Prioritized Role Assignment for Marking

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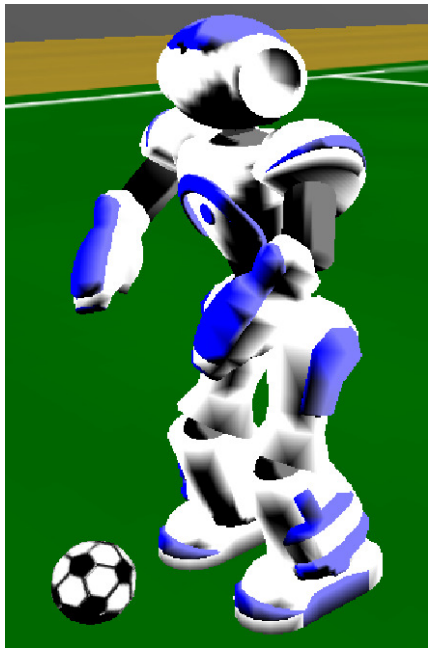
RoboCup 3D Simulation Domain

- Teams of 11 vs 11 autonomous simulated robots play soccer
- Realistic physics using Open Dynamics Engine (ODE)
- Robots modeled after Aldebaran Nao robot
- Robot receives noisy visual information about environment
- Robots can communicate with each other over limited bandwidth channel



RoboCup Gameplay

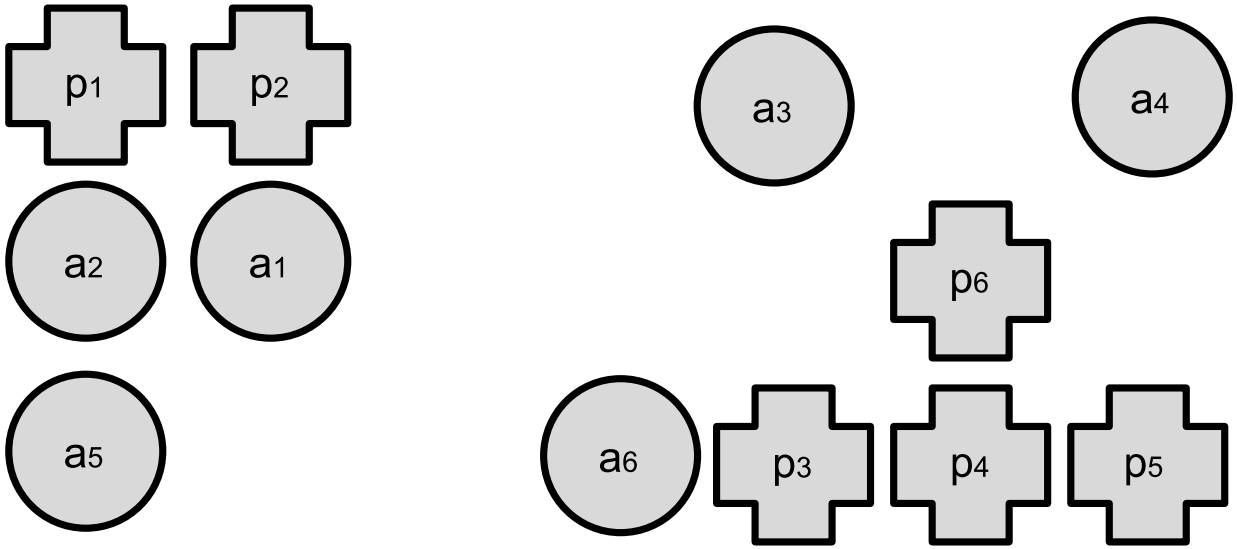
Motivation for Marking

Marking is needed to defend against set plays in the RoboCup 3D simulation league

Outline

- Background
  - Role Assignment Problem
  - SCRAM Role Assignment
- Marking
  - Marking System
  - Prioritized Role Assignment

Role Assignment Problem

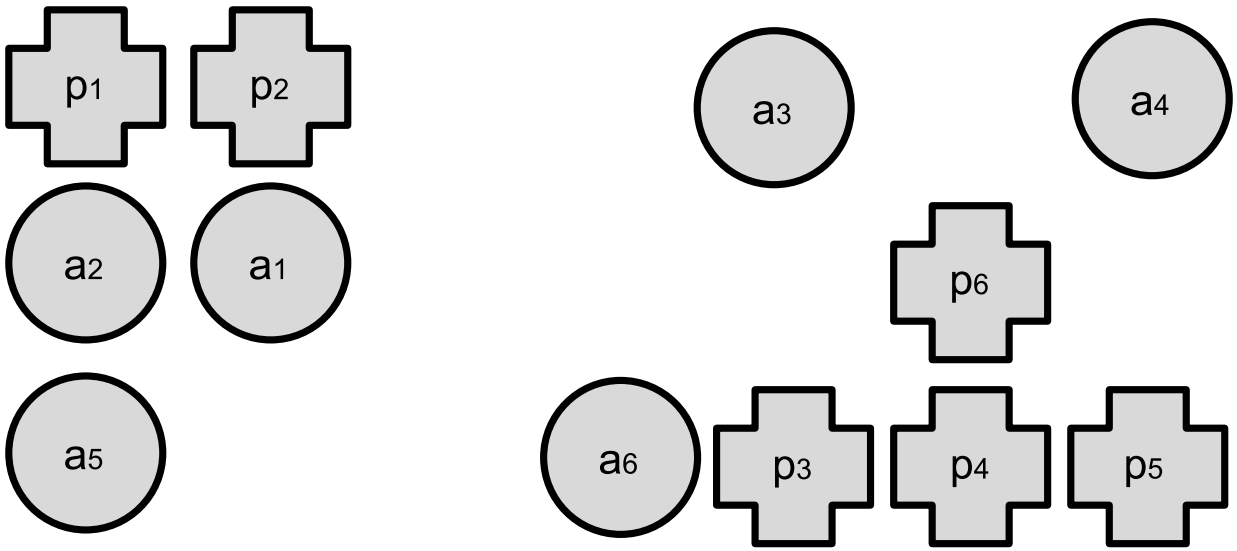


Problem:

How to assign *n* interchangeable robots to *n* targets in a one-to-one mapping so that the makespan is minimized and collisions are avoided.

Makespan = time for all robots to reach their assigned target positions (equivalent to the time for the the robot with the longest distance to travel to reach its assigned target position)

Role Assignment Problem



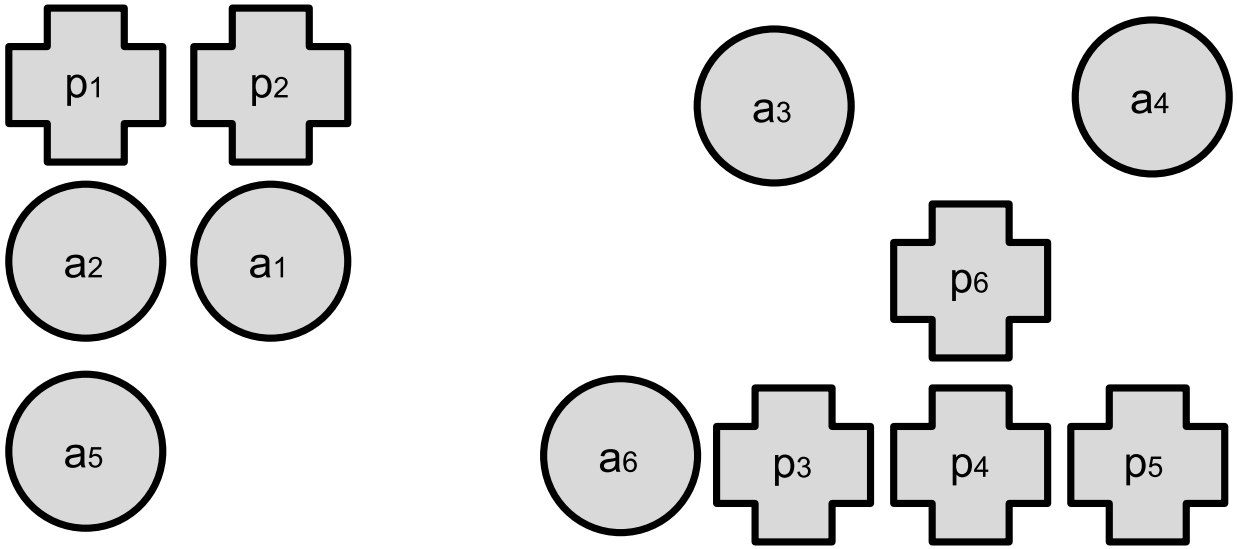
Problem:

How to assign *n* interchangeable robots to *n* targets in a one-to-one mapping so that the makespan is minimized and collisions are avoided.

