Artificial Intelligence Meets Robotics for the Creation of Robotic Soccer Teams

Luís Paulo Reis

lpreis@fe.up.pt

Director of LIACC – Artificial Intelligence and Computer Science Lab., University of Porto
Associate Professor at Faculty of Engineering, University of Porto, Portugal
Vice-President of APPIA – Portuguese Association for Artificial Intelligence

Presentation Outline

- Artificial Intelligence, Robotics and Simulation
- Robotic Competitions, Robotic Soccer and RoboCup
- High-Level Coordination, Interaction and Learning
- FC Portugal Project – Coordination of Multi-Robot Teams
- Intellwheels Project – Intelligent Wheelchair
- Hearbo Project – Robot Dancing/Audition
- Conclusions and Future Work

Artificial Intelligence

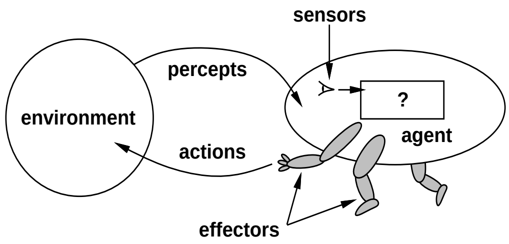
- **Intelligence**
  - "Capacity to **solve new problems** through the use of knowledge"

- **Artificial Intelligence**
  - "Science concerned with building **intelligent machines**, that is, machines that perform tasks that when performed by humans require intelligence"

Autonomous Agents and Multi-Agent Systems

Agent:

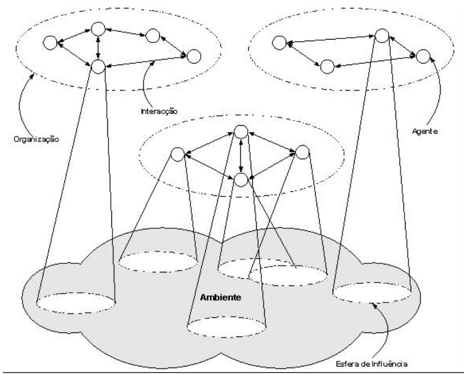
"Computational System, situated in a given **environment**, that has the ability to **perceive** that environment using **sensors** and **act**, in an **autonomous way**, in that environment using its **actuators** to fulfill a given **function**."



Russel and Norvig, "AI: A Modern Approach", 1995

Multi-Agent System:

- Agents exhibit **autonomous behavior**
- **Interact** with other agents in the system



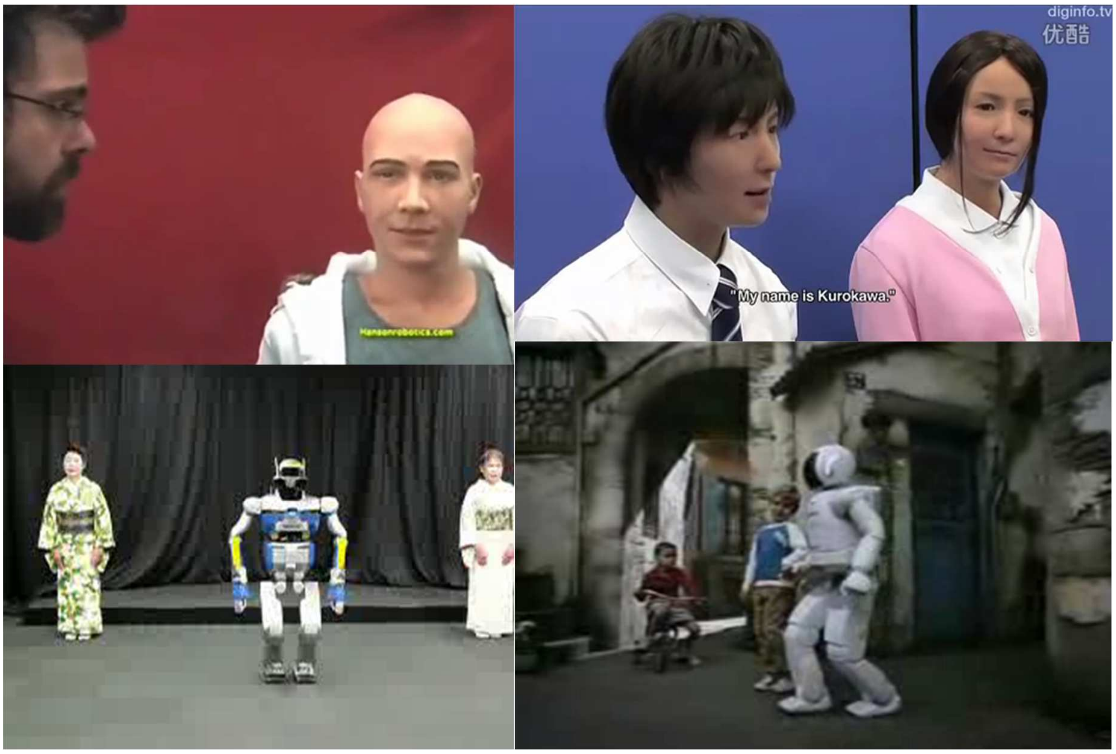
Intelligent Robotics

- **Robotics**
  - Science and technology for projecting, building, **programming** and using Robots
  - Study of **Robotic Agents (with body)**
  - Increased Complexity:
    - **Environments:** Dynamic, Inaccessible, Continuous and Non Deterministic!
    - Perception: Vision, **Sensor Fusion**
    - Action: Robot Control (humanoids, increasing DOFs)
    - Robot Architecture (Physical / Control)
    - Navigation in unknown environments
    - **Learning** of complex task
    - **Interaction** with other robots/humans
    - **Coordination** and Multi-Robot Systems

Current State of Robotics

- **Used to Perform:**
  - **Dangerous** or difficult **tasks** to be performed directly by humans
  - **Repetitive tasks** that may be performed more efficiently (or cheap) than when performed by humans
- **Robots have moved from manufacturing, industrial applications to:**
  - **Domestic** robots (Pets – AIBO, vacuum cleaners)
  - **Entertainment** robots (social robots)
  - Medical and **personal service** robots
  - **Military** and surveillance robots
  - **Educational** robots
  - Intelligent buildings
  - **Intelligent vehicles** (cars, submarines, airplanes)
  - New industrial applications (mining, fishing, agriculture)
  - Hazardous applications (space exploration, military apps, toxic cleanup, construction, underwater apps)
  - **Multi-Robot Applications and Human-Robot Teams!**

Current State of Humanoid Robotics



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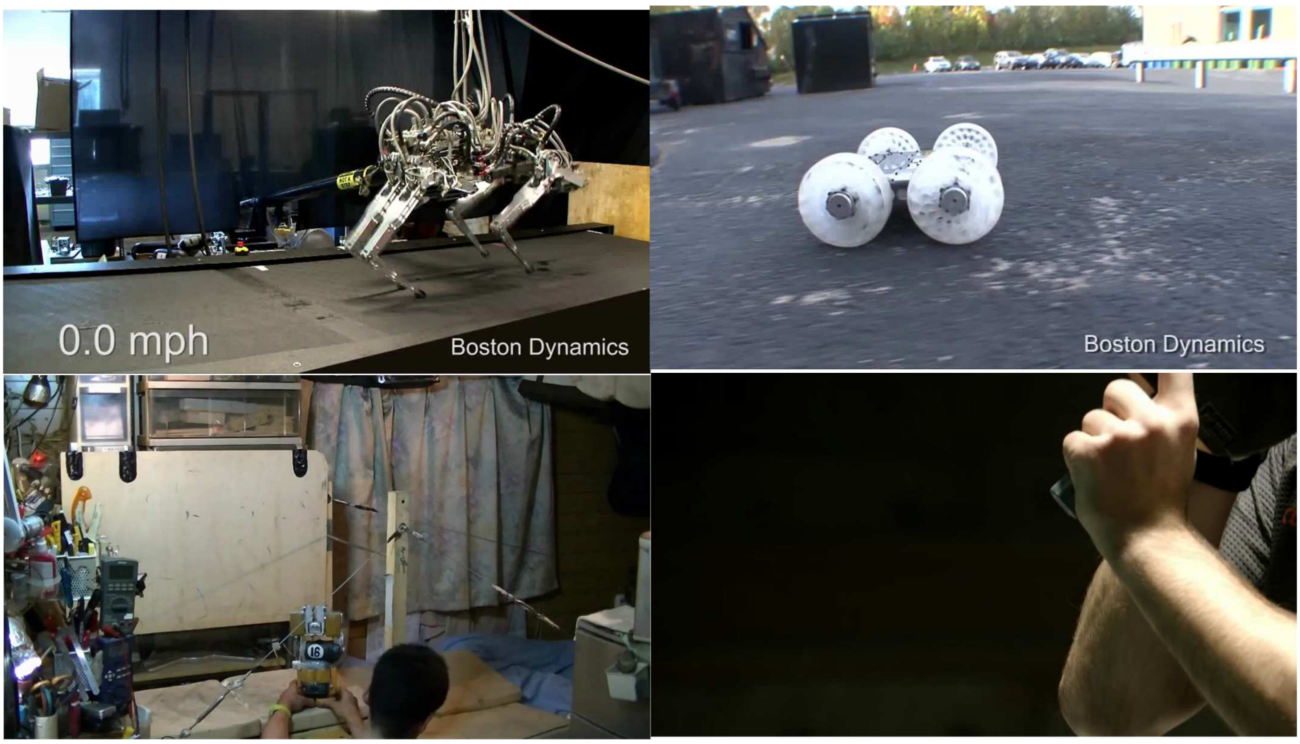
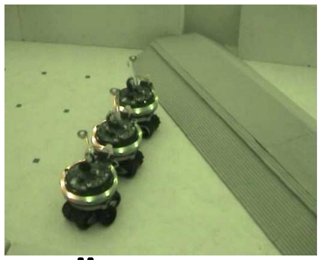
Current State of Sports' Robotics



Coordination in Multi-Robot Systems



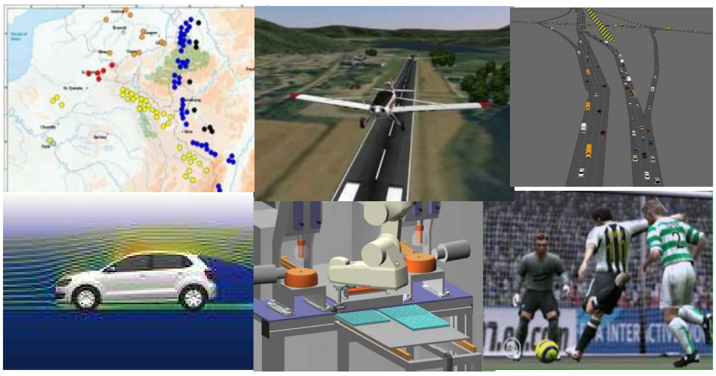
- Agents/Robots don't live alone and have to work in a group…
- **Human-Robot Interaction**
- **Multi-Robot Coordination**

Coordination : "to work in harmony in a group"

- **Dependencies** in agent actions
- Global constraints
- **No agent**, individually **has enough resources**, information or capacity to execute the task or solve the problem
- **Efficiency:** Information exchange or tasks division
- **Prevent anarchy and chaos**: Partial vision, lack of authority, conflicts, agent's interactions

Agent-Based Simulation

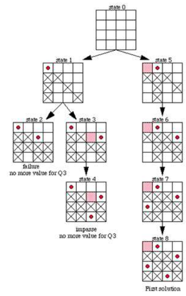
- **Simulation: Imitation of some real thing, state of affairs, or process, over time,** representing certain **key characteristics** or behaviours of the physical or abstract system
- Applications:
  - Understand system **functioning**
  - **Performance optimization**
  - Testing and validation
  - **Decision making**
  - Training and education
  - **Test future/expensive systems**

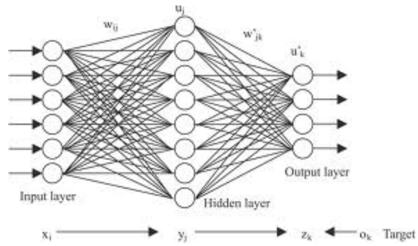


- For complex systems impossible to solve mathematically
- **Agent Based Modeling and Simulation**

Learning and Optimization in MAS

- **Learning**
  - **Use of past experience to improve future performance**
- **Optimization**
  - **Choosing the best solution for a given problem**
- **Interesting topics:**
  - Modelling complex problems as Optimization Problems
  - Simulation Calibration/Validation!
  - **Multi-Agent Learning**
  - Multi-Criteria Optimization
  - Data Mining in new domains
  - Stochastic optimization
  - Meta-heuristics (HC, SA, TS, GA, PSO, AC, …)
  - **Non-Parametric Contextual Stochastic Search**
  - Constraint Logic Programming





Robotic Games and Competitions

Robotic Competitions - RoboGames

Robotic Competitions - RoboGames

Robotic Games and Competitions

Benefits

- Research inspiration
- Hard deadline for creating fully functional system
- Common platform/problem
- Exchange of research ideas/solutions
- Continually improving solutions
- Excitement for students/researchers at all levels
- Large number of teams/solutions created
- Encouragement for flexible software/hardware

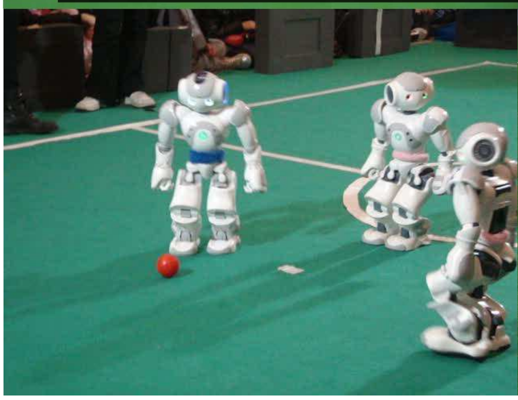
Dangers

- Obsession with winning
- Domain dependent/ hacked solutions
- Cost escalation
- Difficulty in entering at competitive level
- Restrictive rules
- Invalid evaluation conclusions

Robotic Competitions - RoboCup

RoboCup

- Real, Standard, Simulated Robots
- Mini, Small, Medium and Large Robots
- Wheeled, Legged and Humanoid Robots
- Distinct but interrelated Leagues/Problems
- Only a Few Research Groups able to develop code that works in more than one league!



Main Research Questions

How to **Coordinate** heterogeneous **Multi-Robot Teams** executing **flexible tasks** in dynamic, adversarial environments?

How to define **Flexible Human-Robot Interaction** methods enabling Human-Robot Cooperation in dynamic environments?

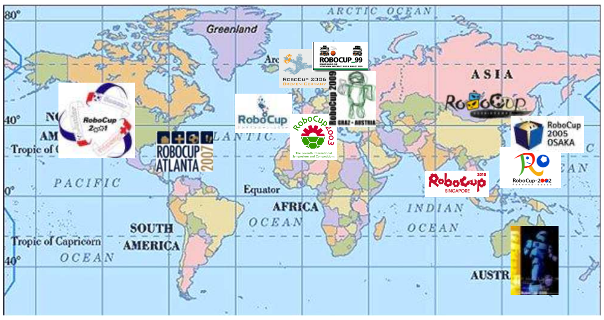
How to **Learn Complex and Flexible (multi)Robot Skills** in dynamic environments?

How to **Formalize Sports' Concepts** to be able to develop **Intelligent Robots** that **Play or Analyze Sports?**

Key Issues in Human-Robot Teams

- Sensor Fusion and Multi-Sensor Intelligent Perception
- **Multi-Robot Coordination**/Flexible Strategy
- Adaptive Strategy
- **Flexible Multimodal Interaction**
- **Human Robot Cooperation**
- Adaptive Interaction
- **Realistic Simulation**
- Bridging the Gap between Simulation and Robotics

RoboCup: Objectives



- Joint International Project:
  - **(Distributed) Artificial Intelligence**
  - **Intelligent Robotics**
- **Soccer** – Central Research Topic:
  - **Very complex collective game**
  - **Huge amount of technologies** involved:
    - Autonomous Agents, Multi-Agent**/Multi-Robot Systems**, **Cooperation**, **Communication**, **Strategic Reasoning**, Robotics, Sensor Fusion, Real-Time Reasoning, Machine Learning, etc

Main Goal:

"By 2050, develop a team of fully autonomous humanoid robots that may win against the human world champion team in soccer!"

