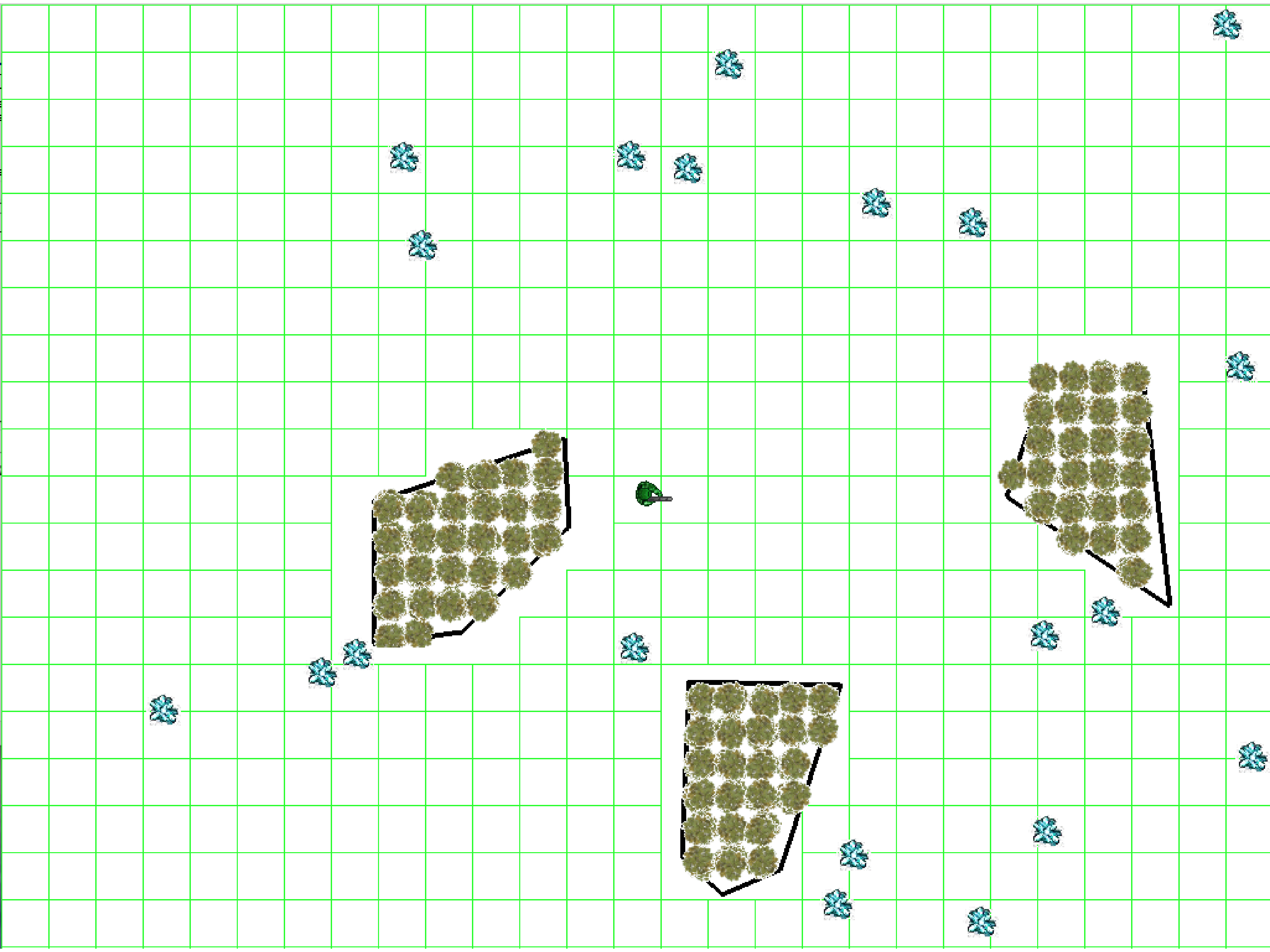
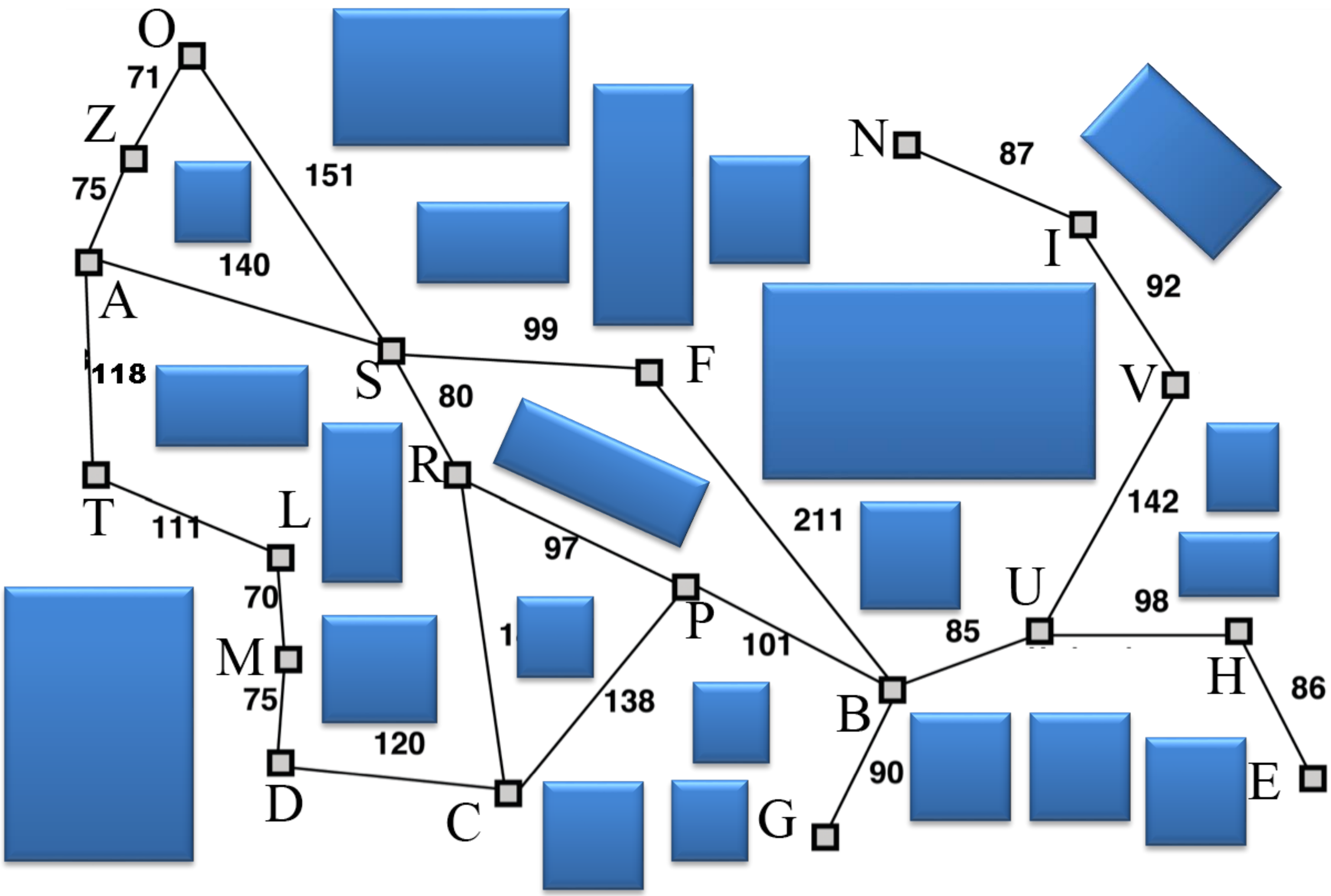
Graphs, Search, Pathfinding

(behavior involving **where** to go)

Steering, Flocking, Formations

(behavior involving **how** to go)

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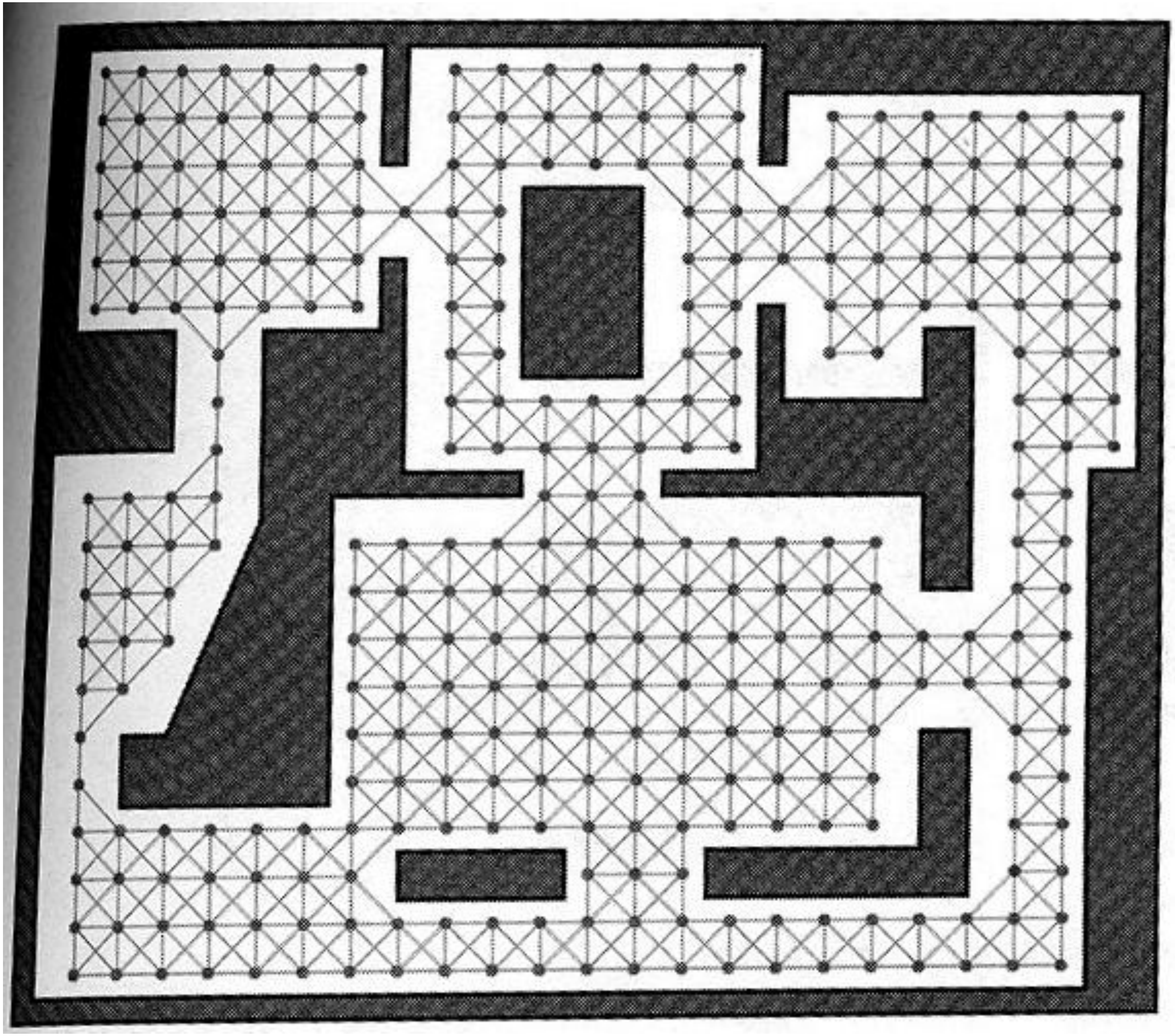