ASSUMPTIONS:

- No two robots or targets occupy the same position
- Robots are treated as zero width point masses
- Robots move at same constant speed along straight line paths to targets

Role Assignment Problem

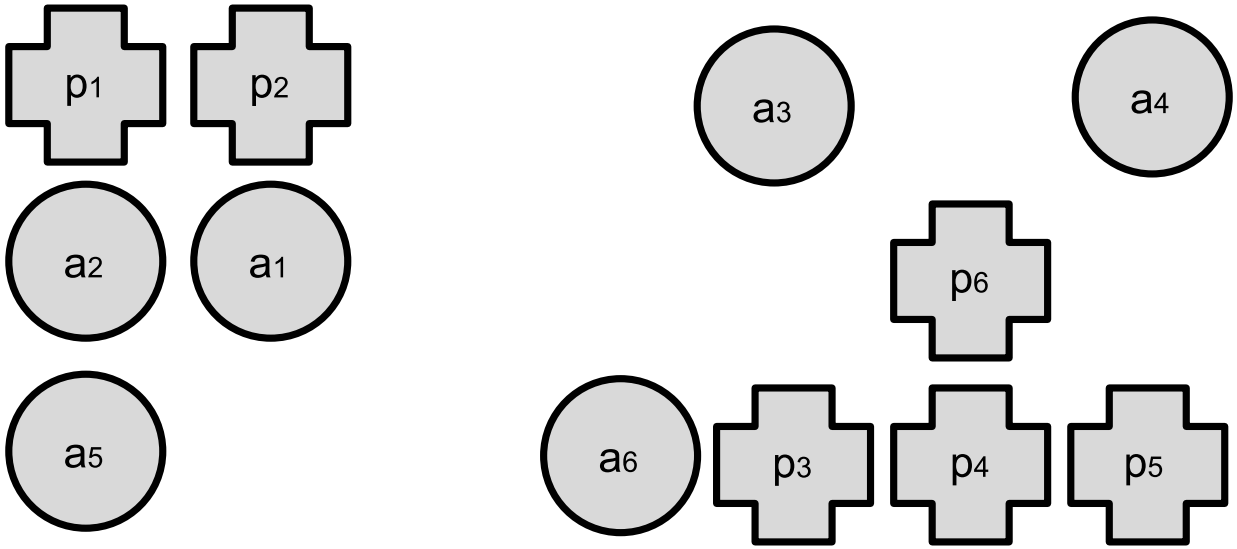


SCRAM: Scaleable Collision-avoiding Role Assignment with Minimal-makespan

Required properties of a role assignment function to be *CM Valid* (Collision-avoiding with Minimal-makespan):

1. *Minimizing makespan* - it minimizes the maximum distance from a robot to target, with respect to all possible mappings
2. *Avoiding collisions* - robots do not collide with each other

Role Assignment Problem



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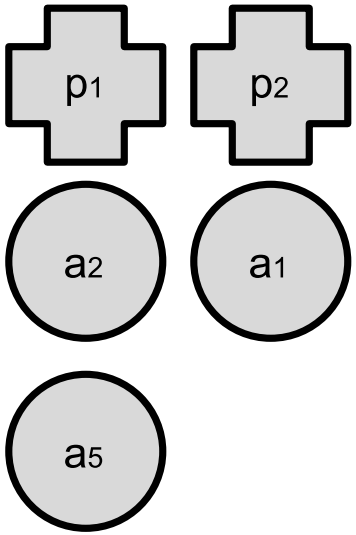
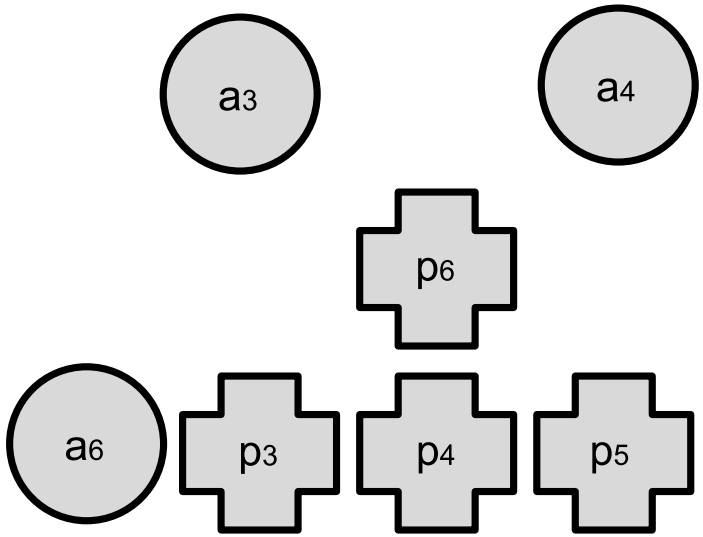
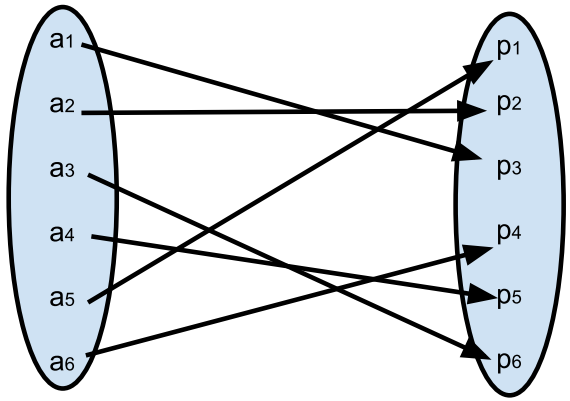
Desirable but not necessary to be *CM Valid*:

3. *Dynamically consistent* - role assignments don't change or switch as robots move toward target positions

