Artificial Intelligence and Multi Agent Systems DD2438

Lecture 3

Module 2

If your partner is slacking, let me know!

Module 2 (4 weeks, 100h of work)

w7 Tue 2023-02-14 13:00 - 15:00 in W25

w8 Tue 2023-02-21 13:00 - 15:00 in U31

w9 Tue 2023-02-28 13:00 - 15:00 in U41

w10 Exam week

w11 Exam week

w12 Mon 2023-03-20 13:00 - 15:00 in U21

At least one problem solved (from 1-5)

At least two problems solved one from 1-3 one from 4-5

Draft of Related work section submitted

Note: Monday (plan accordingly)
(you have 5 weeks)
(deadline on Friday, but Sunday is ok)

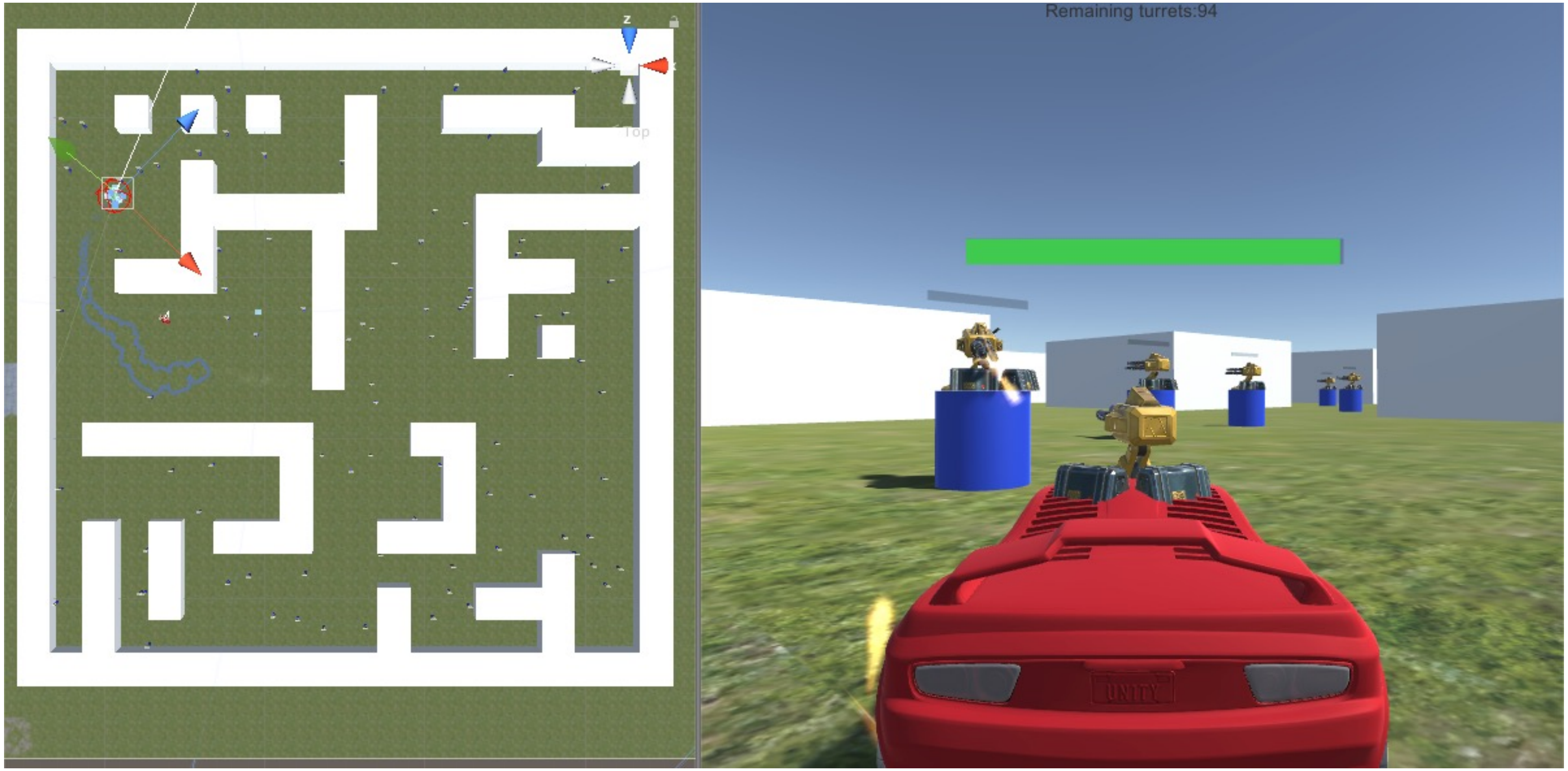
Initial Note:

- These slides are meant to give you **a rough idea** of how the different algorithms work
- You are **not** expected to be able to solve the assignment by just reading the slides
- You are expected to
  - Search for information
  - Combine and modify ideas
  - Do problem solving
  - Discuss at meetings

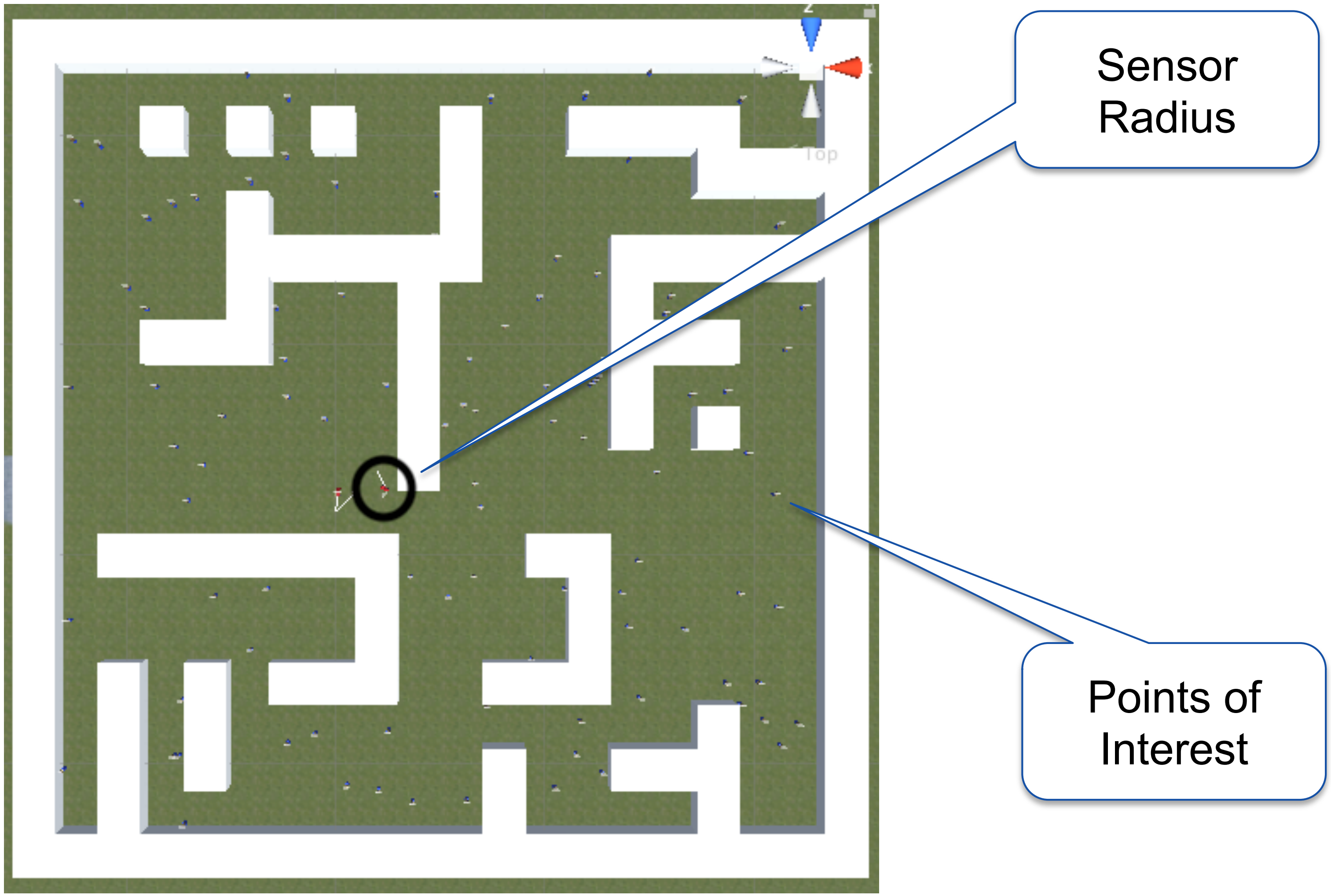
The Problems of Assignment 2

- P1: Short range search
  - Vacuum Cleaner planning
  - UAV search planning
- P2: Long range search
  - Security robot search (indoor UGV)
- P3: Vehicle Routing Problem (VRP)
  - Bread delivery robot
- P4: Formation sweep
- P5: Shooter Coordination

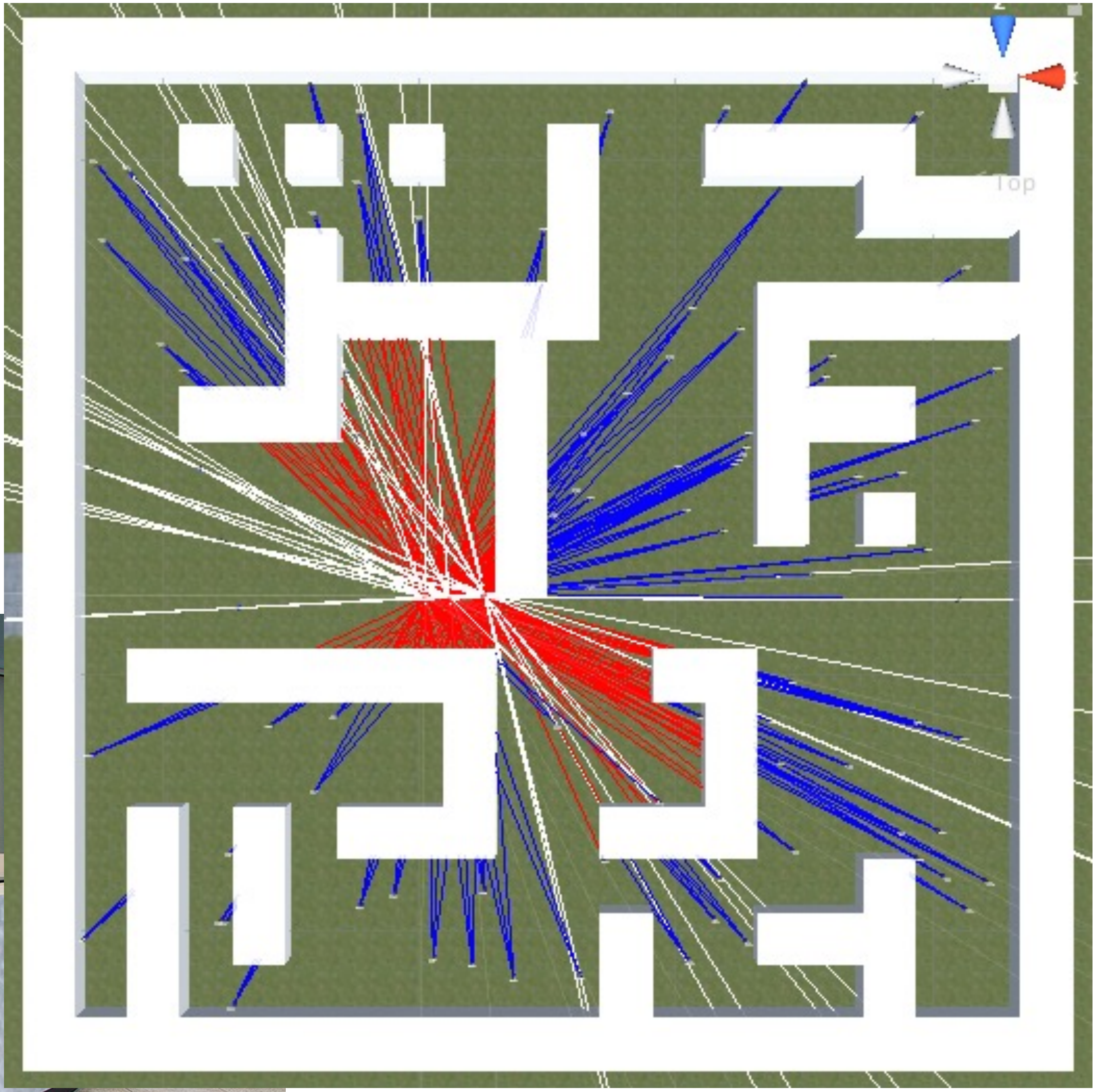
Common simulation objects: Cars and Turrets



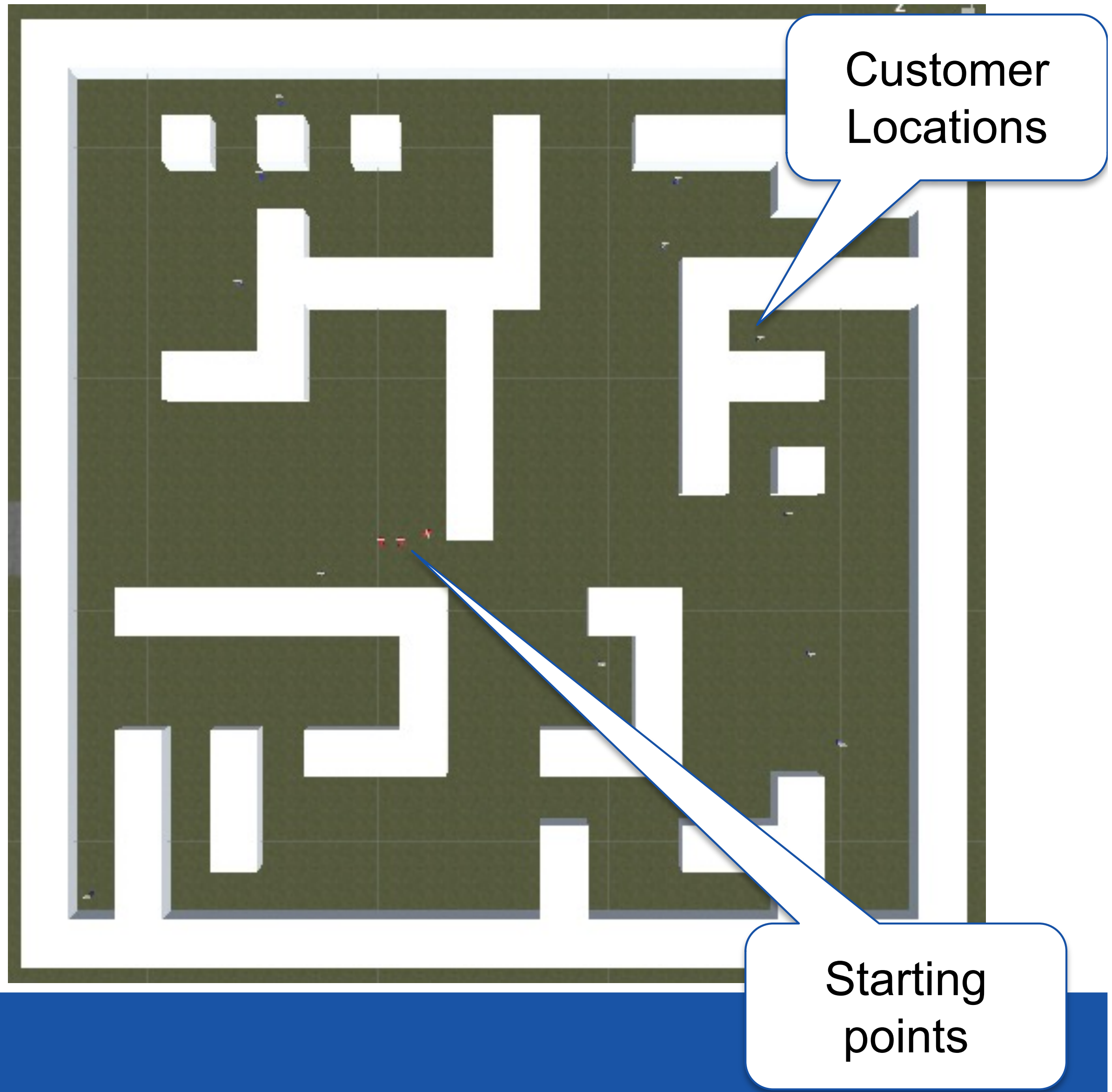
Problem 1: Short range search (vacuuming)