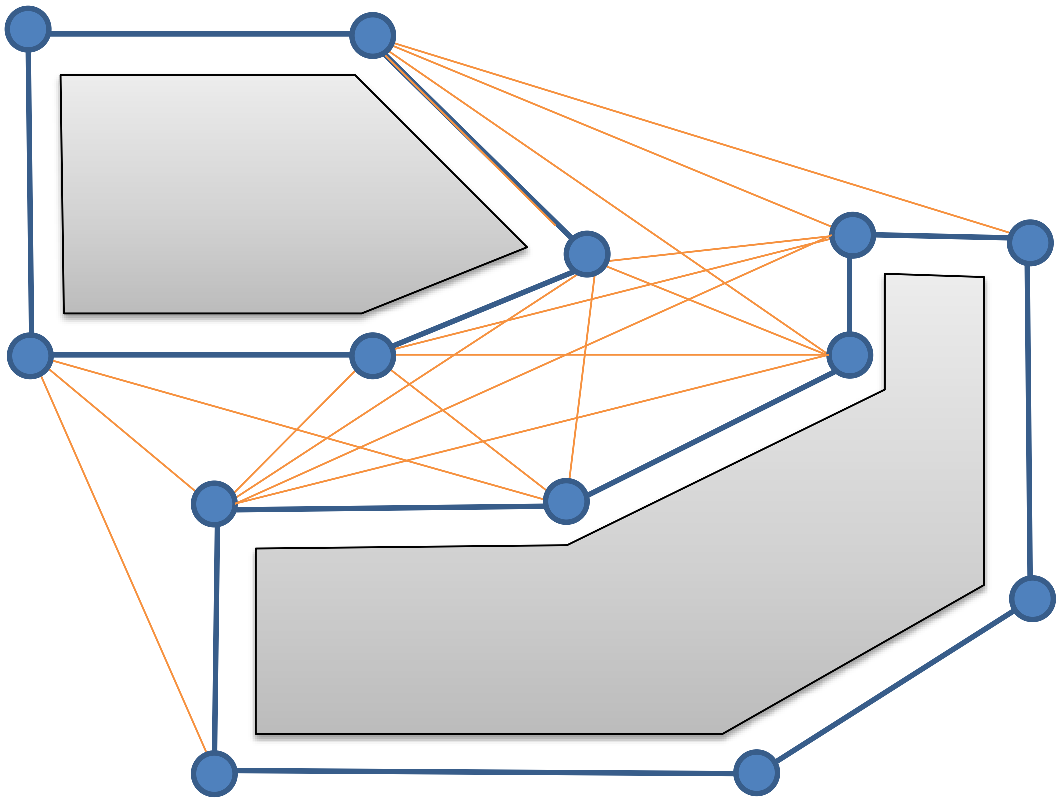

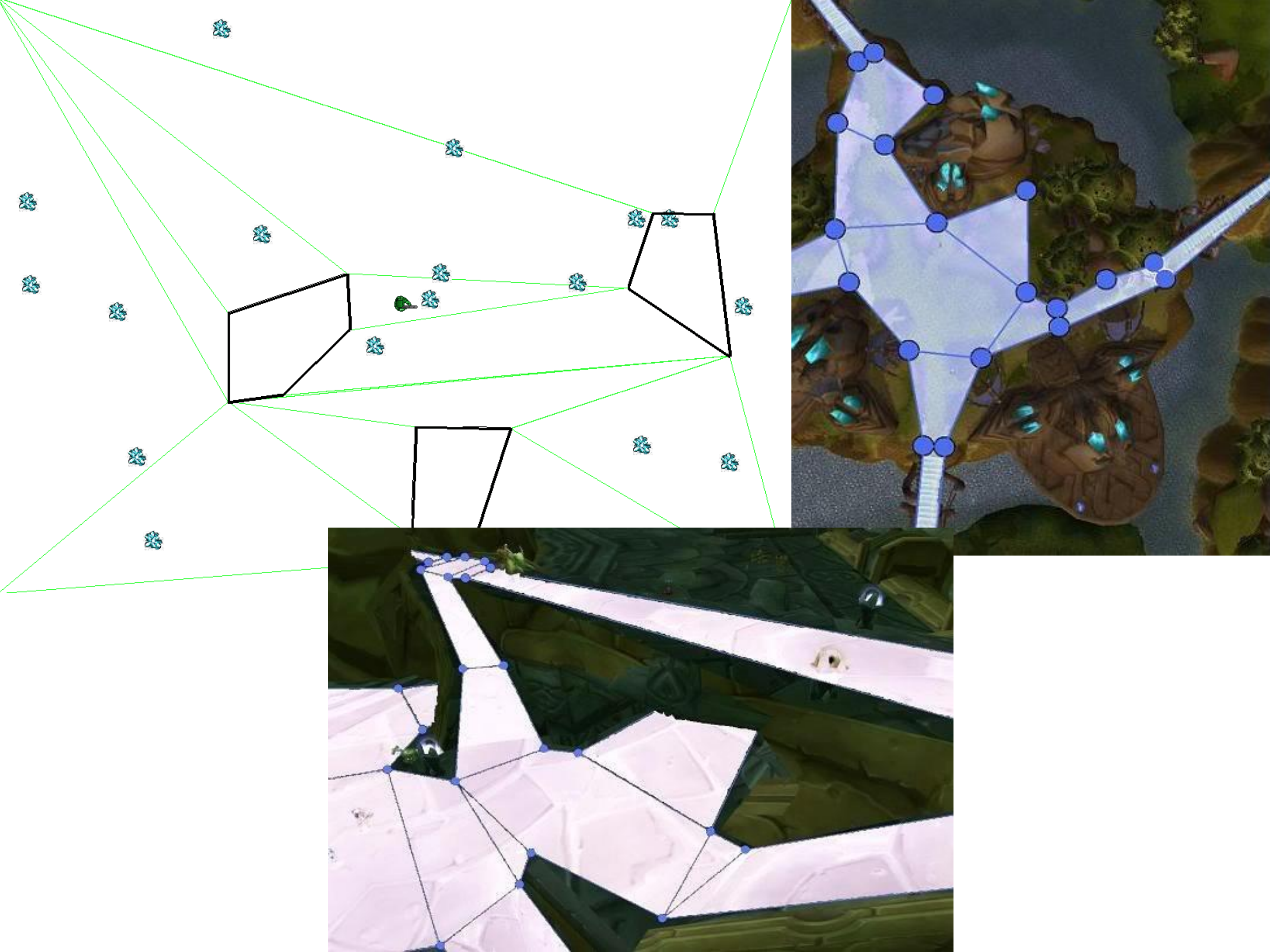

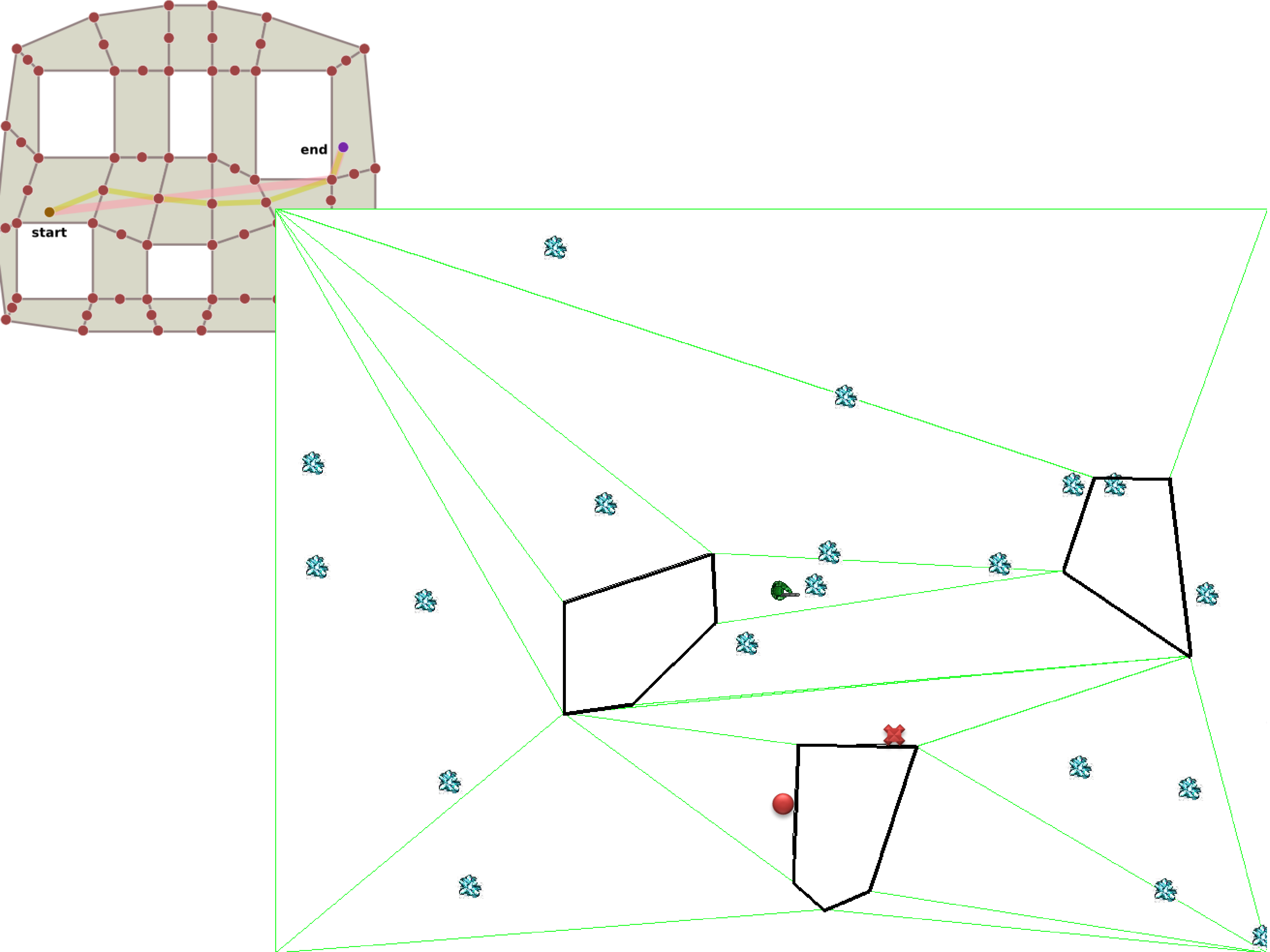
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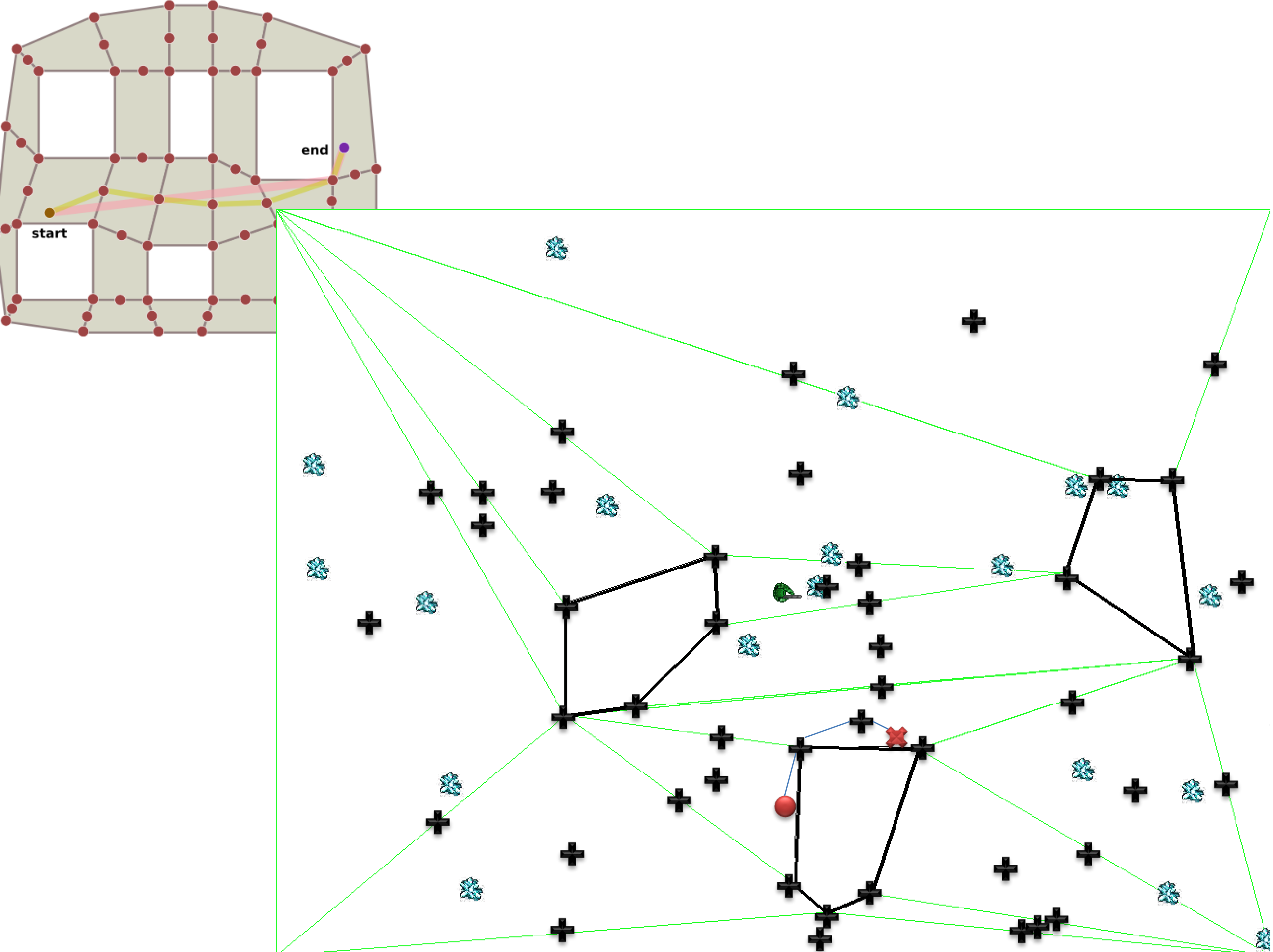

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Class N-2

1. What are some benefits of path networks?
2. Cons of path networks?
3. What is the flood fill algorithm?
4. What is a simple approach to using path navigation nodes?
5. What is a navigation table?
6. How does the expanded geometry model work? Does it work with map gen features?
7. What are the major wins of a Nav Mesh?
8. Would you calculate an optimal nav-mesh?

Class N-1

1. When might you precompute paths?
2. This is a single-source, multi-target shortest path algorithm for arbitrary directed graphs with non-negative weights. Question?
3. This is a all-pairs shortest path algorithm.
4. How can a designer allow static paths in a dynamic environment?
