Player Behavior and Team Strategy in Robocup Simulation 3D League

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Abstract

In this thesis we present...

Outline of Topics

Robocup Competition

RoboCup is an international robotics competition founded in 1997. The official goal of the project is stated as an ambitious endeavor: “By the year 2050, a team of fully autonomous humanoid robot soccer players shall win the soccer game, complying with the official rule of the FIFA, against the winner of the most recent World Cup”.

Robocup Leagues

Soccer Popular, well-known Rules, cooperative multi-agent systems in dynamic adversarial environments.

Rescue Prompt support for planning disaster mitigation, search and rescue.

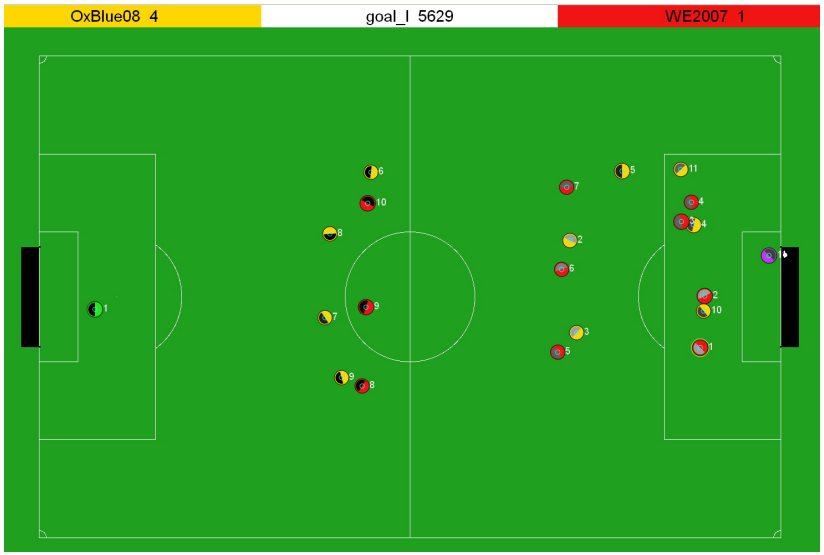
@Home Aims to develop service and assistive robot technology with high relevance for future personal domestic applications.

Junior It is designed to introduce RoboCup to primary and secondary school children

Soccer Simulation League

One of the oldest leagues in RoboCup's Soccer. The Simulation League focus on artificial intelligence and team strategy. Independently moving software players (agents) play soccer on a virtual field inside a computer. There are two sub-leagues: 2D and 3D.

2D vs 3D



3D Simulation Soccer

- At its beginning, the only available robot model was a spherical agent.
- In 2006, a simple model of the Fujitsu HOAP-2 robot was made available, being the first time that humanoid models were used in the simulation league.
- In 2008, the introduction of a Nao robot model to the simulation gave another perspective to the league.
- **SimSpark** is used as the official Robocup 3D simulator.

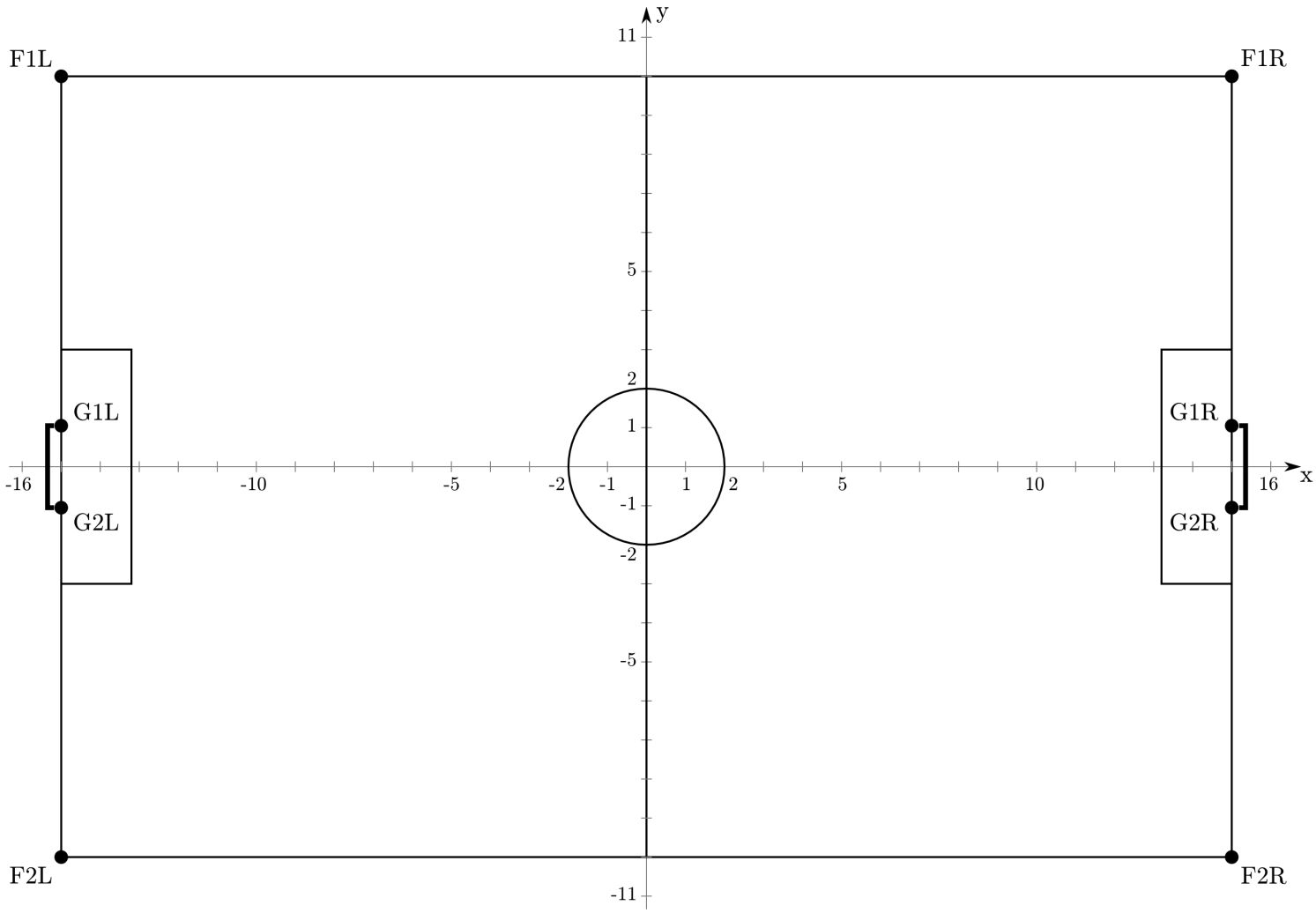
SimSpark

- **SimSpark** is a generic physics simulator system for multiple agents in three-dimensional environments.
- *Rcssserver3d* is the official competition environment for the RoboCup 3D Simulation League. It implements a simulated soccer environment, whereby two teams of up to nine, and in the latest version up to eleven, humanoid robots play against each other.

Server's Versions

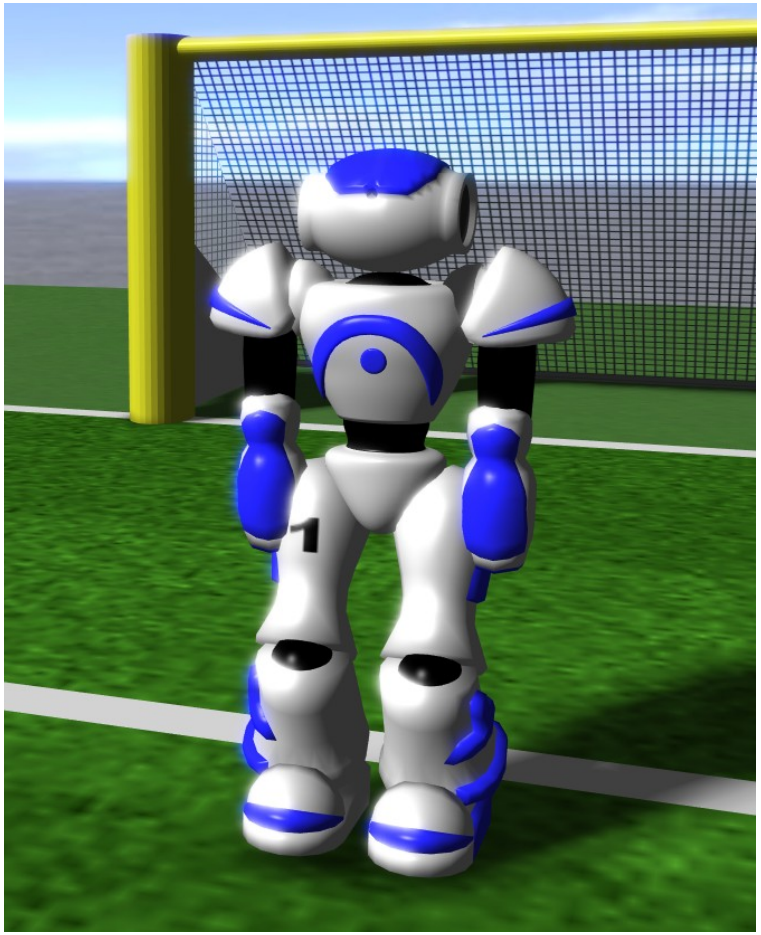
- Version 0.6.5
  - Players 9
  - Length 21m
  - Width 14m
- Version 0.6.6
  - Players 11
  - Length 30m
  - Width 20m

Soccer Field



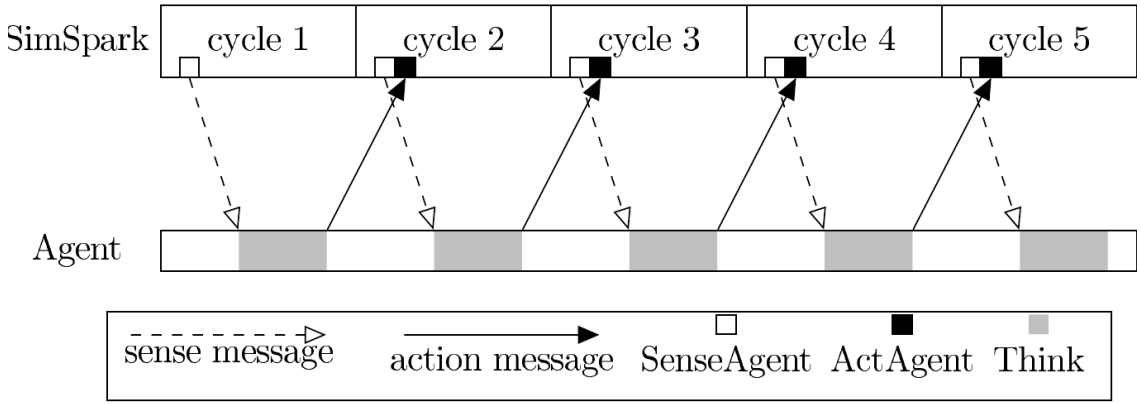
Robot Model

The Nao humanoid robot manufactured by Aldebaran Robotics. Its height is about 57cm and its weight is around 4.5kg. The simulated model comes with 22 degrees of freedom.



