Movement: Path Finding, Flocking, Formation

John Laird

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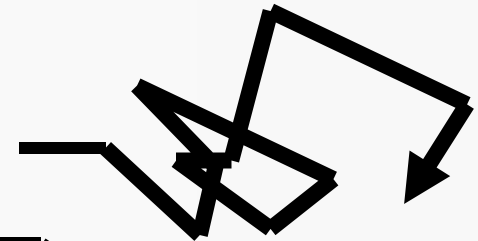
Also based on talks by Lars Lidén and Damián Isla

Movement

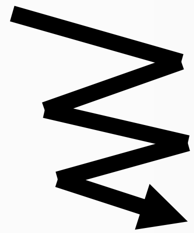
- Movement layer figures out how the character should move in the world
- Avoid obstacles, follow others, …
- Does not figure out
  - where to move or
  - how to animate movement

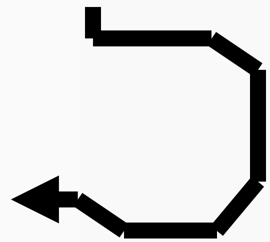
Simple Movement

- Random motion
  - Just roll the dice to pick when and which direction to move



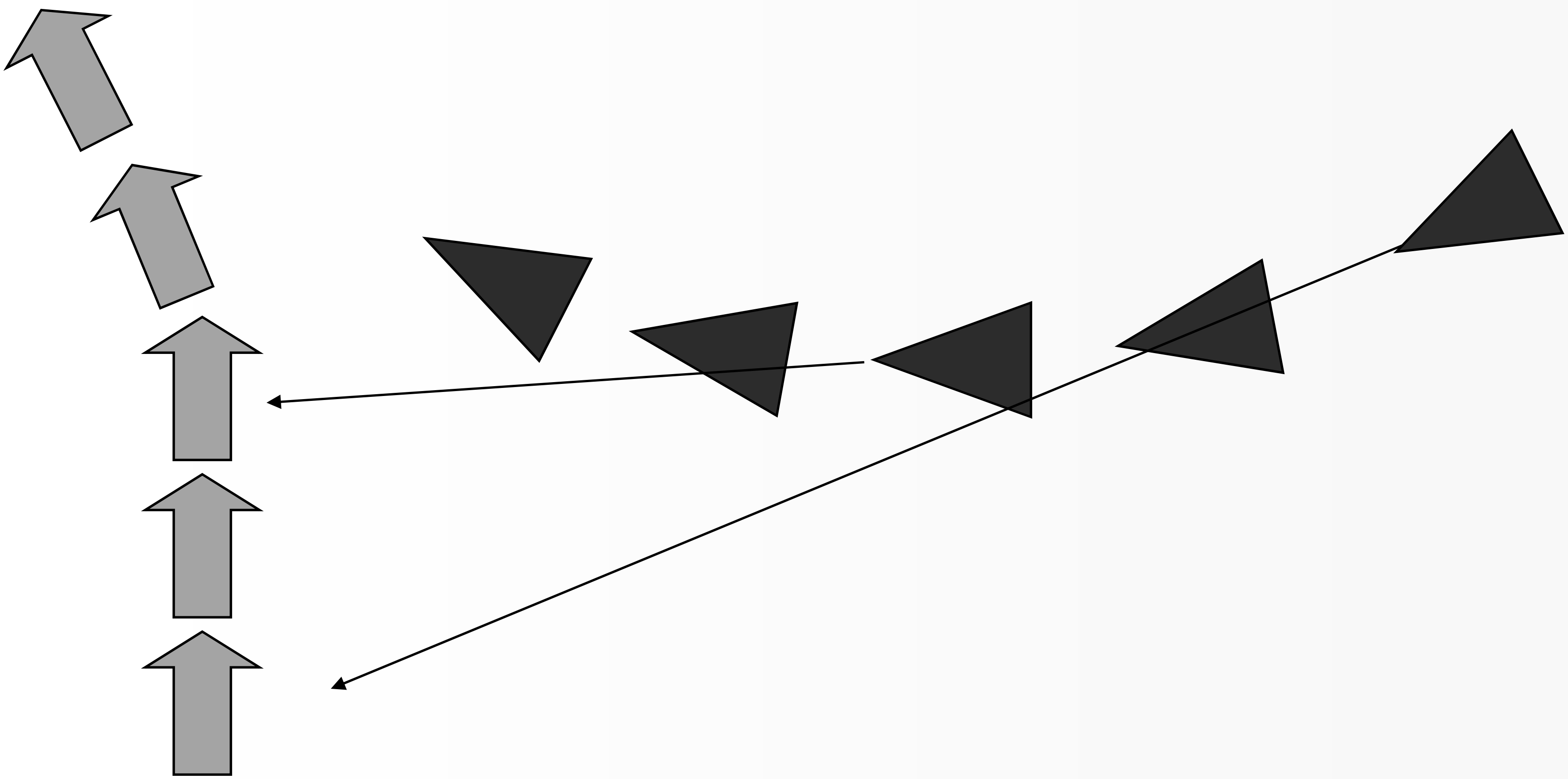
- Simple pattern
  - Follow invisible tracks: Galaxians



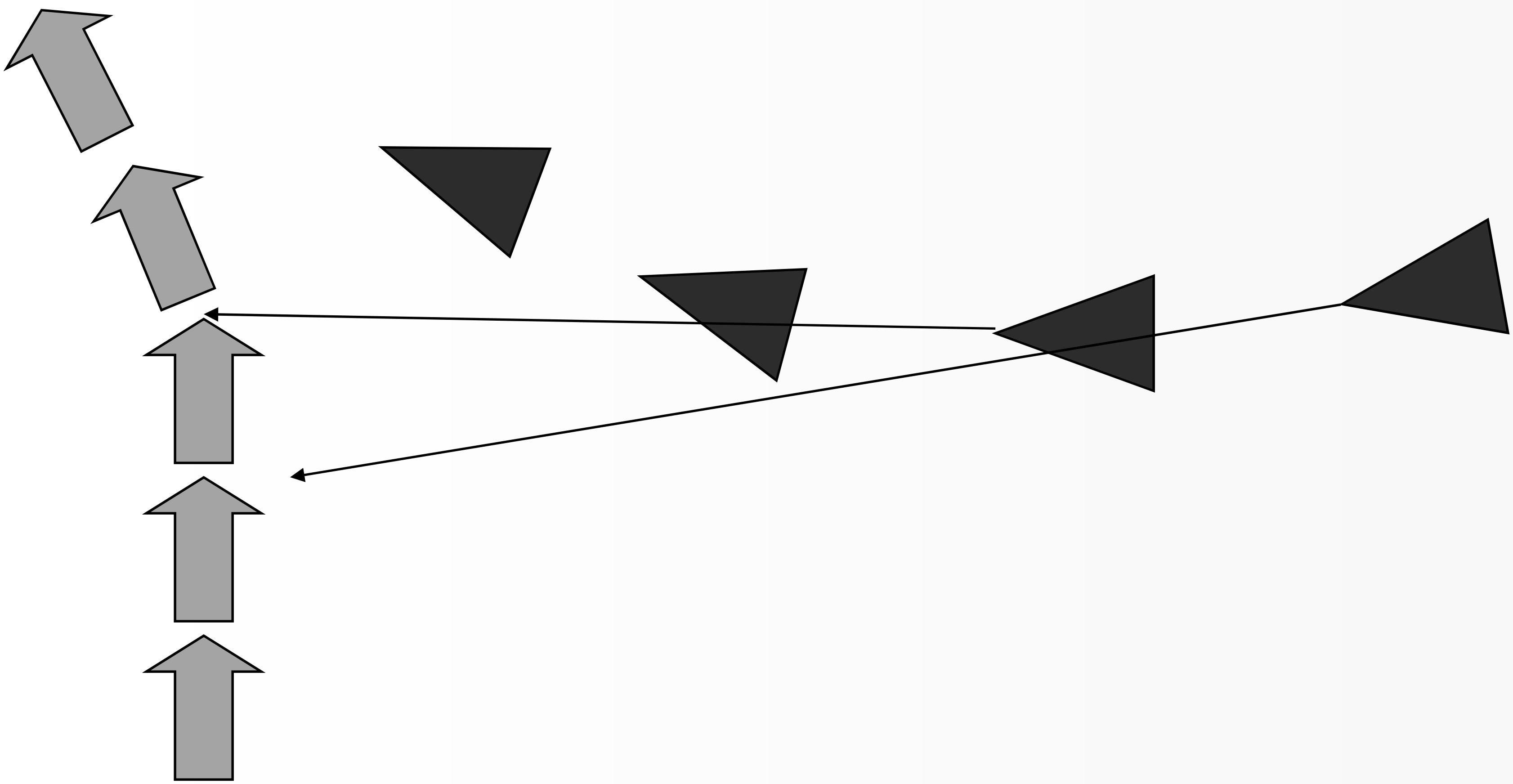


- Tracking
  - Pure Pursuit: Move toward agent’s current position
    - Heat seeking missile
  - Lead Pursuit: Move to position in front of agent
  - Collision: Move toward where agent will be

