

RoboCup: Evolution of Autonomous Robots in Teams

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1. What is RoboCup

RoboCup is an international robotic competition, founded with the aim to make robots that are able to play football. The name is a contraction of “Robot Soccer World Cup”.

a. History

The idea of a competition of robots playing football has been launched by a group of Japanese researchers in the mid-1990s. Started as a Japan-only project, after some time this has attracted the interest of various researchers around the world. In 1997 the international RoboCup competition has been founded. Since that year a lot of teams representing various universities of all over the world has participated to the competition, including some Italian teams.

b. Scientific goals

The official long-term goal of the RoboCup project is:

"By mid-21st century, 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."

With today's robots we are still very far to make this happens, so in order to achieve this goal a lot of research must be done, ranging from mechanics to computer engineering. The more practical aim of RoboCup competition is actually to promote scientific research in the areas of robotics and artificial intelligence.

The most important aspects of RoboCup are certainly on the software part, where engineers must setup a complex multi-agent robotic systems with strong coordination abilities.

The hardware part is too very interesting and challenging, especially on how robots perceive the environment through the use of sensors.

2. The leagues and their rules

The RoboCup competition is divided in many sub-competitions, called **leagues**. Each league has different rules and aim to do research on different goals.

The decision of making many different competitions instead of a single big one, has been chosen because the long-term goal of RoboCup to play football against humans is a very difficult result to achieve, and it involves many branches of research in some relatively different aspects that can easily be separated.

For example in some leagues (Humanoid and Middle Size) there is more focus on the hardware part of the robot, while on other leagues (Simulation and Small Size) there is more emphasis on the software aspects of the coordination of robots.

a. Small Size League

In this league some small robots (18x15 cm) plays a football match in a small field, with rules heavily simplified to better match with the capabilities of these small robots.

The most important peculiarity of this league is that robots has high quality sensory information given from outside by the team organizers: by using a camera above the field, an external computer recognize the position and orientation of each robot and the ball using some visual patterns printed on every robot.

Since there is this spatial information available, robots doesn't have the problem of being able to perceive only a part of the environment around them like an human player do, but they have very high quality information on what's happening on the playfield.

This let engineers to focus on the software aspects of controlling and coordinating the various robots, without having to deal with more hardware-oriented problems.



b. Middle Size League

The competition in this league is much more similar to a real football match. Robots are about as high and move as fast as an human, and they play on a big field. The rules in this league are similar to official FIFA ones.

Robots here must be able to perceive what's happening on the playfield only with their own sensors or the ones from their teammates.

In this league the main focus is more oriented toward the hardware, in particular how to build robot with efficient sensors.



c. Humanoid and Four Legged Leagues

In the Humanoid league the main focus is to make robots that are physically similar to humans. The technical challenge here is mainly to design the robot from the mechanical point of view in a way that can perform movements of their arms and legs in the same way as humans do.

This is the least interesting league from the point of view of this research, because the challenges here are almost only regarding mechanical engineering.

The Four Legged league is in some way similar to the humanoid league: but instead of making robots similar to humans, here are given some dog-like robot, and the challenge is to make them walk and play football efficiently. The focus here is in controlling the 20 degrees of freedom of the four legged robots efficiently.



d. Rescue League

This league, unlike all others, has nothing to do with football. The aim of this league is to make robots that can help people in emergency scenarios, like an earthquake. In this competition robots must find people in a damaged building and give some assistance to them.

In this league robots must be even more autonomous than on all other leagues, because no wireless communication between robots is allowed, in order to better simulate real live scenarios where robots can't rely on not guaranteed reception of wireless signals.



3. Simulation leagues

The main goal of the simulation leagues is to develop a team of player agents that can win a simulated soccer match, using a simplified model of reality.