Server

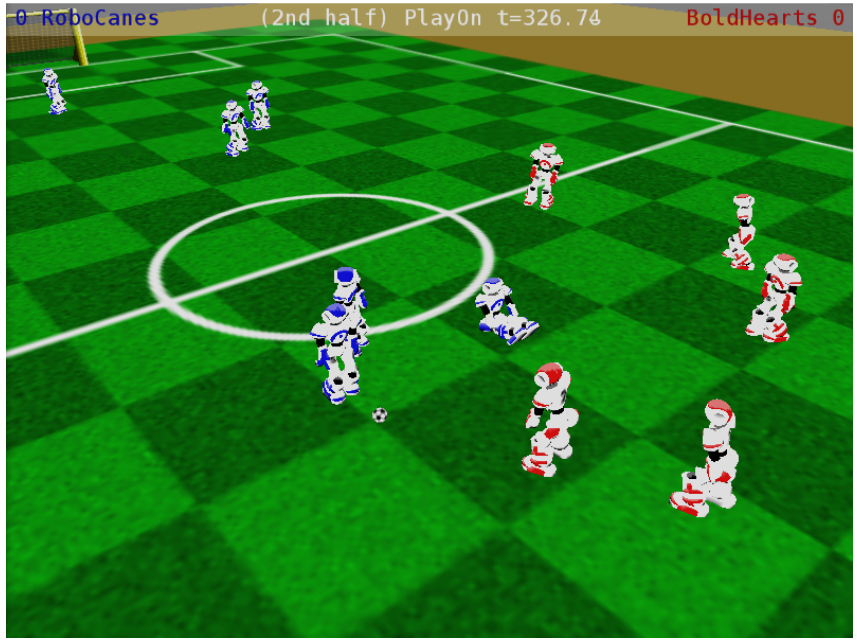
The SimSpark server hosts the process that manages and advances the simulation. The simulation state is constantly modified through the simulation update loop. Each simulation step corresponds to 20ms of simulated time.



Monitor

- SimSpark Monitor
  - Responsible for rendering the current simulation
  - Default SimSpark monitor
- RoboViz Monitor
  - Designed to assess and debug agent behaviors in the RoboCup 3D Simulation League
  - Allow drawing
  - Official monitor of the RoboCup 3D simulation Soccer League

Monitors Comparison



Agent Perceptors I

Perceptors are the senses of an agent, allowing awareness of the agent's model state and the environment.

HingeJoint Perceptor A hinge joint perceptor receives information about the angle of the corresponding single-axis hinge joint.

Message format: `(HJ (n <name>) (ax <ax>))`

Frequency: Every cycle

ForceResistance Perceptor This perceptor informs about the force that acts on a body.

Message format: `(FRP (n <name>) (c <px> <py> <pz>) (f <fx> <fy> <fz>))`

Frequency: Only in cycles where a body collision occurs

GyroRate Perceptor The gyro-rate perceptor delivers information about the change in orientation of a body.

Message format: `(GYR (n <name>) (rt <x> <y> <z>))`

Agent Perceptors II

Frequency: Every cycle

Accelerometer Perceptor This perceptor measures the proper acceleration a body ex- periences relative to free fall.

Message format: `(ACC (n <name>) (a <x> <y> <z>))`

Frequency: Every cycle

Vision Perceptor Vision perceptor delivers information about seen objects in the environment, where objects are either others players, the ball, field lines, or markers on the field.

Message format:
```
(See +(<name> (pol <d> <a1>
<a2>))
+(P (team <name>) (id <ID>)
+(<bodypart> (pol <d> <a1> <a2>)))
+(L (pol <d> <a1> <a2>)(pol <d> <a1>
<a2>)) )
```

Frequency: Every third cycle (60ms)

Agent Perceptors III

Hear Perceptor Hear perceptor serves as an aural sensor and receives messages shouted by other players.

Message format: `(hear <time> self/<direction> <message>)`

Frequency: Only in cycles, where a message is heard

GameState Perceptor The game state perceptor delivers information about the ac- tual state of the soccer game environment.

Message format: `(GS (t <time>) (pm <playmode>))`

Frequency: Every cycle

Agent Effectors I

Effectors allow agents to perform actions within the simulation. Agents control them by sending messages to the server and the server changes the game state accordingly.

Create Effector An agent uses this effector to advice the server to construct the physical representation and all further effectors and perceptors of the agent in the simulation environment according to a scene description file it passes as a parameter.

Message format: `(scene <filename>)`
Frequency: Only once

HingeJoint Effector Effector for all axes with a single degree of freedom.

Message format: `(<name> <ax>)`
Frequency: Once per cycle maximum

Agent Effectors II

Synchronize Effector Agents running in Agent Sync Mode must send this command at the end of each simulation cycle.

Message format: `(syn)`
Frequency: Every cycle

Init Effector The init effector registers the agent as a member of a team with a specific player number.

Message format: `(init (unum <playernumber>) (teamname <teamname>) )`
Frequency: Only once

Beam Effector The beam effector allows a player to position itself anywhere on the field only before any kick-off.

Message format: `(beam <x> <y> <rot>)`
Frequency: Once before each kick-off

Agent Effectors III

Say Effector The say effector permits communication among agents by broadcasting messages in plain ASCII text (20 characters maximum).

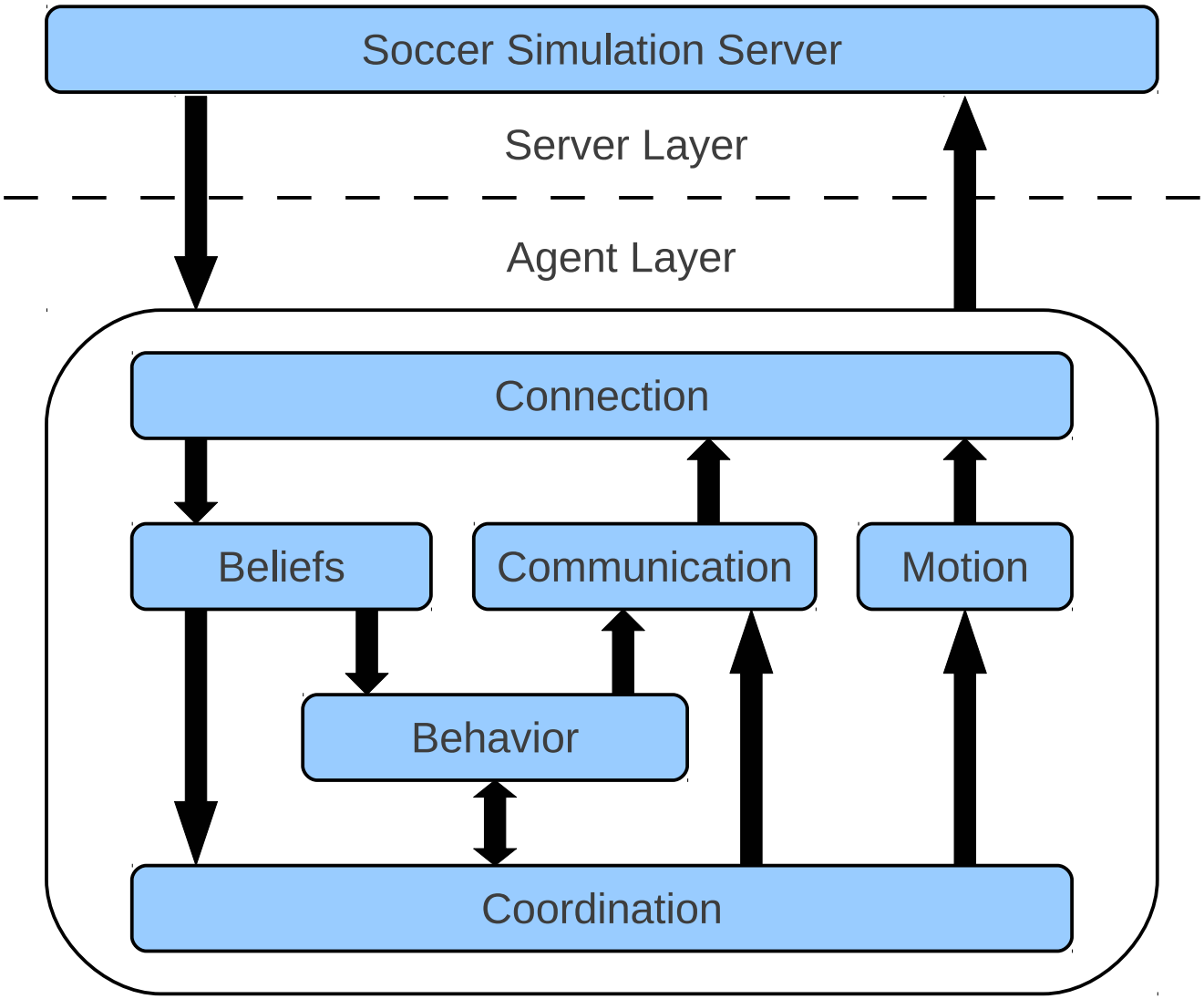
Message format: `(say <message>)`

Frequency: Once per cycle maximum

Architecture

- Connection with Server
- Update Beliefs and Sensors' Data
- Localization Process
- Locomotion
- Actions
- Agent Behavior
- Communication
- Team Coordination

Architecture



Connection

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- Agent receives sense messages from the server every 20ms at the beginning of each simulation cycle.
- Agents willing to send action messages, can do so at the end of their think cycles, which may or may not coincide with the simulation cycles.

Perception

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- Agents do not have to process raw data coming directly from sensors, but rather listen to sensor and higher-level observation messages sent by the server at each cycle.
- Agents update their beliefs and store sensors' data parsing these messages.

Sense Message Example

```
(time (now 46.20))(GS (t 0.00) (pm BeforeKickOff))(GYR (n torso)
(rt 0.00 0.00 0.00))(ACC (n torso) (a 0.00 -0.00 9.81))(HJ (n hj
1)(ax 0.00))(HJ (n hj2) (ax 0.01))(See (G2R (pol 14.83 -11.81 1.
08))(G1R (pol 14.54 -3.66 1.12)) (F1R (pol 15.36 19.12 -1.91))(F
2R (pol 17.07 -31.86 -1.83)) (B (pol 4.51 -26.40 -6.15)) (P (tea
m AST_3D)(id 8)(rlowerarm (pol 0.18 -35.78 -21.65)) (llowerarm (
pol 0.19 34.94-21.49)))(L (pol 8.01 -60.03 -3.87) (pol 6.42 51.1
90 -39.13 -5.17))(L (pol 5.91 -39.06 -5.11) (pol 6.28-29.26 -4.8
8)) (L (pol 6.28 29.34 -4.95)(pol 6.16 -19.05 -5.00)))(HJ(n raj1
) (ax -0.01))(HJ (n raj2) (ax -0.00))(HJ (n raj3)(ax -0.00))(HJ(
n raj4) (ax 0.00))(HJ (n laj1) (ax 0.01))(HJ (n laj2) (ax 0.00)) ...
```

Self-Localization

- Localization is executed every three cycles (60ms).