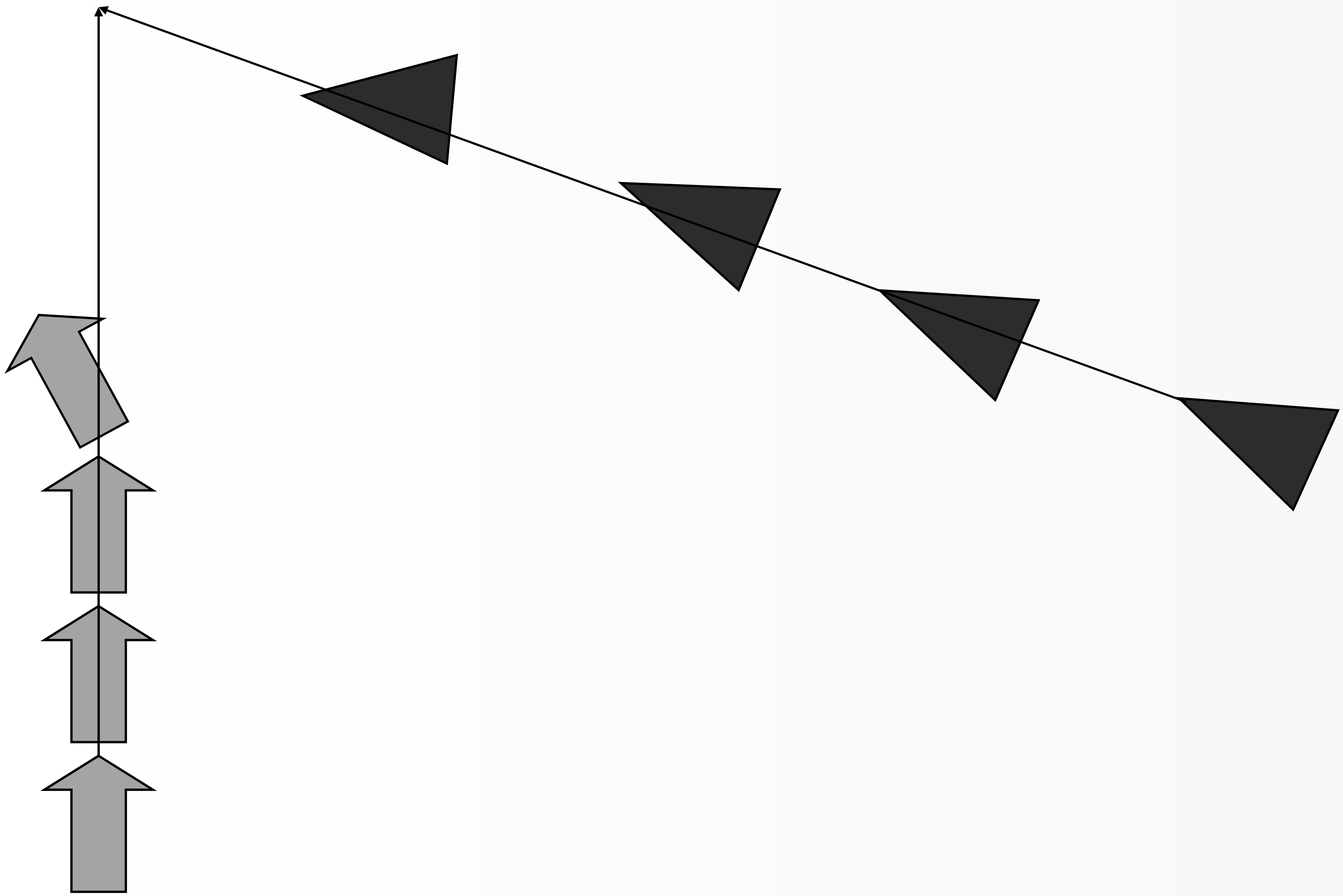
Pure Pursuit



Lead Pursuit



Collision

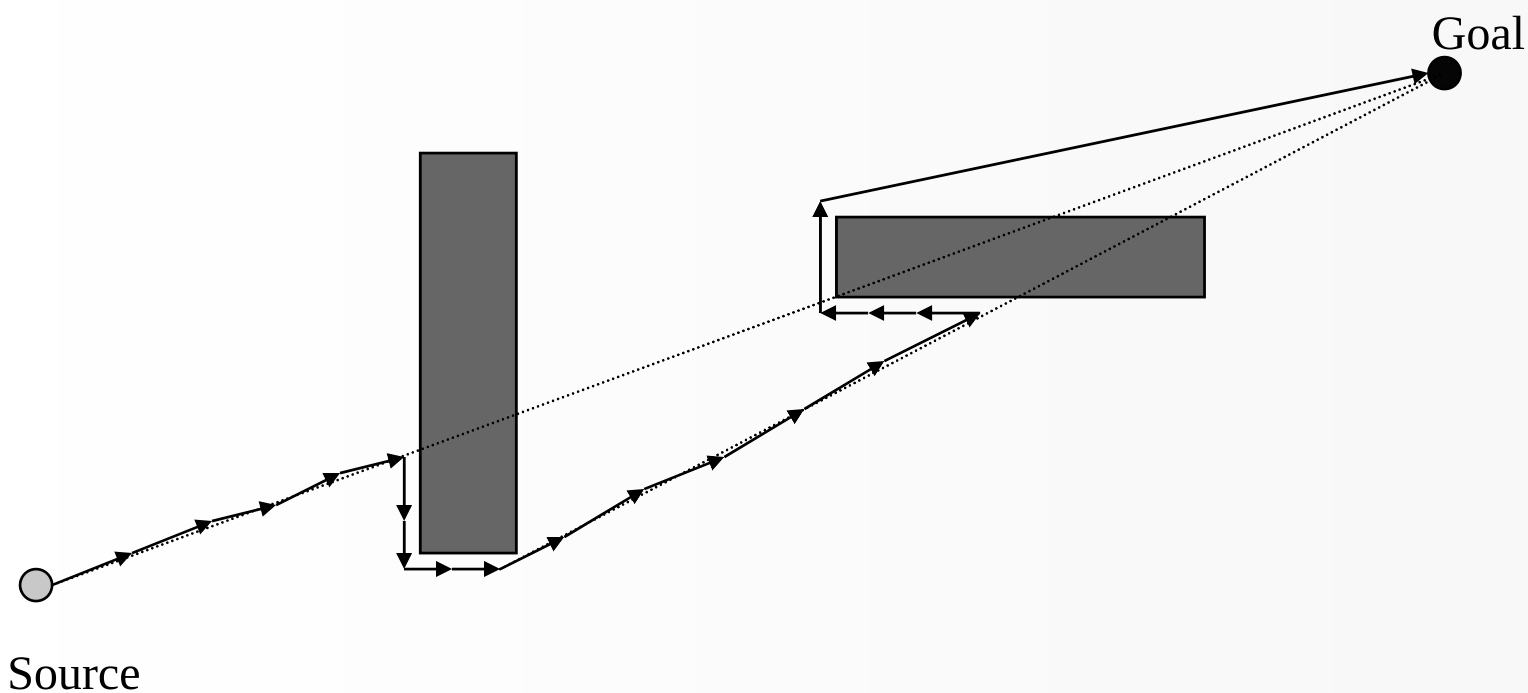


Simple Movement - more

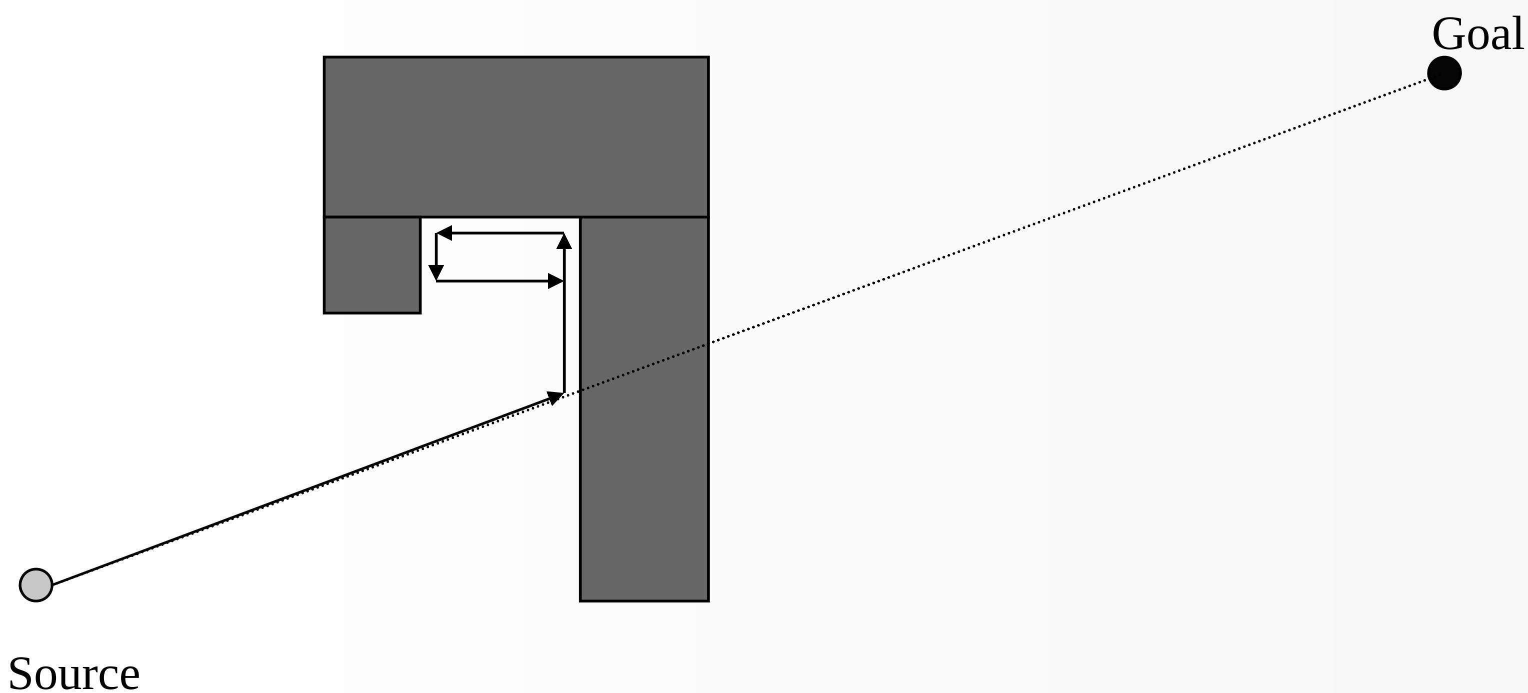
- Tracking
  - Weave: Every N seconds move X degree off opponent’s bearing