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RoboCup: Official Competitions

1997 – Nagoya (Japan)
1998 – Paris (France)
1999 – Stockholm (Sweden)
2000 – Melbourne (Australia)
2001 – Seattle (USA)
2002 – Fukuoka (Japan)
2003 – Padua (Italy)
2004 – Lisbon (Portugal)
2005 – Osaka (Japan)
2006 – Bremen (Germany)
2007 – Atlanta (USA)
2008 – Suzuhu (China)
2009 – Graz (Austria)
2010 – Singapore (Singapore)
2011 – Istanbul (Turkey)
2012 – Mexico City (Mexico)
2013 – Eindhoven (Holland)
2014 – João Pessoa (Brazil)
2015 – Hefei (China)
2016 – Leipzig (Germany)
2017 – Nagoya (Japan)

Local Championships:
German Open (European), Japanese Open, Australian Open, American Open, **Portuguese Open**, Dutch Open, Iranian Open, China Open, LARS/SBR…

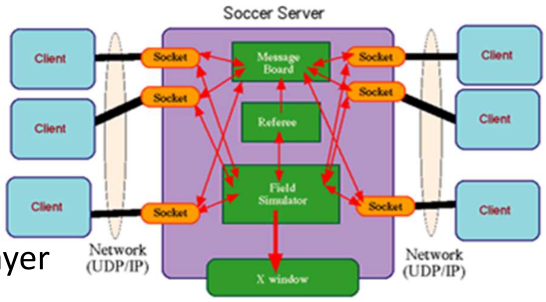
Participant/Awarded Countries:
Germany, USA, Japan, China, Iran, **Portugal,** Brazil, Australia, Holland, Singapore

Soccer Leagues
- **Simulation: Sim2D, Sim3D (Humanoids), Coach, MR**
- **Robots Small-Size**
- **Robots Middle-Size**
- **Standard Platform** (**Aibo**; **NAO**)
- Humanoid Robots (Kid, Adult)

RoboCup Rescue
- **Simulation**, Virtual, Robotic

RoboCup Junior
RoboCup@Home
RoboCup@Work


RoboCup Leagues: Simulation 2D



Server Architecture

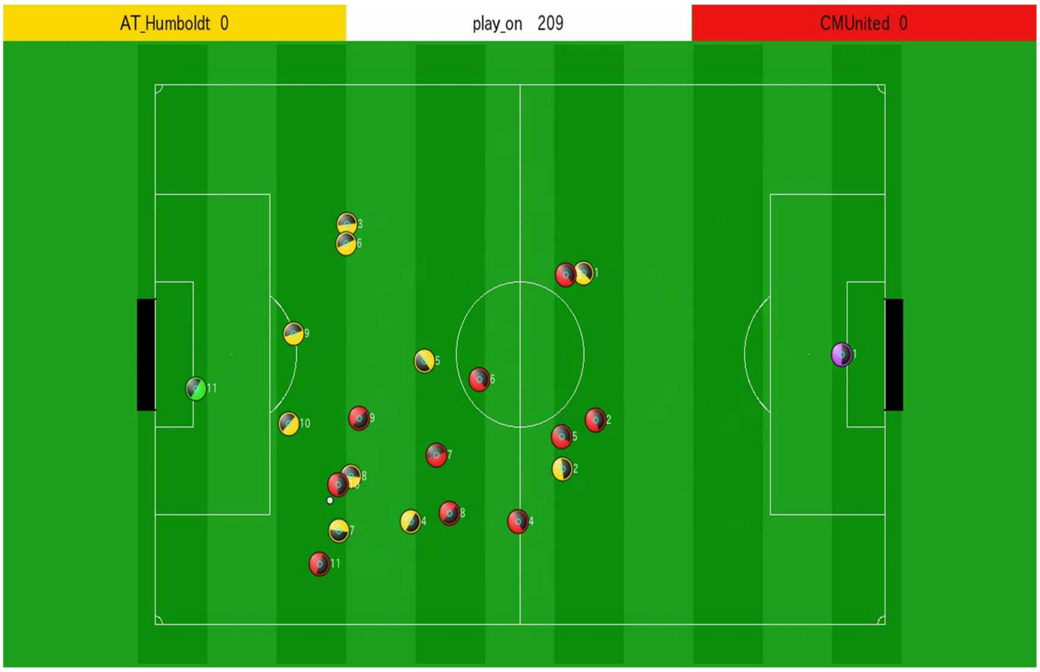
- **Virtual Robots** on a 105*68m Virtual Field
- Teams of 11 players plus a coach
- 2D Simulator+Monitor (Client-Server System)
- Robots controlled by different agents
- Agents (player's brains) control a single player
- **Simulator**/Server:
  - **Receives** agent **commands**
  - **Simulates** objects' **movement**
  - **Sends perceptions** to agents
- **Simulation Characteristics**
  - **Real-Time** - Human
  - Distributed – 24 Processes
  - **Inaccessible** (hidden), Continuous and Dynamic World
  - **Errors** in: Perception, Movement and Action
  - **Limited Resources** and Communication
  - **Multi-Objective**

RoboCup Leagues: Simulation 2D

- **1997: League Start -> Simple Play**

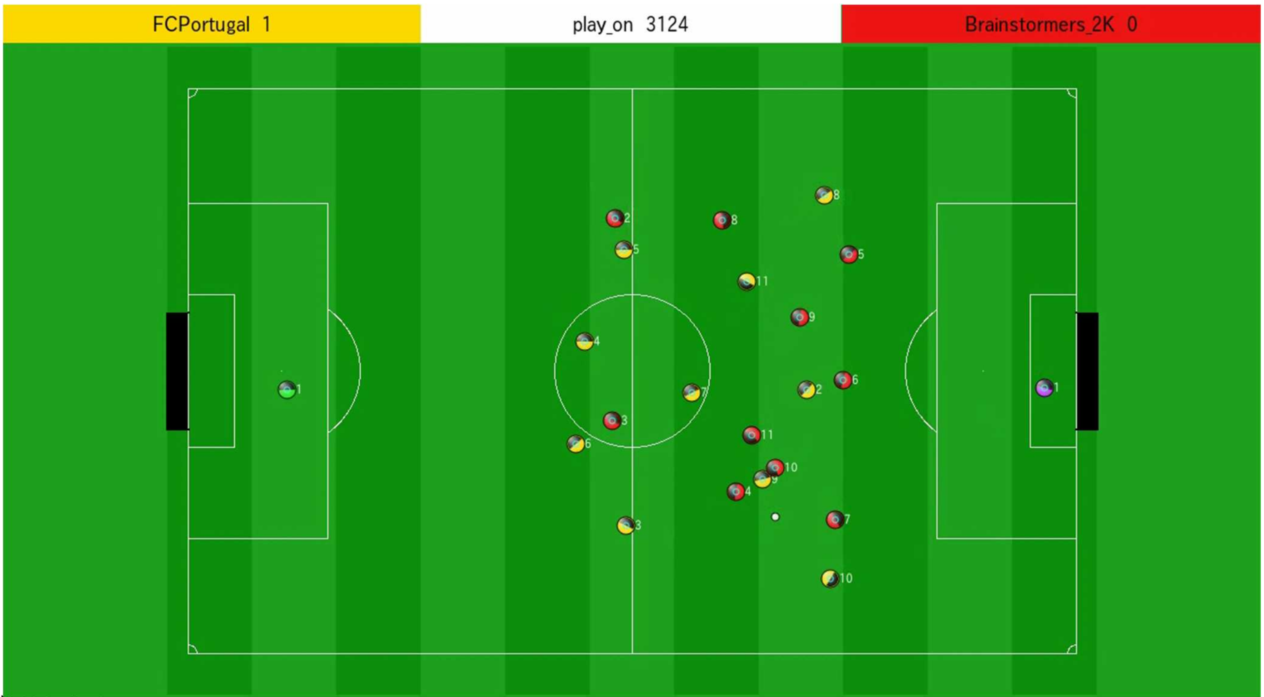
RoboCup Leagues: Simulation 2D

- **1998: Simple Passing and Good Individual skills**



RoboCup Leagues: Simulation 2D

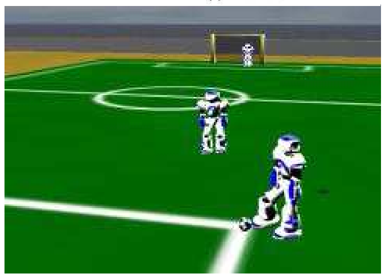
- **2000: Formations and Soccer like Playing**



Simulation 3D League (Humanoids)

- Third dimension and complexities from real robots
- **Realistic physics and Robot Model:**
  - Spheres in 2004
  - Humanoids in 2007
  - NAO Robot Model: 2008
  - Heterogeneous Robots: 2013
- **Strong relation with SPL**
- 2 vs 2 -> 6 vs 6 -> 9 vs 9 -> 11 vs 11
- Server/Simulator (**SimSpark**)
  - Updates world state
  - Forces the "**laws of physics**": collisions, drag, gravity, ...
  - Send sensor information (**perceptors**)
  - Executes actions (**effectors**)
  - Enforces soccer rules – referee
- **Very difficult to create competitive skills by hand!**

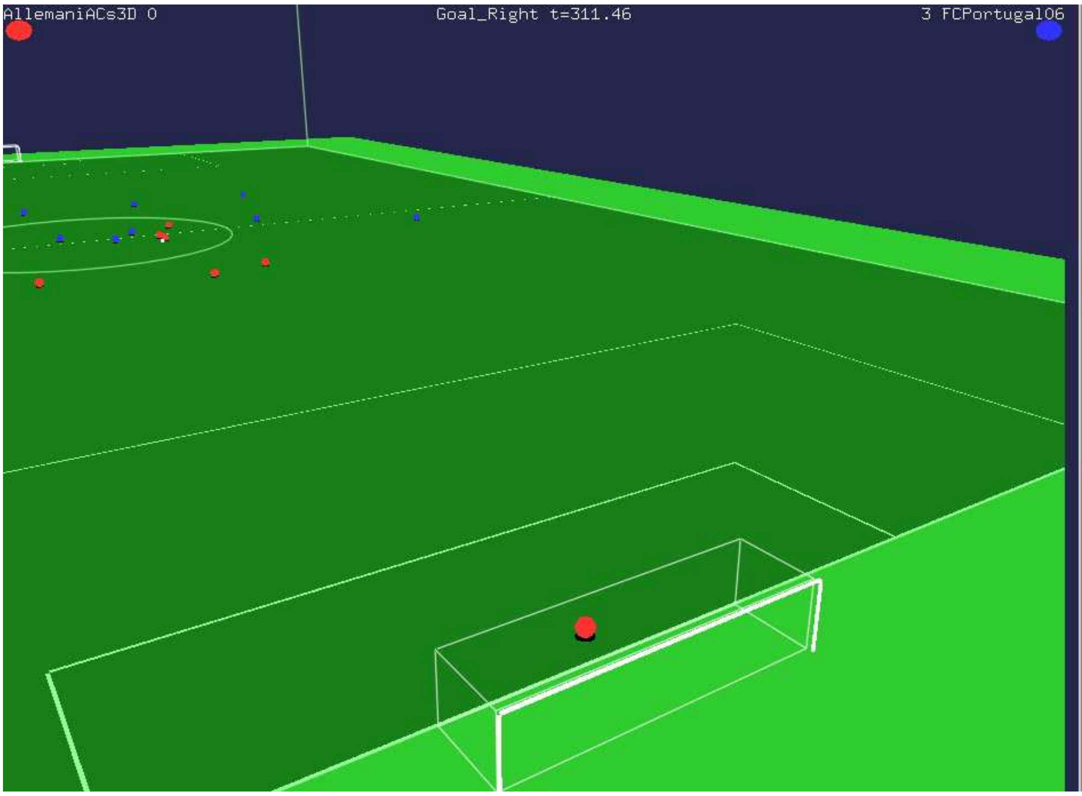
(a) real robot (b) virtual robot



Simulation 3D – Spheres model

- 2004-2005: Very Basic playing!
- 2006: Formations/High-level playing!

Simulation 3D – Spheres model



Simulation 3D – Humanoid model

- 2007-2010: Very Basic playing!
- 2011: Formations/High-level playing!

Simulation 3D – Nao model

- Same Robot but completely different skills: Walk, getup, kick

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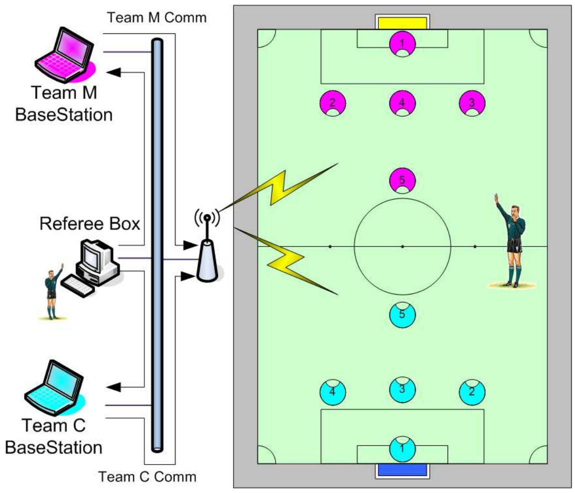
Simulation 3D – Nao model

Middle Size League

- Robots are completely autonomous
- 5 robots per team
- Robots around 50x50cm and 80cm height
- Field 18mx12m, green with white lines
- MSL rules based on official FIFA laws



Middle Size League

- 1998-2007: Very Basic playing! Individual Dribbling!
- 2008: Formations SBSP/High-level playing/Setplays!

Flexible Strategy for RoboCup

- RoboCup Leagues: Simulation 2D, Simulation 3D, Small-Size, Middle-Size, SPL and Search and Rescue
- Applications in four distinct teams:
  - FC Portugal *(University of Porto/Aveiro/Minho)*
    - Simulation 2D, Simulation 3D, Coach, MR, Rescue, SPL
  - CAMBADA *(University of Aveiro) – Prof. Nuno Lau*
    - Middle-Size League, RoboCup@Home
  - 5DPO *(University of Porto) – Prof. A.P.Moreira*
    - Small-Size League, Middle-Size League
  - Portuguese Team *(University of Porto/Aveiro/Minho)*
    - SPL – Standard Platform League
- More than 40 awards in International Competitions for these 4 Teams!

