Human-Robot Intelligent Cooperation: Methodologies for Creating Human-Robot Heterogeneous Teams

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Presentation Outline

- Artificial Intelligence, Intelligent Robotics, Simulation and Coordination of Multi-Robot Teams
- FC Portugal Project – Coordination of Multi-Robot RoboCup Teams
- Intellwheels Project – Intelligent Wheelchair with Flexible Multimodal Interface
- Hearbot Project – Robot Dancing and Robot Audition
- Conclusions and Future Work

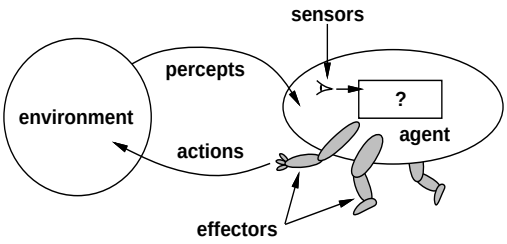
Artificial Intelligence

- **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 Traditional Definition:

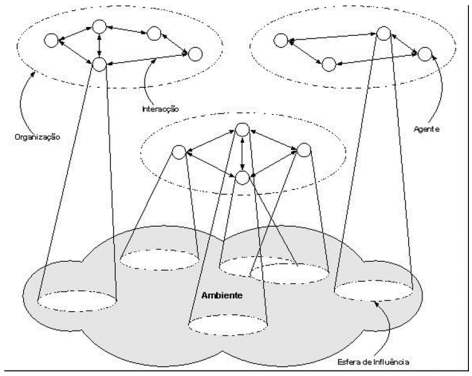
"Computational System, situated in a given **environment**, that has the ability to **perceive** that environment using **sensors** and **act**, in an **autonomous way**, in that environment using its **actuators** to fulfill a given **function**."



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

Multi-Agent System:

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



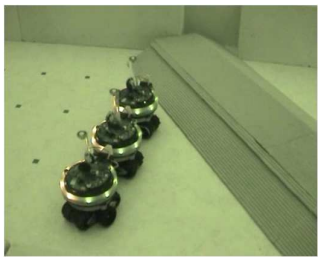
Intelligent Robotics

- **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
    - **Interaction** with other robots/humans
    - 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!**

Coordination in Multi-Robot Systems



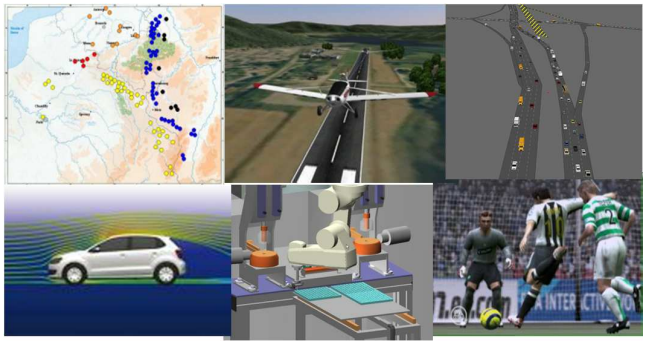
- Agents/Robots don't live alone…
- Necessary to work in group…
- **Human-Robot Interaction**
- **Multi-Robot Coordination**