  - Spiral: Head 90-M degrees off of opponent’s bearing
- Evasive – opposite of any tracking
- Delayed or restricted sensing gives different effects

Moving in the World: Path Finding

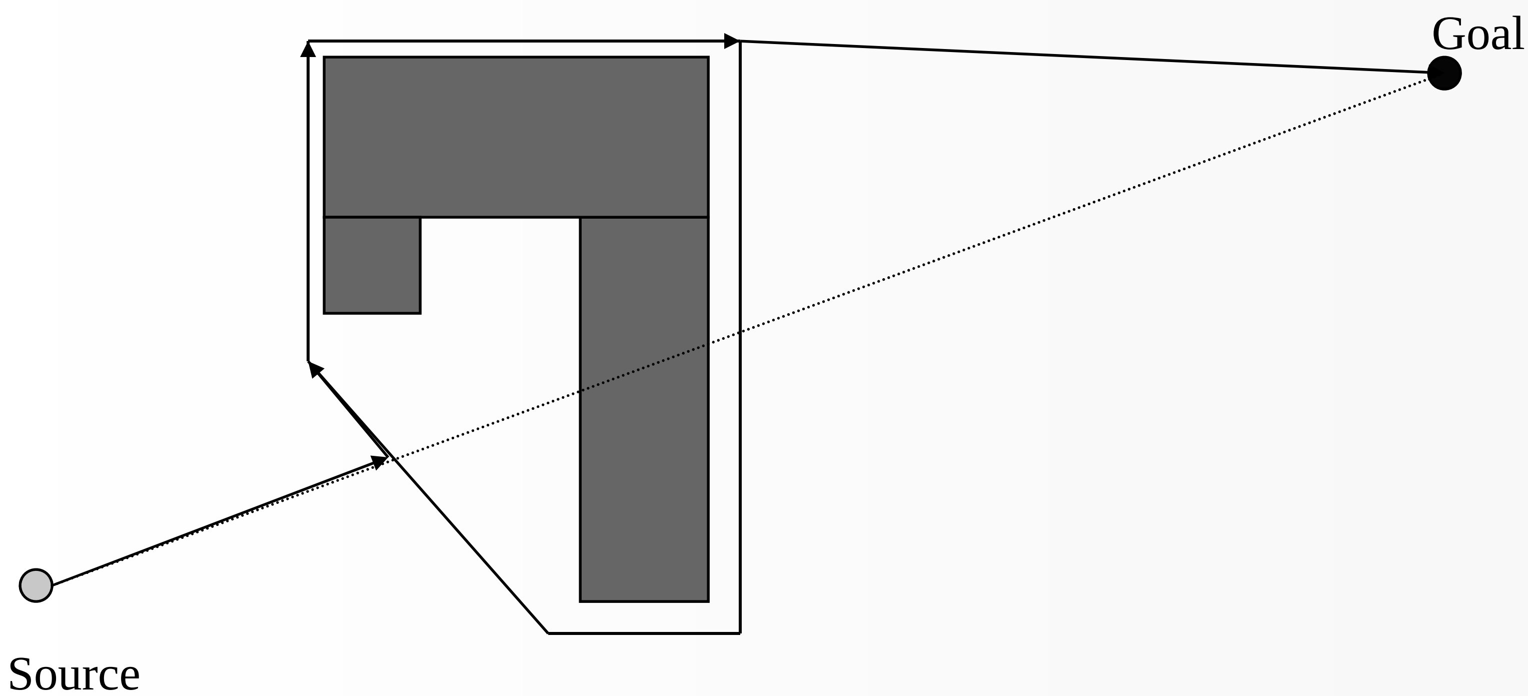
- Just try moving toward goal *while avoiding obstacles*.



