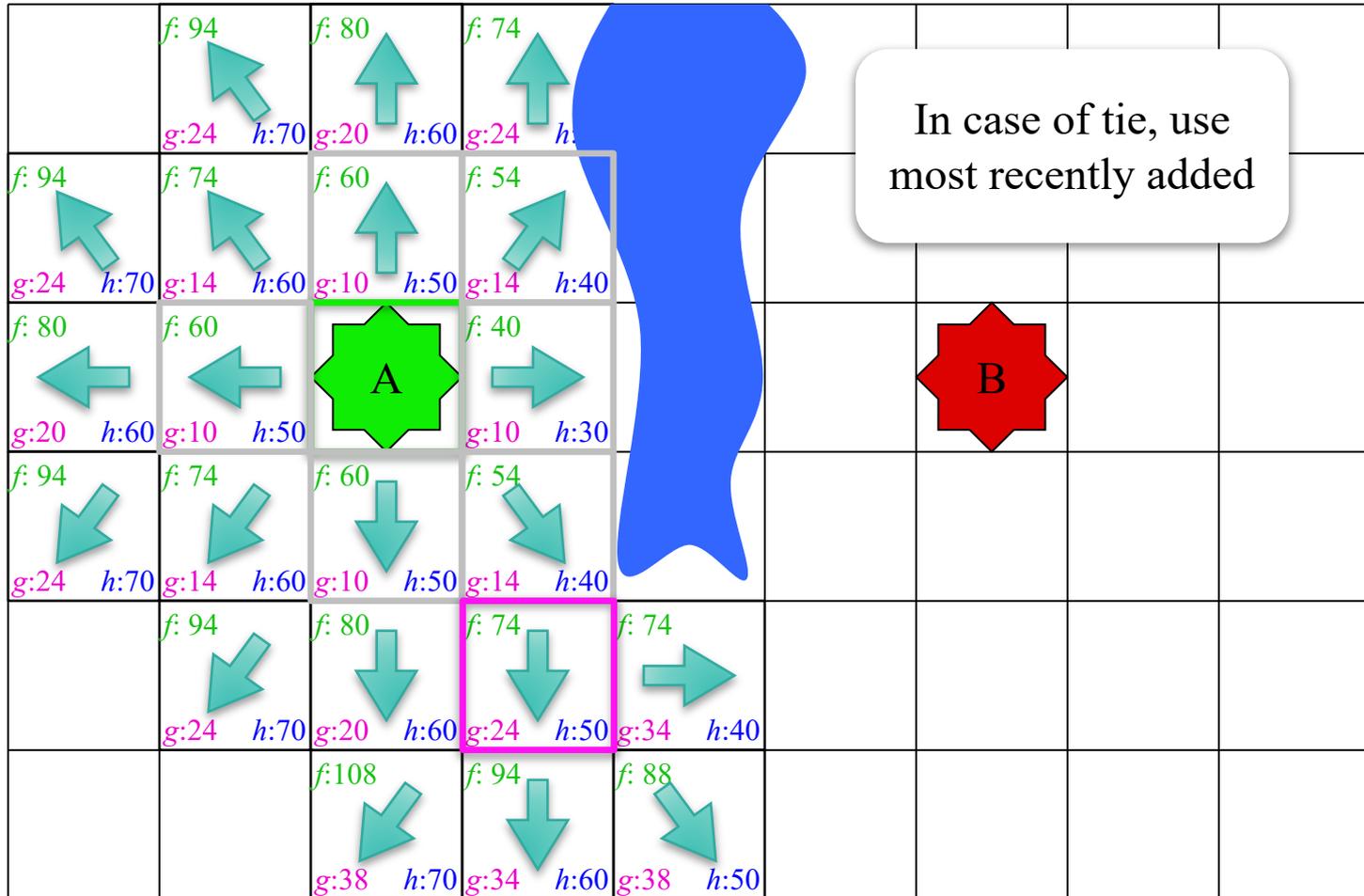
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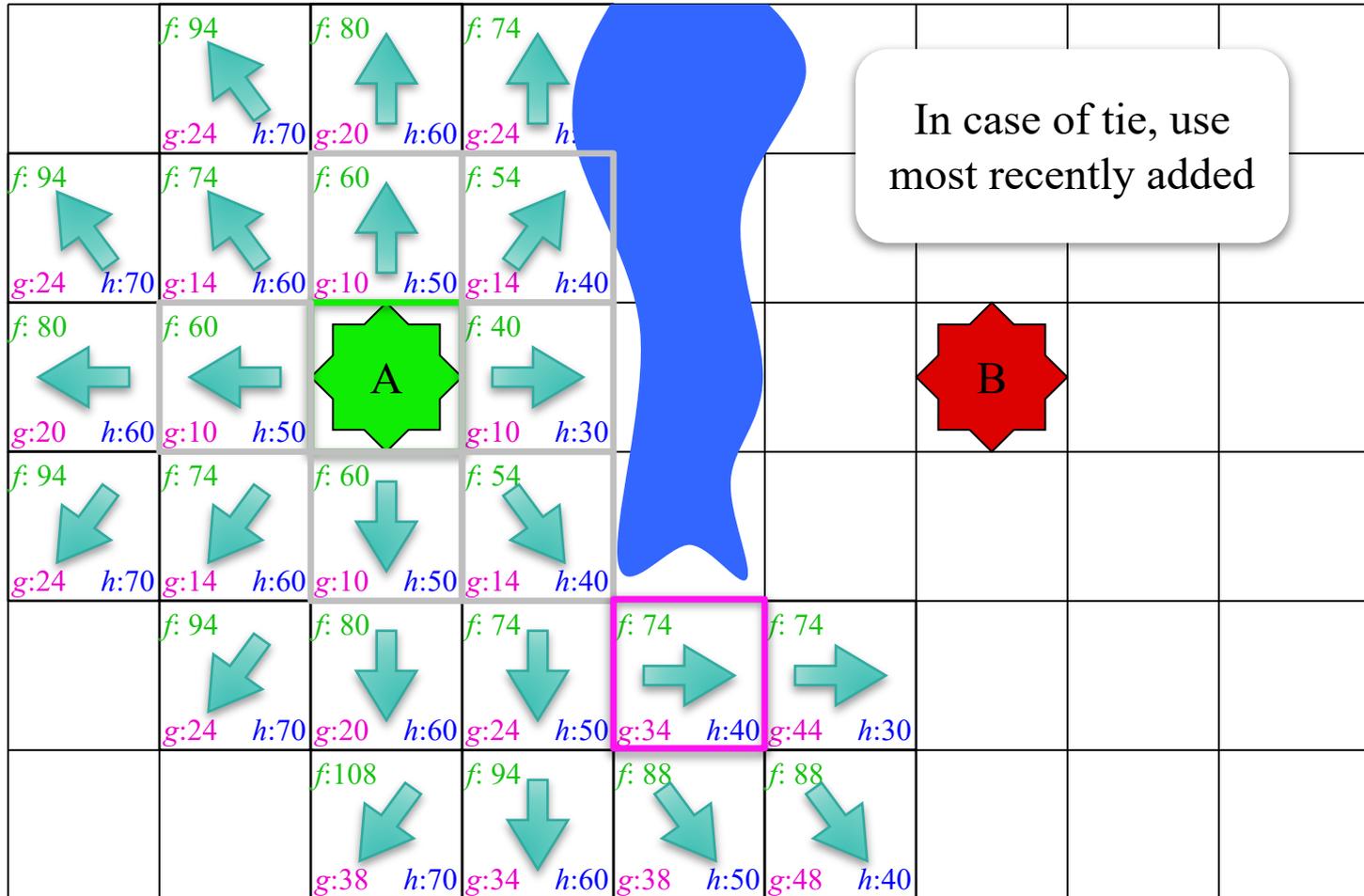
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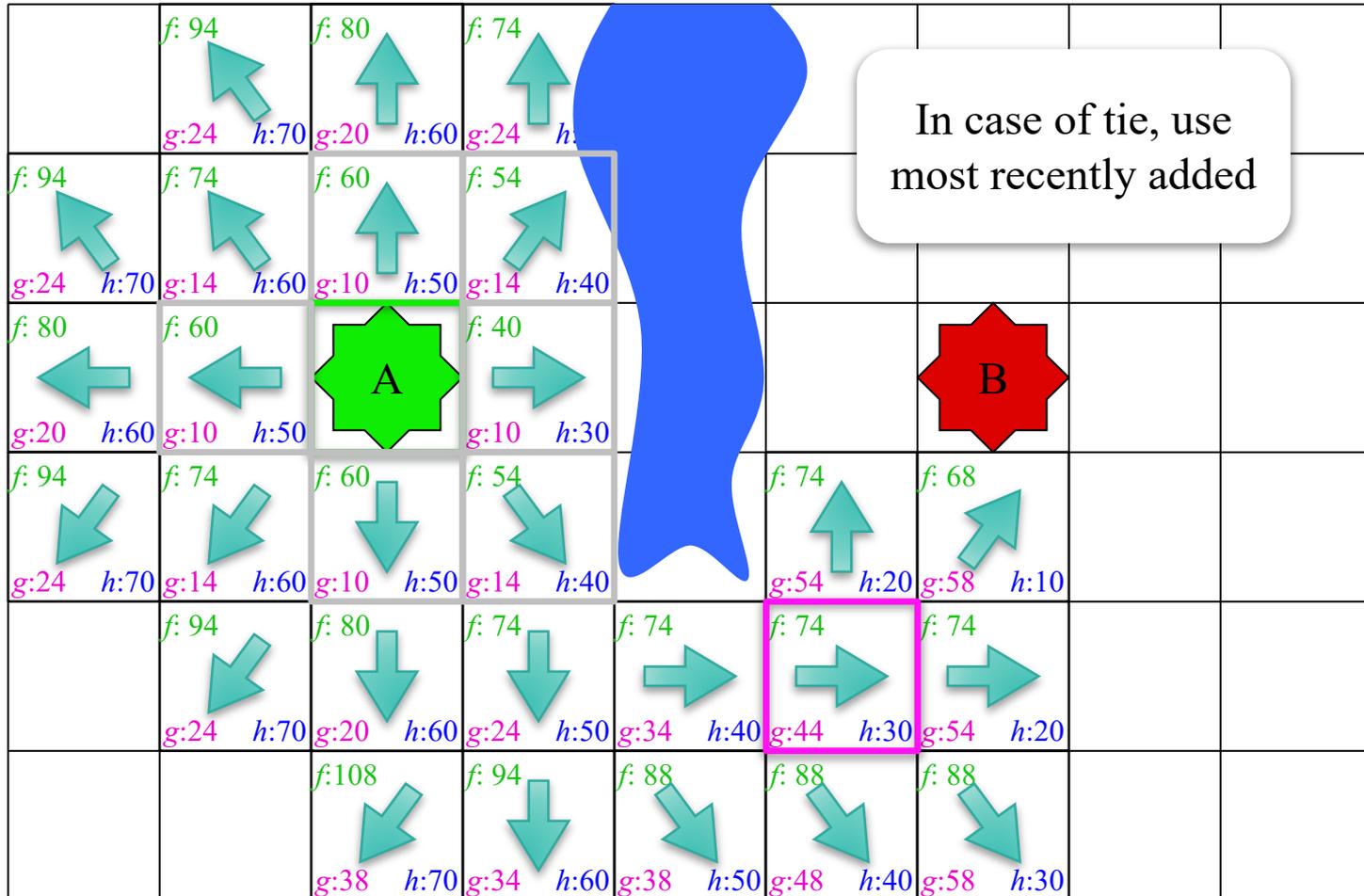
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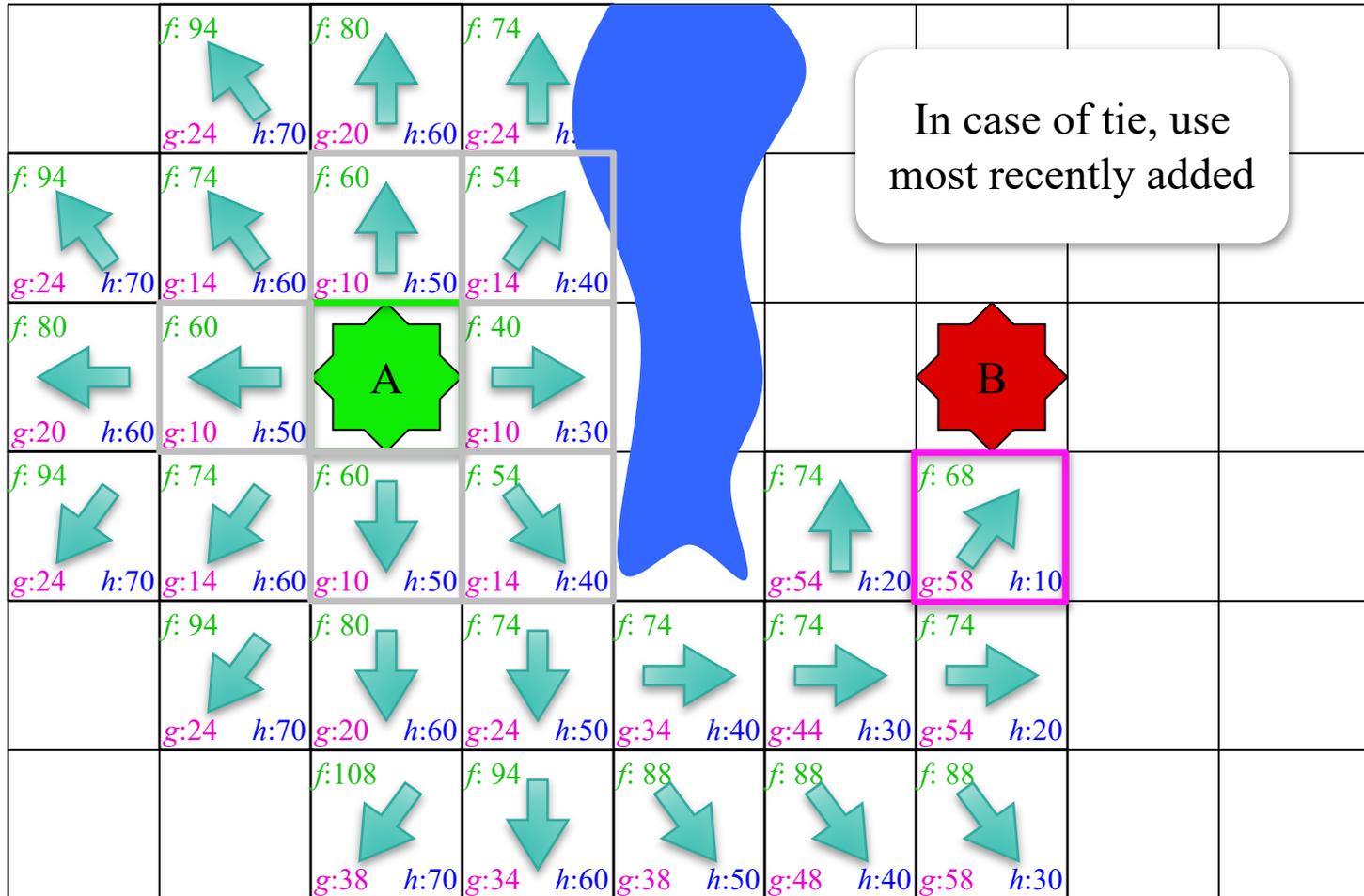
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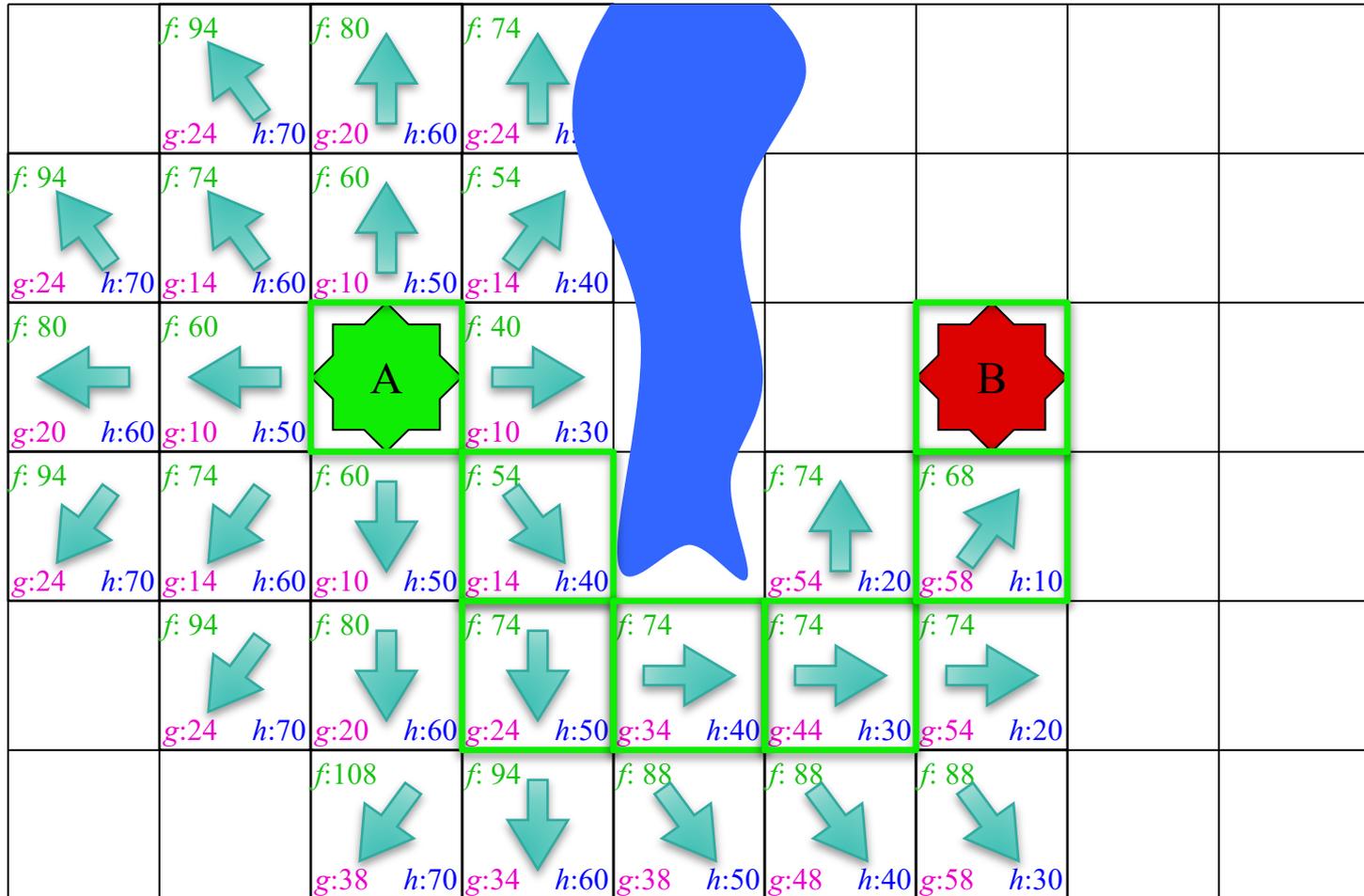
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Pathfinding: A* Algorithm