Problem 2: Long range search

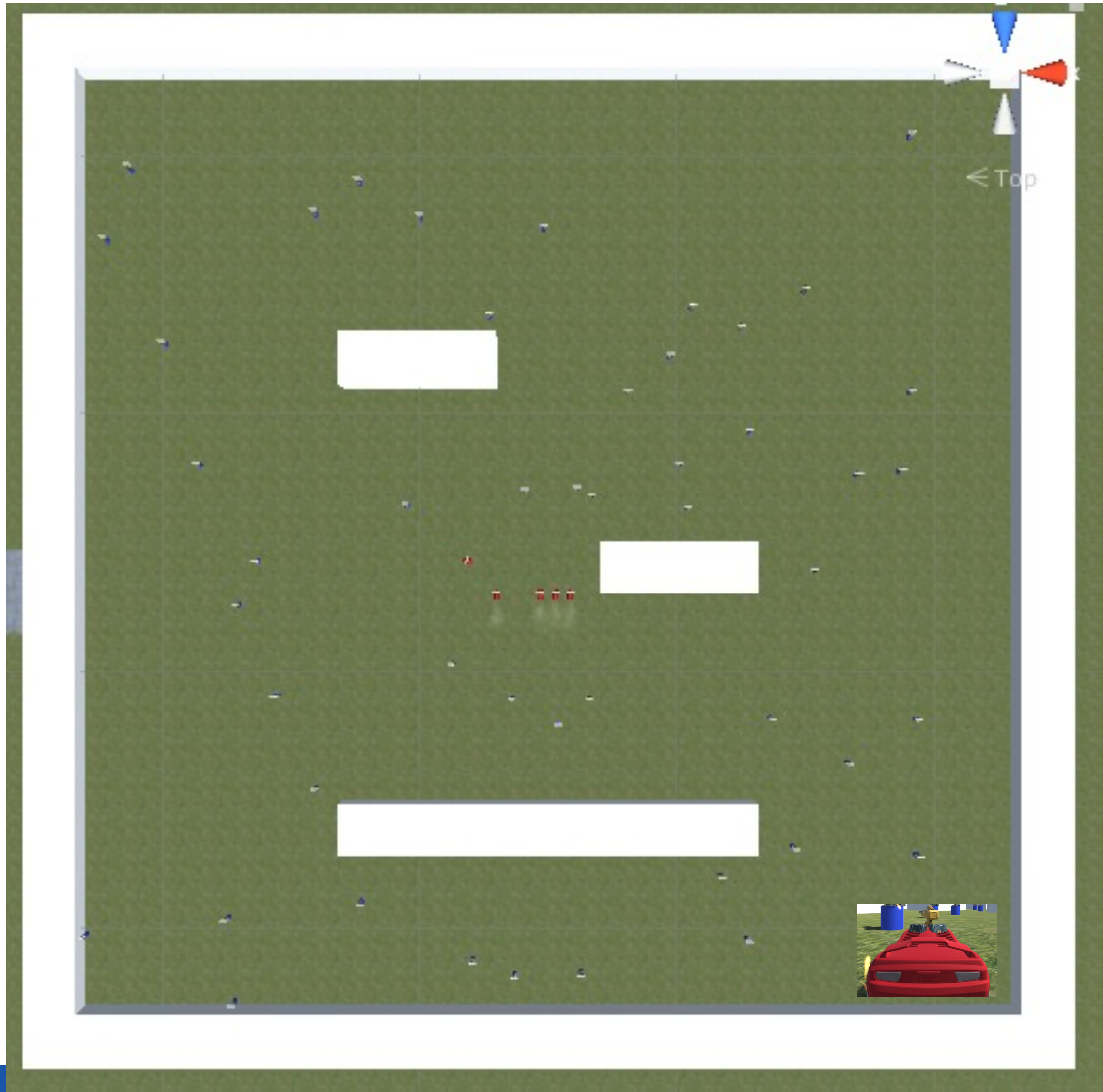


Problem 3: Vehicle Routing Problem

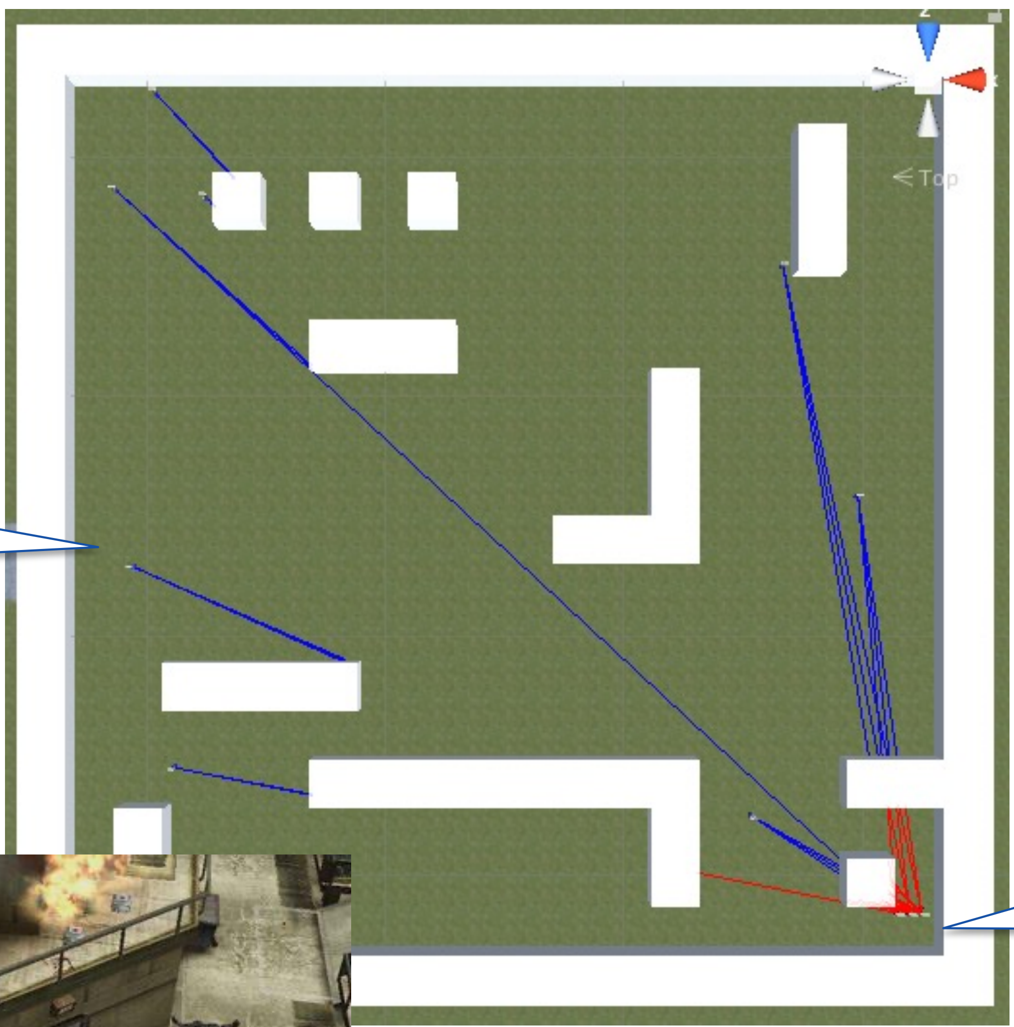


Problem 4: Formation sweep

(follow the Replay car)



Problem 5: Shooter Coordination



Enemies

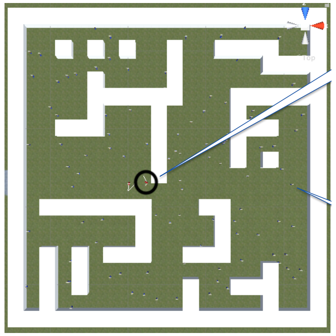
Own team

- How to move team to win and minimize losses?
- Everyone fires at closest enemy within range and sight

Comments on simulation environment

- The car has a low ”max speed” to enable focus on planning not racing
- Problem variation
  - Change ”random seed” if you want a new problem (other turret positions)
  - Additional terrains available ”terrain3B.json”
- Checking ”enemy positions” only allowed in P3 and P5
- Arrays of game objects will contain ”Null” when objects are destroyed (so perhaps you need to update them to avoid error messages in P3-P5)

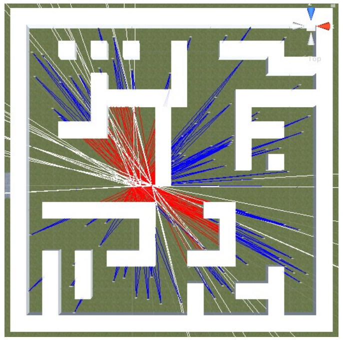
Cooperative Search



Sensor range gives two cases

Range << environment size

- Lawn mowing
- Vacuum cleaning
- Seeding, harvesting
- Mine clearing
- UAV search



Range similar to environment size

- UGV search

The Problems of Assignment 2

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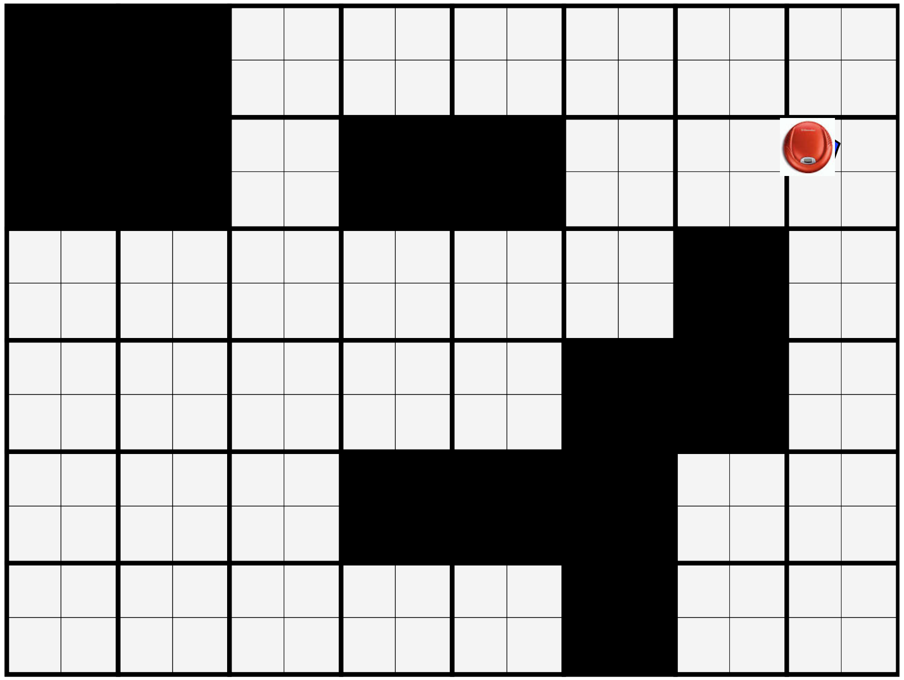
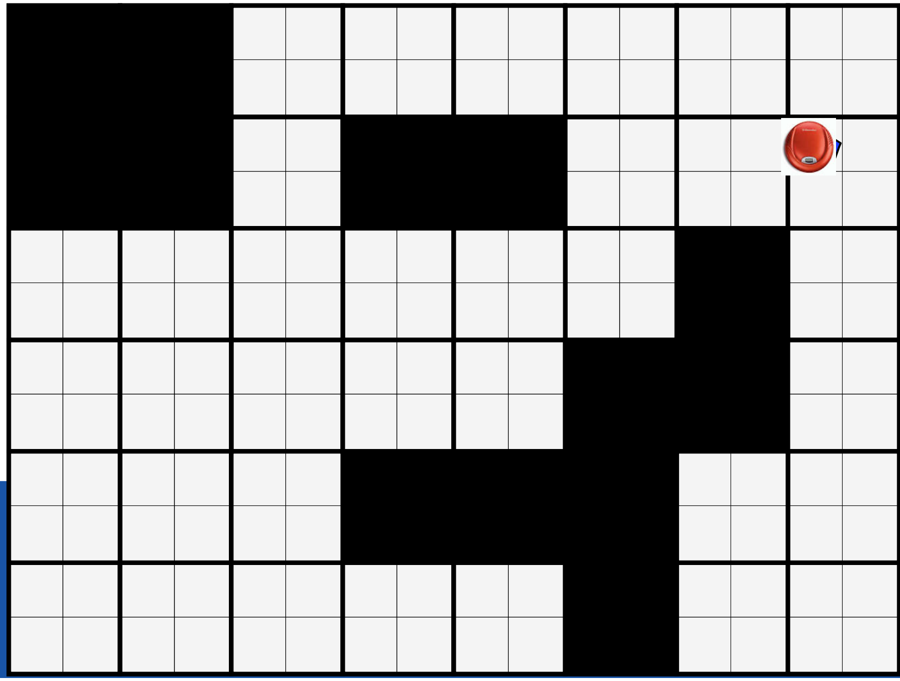
Cooperative search (short range)

Search the area in minimum time



Spanning Tree Coverage (Search)

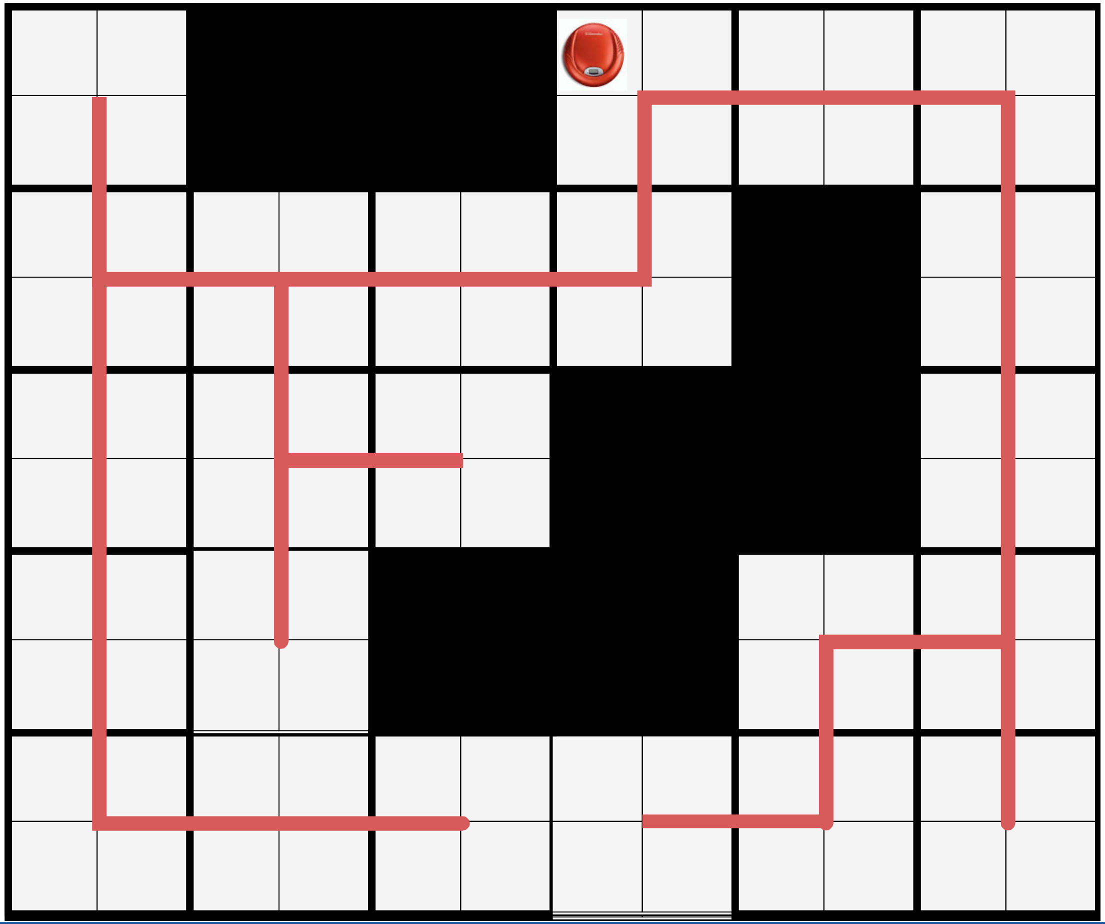
1. Cover the search area with squares 4x the sensor footprint
2. Create a graph G = (V,E)
3. V - Centers of each large square
4. E - Adjacent squares
5. Find a spanning tree T
6. Move clockwise around T



