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CHAPTER 6

The Essence of Soccer, Can Robots Play Too?

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Can there be a Real Ma-droid?

On July 8th, 2007 in Atlanta, GA, USA, five people, including one of the authors, stepped onto a small indoor soccer field to play the first ever exhibition soccer match between humans and autonomous robots. The robots from the University of Osnabrük, which moved on wheels and were outfitted with omnidirectional cameras to allow them to see all over the field, had just won the "middle-sized league" of the annual RoboCup robot soccer competition. The experiment was repeated in 2009 on a larger field against five robots from Stuttgart, the champions from that year.

In both cases, the waist-height robots turned out to be no match for the amateur human players. The people were more mobile, better at passing, and generally able to use the field more effectively. They were able to score quickly, and by the end of the twenty minute game, they were toying with the robots, keeping control of the ball without running—only walking. (You can see for yourself at www.cs.utexas.edu/~AustinVilla/RobotsVsHumans2007.mov.) However, there was a marked improvement in the robots' play in 2009, lending some degree of credibility to the claim that, just like they have already done in chess, machines may someday overtake humans at soccer.

Building robots that will be able to overtake humans at soccer is the goal of a vibrant and continually growing scientific community of computer scientists and roboticists known as "RoboCup" or the robot soccer World Cup. The stated goal of the RoboCup initiative is to develop a team of robots that is better than the best humans soccer team by the year 2050. But this goal begs a central philosophical question: Can robots play soccer? We may be able to build robots that can run, kick a ball, head, dribble and pass. In fact we have already built robots that can do a few of these things. But will they be able to *play* soccer, or will they only be able to *mimic* soccer?

One way to determine if robots can play soccer is to conduct a modified Turing test. Alan Turing originally proposed the following test for determining if a machine is intelligent: A human judge converses by typing in natural language at two different computer screens. At one, the judge is conversing with a person, at the other, she is conversing with a computer program. If the judge cannot tell the difference between the computer and the human, then the computer has passed the Turing test and is deemed to be intelligent. The general idea is that if a human can't tell the difference between the behavior of an intelligent being and a computer, the computer is intelligent (as far as we can tell). This idea can be easily modified to determine if robots can play soccer. In the case of soccer, if a robot team can compete with a human team, and what results is recognizable to the fans as a soccer match, then it is safe to say that robots can play soccer. This is one reason why some RoboCup participants phrase the goal of the initiative as, "to create a team of robots that is capable of beating the World Cup (human) Champion soccer team on a real, outdoor soccer field by the year 2050."

To test whether robots can play soccer, however, we don't really need such a lofty ambition. While being able to beat the World Cup Champions makes for a wonderful slogan, the difference between a world class team and a good lower-division professional team is not all that great. Consider, for example, that it is not uncommon for a League 1 team to defeat a Premier

League club in the English FA Cup. To determine whether robots can play soccer, all that need be done is for them to compete against a serious human team.

To date, RoboCup competitions have always been between teams of fully autonomous robots—with no people "in the loop" via remote control or otherwise. People program the robots, but when the game is being played, the robots are entirely on their own. Detailed sets of rules govern the play in several different "leagues," including simulated robots, wheeled robots, and legged robots of various sizes. But so far, little thought has gone into developing rules that could govern matches between robots and people.

It is clear, however, that to have robots and humans competing on the same field will require a modification of the rules of soccer. Currently, the definitive rules—called *The Laws of the Game*, administered by the International Football Association Board (IFAB), a subcommittee of FIFA—are vague as to what consistutes a player. Under the heading "Players", the Law reads:

> A match consists of two teams, each consisting of not more than eleven players, one of whom is the goalkeeper. A match may not start if either team consists of fewer than seven players. (p. 15)

The tacit assumption is that the players are human. But what if they are not?

The prospect of robots playing the game forces us to consider what aspects of the rules are essential to the game of soccer, and what rules can and should be changed.

Change the Rules, Are You Kidding?