LibGDX Support

IndexedGraph

- Array of **IndexedNode** objs
 - Can implement as an array
 - Hard part is IndexedNode
- Each **IndexedNode** must store
 - Index into the graph array
 - Array of Connection objs
- Each **Connection** must have
 - The start and end node
 - The cost to traverse edge

IndexedAStarPathFinder

- Construct with a graph
 - Must use with **IndexedGraph**
 - Graph reference immutable
- To search for path, give
 - The start and end nodes
 - **Heuristic** implementation
 - **GraphPath** for the answer
- Can give search a *timeout*
 - Abort if it takes too long

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Everything in blue
is an interface

LibGDX Support

IndexedGraph

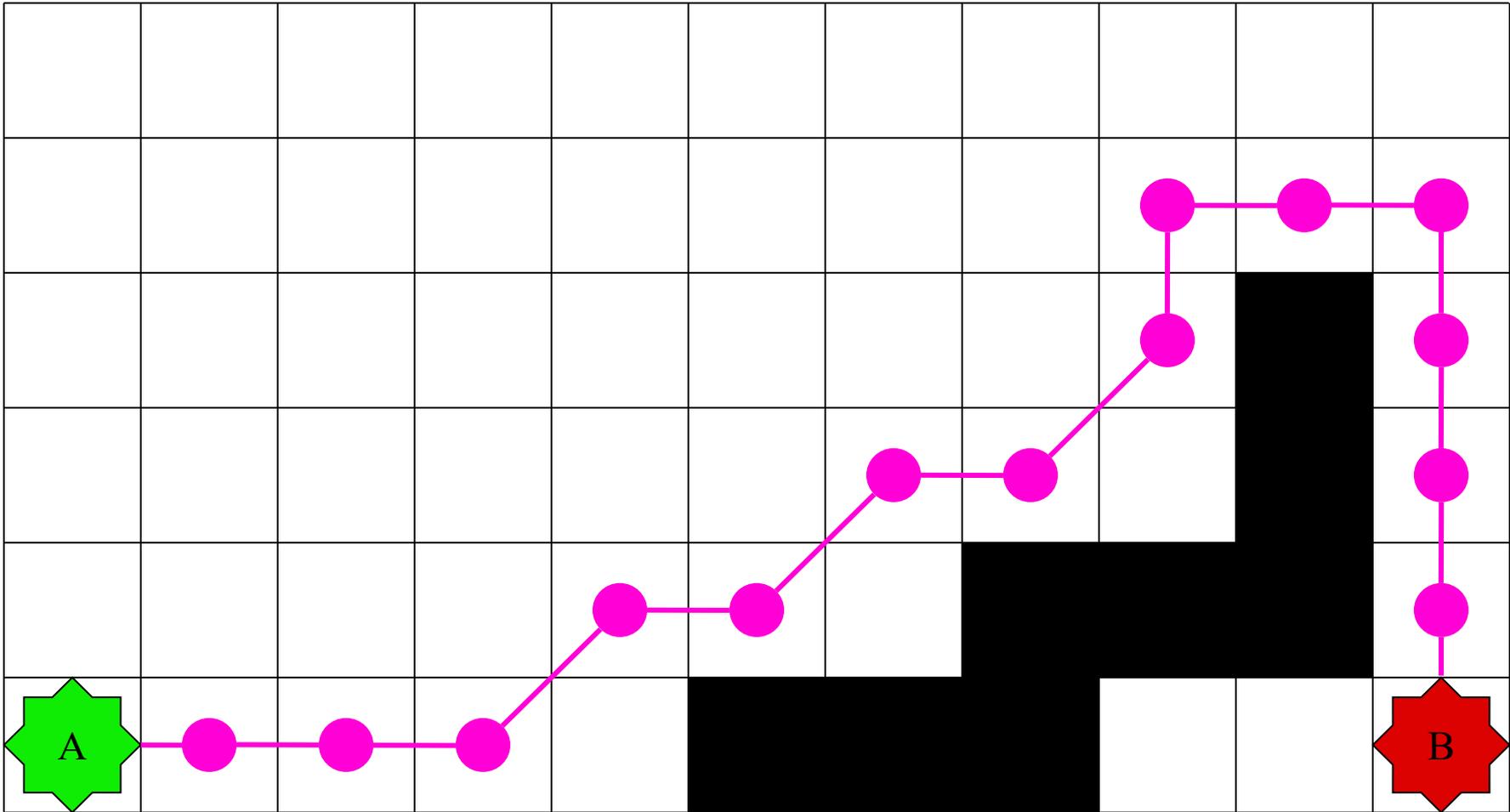
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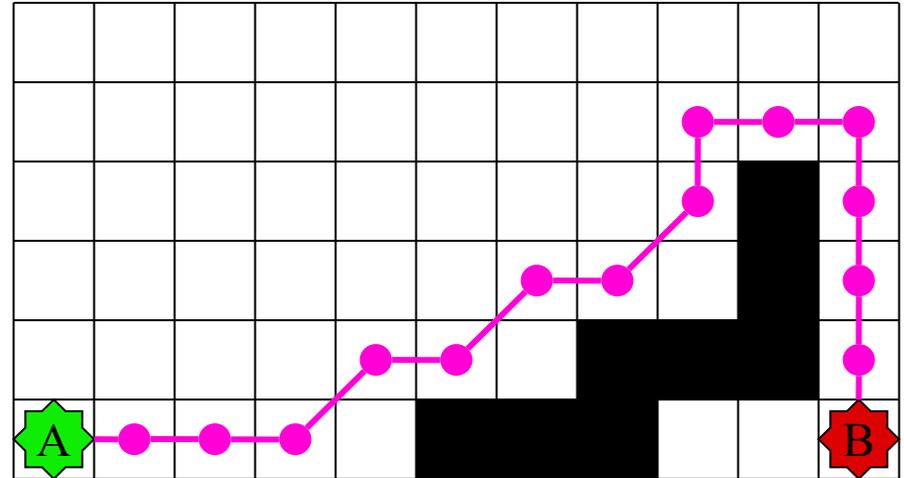
Only these have implementations