Running the algorithm

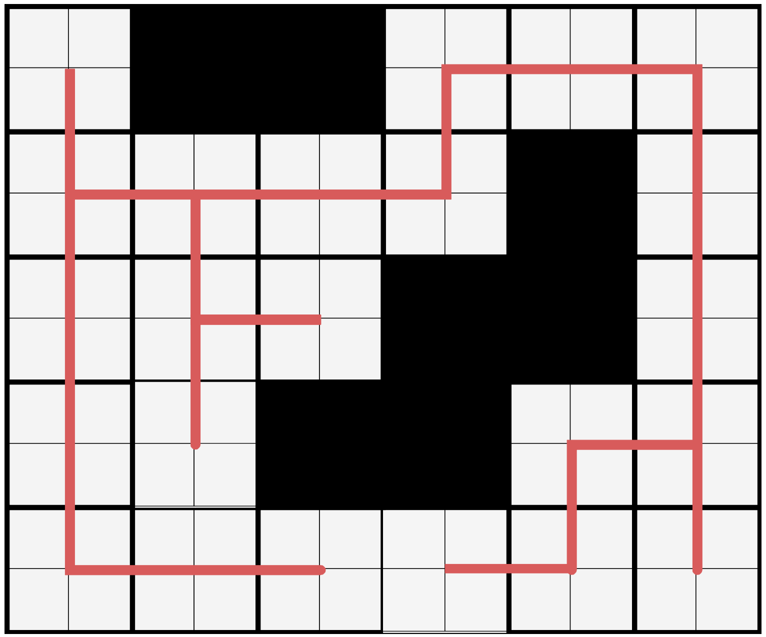
The graph **G**

The tree **T**



Algorithm Properties

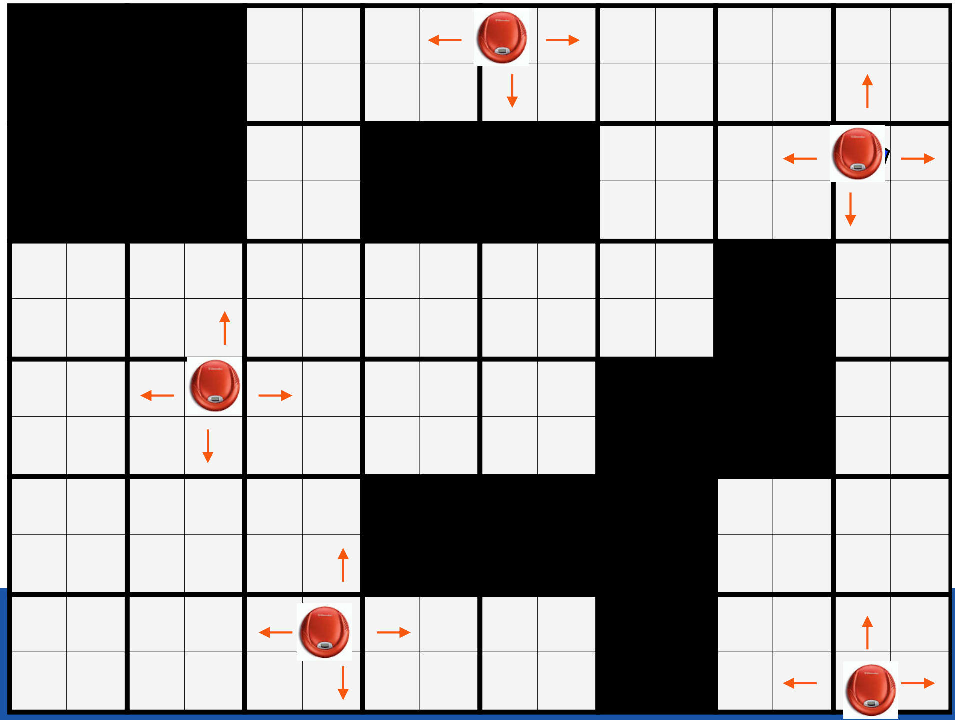
1. The algorithm completes the search
2. The algorithm completes the search in minimum time



Multi-robot search

Given N robots

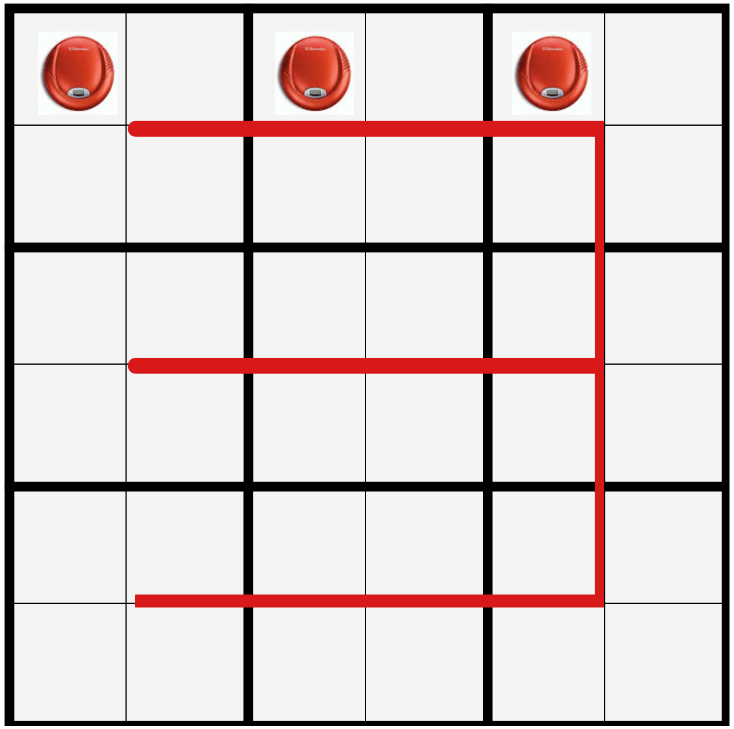
Can we complete the task in 1/N of the time?



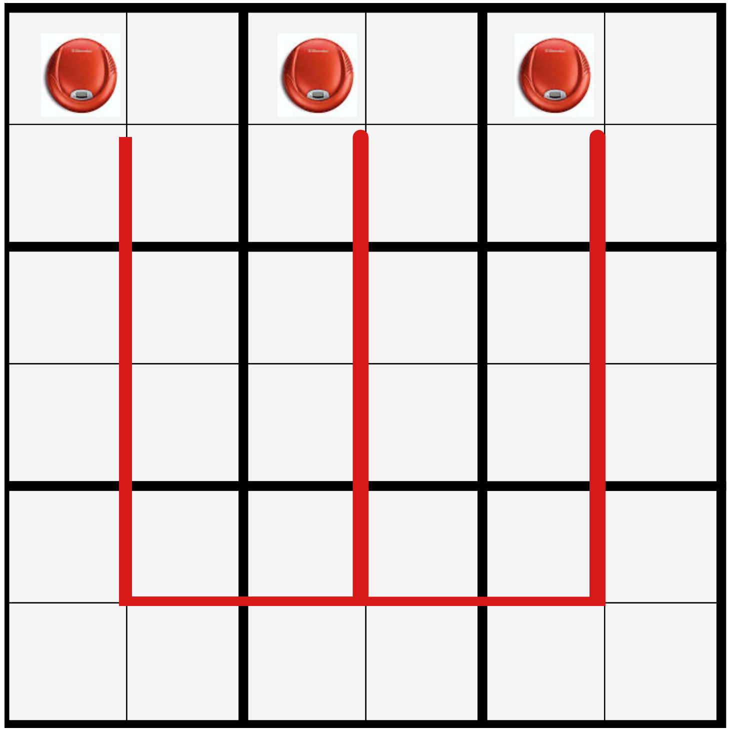
Multi agent search... (extension)

Same as singe agent algorithms

Agents stop when reaching already covered square



Tree 1: 31 steps



Tree 2: 15 steps

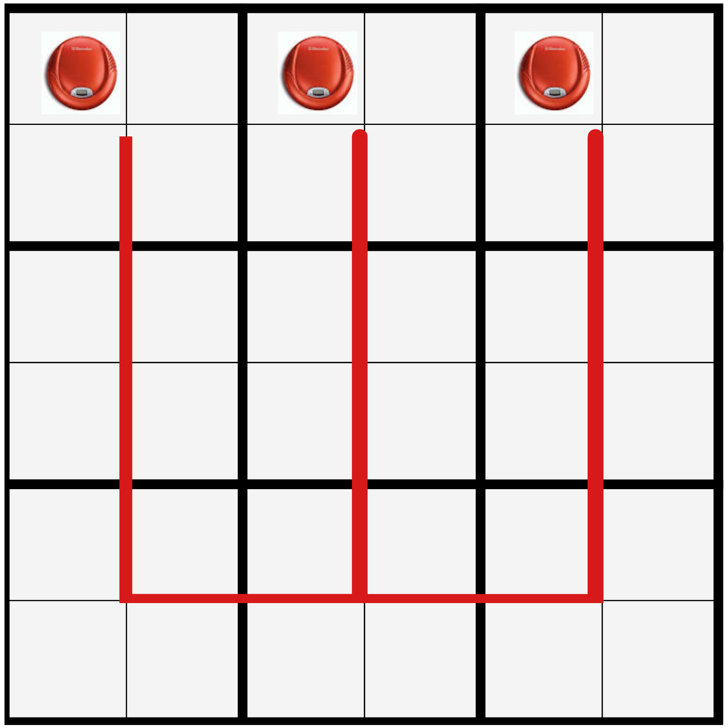
Multi agent search... (extension)

What is the optimal spanning tree?

Optimal Multi-agent search is NP-hard

P-time Heuristics have been proposed

- (Agmon and Kaminka 2006)

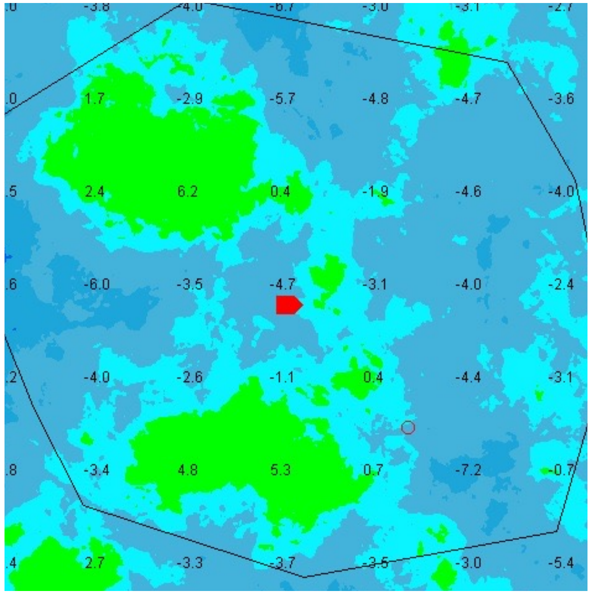


Seabed mapping (search)

Plan and execute a path to

cover the whole seabed

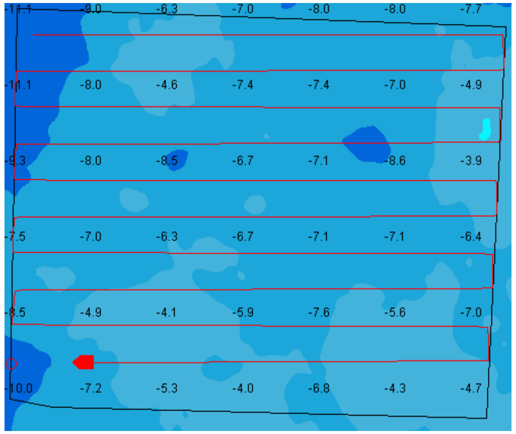
- **mapping depth**
- **finding mines**

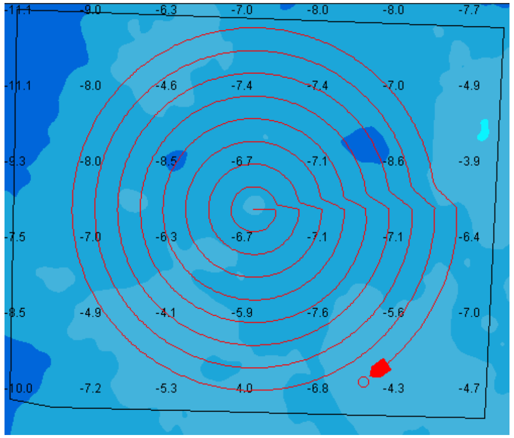


Seabed mapping (search)

Classical Search Patterns

- Scanning
- Spiral





Disadvantages

- Obstacles/Land...

Solution?

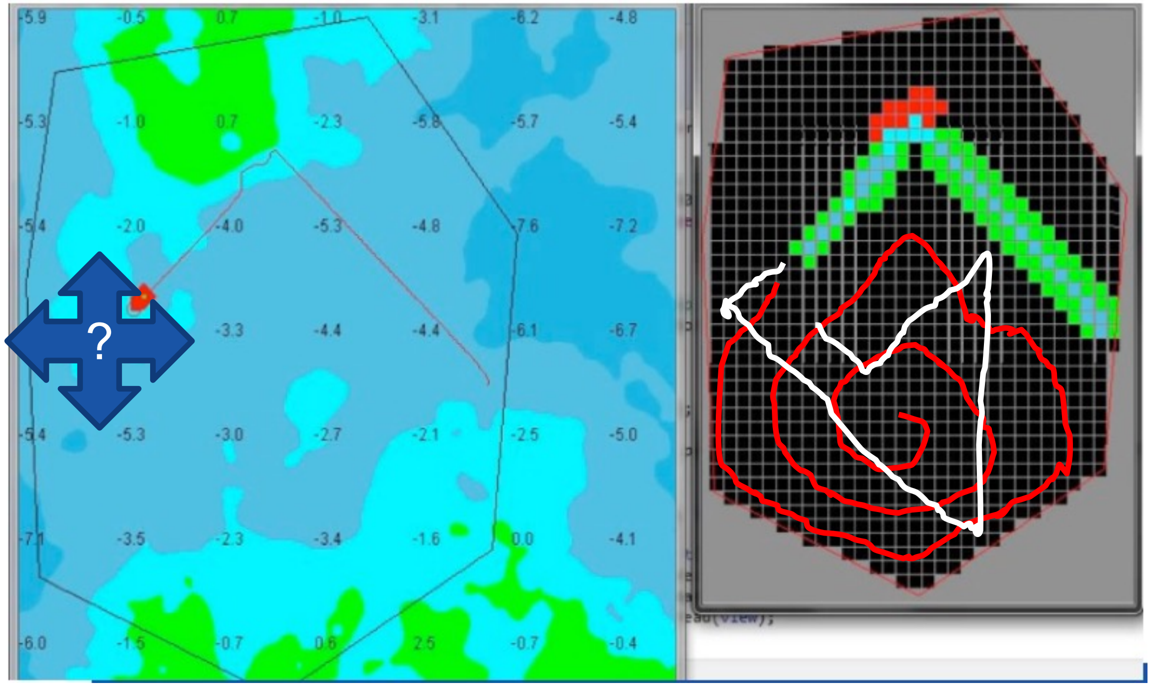
Reactive Greedy approach

Reactive options:

- Greedy (next best 1s)
- Follow the edge
- …

Either case needs

- “Find new starting point”



The Problems of Assignment 2

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- **P2: Indoor UGV search (Long range)**
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Common theme: Discretizing the search space