Role Assignment Problem



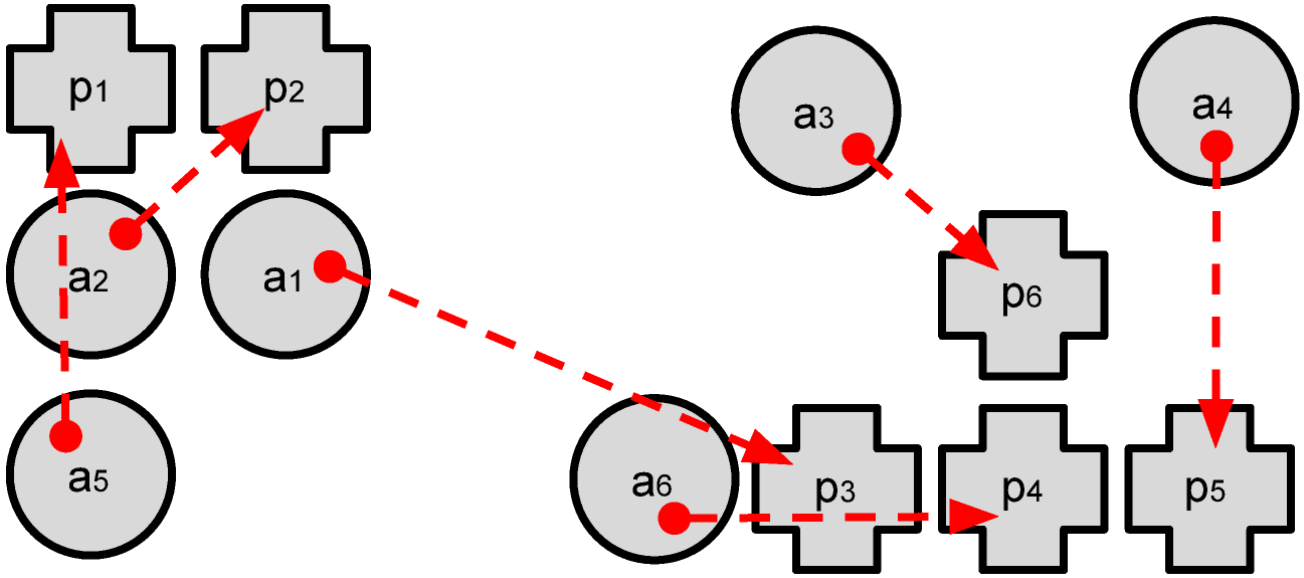




Bipartite Graph Perfect Matching

n! possible mappings

Role Assignment Problem



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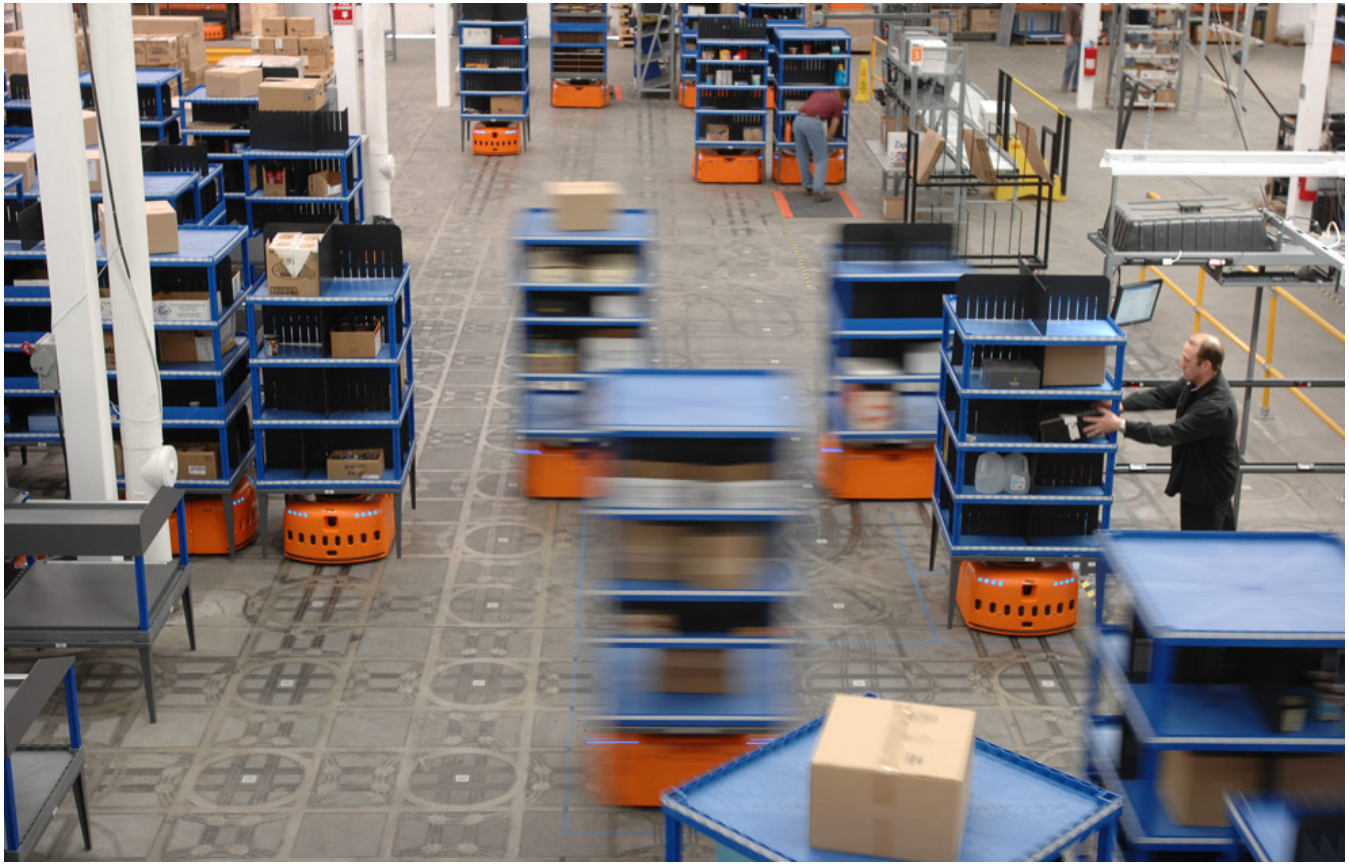
Not include $a_2 \rightarrow p_5$ (longest possible distance), instead $a_1 \rightarrow p_3$ (minimal longest distance)

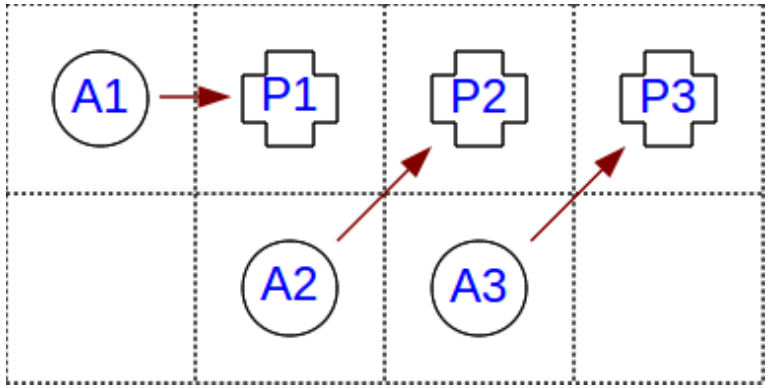
$a_1 \rightarrow p_1$ and $a_2 \rightarrow p_2$ would cause a collision between a_1 and a_2

Motivation for Minimizing the Makespan



- Scenarios for which the bottleneck is the time it takes for the last robot to get to its target (e.g. robots procuring items for an order to be shipped)
- Tasks requiring robots be synchronized when they start jobs at their target positions (e.g. robots on an assembly line)

Minimum Maximal Distance Recursive (MMDR) Role Assignment Function

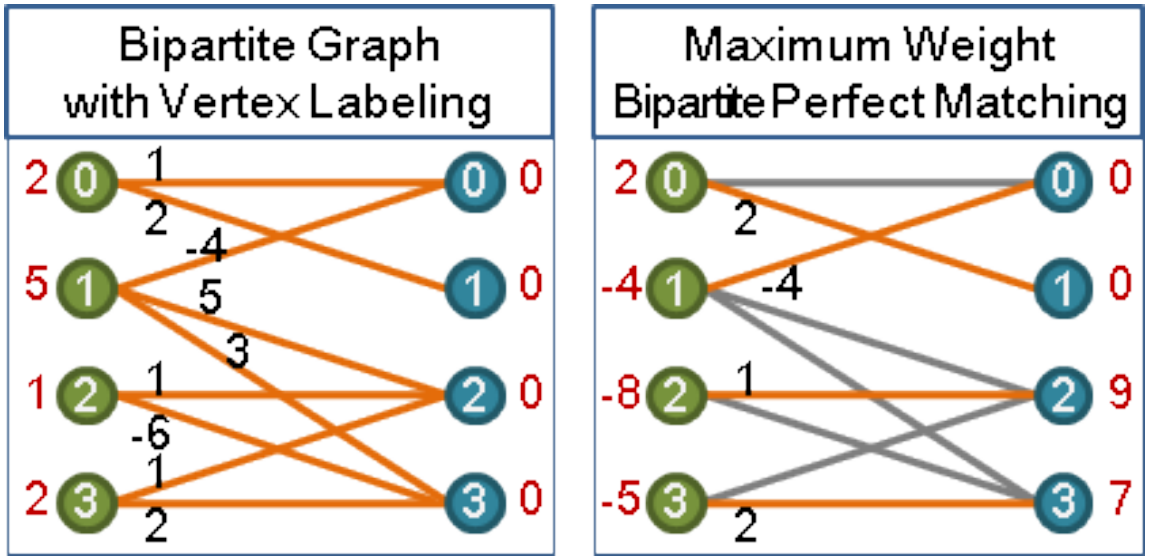


Lowest lexicographical cost (shown with arrows) to highest cost ordering of mappings from agents (A1,A2,A3) to role positions (P1,P2,P3). Each row represents the cost of a single mapping.

1:	$\sqrt{2}$ (A2→P2),	$\sqrt{2}$ (A3→P3),	1 (A1→P1)
2:	2 (A1→P2),	$\sqrt{2}$ (A3→P3),	1 (A2→P1)
3:	$\sqrt{5}$ (A2→P3),	1 (A1→P1),	1 (A3→P2)
4:	$\sqrt{5}$ (A2→P3),	2 (A1→P2),	$\sqrt{2}$ (A3→P1)
5:	3 (A1→P3),	1 (A2→P1),	1 (A3→P2)
6:	3 (A1→P3),	$\sqrt{2}$ (A2→P2),	$\sqrt{2}$ (A3→P1)

- Mapping cost = vector of distances sorted in decreasing order
- Optimal mapping = lexicographically sorted lowest cost mapping

Hungarian Algorithm



- Finds a maximum/minimum weight (sum of weights) perfect matching in a bipartite graph (solves the *assignment problem*)
- Runs in O(n^3) time
- Can leverage Hungarian algorithm to compute MMDR in O(n^5) or O(n^4) time - MMDR scales to 100s of robots

P. MacAlpine, E. Price, and P. Stone. "SCRAM: Scaleable Collision-avoiding Role Assignment with Minimal-makespan for Formational Positioning," in Proceedings of the Twenty-Ninth AAAI Conference on Artificial Intelligence (AAAI), January 2015.