Issues with A*: Stair Stepping



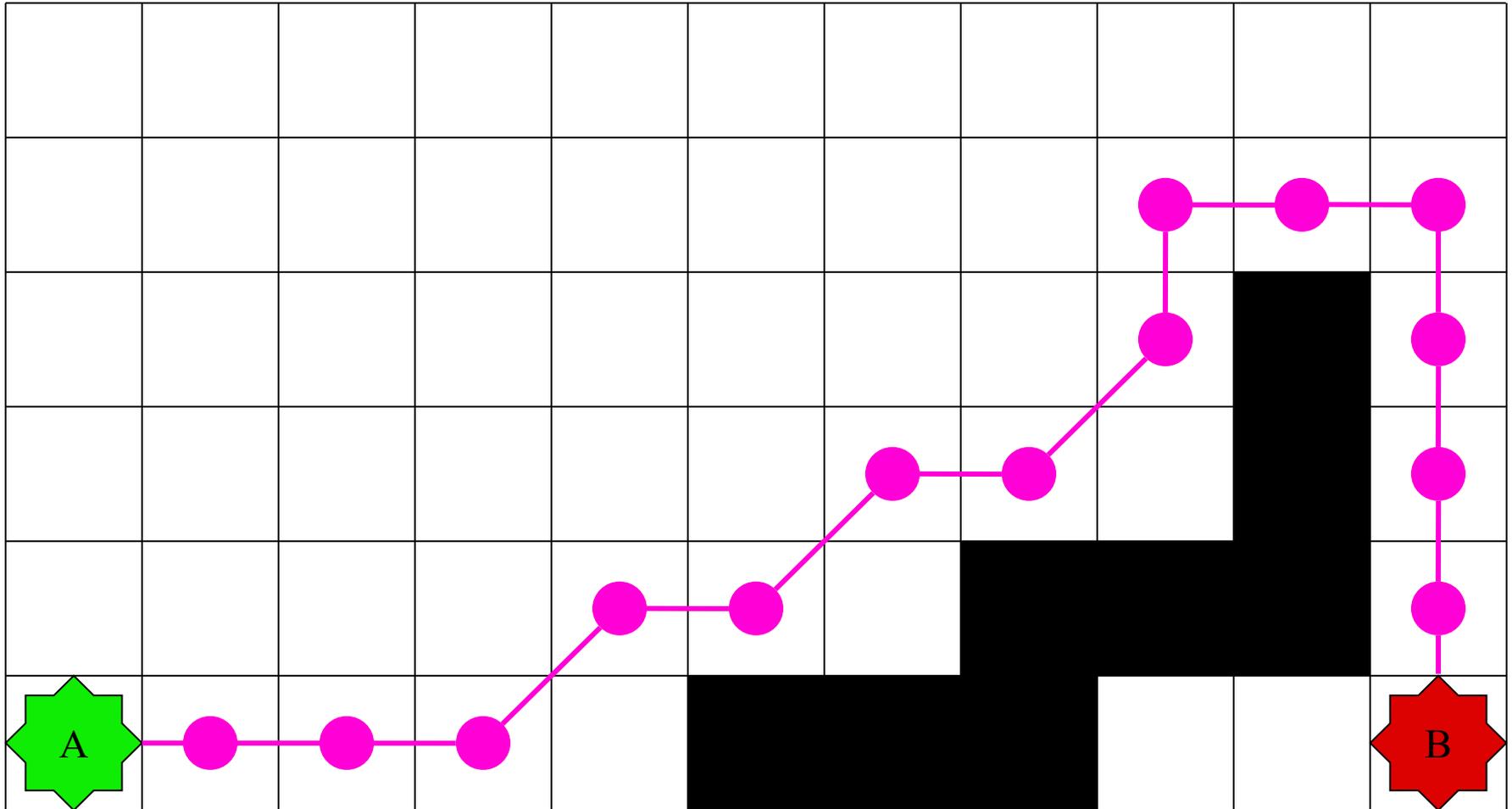
Stair Stepping

- What is the problem?
 - Move one square at a time
 - All turns are at 45°
- **Idea:** Path smoothing
 - Path is a series of waypoints
 - Straight line between points
 - Remove unnecessary points
- Can combine with A^*
 - Get *degenerative* solution
 - Remove to get waypoints

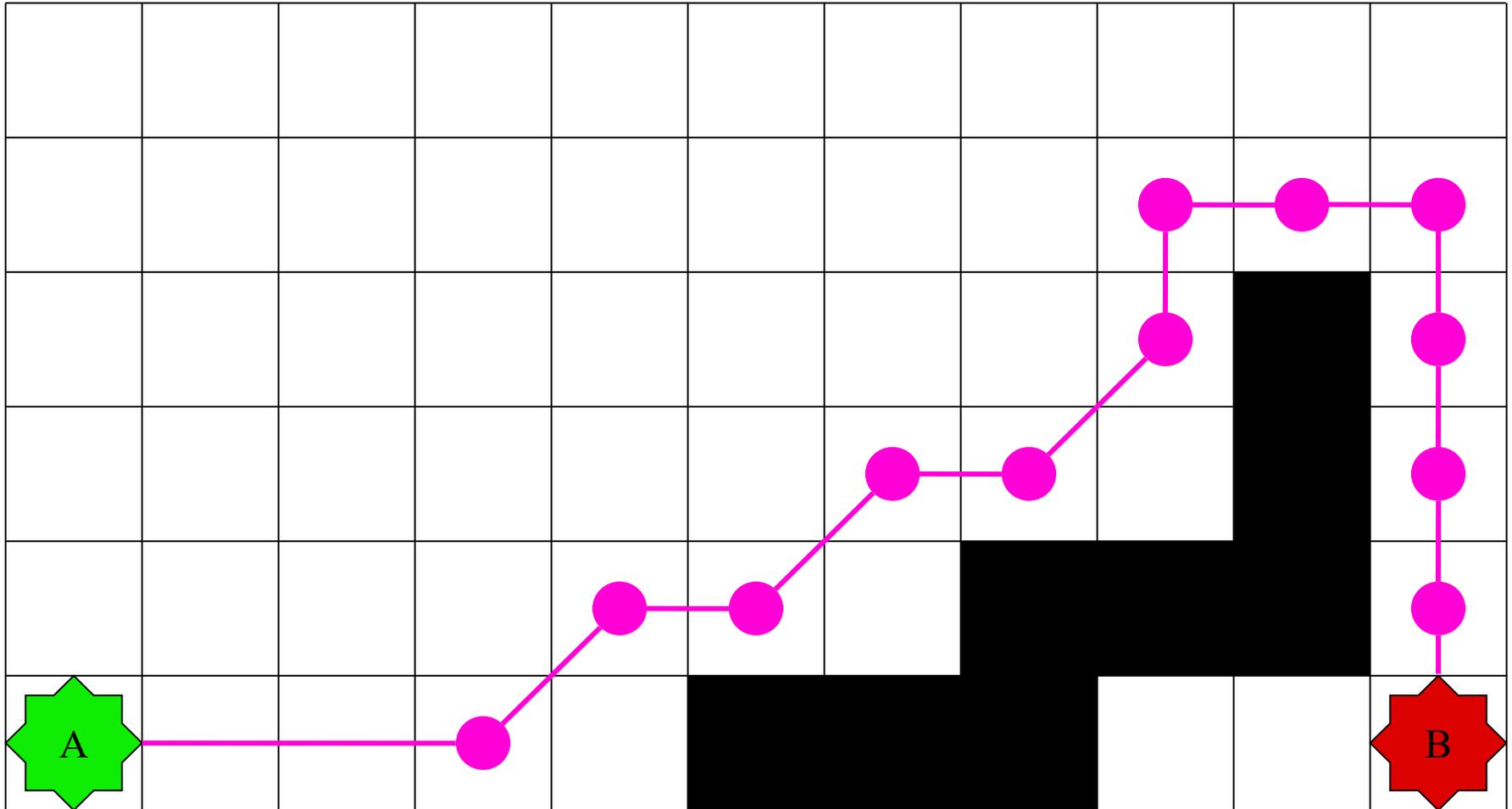


- Choose first q after p where
 - Line pq is valid
 - Point q has successor s
 - Line ps is not valid