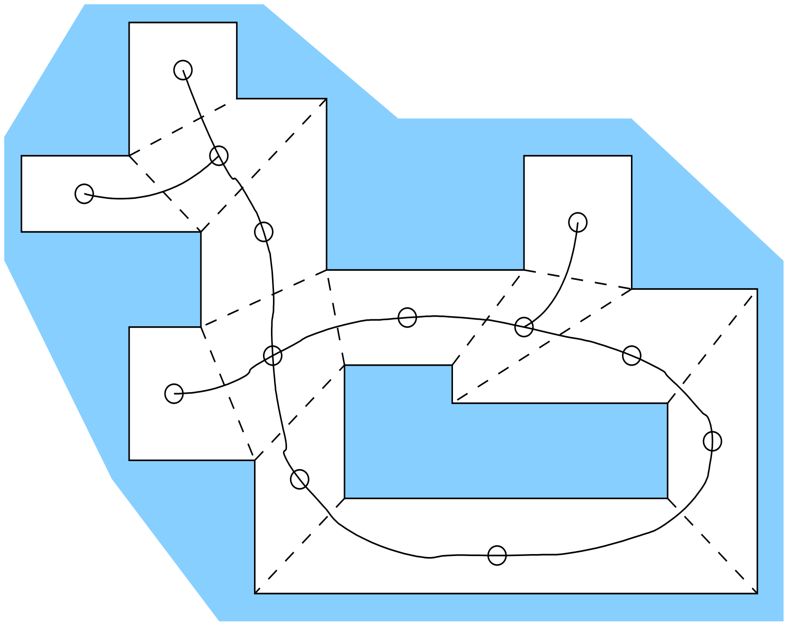
Partitioning search space into convex sets is often useful

Create a graph

- Set <-> vertex
- Neighbor <-> edge

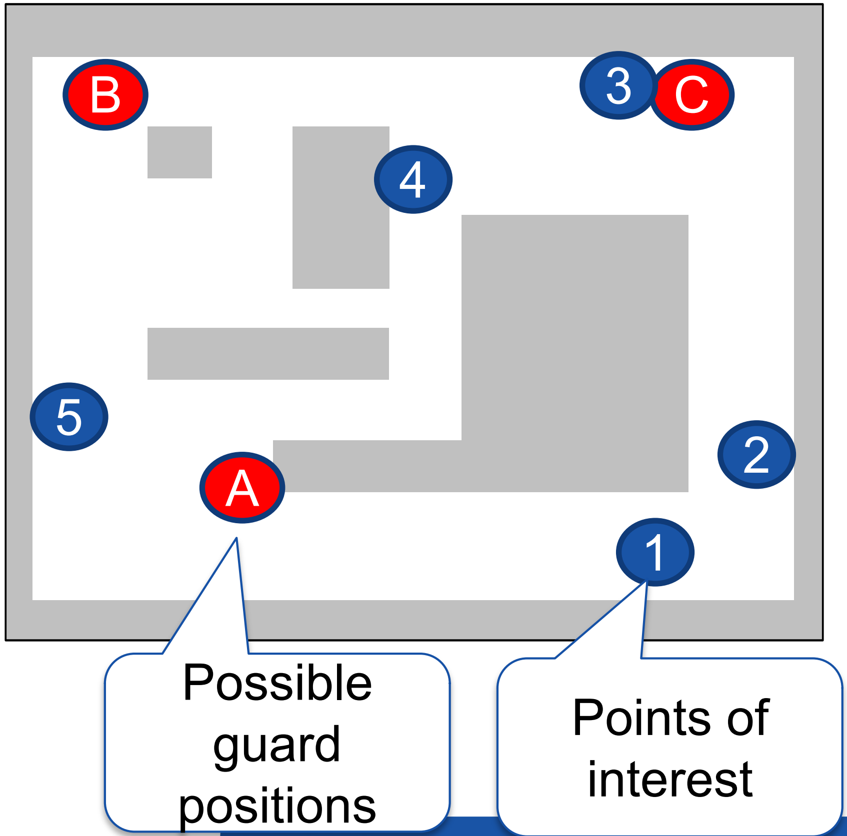
A naïve solution:

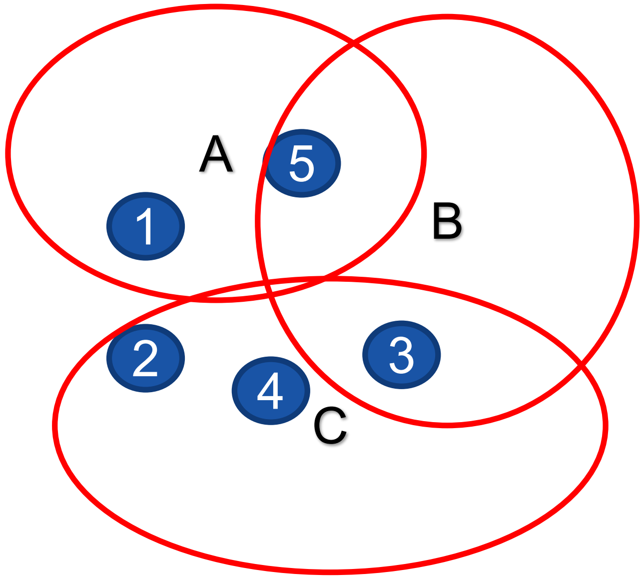
- VRP on graph



Can we improve on this conservative solution?

Min Guard Problem - Min Set Cover problem



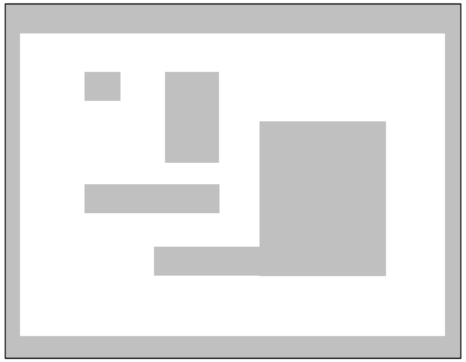


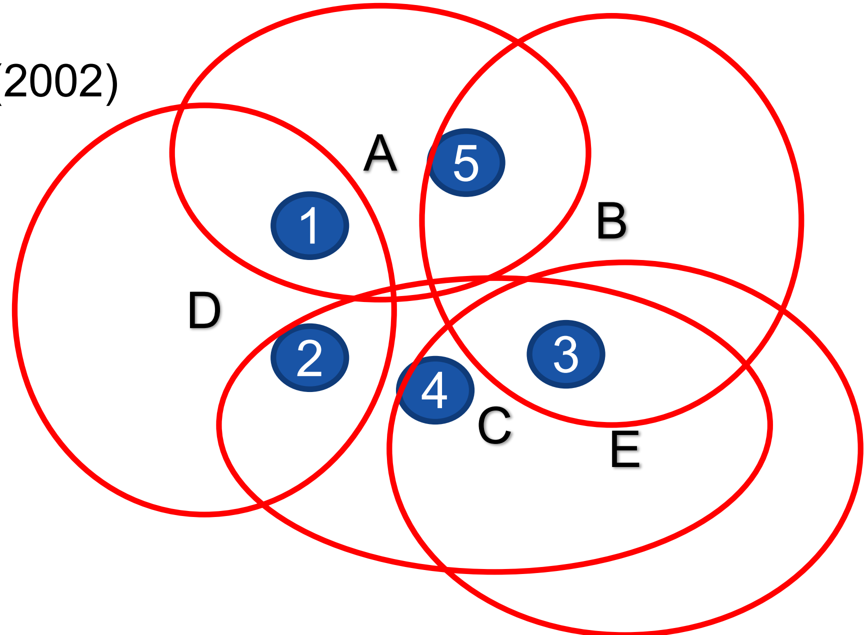
Note: More points of interest are needed to cover all freespace

Minimum set cover

Problem (Minimum set cover) Let $E = \{e1, . . . , en\}$ be a finite set of elements, and let $S = \{s1,...,sm\}$ be a collection of subsets of E, i.e. $sj \subseteq E$. The problem minimum set cover is the problem of finding a minimum subset $S' \subseteq S$ such that every elements $ei \in E$ belongs to at least one subset in S'. We say that E is covered by S'.

- NP-hard
- Greedy algorithm performs well , Eidenbenz (2002)





Cooperative Search (long sensor range)

Possible approaches:

- Discretize to a graph and solve m-TSP

- Solve Guarding problem using Min Set Cover
- Use Guard positions and solve m-TSP

- Other methods…

Further reading on cooperative search

E. Frazzoli and F. Bullo. Decentralized algorithms for vehicle routing in a stochastic time-varying environment. In Proc. of the 43rd IEEE Conference on Decision and Control, CDC, 2004.

Maria John, David Panton, and Kevin White. Mission planning for regional surveillance. Annals of Operations Research, 108:157–173, Nov. 2001.

Shuzhi Sam Ge and Cheng-heng Fua. Complete Multi-Robot Coverage of Unknown Environments with Minimum Repeated Coverage. In IEEE International Conference on Robotics and Automation, Barcelona, Spain, pages 727–732, April 2005.

N Agmon, N Hazon, GA Kaminka, Constructing spanning trees for efficient multi-robot coverage, IEEE International Conference on Robotics and Automation (ICRA), 2006

I. I. Hussein and Stipanovic, “Effective Coverage Control using Dynamic Sensor Networks,” presented at the Decision and Control, 2006 45th IEEE Conference on, 2006.

D. A. anisi, P. Ögren, and X. Hu, “Cooperative Minimum Time Surveillance With Multiple Ground Vehicles,” *Automatic Control, IEEE Transactions on*, vol. 55, no. 12, pp. 2679–2691, 2010.

The Problems of Assignment 2

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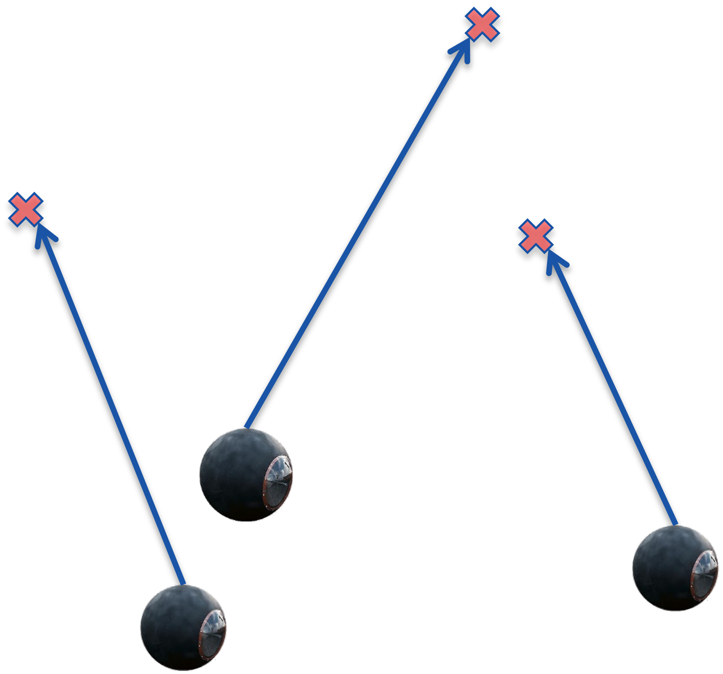
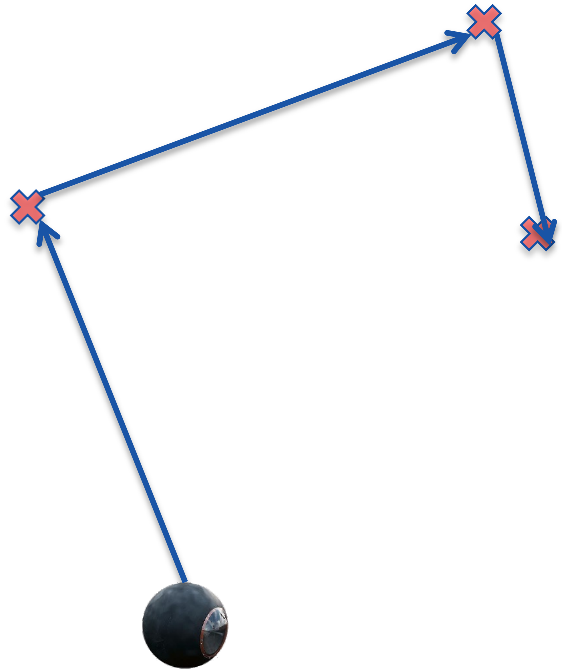
The assignment problem (… then TSP and VRP)

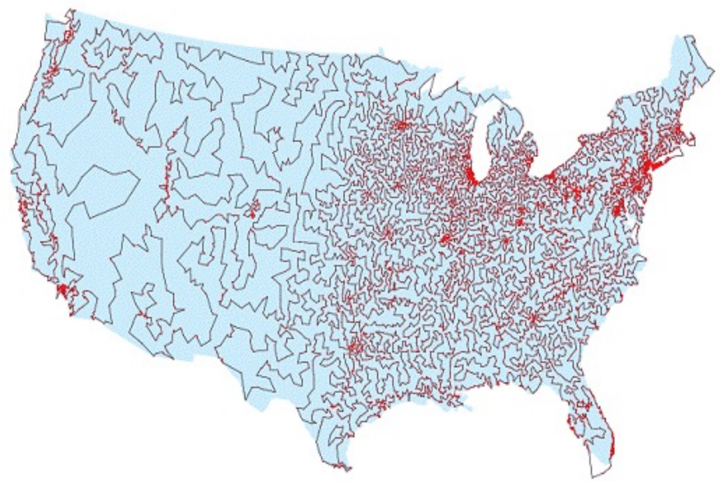
- Assign each agent to a task
- Minimize sum of costs
- Solvable in polynomial time (special case of LP)
- https://en.wikipedia.org/wiki/Hungarian_algorithm



The Travelling Salesperson Problem

- Assign an ordering of the task to the agent
- Minimize sum of costs
- Not Solvable in polynomial time
- NP-hard
- (but very large Euclidean TSPs have been solved…)