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  - G1R, G2R
  - G1L, G2L
  - F1R, F2R
  - F1L, F2L

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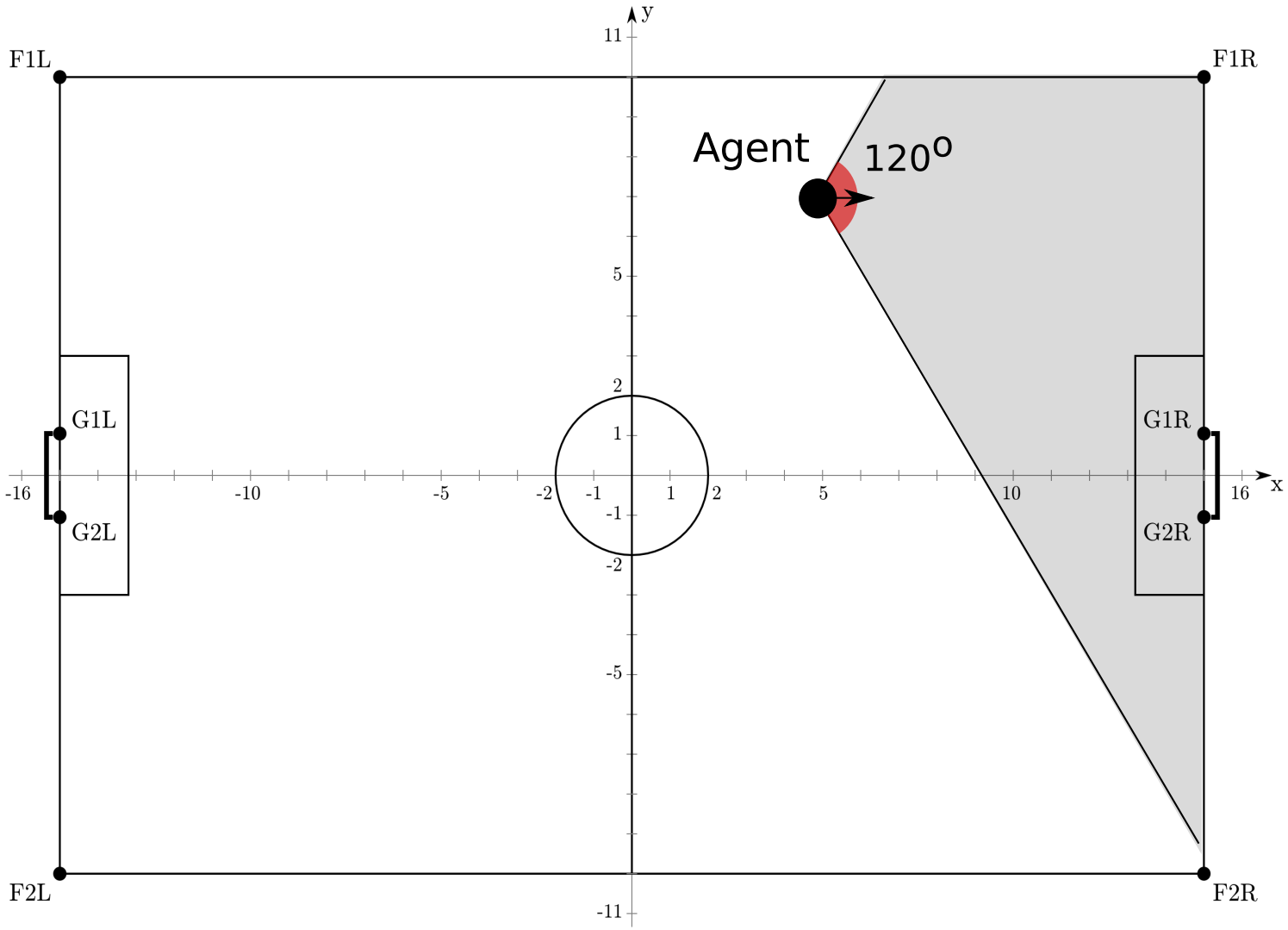
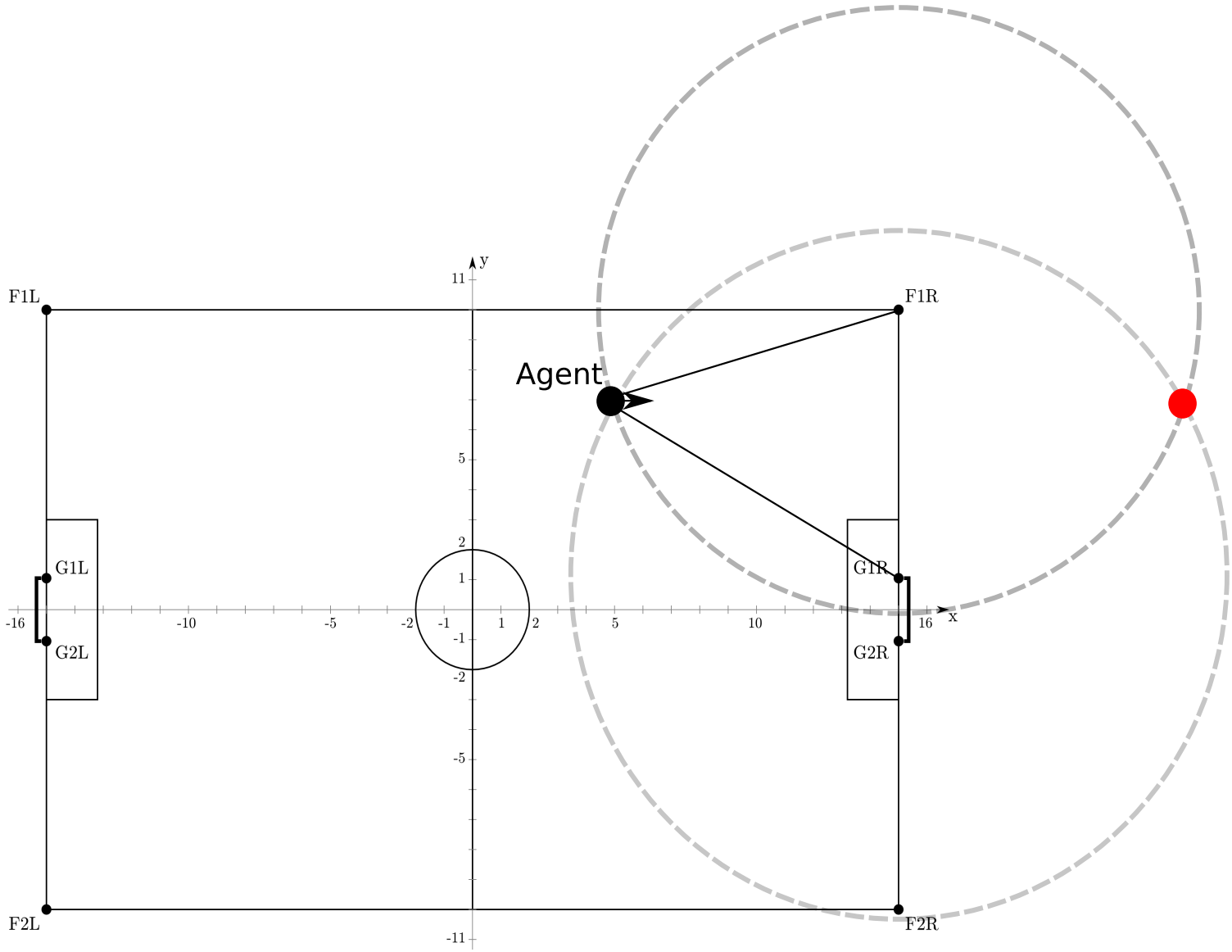
- Localization uses the eight visible landmarks into the field.
  - G1R, G2R
  - G1L, G2L
  - F1R, F2R
  - F1L, F2L
- A key restrictive factor is that the agents are equipped with a restricted vision perceptor which limits the field of their view to 120 degrees.

Simulated Nao's Field of View



Self-Localization Technique



Object Localization

- Computing the position of other visible objects.

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  - Other Players
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- Information about Visible Objects

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  - Distance
  - Horizontal, Vertical Angles

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- Computing the position of other visible objects.
  - Other Players
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- Information about Visible Objects
  - Distance
  - Horizontal, Vertical Angles
- Enough information to compute those objects' positions if we know our exact position.

Localization Filtering

- Absence of a more sophisticated probabilistic localization scheme.

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- Temporary absences of landmarks.
- Noisy observations.

Localization Filtering Algorithm

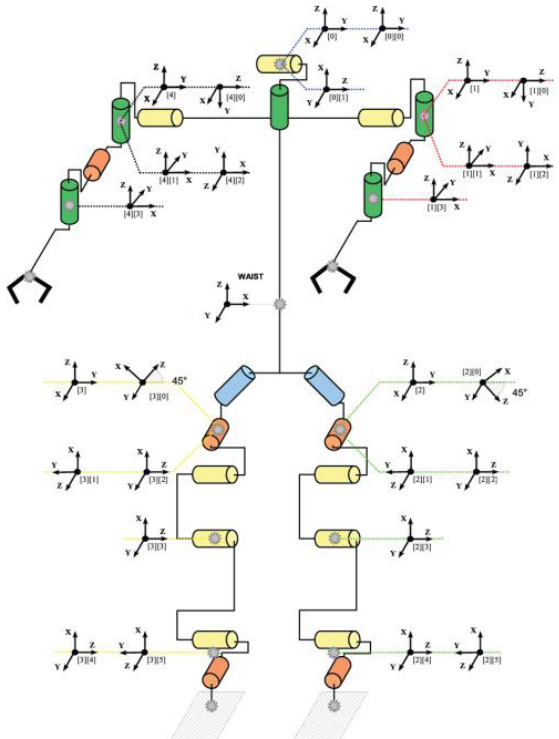
Algorithm 1 Localization Filtering

Input: *LastEstimate*
Output: *FilteredLocation*
Queue: a FIFO queue storing the *MaxSize* (default=10) most recent estimates

if $size(Queue) = 0$ **then**
    $Queue.Add(LastEstimate)$
else if $LastEstimate \not\approx AverageLocation(Queue)$ **then**
    $Queue.Remove()$
else
    if $size(Queue) = MaxSize$ **then**
        $Queue.Remove()$
    end if
    $Queue.Add(LastEstimate)$
end if
return $AverageLocation(Queue)$

Nao's Anatomy

The simulated Nao robot comes with 22 degrees of freedom, corresponding to 22 hinge joints. Figure 4.6 shows Naoćs anatomy with all joints, split in five kinematic chains (head, left arm, right arm, left leg, right leg).



Motion and Movement

In robotics, a complex motion is commonly defined as a sequence of timed joint poses. A pose is a set of values for every joint in the robot's body or in a specific kinematic chain at a given time. For any given set of n joints a pose at time t is defined as:

$$Pose(t) = \{J_1(t), J_2(t), \ldots, J_n(t)\}$$

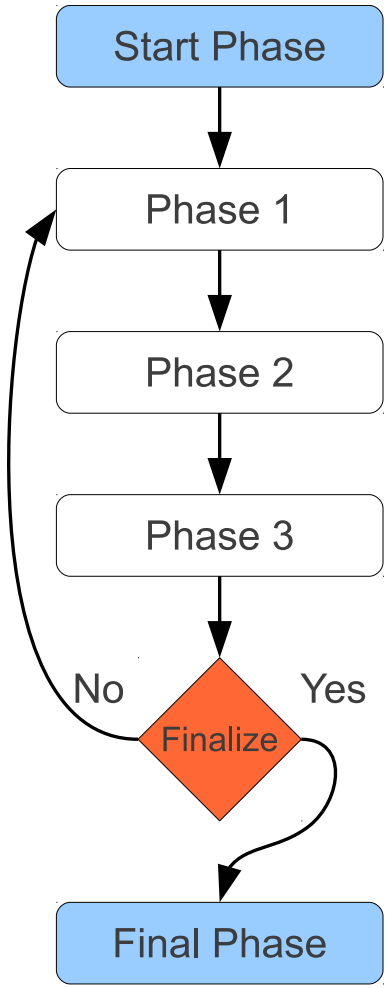
XML-Based Motion Files

```
<phase name="Start" next="Phase1">
   <effectors>
      Joint Values
   </effectors>
   <duration>duration</duration>
</phase>

<phase name="Phase1" next="Phase2">
   <effectors>
      Joint Values
   </effectors>
   <duration>duration</duration>
</phase>

<phase name="Phase2" next="Phase1">
   <effectors>
      Joint Values
   </effectors>
   <duration>duration</duration>
   <finalize>Final</finalize>
</phase>

<phase name="Final">
   <effectors>
      Joint Values
   </effectors>
   <duration>duration</duration>
</phase>
```



XML-Based Motion Controller

To generate motions for our agent we need to create a motion string, which encloses information about each joint's velocity. This velocity is computed as follows:

$$JointVelocity = \frac{DesiredJointValue - CurrentJointValue}{PhaseDuration}$$

A velocity value is calculated for each joint involved in the motion and the final output of the motion controller is sent to the server. In addition, zero velocity is set for every joint not included in the `effector` field of each phase, so that they stop moving.