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

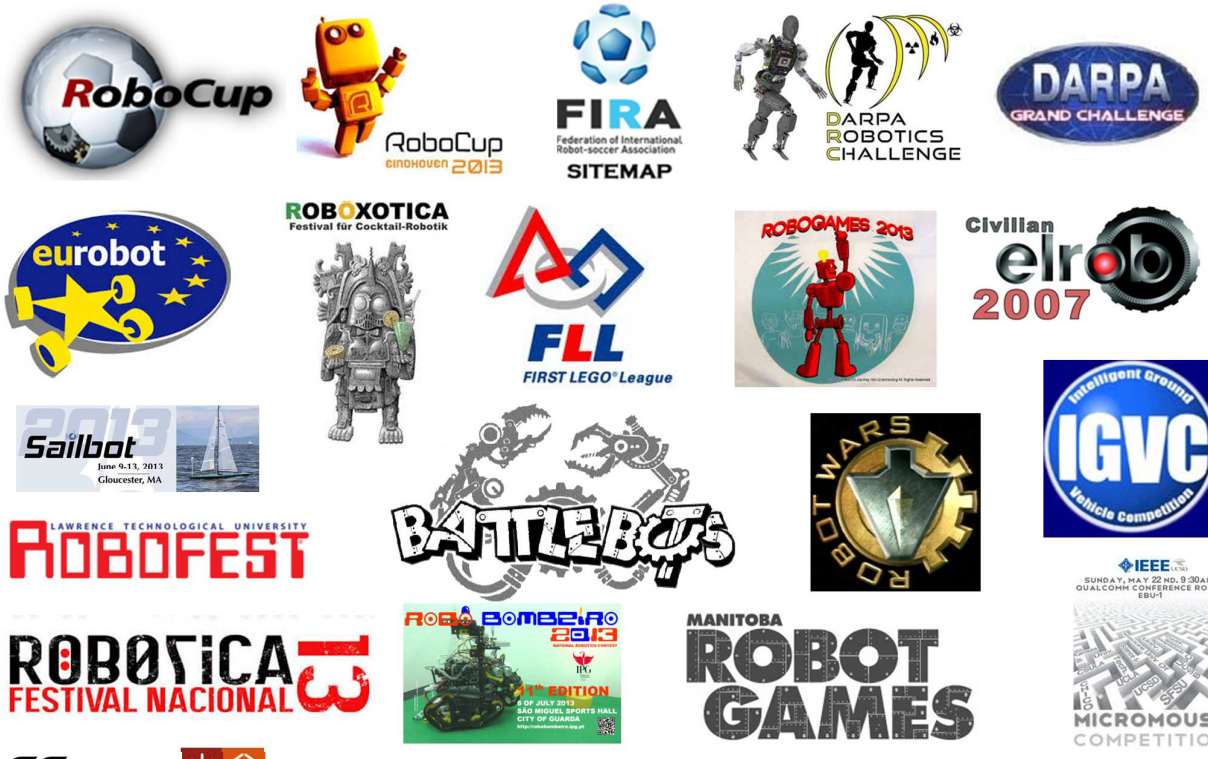
Agent-Based Simulation

- **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**



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

Robotic Competitions



Robotic Competitions - RoboGames

Videos

Robotic Competitions - RoboGames

Videos

Robotic Competitions

Dangers

- Obsession with winning
- Domain dependent/ hacked solutions
- Cost escalation
- Difficulty in entering at competitive level
- Restrictive rules
- Invalid evaluation conclusions
- Large number of teams/solutions created
- Encouragement for flexible software/hardware

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?

Key Issues in Human-Robot Teams

Sensor Fusion and Multi-Sensor Intelligent Perception

Multi-Robot Coordination/Flexible Strategy

Adaptive Strategy

Flexible Multimodal Interaction

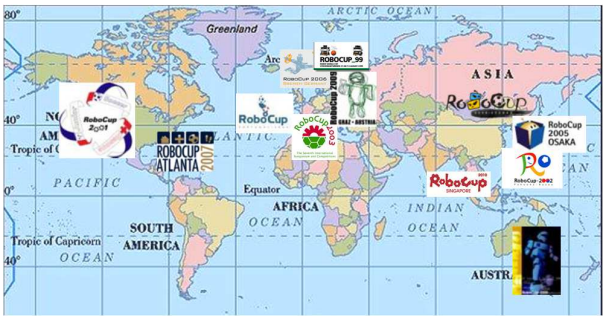
Human Robot Cooperation - Shared Control

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 of the RoboCup Initiative:

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

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)

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

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

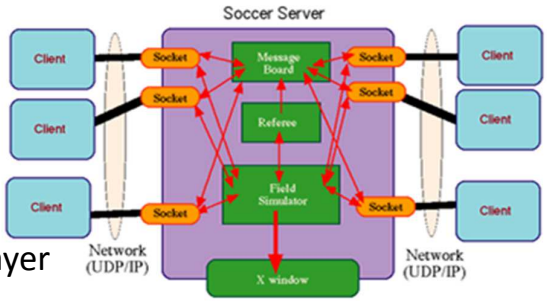
Soccer Leagues:
- **Sim2D, Sim3D (Humanoids), Coach, MR**
- **Robots Small-Size**
- **Robots Middle-Size**
- **Standard Platform** (**Aibo**; **NAO**)
- Humanoid Robots (Kid, Adult)

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

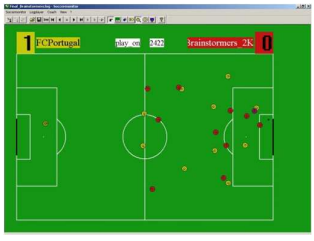
RoboCup Junior
RoboCup@Home
RoboCup@Work