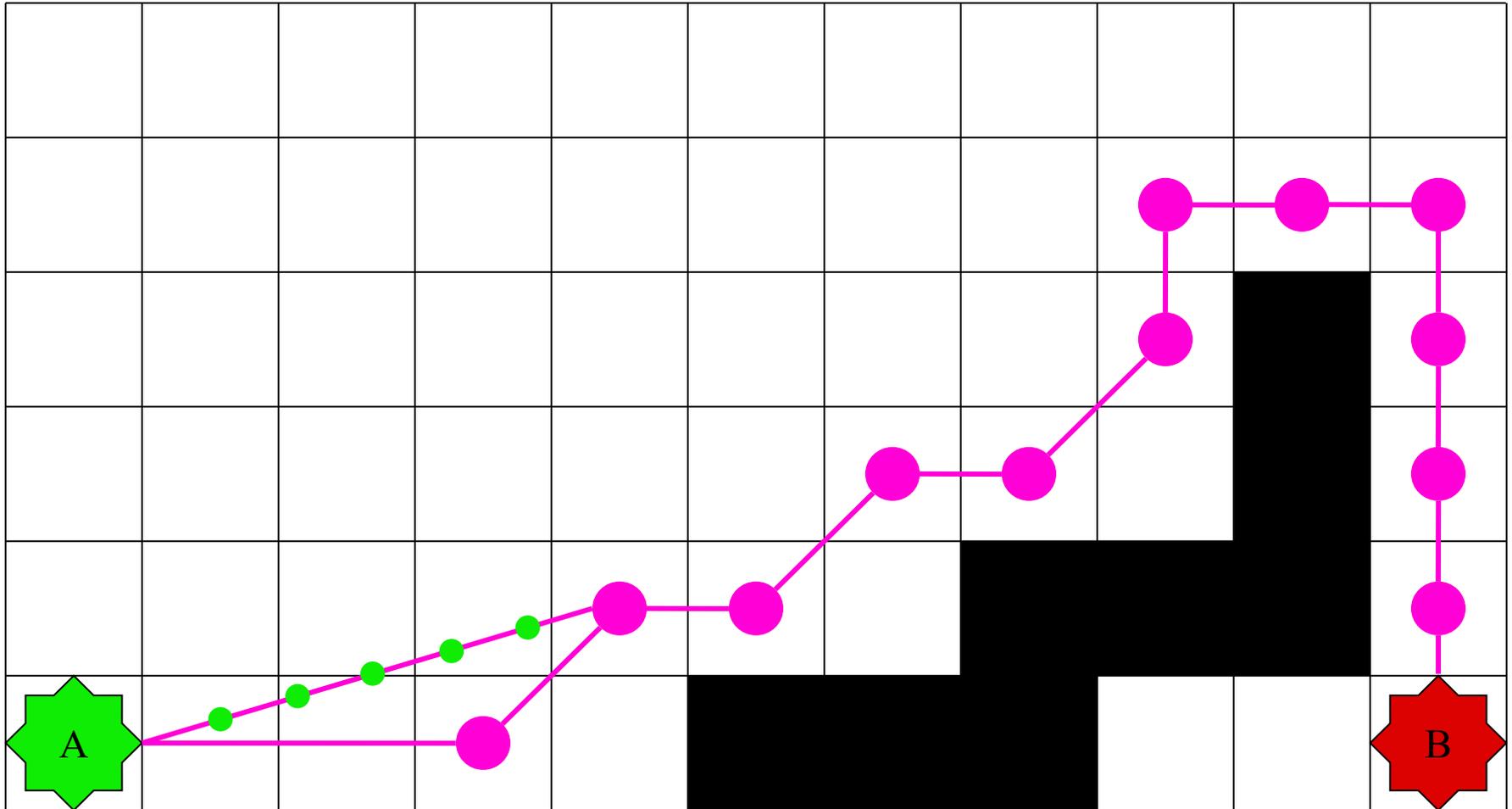
Path Smoothing



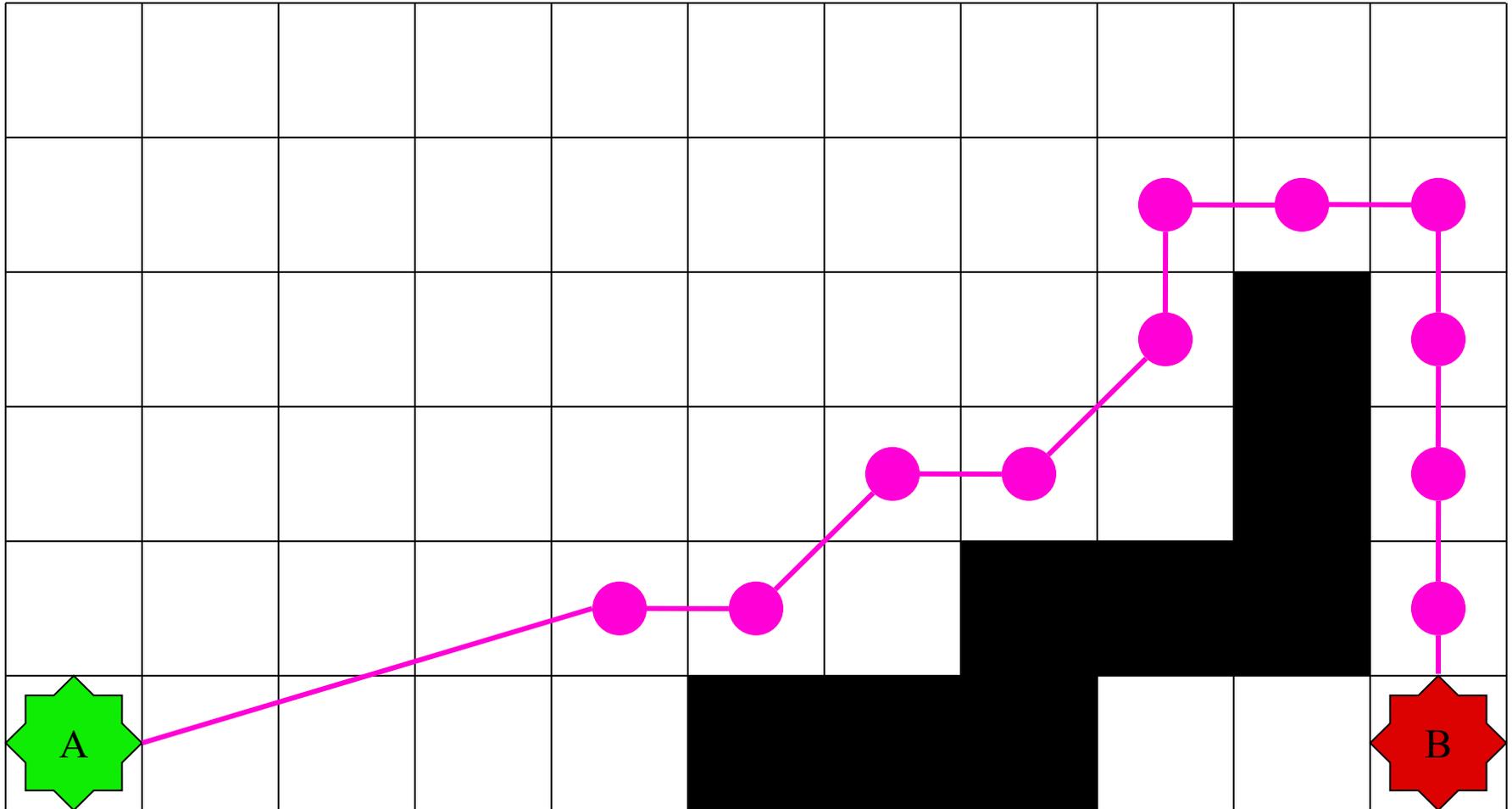
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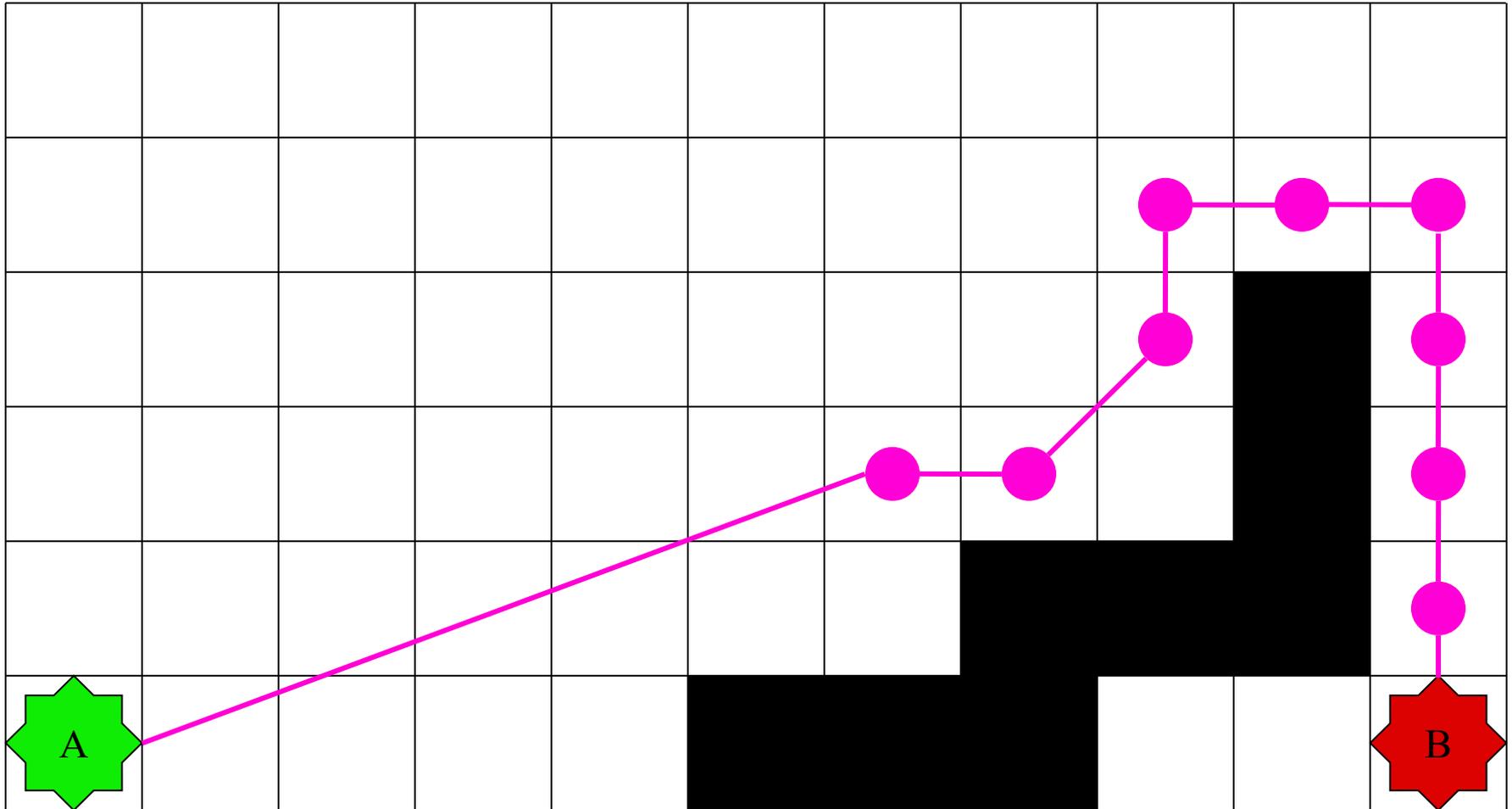
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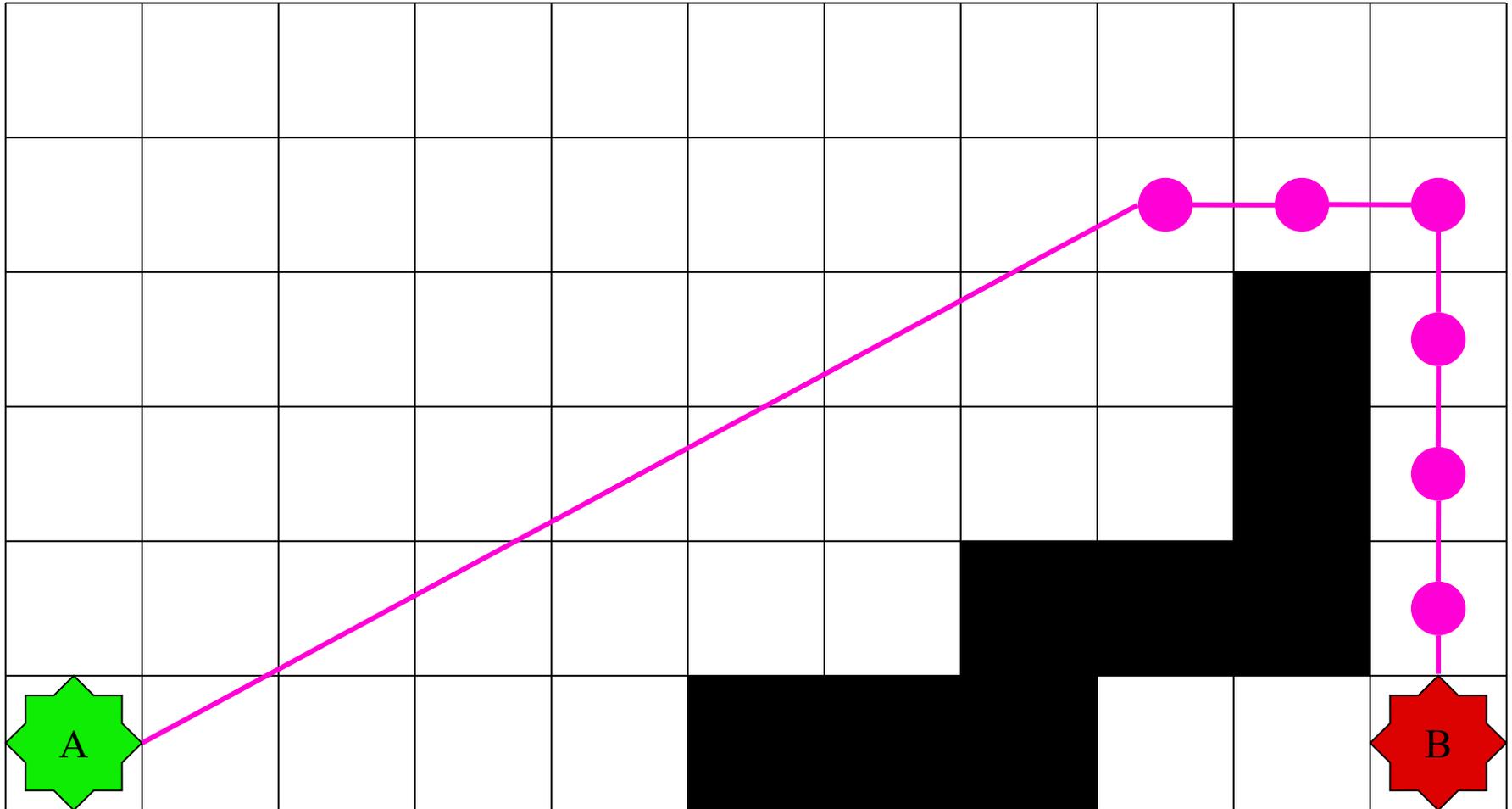
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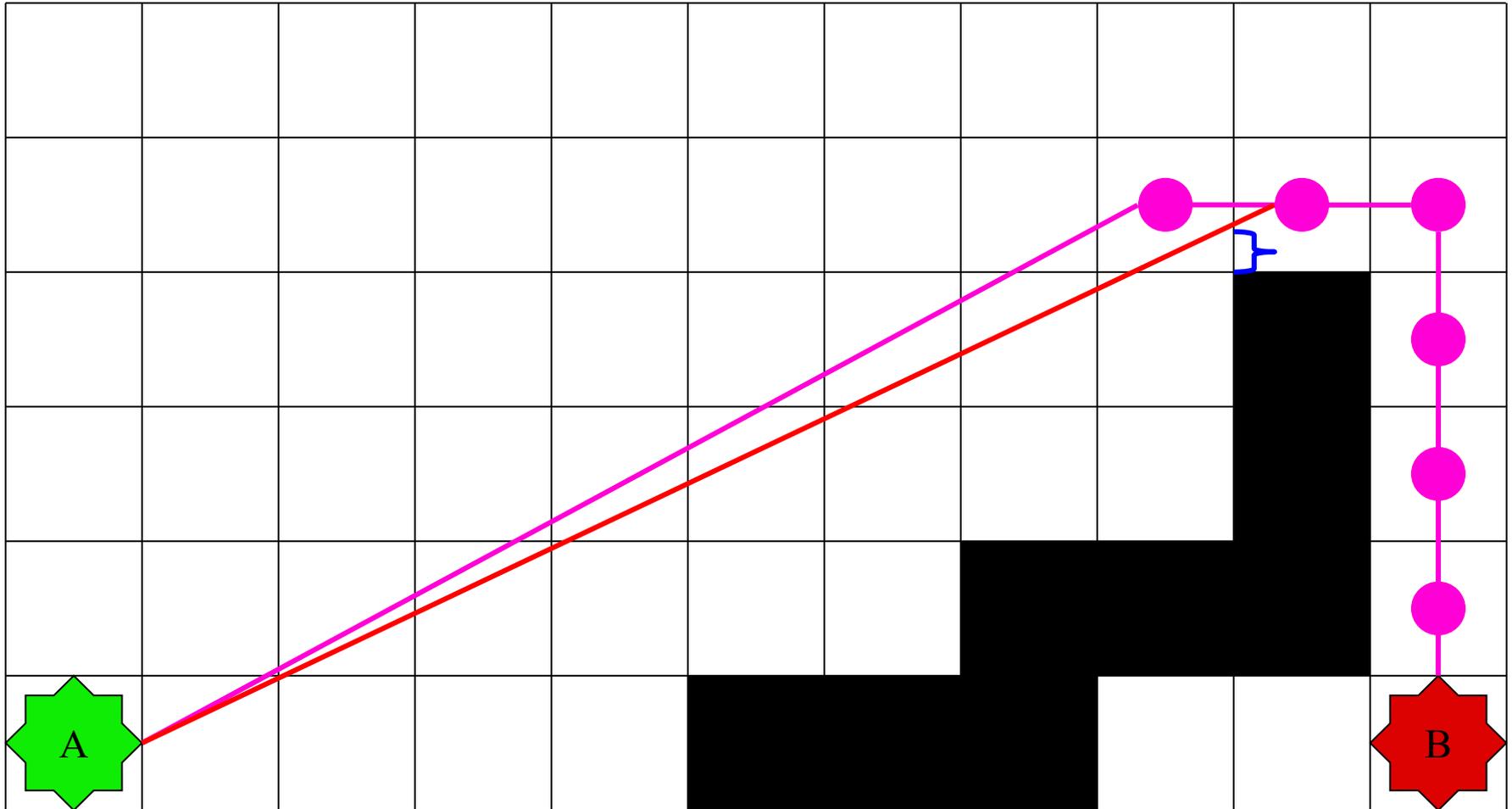
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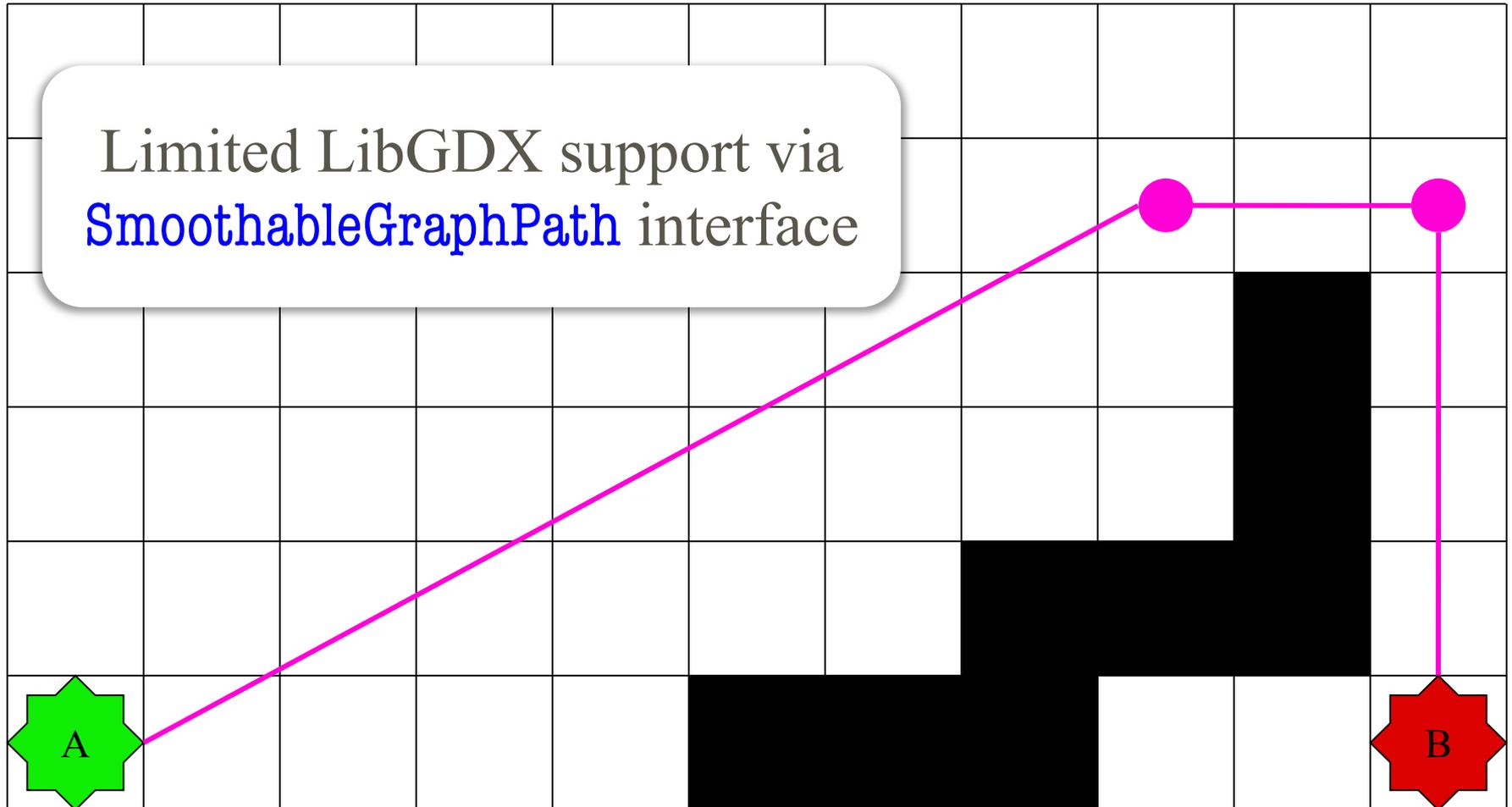
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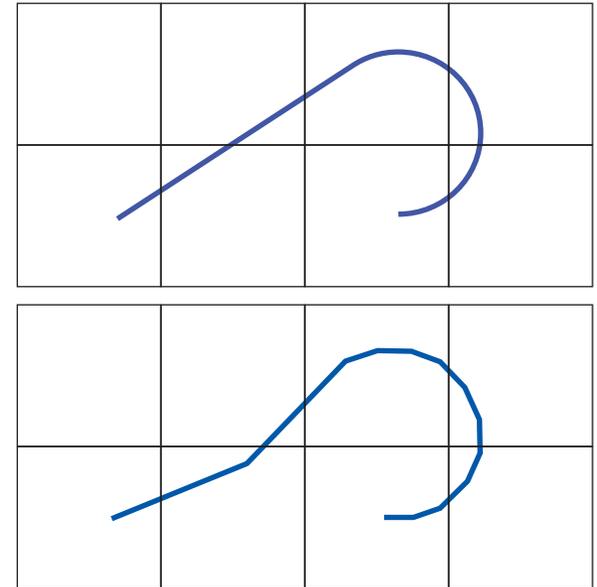