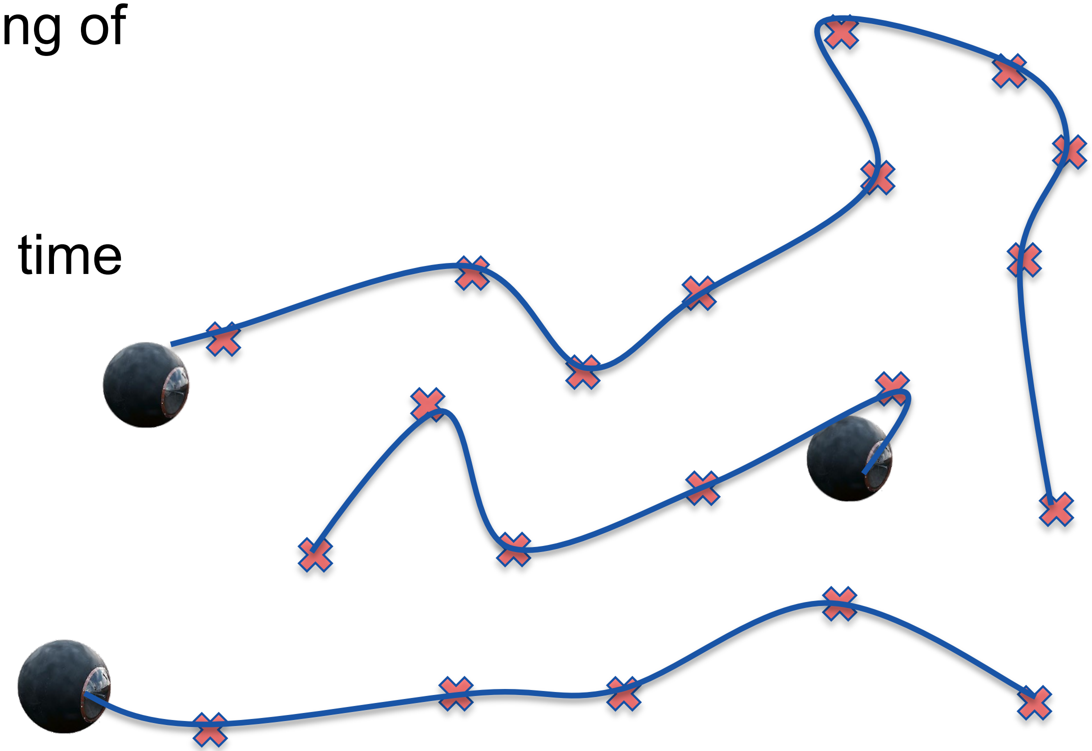




Applegate, Bixby, Cook and Chvatal

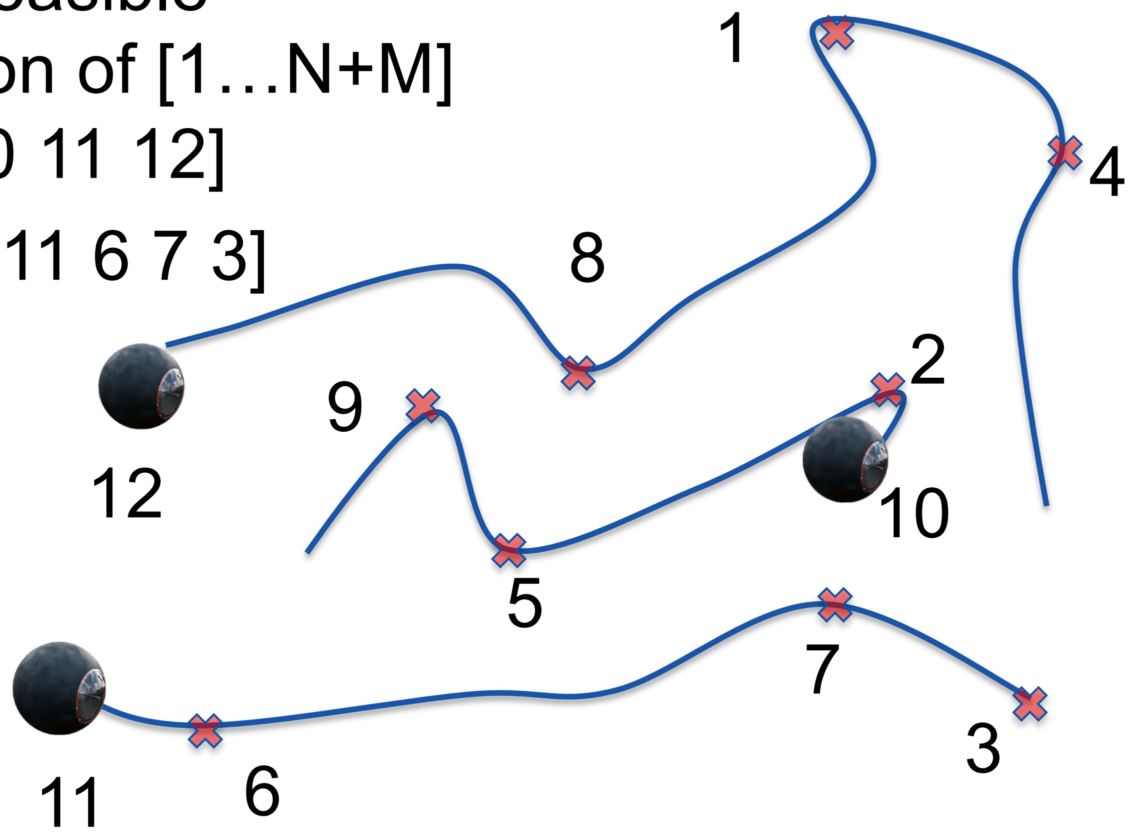
The Vehicle Routing Problem (VRP)

- Assign tasks and an ordering of the task to the agents
- Minimize sum of costs
- Not Solvable in polynomial time
- NP-hard



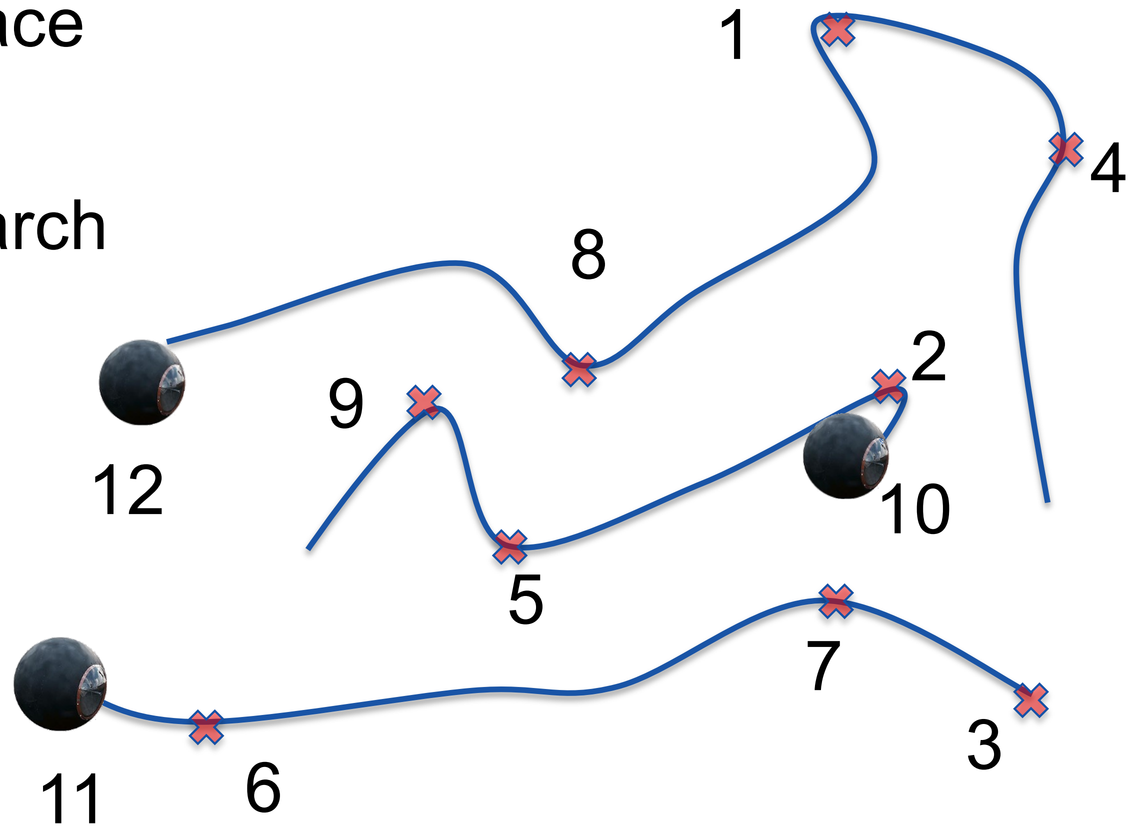
One way of addressing the VRP

- Enumerate robots (M) and tasks (N)
- Goal: Encode every feasible solution as permutation of [1…N+M] = [1 2 3 4 5 6 7 8 9 10 11 12]
- Ex [12 8 1 4 10 2 5 9 11 6 7 3]



One way of addressing the VRP

- [12 8 1 4 10 2 5 9 11 6 7 3]
- Do search in this space
  - Tabu search
  - Granular Tabu search
  - Genetic Alg.
  - …



Further reading on VRP

- P. Toth and D. Vigo, “The Granular Tabu Search and Its Application to the Vehicle-Routing Problem,” *INFORMS Journal on Computing*, vol. 15, no. 4, pp. 333–346, Dec. 2003.
- Bjarnadóttir, Áslaug Sóley. *Solving the vehicle routing problem with genetic algorithms*. Diss. Technical University of Denmark, DTU, DK-2800 Kgs. Lyngby, Denmark, 2004.
- You are allowed to use Google OR-tools (for combinatorial optimization)

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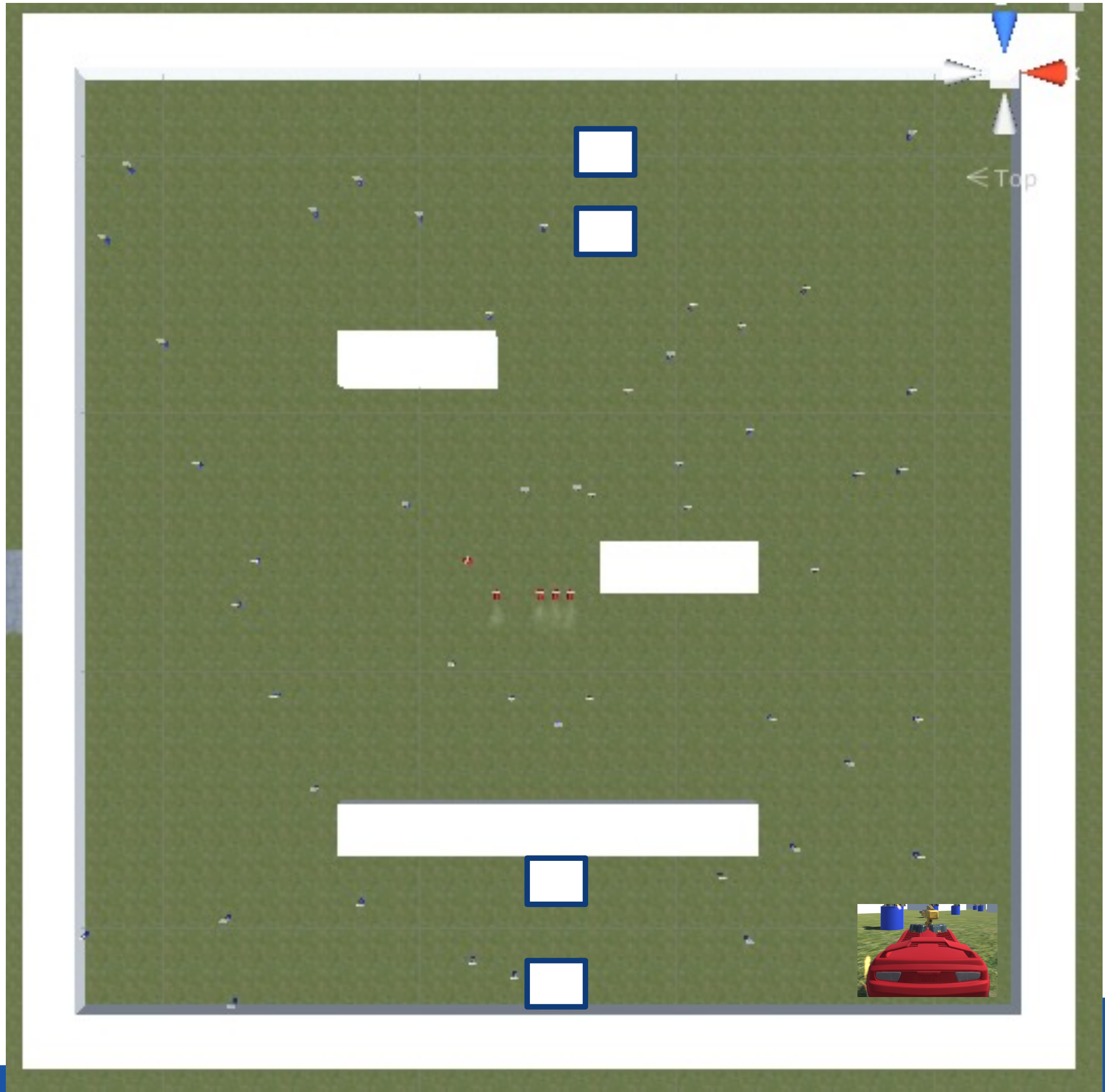
- P5: Shooter Coordination

Problem 4: Formation sweep

(follow the Replay car)

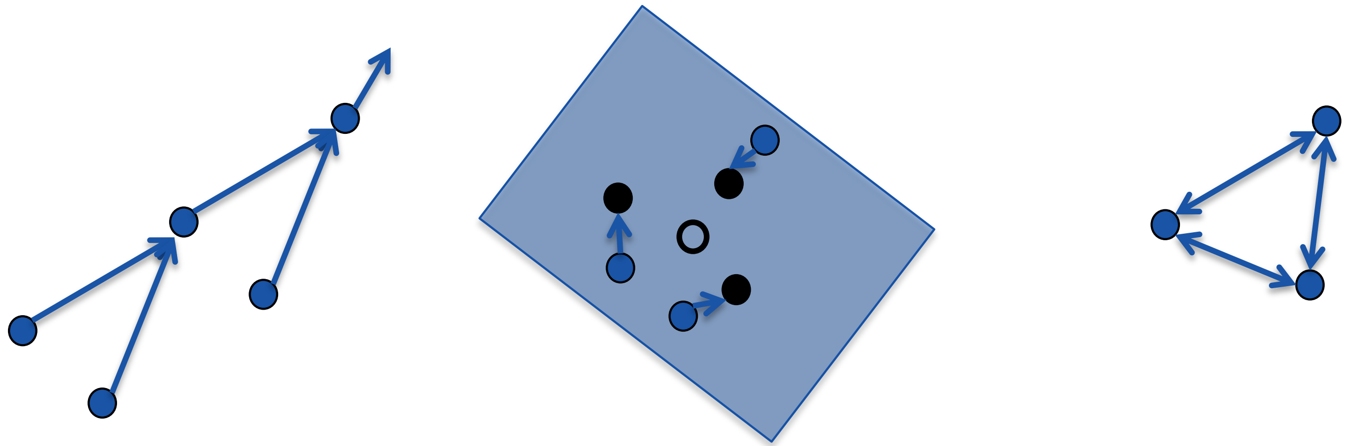


- Performance measure:
  - Cost for not being in “line”
- Strategy:
  - Be “in line” most of the time
  - Avoid obstacles when needed

Formation keeping

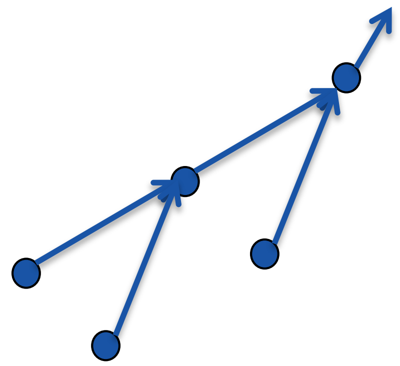
There are 3 different approaches to formation keeping

- Leader-follower
- Virtual Structure
- Decentralized local interaction (leader-less)



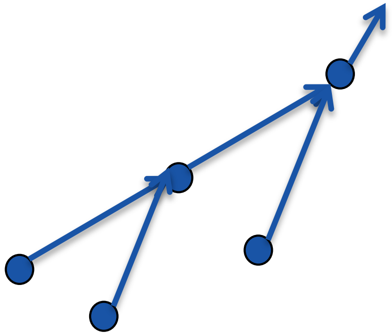
Leader Follower

- One robot has no leader, and moves according to other goal (e.g. navigation)
- All other robots have a designated leader and moves to achieve given distance and bearing (relative to compass or relative to leader velocity)



See Example 2.3 of: P. Ögren and N. E. Leonard, "Obstacle avoidance in formation," presented at the IEEE International Conference on Robotics and Automation. IEEE ICRA 2003, pp. 2492–2497.