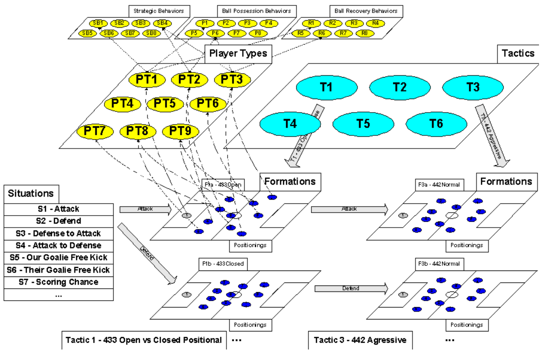
The Coordination Problem

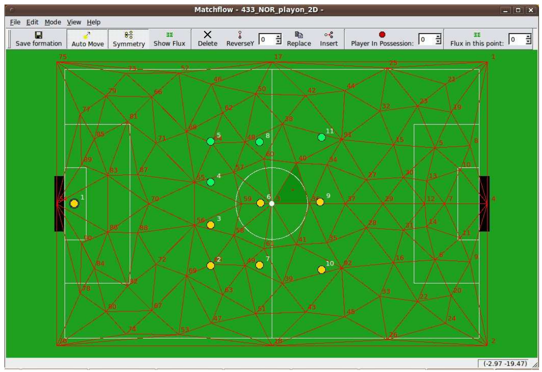
- Coordinate autonomous robots decisions to carry out team tasks as efficiently as possible
- Coordination challenges
  - Strategy
  - Coaching
  - Role assignment
  - Formation
  - Plan execution
  - Interaction
  - Learning
  - Communication

Formalizing Sports' Concepts

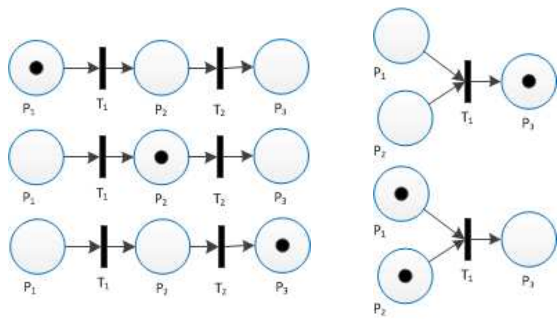
- Team/Collective Behaviour
  - Strategy
  - Tactics
  - Formations
  - Setplays
  - …
- Player/Individual Behavior
  - Action
  - Pass/Shot
  - Tackle/Interception
  - …

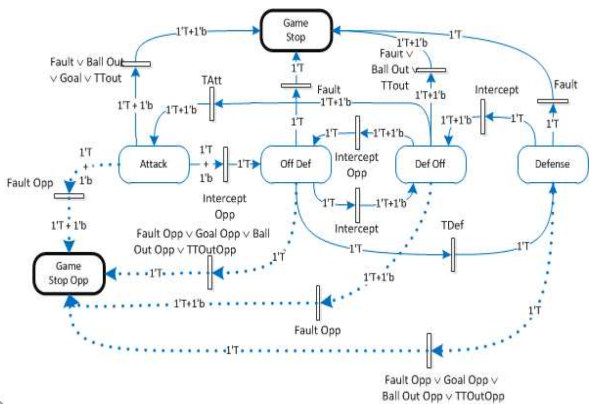
- Petri Nets
- BNF – Bakus Naur Forms
- SExpressions
- Ontologies
- Logic and Fuzzy Logic
- Data Mining

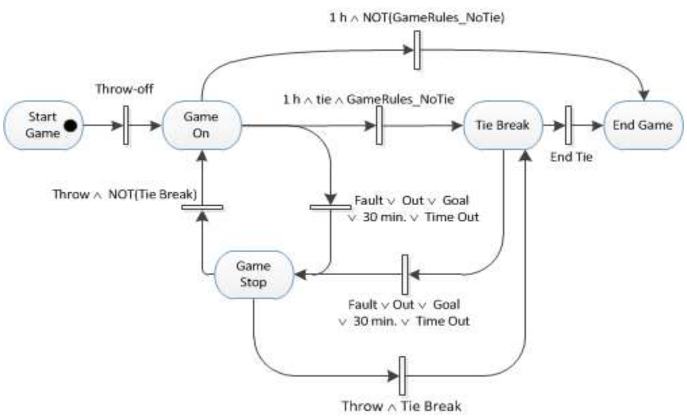




Game Analysis with Petri Nets







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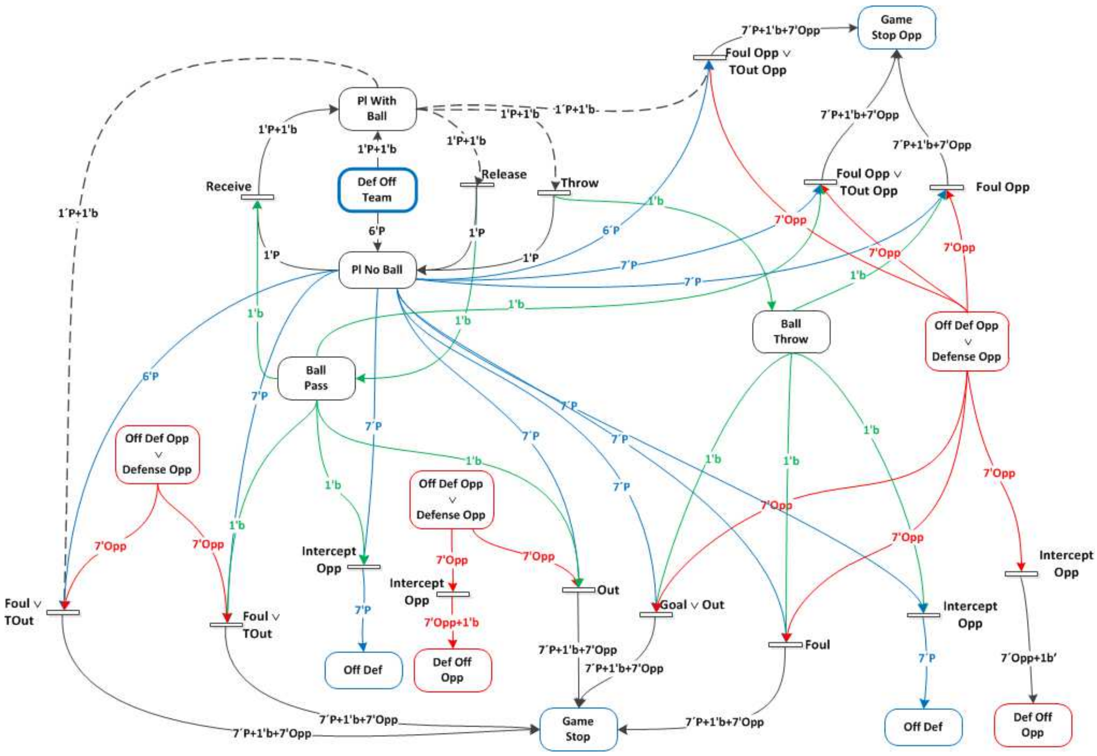
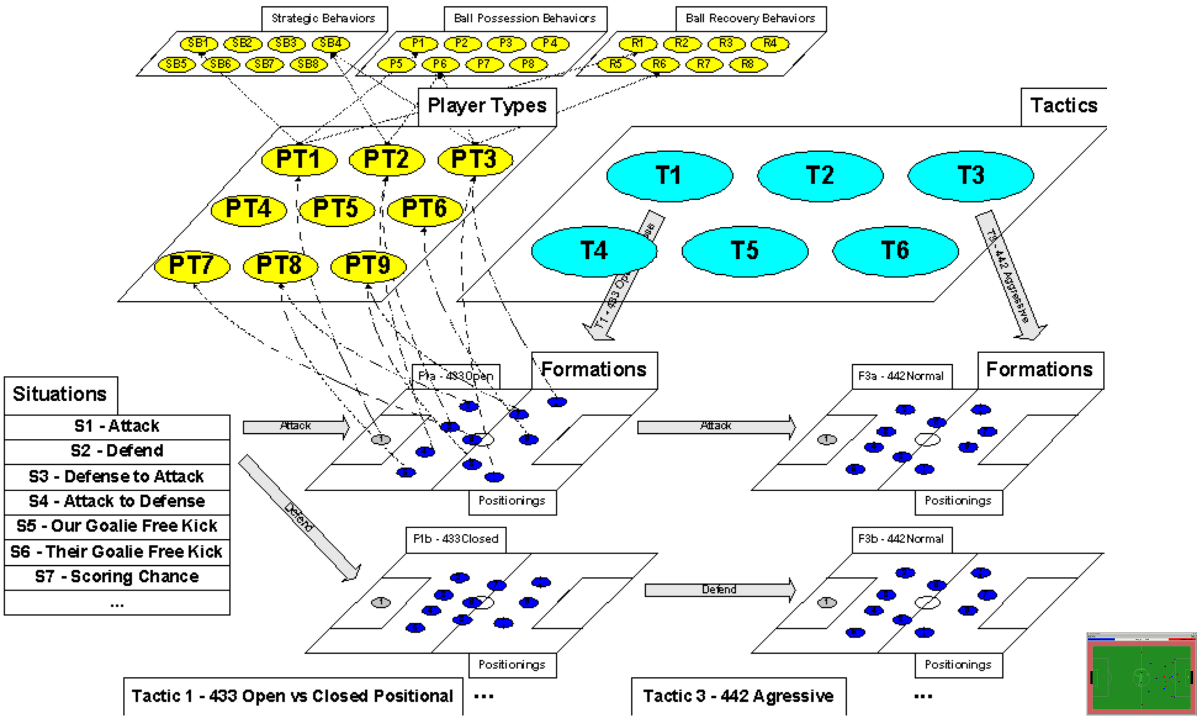
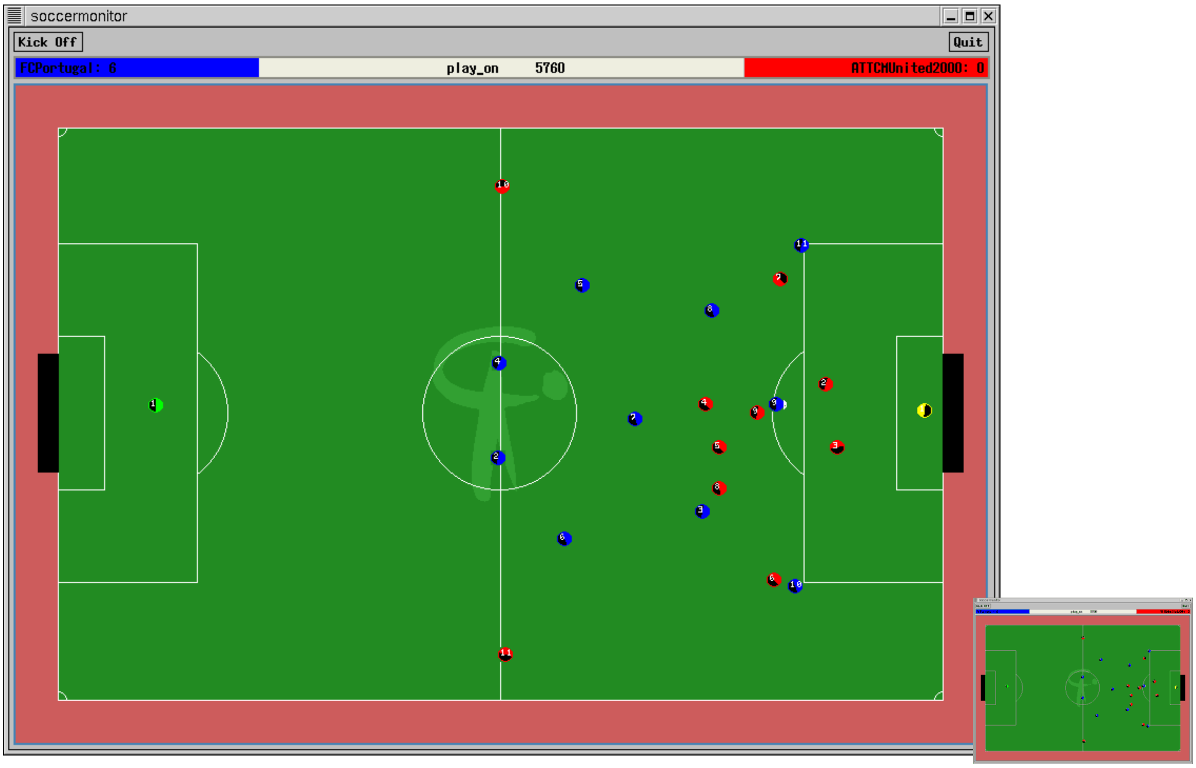