5. When will we typically use heuristic search?
6. What is an admissible heuristic?
7. When/Why might we use hierarchical pathing?
8. Does path smoothing work with hierarchical?
9. How might we combat fog-of-war?

(kinematic) Movement, Steering, Flocking, Formations

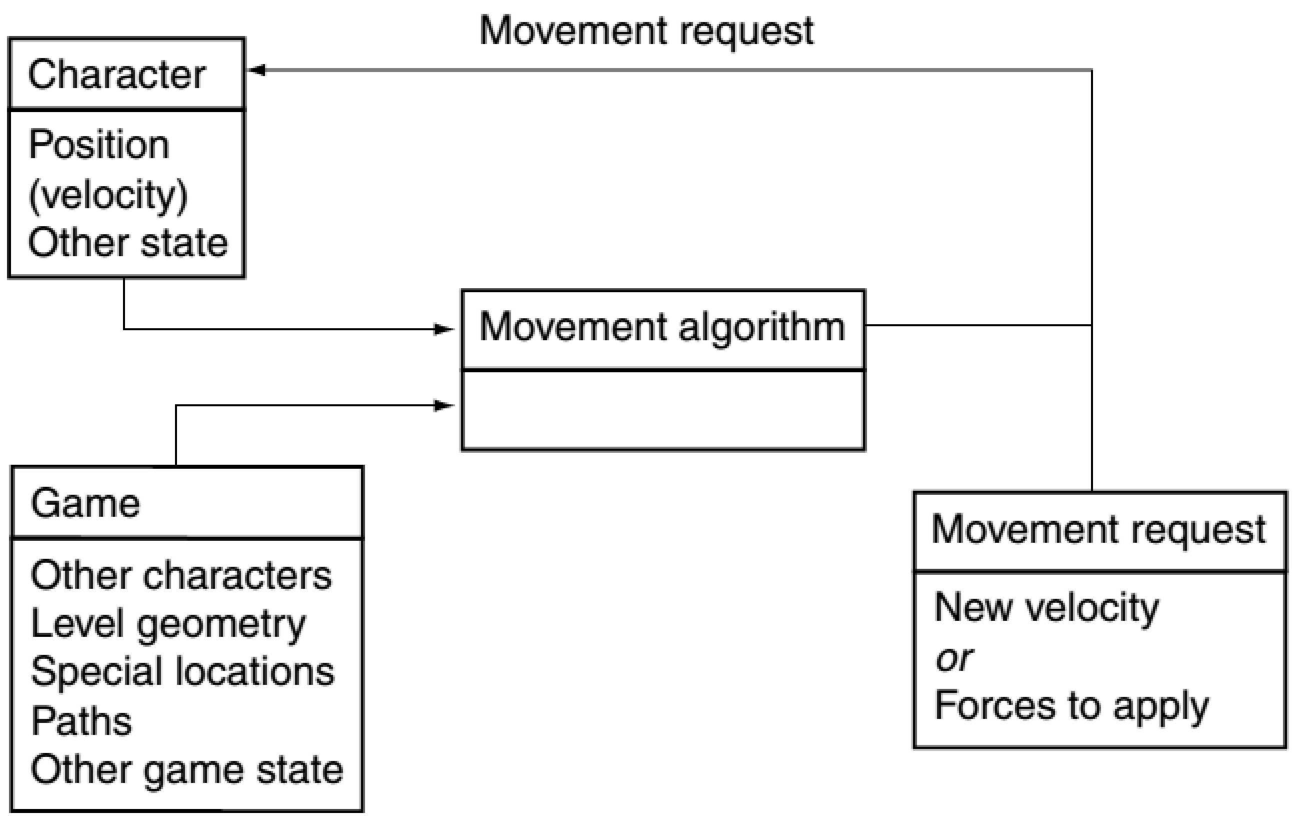
2016-05-31

Basics

- Movement calculation often needs to interact with the "Physics" engine
  - Avoid characters walking through each other or through obstacles
- Traditional: *kinematic movement* (not dynamic)
  - Characters move (often at fixed speed) instantaneously
  - No regard to how physical objects accelerate or brake
  - Output: direction to move in
- Newer approach: *Steering behaviors* or dynamic movement (Craig Reynolds) –
  - Characters accelerate and turn based on physics
  - Take current motion of character into account
  - Output: forces or accelerations that result in velocity change
  - flocking ⊂ steering