Leader Follower (ex 1)



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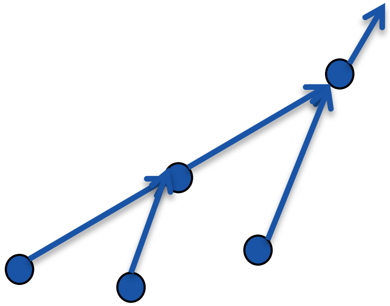
Leader Follower (ex 2)



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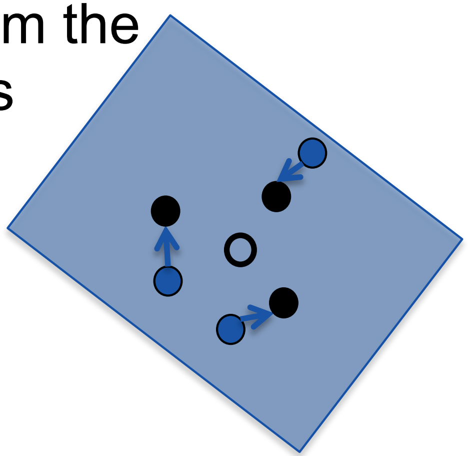
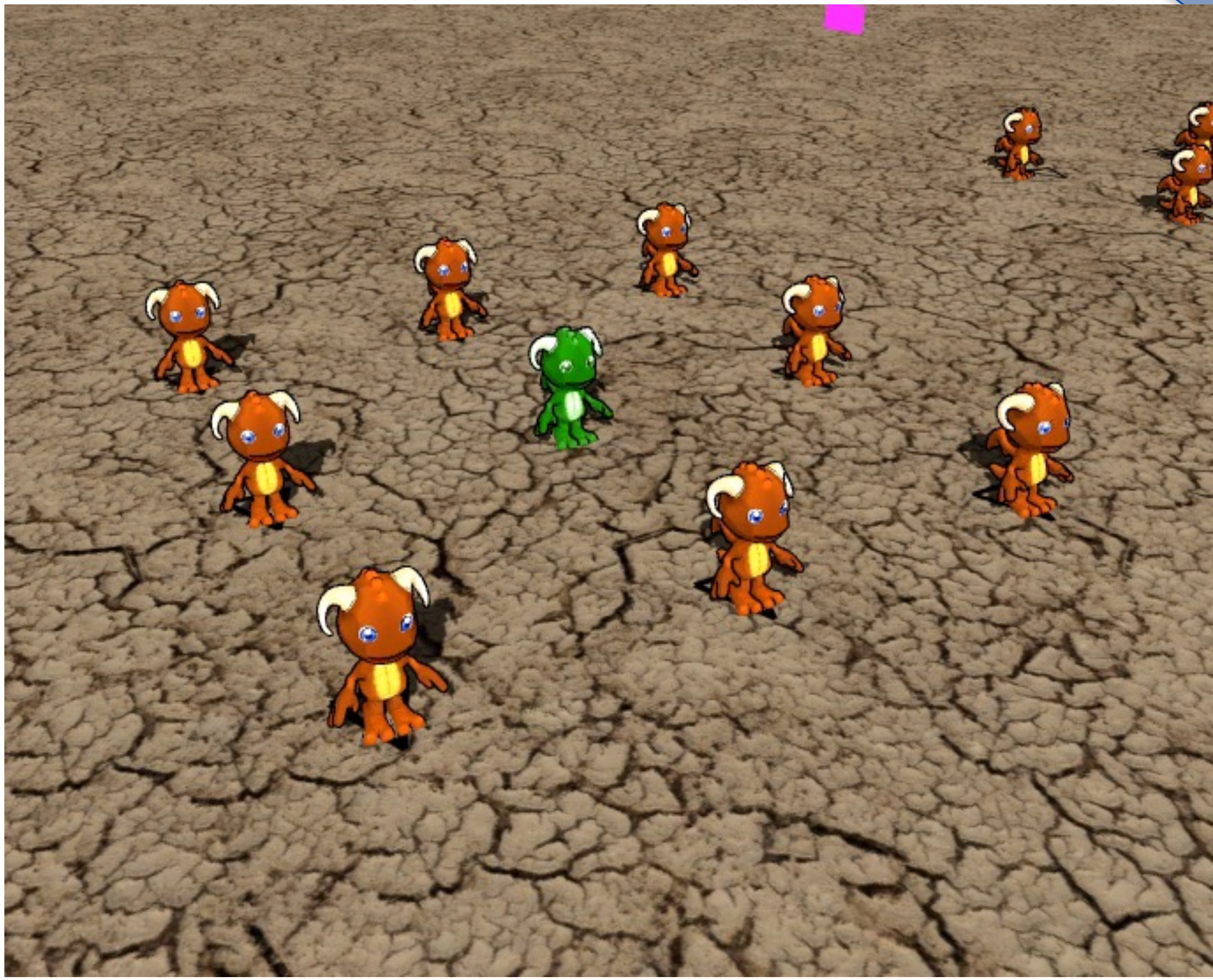
Virtual Structure

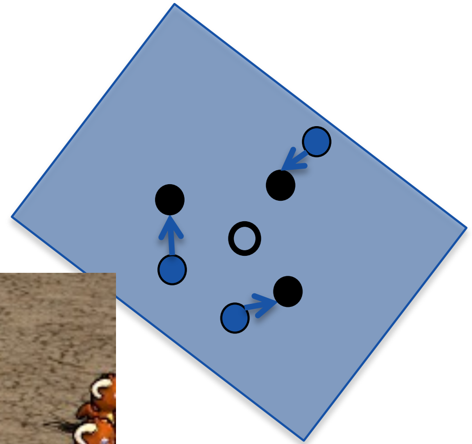
- All vehicles have unique numbers
- The positions of each vehicle in the formation is given relative to a “virtual structure”
- The virtual structure is moved (either in a pre-programmed way, or according to the current average velocity and average position
- The individual robots get their desired positions from the virtual structure, and move to reach these positions



See Section 3 of: B. J. Young, R. W. Beard, and J. M. Kelsey, “A Control Scheme for Improving Multi-Vehicle Formation Maneuvers,” presented at the Proc. American Control Conference, 2001, pp. 704–709.

Virtual Structure (ex)





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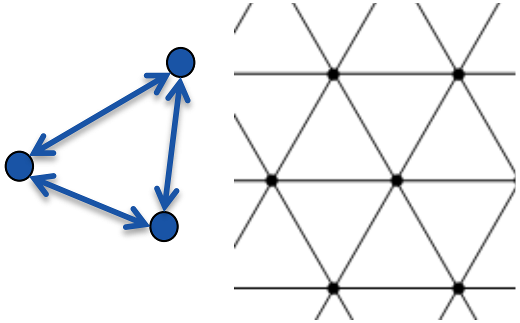
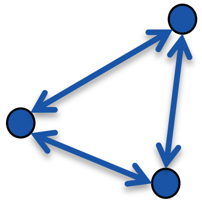
Decentralized local interaction

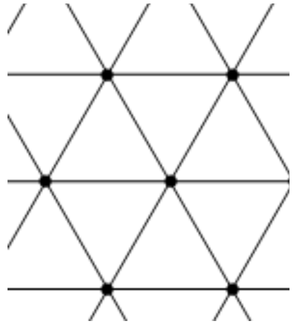
- All robots can sense their neighbors
- All robots adapt their motion (velocity or acceleration depending on model) to achieve a given neighbor distance
- Often results in "Hexagonal lattice"



See Section II of: P. Ögren, E. Fiorelli, and N. E. Leonard, "Cooperative Control of Mobile Sensor Networks: Adaptive Gradient Climbing in a Distributed Environment," *IEEE Trans. Automat. Contr.*, vol. 49, no. 8, pp. 1292–1302, Aug. 2004.

Decentralized local interaction (ex)





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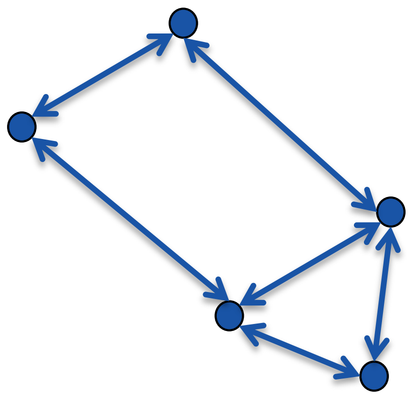
Local interactions with given pattern

- Same as above, with a desired distance d_ij for every pair of agents
- Spring damper system with given link lengths
- Some links missing...



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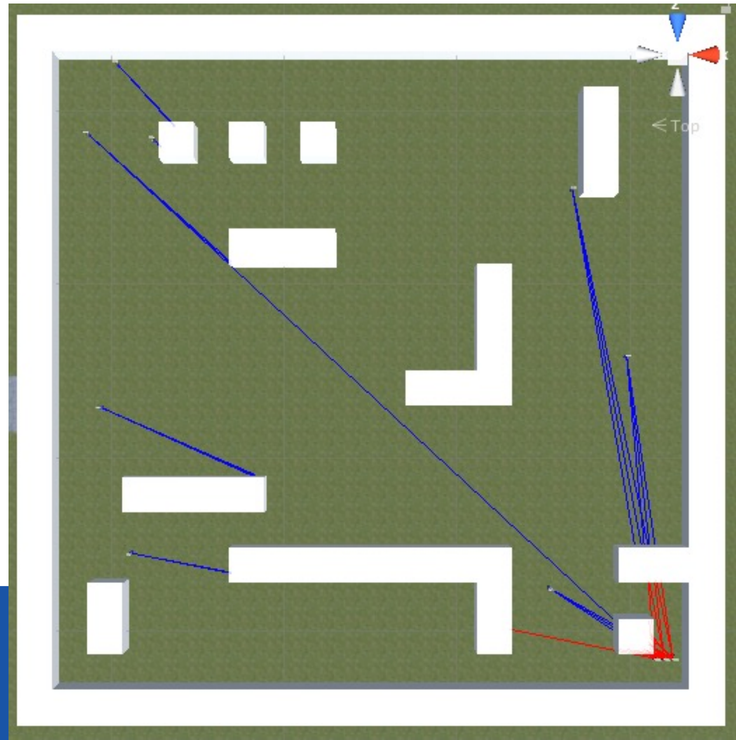
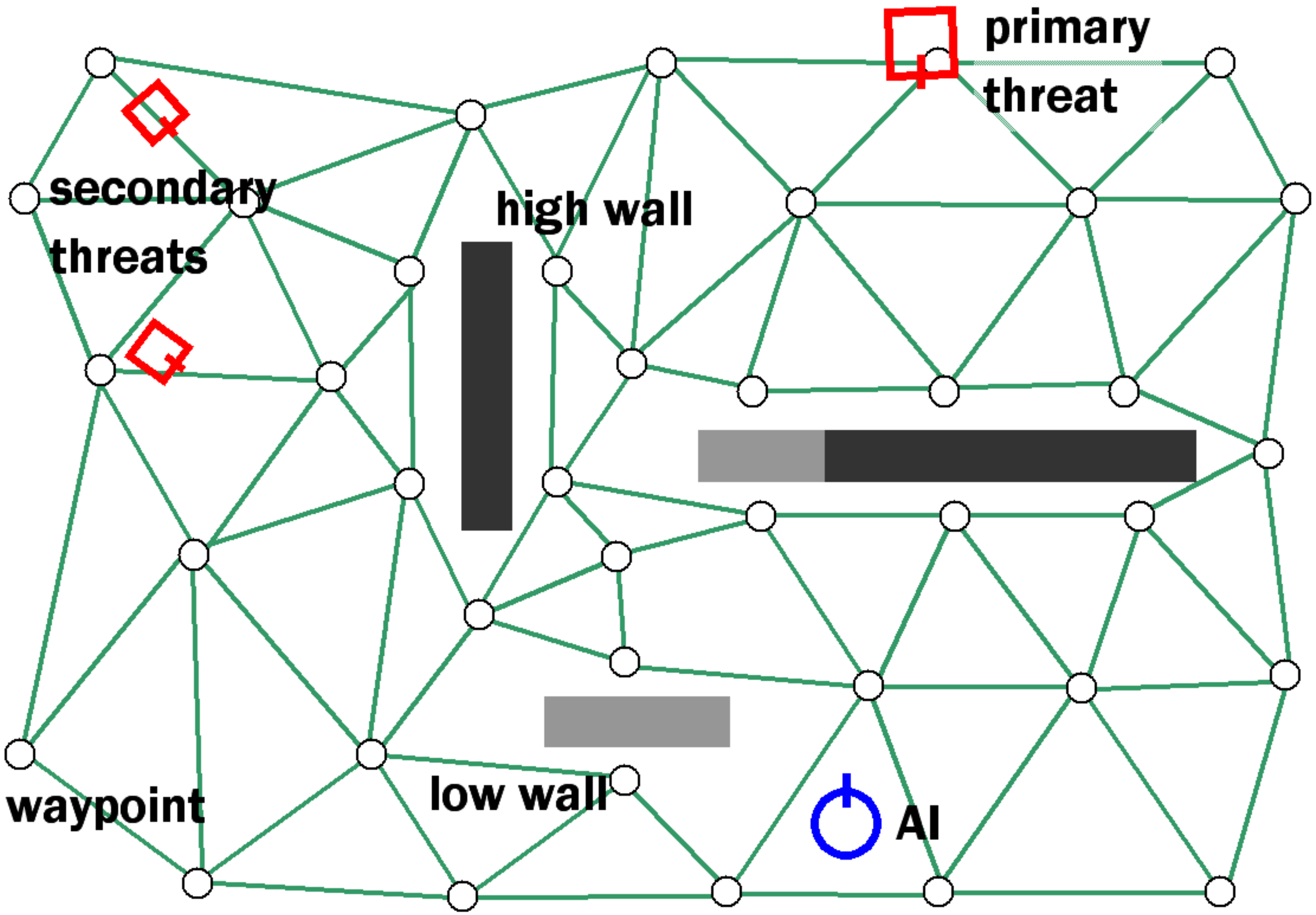
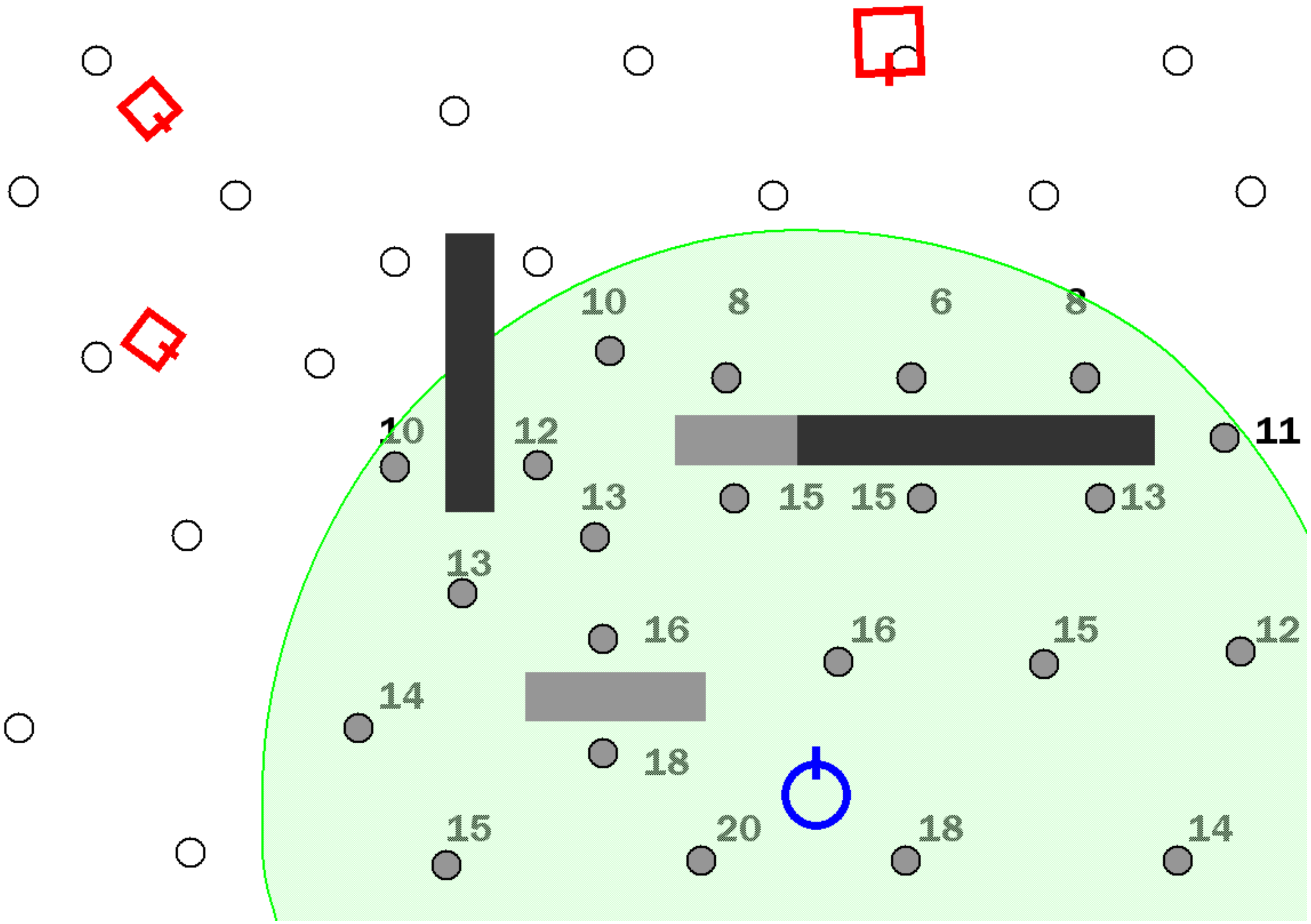