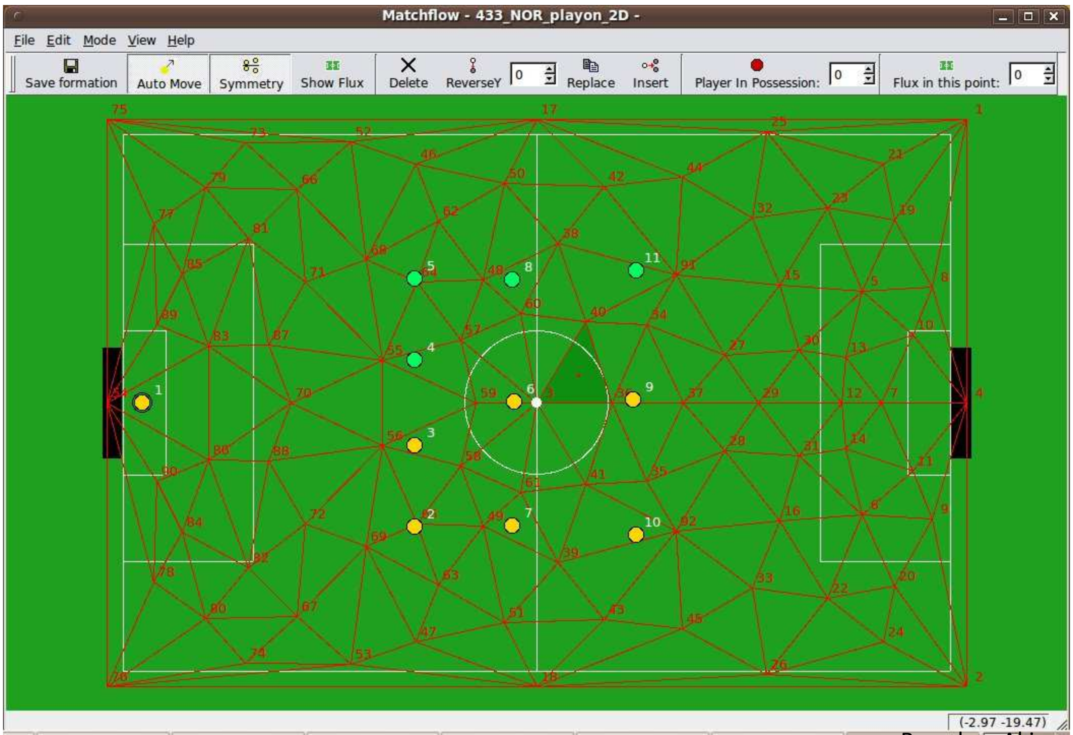
Simulation of a Team Strategy



Formations: SBSP vs SPAR and DPRE

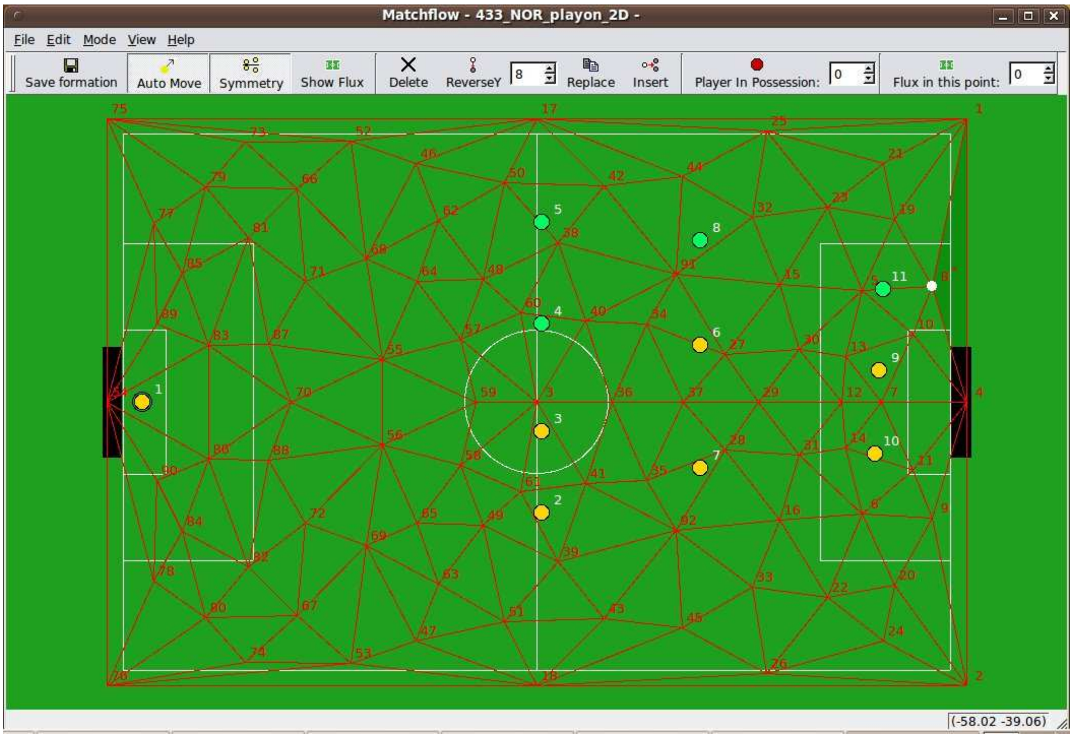


SBSP with Delaunay Triangulation

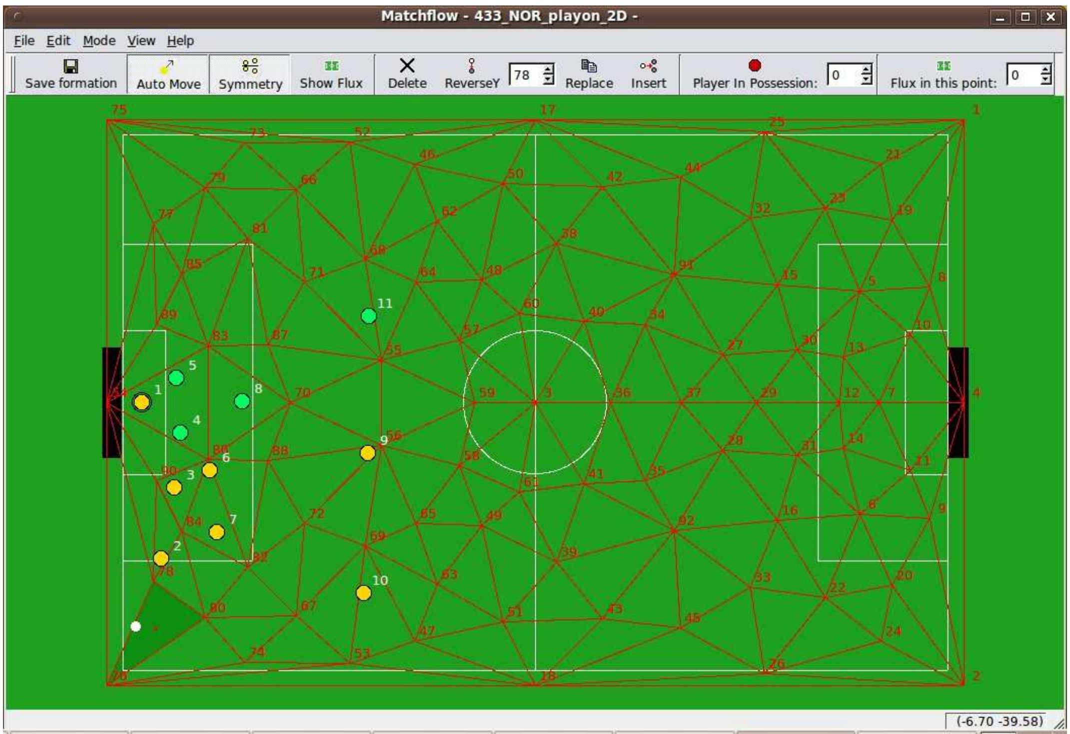


Based on Akiyama, 2007

SBSP with Delaunay Triangulation



SBSP with Delaunay Triangulation



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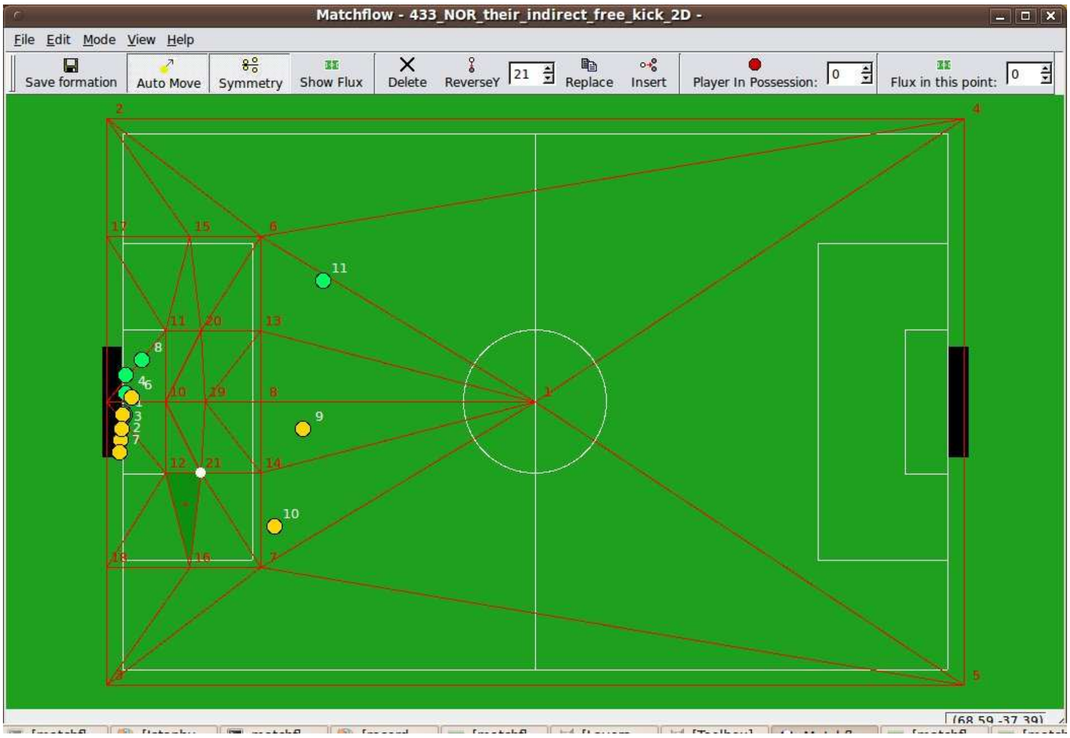

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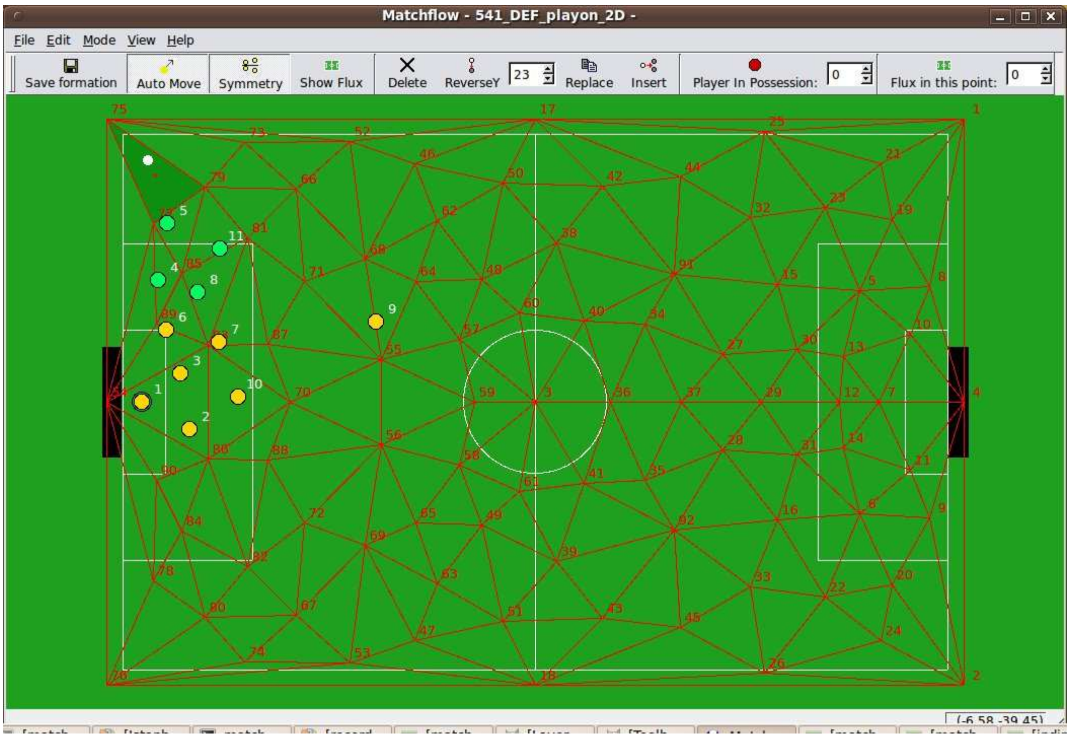

SBSP with Delaunay Triangulation

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SBSP with Delaunay Triangulation

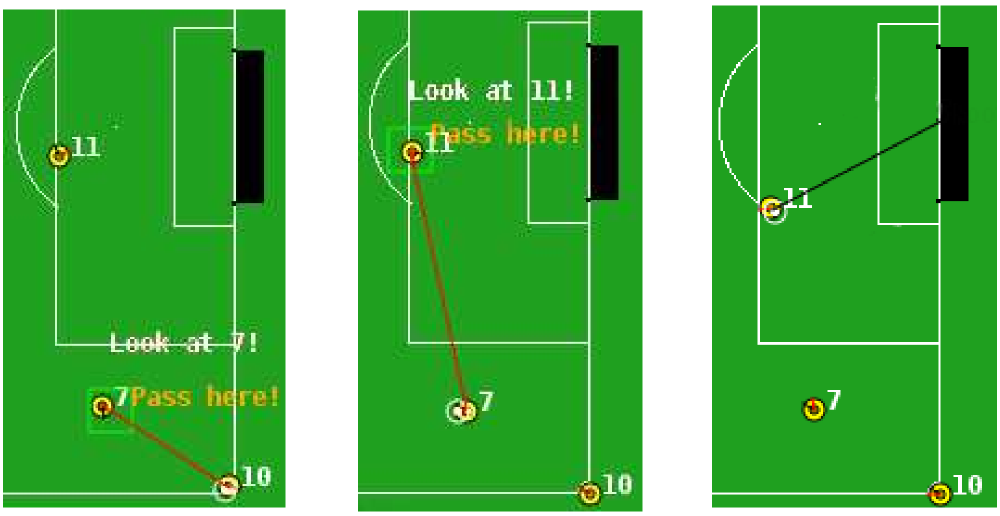
SBSP with Delaunay Triangulation

Formations in the MSL

Formations in the MSL

Setplay Example (Sim2D)

Simple, pre-defined but flexible plans, which describe cooperation and coordination between agents/robots



Setplay Definition

(setplay :name simpleCorner
:players (list (playerRole :roleName CornerP)
(playerRole :roleName receiver) (playerRole :roleName shooter))
:steps (seq (step :id 0 :waitTime 15 :abortTime 70
:participants
(list (at CornerP (pt :x 52 :y 34))
(at receiver (pt :x 40 :y 25)) (at shooter (pt :x 36 :y 2)))
:condition (playm fk_our)
:leadPlayer CornerP
:transitions (list
(nextStep :id 1:condition (canPassPl :from CornerP :to receiver)
:directives (list
(do :players CornerP :actions (bto :players receiver))
(do :players receiver :actions (receivePass))))))

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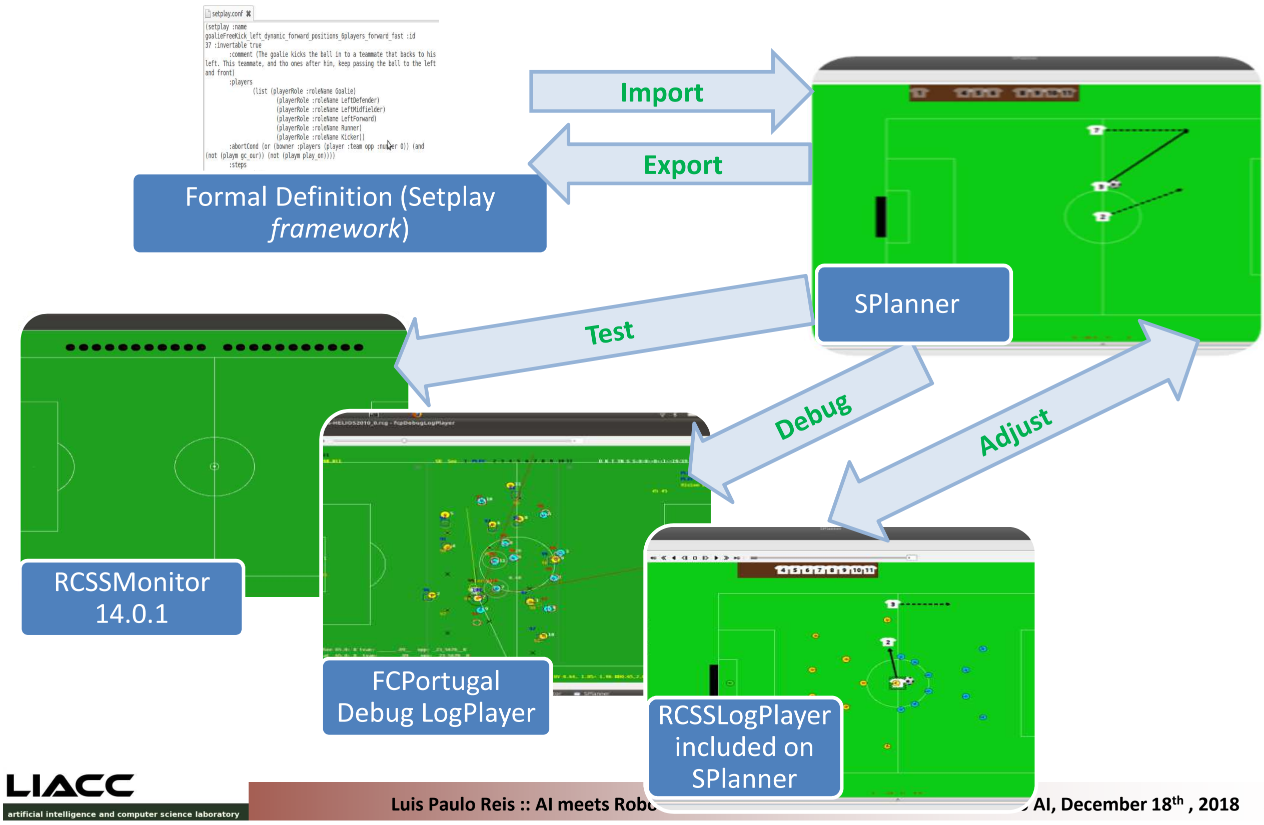
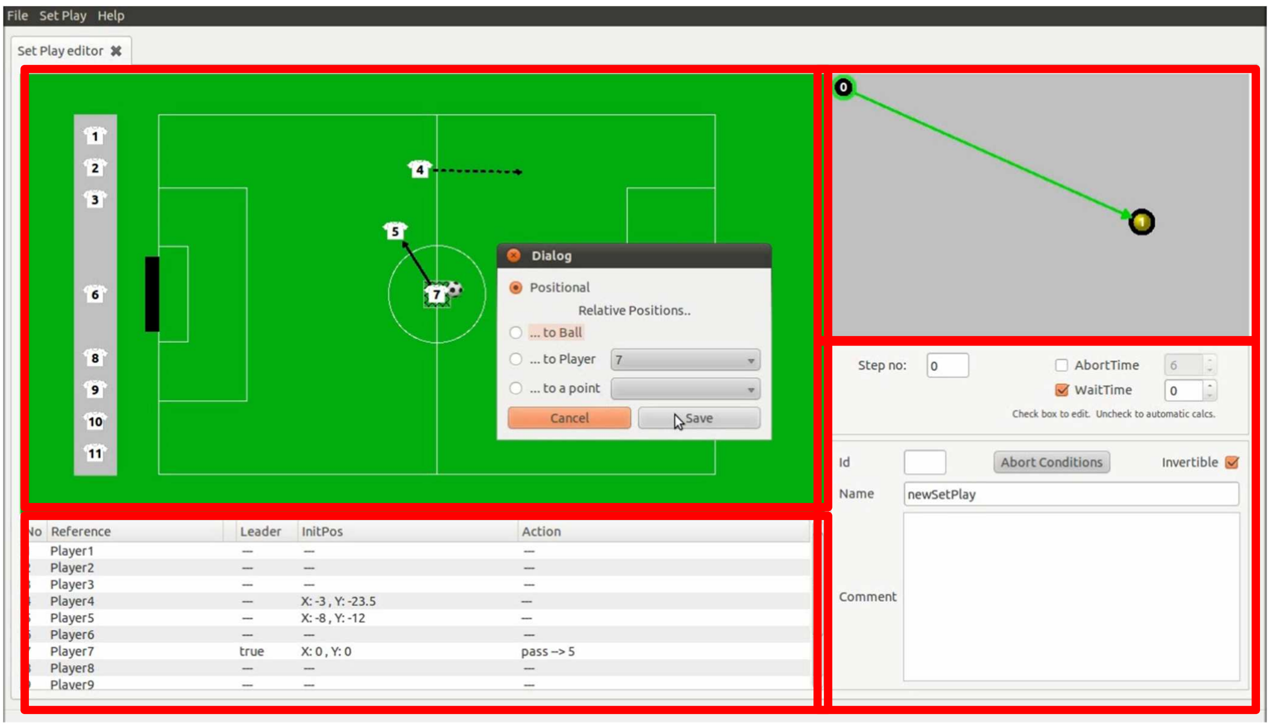
Setplay Definition