RoboCup 3D Positioning Video

Each position is shown as a color-coded number corresponding to the robots's uniform number assigned to that position. Robots update their role assignments and move to new positions as the ball or a robot is beamed (moved) to a new location.

Key component to winning competition 5 of the past 6 years!

Role Assignment Function Properties

Function Properties

Function	Min. Makespan	No Collisions	Dyn. Consistent
MMDR	Yes	Yes	Yes
MMD+MSD^2	Yes	Yes	No
MSD^2	No	Yes	No
MSD	No	No	No
Greedy	No	No	No
Random	No	No	No

MMDR: Minimize maximal distance between robots and targets recursively.

MMD+MSD^2: Minimize maximal distance and then minimize sum of distances^2 between robots and targets.

MSD^2: Minimize sum of distances^2 between robots and targets.

MSD: Minimize sum of distances between robots and targets.

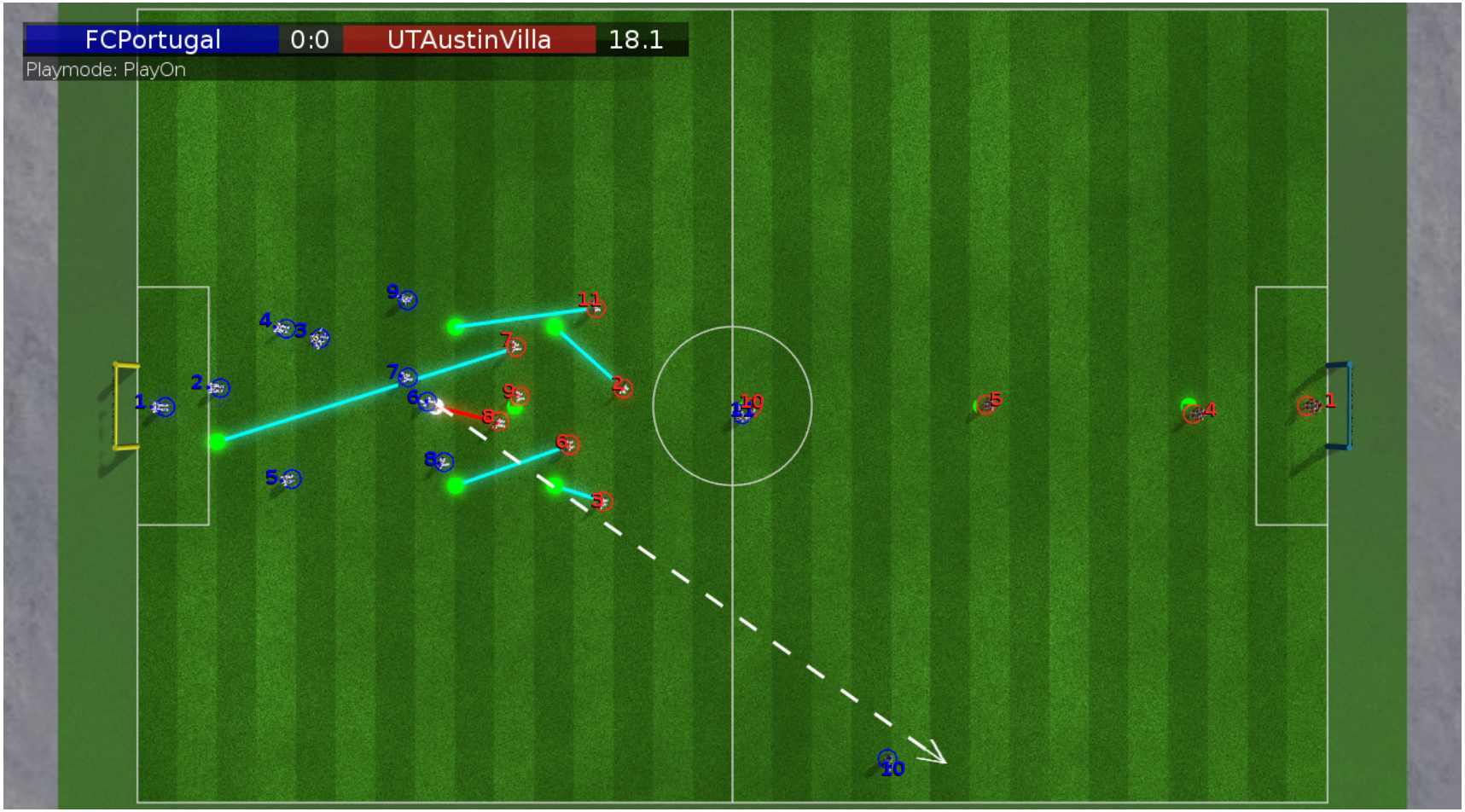
Greedy: Assign robots to targets in order of shortest distances.

Random: Random assignment of robots to targets.

Role Assignment Functions Video

- Yellow robots moving to green targets turn red if they collide
- Robot paths turn light blue if robot switches targets (not dynamically consistent)
- Background turns green when all robots have reached targets (makespan completed)

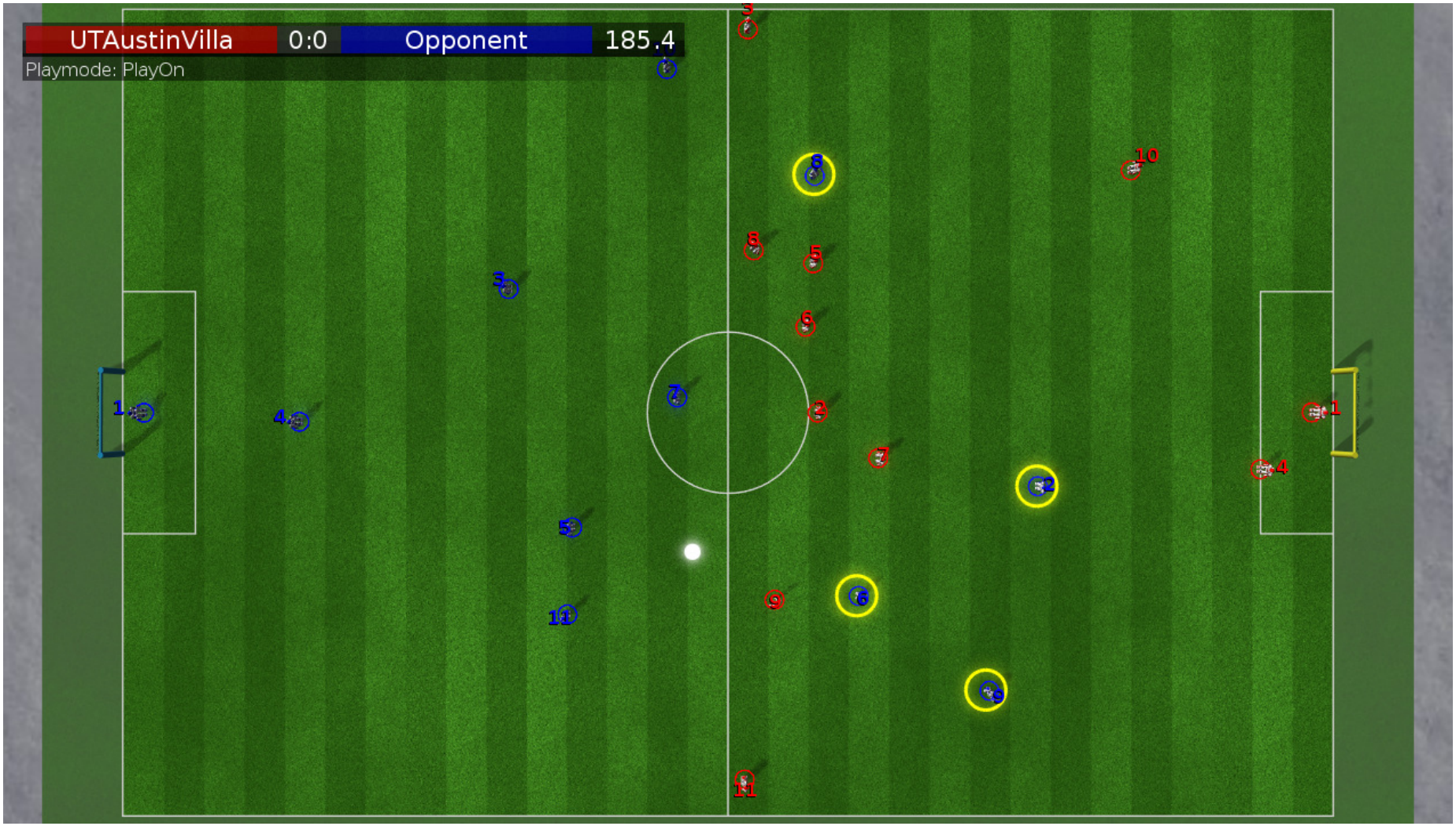
Marking System



Three Step Process:

1. Select Opponents to Mark
2. Select Role Positions for Marking
3. Assign Players to Target Positions

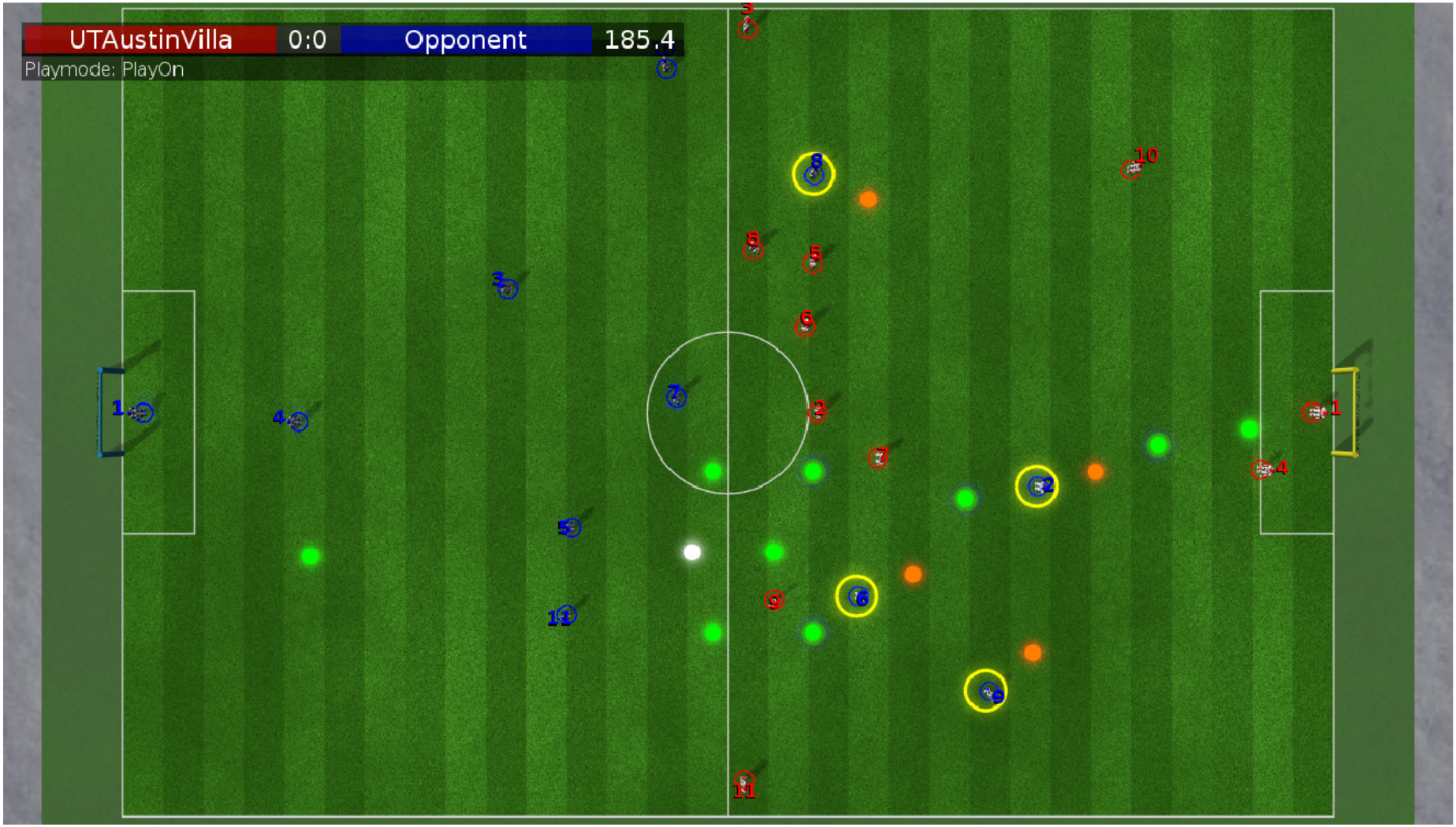
1. Select Opponents to Mark



Opponents selected to be marked circled in yellow

- Mark opponents in dangerous offensive positions based on heuristics

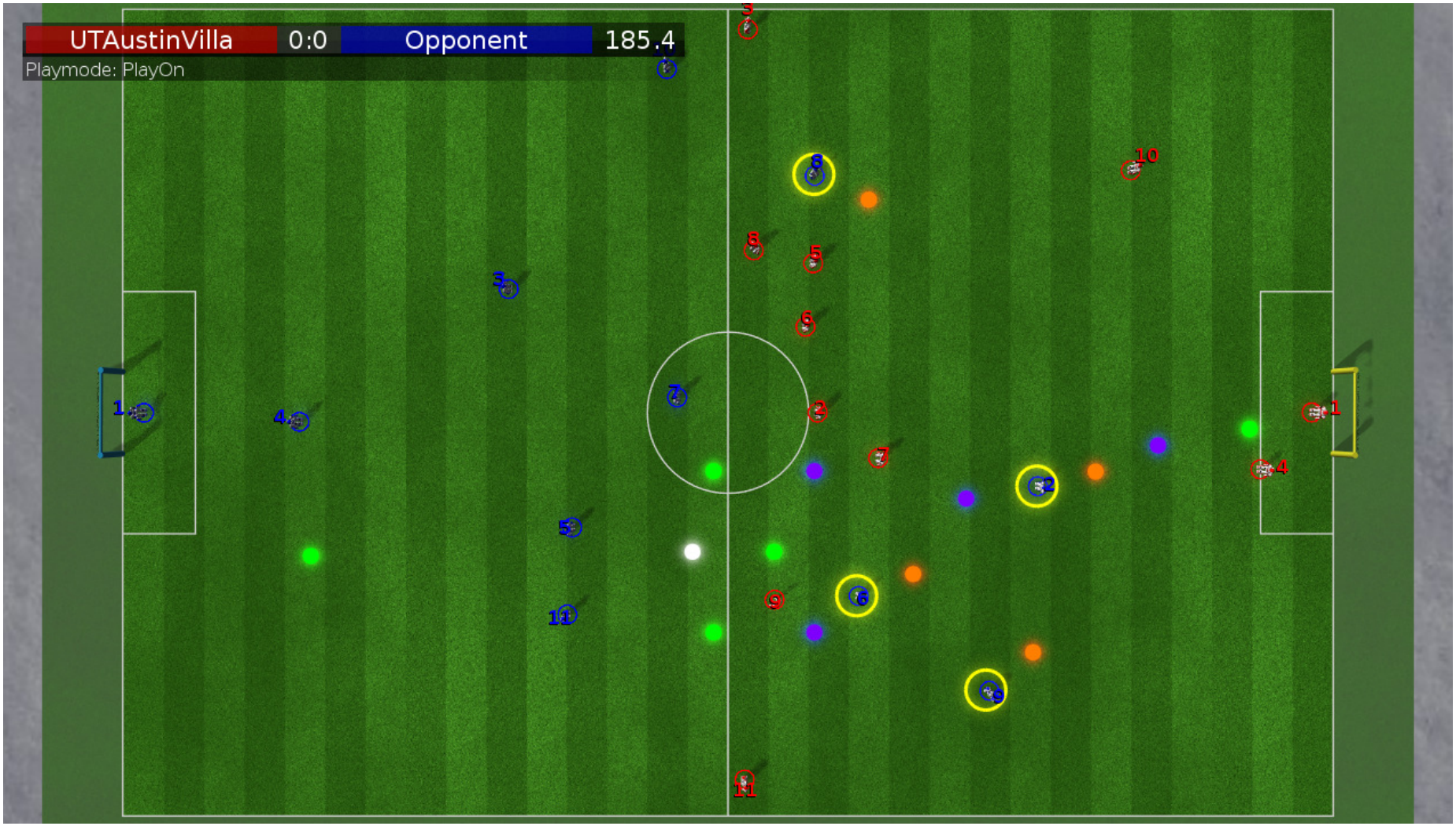
2. Select Role Positions for Marking



Dots: orange = marking, green = formation

- Select set of formation positions to replace with marking positions that minimize sum of distances between marking positions and the positions they replace (Hungarian algorithm)

