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# An Architecture for Action Selection in Robotic Soccer

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*Joint work with*  
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# RoboCup

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An international AI and Robotics research initiative

- Use **soccer** as a rich and realistic test-bed

## Research challenges

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- Multiple **teammates** with a common goal
- Multiple **adversaries** — not known in advance
- **Real-time** decision making necessary
- **Noisy** sensors and actuators
- Enormous state-space

# CMUnited-99

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- Stone, Riley, Veloso
- 1999 simulator league world **champions**
- 37-team field; Total score: **110–0** (8 games)
  
- **Learned** low-level behaviors
- **Heuristic** high-level action decision
  - Dribble; Shoot; Hold; Clear; **Pass (10)**

Here: Improvements over CMUnited-99

# Outline

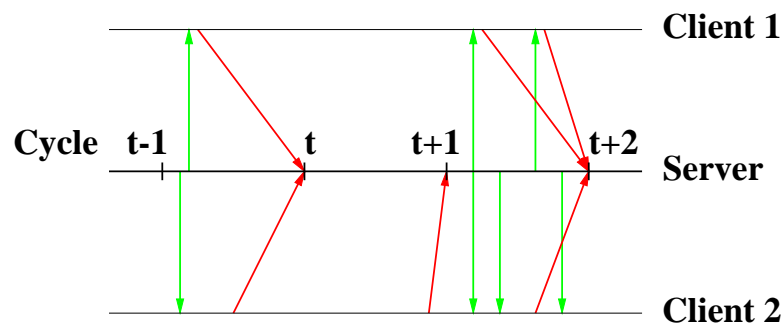
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- **RoboCup simulator**
- Action Selection Architecture
- Leading Passes
- Force Field Control for Off-Ball Motion
- Results

# RoboCup Simulator



- **Distributed**: each player a separate client
- Server models dynamics and kinematics
- Clients receive **sensations**, send **actions**



- Parametric actions: **dash, turn, kick, say**
- **Abstract, noisy** sensors, hidden state
  - **Hear** sounds from limited distance
  - **See** relative distance, angle to objects ahead
- $> 23^{10^9}$  states
- **Limited resources**: stamina
- Play occurs in **real time** ( $\approx$  human parameters)



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# Motivation

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## Decisions based on a **Value Function**

- $v(s) \equiv$  expected reward from state  $s$  (RL)
- $P(s'|s, a) \equiv$  probability of outcome  $s'$  when selecting option (action)  $a$  from  $s$
- Select option with highest

$$\sum_{s'} P(s'|s, a)v(s')$$

# Options

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An option can be **scored** and **executed**

- **Execute** the option with the highest **score**
- Scoring:
  - $p_s \equiv$  probability of success
  - $v_s, v_f \equiv$  values of succeeding, failing
  - Score:  $p_s v_s + (1 - p_s) v_f$
  - value function currently hand-written
  - Scoring across options must be **comparable**



# Aside: Soft Boolean Expressions

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## Avoid discontinuities

- $x <^\delta y \in [0, 1]$  (continuous)

$$x = y \Rightarrow x <^\delta y = 1/2$$

$$x \ll 0 \Rightarrow x <^\delta y \sim 0$$

$$x \gg 1 \Rightarrow x <^\delta y \sim 1$$

- $\text{if}^*(p, x, y)$  assumes  $p \in [0, 1]$

$$\text{if}^*(p, x, y) \equiv px + (1 - p)y$$

- Often write  $\text{if}^*(x <^\delta y, z, w)$ .

# Pass Option

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- Consider **hundreds** of passes:
  - angle increments of  $4^\circ$
  - speed increments of  $0.2m/sec$
- $I_t$  ( $I_o$ )  $\equiv$  teammate (opponent) interception time
  - Approximate, **fast** computation
- **Score**: larger margin  $\Rightarrow$  larger  $p_s$ 
$$p_s = \text{if}^*(I_t <^5 I_o, .9, 0)$$
- $v_s$  based on ball's predicted location after pass
- $v_f = 0$

# Other Options

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**Shot Option:** kick towards a point in the goal

- $p_s$  related only to  $I_o$
- $v_s \gg 0$
- $v_f = 0$

**Clear Option:** kick the ball down the field

- $p_s$  related only to  $I_o$
- $v_s > 0$
- $v_f = 0$

**Others:** dribble, send, hold, cross, ...

- Difficult to calibrate many

# Leading Passes

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**CMUnited-99:** only direct passes