(step :id 1 :waitTime 5 :abortTime 70
:participants (list (at CornerP (pt :x 52 :y 34)) (at receiver (pt :x 40 :y 25))
(at shooter (pt :x 36 :y 2)))
:condition (and (bowner :players receiver) (playm play_on)) :leadPlayer receiver
:transitions (list
(nextStep :id 2
:condition (canPassPl :from receiver :to shooter)
:directives (list
(do :players receiver :actions (bto :players shooter))
(do :players shooter :actions (receivePass))))))
(step :id 2 :abortTime 70
:participants (list (at CornerP (pt :x 52 :y 34)) (at receiver (pt :x 40 :y 25)) (at shooter (pt :x 36 :y 2)))
:condition (and (bowner :players shooter) (playm play_on))
:leadPlayer shooter :transitions (list
(nextStep :id 3 :condition (canShoot :players shooter)
:directives (list
(do :players shooter :actions (shoot)))))

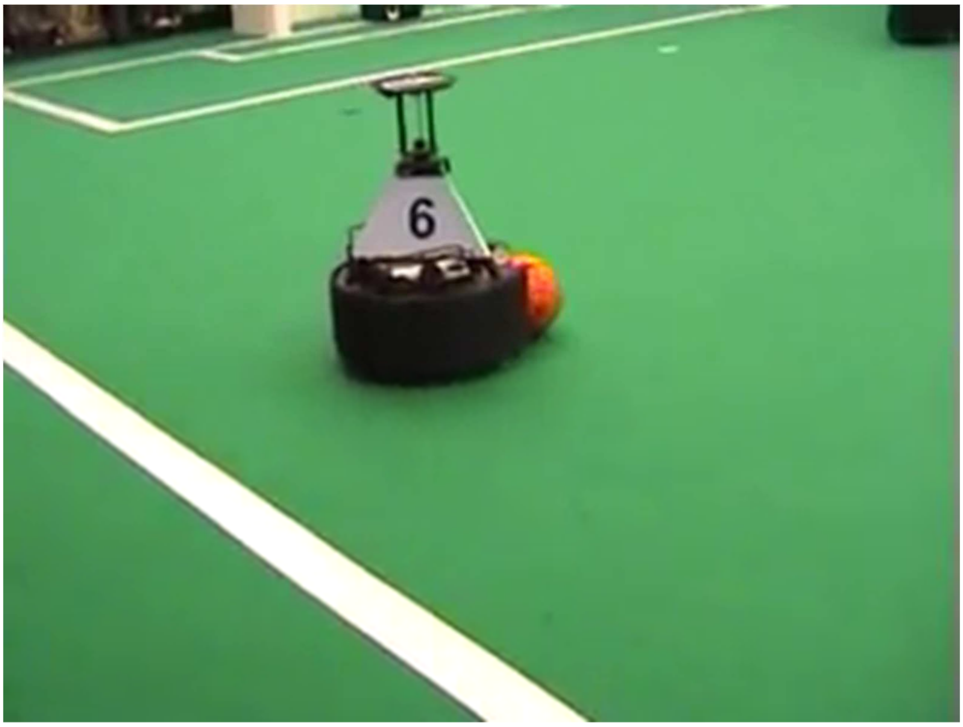
Setplays: Graphical Definition



Setplays: Graphical Definition



SetPlays in the MSL



Machine Learning Motivation

Programming Robots is a hard task:

- **No high-level programming language**
- **Sensors and actuators are noisy**
- **Robotics is moving towards increasingly unstructured environments**

If only robots could learn how to perform tasks by themselves…

$\Rightarrow$ **Machine Learning in Robotics**

Machine Learning in Robotics can be used for:

- Robot **Perception**
- Robot **Decision**
- Robot **Actuation** (Behaviors)
- Multi-robot **Coordination**
- Adapt **Human-Robot Interaction**

Machine Learning Motivation

Table-Tennis

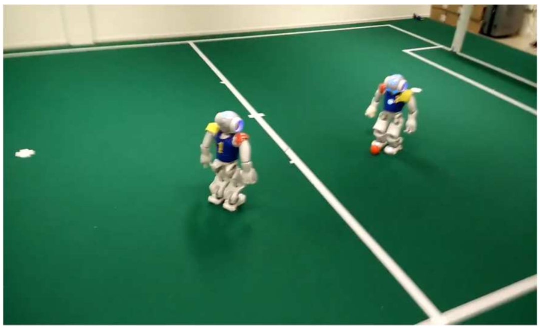
Robots

Mülling + Peters

Humans

Soccer Ball Passing

Robots



Erik Orjehag – LIU H1

Humans

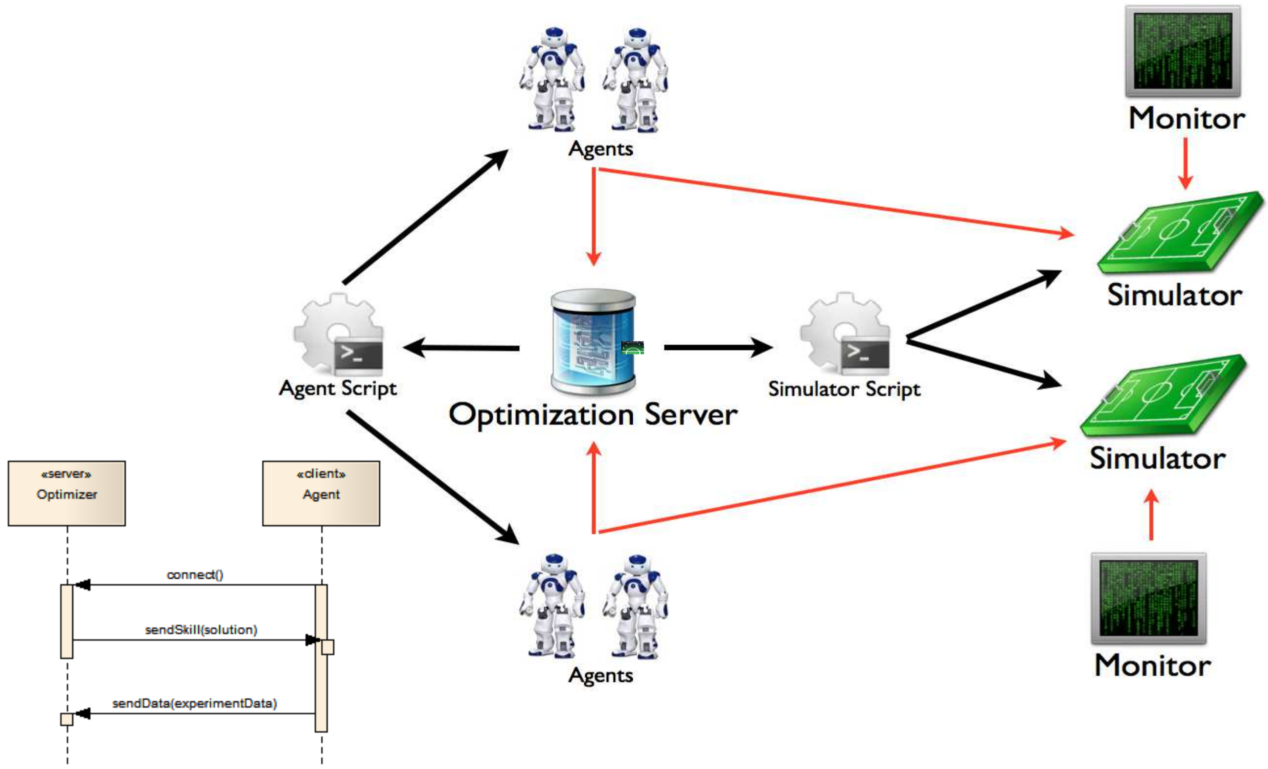
We need **learning** and **adaptation** to improve robot skills!

Machine Learning Motivation

Challenges in Robot Learning

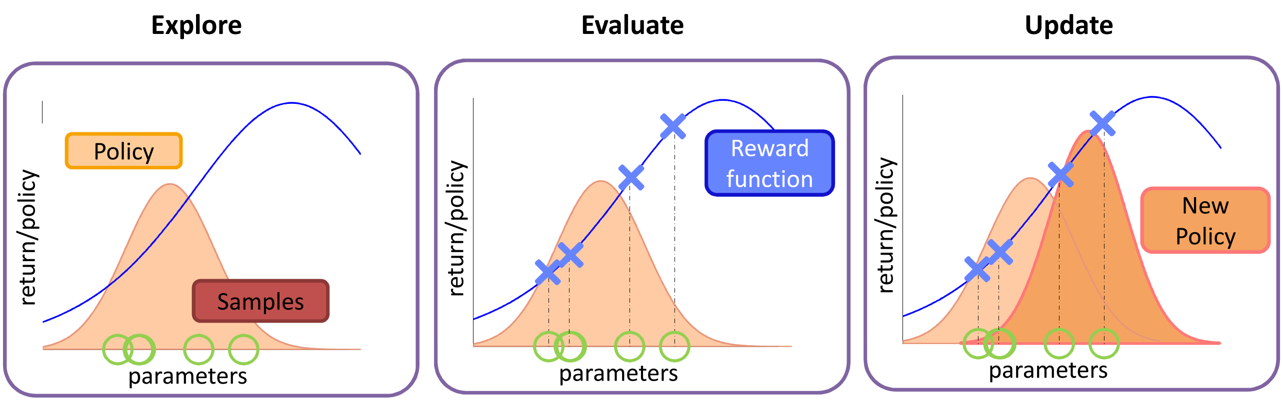
– Cost of experimentation
– Cost of failure
– Limited data
– Generalization
– Curse of dimensionality
– Real time requirements
– Changes in environment
– Changes in task specification

Generic Optimization



Stochastic Search

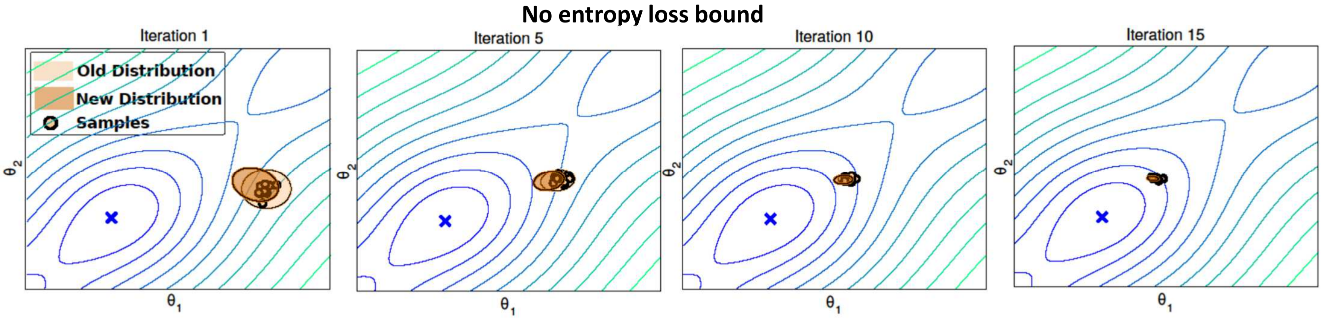
- **Use Search-Distribution:** $\pi(\boldsymbol{w}) = \mathcal{N}(\boldsymbol{\mu}, \boldsymbol{\Sigma})$
- **Objective: Find search distribution** $\pi(\boldsymbol{w})$ **that maximizes** $J_\pi = \int \pi(\boldsymbol{w}) R(\boldsymbol{w}) d\boldsymbol{w}$



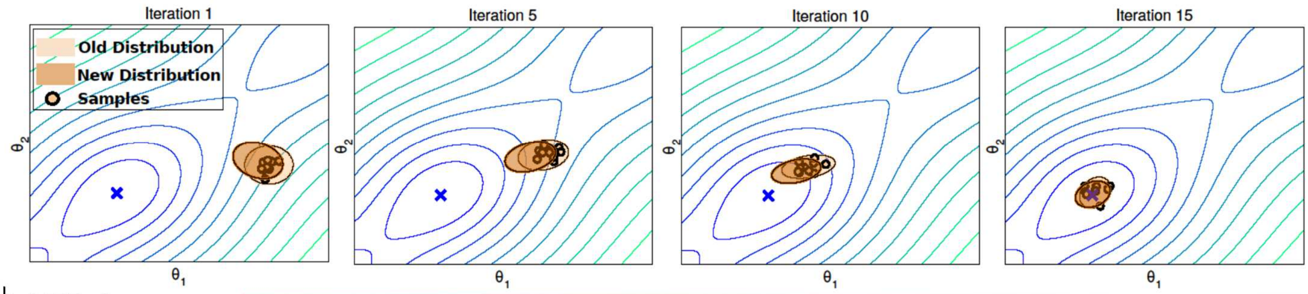
Stochastic Search

- Use Search-Distribution: $\pi(\boldsymbol{w}) = \mathcal{N}(\boldsymbol{\mu}, \boldsymbol{\Sigma})$
- Objective: Find search distribution $\pi(\boldsymbol{w})$ that maximizes $J_\pi = \int \pi(\boldsymbol{w}) R(\boldsymbol{w}) d\boldsymbol{w}$

No entropy loss bound



With bounded entropy loss



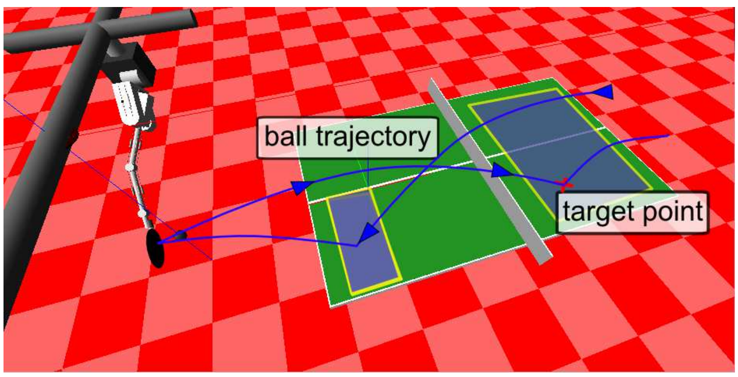
Contextual Stochastic Search

Goal: Adapt parameters w to different situations

- Different ball trajectories
- Different target locations

Introduce context vector s

- Continuous valued vector
- Characterizes environment and objectives of agent



Abdolmaleki, et. al, *Model-Based Relative Entropy Stochastic Search,* NIPS 2015

Learn contextual search policy $\pi(\boldsymbol{w}|\boldsymbol{s})$

Adaptation of Skills

Contextual distribution:

$$\pi(\boldsymbol{w}|\boldsymbol{s}) = \mathcal{N}(\boldsymbol{s}^T\boldsymbol{M} + \boldsymbol{m}, \boldsymbol{\Sigma})$$

Compatible Function Approximation:

$$R(\boldsymbol{s}, \boldsymbol{w}) \approx \boldsymbol{w}^T\boldsymbol{A}\boldsymbol{w} + \boldsymbol{s}^T\boldsymbol{B}\boldsymbol{w} + \boldsymbol{a}^T\boldsymbol{w} + a_0$$

Contextual distribution update:

1. Maximize expected return

$$\arg\max_{\pi} \mathbb{E}_{p(\boldsymbol{s})}\left[\int \pi(\boldsymbol{w}|\boldsymbol{s})R(\boldsymbol{s},\boldsymbol{w})d\boldsymbol{w}\right]$$

2. Bound expected information loss

$$\text{s.t.:} \quad \mathbb{E}_{p(\boldsymbol{s})}\left[\mathrm{KL}\left(\pi(\cdot|\boldsymbol{s})||\pi_{\text{old}}(\cdot|\boldsymbol{s})\right)\right] \leq \epsilon$$

3. **Bound entropy loss – Controls Step Size of Covariance**

$$\underbrace{H(\pi_{\text{old}}) - H(\pi)}_{\text{loss in entropy}} \leq \gamma$$

New distribution:

$$\pi(\boldsymbol{w}|\boldsymbol{s}) \propto \pi_{\text{old}}(\boldsymbol{w}|\boldsymbol{s})^{\frac{\eta}{\eta+\omega}} \exp\left(\frac{R(\boldsymbol{s},\boldsymbol{w})}{\eta+\omega}\right)$$

$$\propto \mathcal{N}(\boldsymbol{s}^T\boldsymbol{M}_{\text{new}} + \boldsymbol{m}_{\text{new}}, \boldsymbol{\Sigma}_{\text{new}})$$ ⇐ **Compatible Function Approximation**

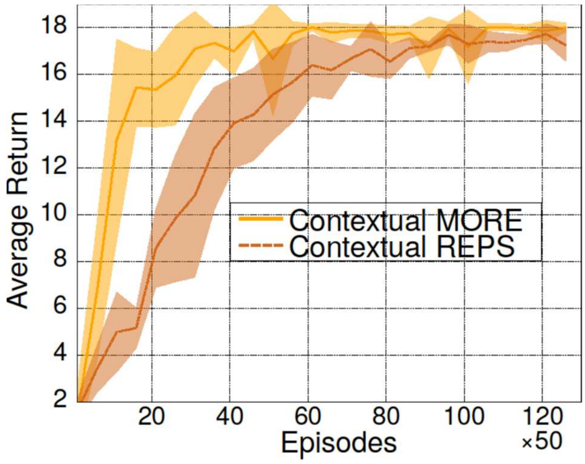
Adaptation of Skills: Table Tennis

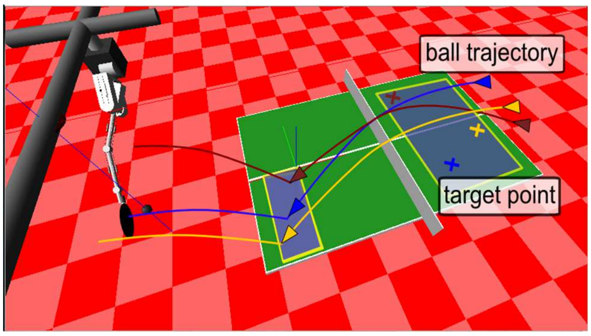
Contextual Stochastic Search:

- Context: Initial ball velocity

Reward:

- Hit ball
- Ball impacts at target position





Skills Improvement:

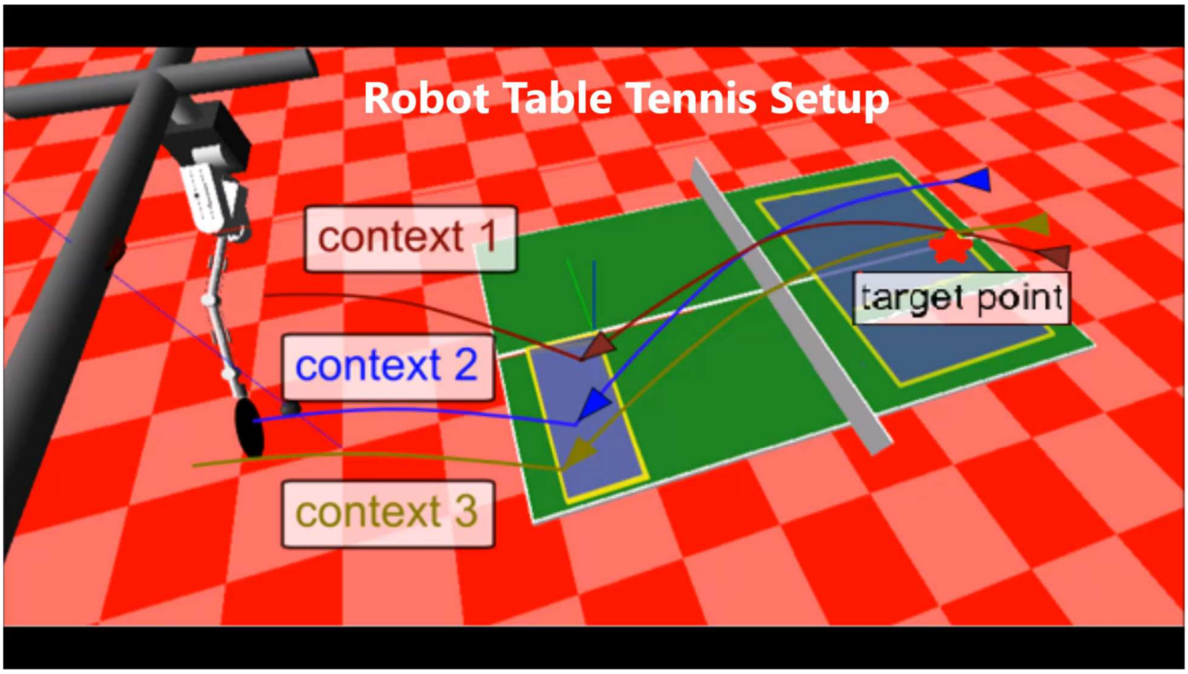
✓ **Hot-start with imitation**

✓ **Continuous-valued decision making**

✓ **Low number of samples**

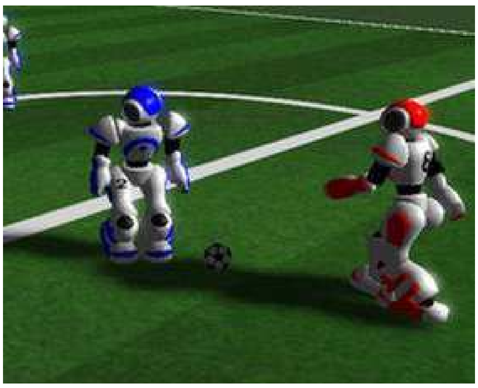
✓ **Adaptation**

Experiments: Table Tennis

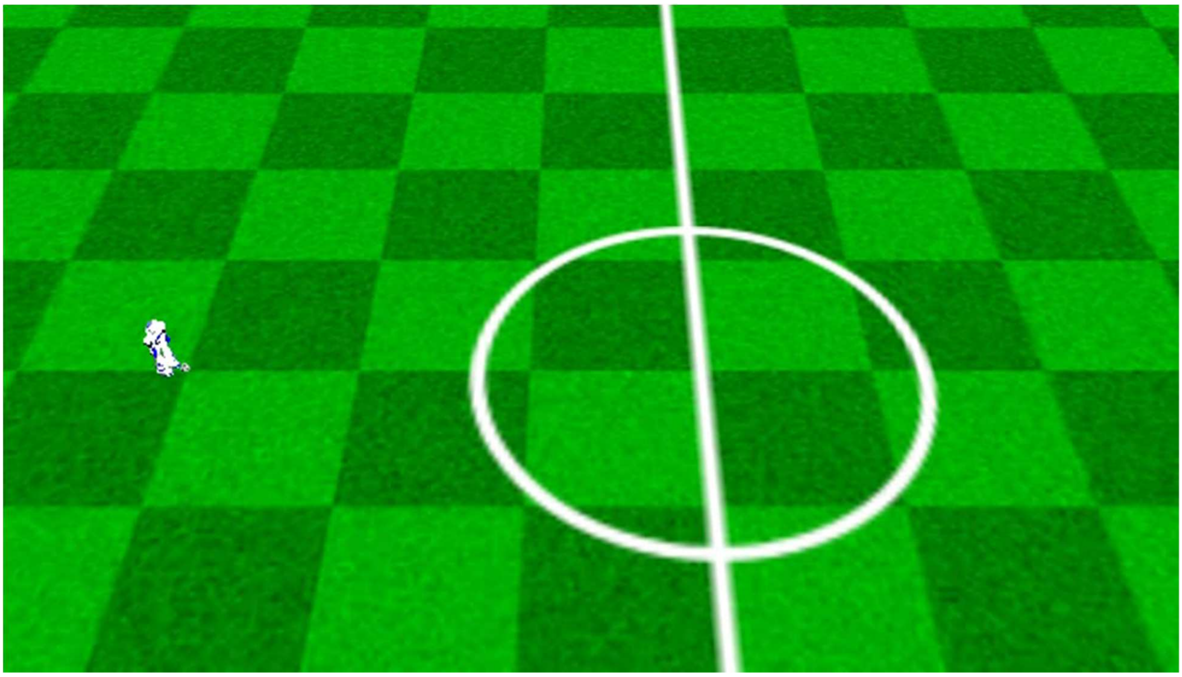


Skill Improvement: Controlled Kick

- **Task**
  - Develop a **kick with controlled kicking distance**
  - From 10 different positions in the soccer field (with distances ranging from 3m to 12m), kick the ball so that it stops in the center of the field
- **Classical approach**
  - Optimize for each distance
- **Contextual approach**
  - Optimize for all distances in a single process
  - Use all data to improve performance
  - Generalize for unknown contexts



Skill Improvement: 20 m Kick



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Skill Improvement: 20 m Kick

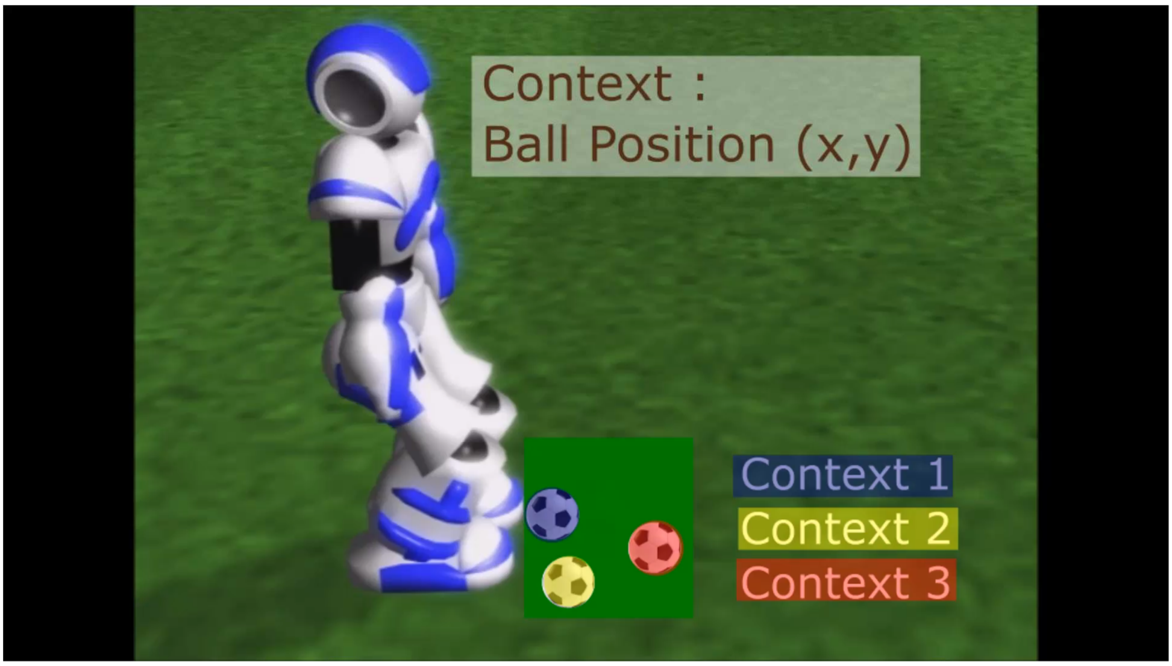
Skill Improvement: Controlled Kick

Abbas Abdolmaleki et al. Learning a Humanoid Kick With Controlled Distance. RoboCup 2016: Robot World Cup, Springer, July 2016

Results – Formation and Kick

Results – Formation and Kick

Contextual Learning: Humanoid Kick



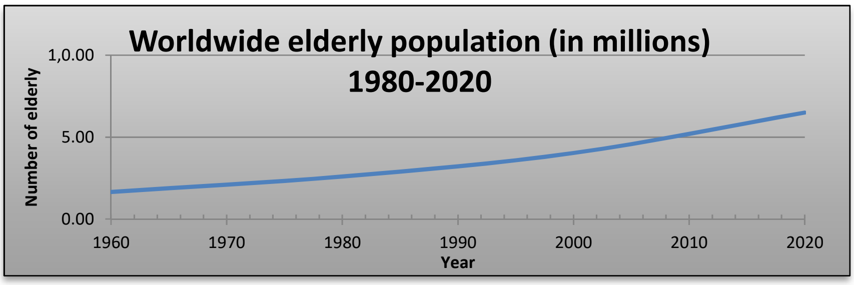
Results – Contextual Learning

Conclusions

- **Coordination** of Teams in Adversarial Environments:
  - **Strategy, Formations (SBSP/DT), DPRE, Setplays**
- Complete **Tactical/Formation Framework and Setplay Framework** including graphical interfaces
- **Generic Coordination Framework/Library:**
  - May be used for coordinating any team:
    - World State -> High-Level Decision!
  - Useful for researching on Low-Level Robotics!
- Methodologies with competition success
- **Different robots, distinct cooperative robotic** tasks and also to **other domains**: Rescue, surveillance, military apps

Intellwheels Project Motivation

- **Limited mobility of certain individuals**
  - Increment of the population aged over 60 years



- **Individuals with severe physical disabilities**
  - Cerebral palsy
  - Tetraplegia
- **Inability to control conventional electric wheelchairs**

Intelligent Wheelchair

- **Definition:**

  Robotic device with sensorial and actuation systems and processing capabilities:
  - Semi-Autonomous behavior with **obstacle avoidance**
  - **Autonomous navigation** and planning capabilities
  - Flexible **Human-Machine interaction**
  - **Cooperation** with other IW and with other devices (e.g. automatic doors)

Related Work

- **More than 50 IW international projects**
  - Obstacle avoidance
  - Human-machine interface
  - MAS very restricted use
  - IW built from scratch
- **Inexistence**
  - IW useful in practice:
    - Very low cost
    - Low ergonomic impact
    - Useful for handicapped individuals
  - Mixed reality environment
  - Flexible multi-modal interface
  - IW development platform

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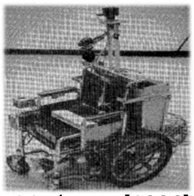
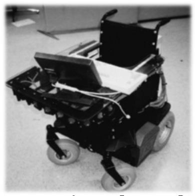
Related Work

- **Projects and Prototypes**


Madarasz [1986]


Omnidireccional IW [1993]


Two legs´IW [1994]

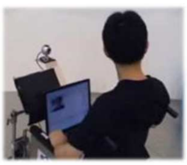

NavChair [1996]


Tin Man I [1995]


Tin Man II [1998]


FRIEND´s Project [1999]


LURCH [2007]


Robochair[2009]


VAHM [2010]

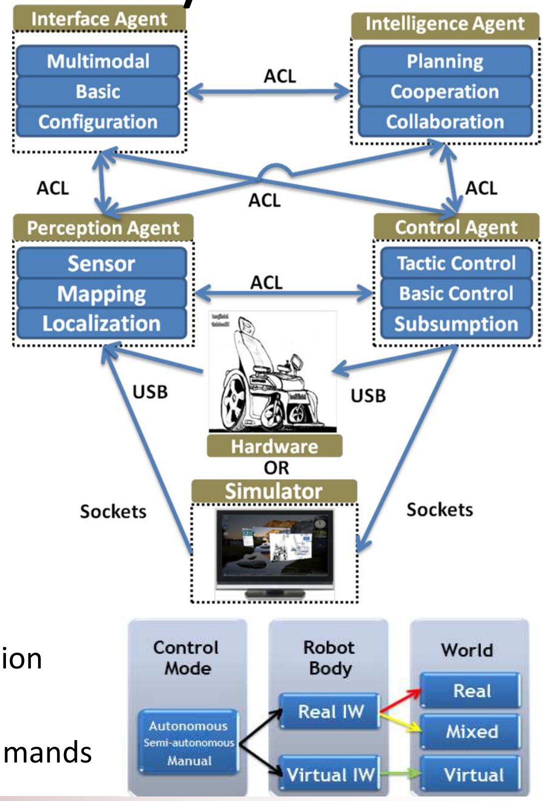

ARTY [2012]