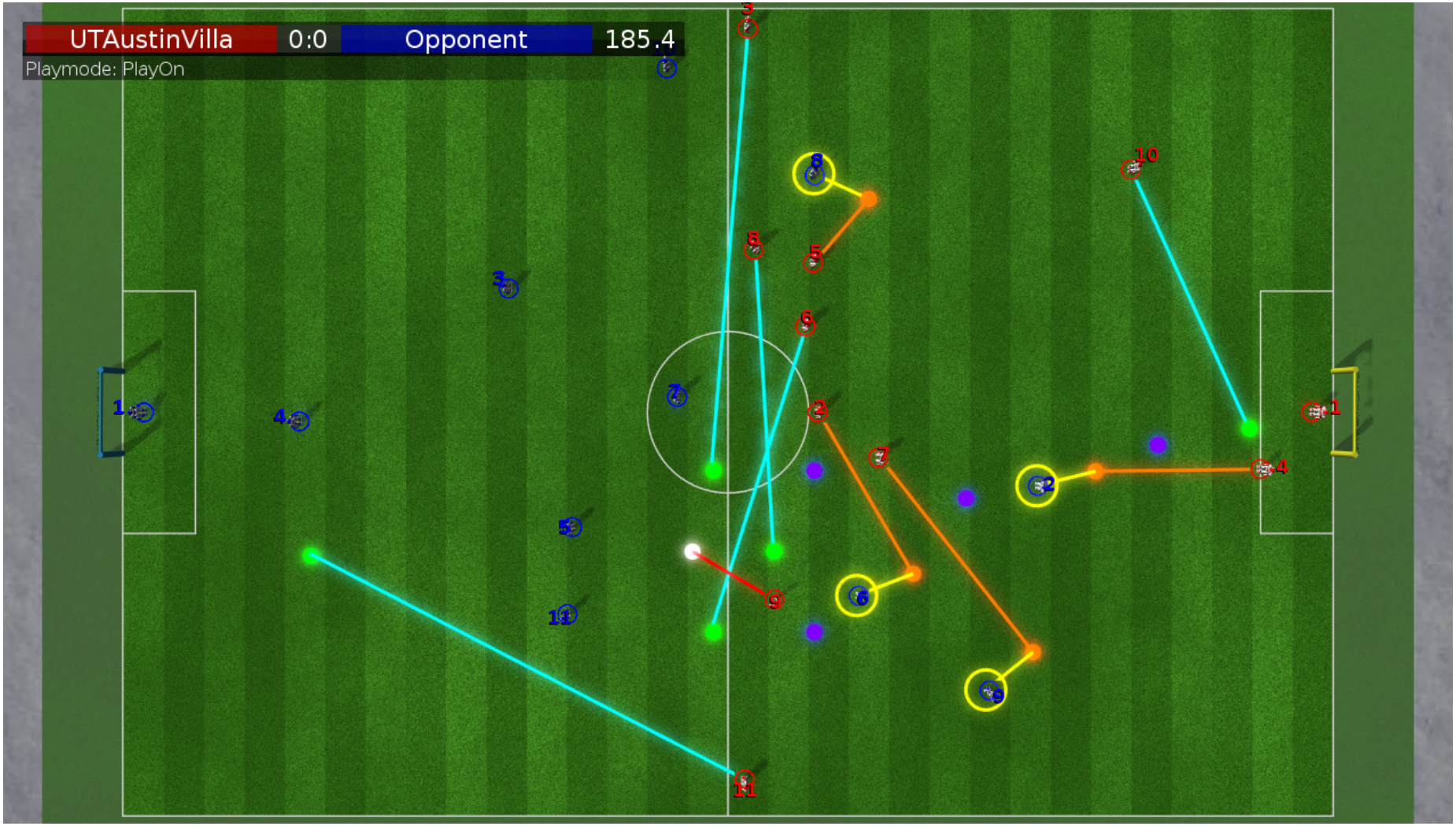
2. Select Role Positions for Marking



Dots: orange = marking, green = formation, purple = replaced

- Select set of formation positions to replace with marking positions that minimize sum of distances between marking positions and the positions they replace (Hungarian algorithm)

3. Assign Players to Target Positions



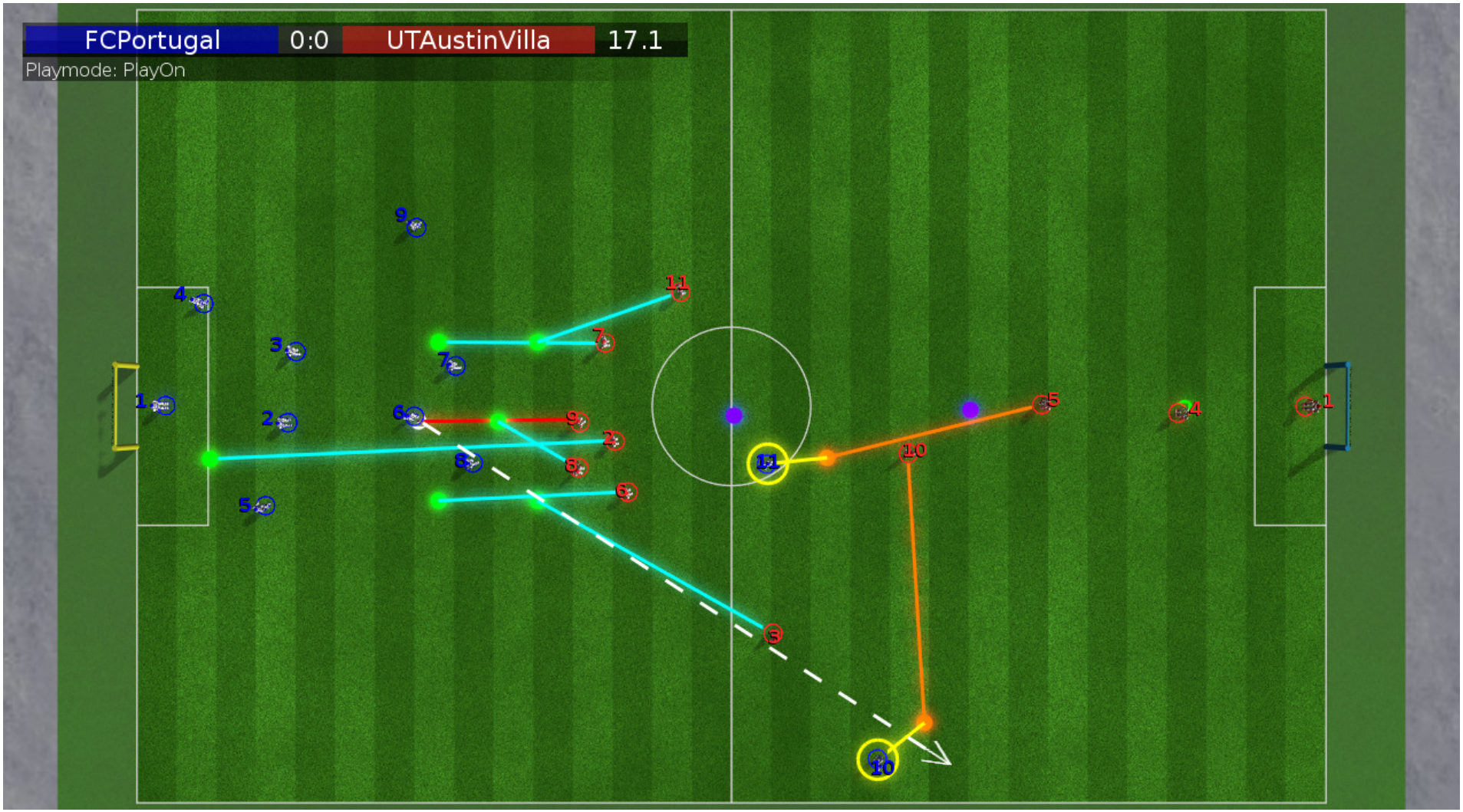
Lines: orange = mark, light blue = formation, red = ball

- Select assignment that recursively minimizes the makespan with SCRAM role assignment