Currently, there are no size or weight limits placed on human players: all people are eligible. However the physical form of robot players must clearly be restricted in some way. Consider, for example, a "robot" that is exactly the size and shape of a goal that remains stationary on the goal line, thus guaranteeing no goals against. Surely such robots should not be allowed.

That modifications to the rules would be necessary for robots to compete against humans should come as no surprise. The same situation was previously addressed in the world of tournament chess. Leading up to the famous match between the computer Deep Blue and the human champion Gary Kasparov, the rules of chess had to be modified to address issues such as what to do if a person makes an error carrying out the program's move, and what to do in the event of a power failure, due to the fact that the computer may lose vital information about the match.

Nor should any hue and cry about preserving the purity of the game prevent us from considering a change of the rules. Soccer is a game that is easily modifiable. It is played worldwide in many variations: indoor soccer, futsol, beach soccer, 3 versus 3, kids games with no goalies, and many others. There are different rules in friendlies versus international tournaments, and the rules have changed over the years (for example, modifying the definition of offsides, and the addition of the "pass-back" rule). But in all these variations, nobody questions whether the game is still soccer. Indeed, *The Laws of the Game* specify that modifications to the ball, goals, field size, length of play, and substitution procedure are permissible (p. 4). Arguably these allowances, written into the rules of the game as they are, add to the popularity of soccer by making it accessible to players in a wide range of age, skill and ability. All other modifications require the consent of the IFAB. Presumably, this is because other changes run the risk of violating the essence of the game. For example, few would consider it soccer if players other than the goalie were permitted to use their hands.

But changing the ball, goals, field size, time, or substitutions won't help us with our robot wall problem. If we're going to have robot versus human matches, we are going to have to brave the wrath of the IFAB and suggest rules that go beyond those allowed by fiat. And we will have to do it without changing the essence of the game; because if we change the essence of the game, then the robo-human match will no longer be a test of whether robots can play soccer.

Preserving the Essence of Soccer in a Human vs Robot Match

There are three alternatives for defining the essence of soccer, each of which leads to very different rules for a match between robots and humans. The first alternative is to define soccer as essentially a game played by humans. In that case, there is no way for robots to participate.

The second alternative is to treat soccer as being defined essentially by its rules. By this view, the current rules of soccer should be altered as little as possible to accommodate robots. If people can build robots that run twice as fast as people, that can shoot the ball into the corner of the net every time, or that can prevent any shot from scoring (a robot wall), then robots are better than people at soccer, end of story.

The third alternative, and the one we espouse, is to identify soccer as being defined essentially by the set of possible behaviors and strategies that can be used. This alternative is the trickiest to specify. This set of behaviors and strategies is already constrained by the *Laws of the Game*, but not enough for a human-robot competition. From our perspective, a game without teamwork, passing, and creative movement off the ball would no longer be soccer. If the robots can easily and reliably score from any location on the field, therefore never needing to pass or move, then even if they can win a game of soccer according to the current rules, we would not be comfortable saying that they are better at *soccer*.

In taking this perhaps controversial position, we do not seek to deny or remove the physical component of soccer. This physical component is what makes our task different from defining the rules of computer chess in which the computer and the person are constrained by the game to have identical sensing and action capabilities. They can both see the whole board and they have the same moves available to them. Thus computer chess programs are (usually) completely free to solve the problem in their own way, such as searching millions of board positions and storing large databases of positions. Similarly, it is important to us to allow robots to excel at soccer in their own way, including its physical components. They should be free to trap the ball and dribble with as much finesse as they can muster. But we are concerned that if we do not place any limitations on their speed and power, that the essence of soccer will be lost.

The challenge is to give a set of rules, to add to the *Laws of the Game*, such that if they were used for a soccer game between humans and robots and the robots won, it would become clear that robots were better at soccer than people. For this to happen, the rules must preserve the essence of soccer and also be fair to both the people and the robots.

Rules to be considered fall roughly into four categories: Individual robots, teams of robots, coaches of robots, and humans. (Those rules we endorse are bulleted in the sections below.)