SDA [2012]

IntellWheels Software/MAS

Multi Agent approach
- Interaction, communication, redundancy
- Easy to add new functionalities

- **Hardware module**
  - Electric wheelchair, sensors, actuators, microprocessor, PC
- **Simulator module**
  - Virtual environment and mixed reality
- **Control Agent**
  - Low-level control algorithms
- **Perception Agent**
  - Sensors, mapping and localization
- **Intelligence/Cognitive Agent**
  - High-level decision, planning and cooperation
- **Interface Agent**
  - Interprets user’s inputs into high level commands



IntellWheels Multimodal Interface

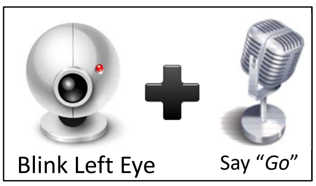
- **There is no single input well adapted for all physical limitations**

  IntellWheels combines user inputs (e.g. speech, pen, touch, gestures)

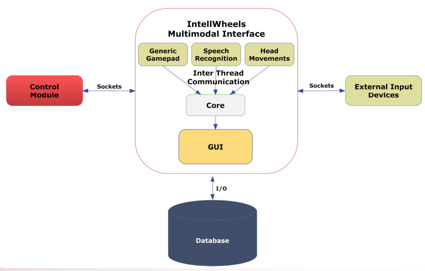
  User may define his own language

  Free association input sequence->command

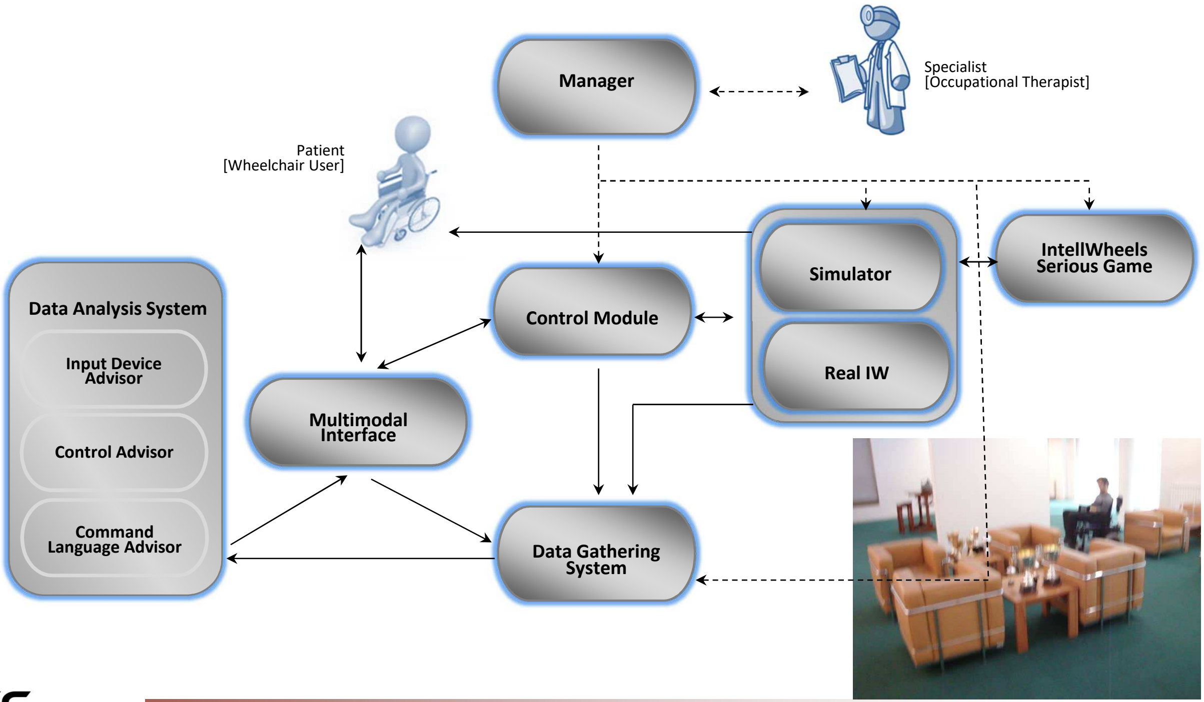
Joystick / Buttons **Facial Expressions** **Voice Commands** **Head Gestures**



**Action:
Wheelchair goes to
Room A**

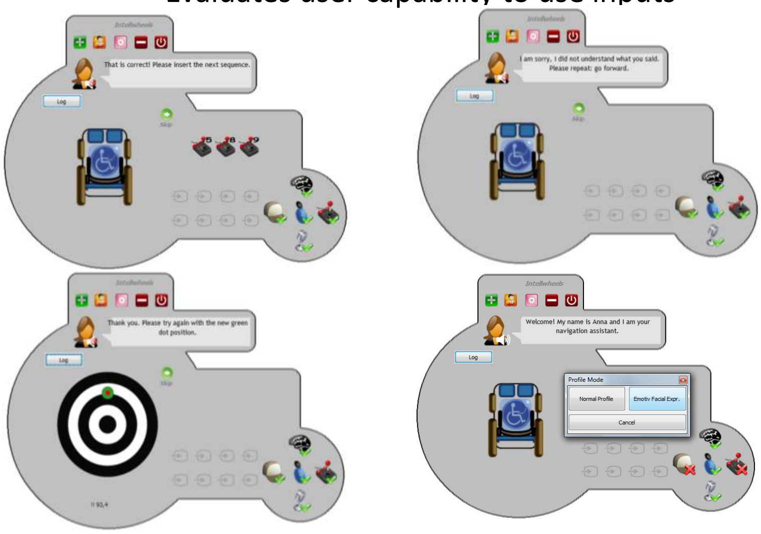


System Architecture



Multi-Modal Interface User Profiling

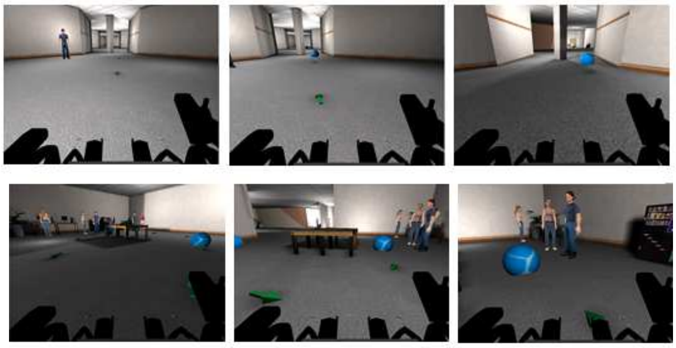
- **User Profiling**
  - Integrated in the Multimodal Interface
  - Simple interactive tests that do not involve the IW
  - Evaluates user capability to use inputs



Simulated Environment and Wheelchair





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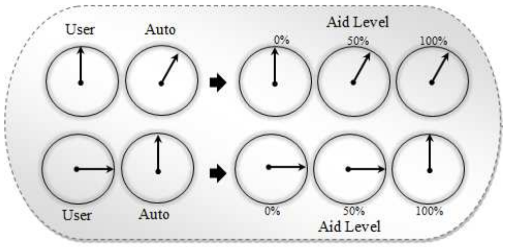
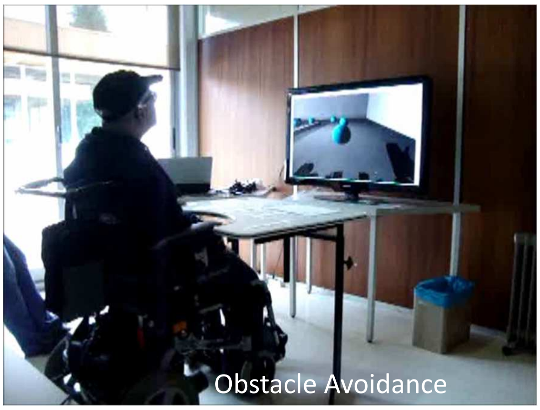
IntellSim – Tests With Cerebral Palsy Patients

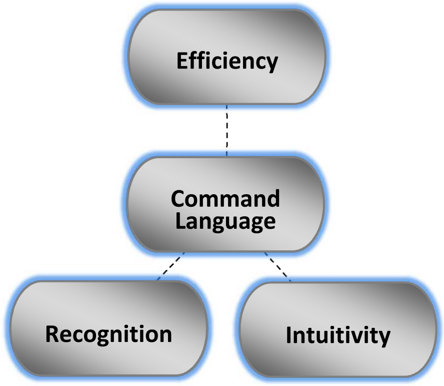
- **Shared Wheelchair Control**
  - Aid level of 100%
  - Aid level of 50%
  - Manual with obstacle avoidance





Data Analysis System

Command Language



Sequence S_i recognition value

$$regS_i = \prod_{k=1}^{N_i} F^{ID}_{I^{(i,k)}}$$

Total recognition value of a set of commands

$$T_{reg} = \sum_{j=1}^{C_j} regS_j$$

Sequence of inputs $S_i : I^{(i,1)}\ I^{(i,2)}\ I^{(i,3)} \ldots I^{(i,Ni)}$

Efficiency:

$$t_{S_i} = \underbrace{\sum_{k=1}^{N_i} t^{ID}_{I^{(i,k)}}}_{\text{time to select inputs}} + \underbrace{t_{timeout\,(i)}}_{\text{timeout}}$$

$$T_C = \sum_{j=1}^{C_j} t_{S_j} \quad \text{total time for all the commands}$$

$$T_{C_{eff}} = \sum_{j=1}^{C_j} eff\,(t_{S_j}) \qquad eff : [0,+\infty[\to [0,1], \quad t_{S_i} \mapsto \frac{1}{t_{S_i}+1}$$

Intuitiveness of a sequence of inputs S_i

Commands	I_1 ("Go")	I_2 ("Left")	I_3 ("Right")	I_4 ("Back")	I_5 ("Stop")	I_6 ("Front")	I_5 ("Forward")
Forward	1	0	0	0	0	1	1
Left	0	1	0	0	0	0	0
Right	0	0	1	0	0	0	0
Back	0	0	0	1	0	0	0
Stop	0	0	0	0	1	0	0

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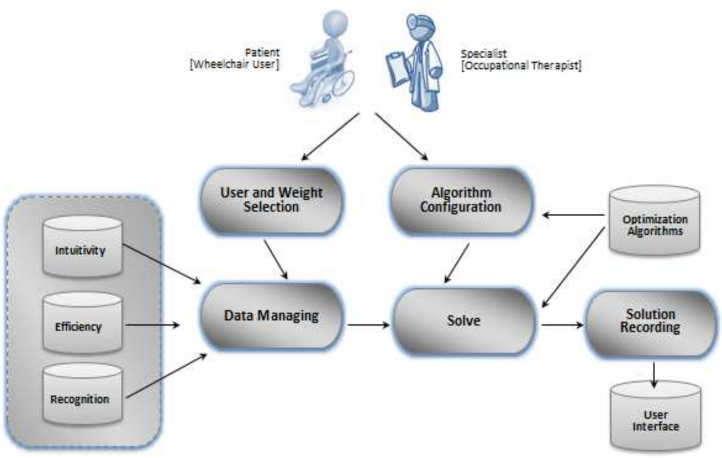
Data Analysis System

Command Language

Maximizes the function composed by the total time efficiency, total recognition and intuitiveness

$$\arg\max_{T_{eff}, T_{reg}, T_{\text{int}}} (\alpha T_{eff} + \beta T_{reg} + \gamma T_{\text{int}})$$

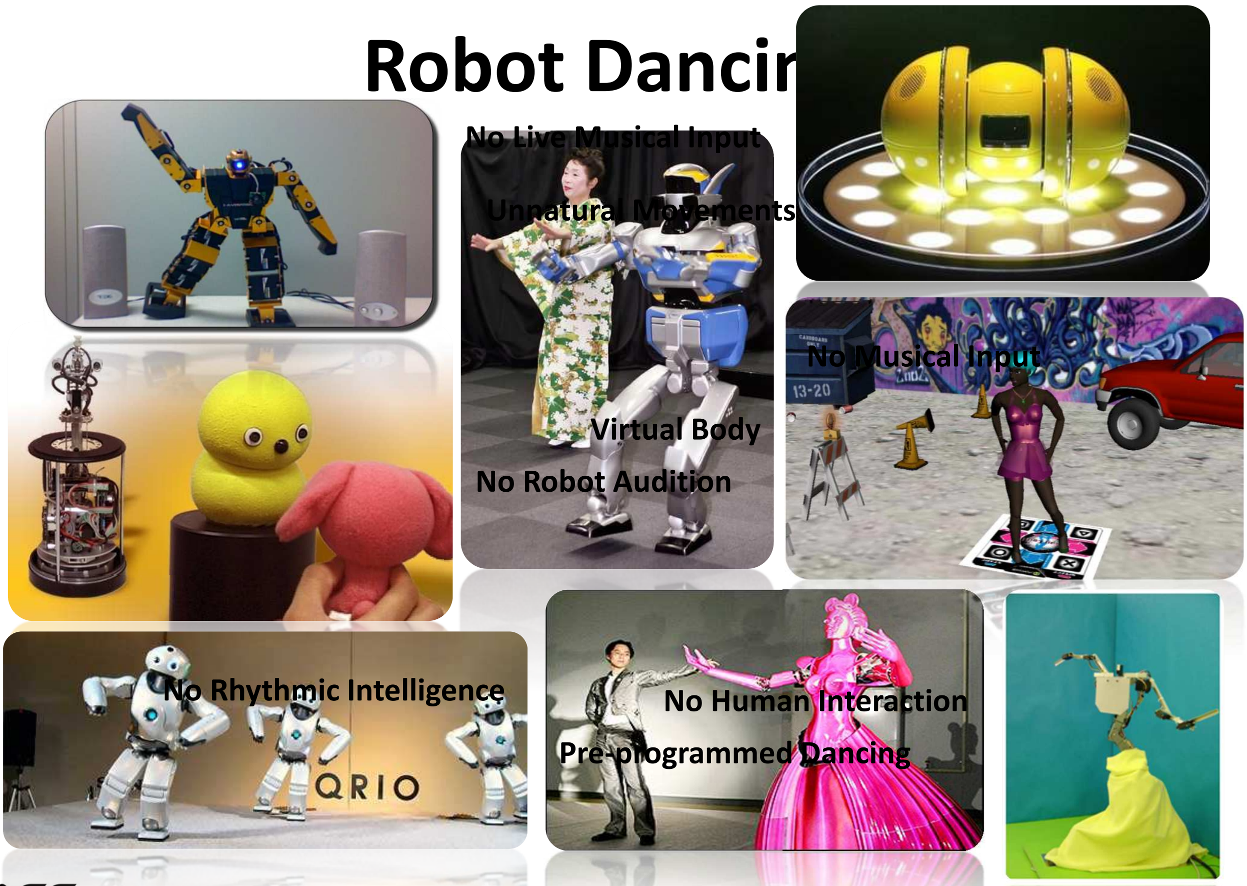



```
(w_rec, w_time, w_intu) = weights; evaluation ← 0
for ncom = 1 to NC do
  recVal ← 1; timeVal ← 0;  intuVal ← 1
  for nseq = 1 to NS do
    inpDev ← inputDevice(solution[ncom][nseq])
    inp ← input(newSolution[ncom][nseq])
    if inpDev = NULL then break
    else
      recVal ← recVal * rec[inpDev][inp]
      timeVal ← timeVal + time[inpDev][inp]
      intuVal ← intuVal * intu[ncom][inpDev][inp]
    endif
  endfor
  evalComm ← w_rec* recVal + w_time*1/(timeVal+1)
            + w_intu*intuVal
  evaluation ← evaluation  +  evalComm
endfor
return evaluation
```