Marking Against FCPortugal Kickoff

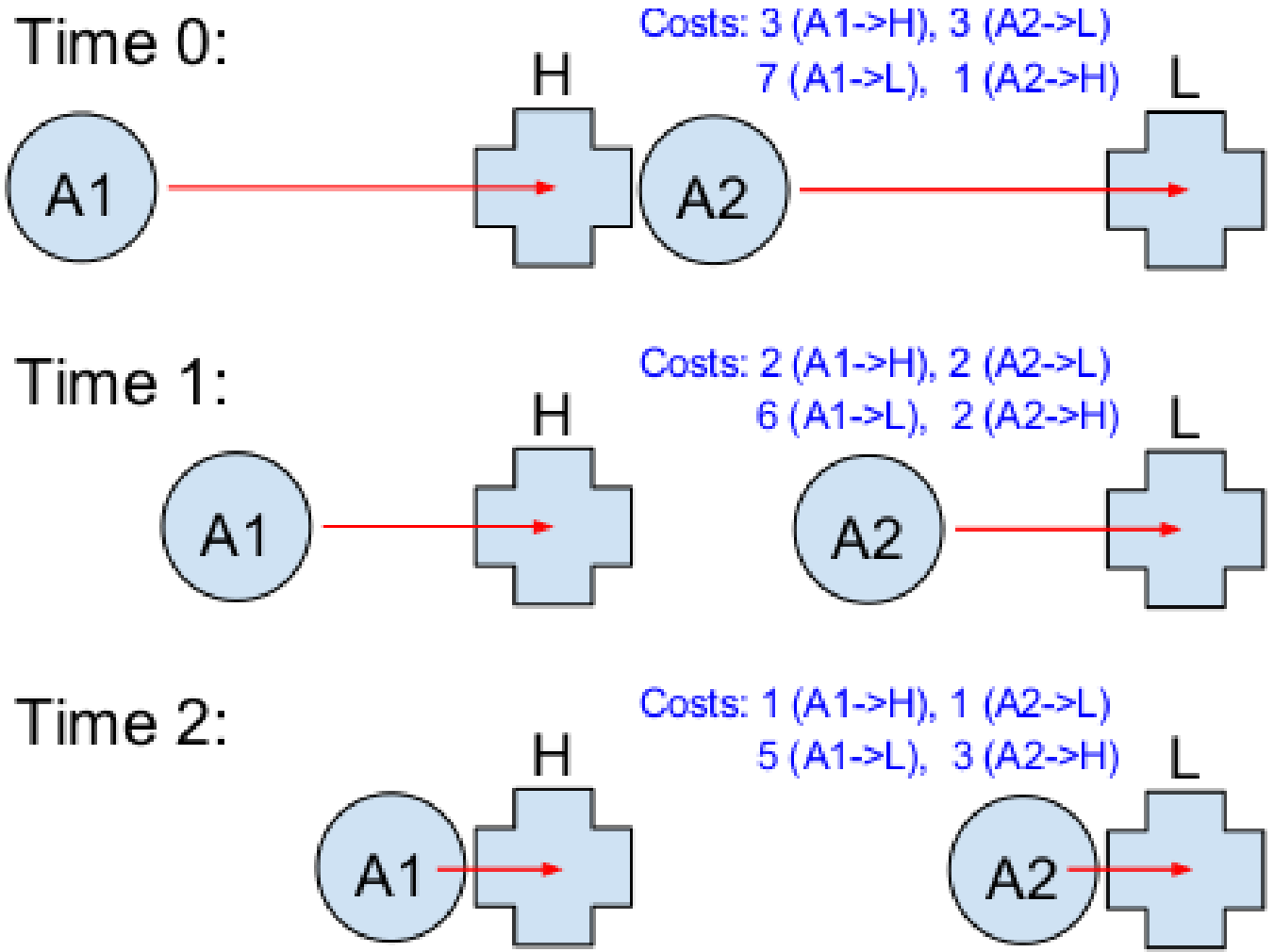
Video

Marking Against FCPortugal Kickoff



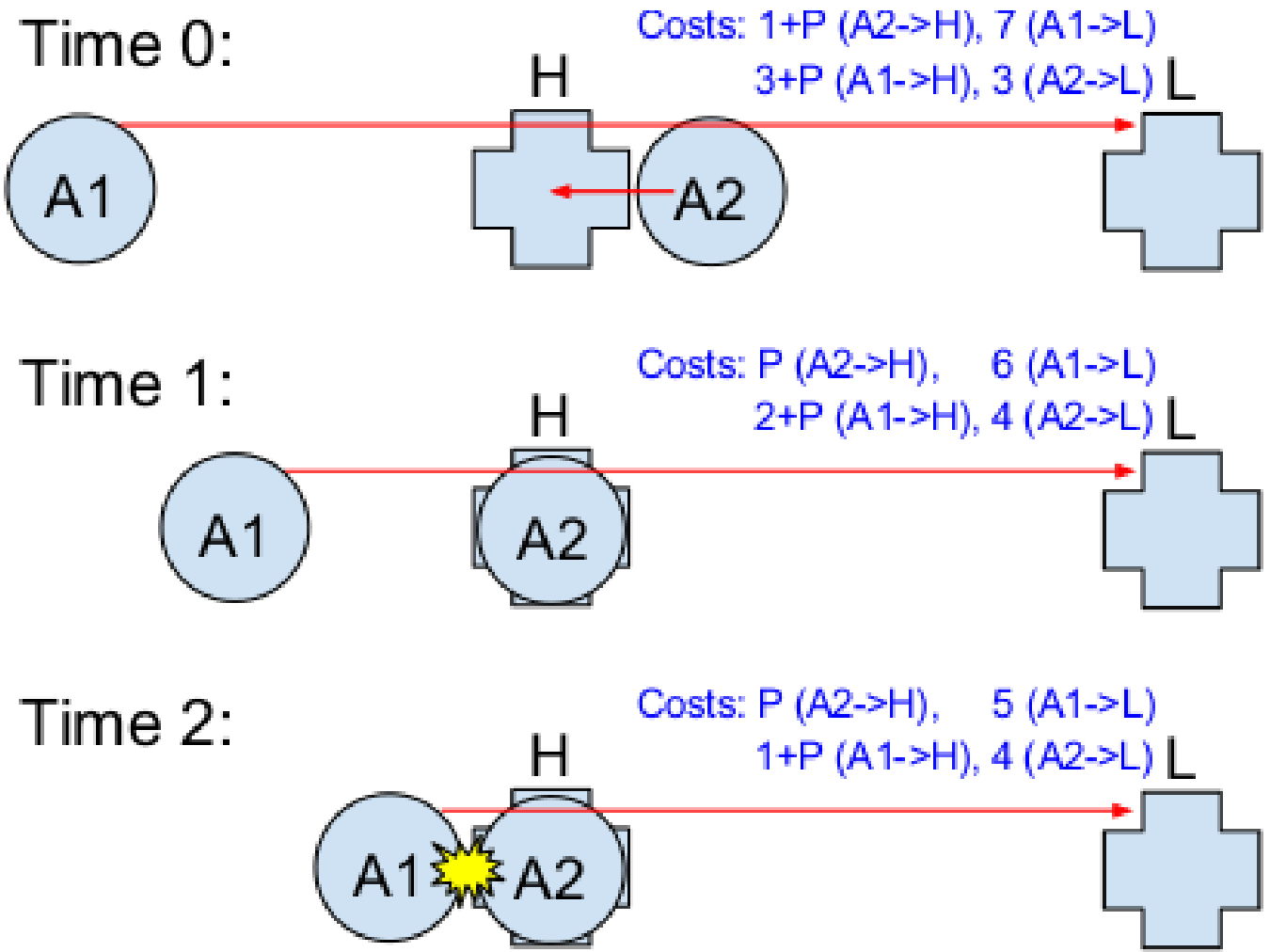
What went wrong?