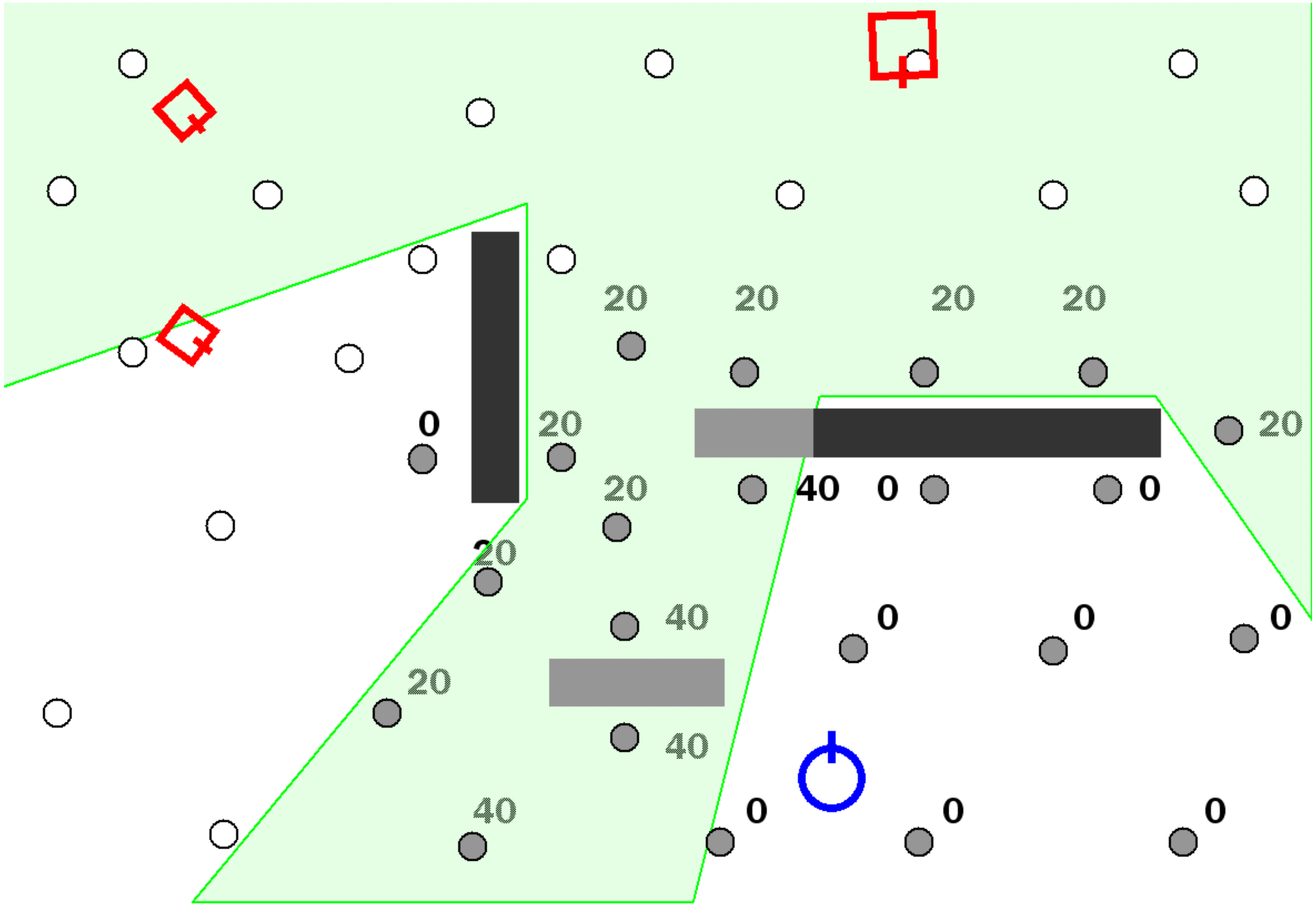
Example: Picking an Attack Position



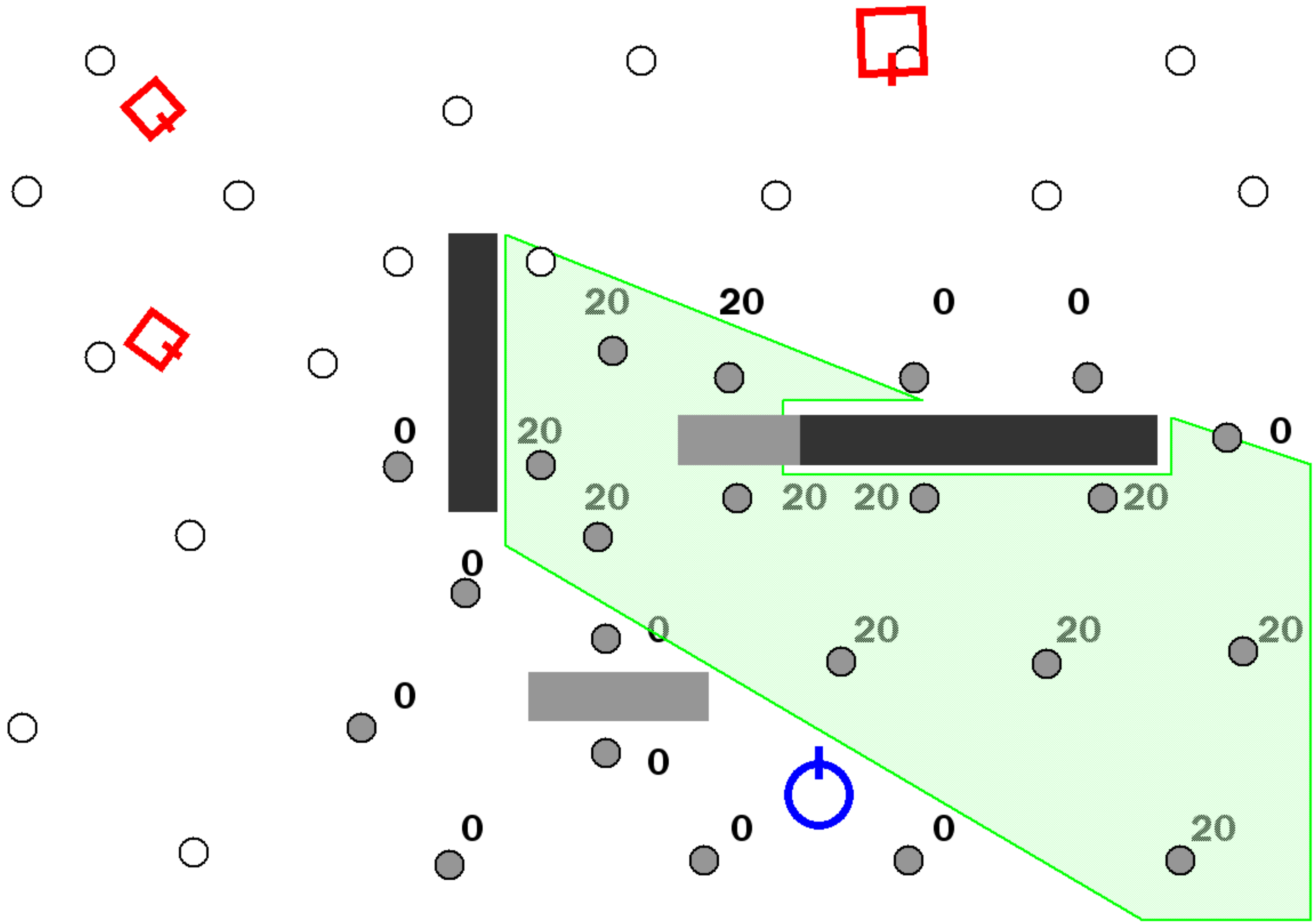
Nearby positions



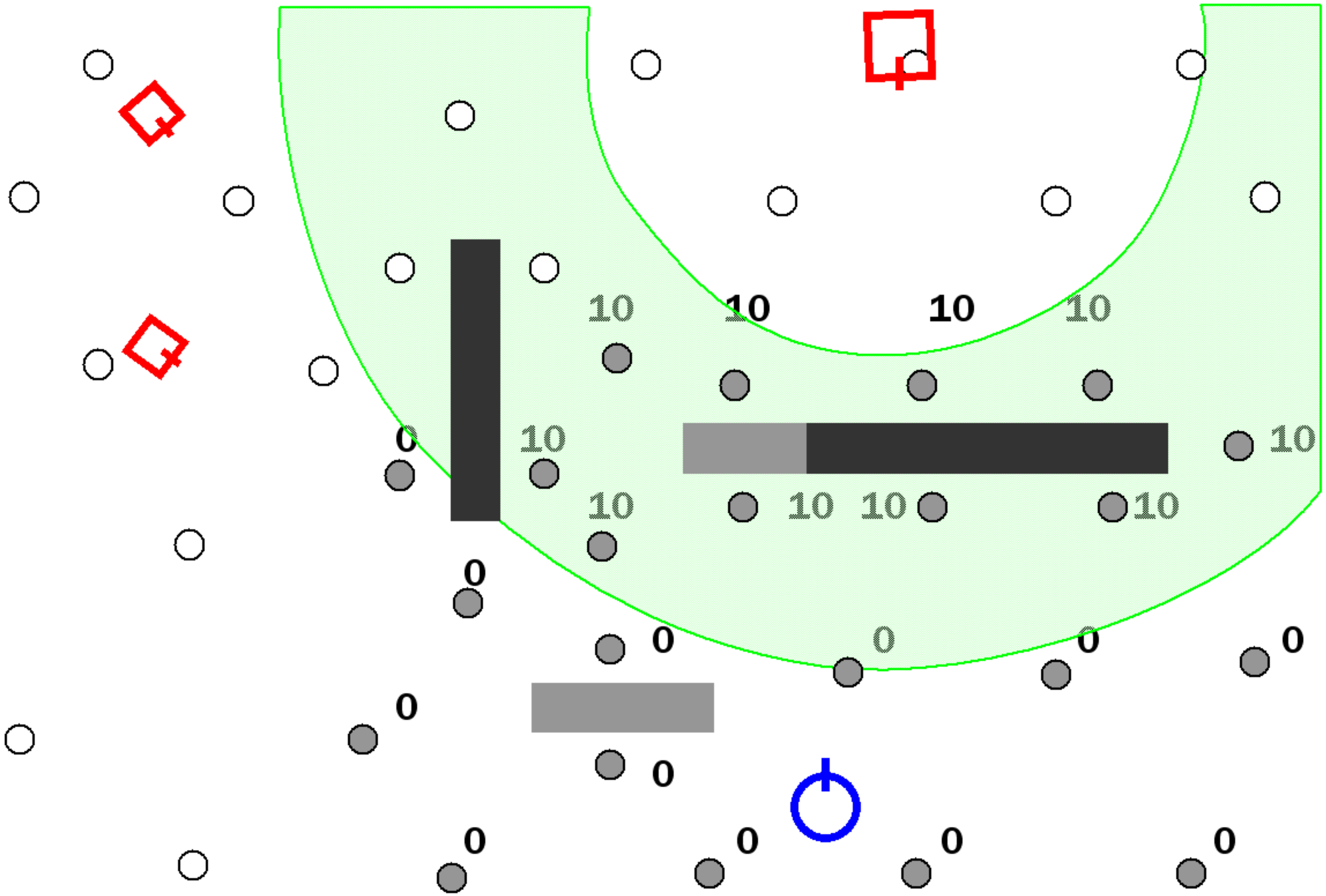
Target not in sight



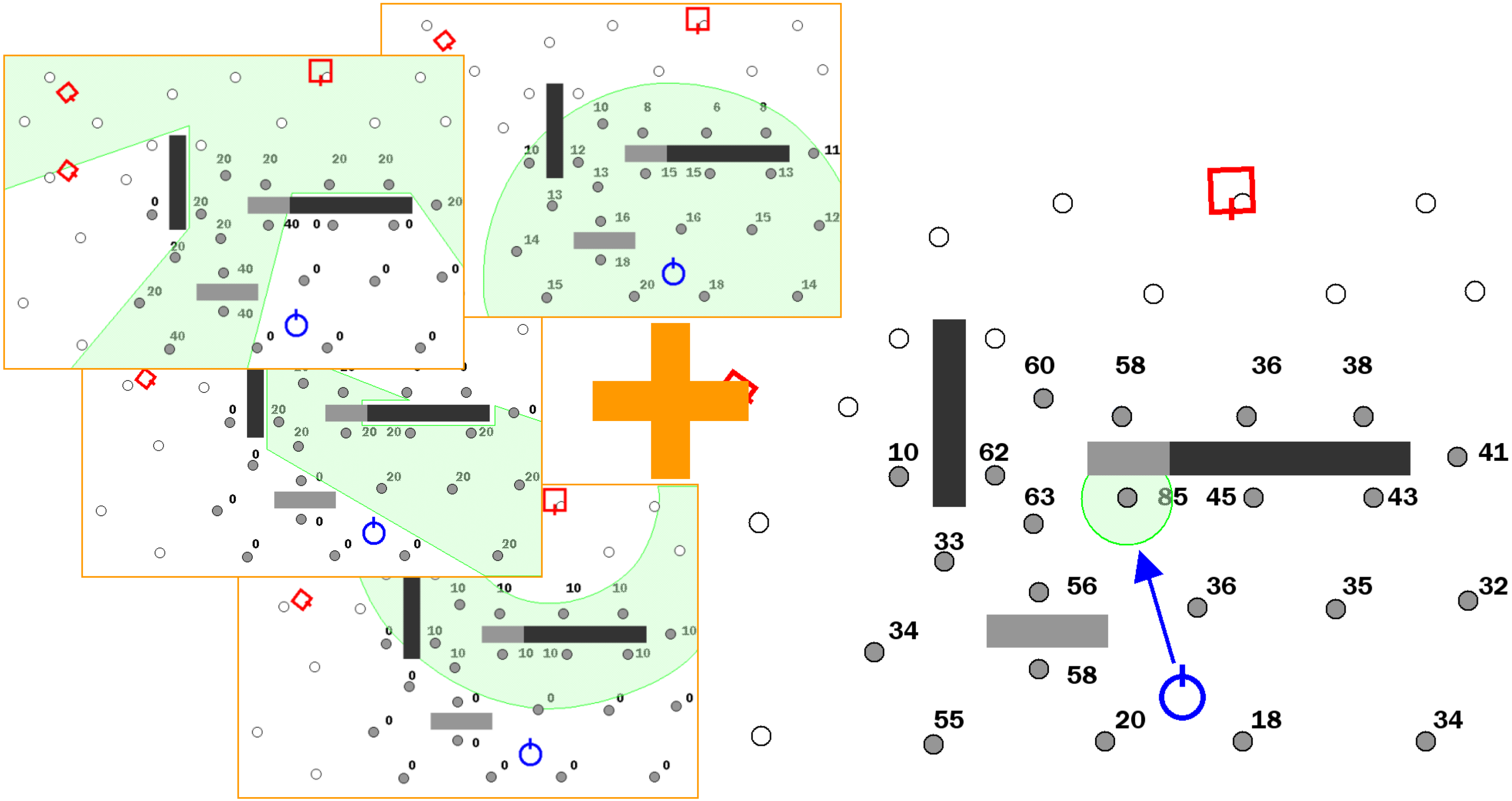
Exposed to other enemies



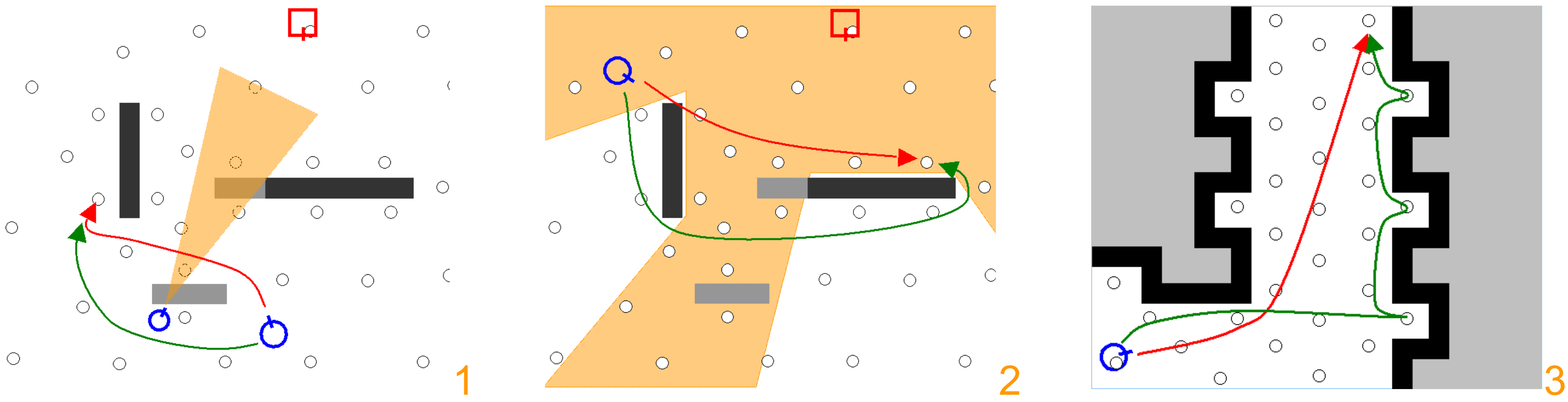
Proper distance, given weapons



Combining scores to find “Best” option

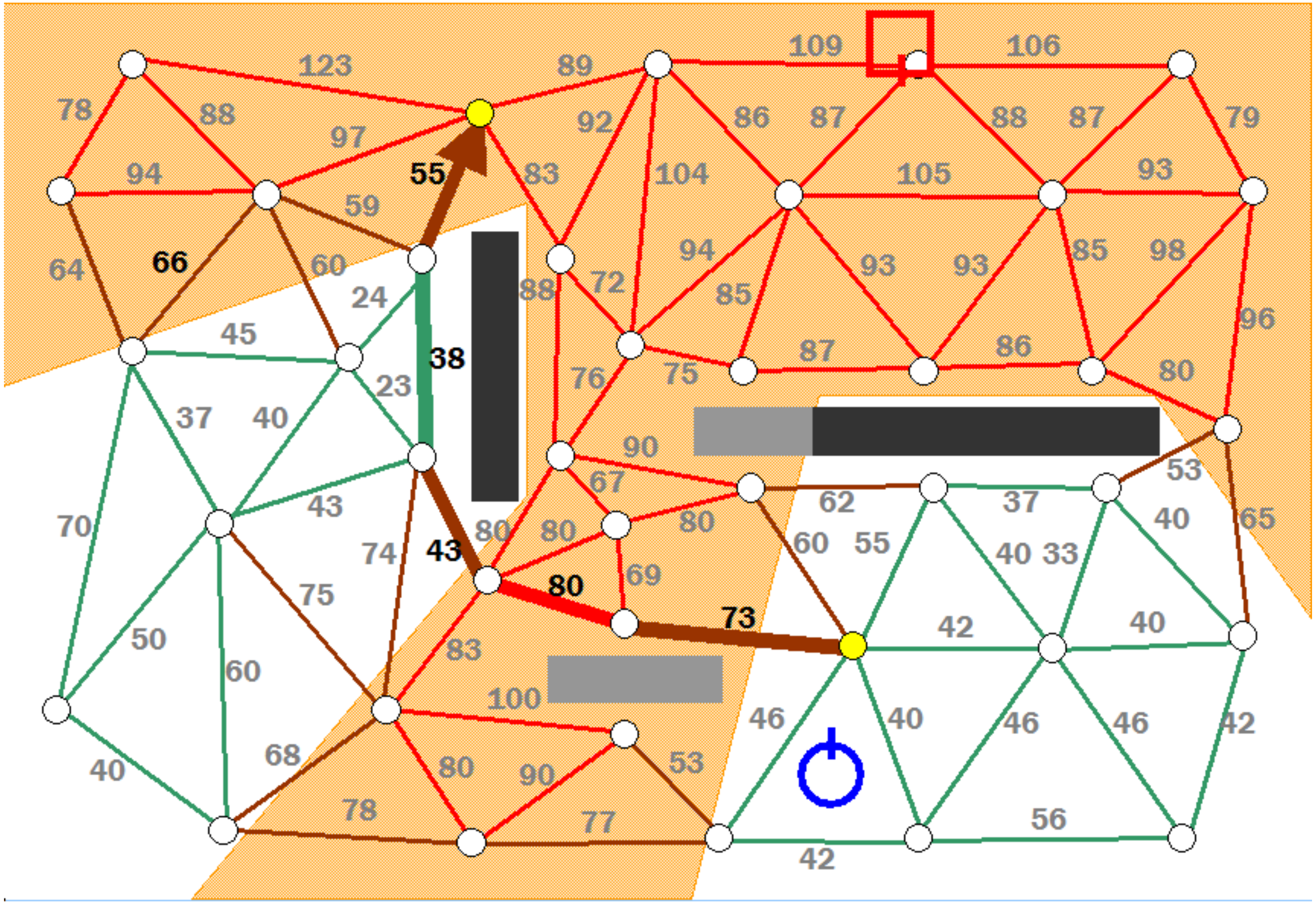


Tactical Path-finding

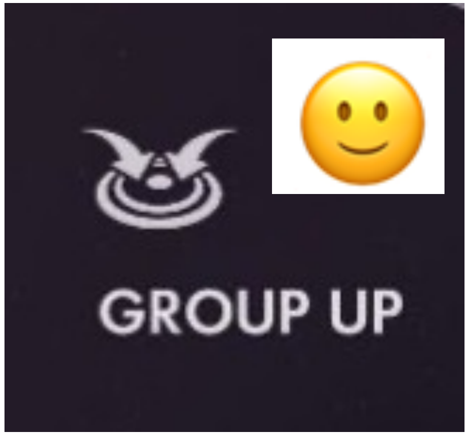


Idea: Compute edge costs as above

Tactical Path-finding

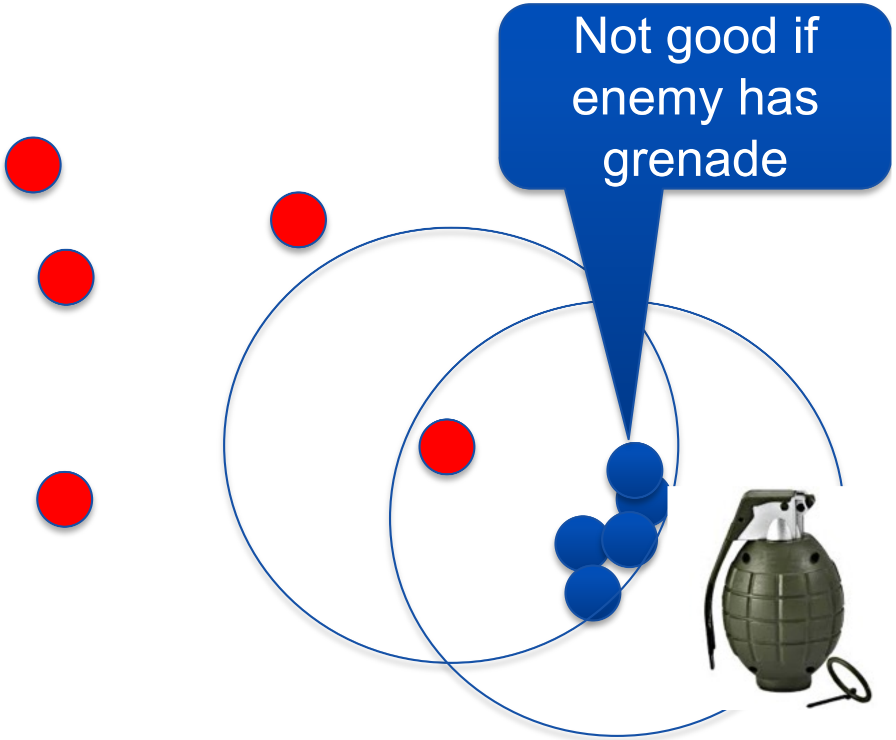


What about coordination of multiple agents?



No other piece of advice matters in Overwatch if your team is trickling. Map position, team comp, skill of individual players, it's all irrelevant if the team doesn't WORK as a team. I wish we could put this up as a flashing red banner on all Overwatch pages everywhere.

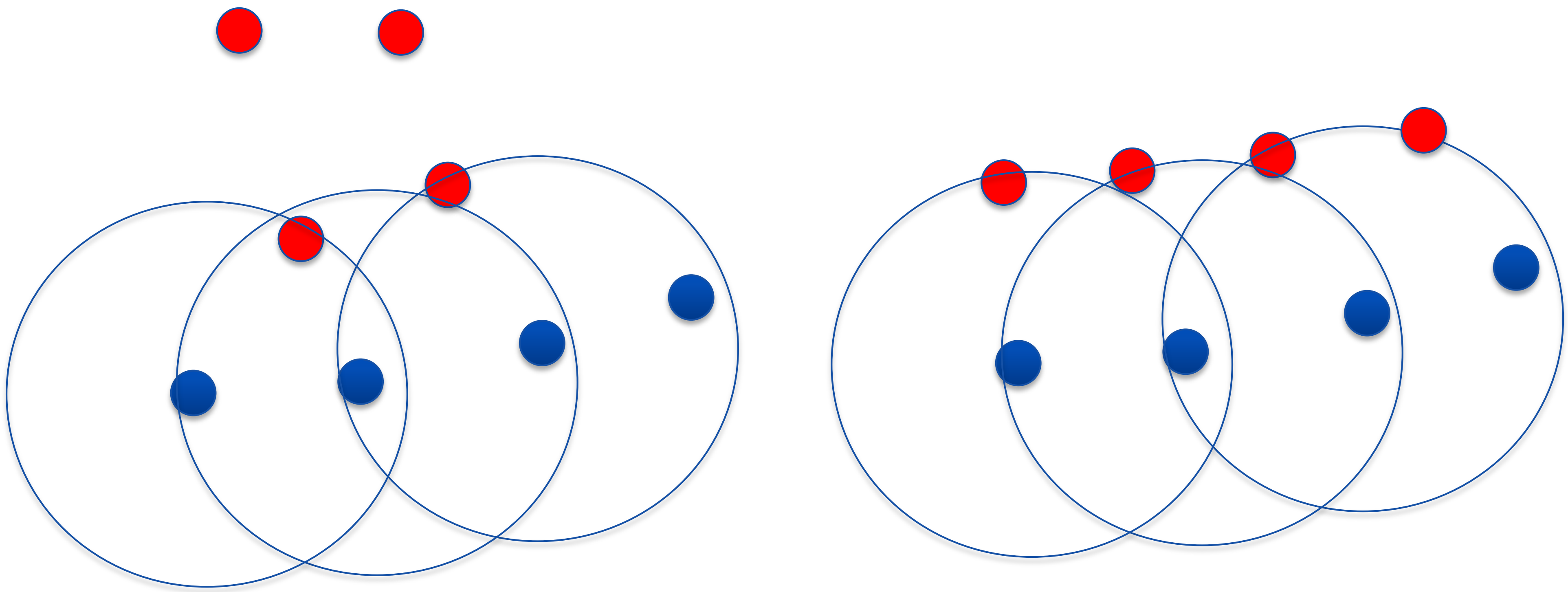
The Police are good at grouping up



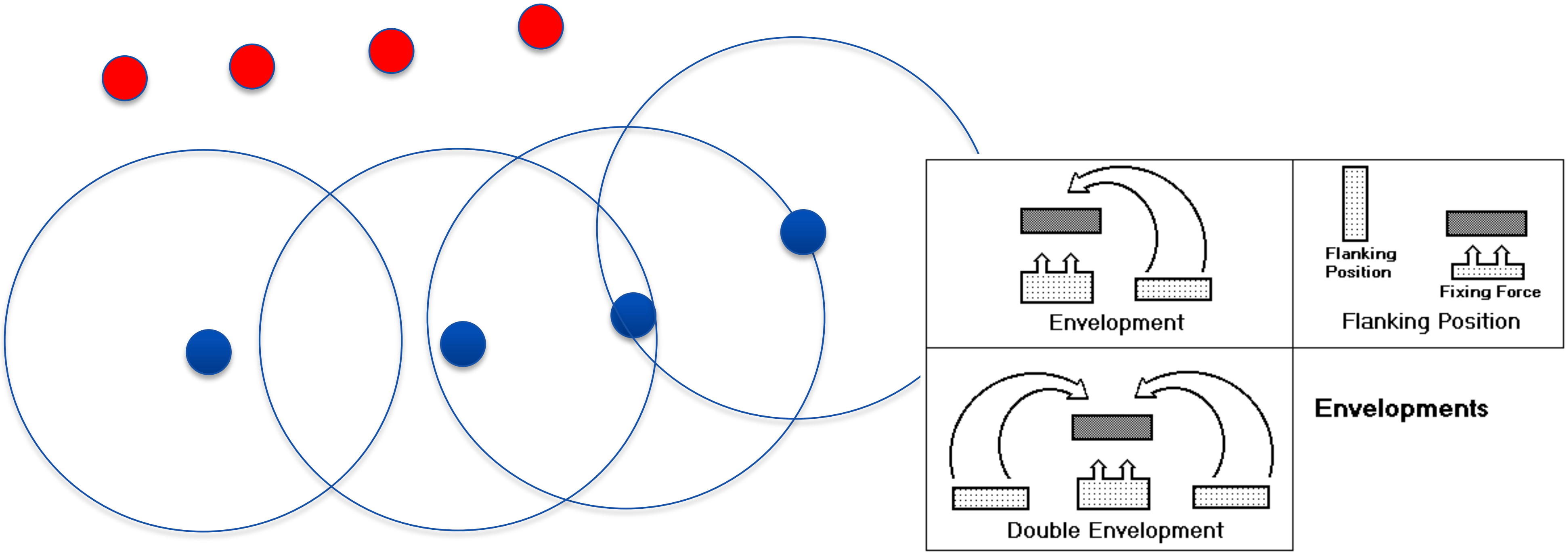
- 30% chance of blue hit
- 83% (1-0.7^5) chance of red hit

Coordinating Firepower: The Line

Coordinating Firepower: The Line



Coordinating Firepower: Flanking



Shooter Coordination

- Minimize risk when moving
- Control when to engage opponents
- Try to achieve firepower advantages (**more agents able to fire**) through
  - Formations
  - Coordinated advances
  - Flanking maneuvers

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Classical Formation Patterns and Flanking Strategies as a Result of Utility Maximization

Edvards Scukins and Petter Ögren