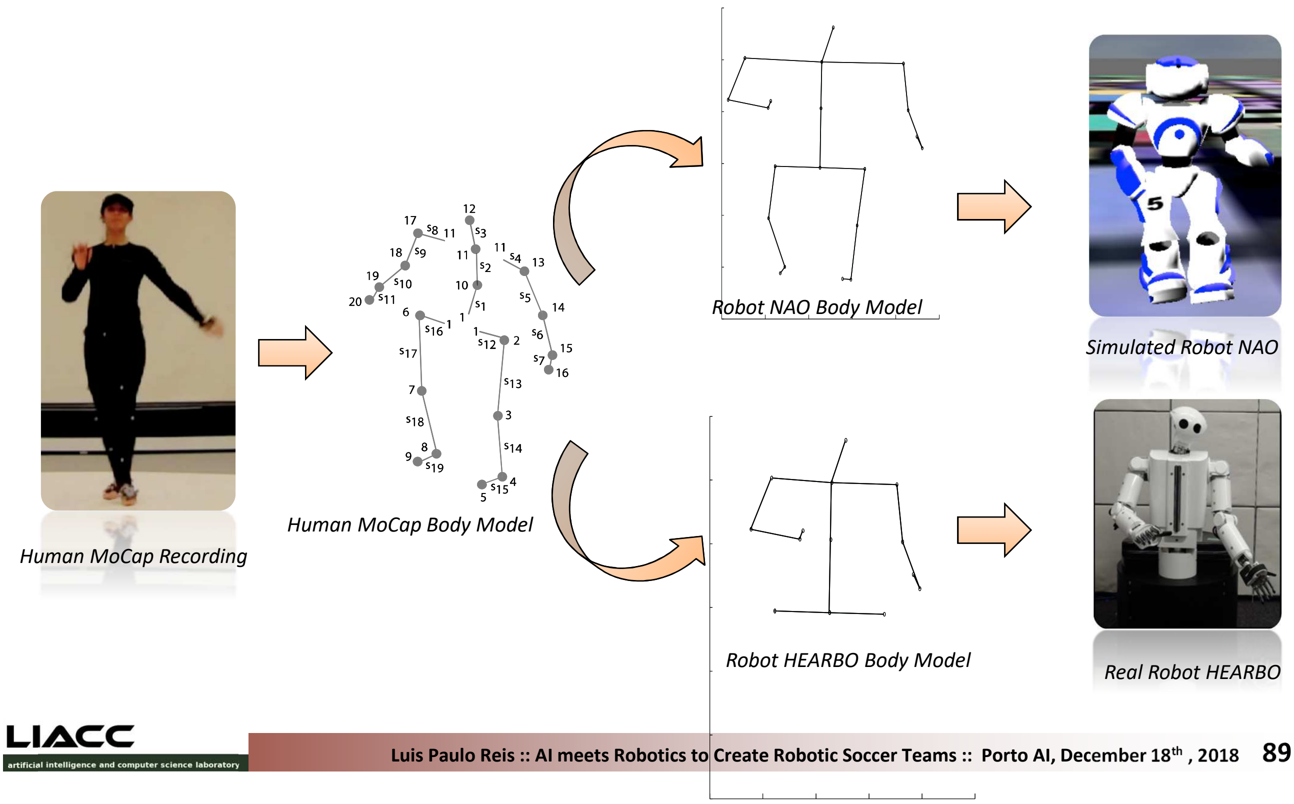
Conclusions

- **Many IWs prototypes and games:**
  – User adaptation is often neglected
  – Non realistic games with simple wheelchair model
  – Rigid Interfaces adapted to a single user (or user group)
- **IntellWheels project:**
  - High-level commands through **Multimodal** interface
  - Interface **adapted** to users' characteristics
  - IntellSim is a **realistic simulator** for testing and training
  - **Serious Game** for driving Wheelchair integrated with IntellSim
- **Automatic adaptation** using user profiling and Command language adapted to the user
- **Shared control** with appropriate aid level

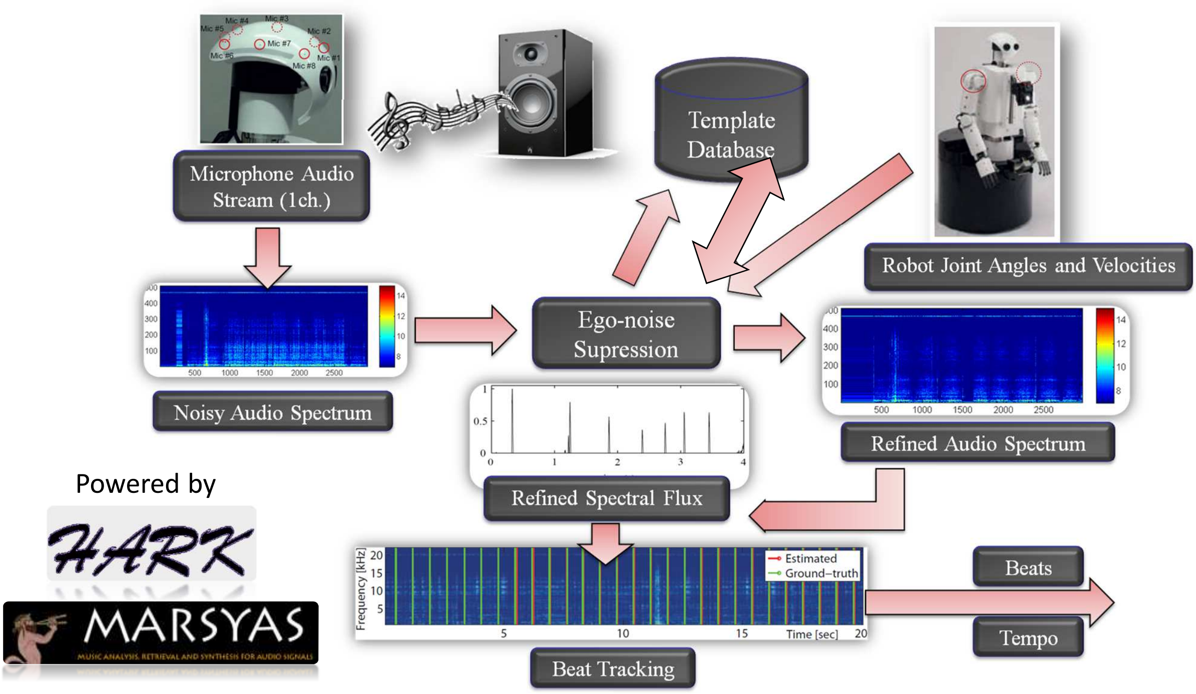
Robot Dancin



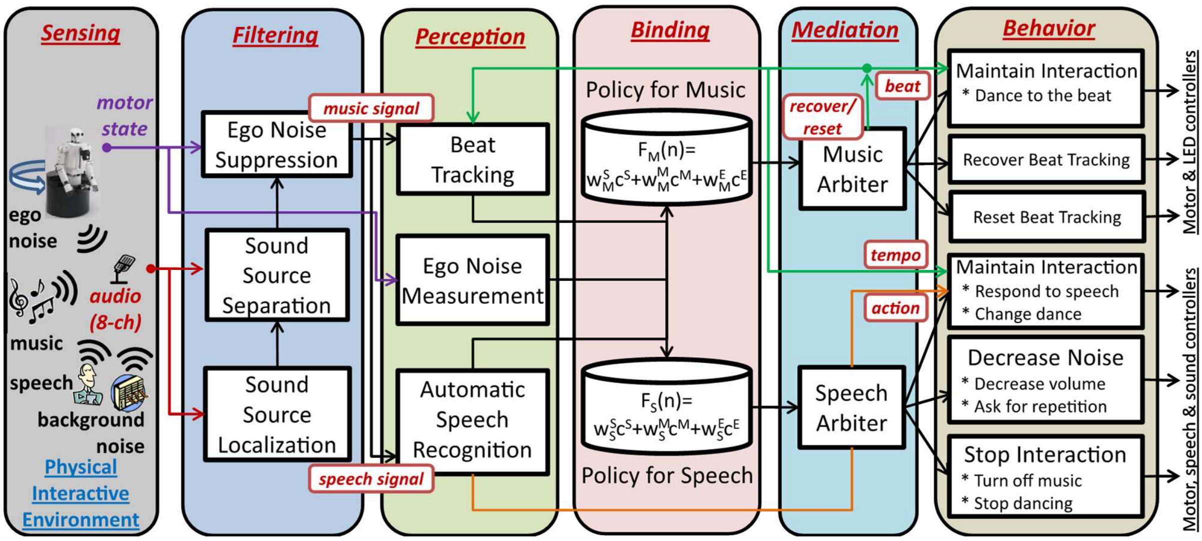
Mapping Samba onto Humanoids



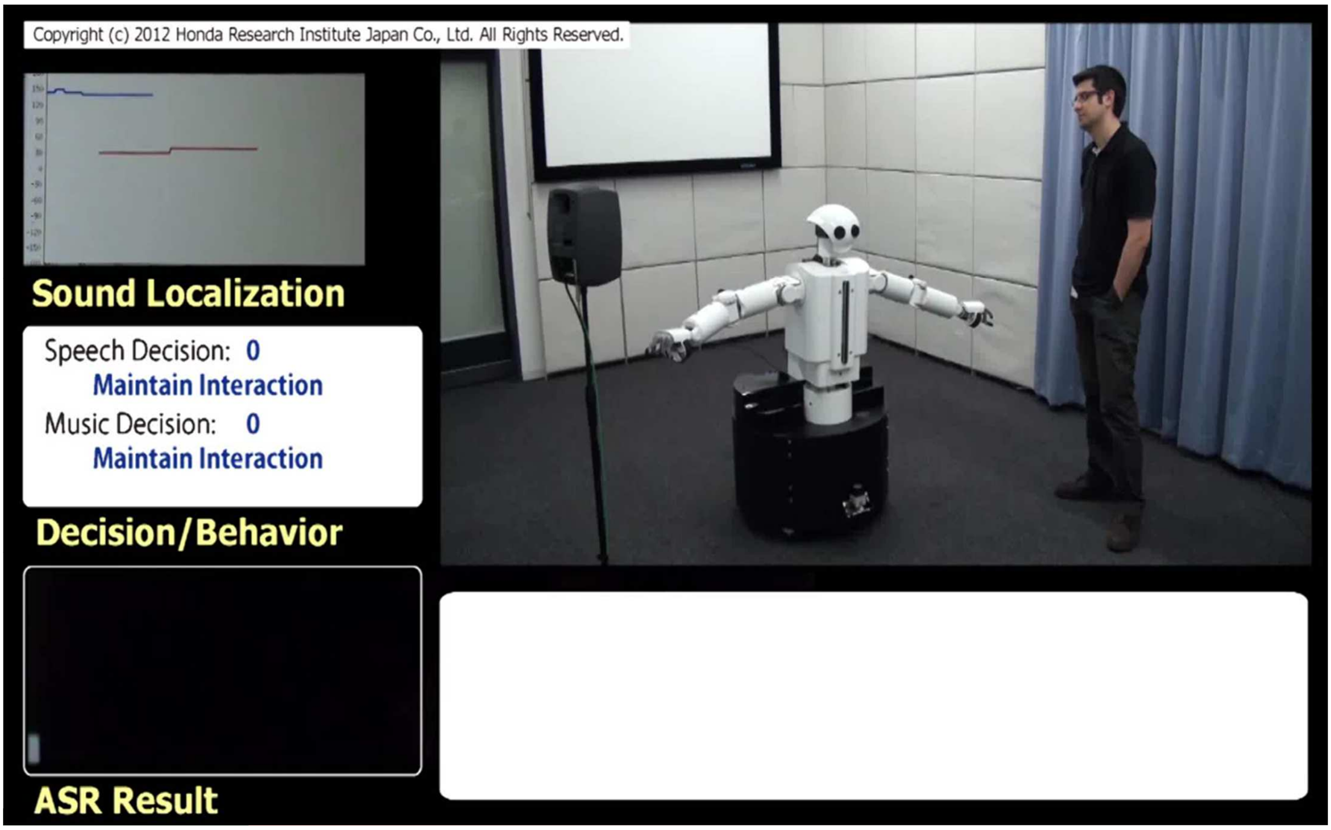
Live Ego Noise-Robust Beat Tracking Demo



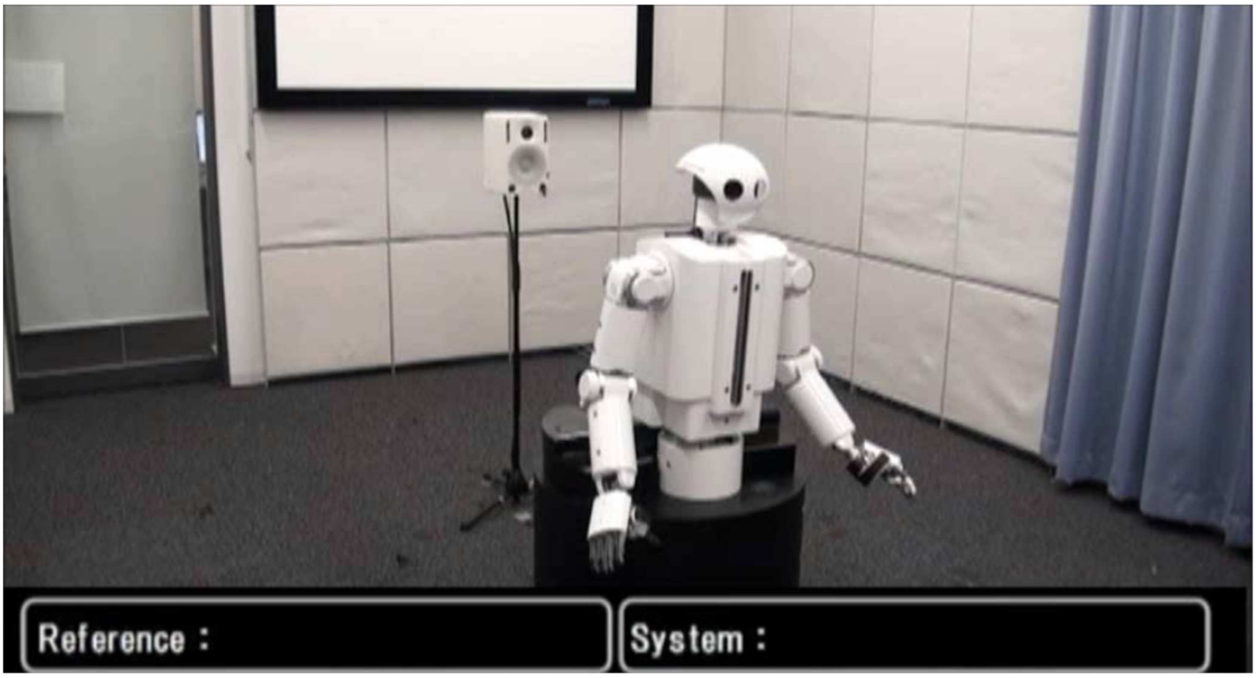
An Active Audition Framework for Auditory-driven HRI



Human-Interactive Robot Dancing Demo



Human-Interactive Robot Dancing Demo



Conclusions

- Artificial Intelligence: Intelligent Perception, Decision, Coordination and Action!
- Multi-Robot Coordination/**Flexible and Adaptative Strategy**
- **Flexible and Adaptative Multimodal Interaction** for Human-Robot Cooperation
- Learning of Complex Robot/Multi-Robot Tasks with **Contextual Stochastic Search**
- **Realistic Simulation** and Bridging the Gap between Simulation and Robotics
- More than 150 papers at ISI Web of Knowledge/Scopus about these projects

Artificial Intelligence Meets Robotics for the Creation of Robotic Soccer Teams

Luís Paulo Reis

lpreis@fe.up.pt

Director of LIACC – Artificial Intelligence and Computer Science Lab., University of Porto
Associate Professor at Faculty of Engineering, University of Porto, Portugal
Vice-President of APPIA – Portuguese Association for Artificial Intelligence

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