Individual Robots

Clearly we must place some restrictions on individual robots in order to prevent unfair advantages, such as being able to trivially block the whole goal. One key limitation that we propose for the robots is that they should have roughly human form: two legs, two arms, and similar sensing and motion capabilities to humans. The robots should have arms and hands to

execute throw-ins, but of course they must not touch the ball with their arms during the course of play.

This restriction on form is somewhat more subtle than it appears on the surface. For example, if a robot has two legs and two arms, but no torso (the legs go all the way to its head), is that permissible? Similarly, the exact definition of "leg" needs to be specified. On the flip side, need we place any new restrictions on the human participants? If the robots must have two arms, can a person who has lost his arms play soccer? Can the people have any artificial or robotic parts? Such a question came up in the 2008 summer Olympic games when Oscar Pistorius, who was was born without tibia bones in his legs, wanted to compete with the prosthetic devices, or blades that he uses to allow him to walk and run. Just as Pistorius was not allowed to compete, presumably because his blades could give him an unfair advantage, we suggest that the people must not have significant robotic parts. But this still leaves many grey areas, such as whether a person should be allowed to use a hearing aid. For now we prefer to leave the rule somewhat ambiguous, subject to interpretation based on the medical and robot technology of the day:

- The robots must have two legs, two arms, and a head where any visual and audio sensors can be located. They should have at most two cameras for visual sensing, placed side by side such that the field of view is similar to a person's.
- The people must not have artificial parts that endow them with any superhuman capabilities.

In addition to restrictions on form, the size, weight, and various capabilities of the robots must be restricted in order to ensure fairness. If no such limitations were in place, it would be possible to play with robots that could run twice as fast as any human, or that could shoot the ball at such a speed that no person would step in front of it.

Again, it can be tricky to figure out exactly what the restrictions should be. On the one hand, we do not want the robots to have an unfair advantage by being significantly bigger, faster, or better shooters than people. On the other hand, we do not want to limit the robots excessively such that they have no chance.

To this end, we propose limiting any *individual* robot to being no bigger or better than the *biggest* or *best* human professional soccer player. We compare against soccer players rather than against all humans for the practical reason that the robots will be playing against them rather than against Olympic sprinters or sumo wrestlers. We also believe that it would not be fair for *all* of the robots to be as fast as the fastest human player. We address this concern in the section on robot teams below.

It may always be a technical challenge to build a robot that can run as fast as a person. If so, this restriction will be unnecessary: the robots may always be slower than people such that the people always have an advantage in this regard. But if it turns out to be possible to build robots that can run faster than people, then we believe that they will need to be restricted in order to preserve the essence of soccer.

To this end, we propose the following rules on robot capabilities. The first is necessary; the other five are debatable as indicated above.

- No individual robot should be heavier or bigger (in any dimension) than the heaviest or biggest professional soccer player.
- No individual robot should be able to run faster than the fastest professional soccer player.

- No individual robot should be able to kick harder or more accurately than the best professional player.
- No robot should be able to execute a throw-in that is farther or more accurate than the best human soccer player's.
- The robot goalie should not be able to jump farther or higher than the best professional goalie.
- The robot goalie should not be able to throw or punt harder or more accurately than the best professional goalie.

In order to enact these limitations on the robots' capabilities, there will need to be a way to measure the abilities of both humans and robots. For example, how exactly do we measure things like kicking strength or accuracy? When measuring speed, do we measure top speed, acceleration, distance running, or some combination of all three? Do all of the human players need to be measured, or is sampling sufficient? How are the robots tested? Must there be hardware limits, or is it sufficient for the limits to be in software? We leave these implementation details to be determined in the future.

Two other concerns related to individual robots are stamina and safety. The robots should be able to operate autonomously for a full 45 minutes without any intervention, including battery changes (though one might argue that a battery change is akin to a human drinking water, which is permitted). On the other hand, humans get tired as the game goes on, so it is tempting to require that the robots get tired as well. However it appears to be too difficult to precisely measure "tiredness" to place a restriction on the robots in this regard. For example, how do you model the ability to "dig down" and find the energy for one last sprint in the 90th minute? We therefore suggest that robot stamina should only be limited by what is possible based on battery and power management technology. It is for this reason that we suggest prohibiting battery changes except at halftime.