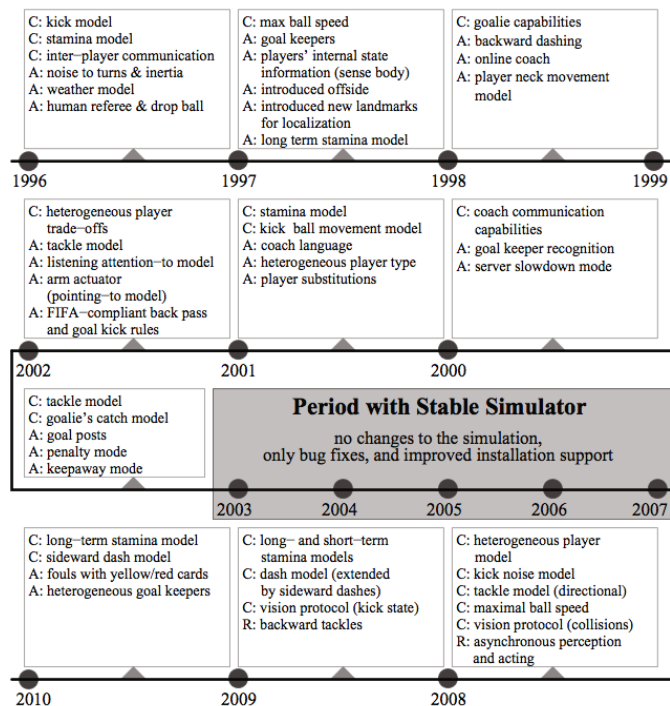
The simulation league let engineers focus in the software development without having to deal with hardware. Infact, a robot might perform well in the simulator but poorly in the real world. Another reason that support that kind of leagues is the possibility of run thousand of soccer matches in a matter of seconds, that is useful for statistical analysis and performance comparing.

a. Server simulation

In the simulation leagues a server simulates the world of the ball and players, which are fully autonomous client agents that separately interact with the server. The interaction follows these steps:

- each player receives sensations representing the view from its current location
- decides what actions to execute
- sends the actions back to the server, for execution

Over the years the simulation became more complex and it was hard for engineers to keep pace with the changes introduced. Since the simulation environment was annually modified, a meaningful comparison across teams from different years was impossible.



To overcome this issues, from 2003 to 2007 the simulator development was frozen and the simulator retained as a testbed for multiagent research, allowing to compare and measure performance and progress over the years.

b. 2D simulation

From the early stages, the 2D simulation league had realistic team-level strategic interactions. Both the ball and the player are modeled as circles that has:

- a direction that its body is facing, which affects the direction it can move
- a direction in which it is looking, which affects its sensations

Actions are abstract command:

- moving forward or backward with a specified power
- turning the body or neck by a specified angle
- kicking at a specified angle with a specific power
- slide or tackling in a given direction
- catching the ball
- ...

<https://www.youtube.com/watch?v=cDhSjSYPvdE>

c. 3D simulation

The 3D simulation league implements a physically realistic world model and an action interface that is reflective of that experienced by real robots.

The agents interact with the simulator by sending actuation command to each of the robot's joints and it's a real challenge to enable robots to walk and kick without falling over.

https://www.youtube.com/watch?v=3N_WSNf_aBI

4. Main topics:

a. Player learning

The problem of developing a software agent that is able to play football is a very complex challenge for software engineering. To make the work easier, some **machine learning** techniques from Artificial Intelligence could be used to develop an agent that perform decisions about what the player robot should do in every moment.

For example an **Artificial Neural Network** could employed in a scenario where there are two attackers versus a defender of the other team near the goal. The ANN is used to calculate what is the best decision among shoot the ball or pass the ball to a teammate. In this case study, some inputs about the spatial position of other player and ball are given to the ANN, and it's expected as output the probability of doing a successfull pass or shot. As usual, the neural network is trained with backpropagation.

To perform training of the ANN, the game simulator could be very useful, because it can generate many data needed to create a big training set in a short time without the use of physical robots.