RoboCup Leagues: Simulation 2D

- **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**



Server Architecture



RoboCup Leagues: Simulation 2D

- 1997: League Start -> Simple Play

Videos

RoboCup Leagues: Simulation 2D

- 1998: Simple Passing and Good Individual skills

Videos

RoboCup Leagues: Simulation 2D

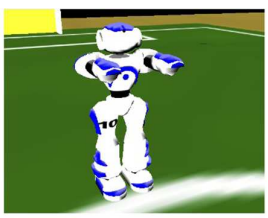
- **2000: Formations and Soccer like Playing**

Videos

Simulation 3D League (Humanoids)

- Third dimension adds complexity
- Complexities from real robots
- **Realistic physics and Robot Model:**
  - Started with sphere 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

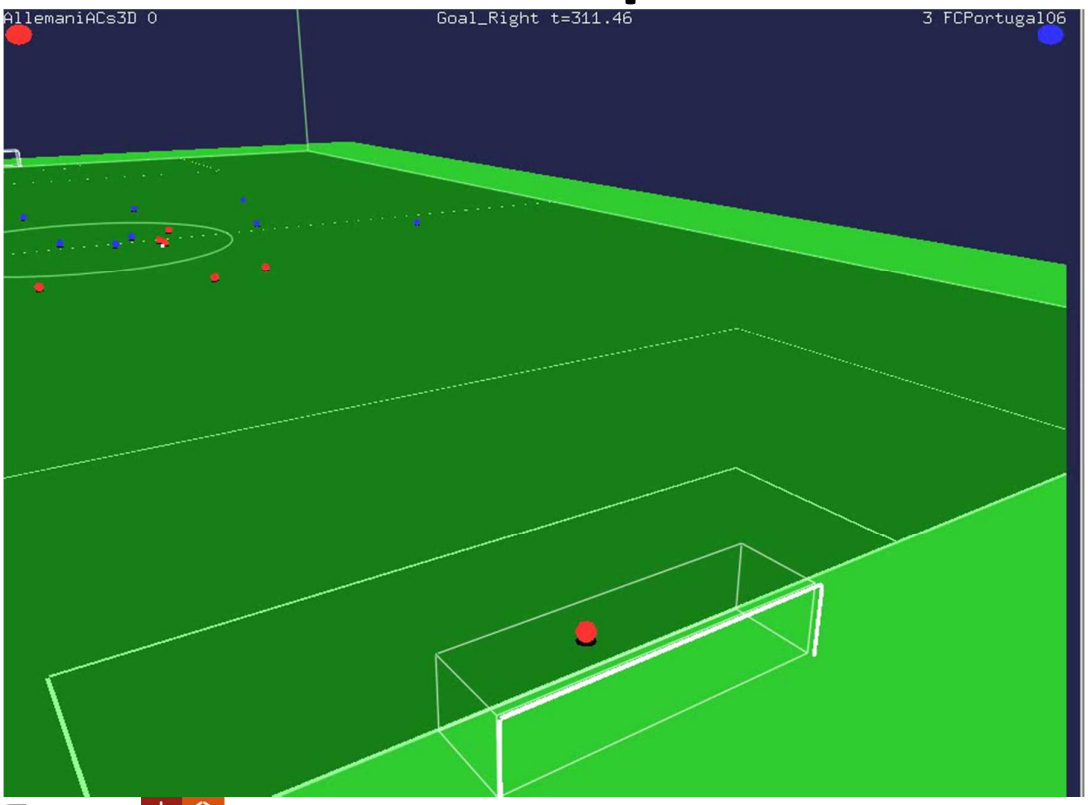


(b) virtual robot

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!

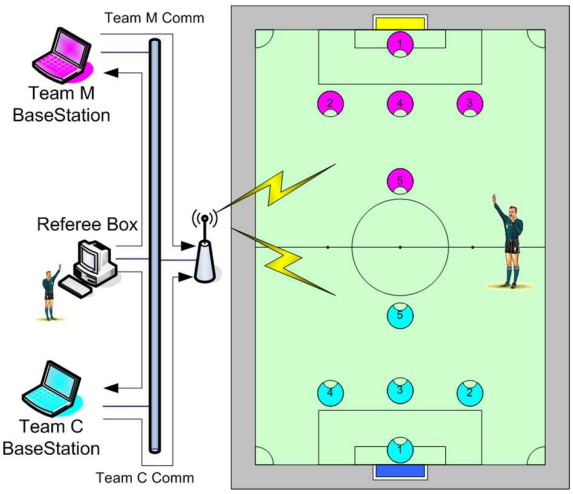
Videos

Simulation 3D – Nao model

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!