Similarly, we do not suggest placing limitations on the robots' abilities to plan ahead, react quickly, or "read" the opponents. In some sense, this is exactly what we aim to test: whether a team of robots that have similar physical characteristics to humans can be programmed with better ball-manipulation, passing, and decision-making skills than people.

Finally, if we really intend to stage a match with the rules that we are proposing, it is essential that we consider the human players' safety. The humans will (rightly) never agree to play such a match without some assurances that the robots are not likely to injure them seriously. The robots must place human safety above all other goals, including winning the match. They may commit intentional "professional" fouls for strategic reasons, but only in such a way that does not endanger any person.

Again, the method of enforcing such a restriction is not straightforward. After all, the best way for the robots to minimize the risk to humans is to stand still the entire game, which is clearly not our intention. Perhaps the robots should be required to generate a log of all their decisions so that, after the fact, it could be determined whether there was any "intent" to injure. But an unethical programmer could easily bypass such a requirement by generating false logs. In practice, we will probably need to rely on the robot developers' sense of the high cost of human injury (at least in today's climate, a single injury to a human star could spell the end of human-robot sports forever) to make sure that the robots are as careful as can be in this regard.

Based on this discussion, we thus suggest only two additional rules with regards to individual robot capabilities, the second of which is again open to interpretation and further specification:

- The robots must be able to play completely autonomously for the entire time that they are on the field: program changes and battery changes are not allowed.
- The robots must not plan to commit any dangerous fouls and must make every reasonable effort to avoid injury to the humans.

The philosophy behind this section has been that soccer is essentially a game played by players with *limited* capabilities. An essential quality of the game is figuring out how a *team* of players can compensate for the limits within the team and exploit the opponent team's limitations.

Robot Teams

In this vein, a team is not just defined by the capabilities and limitations of its individual players, but is also defined by how the capabilities of the *different* team members interact. In principle, the robot team could be built with identical characteristics in each of its players: once we have discovered how to make one robot run as fast as the fastest professional soccer player, we could easily build all robots to run at the same speed. However, we feel that a team of identical players violates an essential component of the game. Rather, we suggest stipulating that no two robots on the team can be identical in their combination of speed, size, weight, kick strength, and kick accuracy. Just like in human soccer, different robots will be best suited to play different roles on the team based on their particular skills.

One way to implement this requirement that the robots not be identical is to have a total "budget" for each skill to be distributed among the team. Just as we suggested limiting individual robots' characteristics based on the characteristics of the best individual human players, we also suggest limiting the team based on the collective characteristics of the best professional soccer teams. For example, suppose that a team's speed is defined to be the speed with which the team could run a relay race in which each team member ran 400 meters. We propose that the robot team be limited to run the same relay no faster than the humans (when each robot is running as fast as it can). Similarly, there should be team budgets for all the other important player characteristics, for example total height or weight of the set of robots. The robots could be designed such that one player is a superstar, able to run and kick as well as the best human player. But then the rest of the robots would need to be limited significantly. On the other hand, the robots could have skills that are more evenly distributed among the team, subject to the limitation that no pair be identical. Just as human coaches need to select carefully a mix of players for their team, the robot designers will need to trade off between the various robot capabilities.

- The total budget of speed, size, weight, kick strength, and kick accuracy must be distributed across the robot team such that the total team capacity in each dimension is no better than that of the fastest, biggest, heaviest, and best-kicking human professional teams.
- No two robots can have an identical (or close to identical) set of these characteristics.
- The robot team should be allowed the same number of substitutions as the human team. Robot malfunctions should be treated in the same way as human injuries with regards to

whether they need to be removed from the field, when they can re-enter the field, and how much injury time should be added.