http://www.cse.scu.edu/~tschwarz/coen266_09/PPT/Movement%20for%20Gaming.ppt

General Algorithm



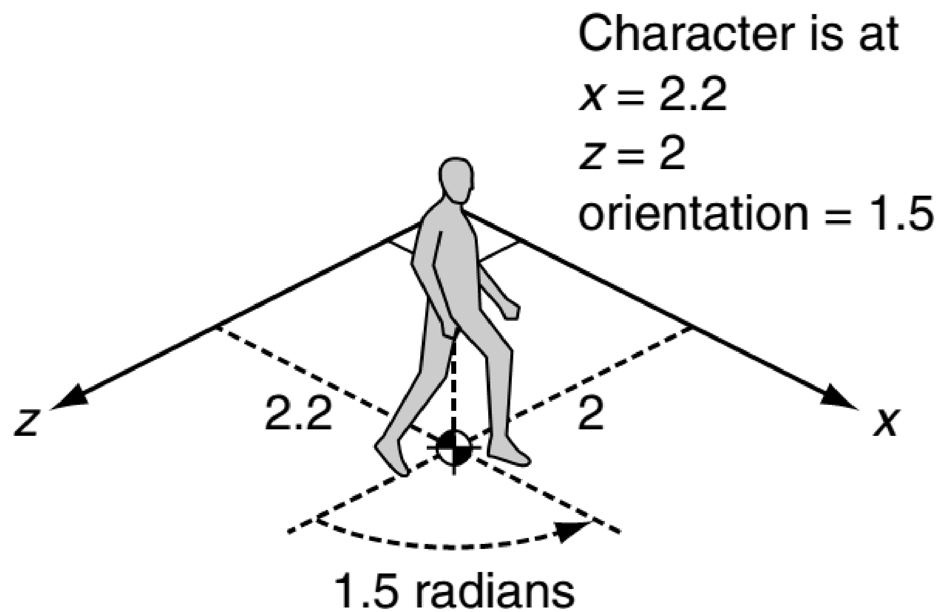
Millington Fig 3.2

Assumptions

- Computed quickly
- Impression of intelligence, not a simulation
- Character position model: point + orientation
- Full 3D usually unnecessary (ie scalar Θ)
  - 2D suffices, thanks to gravity
    - (x, y, Θ) … 3 degrees of freedom
  - 2½ D (3D position, 2D orientation) covers most
    - (x, y, z, Θ) … 4 degrees of freedom
- *Rotation* is the process of changing *orientation*

Space

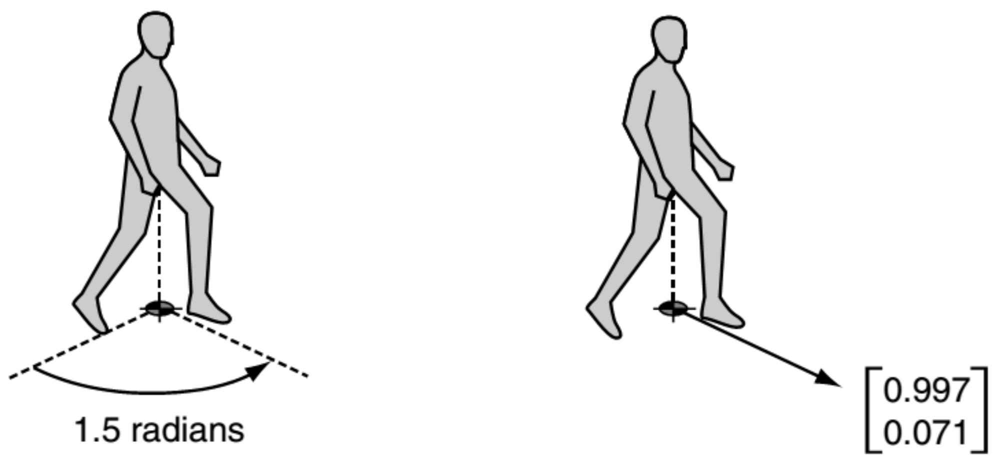
- Axes
- Orientation
- Local vs global coordinate systems



Millington Fig 3.4

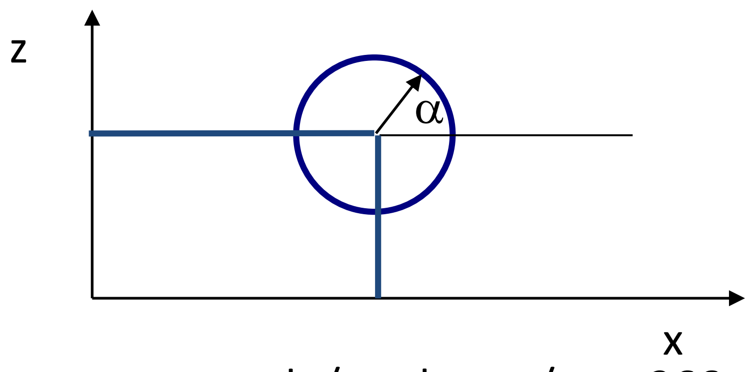
Vector Form of Orientation

- Convenient to represent orientation as unit vector (len = 1)



Millington Fig 3.5

- $\overrightarrow{\omega_v} = [\sin \alpha_s, \cos \alpha_s]$



http://www.cse.scu.edu/~tschwarz/coen266_09/PPT/Movement%20for%20Gaming.ppt

Statics

- Static, because no information about movement
  - Position
    - 2 or 3-dimensional vector
  - Orientation
    - 2-dimensional unit vector given by an angle, a single real value between 0 and 2 π

Kinematics

- We describe a moving character by
  - Position: 2 or 3-D vector
  - Orientation
    - 2-dimensional unit vector given by an angle, a single real value between 0 and 2 π
  - Velocity (linear velocity): 2 or 3-D vector
  - Rotation (angular velocity)
    - 2-dimensional unit vector given by an angle, a single real value between 0 and 2 π
- Movement behaviors output
  - Velocity
  - Rotation

Time & Variable Frame Rates

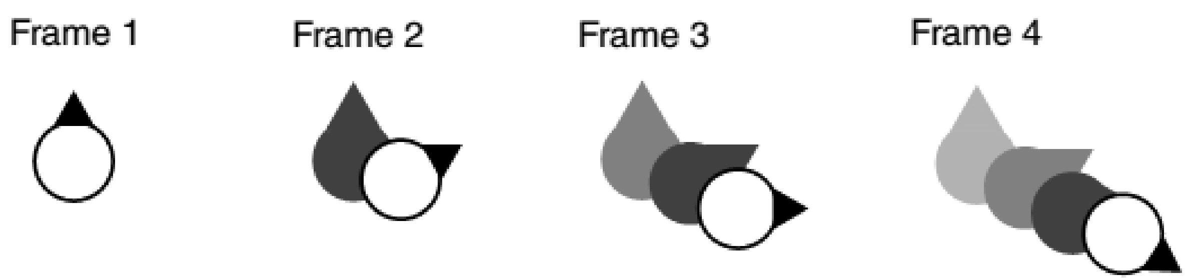
- Velocities are given in units per second rather than per frame
- Older games often used per-frame velocity
- Explicit update time supports VFR. E.g:
  - character going 1 m/s
  - Last frame was 20ms duration
  - Next frame, character moves 20 mm

Kinematics

- Computing a new target velocity based on {x,z} + ϕ can look unrealistic
  - Can lead to abrupt changes of velocity
  - Must smooth velocity, or use acceleration model
- {x,z} + ϕ + *v* → can increment velocity by some Δ from $curr_v$ up to $target_v$
- Must track velocity in all dimensions plus rotation

Facing

- Motion & facing need not be coupled
- Many games simplify & force character orientation to be in direction of the velocity
  - Instant (can be awkward)
  - Smoothing



Millington Fig 3.6

Changing Orientation

- Uses static data (position & Θ, no velocity)
- Outputs desired velocity
  - On/off in target direction
  - Smoothing may be done (without *a*)
- New *v* determines new Θ
  - If v > 0, return atan2(-static.x, static.z)
  - Else use current orientation

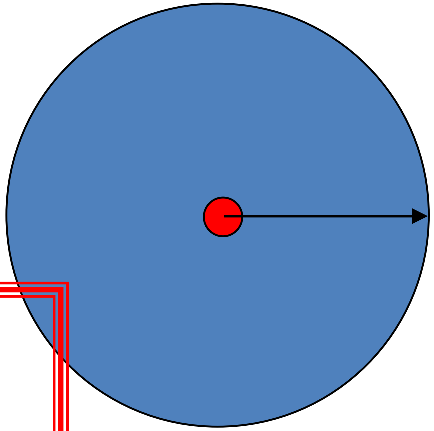
Kinematic Seek

- Input: character's & target's static data
- Output: velocity in direction from *char* to *targ*
  - velocity = target.position – character.position
- Normalize velocity to maximum velocity
- Can ignore orientation, or update (prev slide)
- Flee = character.position – target.position
- O(1) in time and memory