Middle Size League

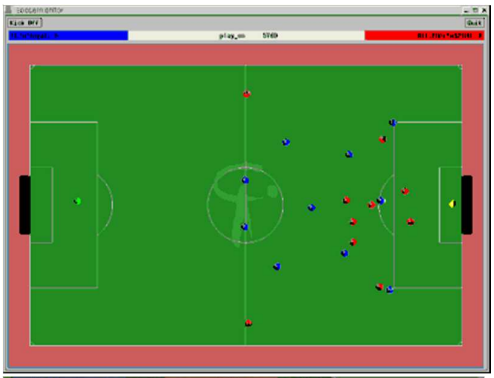
Videos

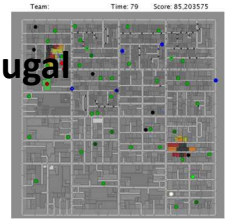
Flexible Strategy for RoboCup

- **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!**

Our Teams: University of Porto/Aveiro/Minho

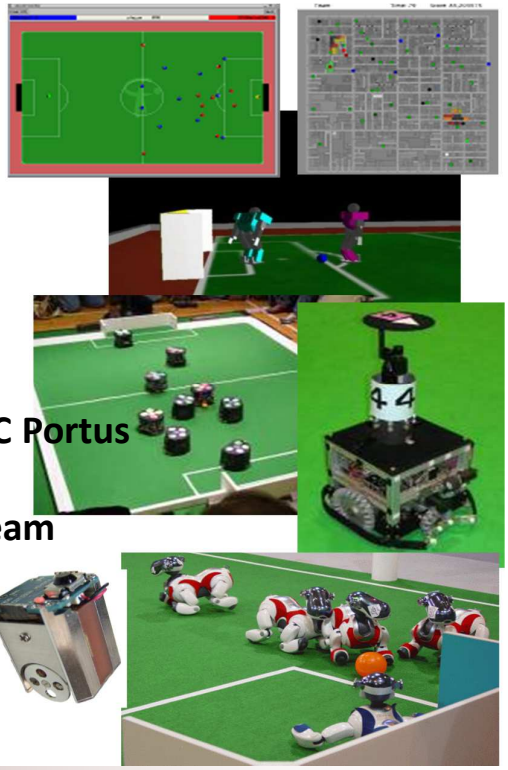
- **Simulation 2D: FC Portugal**
  - Best: Winners RoboCup 2000,
  - Winners Euro 2000, Euro 2001
  - Scientific Award 2013
- **Simulation 3D: FC Portugal**
  - Best: Winner RoboCup 2006,
  - Winners Euro 2006, Euro 2007
  - Scientific Award 2013
- **Simulation – Coach: FC Portugal**
  - Best: Winner RoboCup 2002,
  - 2nd RoboCup 2003, 2004
- **Simulation – MR League: FC Portugal**
  - Best: 2nd RoboCup 2007
- **Rescue Simulation: FC Portugal**
  - Best: Winner Euro 2006