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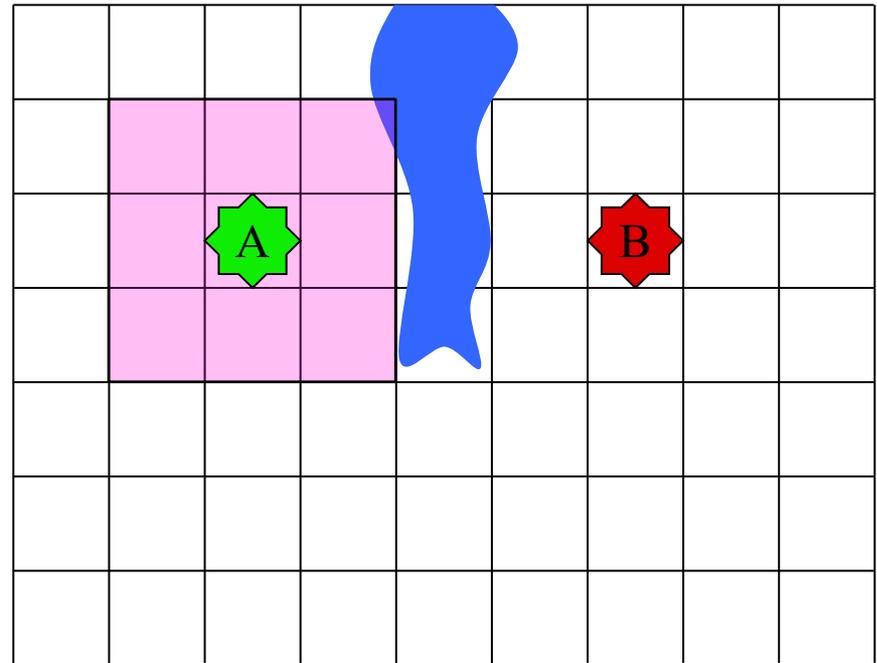
Turning

- **Realistic** turns
 - Smooth paths into line segments
 - Round corners for realistic movement
- **Restricted** turns
 - Limit turns to angles drawn by artist
 - 16 angles standard for 2D top-down
- See online reading for today
 - Pinter, “Toward More Realistic Pathfinding”
 - Techniques from the sprite days of RTSs



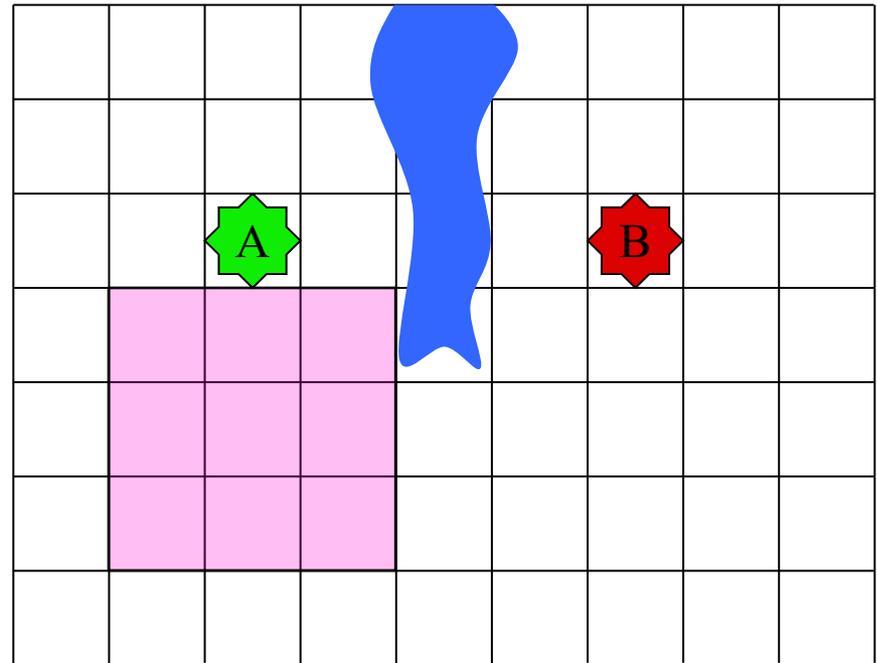
Multiple NPC Sizes

- Grid to largest NPC?
 - Bad for small units
 - Unnecessary blocking
- Grid to smallest NPC!
 - Multiple squares for larger
 - Center fits on grid square
- Pathfinding larger NPCs
 - A* for center-to-center
 - Size to check blocking
 - May alter the path



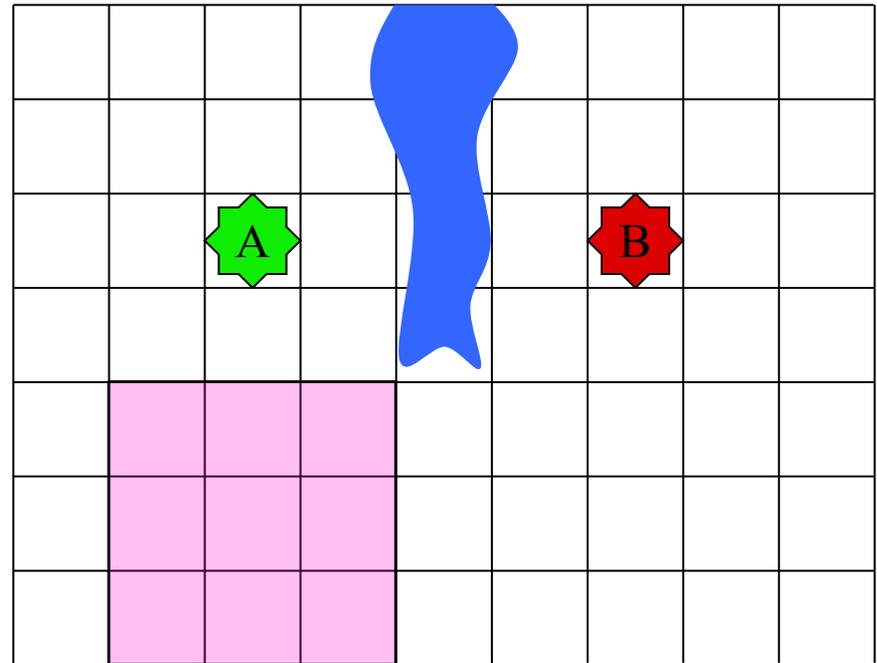
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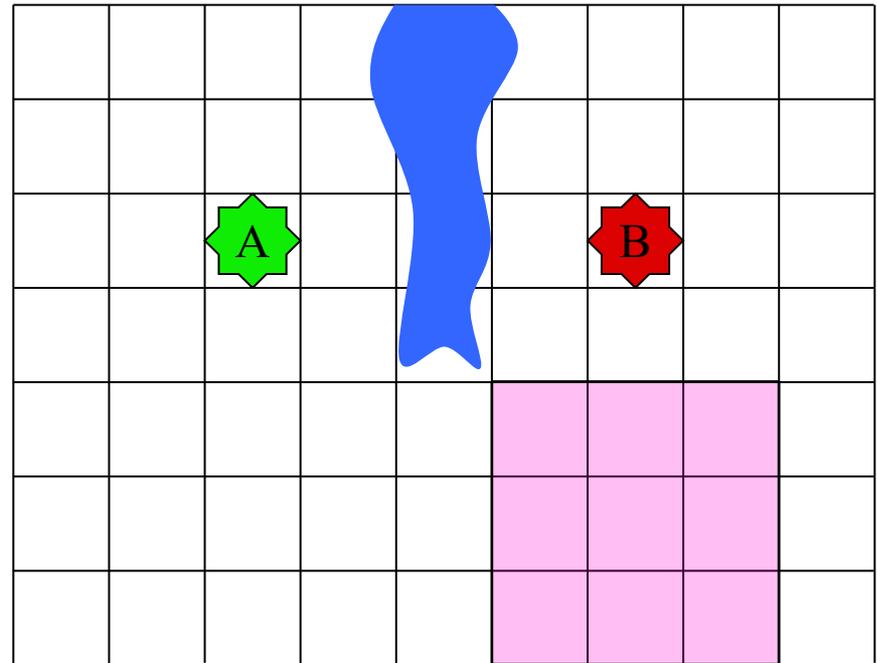
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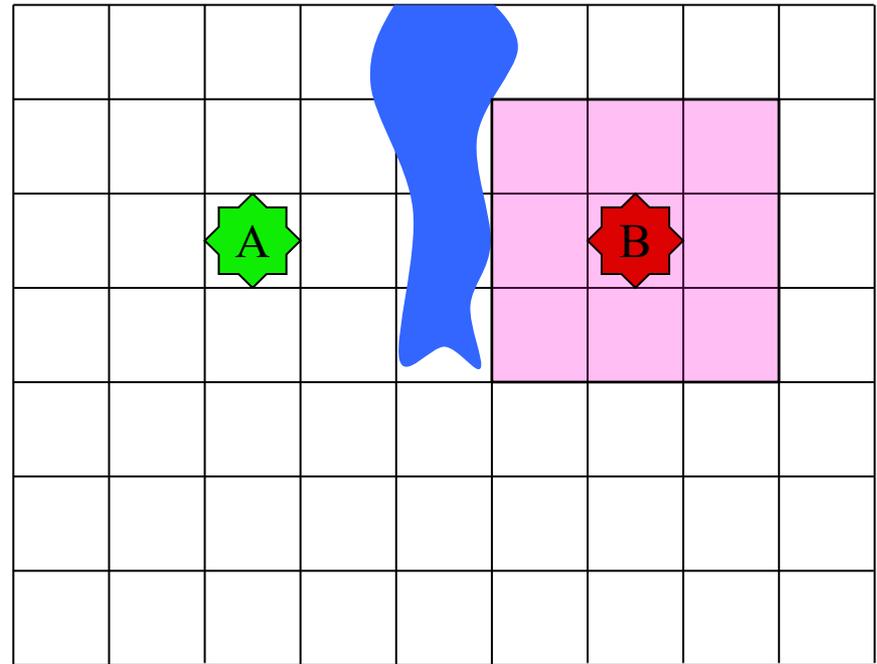
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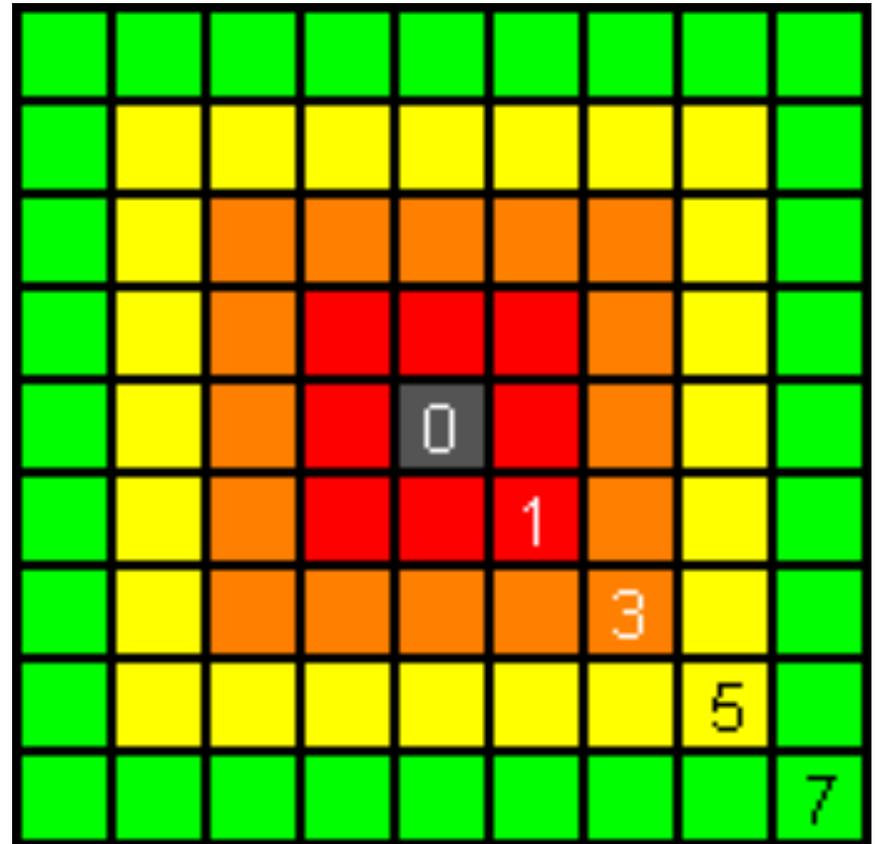