Problem



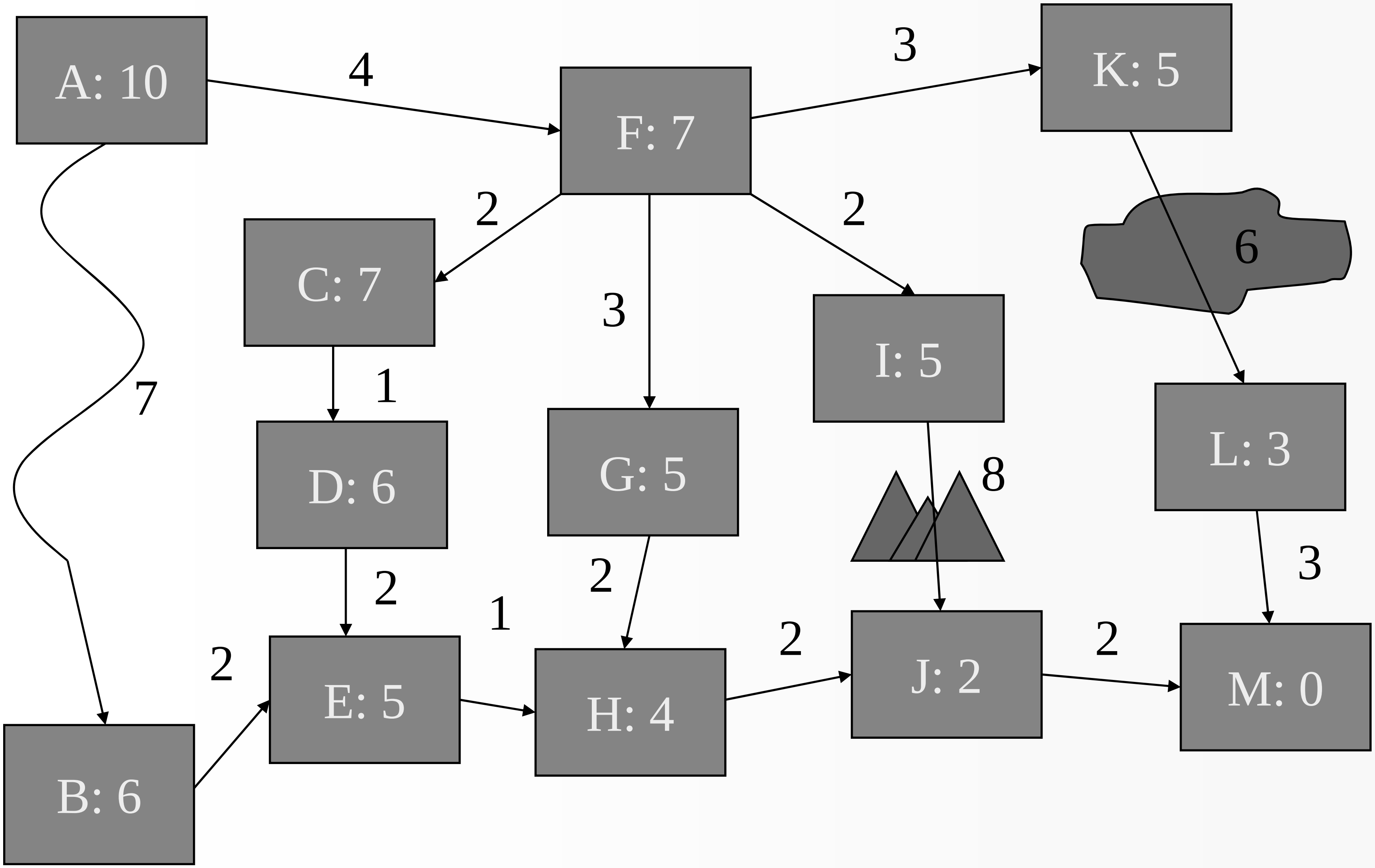
Create Avoidance Regions



Path Planning Problem

- Given a graph with some cost function, find the shortest path between two vertices in the graph
- Arbitrary graph
- 2D world – node-based, or tile based, convex regions, squares, rectangles, hexes
- 2½D world – no arches – same thing
- 3D world – node-based, or treat mostly as 2D tiles with unusual connectivity

Path Finding



Analysis

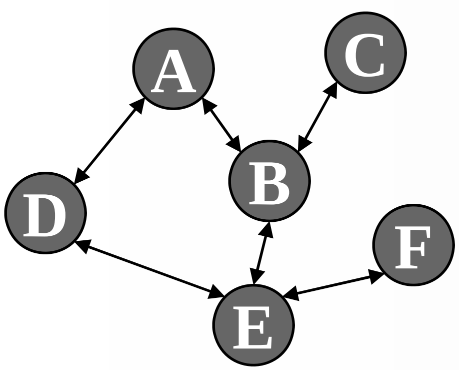
- Find the shortest path through a maze of rooms
- Approach is A*:
  - At each step, calculate the cost of each expanded path
  - Also calculate an estimate of remaining cost of path
  - Extend path with the lowest cost + estimate
- Cost can be more than just distance:
  - Climbing and swimming are harder (2x)
  - Monster filled rooms are really bad (5x)
  - Can add cost to turning – creates smoother paths
  - But must be a numeric calculation
  - Must guarantee that estimate is not an overestimate
- A* **will** always find shortest path

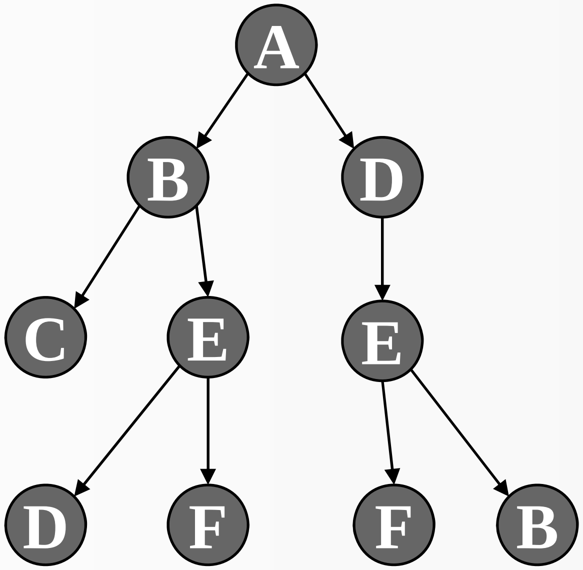
A* Advantages/Disadvantages

- Advantages:
  - Provably optimal
  - Usually limits search
    - Especially for simple graphs
    - Linear with straight lines
  - Can have complex cost function that includes many things
    - Visibility, effort, …
- Disadvantages:
  - Can spend a lot of resources getting optimal result
  - Can be compute and memory intensive
  - Exhaustive if no path
  - Requires admissible heuristic

A* Nuts and Bolts

- Best-first search (with dynamic programming)
  - Generating partial paths
- Evaluation function $f = g + h$
  - g = *actual* cost from start node to current node along current path
    - Must be monotonic
  - h = estimated cost from current node to goal node
    - h must *not overestimate* the cost to the goal
    - Used to guide the search – closer to actual cost the smaller the search





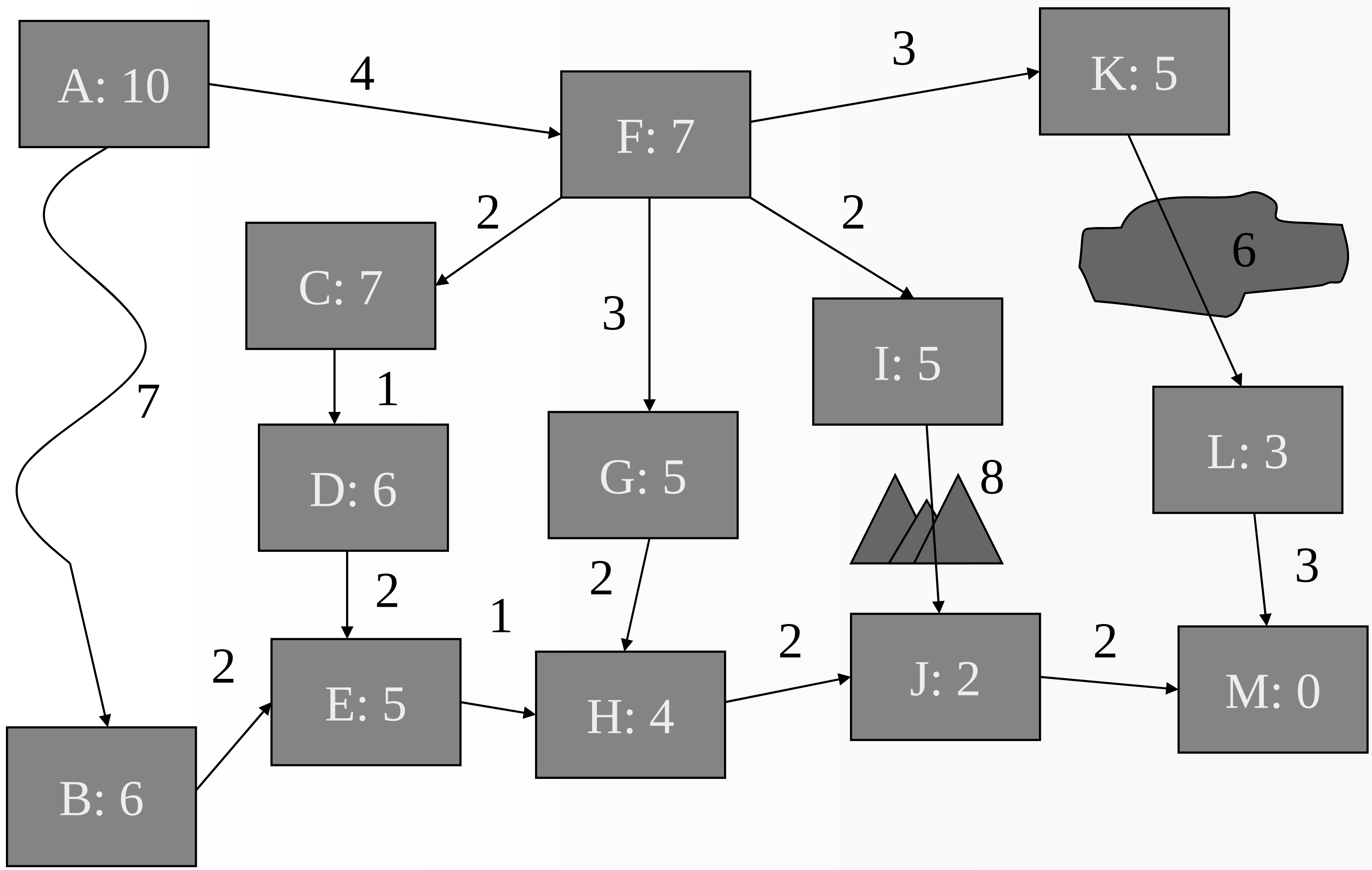
Cost Functions

- Examples:
  - Distance
    - Geometric Distance
    - Manhattan distance (when moving through tiles)
  - Traversal speed based on terrain type
  - Danger (near enemy)
  - Visibility [Vision, Radar]
  - Amount of turning
- Things can’t do:
  - Negative cost (time travel)