In addition to a soccer team consisting of players with differing capabilities, a second essential team-related property of soccer is that the players can communicate with one another. In human soccer, the players may communicate in any language and by any means, including via gestures and body language. Typical things that are communicated are marking assignments, directions regarding where to move, forewarnings of future actions ("I'm going to pass to you"), or multi-player play calls ("give and go"). However robots could potentially also be equipped with wireless communication that would allow communication of much more detailed information, such as the precise location of the ball, and a player's full conception of where all the other players are on the field. In addition, such wireless communication would be imperceptible to the human players, thus not revealing anything about the speaker's location, as happens when a person speaks.

Just as is the case for running speed and kick power, our intention is to prevent capabilities that would enable unsoccer-like strategies. It is tempting to suggest a limitation either on what is communicated or on the communication "bandwidth" (rate) such that the robots may not communicate more information than humans can. However, like stamina, the bandwidth of human communication is difficult to define, especially when things like tone of voice are taken into account. Thus, we suggest for now that robot communication should only be limited to be in the same medium as that of humans, and that body language of any form be allowed:

- The robots may not emit any signals for the purpose of communication other than sounds of limited volume that are perceptible to the human ear.

If it turns out that the robots are able to communicate much more information than humans in this way, then it may eventually be necessary to find a way to limit communication rate and/or content.

Coaching

A team of robot soccer players may have two types of coaches. There will certainly be human coaches, including the engineers and programmers, that prepare them for the match ahead of time. There may also be a "robot" or software coach that observes the game and imparts strategic information to the robot players during the game.

Devising strategies suited to a particular opponent is an important part of the game, sometimes consuming the attention of many people for countless hours prior to an important match. There will be no bound on the amount of coaching the human players get prior to their match against the robots, and similarly, we do not suggest any limitations on the human coaches of the robots.

However once the game has started, it is an essential quality of the game that the players must decide for themselves what to do. A robot (or software) coach may yell information from the sidelines. But it may not take advantage of his global view of the field to "micromanage" the players, telling them where to pass or where to move at every instant. Thus the robot coach should only be able to communicate in the same way as the players: orally and with limited volume.

Even this restriction may not be enough to prevent the coach from micromanaging. It may be possible to devise a language that the robots can speak and understand quickly enough for the coach to call out every pass decision to its players. For this reason, we also suggest borrowing a

technique from the RoboCup simulation league and requiring that coach messages be delayed by five to ten seconds. The coach will submit what it wants to say to a separate computer program that will then emit the sound after the delay. Thus the coach will only be able to communicate strategic information that is relevant over long periods of time, not instantaneous action decisions that should always be the responsibility of the individual players.

- The robot team is allowed a software coach that may have an overhead view of the field, but that can communicate with its team only orally with limited volume and with a five to ten second delay.

Similarly to the players themselves, we do not recommend placing any computational restrictions or bounds on the "intelligence" of the coach.

Human Players

So far the only restriction that we have placed on the human players is that they should not have artificial parts that give them superhuman capabilities. The only other restriction that we envision needing to place on the human players is that they not intentionally engage in any activity that disrupts the robots' communication or other normal mode of operation through any form of deception or trickery. They should play soccer as they do when playing against other humans.

This restriction probably does not actually need a special rule as it can fall under the current law of the game that "unsporting behavior" is a cautionable offense.

Will It Work?

The rules given above have been designed with an eye both towards fairness and towards faithfulness to the essence of soccer, so that the team that wins a match played under these rules can credibly be seen as being better at *soccer*. In designing the rules, the essential elements of soccer that we have preserved are the following:

- Soccer is a game played between teams of players with *incomplete sensing* and with *different capabilities* and *limitations*.
- The players move and kick at *roughly* the same speeds, thus requiring passing and *movement* off the ball for effective play.
- The players can *communicate*, but with limited bandwidth.
- The individuals are completely *autonomous* while on the field.
- The coach can provide only *strategic advice* during the game.