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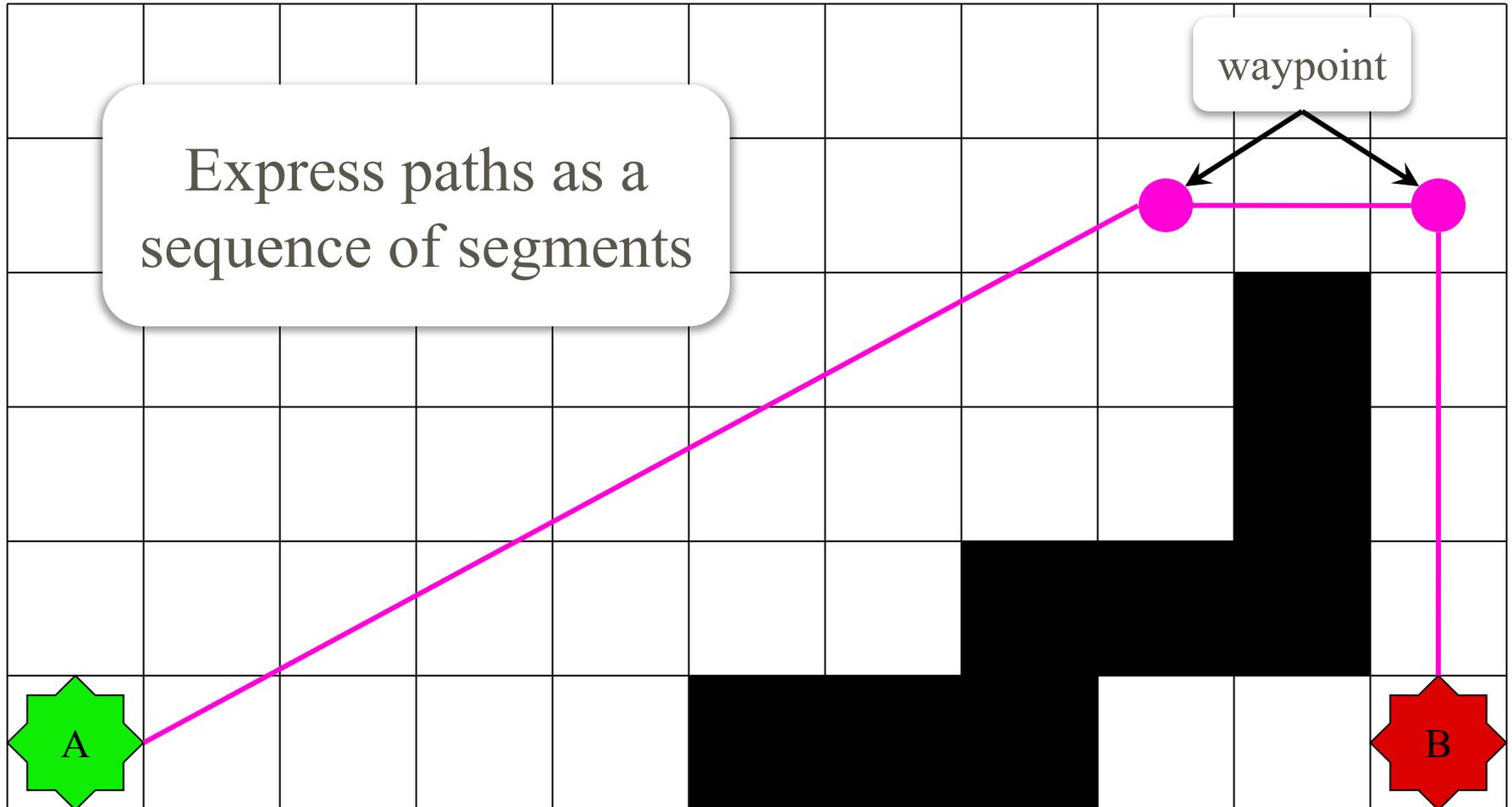


Fitting NPCs on a Grid

- Assume NPC is square
 - Represents “reach”
 - Simplifies turning
- Requires “odd” sizes
 - Center must be a grid
 - Radius in full grid squares
 - What about even sizes?
- “**Tabletop**” solution
 - Round down when moving
 - Round up when in place

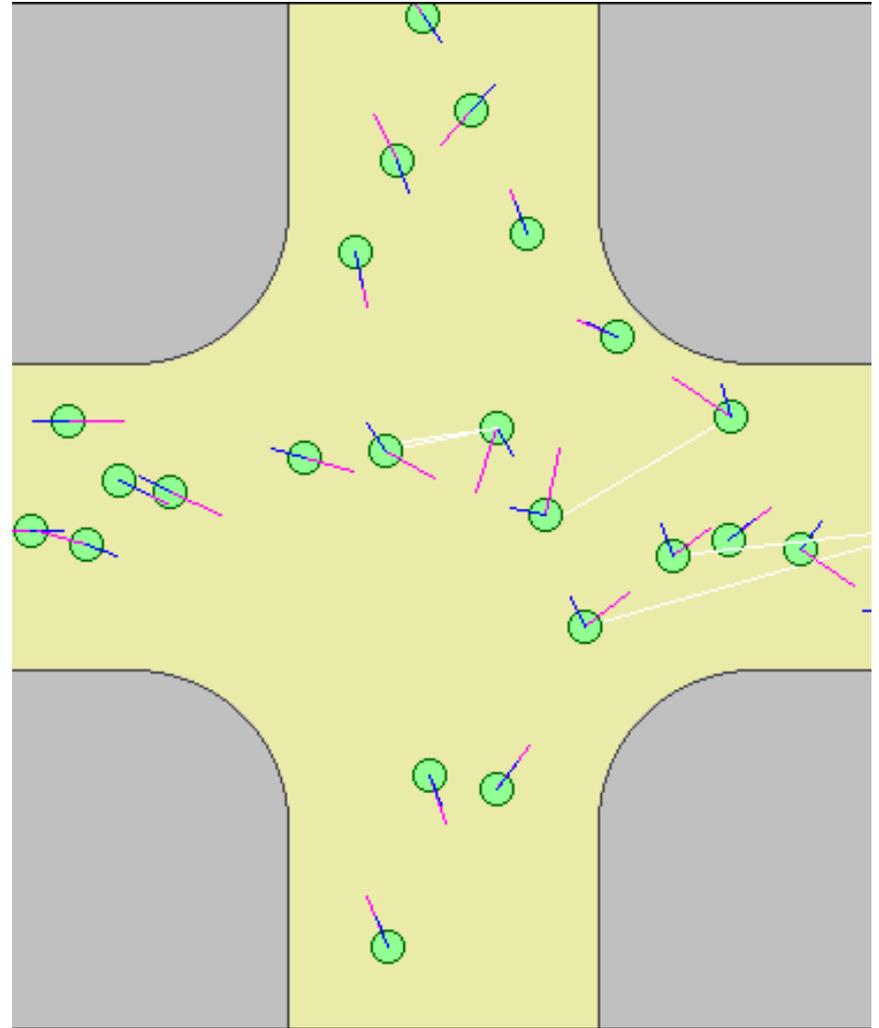


Waypoints



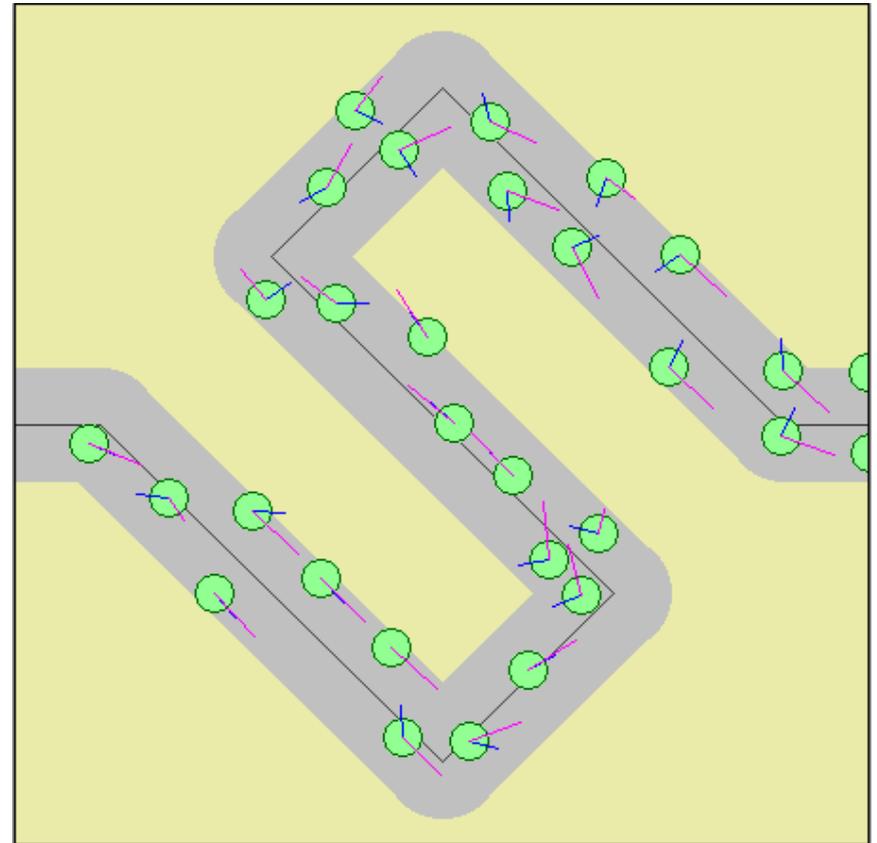
Steering

- Alternative to pathfinding
 - Uses forces to move NPCs
 - Great for **small** paths
- **Examples**
 - Artificial potential fields
 - Vortex fields
 - Custom steering behaviors
- See Craig Reynold's page
 - See "Physics & Motion"
 - com.badlogic.gdx.ai.steer