Text-Based Motion Files

```
#WEBOTS_MOTION,V1.0
LHipYawPitch,LHipRoll,LHipPitch,LKneePitch,LAnklePitch,...
00:00:000,Pose1,0,-0.012,-0.525,1.05,-0.525,0.012,0,...
00:00:040,Pose2,0,-0.011,-0.525,1.05,-0.525,0.011,0,...
00:00:080,Pose3,0,-0.009,-0.525,1.05,-0.525,0.009,0,...
00:00:120,Pose4,0,-0.007,-0.525,1.05,-0.525,0.007,0,...
00:00:160,Pose5,0,-0.004,-0.525,1.05,-0.525,0.004,0,...
00:00:200,Pose6,0,0.001,-0.525,1.051,-0.525,-0.001,0,...
00:00:240,Pose7,0,0.006,-0.525,1.05,-0.525,-0.006,0,...
00:00:280,Pose8,0,0.012,-0.525,1.05,-0.525,-0.012,0,...
00:00:320,Pose9,0,0.024,-0.525,1.05,-0.525,-0.024,0,...
```

Text-Based Motion Controller

The motion controller could be customized easily to perform these motions in different ways. The following parameters can be modified:

Duration The time between poses in simulation cycles. By default, $Duration = 2$.

PoseStep The step for advancing from pose to pose. By default, $PoseStep = 1$, but we can subsample the motion with other values, e.g. for $PoseStep = 2$, we execute pose1, pose3, pose5, ...

The desired velocity of each joint is computed by:

$$JointVelocity = \frac{DesiredJointValue - CurrentJointValue}{Duration \times CycleDuration}$$

A velocity value is calculated for each joint involved in the motion and the final output of the motion controller is sent to the server.

Dynamic Motion Elements

Walk Leaning The XML-based walk motion can be dynamically modified to lean to the right or to the left. This is accomplished by altering the joint values of the (left or right) HipPitch and AnkePitch joints in specific phases of the walk motion.

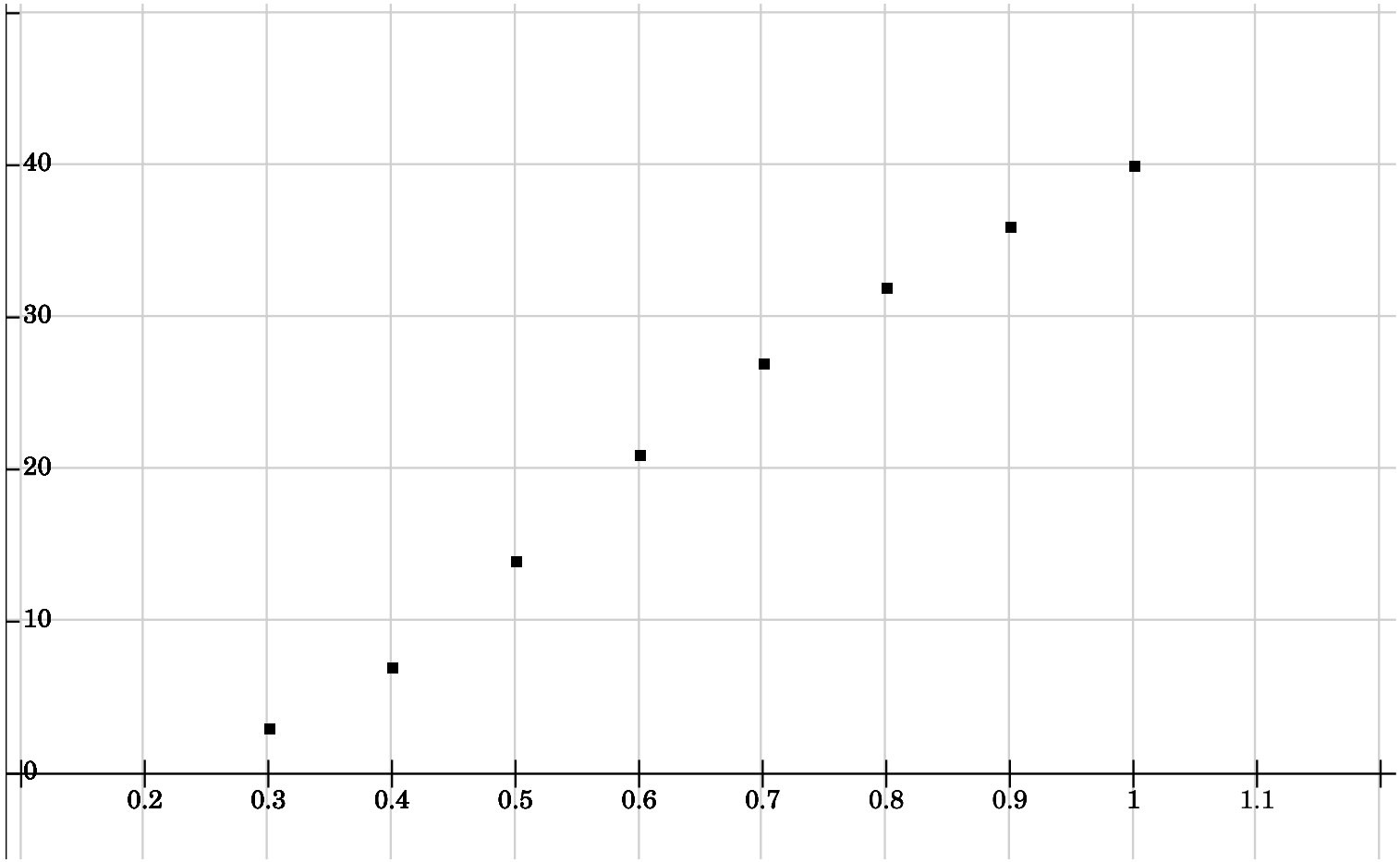
Walk Slowdown Increasing the phase durations dynamically by about 35% yields a smooth approach to a stopping position.

Dynamic Turn The text-based turn motion can be dynamically modified using a gain value for scaling the resulting velocities in order to perform the motion in a smoother or rougher way. By dynamically changing this value between 0.3 and 1.0, the agent is able to turn its body anywhere between 3 and 40 degrees.

Dynamic Turn Example

X-Axis Gain factor

Y-Axis Agent turn



Actions

Actions are split into groups in terms of their complexity:

Basic Actions Basic actions combine perceptual information and motion files in simple ways to achieve something useful.

Complex Actions Complex actions combine perceptual information, motion files, and basic actions. They have a more complicated structure and aim to achieve specific goals.

Simple Actions I

Look Straight Straight Moves the head to its nominal position. Both head joints are set to 0.

Scan Moves the head to perform periodic panning and tilting.

Pan Head Moves the head to perform periodic panning at zero tilt.

Track Object Moves the head to bring a particular object to the center of the field of view. This action is applicable only when the object being tracked is visible, but is limited by the joint ranges.

Simple Actions II

Track Moving Object This action estimates the direction and the speed of a moving object using a small number of observations, obtained while performing the Track Object action. It records a set of five consecutive observations and another set of five consecutive observations delayed by a fixed time period (the default is 5 cycles). The difference between the average positions of each set gives a vector that reveals the direction of motion. Taking the ratio of the magnitude of this vector and the time delay yields the speed of the moving object.

Find Opponentćs Goals This action estimates the direction of the opponent's goal with respect to the agent by performing the Scan action.

Look For Ball Turns the body of the agent, while performing the Scan action, until the ball appears within the field of view.

Simple Actions III

Turn To Ball Turns the body of the agent towards the direction of the ball, while performing the Track Ball action. It can applied only when a ball is visible.

Turn To Localize Turns the body of the agent, while performing the Pan Head action, until the agent's belief about its own location is updated with confidence.

Stand Up Makes the agent stand up on its feet, after a confirmed fall on the ground, whether face-up or face-down. This action monitors the inertial sensors (accelerometers and gyroscopes) to check if our agent has fallen on the ground. Incoming gyroscope and accelerometer values above a specific threshold indicate a possible fall, but this has to be confirmed, because it is not unusual to receive values above threshold due to collisions without a fall. To confirm a fall, the action checks the force resistance perceptors located

Simple Actions IV

under the agent's feet. If these perceptors imply that the legs do not touch the ground, then we are pretty sure that a fall has occurred. In this case, a stand up motion is executed. Foot pressure values are also used to determine whether the stand up motion succeeded or not. The stand up motion is repeated, until it succeeds.

Prepare for Kick Positions the agent to an appropriate position with respect to the ball in order to perform a kick successfully.

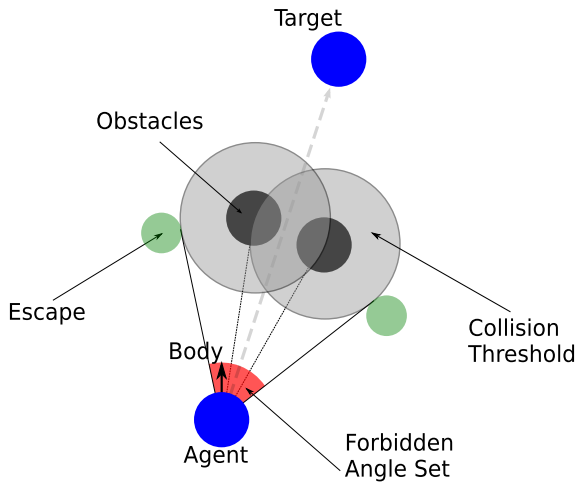
Complex Actions I

Avoid Obstacles Helps agent to avoid possible obstacles.

- Simulated Nao's head can pan from -120° to $+120^\circ$ and the field of view is 120°, we can obtain a complete imaging of all obstacles located close to our agent.
- For each recorded obstacle, we calculate two escape angles that determine the two directions which guarantee avoidance of the obstacle at a safe distance.
- Any escape angle of some obstacle that falls within the forbidden area of some other obstacle is discarded.
- The remaining escape angles, and particularly the escape way points they define (the points closest to the obstacle along the direction of the escape angles), are evaluated in terms of the angle and distance overhead they incur with respect to the agent orientation (for the angle) and the target (for the distance).

Complex Actions II

- The way point that minimizes the total overhead is selected as a temporary target for avoiding the obstacles, while making progress towards the target.