SCRAM Role Assignment



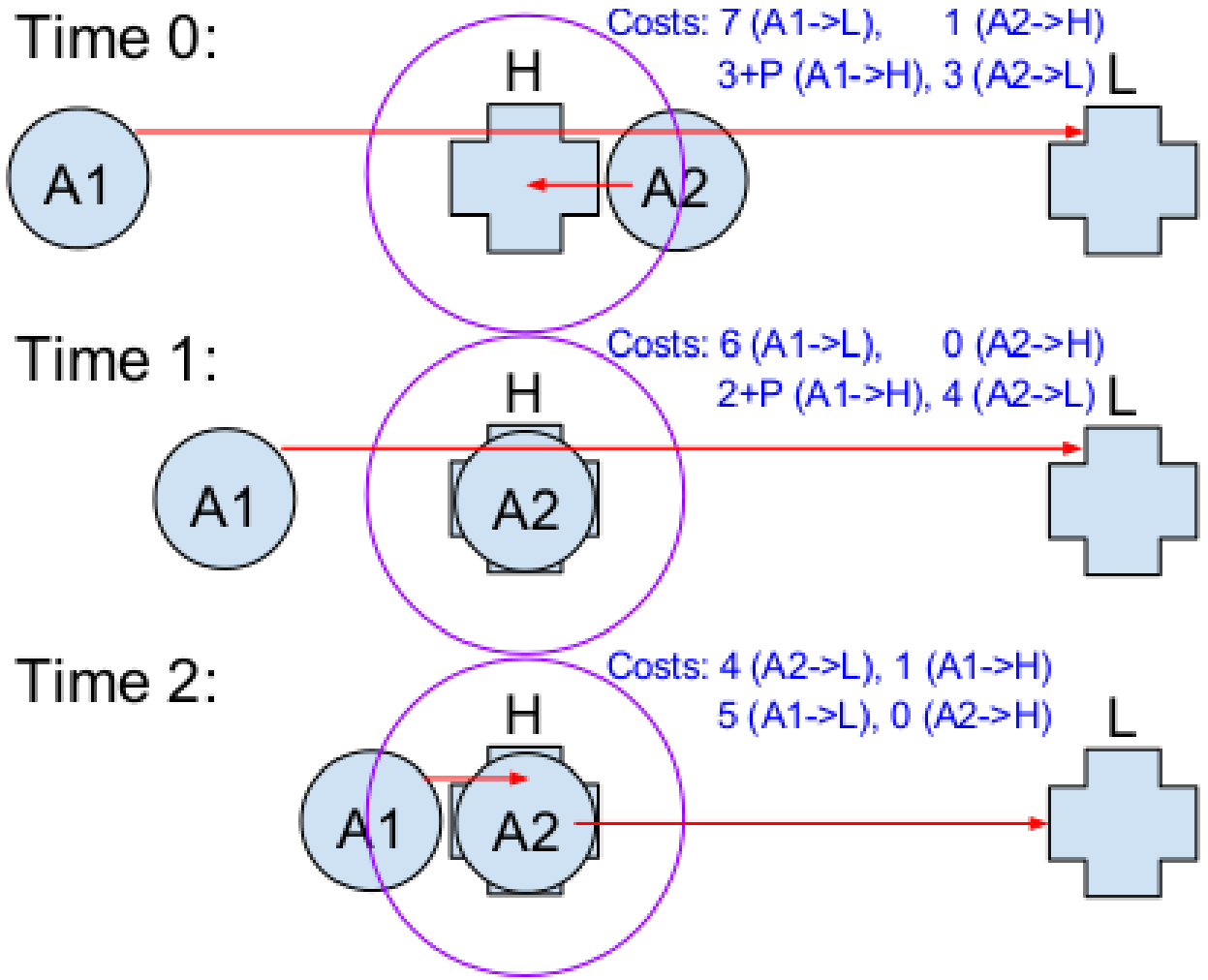
Agents A1 and A2 being assigned and moving to the high priority (H) and low priority (L) target positions using SCRAM role assignment.

Prioritized Role Assignment



Large priority value P added to the costs of reaching high priority targets (H)

SCRAM Prioritized Role Assignment



Large priority value P added to the costs of reaching high priority targets (H) for any agents outside the priority distance of H (purple circle).

SCRAM Prioritized Marking Against FCPortugal Kickoff

Voting Coordination System

- Each agent broadcasts ball position, own position, and suggested role mapping during allotted time slot
- Historesis for players currently being marked
- Historesis for selection of positions to use for marking

Results of Marking

Number of goals against when playing 1000 games against the released binaries of UTAustinVilla and FCPortugal from RoboCup 2015.

Opponent	No Marking	Marking No Prior.	Prior. Marking
FCPortugal	230	40	37
UTAustinVilla	1525	336	319

Scoring percentage of opponents' set plays when playing 1000 games against the released binaries of UTAustinVilla and FCPortugal.

Set Play	No Marking	Marking No Prior.	Prior. Marking
FCP Kickoff	6.22	0.06	0.06
UTA Kickoff	48.31	0.16	0.16
UTA Corner Kick	15.97	12.31	7.59

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Marking big improvement, Prioritized Marking even better!

SCRAM Prioritized Role Assignment Marking Against UTAustinVilla Kickoff

SCRAM Prioritized Role Assignment Marking Against UTAustinVilla Corner Kick

SCRAM Prioritized Role Assignment Summary

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- Minimizes the makespan or longest distance any robot has to travel to higher priority targets

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- Effective in complex RoboCup domain

SCRAM Prioritized Role Assignment Summary

- Minimizes the makespan or longest distance any robot has to travel to higher priority targets
- Avoids collisions between robots
- Role assignment algorithms run in polynomial time and scales to 100s of robots
- Effective in complex RoboCup domain
- Useful for patrol and coverage tasks

Future Work

- Task specialization where robots can only be assigned to a subset of target position
- Heterogeneous robots moving at different varying speeds
- Have robots also avoid known fixed obstacles and model robots as having true mass instead of zero width point mass
  - Concurrent Assignment and Planning of Trajectories (CAPT), Turpin et al.
- Make algorithms distributed
  - Auction algorithms

World Champions, Undefeated Record 14-0
88 Goals For and 1 Goal Against

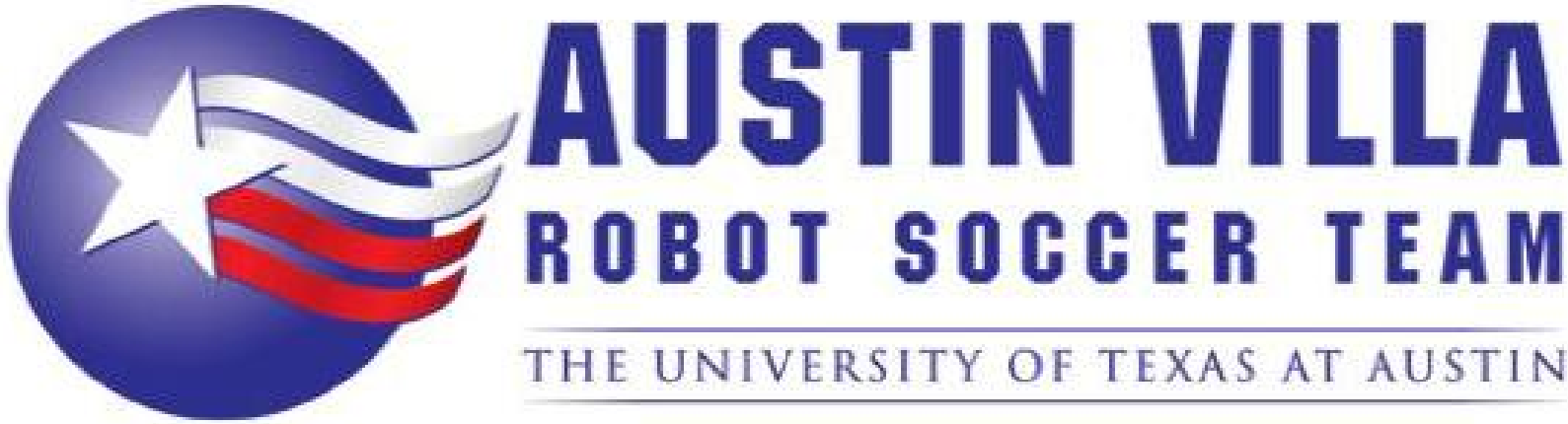
Number of goals against (and percentage of goals scored off set plays) when playing 1000 games against released binaries from RoboCup 2016.

Opponent	No Marking	Marking No Prior.	Prior. Marking
FCPortugal	160 (81.88%)	33 (48.48%)	21 (23.81%)
FUT-K	288 (66.67%)	85 (34.12%)	63 (25.40%)
UTAustinVilla	667 (61.17%)	307 (19.87%)	290 (18.62%)

Marking big improvement, Prioritized Marking even better in reduction of goals against and percentage of goals scored off set plays.

RoboCup 2016 Highlights

More Information



Homepage: www.cs.utexas.edu/~AustinVilla/sim/3dsimulation/
(Google "Austin Villa 3D")

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