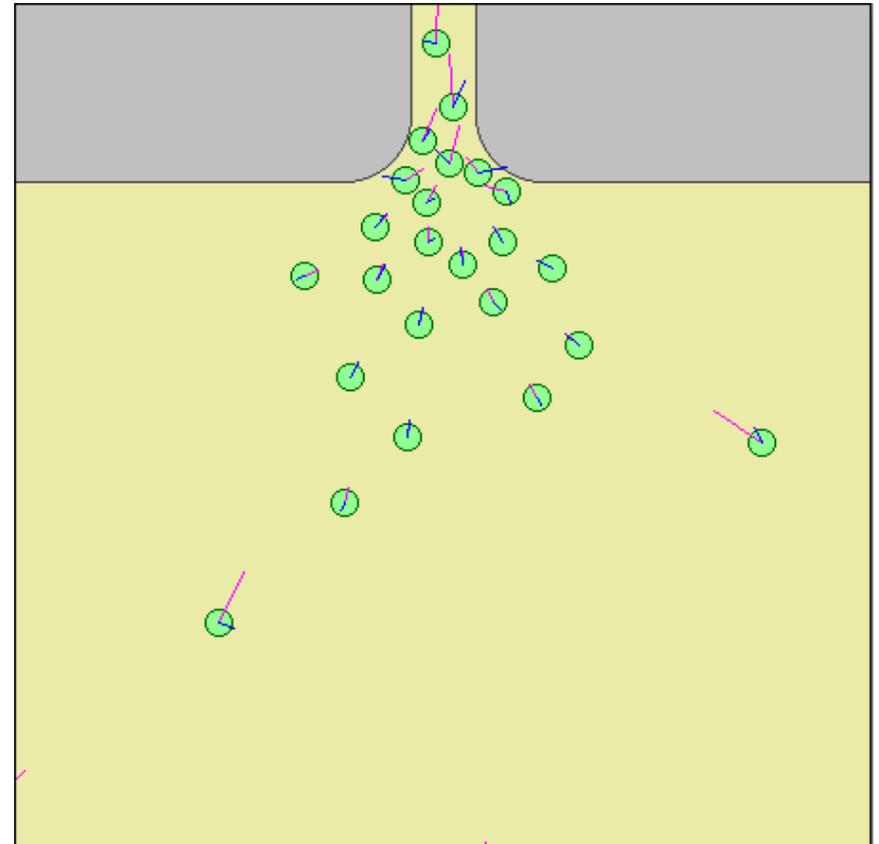
Steering and Pathfinding

- Use waypoint as “goal”
 - Attract NPC to waypoint
 - When close, next waypoint
- Great for multiple NPCs
 - Pathfind for largest NPC
 - Steering to move along path
 - Repulsion keeps NPCs apart
- **Drawbacks:**
 - Military formations are hard
 - Get stuck at bottlenecks



Dynamic Obstructions

- Others can get in way
 - Enemies guarding locale
 - Friends waiting in queue
- Correct response?
 - Compute a new path?
 - Wait to be unblocked?
- What would you do?
 - See what is blocking
 - Making an educated guess
 - Character AI solution



Why Obstructions Matter



Steering Interfaces in LibGDX

Steerable

- Access to **physics data**
 - `getLinearVelocity()`
 - `getAngularVelocity()`
 - `getBoundingRadius()`
- Also has **limiter** info
 - `get/setMaxLinearSpeed()`
 - `get/setMaxAngularSpeed()`
 - `get/setMaxLinearAccel()`
 - `get/setMaxAngularAccel()`

SteeringBehavior

- Has a Steerable **owner**
 - Object being steered
- Other potential attributes
 - **Target** (goal location)
 - **Path** (path following)
- Calcs `SteeringAcceleration`
 - Physics *recommendation*
 - DOES NOT set physics

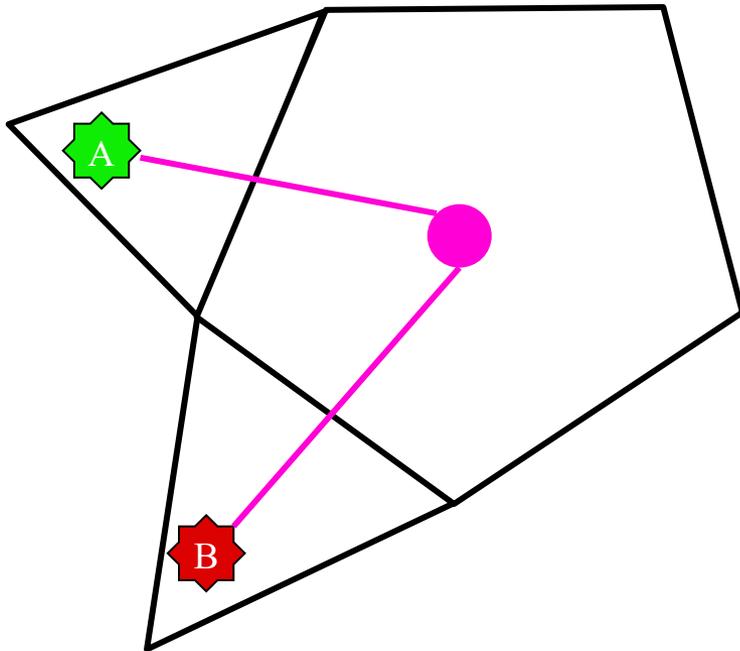
Pathfinding in Practice

- Navigation Meshes
 - Indicates walkable areas
 - 2D geometric representation
 - Connected convex shapes
 - A* graph: center-to-center
- Making Nav Meshes
 - Often done by level editor
 - Can be modified by hand
 - Annotate special movement
 - **Example:** jump points