Kinematic Arrival

- Seek with full velocity leads to overshooting
  - Arrival modification
    - Determine arrival target radius
    - Lower velocity within target for arrival

```
steering.velocity = target.position - character.position;
if(steering.velocity.length() < radius)    {
  steering.velocity /= timeToTarget;
  if(steering.velocity.length() > MAXIMUMSPEED)
    steering.velocity /= steering.velocity.length();
}
else
 steering.velocity /= steering.velocity.length();
```



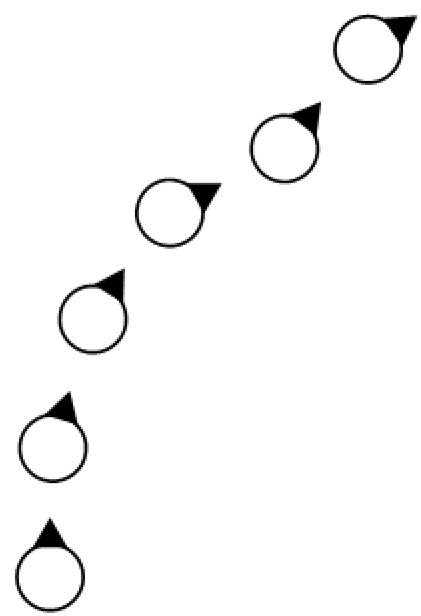
Arrival Circle:

Slow down if you get here

http://www.cse.scu.edu/~tschwarz/coen266_09/PPT/Movement%20for%20Gaming.ppt

Kinematic Wander

- Move in current direction at max speed
- Vary orientation by some random amount each frame



Millington Fig 3.7

See also

- M website: www.ai4g.com
  - Algorithms for K {wander, arrive, seek, flee}
  - https://github.com/idmillington/aicore
- B Ch 3 (B Ch 1)
- Animations (for simple)
  - http://www.red3d.com/cwr/steer/
- http://en.wikipedia.org/wiki/Radian

Steering Behaviors (Dynamic)

- Steering extends kinematic movement by **adding acceleration and rotation**
  - Remember:
    - $\mathbf{p}(t)$ – position at time t
    - $\mathbf{v}(t) = \mathbf{p}'(t)$ – velocity at time t
    - $\mathbf{a}(t) = \mathbf{v}'(t)$ – acceleration at time t
  - Hence:
    - $\Delta\mathbf{p} \approx \mathbf{v}$
    - $\Delta\mathbf{v} \approx \mathbf{a}$
- Steering behaviors output accelerations
  - Linear acceleration: 2 or 3-D vector
  - Angular acceleration: single float value

Kinematic Updates

- def update(steering, time)
  - Assume frame rate is high enough
  - Steering is given as
    - Steering.Linear – a 2D vector
      - Represents changes in velocity (linear acceleration)
    - Steering.Angular – a real value
      - Represents changes in orientation (angular acceleration)
  - Update at each frame (Newton-Euler-1)
    - Position += Velocity * Time
    - Orientation += Rotation * Time
    - Velocity += Steering.Linear * Time
    - Rotation += Steering.Angular * Time

Dynamic Movement

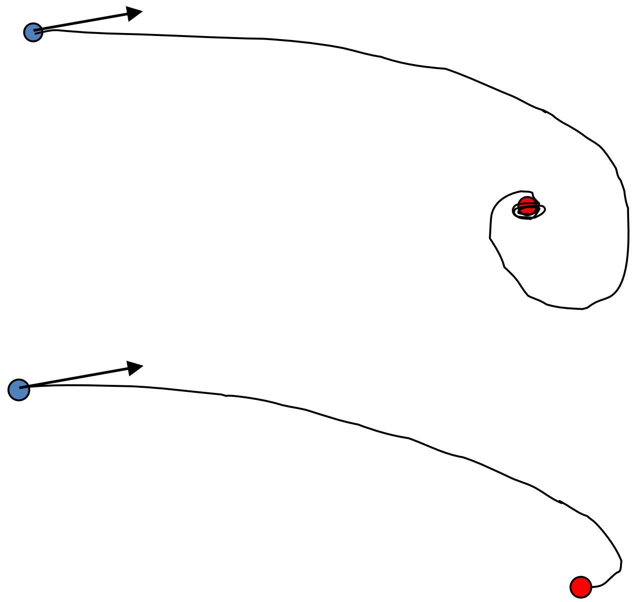
- Dynamic movement update
  - Accelerate in direction of target until maximum velocity is reached
  - If target is close, lower velocity (Braking)
    - Negative acceleration is also limited
  - If target is very close, stop moving
- Dynamic movement update with Physics engine
  - Acceleration is achieved by a force
  - Vehicles etc. suffer drag, a force opposite to velocity that increases with the size of velocity
    - Limits velocity naturally

Steering Input Basics

- Input: agent kinematic and target info
  - Target collision info
  - Target trajectory
  - Target location
  - Average flock information
- Steering behavior doesn’t attempt to do much
  - Each alg. Does a single thing. Fundamental behaviors
  - Combine simple behaviors to make complex
  - No: avoid obstacles while chasing character and making detours to nearby power-ups

Steering Behaviors

- Variable Matching
  - Seek (flee)
  - Arrive (leave)
  - Align
  - Velocity Matching



- Best way to get a feel: run steering behavior program from source www.ai4g.com
  - https://github.com/idmillington/aicore

Variable Matching

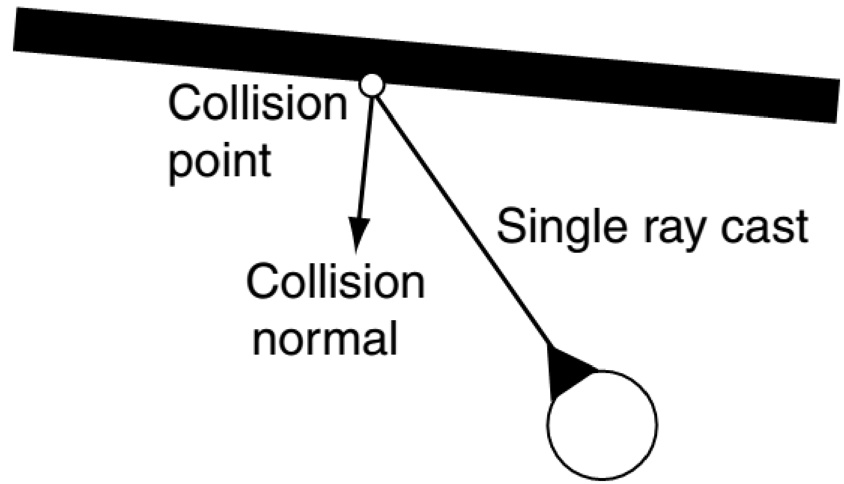
- Simplest family: match one or more elements of source to target
  - Match **position** (seek): accelerate toward target, decelerate once near
  - Match **orientation** (align): rotate to align
  - Match **velocity**: follow on a parallel path, copy movements, stay fixed distance away
- Match position and orientation? Ok
- Match position and velocity? Conflict
- Moral: have individual matching algorithms, and conflict-resolving combination algorithm

Basic Steering Behaviors

- Used as elements of more complex behaviors
  - Pursue = Seek based on target motion (instead of position)
  - Collision avoidance = flee based on obstacle proximity
  - Wander = Seek some fictitious moving object

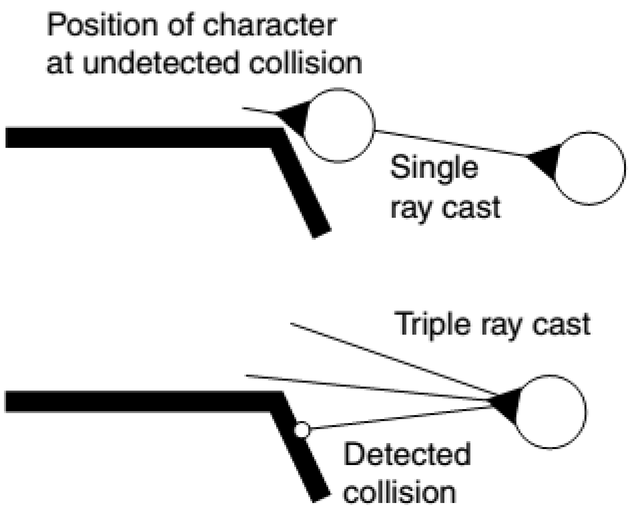
Obstacle and Wall Avoidance

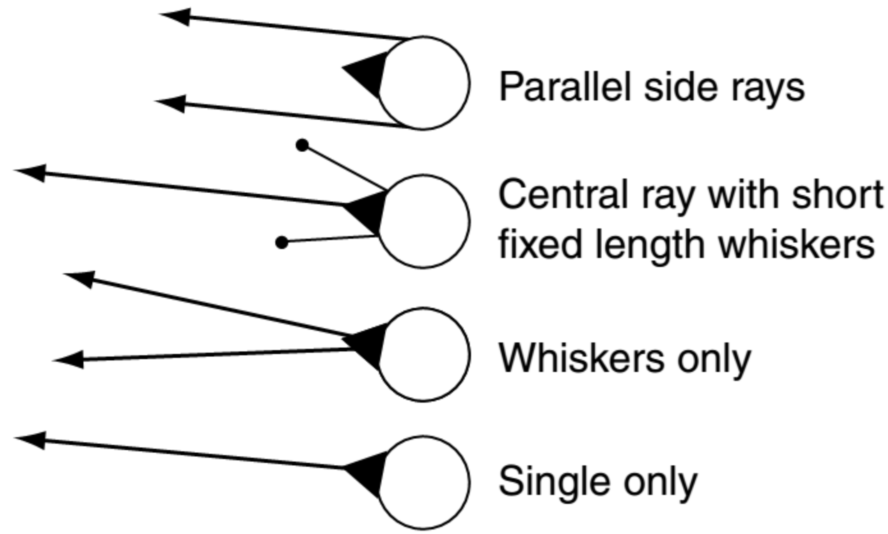
- Cast one or more (distance-bounded) rays out in direction of motion
- Use collisions to create sub-target for avoidance
- Perform basic seek on sub-target