Nodes

- Information associated with each node:
  - *g* = cost of shortest path from start to node
  - *h* = estimated cost to goal
  - $f = g + h$
  - *Parent* = parent on shortest path from start to node
    - Node is really a path!
  - *Children* = all children of this node
  - *Other task dependent data – x, y, z location,…*
- Links have cost of traversal

Path Finding



Algorithm

1. Let P = starting point
2. Assign *f*, *g*, *h* to P
3. Add P to Open list
4. <u>Let *B* = the best node from the Open list (lowest *f*)</u>
    1. If *B* is the goal node, then quit – a path is found
    2. If the Open list is empty, then quit – no path
5. Let C = a valid node connected to B (child)
    1. Assign *f*, *g*, *h* to C
    2. <u>Check if C is part of path on Open or Closed List</u>
        1. If so, check whether the new path is better (lower f)
            1. If so, recursively update all *super-paths*
        2. <u>Else, add C to the Open list</u>
    3. Repeat 5 for all valid children of B
    4. <u>Add B to Closed List</u>
6. Repeat from step 4

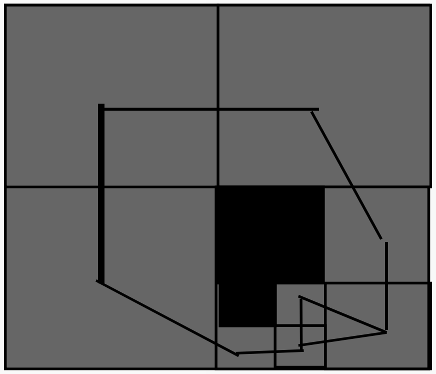
Costly operations: Optimize execution

1. Let *B* = the best node from the Open list (lowest *f*)
   1. Sorted open list: heap
2. Check if C is on Open or Closed List
   1. Have bit vector associated with map nodes – in open/closed
   2. Hash – heap sort
3. Else, add C to the Open list
   1. Heap
4. Add B to the Closed list
   1. Don’t sort Closed list – make a hashtable
5. If so, recursively update all *super-path*

Optimization: Cache top of open-list – don’t sort all of it – don’t expect to go through all of it

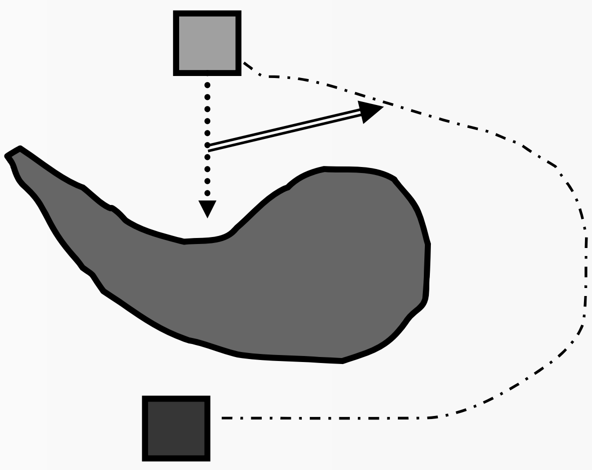
Lots of large spaces and obstacles

- Add all regions of high terrain cost
  - If the added region entirely covers the current cell, set the current cell's cost to the new cost.
  - Otherwise, divide the current cell into four equal size quarters, and recursively add the new region to each child cell.
- Simplify Quad-trees
  - Recombine any cell that has all children of equal cost
- Extract the graph of neighboring cells
  - If impassable, skip the rest
  - If current cell is undivided, add it to list of cells, that border the n,s,e,w and skip
  - Else recur through all children
    - Create the list of internal cells that border our north border by merging the northborder lists of ne and nw children.
    - Create neighbor links.
- Need to smooth paths
  - Find best corners of cells
  - Use last-visible point –
    - Draw a straight line from the current point to
    - The earliest point on path and not exit cells in our path



Time-Slicing

- Can't always compute complete path in one frame
  - Increase resources the longer it takes
- Do a very quick search to start
  - Search N nodes or search for M msec
- Do full search while moving through first N nodes
  - If don't complete, take best so far
- Splice from current [N] to final



Details

- Cache paths – reuse and splice onto them
  - PRECOMPUTATION!
- If tried same failed path multiple times – kill unit, …
- Design maps so there aren't big obstacles in the middle
- If maps have choke points, can precompute

Is optimal really necessary?

- What can we do to get a pretty good solution?
- If find a path to the goal, just take it
- Bias search by inflating h [dangerous, but possible]

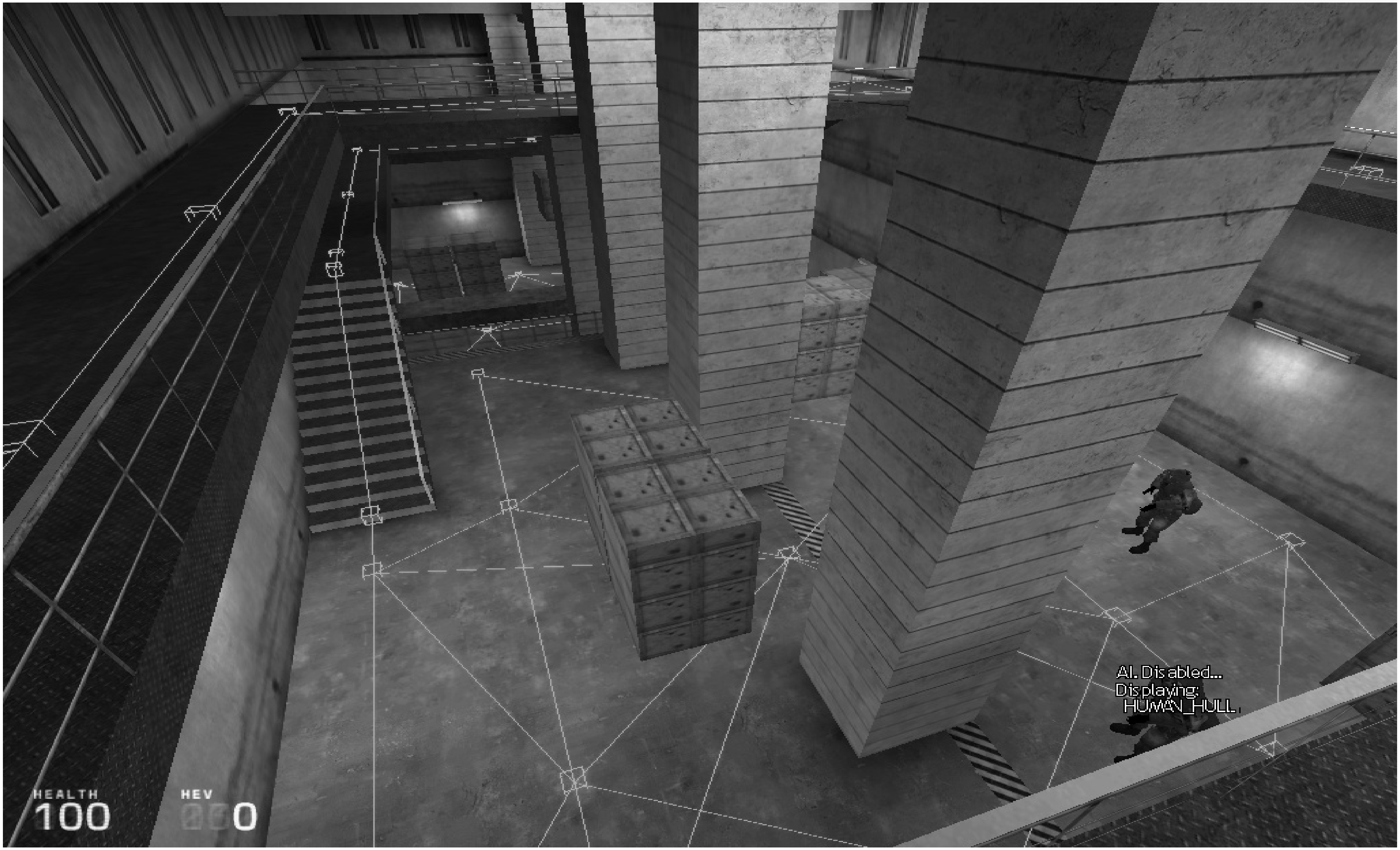
Dynamic Terrain

- Re-plan when get to changed part of path
- Periodically re-plan
- Set trigger for terrain that is used and then re-plan
  - Expensive if terrain will change and change back