Our Teams: University of Porto/Aveiro/Minho

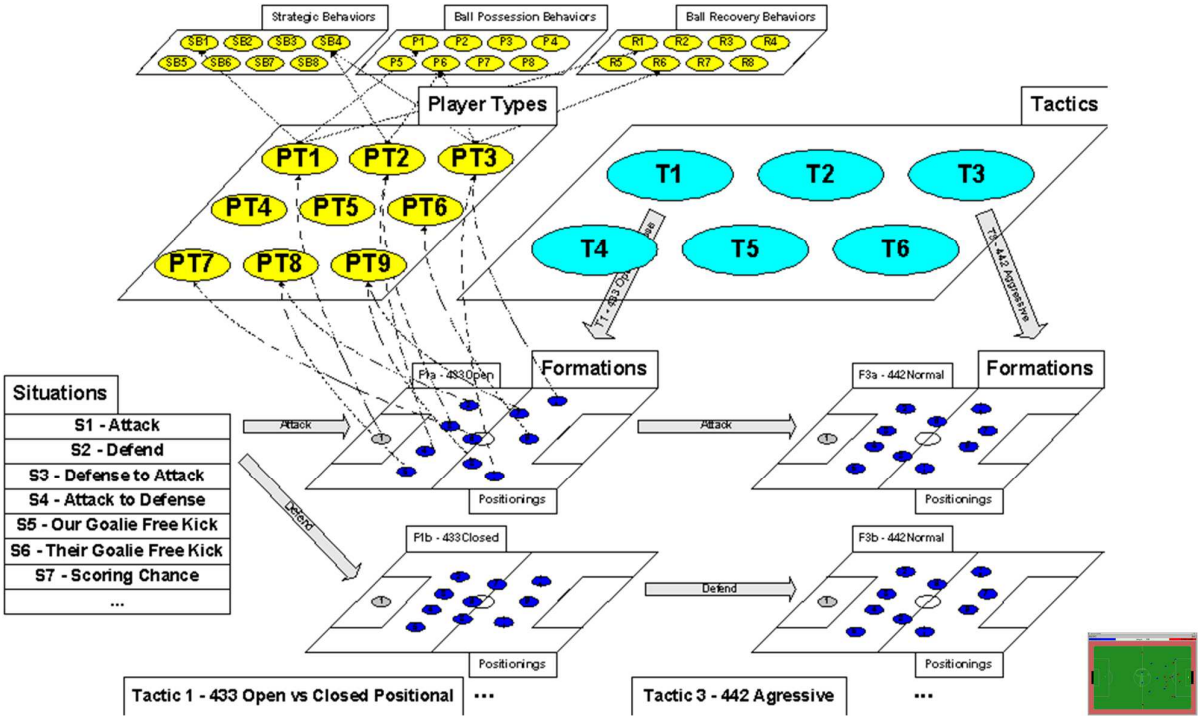
- **Middle-Size: CAMBADA (Univ.Aveiro)**
  - Best: Winners RoboCup 2008
  - Technical and Scientific Awards (2011, 2013)
- **Small-Size: 5DPO (Univ.Porto)**
  - Best: 2nd RoboCup 2006,
  - Winners Euro 2001, 2006, 2007
- **Middle-Size: 5DPO (Univ.Porto)**
  - Best: 3rd Euro 2001
- **Standard Platform (Aibo): FC Portugal/FC Portus**
  - Best: 5th RoboCup 2003
- **Standard Platform (NAO): Portuguese Team**
  - Best: 9th RoboCup 2012



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
  - Communication

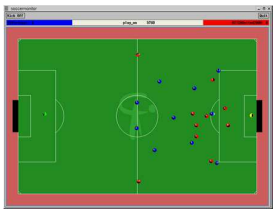
Formalization of a Team Strategy



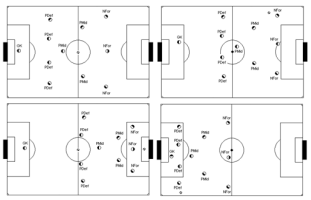
Formations in Robotic Soccer

- **Formations are essential concept in multi-robot teams:**
  - Provide a coordination framework:
    - tasks/role assignment
  - Real impact on team performance
  - Can/should be adapted to team and opponent capabilities
  - Common concept with military units coordinated movements or real soccer formations