Millington Fig 3.24

One is not enough





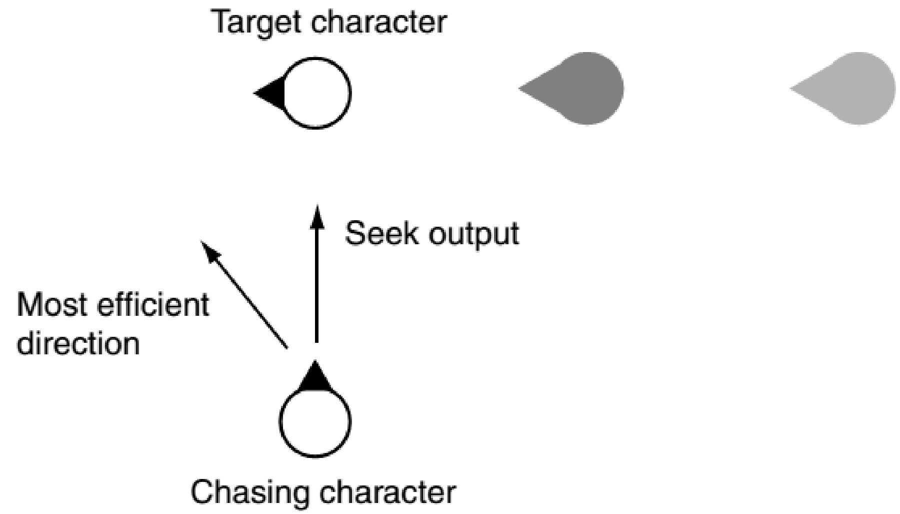
Millington Fig 3.25 & 3.26

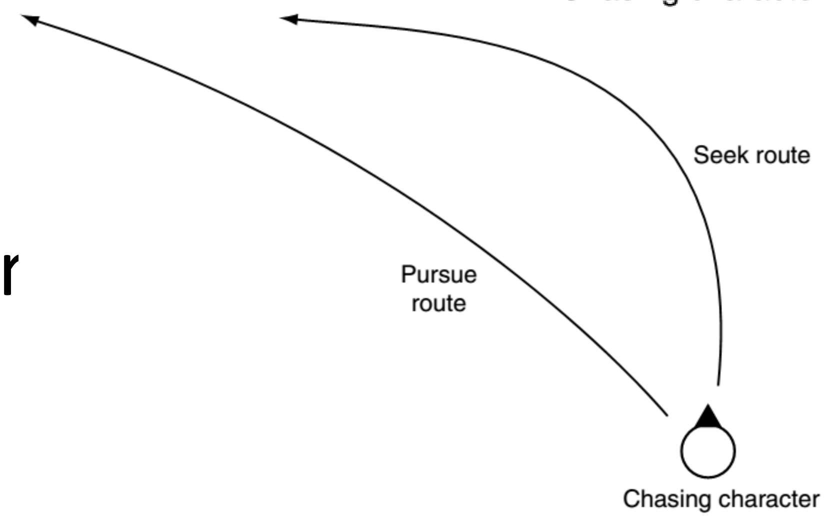
Dynamic Seek

- Match position of character with the target
- Like kinematic seek, find direction to target and go there as fast as possible
  - Kinematic outputs: velocity, rotation
  - Dynamic output: linear and angular acceleration
- Kinematic seek:
  - velocity = target.position – character.position
  - velocity = (velocity.normalize())*maxSpeed
- Dynamic seek:
  - acceleration = target.position – character.position
  - acceleration = (acceleration.normalize())*maxAcceleration

Composite Behaviors

- Pursue = Seek based on target motion (instead of position)
- Evade?
- Face?
- Looking wher going?
- Wander?

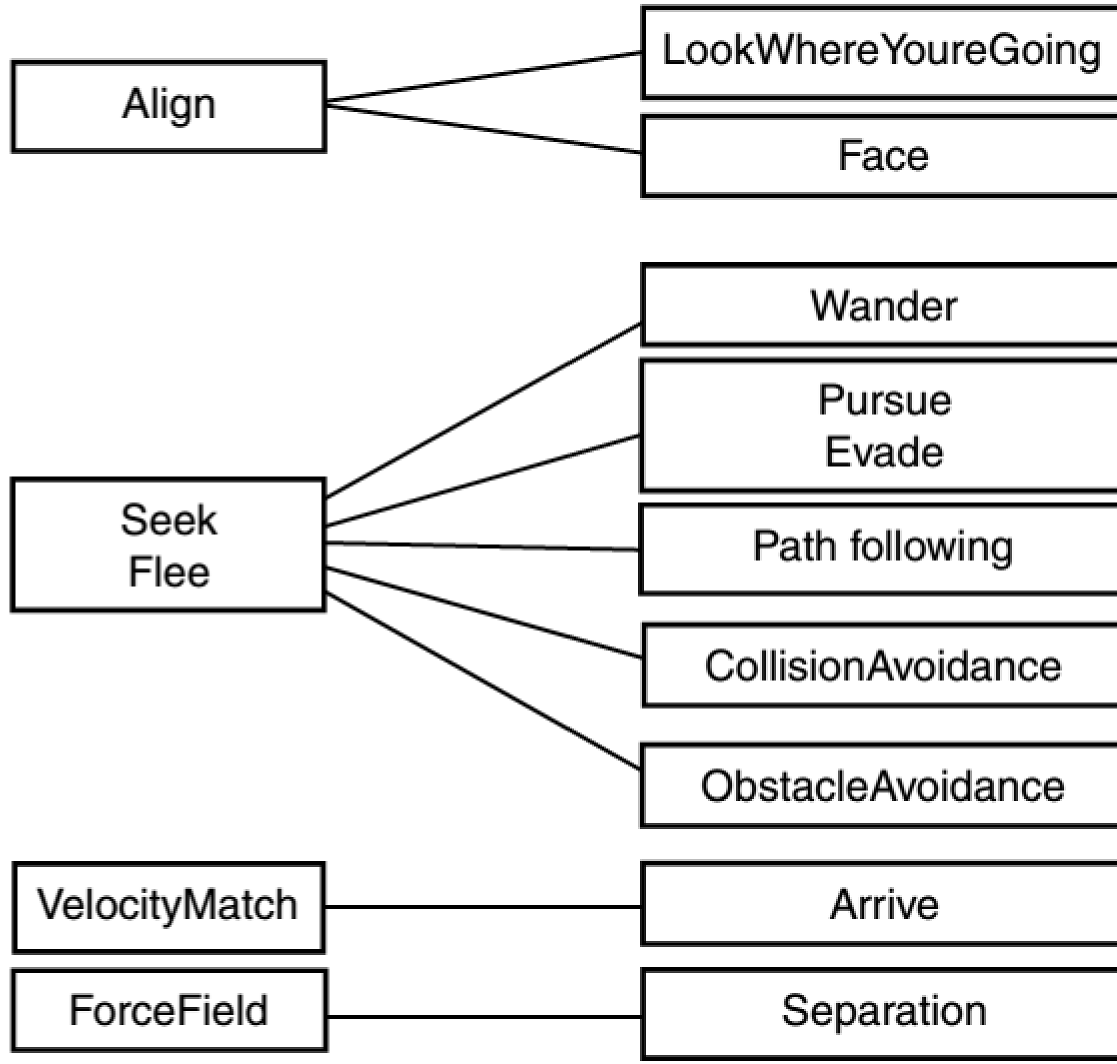




Millington Fig 3.11 & 3.12

Composite Behaviors

- Pursue / Evade
- Face / Look where going
- Wander
- Collision Avoidance
- Obstacle Avoidance
- Separation



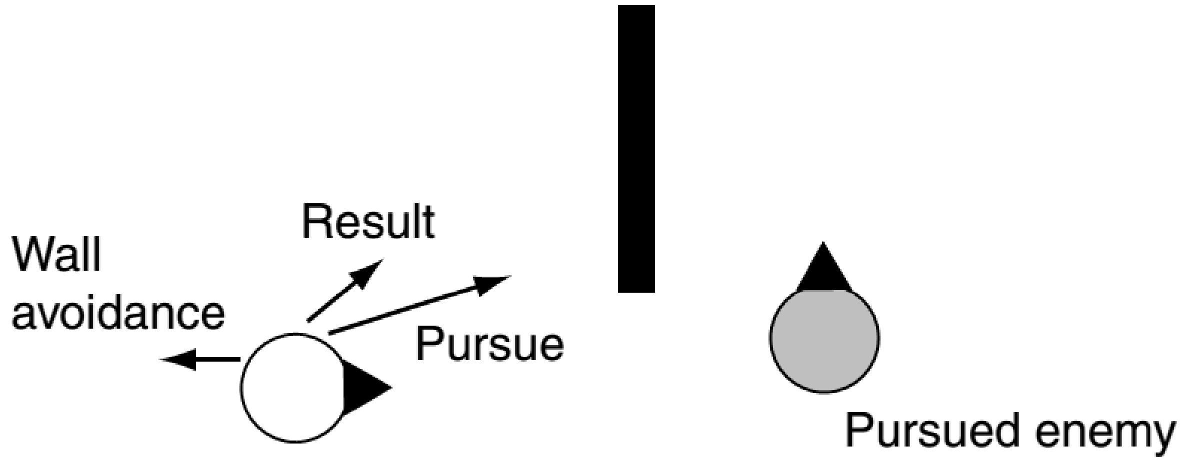
Millington Fig 3.29

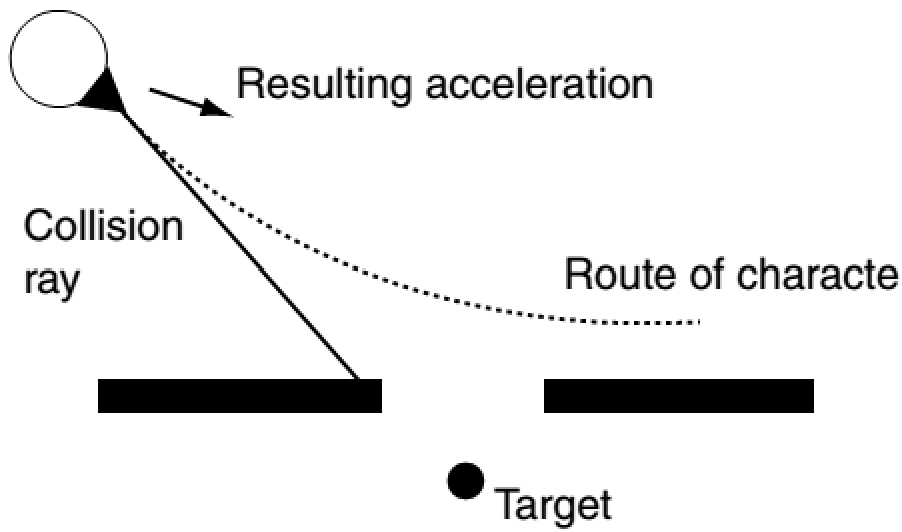
Combining Steering Behavior

- (Weighted) Blending
  - Execute all steering behaviors
  - Combine results by calculating a compromise based on weights
    - Example: Flocking based on separation and cohesion
- Arbitration
  - Selects one proposed steering
- Not mutually exclusive
- Emergent Behavior