Movement: Pathfinding Tools

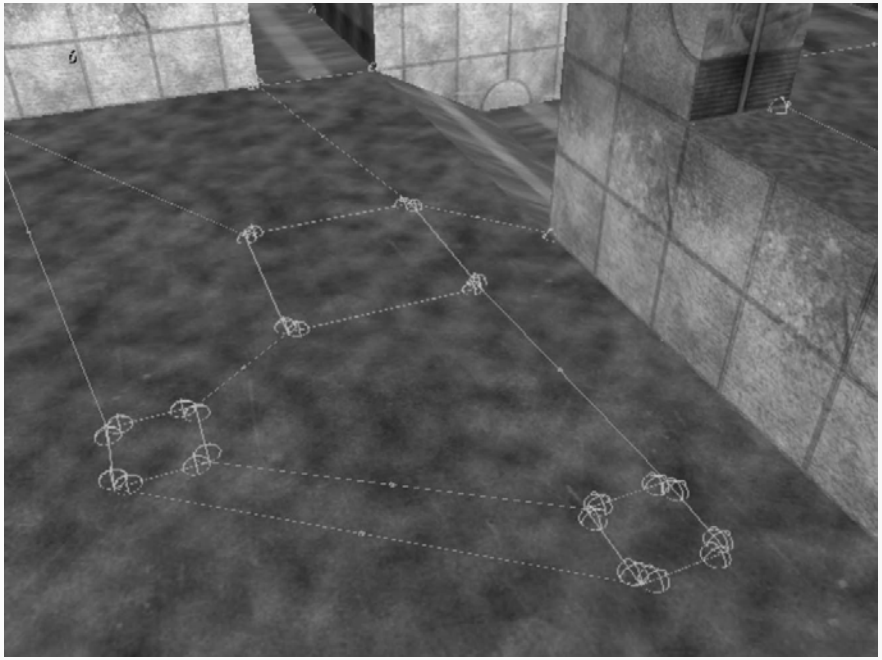
- Waypoint
  - Position in a map that is used for navigation
  - Usually placed in word manually by a level designer
  - A* is the preferred pathfinding algorithm for quickly finding a short path between two waypoints
- Link
  - Connection between two waypoints
  - Often annotated with the required navigation type (Jump, Swim, Climb)
  - For a given NPC, two waypoints are linked when:
    - The NPC has room enough to move from one node to another without colliding with the world geometry
    - The NPC has the required navigation ability
- Node Graph
  - Data structure holding all waypoints and links
  - Either generated manually by a level designer or automatically by the computer and annotated by a level designer

Movement: Node Graph



Spatial Feature Extraction

A lot of features we're interested in can be extracted automatically …



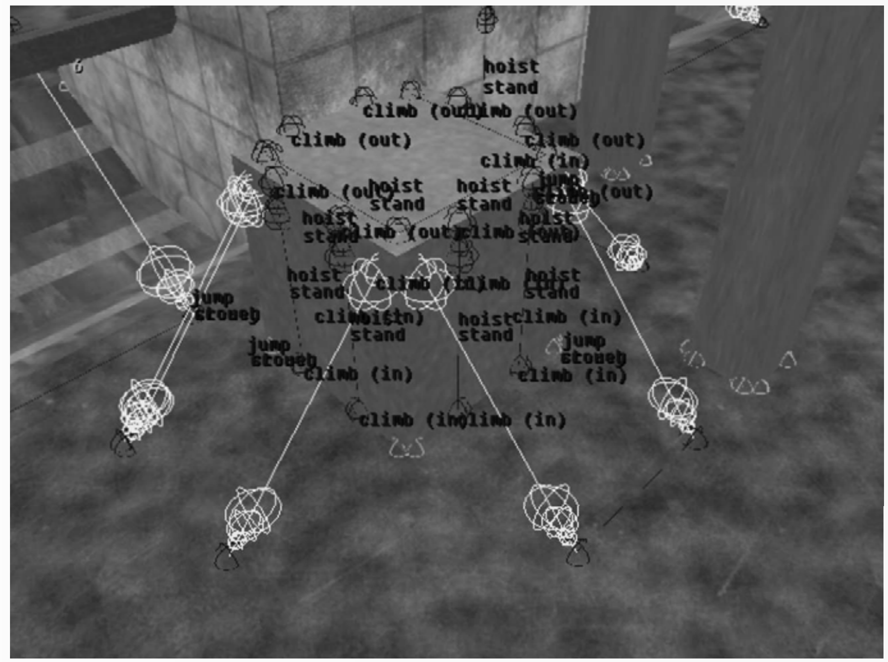
- Surface categorization / characterization
- Surface connectivity
- Overhang detection
- Interior/exterior surfaces
- Ledges
- Wall-bases
- "Leanable" walls
- Corners
- "Step" sectors
- Thresholds
- Local environment classification
  - Captures the "openness" of the environment at firing positions

Spatial Feature Extraction

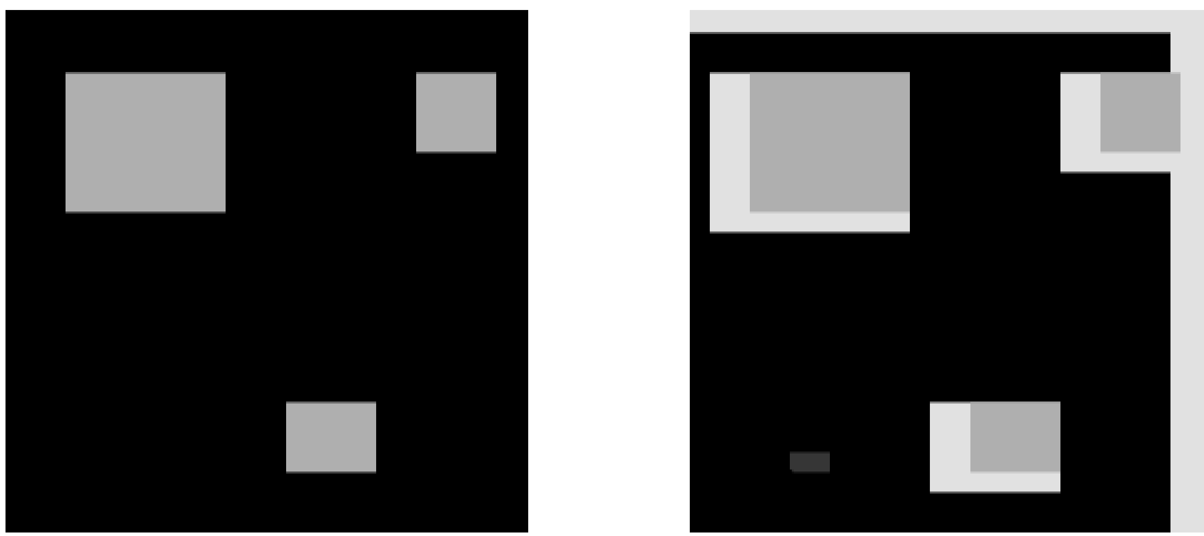
… and a lot can't. So we make the designers do it.

Designer "hints":

- Jumping
- Climbing
- Hoisting
- "Wells"
- Manual fix-up for when the automatic processes fail:
  - Cookie-cutters
  - Connectivity hints