Abstract—In this letter, we show how classical tactical formation patterns and flanking strategies, such as the line formation and the enveloping maneuver, can be seen as the result of maximizing a natural formation utility. The problem of automatic formation keeping is extremely well studied within the areas of control and robotics, but the reasons for choosing a particular formation shape and position is much less so. By analyzing a situation with two adversarial teams of agents facing each other, we show that natural assumptions regarding the target selection of the agents and decreasing weapon efficiency over distance, can be used to optimize a measure of utility over agent positions. This optimization in turn results in formations and positions that are very similar to the ones being used in practice. We present both analytical results for simple examples as well as numerical results for more complex situations.

Index Terms—Cooperative control, game theory, optimization.

(a)

(b) (c)

I. INTRODUCTION

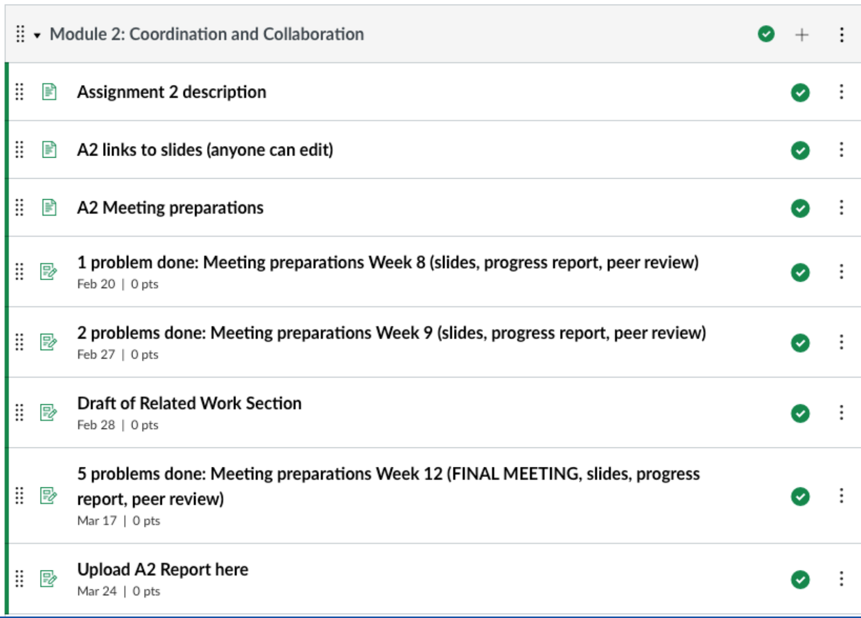
FOR THOUSANDS of years, formations and relative positioning have played a central role in military tactics, from Roman Legionaries to modern tank units and special forces [1].

It is clear that the use of formations is beneficial from an

Fig. 1. (a) Flanking (envelope) tactics, in combination with line forma-

The Problems of Assignment 2

- P1: UAV search or Vacuum Cleaner (Short range)
- P2: Indoor UGV search (Long range)
- P3: Vehicle Routing Problem (VRP)
- P4: Formation sweep
- P5: Shooter Coordination



New groups in Canvas (find your teammate now)