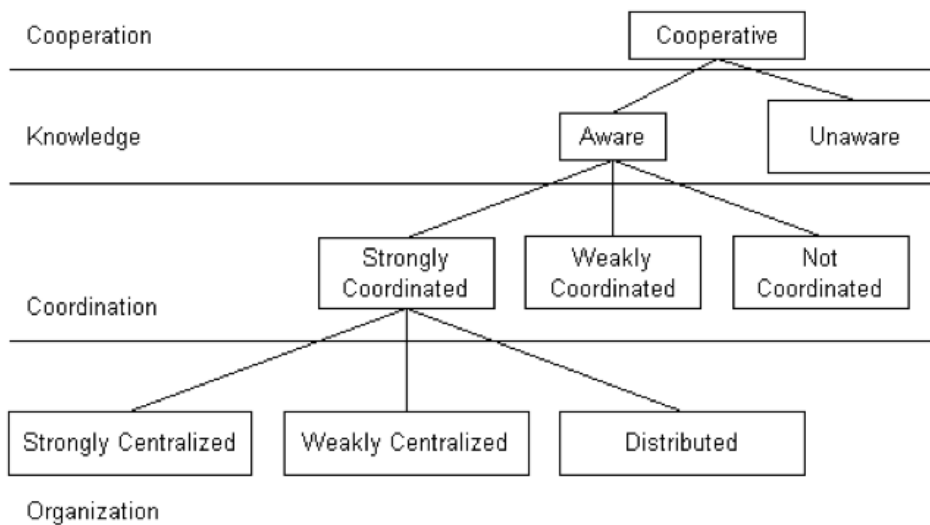
Machine learning techniques can be used not only for controlling the behaviour of players, but also for other tasks like for example preprocessing of information coming from robot sensors. For example Support Vector Machines has been used to detect collisions with other robots and recognize the color of objects in images coming from the robot's camera.

b. Teamwork

In a football team of humans, their ability to cooperate well in order to achieve a goal is an almost essential skill, since it makes the whole team perform better. Also in RoboCup to achieve good results, player agents must be able to organize themselves in some way, in order to improve the overall performance of their team and achieve victories.

To describe some of the issues that these goals imply, we first present a taxonomy of the multi robot systems, centered on their cooperative capabilities.

i. Multi Robot System Taxonomy



The first level contains cooperative systems, in which **cooperation** is defined as: a situation in which several robots operate together to perform some global task that either cannot be achieved by a single robot, or whose execution can be improved by using more than one robot, thus obtaining higher performances.

The second level refers on **awareness**, defined as: the property of a robot in the MRS to have knowledge of the existence of the other members of the system. Unaware coordination is achieved when agents perform their task as if they were the only robots within the system.

The next level depicts how an aware agent can cooperate with other agents. We define **coordination** as: cooperation in which the actions performed by each robotic agent take into account the actions executed by the other robotic agents in such a way that the whole ends up being a coherent and high performance operation. It's obvious that only a system of aware robots can be coordinated, but it is also true that these systems may be not coordinated at all. The coordination level can be classified as **strong(weak)**, defined as: a form of coordination that relies (does not rely) on a coordination protocol.

The last level shows a distinction at the organization level between:

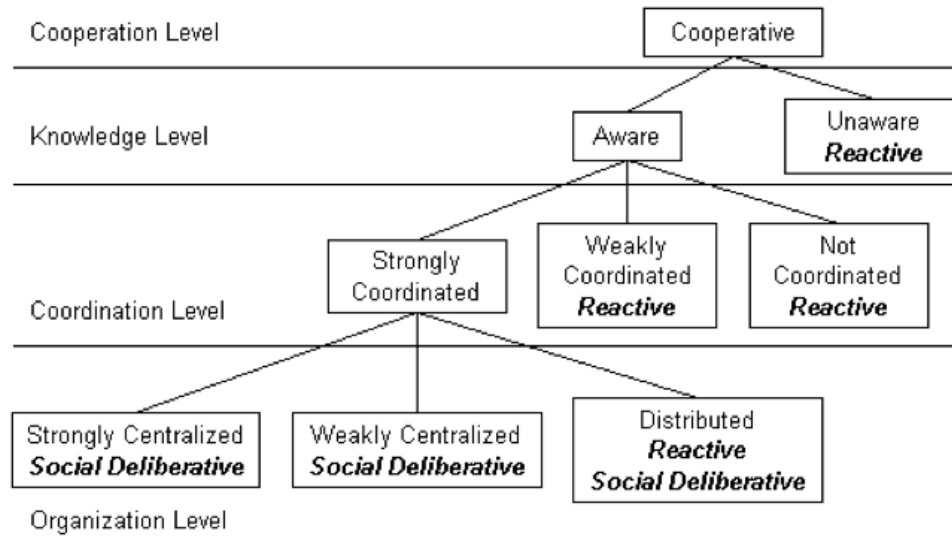
- **centralized** approaches, defined as:

the organization of a system having a robotic agent (a leader) that is in charge of organizing the work of the other robots; the leader is involved in the decisional process for the whole team, while the other members act according to the directions of the leader.