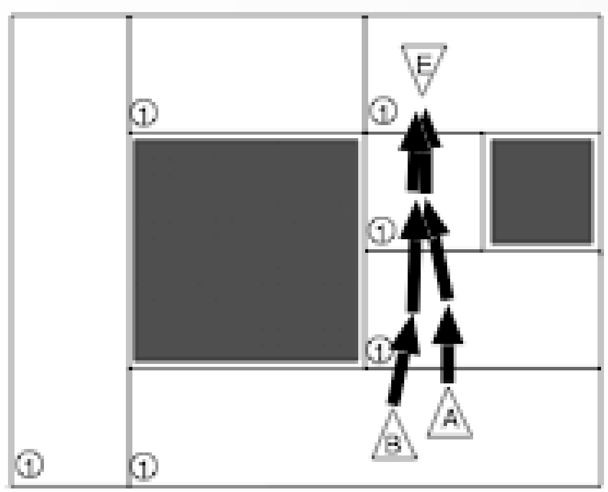
Configuration space approach

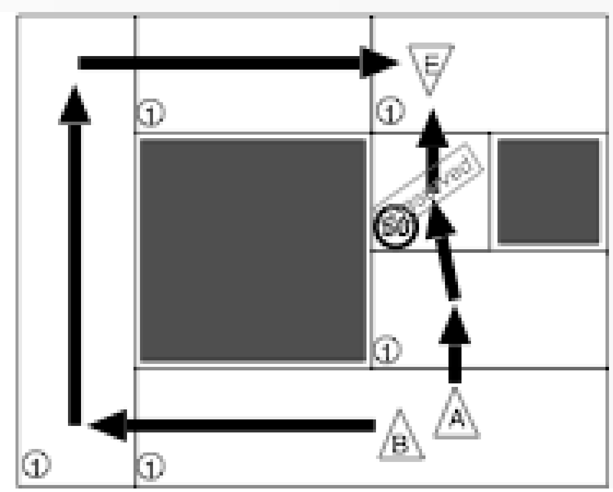


Embedded Info, Animation, Sound

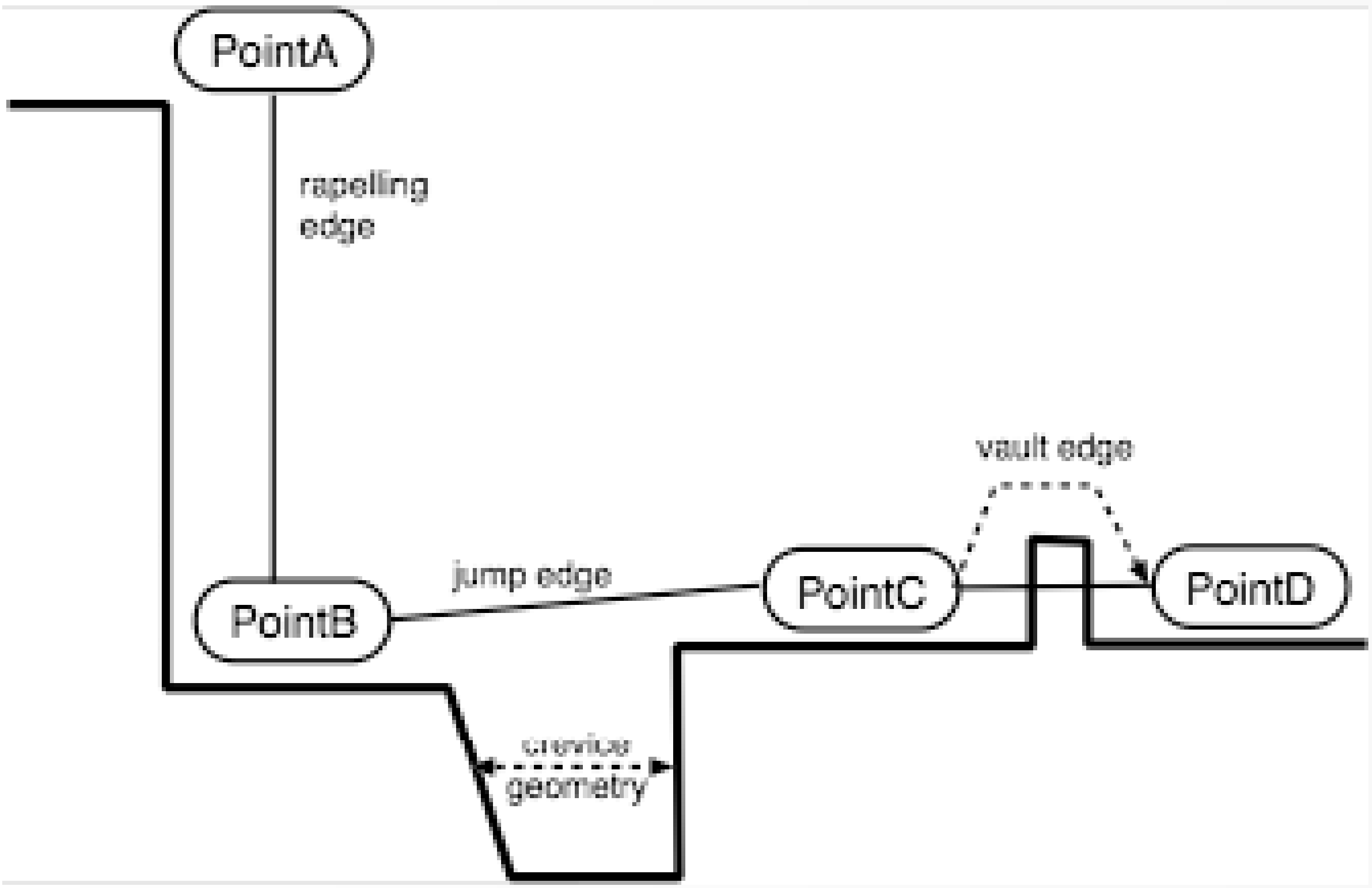
Embedded info can be used in path finding:

- Node graph is an example embedded environment information
- embed in path how to jump over crevices or how to open door (*Soldiers of Fortune 2*)
- illusion of coordination by “reserving” a path





Embedding Animation



Quake III Arena

- Released in 1999 by id Software
- Designed to be a multiplayer only game
- The player battles computer-controlled opponents, or bots
- Bots developed by Jan Paul van Waveren

Quake III Bot AI

- FSM based – Uses a stack for short-term goals
- Use Fuzzy Logic for some decision making
  - Collecting weapons and armor
  - Choosing a weapon for combat
- Fuzzy Relations were selected using Genetic Algorithms
- Each bot has a data file containing weapon preferences and behavior-controlling variables

Bot Network

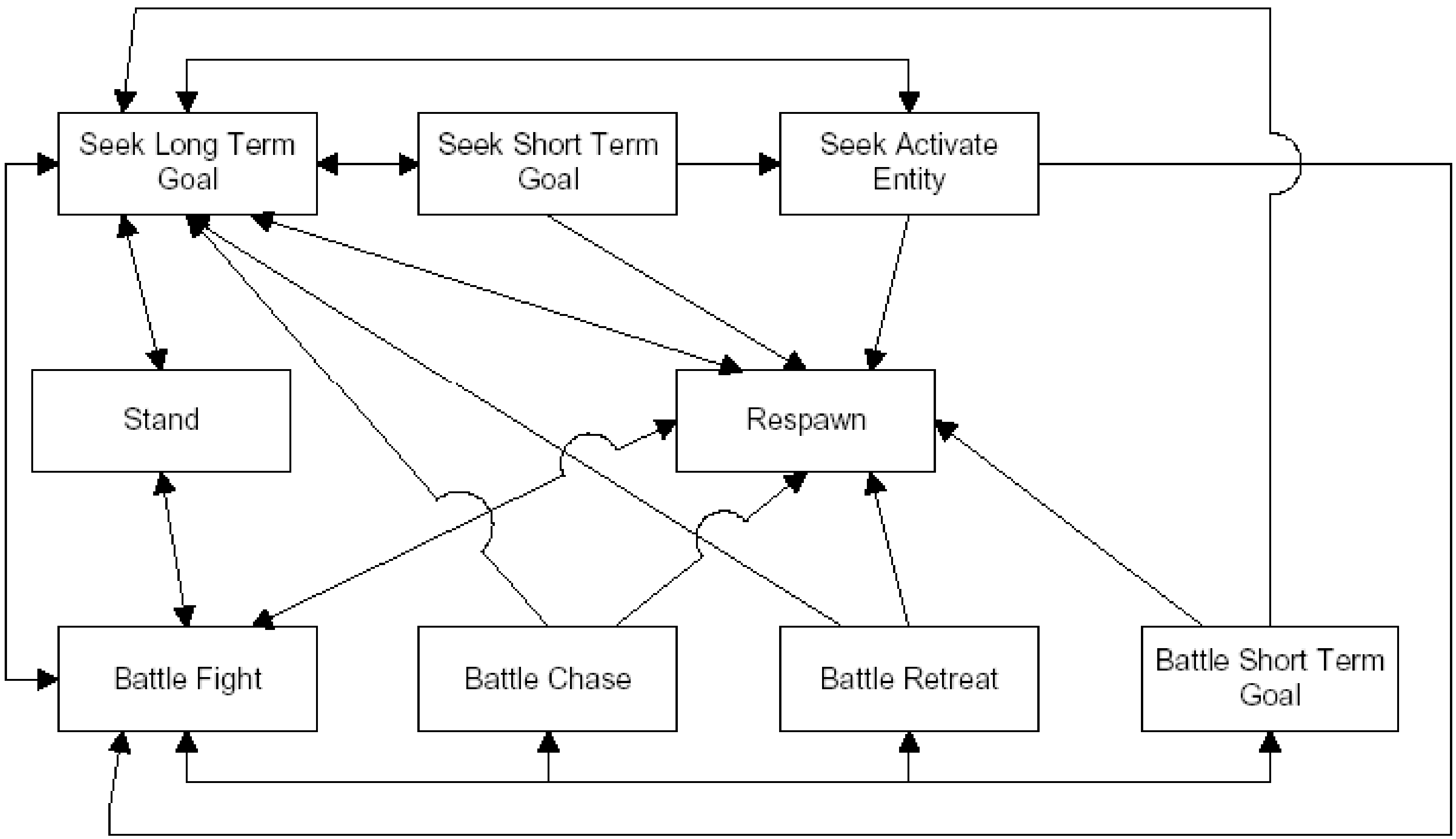


Figure 15.1: AI network.