Weighted Blending

- Simplest way to combine steering behaviors
- Weighted linear sum of accelerations from all involved steering behaviors
- Post-processing velocity threshold
- E.g. rioting crowd may have 1*sep + 1*cohes
- Finding "right" weight can be challenging
  - Characters can get stuck (equilibrium)
  - Constrained environments (conflicts)
  - Jidder



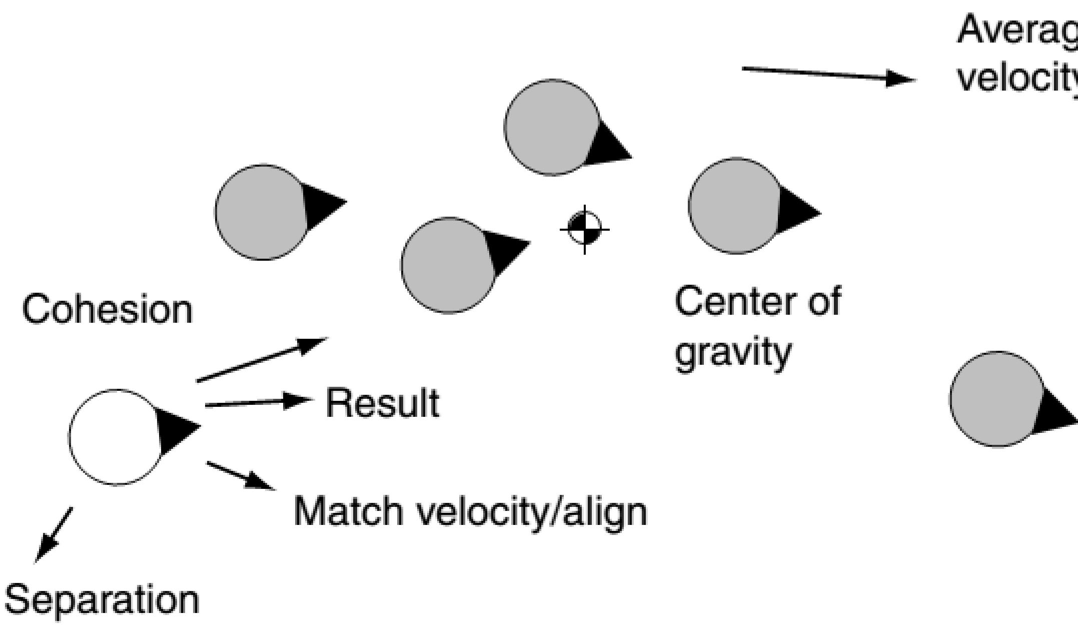


Millington Fig 3.35 & 3.36

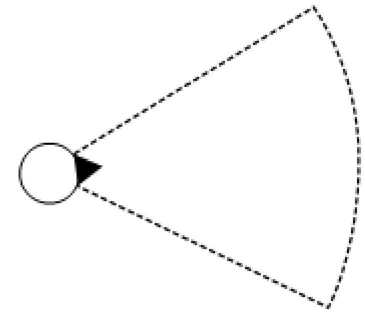
Flocking and Swarming

- Craig Reynold’s “boids” (Flocking != Swarming)
  - Simulated (apparent behavior of) birds, 1986
  - Blends three steering mechanisms (ordered)
    - Separation
      - » Move away from other birds that are too close
    - Cohesion
      - » Move to center of mass of flock
    - Alignment
      - » Match orientation and velocity of flock
  - Equal Weights for simple flocking behavior

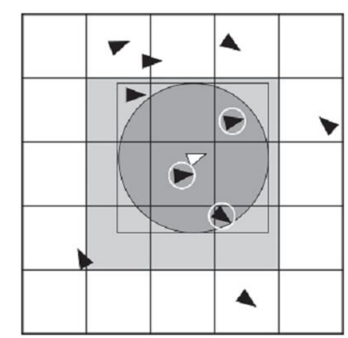
Won’t you be my neighbor



Millington Fig 3.31



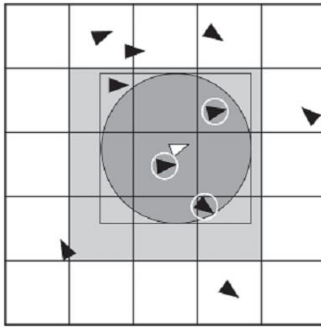
Millington Fig 3.32



Buckland Fig 3.18

Recall findNearestWaypoint()

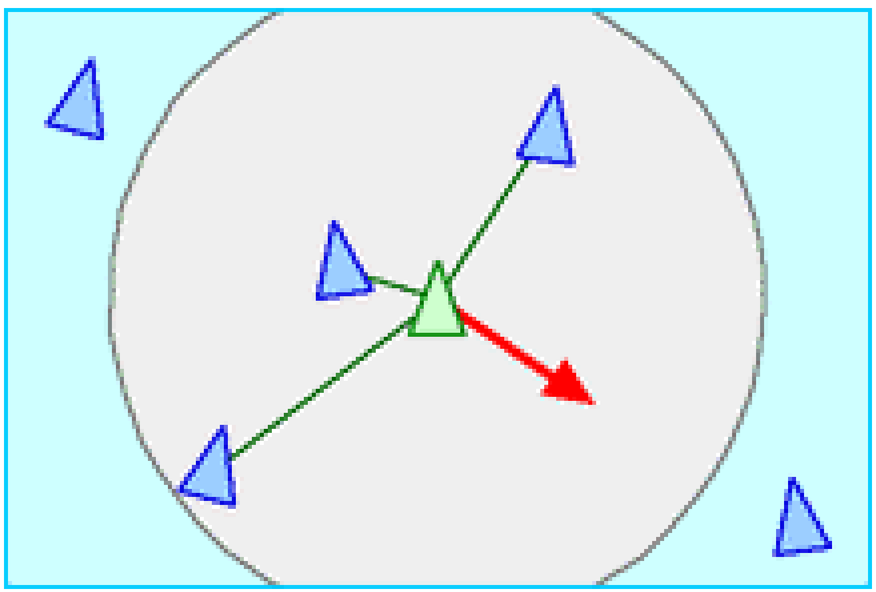
- Most engines provide a rapid "nearest" function for objects
- Spatial partitioning w/ special data structures:
  - Quad-trees (2d), oct-trees (3d), *k*-d trees
  - Binary space partitioning (BSP tree)
  - Multi-resolution maps (hierarchical grids)
- The gain over all-pairs techniques depends on number of agents/objects

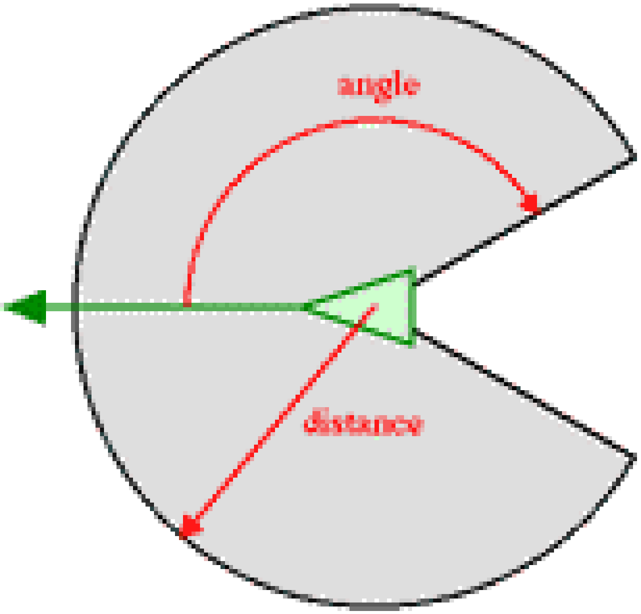


Buckland Fig 3.18

Separation

- Steer to avoid crowding local flockmates
  - Neighborhood is a sphere of certain radius, or possibly a cone of perception