- **distributed** approaches, defined as:

the organization of a system composed by robotic agents which are completely autonomous in the decisional process with respect to each other; in this class of systems a leader does not exist.

ii. Reactivity and Social Deliberation



The previous taxonomy can be further extended with the notions of how the team of robots act in response to the dynamics of the environment. There are two main possibilities:

- **social deliberation**, defined as:

a system behavior that allows the team to cope with the environmental changes by providing a strategy that can be adopted to reorganize the team members' tasks, so as to use all the resources available to the system itself to effectively achieve the global goal.

- **reactivity**, defined as:

a system behavior in which every single robot in the team copes with the environmental changes by providing a specific solution to reorganize its own task in order to fulfill the accomplishment of its originally assigned goal.

iii. Cooperation in Robocup

Starting from the previous taxonomy, we can now proceed classifying the different leagues of Robocup.

In the **simulation leagues**, each agent perceives only its local information about the environment. This makes simulation leagues an interesting testbed for MAS and every kind of cooperation can be successfully used.

In **Small-Size league** the main strategies used are **centralized**, since the remote host can be considered as an agent acting as a leader of the team.

In **Middle-Size leagues** robots are more autonomous since they have sensor on-board. In this league we can find **both reactive and deliberative centralized approaches**. In particular, the deliberative centralized approaches are used when it is possible to reconstruct global information about the environment starting from the each robot perception.

In **Four-legged and Humanoid** leagues the only strategy used is centralized, due to the difficulties of communication among different robots.

c. Opponent modeling

From 2001 to 2006 a new further agent was introduced in the competition: the coach agent. The coach agent received a noise free global view over the field, allowing allowing more informed decisions. Its main purposes were the following:

- recognizing or predicting the behavior of the agents or team (formation, defense and offense system), using data mining techniques
- identify weakness and strengths of opponents (behavior detection with data mining techniques)
- provide additional advice and information to players (adjustable autonomy)

5. Human vs. Robotic Soccer: How Far Are They?

In this final part, we present a generic comparison between human versus robotic soccer, to detect similarities between these two games.

The following image shows the results of the analysis of six games (three robotics and three human) corresponding to the latest final game competition (Robocup and Fifa World Cup).

Groups	Final Game Statistics	Human Soccer			Robotic Soccer		
		Average per Game	Standard Deviation	Percentage	Average per Game	Standard Deviation	Percentage
Pass	Successful Pass	544	117,9	77,9%	176,3	48,8	65,9%
	Missed Pass	154,3	21,3	22,1%	91	20,6	34,1%
Shots	Shot on Target	17,3	1,6	69,55%	3,3	0,5	47,6%
	Shot	2,7	0,5	11,64%	1,3	0,9	19,1%
	Intercepted Shot	4,3	1,7	18,81%	2,3	0,5	33,3%
Not Applicable	Goal	1	0,5	100%	2,1	1,2	100%
	Offside	6,6	2,4	100%	1,6	0,8	18,76%
Offside	Intercepted Offside	0	0	0%	4,3	1,2	81,24%
Outside	Goal Kick	17,4	2,4	26,37%	3,9	1,6	15,6%
	Corner	9,1	1,6	13,76%	2,3	1,4	10,3%
	Throw-in	39,3	5,7	59,87%	14,8	5,4	74,1%

From the results the following conclusion emerge:

- in both scenarios the successful passes are the most frequent event
- in every event, the human soccer tends to be more efficient and accurate, infact if has:
 - bigger percentage of shots on target and successful passes
 - smaller percentage of missed passes and intercepted shots

These results are not intended to be exhaustive, infact many other elements could influence the evaluation, such as:

- the defensive/offensive style adopted by the teams
- the level of competitiveness, determined by the number of different teams in the final games
- the performance deterioration of players during the match
- ...

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