Quake III Bot Navigation

- AAS (Area Awareness System)
  - Level is subdivided into convex hulls that contain no obstacles
  - Connections between areas are formed

Figure 18.2: jump reachability

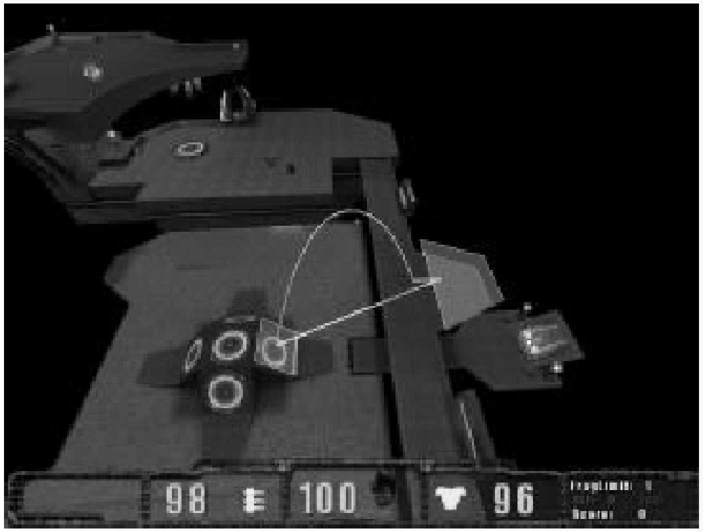


Figure 18.3: jump pad reachability

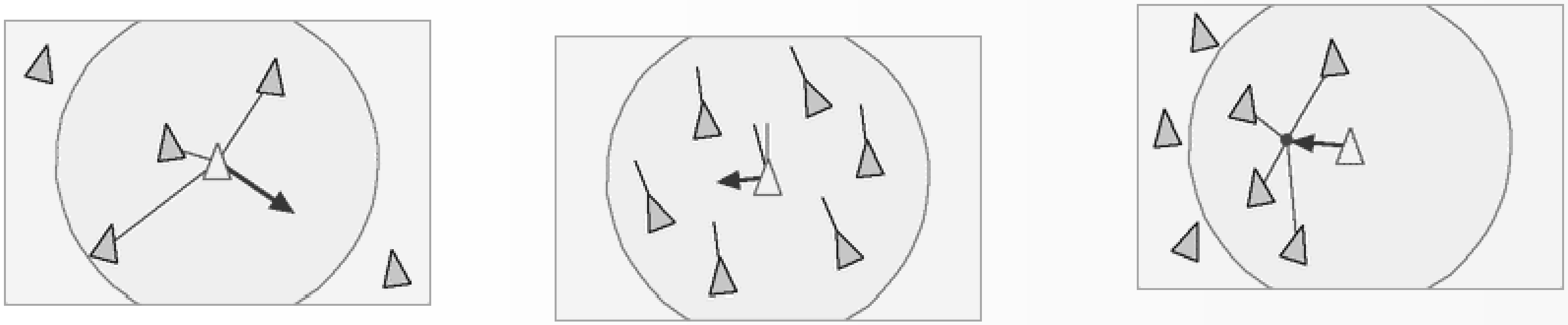
Simple Animate Objects

- Bugs
  - Never fly in a straight line
  - Don’t always flap their wings
  - Attracted toward certain objects
  - Avoid moving objects
  - Affected by wind/breezes
- Solitary birds: Soaring Bird of Prey
  - Flap their wings rarely: glide/soar
  - Move to area to catch thermals
  - Move in circle
  - Dive to get food (either bird or ground animal)
  - Stay away from planes, etc.
- Ground animals
  - Stay in limited area [bounding box]
  - Feed most of the time
    - look for food, Eat food, Bring food to nest, Fight over food
  - Startled/alerted by motion of bigger animal
- Flocks
- Schools of Fish
- Primary and secondary animals

Flocking Things:
What to measure/model

- Nearby entities
- Current path
- Interaction with weather
- Simple model of hunger, thirst…
- *Don’t really need physics – can “embed” physics in behavior*

Flocking

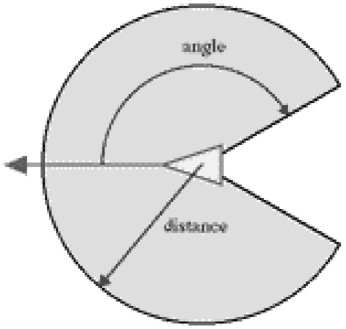


Separation: steer to avoid crowding local flockmates

Alignment: steer towards the average heading of local flockmates

Cohesion: steer to move toward the average position of local flockmates

Avoidance: Steer to avoid running into local obstacles or enemies



a boid's neighborhood

Issues

- Stateless
- Leader can have more influence than others
- Roll, pitch, yaw
- Perceptual range
- Acceleration – change velocity by up to some fixed percent

Schools of fish

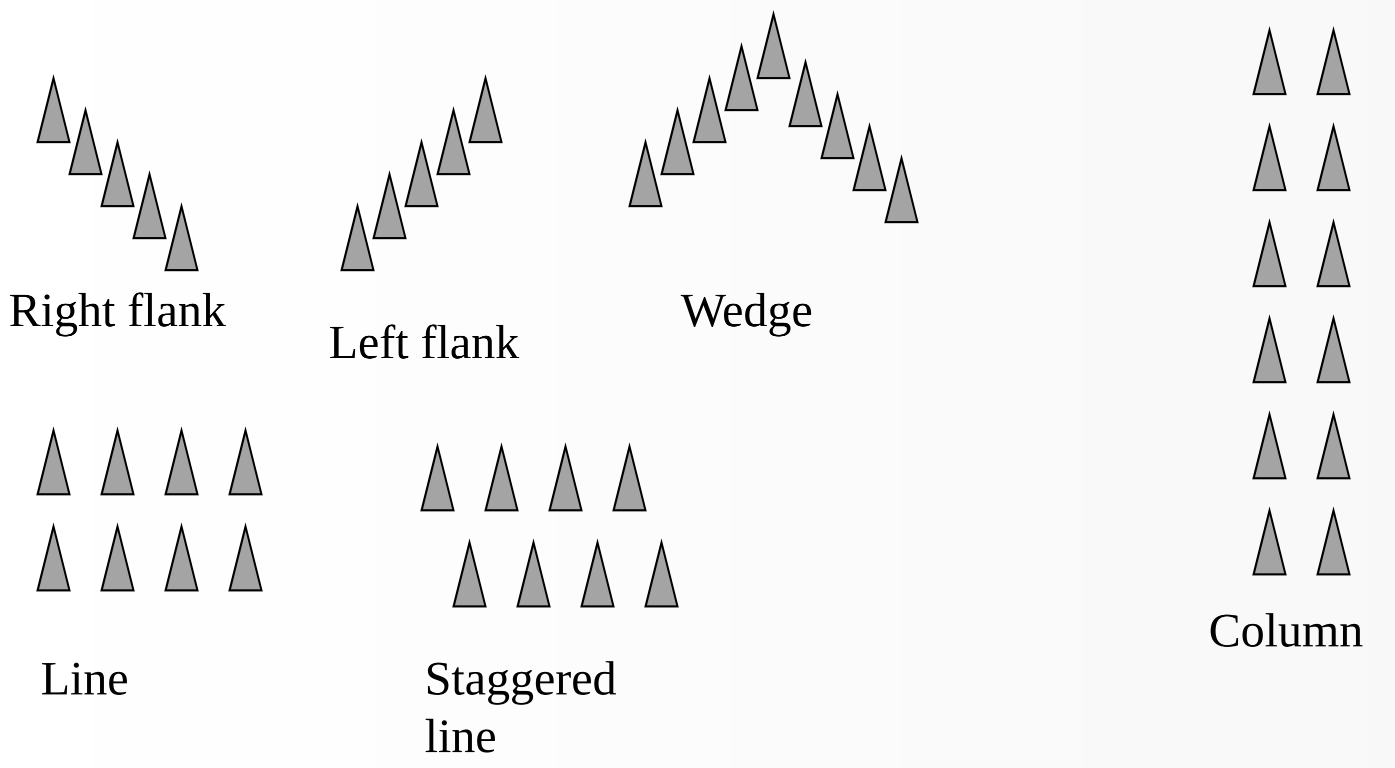
- Sudden change of motion every 2-10 seconds
- Random targets to head toward
- Targets change as they are achieved

Swarms

- Lots of agent
- Flies toward *N* nearest neighbors – don’t avoid collisions
- No alignment, computationally more efficient

Formations

- Organized movements
  - Usually same orientation – but fixed position



Issues

- Movement
- Spacing Distance
- Field of fire
- Protection of range attack
- Different turning radius
- Mixed types

- User control – automatic control

Web sites

- http://www.red3d.com/cwr/boids/ - reynolds boids
- http://www.riversoftavg.com/flocking.htm - flocking
- http://www.riversoftavg.com/formation_flocking.htm - formation