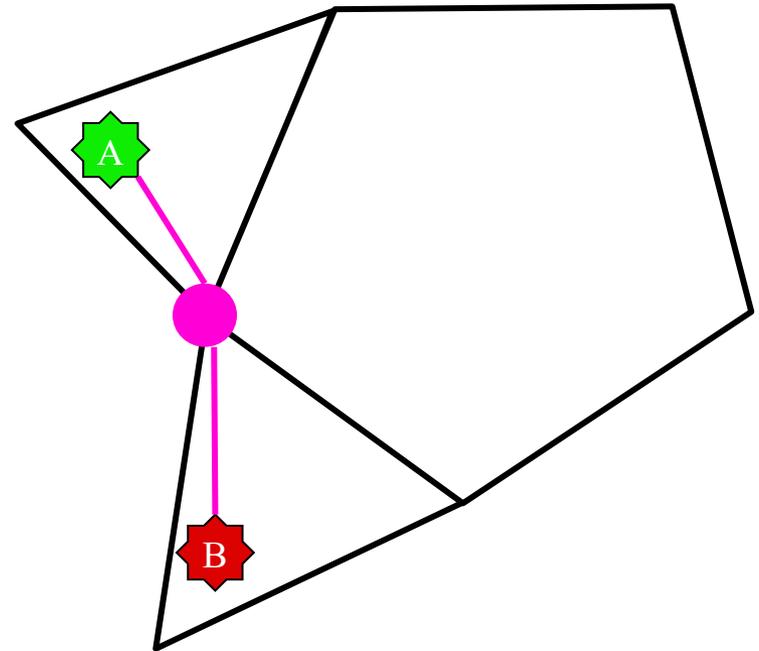


Easy Pathfinding on Meshes

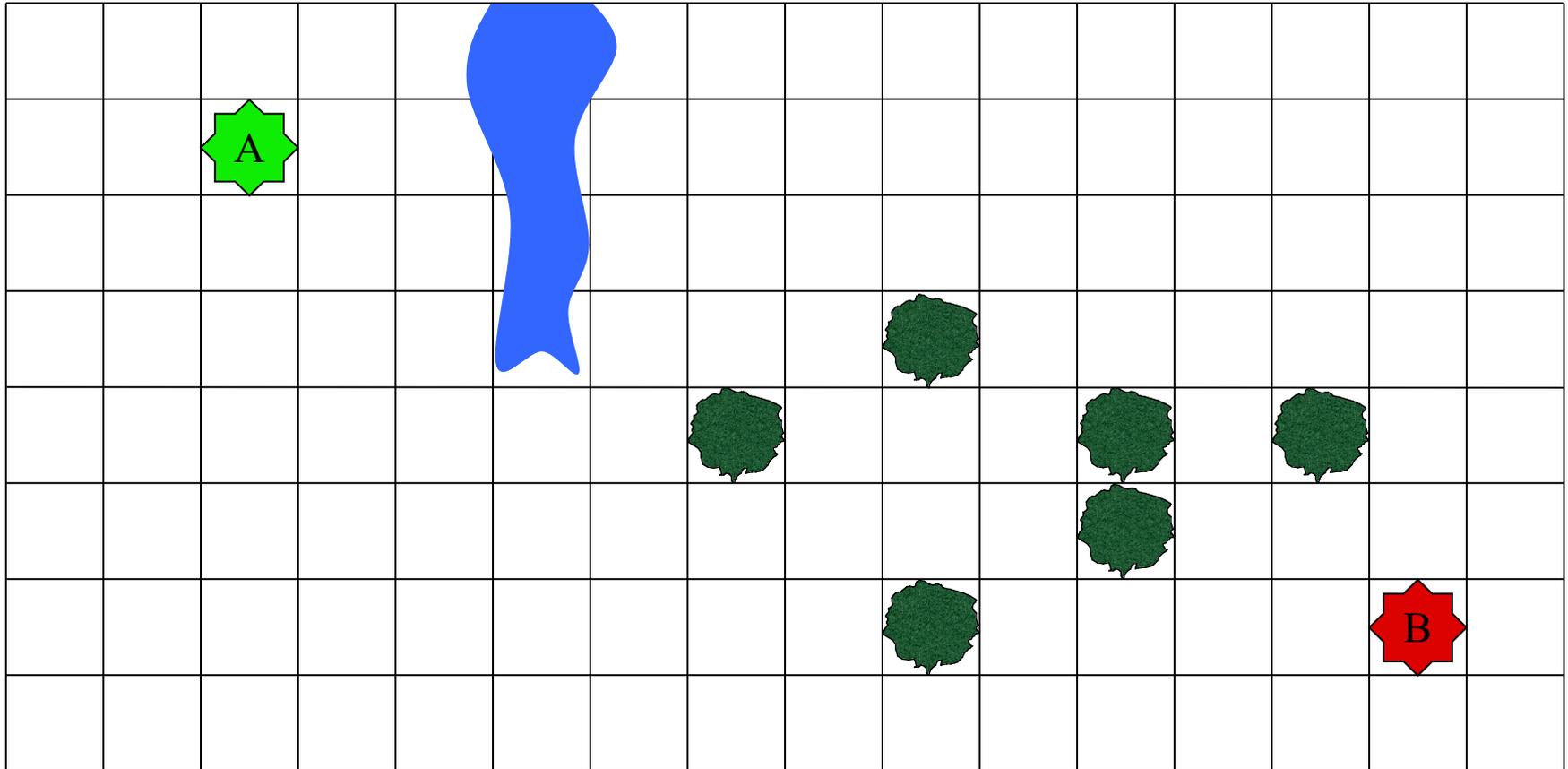
Center of each Region



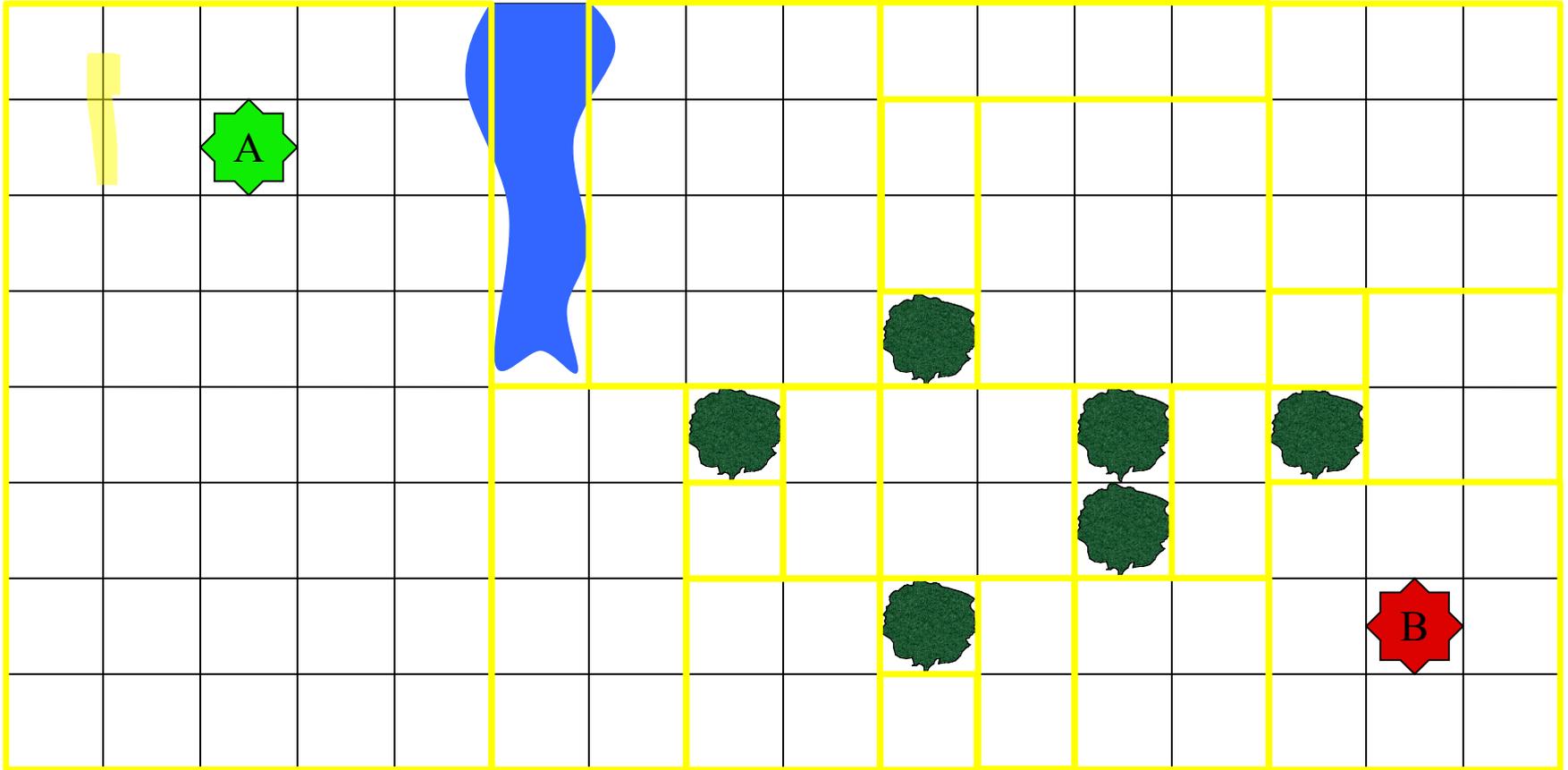
Corners of the Mesh



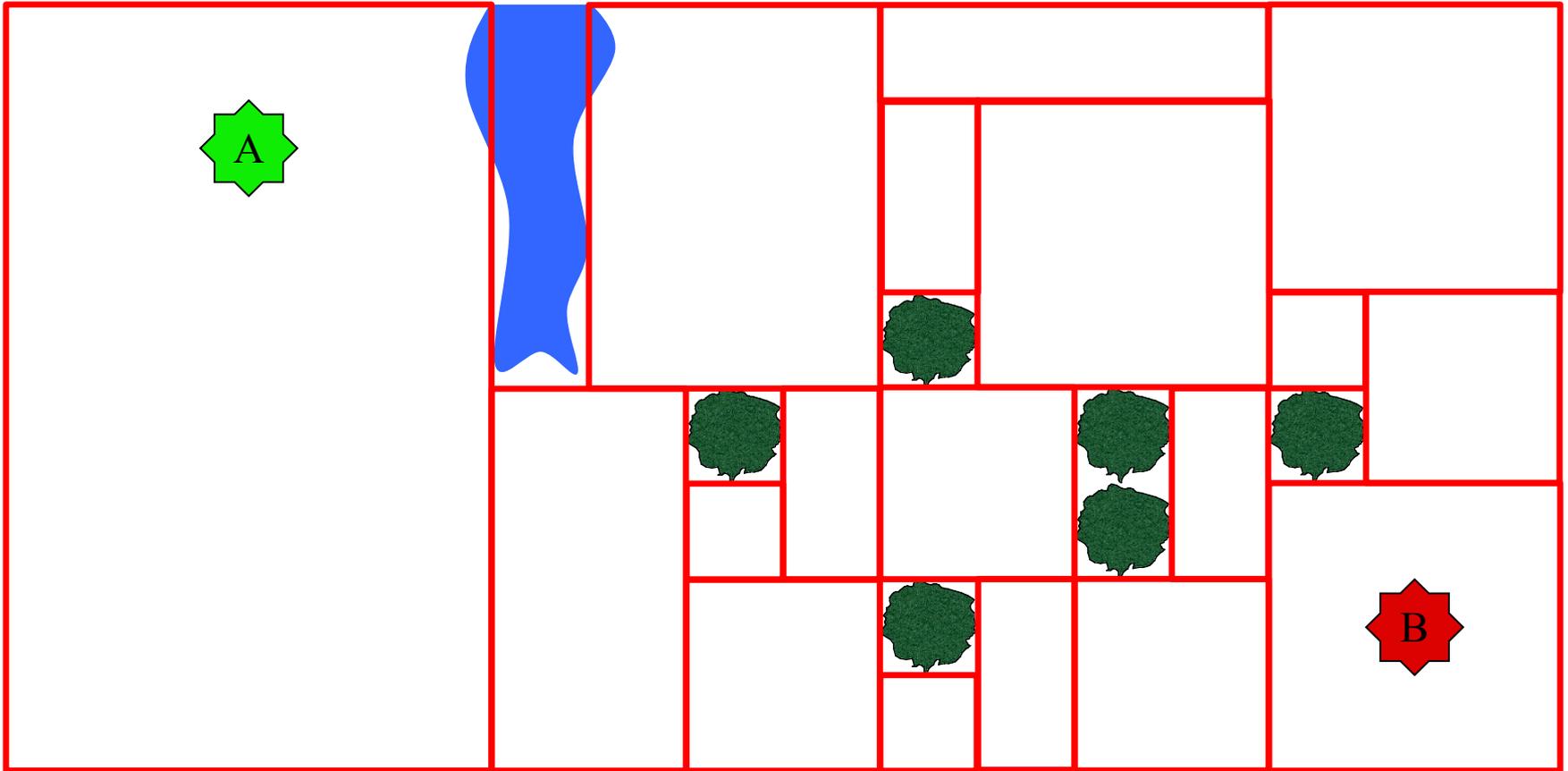
Optimization: Hierarchical Pathfinding



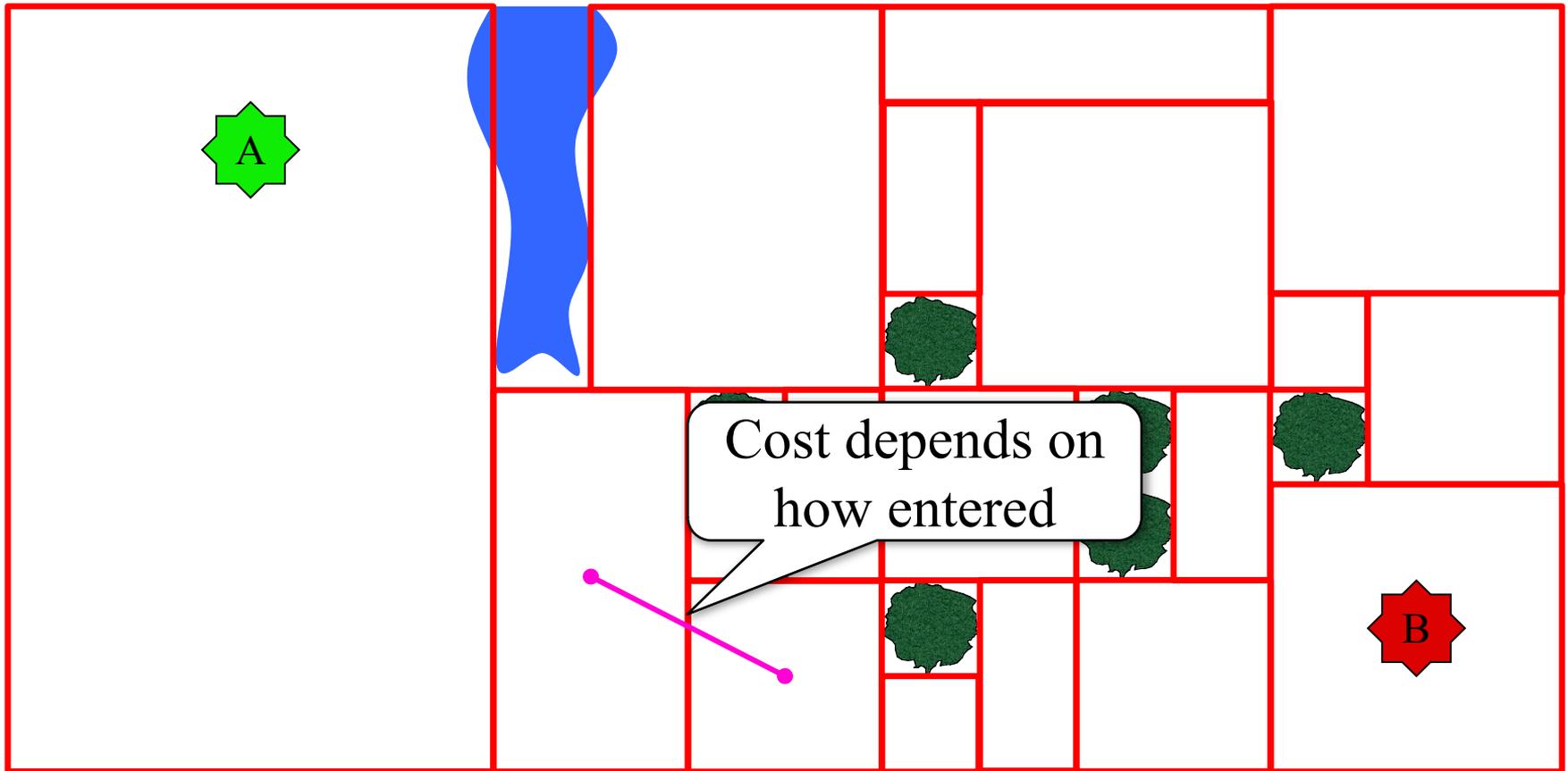
Optimization: Hierarchical Pathfinding



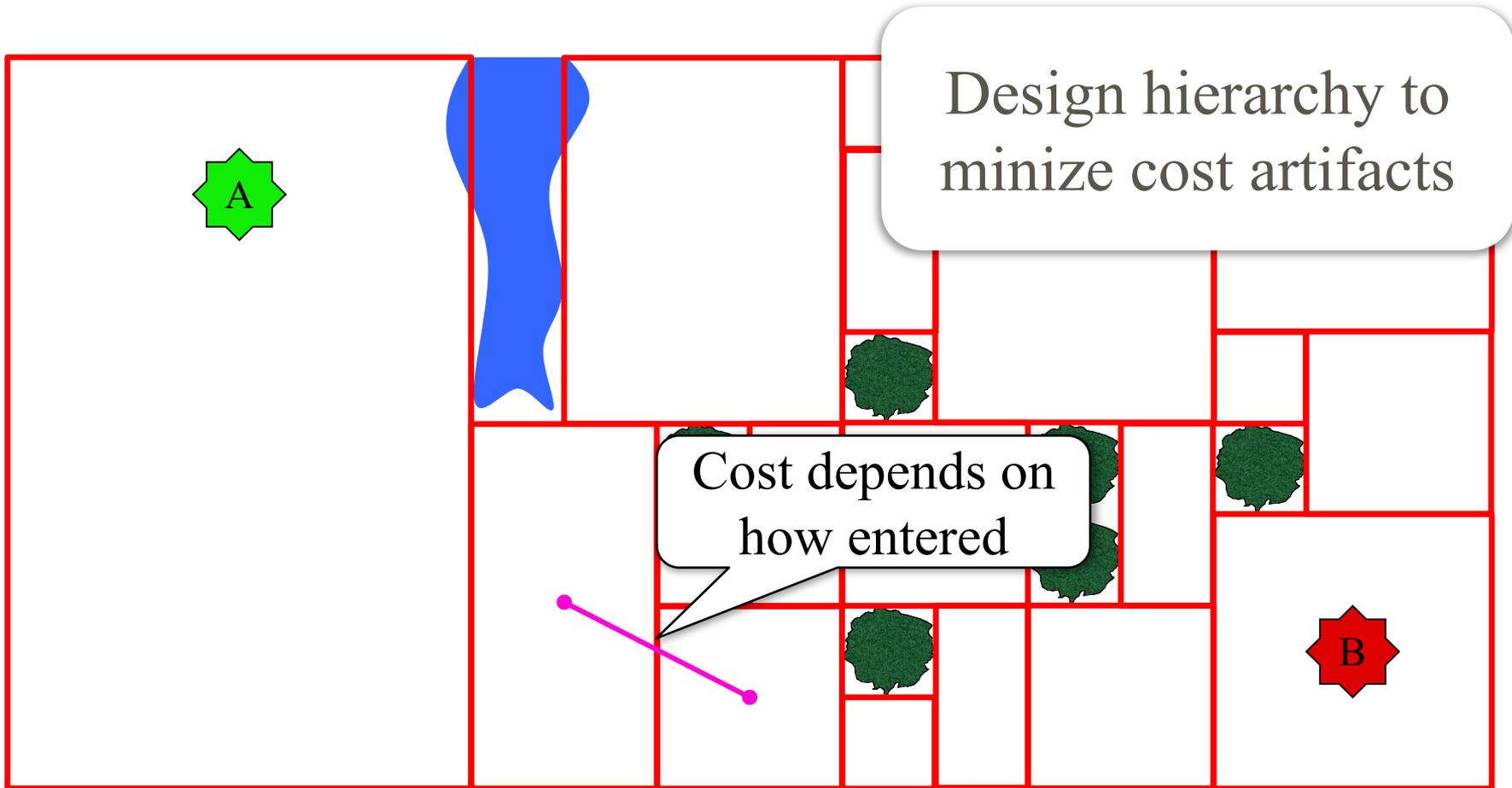
Optimization: Hierarchical Pathfinding



Optimization: Hierarchical Pathfinding



Optimization: Hierarchical Pathfinding



LibGDX Support

HierarchicalGraph

- Graph with multiple levels
 - Has a current active level
 - Graph API matches level
 - Can switch this level on fly
- Also can convert levels
 - node + level => node
 - Rules to group nodes
 - Rules to split nodes

HierarchicalPathFinder

- Specify a pathfinder to use
 - Could be A* or otherwise
 - Will use it on each level
- The implementation
 - Finds path at highest level
 - Expands nodes to next level
 - Refines path to expansion
 - Repeats until level 0

LibGDX Support

HierarchicalGraph

- Graph with multiple levels
 - Has a current active level
 - Graph API on level
 - Can fly
- Also can convert levels
 - node + level => node
 - Rules to group nodes
 - Rules to split nodes

Interface

HierarchicalPathFinder

- Specify a pathfinder to use
 - Could be A* or otherwise
 - Will use it on level
- The pathfinder class
 - Finds path at highest level
 - Expands nodes to next level
 - Refines path to expansion
 - Repeats until level 0

Class

Summary

- **A* algorithm** is primary pathfinding tool
 - Make world into a grid/navigation mesh
 - Search for a path on associated graph
 - Adjust heuristics for terrain, threats
- But there are a lot of “special tricks”
 - Tricks to make movement realistic
 - Tricks to handle coordinated movement
 - Talk to Instructor (or TAs) if need more tricks