**Now:** hundreds considered

- Usually a pass option is selected
- **Many leading passes seen**

Movement without the ball is also crucial

**CMUnited-99:** SPAR

- Forces over limited regions
- Boundaries treated as hard constraints

# Outline

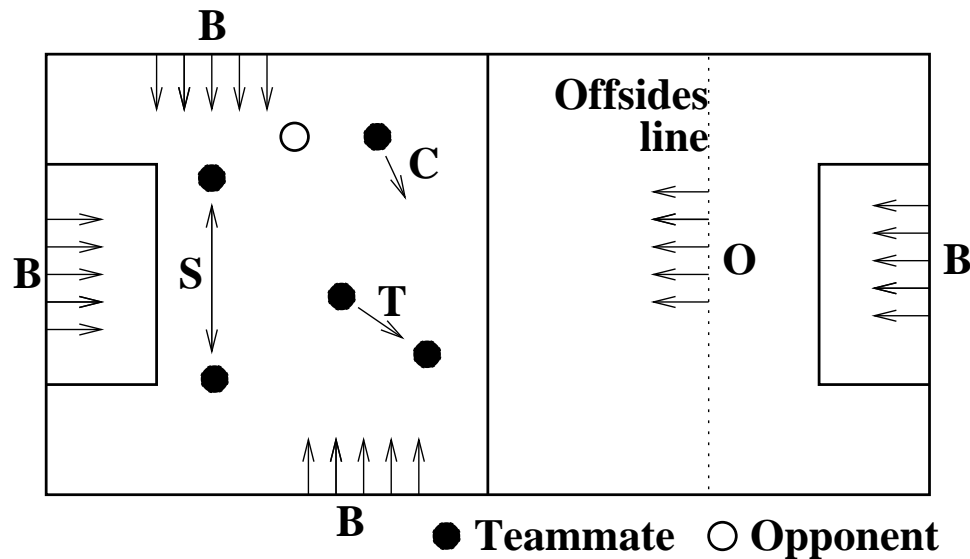
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# Movement Off the Ball

**In principle:** derivative of value function

**Here:** vector sum of force fields

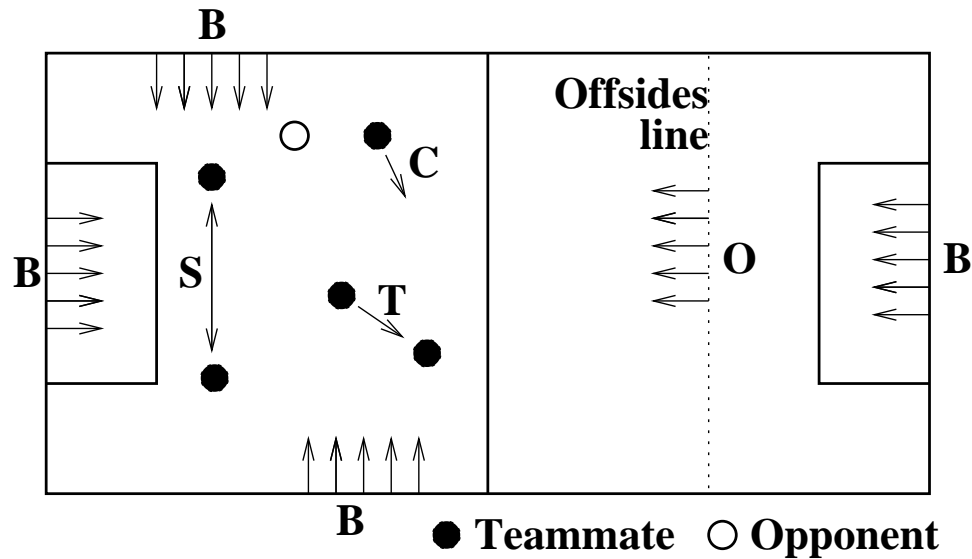


$d_b \equiv$  distance of the player to the ball

$$F \equiv B + O + \text{if}^*(d_b <^{10} 20, T + C, S)$$

# Force Fields

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**Bounds-Repellent (B):** Stay on the field

**Offsides-Repellent (O):** Stay on-sides

**Strategic (S):** Stay about 20m from teammates

**Tactical (T):** But not too close

**Get-clear (C):** Move away from “key” defender

# Results

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- **Keepaway** vs. CMUnited-99
  - Goal: maintain possession
  - No offensive or defensive reasoning
- Possession time in 95% confidence intervals

Program	Possession Time	Mean Ball $x$ Position
CMUnited-99	5.7-6.6 sec	-19.5
New Team	16.9-18.7 sec	-33.6

**Very insensitive to most parameters**



## Varying $S$

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$S^b$ : Force of unit magnitude towards the ball

$S^d$ : Force downfield

$S^*$ :  $S$ ,  $S + S^b$ ,  $S + S^d$ , or  $S + S^b + S^d$

$$F \equiv B + O + \text{if}^*(d_b <^{10} 20, T + C, S^*)$$

Program	Possession Time	Mean Ball $x$ Position
CMUnited	5.7-6.6	-19.5
$S$	16.9-18.7	-33.6
$S + S^b$	24.8-27.9	-35.9
$S + S^d$	22.2-25.2	25.7
$S + S^b + S^d$	23.7-26.8	26.6

# Overall Results

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- CMUnited-99 vs. CMUnited-99: **0.3 – 0.3**
- New Team vs. CMUnited-99: **2.5 – 0.3**

## RoboCup-2000 Competition

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- **ATT-CMUnited-2000**: 3rd place
  - Stone, Riley, McAllester, Veloso
  - Also included **dynamic set plays**  
[Riley & Veloso, 2001]
  - 35-team field; Total score: **26–11** (8 games)

# Summary

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- An option-based **action-selection architecture**
- **Leading Passes** in RoboCup soccer
- **Force Field Control** for Off-Ball Motion

## Related Work

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- **Samba** [Riekki & Roenig, '98]: force fields for action selection
- **SPAR** [Veloso et al., '99]: limited regions, hard constraints

## Future Work

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- **Learn** the option value functions using **RL**