Complex Actions III

Algorithm 2 Escape Angle Set Calculation

Input: $Obstacles = \{O_1, O_2, ..., O_n\}$
Output: $EscapeAngleSet$

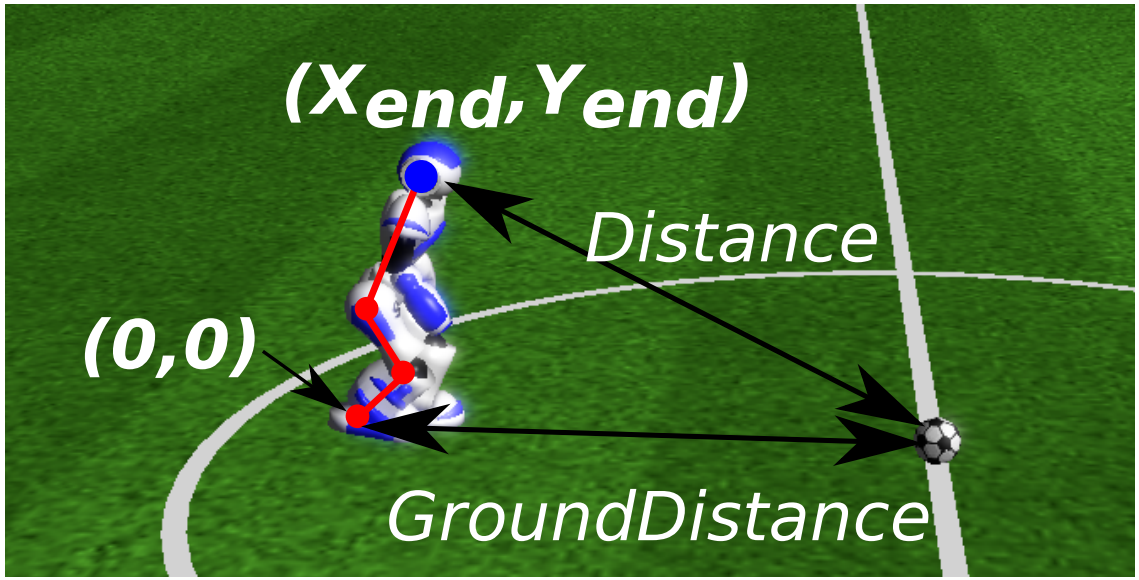
for $i = 1$ **to** n **do**
    find $LeftEscapeAngle_i$ for obstacle O_i
    find $RightEscapeAngle_i$ for obstacle O_i
end for
$EscapeAngleSet = \emptyset$
for $i = 1$ **to** n **do**
    if $LeftEscapeAngle_i \notin [LeftEscapeAngle_j, RightEscapeAngle_j], \forall j \neq i$ **then**
        $EscapeAngleSet = EscapeAngleSet \cup \{LeftEscapeAngle_i\}$
    end if
    if $RightEscapeAngle_i \notin [LeftEscapeAngle_j, RightEscapeAngle_j], \forall j \neq i$ **then**
        $EscapeAngleSet = EscapeAngleSet \cup \{RightEscapeAngle_i\}$
    end if
end for
return $EscapeAngleSet$

Complex Actions IV

Walk to Ball Makes the agent walk towards the ball and stop when the ball is close enough to perform a kick.

- It performs the Turn to Ball action and then walk towards the ball, slowing down when it comes close to the ball.
- Ball distance returned by the vision perceptor is the distance between the camera, which is attached to agent's head, and the ball.
- Forward kinematics along the sagittal plane of the robot to derive the current height of the camera.

Complex Actions V



Having the ball distance and the height of the camera, the ground distance can be easily derived using the Pythagorean Theorem.

$$GroundDistance = \sqrt{BallDistance^2 + CameraHeight^2}$$

Complex Actions VI

On Ball Action This action moves the agent close to the ball and executes an appropriate kick depending on the current state of the game.

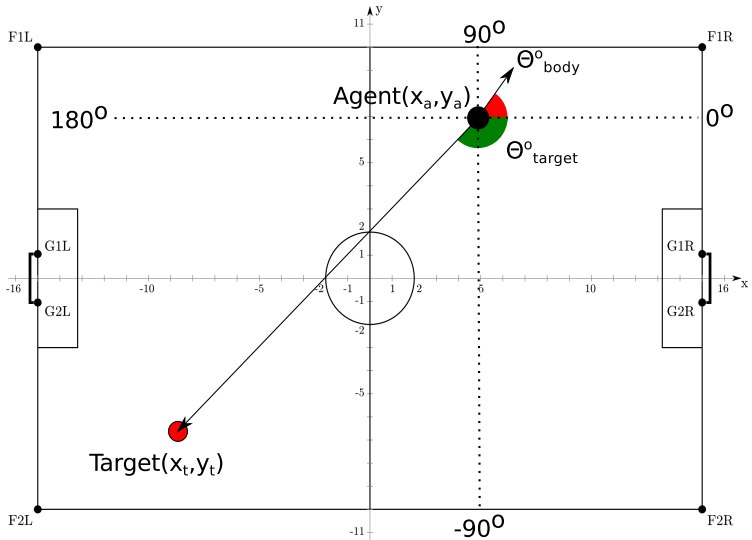
- It first performs the Walk To Ball action in order to reach the ball.
- After the successful completion of the Walk To Ball action, the agent performs the Find Opponent's Goal action.
- Subsequently, it aligns itself with the direction of the opponent's goal.
- The precision of this alignment is inversely proportional to the distance from the opponent's goal.
- Afterwards, it performs the Position for Kick action and finally it executes a kick motion.

Complex Actions VII

Walk to Coordinate This action moves the agent to a specific location (x_t, y_t, θ_t) in the field.

$$\phi = \text{atan2}(x_t - x_a, y_t - y_a)$$

$$d = \sqrt{(x_t - x_a)^2 + (y_t - y_a)^2}$$



Complex Actions VIII

- Distance and direction are recalculated as the agent makes progress toward its target.
- After the position (x_t, y_t) has been reached, a final rotation in place turns the agent towards the desired direction θ_t.
- The action terminates when the agent reaches the desired location (x_t, y_t, θ_t).

Walk To Direction This action makes the agent walk towards a specific direction.

- It employs a turn in-place action to align with the given direction and then a straight walk action to move along the given direction.
- This action is not terminated by itself but there has to be a new action request.

Complex Actions IX

Dribble Ball To Direction This action attempts to dribble the ball towards a specific direction.

- It is quite similar to the Walk To Direction action, however the agent tries to keep the ball in front of its feet at all times.
- This action is not fully functional in our software.

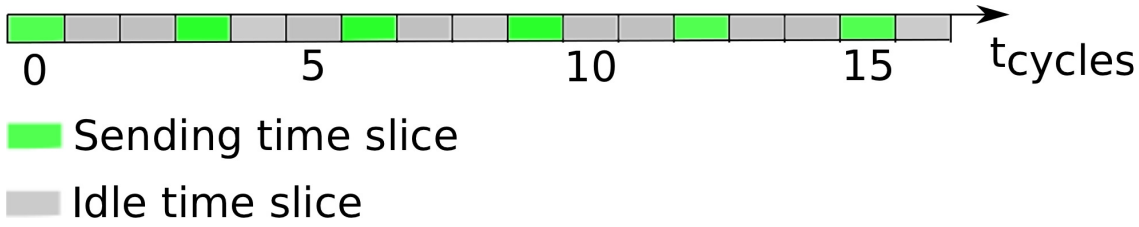
Communication I

Communication in Simspark is not ideal. There are no restrictions about the use of the say effector and every agent can use it at each cycle. However, the hear perceptor comes with some restrictions.

- The agent processes are not allowed to communicate with each other directly, but the agents may exchange messages via the simulation server.
- Messages should not have a length of more than 20 ASCII characters.
- Messages shouted from beyond a maximal distance (currently 50 meters) cannot be heard.
- Only one message can be heard at any given time and messages from the same team can be heard only every other cycle.

Communication II

A simple communication protocol has been created in which time is sliced into pieces lasting one server cycle (20ms) each and repeats every three cycles (60ms).



- Every time slice of the protocol has an associated integer label which indicates the uniform number of the player able to send its message at that slice.
- This label starts at 1 and grows by 1 every time a player sends a message.

Communication III

- Every player can receive reliably the messages from all teammates every 540ms (27 cycles) for a team of 9 players or every 660ms (33 cycles) for a team of 11 players.

Team Coordination I

- Agents miss a thinking process with which they will be able to decide about what action they should do for their team's benefit.
- Instead of each agent having its own behavior, players are depend on a centralized process called team coordination.
- Goalkeeper it the coordination's administrator who is going to execute this procedure.
- Team coordination is accomplished through communication.

Coordination's procedure is executed in several phases and not at once. These phases are:

Update coordination beliefs Multiple world state beliefs from field players have to be combined in order to update our belief for the world state.

Team Coordination II

Split field player into groups Field players are split into groups according to their significance to each game state. These groups are:

- Active
- Inactive
- Support
- Goalkeeper

Compute positions for active players All possible positions which are best candidates for assigning active players.

Assign actions for active players Computation of the best two positions according to their cost.

Generate team's formation Formation is generated according to ball's position into the soccer field.

Assign roles for all players Team players are assigned roles in relation to the team's formation and their current position.

Team Coordination III

Find positions for support players All possible team formation's positions which are best candidates for assigning support players there.

Assign actions for support players Computation of the best mapping according to its cost.

Team Coordination IV

Algorithm 3 Coordination Algorithm

Input: $CoordinationMessages = \{M_1, M_2, ..., M_{N-1}\}, N = numberofplayers$
Output: $Actions = \{A_1, A_2, ..., A_{N-1}\}$
if $Step = 1$ **then**
    $B \leftarrow UpdateBeliefs()$
else if $Step = 2$ **then**
    $S \leftarrow CoordinationSplitter(B)$
else if $Step = 3$ **then**
    $A_p \leftarrow ActivePositions(B, S)$
else if $Step = 4$ **then**
    $A_c \leftarrow ActiveCoordination(A_p, S)$
else if $Step = 5$ **then**
    $F \leftarrow TeamFormation(B)$
    $R \leftarrow RoleAssignment(A_c, B, F)$
    $S_p \leftarrow SupportPositions(R, F, S)$
else if $Step = 6$ **then**
    $SupportCoordination(R, F, S, B, A_c, S)$
end if

Messaging I

Types of messages:

Init Message This type of message declares the initialization for each agent into the field.

Message format: `i,<Uniform number>`

Start Message This type of message is only sent by the administrator, it declares that all agents are now initialized in the process.

Message format: `s,<Uniform number>`

Messaging II

Coordination Message This is the most important type of message. It includes information about each agent's beliefs. There are four types of these messages in respect to the agent's situation in the game. these types are:

Type C Agent has complete awareness of the world state. He sends his uniform number, his position and the ball's position accurately.

Message format: `c,<Uniform number>,<Agent X>,<Agent Y>,<Ball X>,<Ball Y>`

Type L Agent has complete awareness only for his position in the field, ball is not in his field of view.

Messaging III

Message format: `l,<Uniform number>,<Agent X>,<Agent Y>`

Type B Agent has complete awareness only about the ball's distance from his body, its horizontal, and its latitudal angle.

Message format: `b,<Uniform number>,<Ball Distance>,<Ball Horizontal-Angle>`

Type X Agent has complete unawareness of the world state.

Message format: `x,<Uniform number>`

Messaging IV

End Message This type of message serves to stop field players from sending coordination messages.

Message format: `e,<Uniform number>`

Action Message These messages are only sent by the administrator in the end of the coordination procedure, when actions for all field players have been computed.