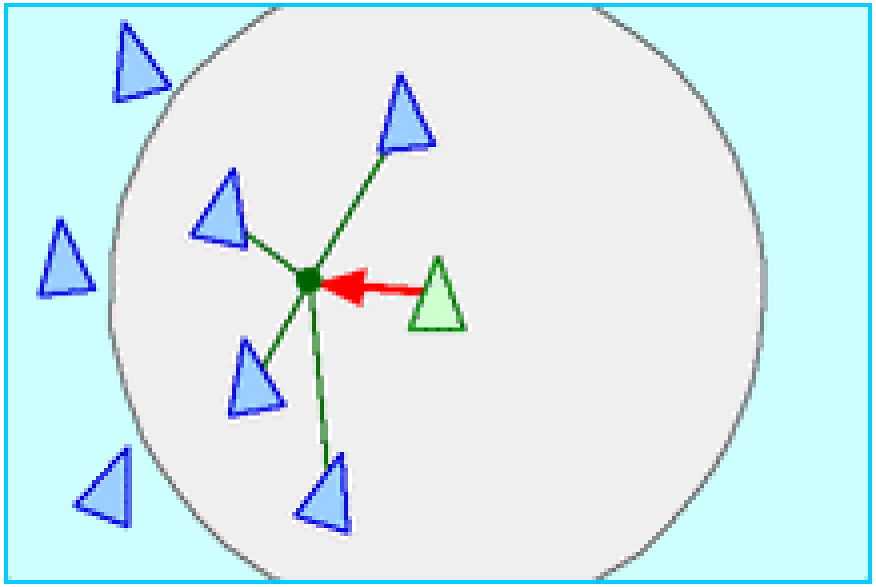




http://www.red3d.com/cwr/boids/

Cohesion

- Steer to average **position** of local flockmates

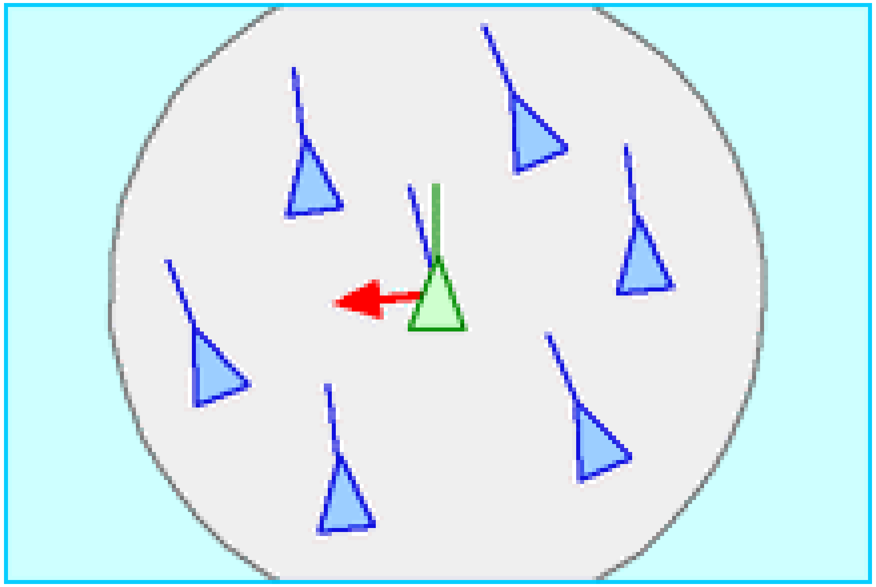


* Center of mass is the average position (X,Y,Z) of boids in neighborhood.

http://www.red3d.com/cwr/boids/

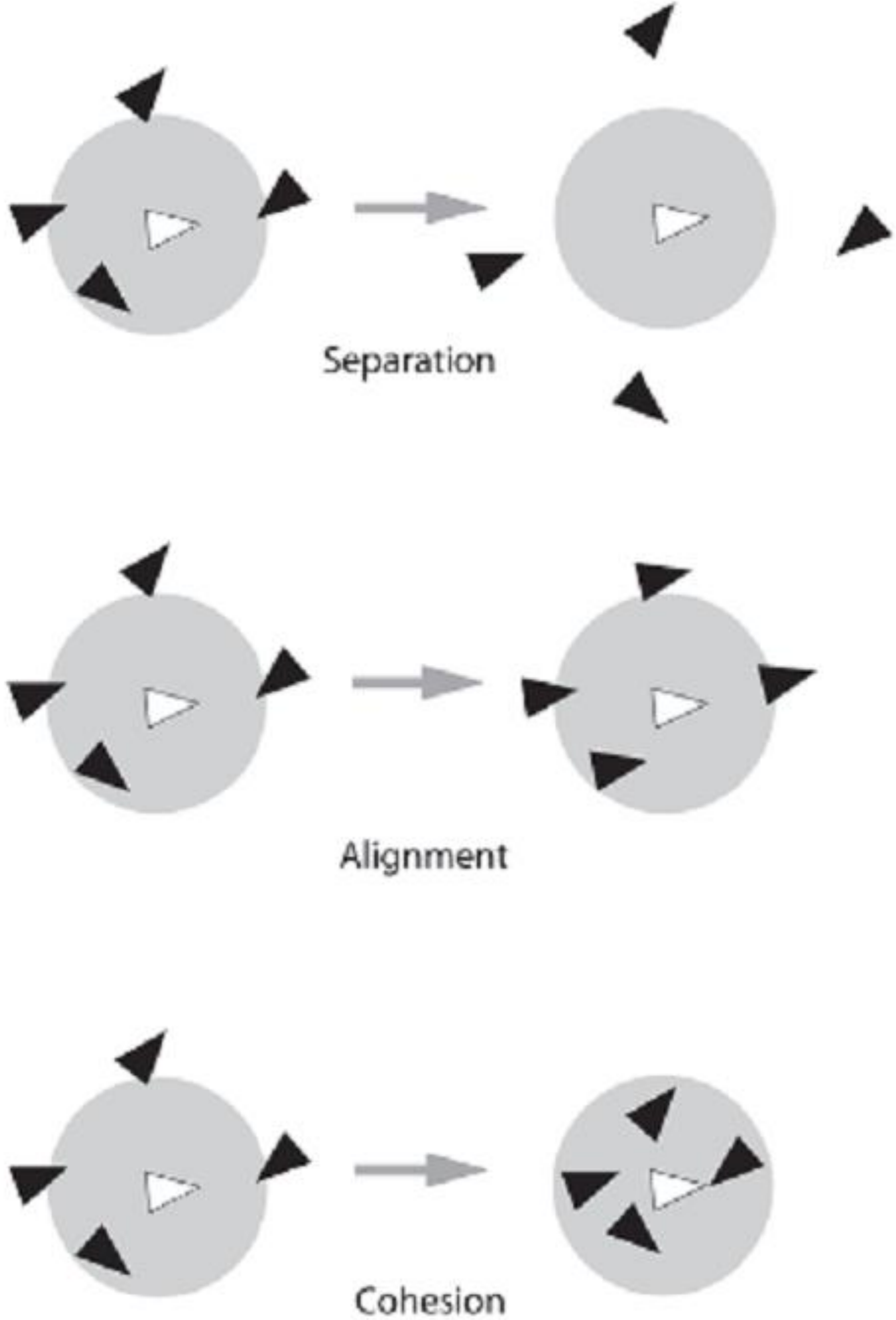
Alignment

- Steer towards average **heading**



* Average heading and velocity of other boids in neighborhood

http://www.red3d.com/cwr/boids/



Buckland Fig 3.16

Flocking Demos

- http://www.red3d.com/cwr/boids/
- http://www.red3d.com/cwr/boids/applet/

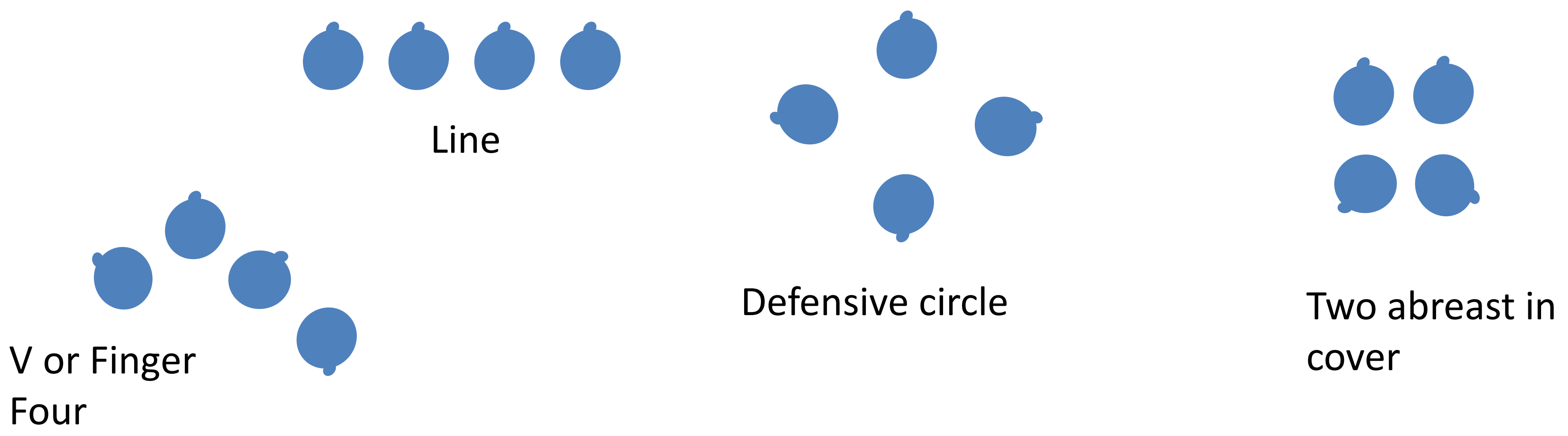
See Also

- M Ch 3, B Ch 3 (& Ch 1)
- Source from Millington
  - https://github.com/idmillington/aicore
- Java-based animations (combined behaviors)
  - http://www.red3d.com/cwr/steer/
- http://www.cse.scu.edu/~tschwarz/coen266_09/PPT/Movement%20for%20Gaming.ppt

Formations

- Coordinated Movement: M Ch 3.7
- Path plan for leader (naive)
  - All others move toward leader
- Replace team with a virtual bot
  - All members controlled by a joint animation
- Path plan for leader (alt)
  - All team members path plan to an offset
  - Flow around obstacles and through choke points

Fixed Formations



Entities of different sizes

- Large entities can be surrounded by smaller entities and collision boxes can parallelize large entities
- Path plan without regard
- Send messages for smaller entities to move out of the way

Next Class

- Finite state machines
- Read: Buckland, CH 2 (M Ch 5.1-4)