The rules should be taken as a starting point to be modified based on the technological state of the day. Though a lot of our focus has been on limiting the robots to be no better in any dimension than the humans, it is quite possible that such a perspective is overly optimistic with regards to robot technology. Robots may never be able to run as fast as people, or kick as hard and as accurately as people. In that case, many of the rules we proposed will be irrelevant. However if we had to bet, we would say that eventually, robots will indeed be able to run faster and kick better than people.

While the rules have been designed with an eye towards the theoretical goals of fairness and essence preservation, we also want the game played under these rules to determine whether

robots can *play* soccer. Towards that end, there are some pragmatic questions concerning these rules worth considering:

• *Aren't these rules 'stacked' against the robots?* There are some who, upon reading these rules, will conclude that the rules are rigged so that the humans will always win. There are clearly more limitations on robots than on humans, making the robots more 'human' and less 'robotic'—they take away any inherent advantages the robots may have. On the contrary, we propose these rules precisely so as to give the robots a chance of decisively demonstrating that they are better than humans at soccer. If there comes a time when a team of robots defeats a team of humans under these rules, then no spectator will be able to cry "foul!" The robots will not have won because they were all faster than the humans, nor because they used wireless communication. They will have defeated the humans because they had better finesse with the ball, they worked better as a team including managing the players' strengths and weaknesses, had better vision with regards to passing, and had better movement off the ball. In other words, they were better at the essential components of soccer. Only then will we be able to say with confidence that the robots can *play* soccer.

• *Will human players agree to play?* People are only likely to be willing to play against robots if they are confident that they are no more likely to sustain an injury than were they playing against other people (or at least they will require much higher payment for playing if injuries are likely). Even once the robots have a credible chance to beat a human club, it will probably be a long and involved process to convince the team to actually risk their players in such a game.

One possible way to ease the transition would be to first allow the human players to play in friendly matches on mixed human-robot teams, where the robots act as teammates to the humans. In fact, within the RoboCup initiative there has already been a brief experiment with such mixed teams in which Segway-based robots teamed up with humans riding Segways. The rules were carefully designed to prohibit any direct contact between the humans and the robots: any player with the ball was given a one-meter buffer zone, but was not allowed to dribble (similar to the rules of ultimate frisbee). It is possible that if players initially gain experience playing *with* the robots in such a setting, they may become more confident that it is safe to play *against* them in a regulation match.

• *Will fans be interested?* Soccer is enjoyed by both fans and players worldwide, and their enjoyment is one of soccer's most important qualities. When the first robots versus humans soccer matches are played, the level of enjoyment and acceptance by fans may reveal a lot about what is essential to soccer.

If fans are not interested in watching robot soccer, it may tell us that the players being human is important to soccer's essence. Without human players, including their limitations, motivations, and emotions, soccer may not be the same game. Then again, it may turn out that fans flock to the games because the robots play better, more precisely, and even more creatively than humans, implying that the skills and the game are more important to soccer than who or what is playing.

A side effect of trying to preserve the essence of soccer in our proposed rules is that we believe that the resulting matches will indeed be entertaining and compelling to watch, especially when the robots and humans are relatively evenly matched and the games are close.

But a FC Bot-celona?

Let's assume that all agree that our proposed rules preservefairness and the essence of soccer, and that the pragmatic questions can all be resolved. Will the robots win? Even if the robots lose, will the match be enjoyable and identifiable as soccer? Will we be able to conclude at the end of the match that robots can *play* soccer?

We don't know. There is no way to know until the match takes place. In that way, it's a lot like the human matches we all love: it will have to be decided on the pitch. Though today it may seem like a long time before a humans versus robots sporting event could be held, the incredible progress of roboticists around the world, including our many RoboCup colleagues, is making the prospect ever more realistic. We hope that we can be in the audience for the first World Cup match between robots and people![1]

[1] Thanks to David Levy forhelpful discussions related to the rules of the first human-computer chess matches, Manuela Veloso for helpful discussions related to RoboCup, and to Jeff Andrews for comments regarding the nature of the human game, as well as many of our colleagues from the RoboCup initiative for their on-going inspiring efforts towards the point where this chapter could be put to practical use.