Message format: `a,<Uniform number>,<Action ID>,<Action parameter 1>, <Action parameter 2>,<Action parameter 3>`

Messaging V

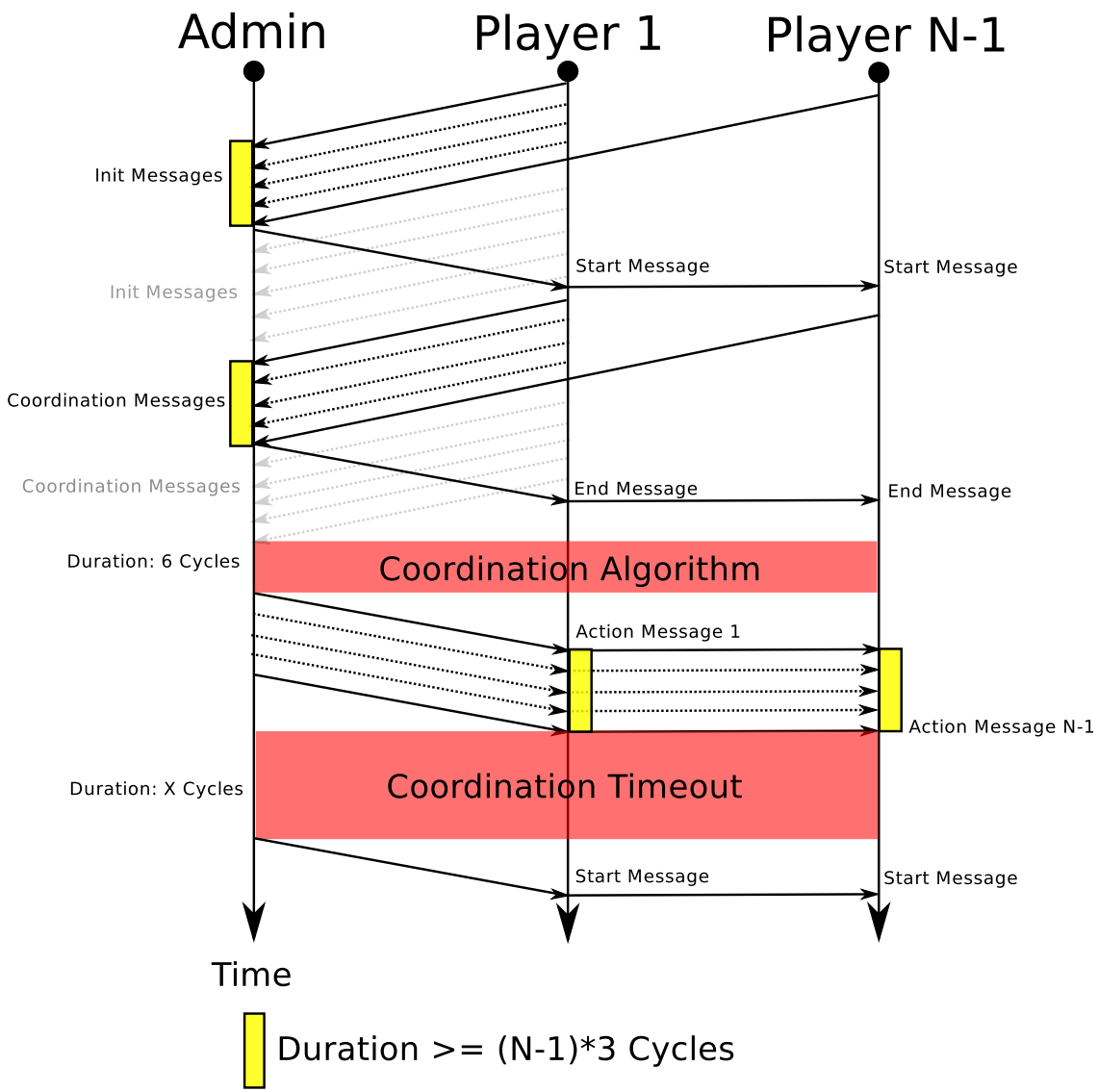
Messaging Process:

- Agents have to initialize their presentation into the field with “init” messages.
- Goalkeeper saves these messages in a temporal array and when this array implies that all field players have been initialized themselves, sends them a “start” message.
- Field players send “coordination” messages to the goalkeeper.
- When goalkeeper gathers these messages from all field players, sends them an “end” message to stop them from broadcasting unnecessarily.
- The next phase of this process is the execution of the coordination algorithm which lasts for six simulation cycles, approximately 120ms.
- When coordination’s administrator is ready to broadcast computed actions to field players, goalkeeper uses “action” messages in order to accomplish this procedure.

Messaging VI

- After this phase, the same process is repeated after a timeout which can be defined manually.

Messaging VII



Coordination's Beliefs

How could a specific agent, in a multi-agent environment, have the adequate knowledge about the state of the world, receiving different observations from different agents?

This agent has to combine all these observations, without knowing which of them are faulty or correct, in order to obtain a realistic representation of the world.

What do we need to know?

- Ball position
- Agents positions
- Agents distances from ball

Ball Position I

Observations source:

- Agents who have sent "type C" coordination messages.
- Goalkeeper uses his own observation too.

Weighted Observation Sets:

$$\textbf{Obsevation}_\textbf{i} = (x, y)$$
$$\textbf{Weight}_\textbf{i} = 1$$

These observations sets are correlated, for every two sets which are been correlated, a new set is formed which contains observations from the two parent sets. The weight of the new set will be the sum of its parents' weight.

Ball Position II

$$\textbf{ObsevationSet}_\textbf{i} = \{(x_1, y_1), ..., (x_k, y_k)\} \vee k \in [1, n], k \in \mathbb{Z}$$
$$\textbf{Weight}_\textbf{i} = k$$

Consequently, we have to compute our belief about ball position. Given a total number of N-observations, n-observation's sets, each one of them has k-observations, the final ball belief will be:

$$\textbf{BallBelief} = \sum_{i=1}^{n} \frac{Weight_i}{N * k} \sum_{j=1}^{k} ObsevationSet_i[j]$$

Agents' distance from ball

- For agents who have sent "Type C" and "Type L" coordination messages and they are able to know their exact position in the field, this distance is calculated by finding the distance between the ball belief's position and the agent's position.
- For agents who have sent "Type B" coordination messages we just take the distance part of the message.
- For agents who have sent "Type X" messages we assume ∞ distance.

Subsets

- The existence of multiple agents makes coordination function be too complex and computationally expensive to solve.
- Split players into subsets would make easier for us to coordinate their actions in real-time.

there are three subsets:

Active Active subset consists of three agents and it is the most important set of agents in the coordination.

Support Support subset consists of agents who are neither in the active subset nor in the inactive one.

Inactive Inactive subset consists of agents who have sent "Type X" messages. Agents who constitute this subset assigned the same action, to find their positions in the field.

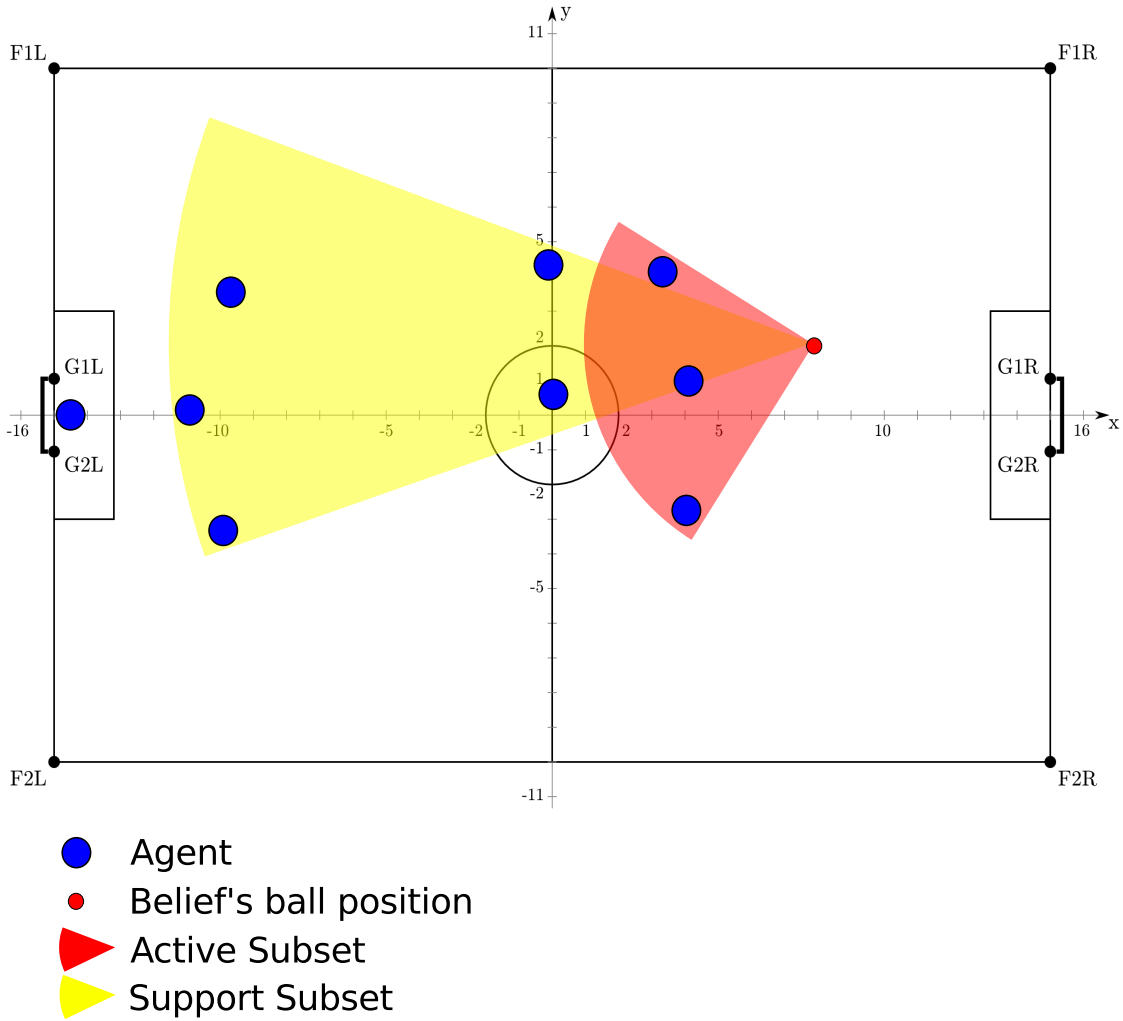
Goalkeeper Agent with the uniform number one is selected to be this agent which is responsible for guarding our goal.

Coordination Splitter I

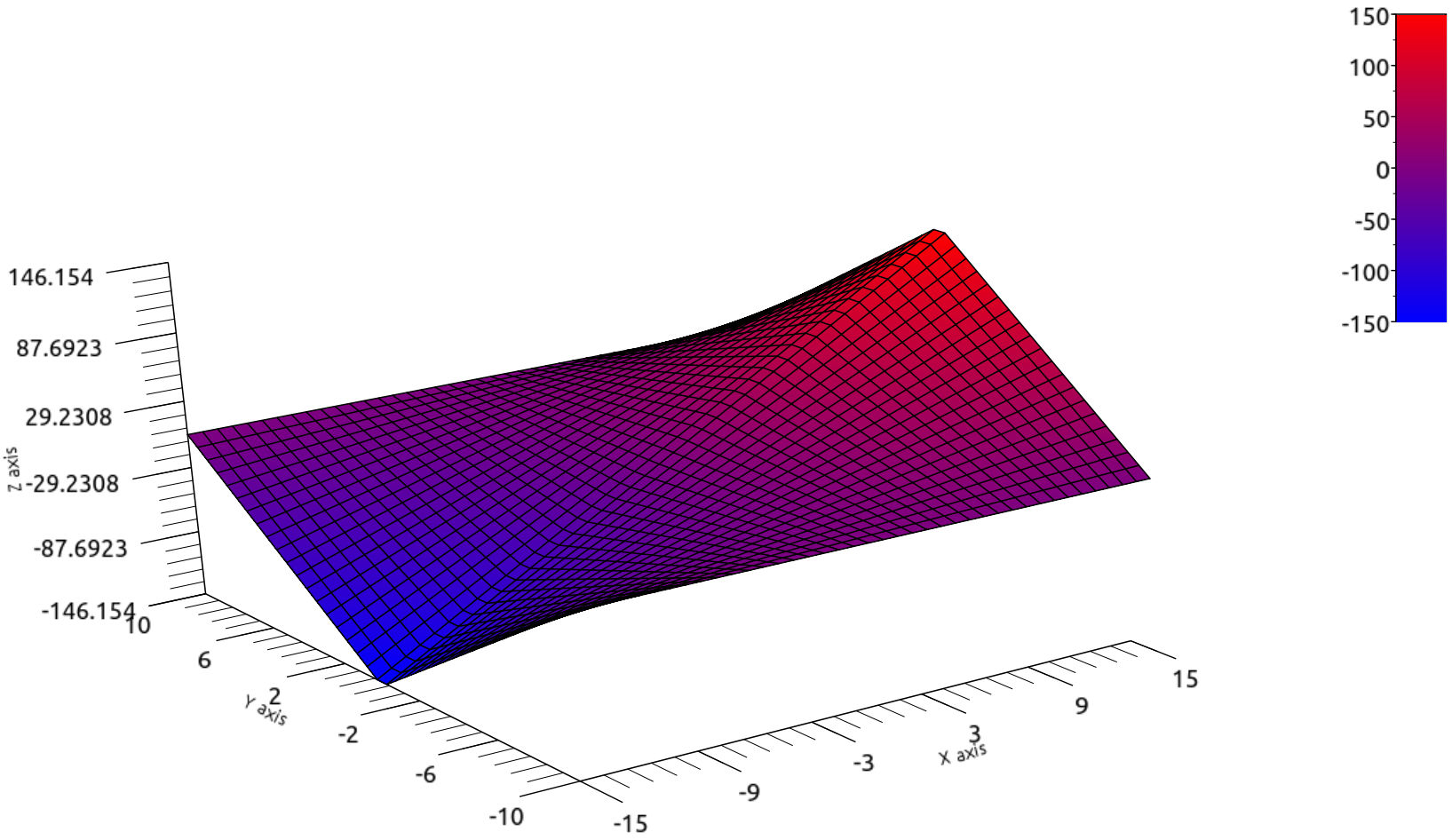
How the above three groups are generated by coordination splitter?

- An array full of team's agents is sorted according to the distance each agent has from the ball.
- We assign to the active subset the agents in the three first positions of the sorted array.
- Other agents with distance less than infinity join the support subset.

Coordination Splitter II



Soccer Field Value



On Ball Player

An agent from the active subset has to be selected to do an action related to the ball. We have to find the agent who has minimum cost according to two parameters:

1. **Distance from ball** d_i
2. **Angle towards goal** ϑ_i

Given an active subset:

$$\begin{aligned} \textbf{ActiveSubset} &= \{Agent_1, Agent_2, Agent_3\} \\ \textbf{Cost}_\textbf{i} &= d_i + a \times \vartheta_i, a \in \mathbb{R} \\ \textbf{OnBallPlayer} &= \arg\min_i(Cost_i) \end{aligned}$$

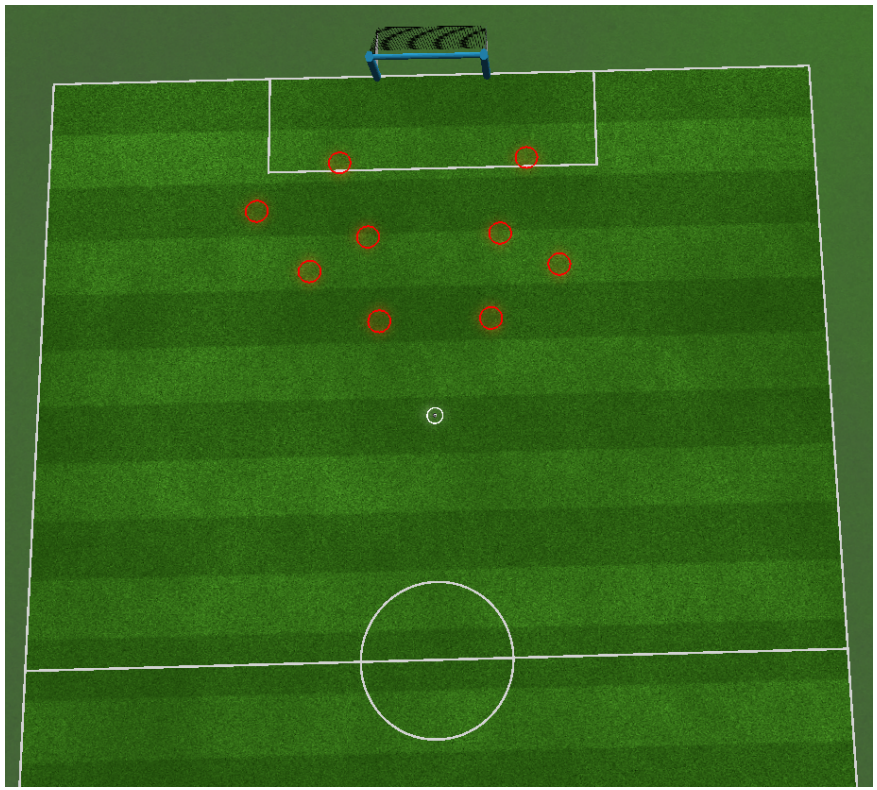
Additionally, we give to the agent who had been assigned an action towards the ball in the previous coordination cycle a small advantage over the others to be again the on ball player.

Active Positions I

Possible candidate positions for the rest players who are assigned to the active subset.

- Depend on the position of the ball.
- Defensive or offensive approach to compute these positions.
- In both cases we create an array of equidistant coordinates which are located in a radius which is determined by the ball's location and they are not out of soccer field's limits.
- From these candidate positions we keep only a max number of nine positions according to their values.

Active Positions II



Active Mapping

- 2 Players
- 9 Positions

We have to find which positions from these nine can be assigned to the two agents with the minimum cost. Making use of a brute force algorithm we compute the cost for each and every combination of possible mappings. Using a brute force method the number of possible mapping remains able to be computed in real-time. Assuming maximum number of active positions in our case nine, the possible mappings are: $\binom{9}{2} = 72$ mappings.

Properties for Active Mapping I

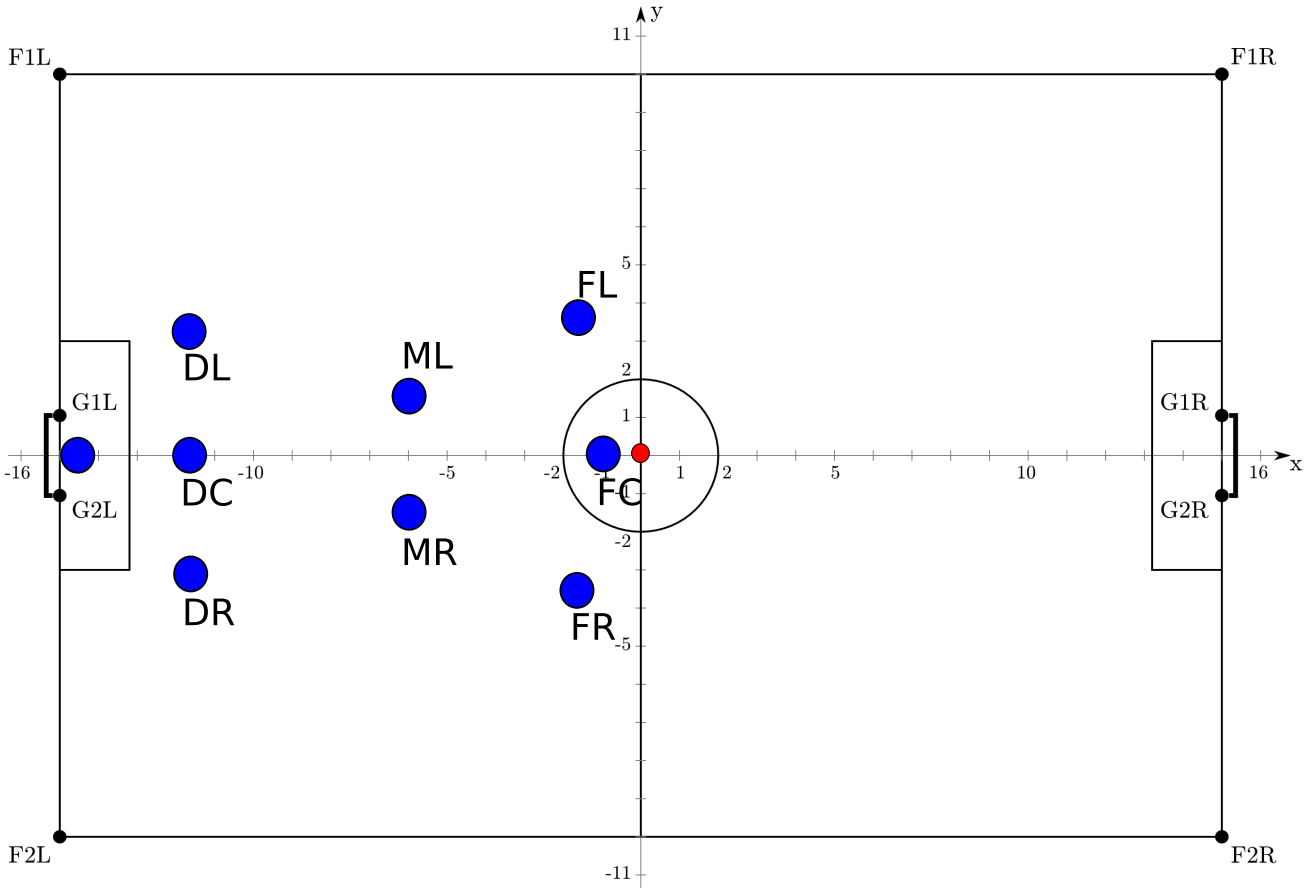
1. **Total distance** C_d - Total distance agents have to travel in order to reach in their optimized mapping positions.
2. **Possible Collisions** C_c - In each mapping we check every combination of two agents and their assigned positions if it is possible for them to collide with each other.
3. **Field's value** C_v - Agents will try to maximize this cost according to the game's state and the value which has every position in the field.
4. **Close routes** C_r - Agents routes should be safe, so we calculate the difference between start positions' distance and target positions' distance.
5. **Neighboring positions** C_p - In general agents will try to avoid be assigned in neighboring positions. So if their target positions are near to each other this is going to add more cost.

Properties for Active Mapping II

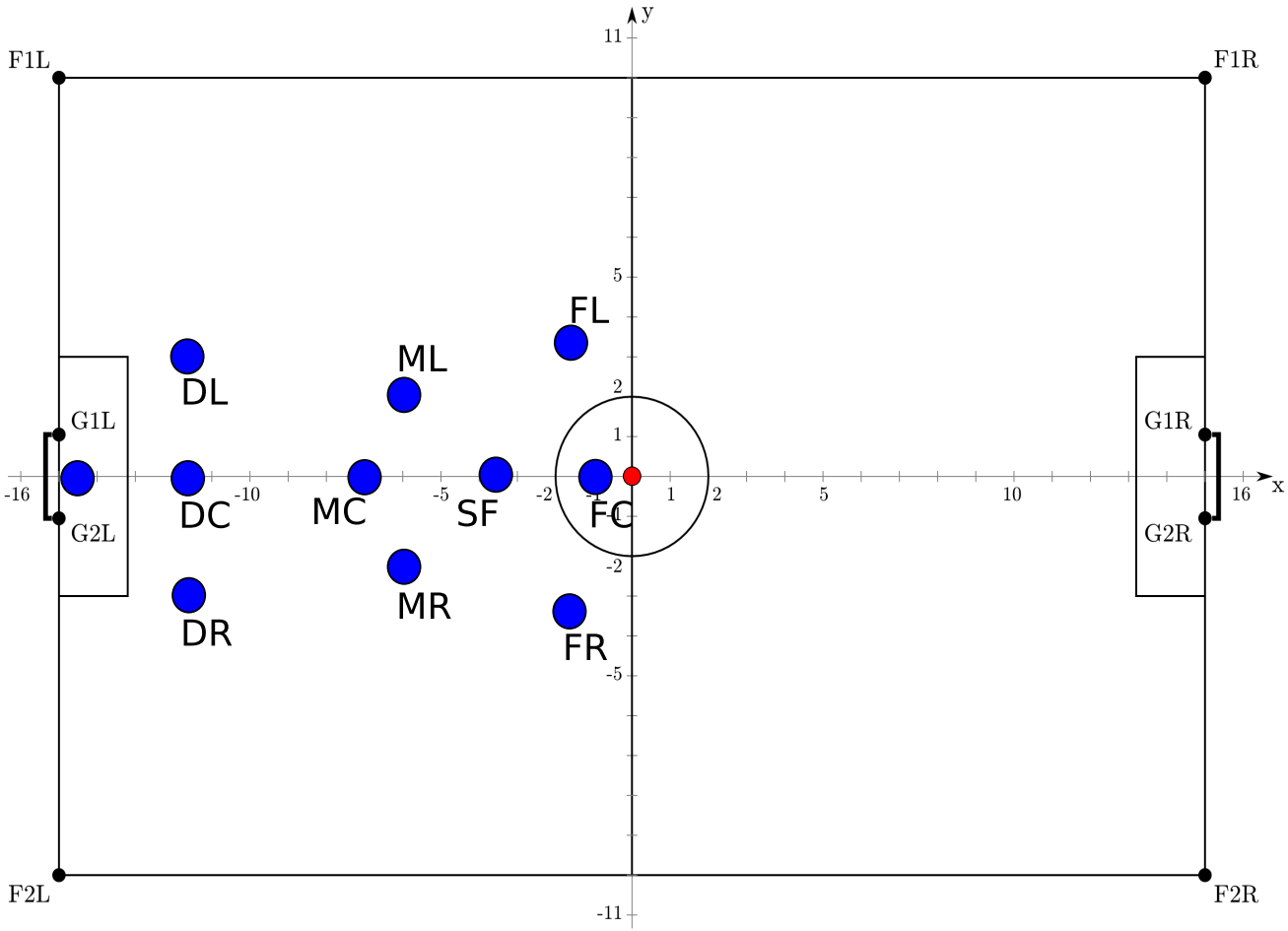
6. **Positions aligned to X-axis** C_a - We want team stretching into the field in order to have players in most regions of the soccer pitch.

$$Totalcost = C_{d,i} + C_{c,i} - C_{v,i} - C_{r,i} - C_{p,i} - C_{a,i}$$
$$OptimizedCost = \arg\min_i(TotalCost_i)$$

Team Formation 9-Players Version



Team Formation 11-Players Version

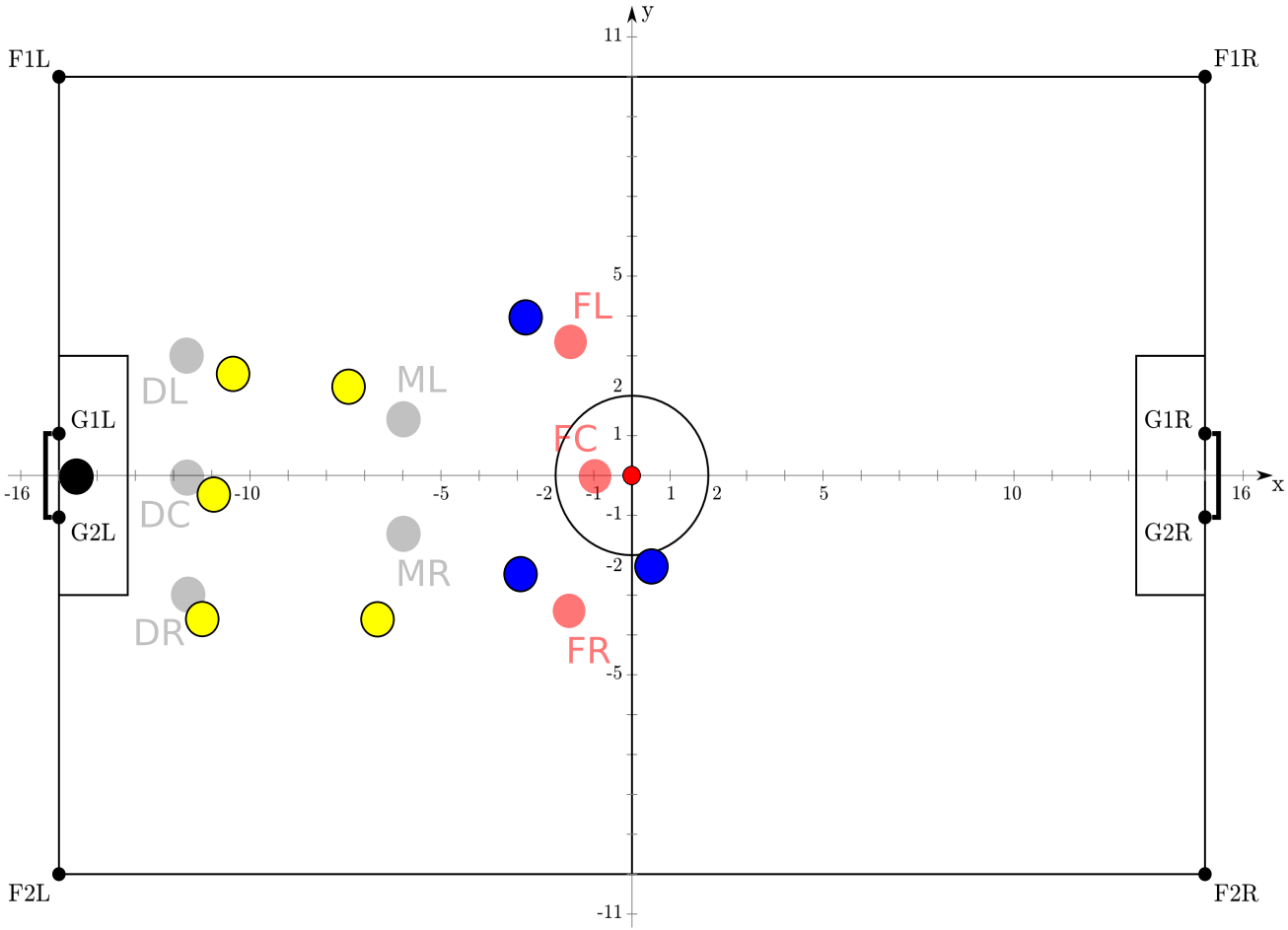


Role Assignment I

Given a computed team formation we have to assign roles to the active subset's players.

- So, for N active players we choose N team formation positions which minimize the distance from the ball.
- Roles which these positions represent will be assigned to the active players.

Role Assignment II



- Formation role positions
- Formation role positions near to ball
- Ball position
- Support player
- Active player

Support Coordination I

- Same number from positions, agents.
- Brute force algorithm for 9 players, factorial complexity, $\leqslant 5! \Leftrightarrow \binom{5}{5} = 120$ mappings.
- For 11 players, factorial complexity,$7! \Leftrightarrow \binom{7}{7} = 5040$ mappings.

Solution?

Dynamic programming algorithm, based on a simple property.

Theorem

For every mapping there is a subset of a lower cost with which we can reduce the cost of the complete mapping by augmenting it with that of the subset's lower cost mapping.

Support Coordination II

Algorithm 4 Dynamic programming implementation

Input: $SupportPlayers = \{A_1, A_2, ..., A_n\}$
Input: $SupportPositions = \{P_1, P_2, ..., P_n\}$
Output: $OptSupportMap$
$OptSupportMap = \varnothing$
for $k = 1 \rightarrow n$ **do**
    for each α in SupportPlayers **do**
        $S = \binom{n-1}{k-1}$, sets of k-1 agents for supportPlayers - $\{\alpha\}$
        for each s in S **do**
            $SupportRoleMap\ m_0 = RoleMap[s]$
            $SupportRoleMap\ m = m_0 \cup (\alpha \rightarrow P_k)$
            $OptSupportMap[\{\alpha\} \cup s] = mincost(m, OptSupportMap[\{\alpha\} \cup s])$
        end for
    end for
end for

Support Coordination III

As we see in this table, an optimal mapping is built iteratively for position sets from $\{P_1\}$ to $\{P_1, P_2, ..., P_n\}$. In every step of this algorithm we use the lower cost's mapping for a subset of agents and positions which are compatible with our current mapping.

$\{P_1\}$	$\{P_1, P_2\}$	$\{P_1, P_2, P_3\}$
$A_1 \rightarrow P_1$	$A_1 \rightarrow P_2, min(A_2 \rightarrow P_1)$	$A_1 \rightarrow P_3, min(\{A_2, A_3\} \rightarrow \{P_1, P_2\})$
$A_2 \rightarrow P_1$	$A_1 \rightarrow P_1, min(A_3 \rightarrow P_1)$	$A_2 \rightarrow P_3, min(\{A_1, A_3\} \rightarrow \{P_1, P_2\})$
	$A_2 \rightarrow P_2, min(A_1 \rightarrow P_1)$	$A_3 \rightarrow P_3, min(\{A_1, A_2\} \rightarrow \{P_1, P_2\})$
	$A_2 \rightarrow P_2, min(A_3 \rightarrow P_1)$	
	$A_3 \rightarrow P_2, min(A_1 \rightarrow P_1)$	
	$A_3 \rightarrow P_2, min(A_2 \rightarrow P_1)$	

Support Coordination IV

These assignments result in a total of $\binom{n-1}{k-1}$ mappings to be evaluated in each iteration. Summing to $\sum_{i=1}^{N} \binom{n-1}{k-1}$ possible mappings.

$$\sum_{i=1}^{N} \binom{n}{k-1} = \sum_{i=0}^{n-1} \binom{n-1}{k} = 2^{n-1}$$

- For nine players in each team, this algorithm would not have any impact. As the previous brute force algorithm was having 5! (120 mappings), which is not much bigger computational complexity than this approach $5 * 2^4$ (80 mappings).
- For seven players in our support subset, this approach gives us great improvement in our coordination time, $7 * 2^6$ (448 mappings) $\ll$ 7! (5040 mappings) in comparison to the brute force algorithm.

Properties for Support Mapping

1. **Total distance** C_d - Total distance agents have to travel in order to reach in their optimized mapping positions.
2. **Possible Collisions** C_c - In each mapping we check every combination of two agents and their assigned positions if it is possible for them to collide with each other.

$$Totalcost = C_{d,i} + C_{c,i}$$
$$OptimizedCost = \arg\min_i(TotalCost_i)$$

Movement Results and Improvements

Motion Version	Walk(m/s)	Turn(d/s)	Kick(m)	Strong Kick(m)
Webots (Text-Based)	0.11	21	3	-
FIIT (XML)	0.22	25	3 (4 sec)	4 (5 sec)
AST_3D	0.45	30	3 (2.5 sec)	5.5 (2.5 sec)

Communication Results

Communication Phase	Ideal (Cycles)	During Match (Cycles)
Init Messages	24 (0.48 Sec)	24 (0.48 Sec)
Coordination Messages	24 (0.48 Sec)	42.5 (0.85 Sec)
Action Messages	24 (0.48 Sec)	24 (0.48 Sec)

Coordination Results

Goalkeeper Results

GoalKeeper Type	Goals Conceded
No Goalkeeper	7
Goalkeeper with “Empty” Behavior	7
Goalkeeper with “Full” Behavior	3

Full-Games Results

Team	W	D	L	AGD	Games
UTAustinVilla	0	0	4	-5.2	4
Robocanes	0	0	1	-6.0	1
BeeStanbul	0	0	3	-4.0	3
NomoFC	1	2	0	+0.3	3
Rail	0	4	0	0.0	4
OxBlue	0	0	2	-1.5	2
FUTK3D	0	5	0	0.0	5
FARZANEGAN	1	1	0	+0.5	2
MAK	2	0	0	+2.0	2
L3M-SIM	3	2	0	+0.6	5

Future Work

Reaching to a level to oppose teams that have already participated in this robotic soccer competition gives us an incentive to keep working in order to improve further our team. In this section, we present some of these possible improvements.

- Probabilistic Localization System
- Dynamic Omni-Directional Movement
- Passing
- Testing and Debugging in New Server's version
- Participation in Robocup

Final