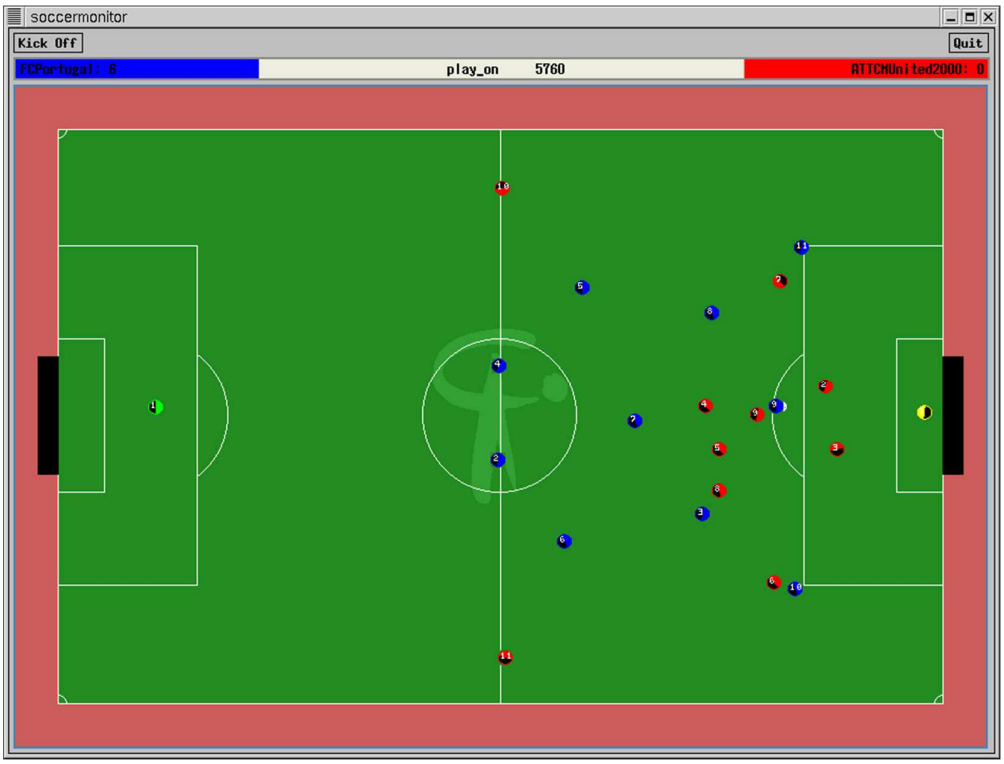
Formation Models



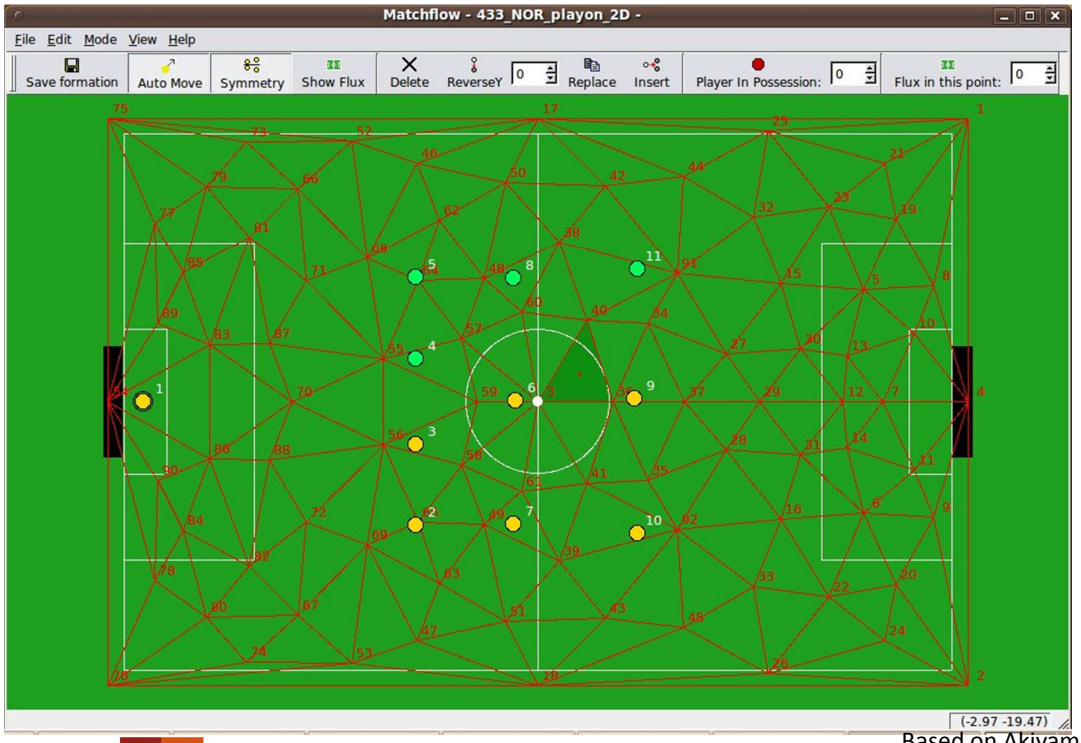
- **Role based models**
  - Ex: Striker, Supporter, Defender, Goalie
- SPAR – Strategic Positioning with **Attraction and Repulsion**
  - Locker-Room agreement
- **SBSP – Situation Based Strategic Positioning**
  - Active and Passive situations
  - Distinct team formation for different situations
  - Strategic position based on global information (such as current ball position) keeps the team in the selected formation
- SBSP/DT – **Situation Based SP with Delaunay Triangulation**
  - Added flexibility in the definition of positionings



SBSP vs SPAR

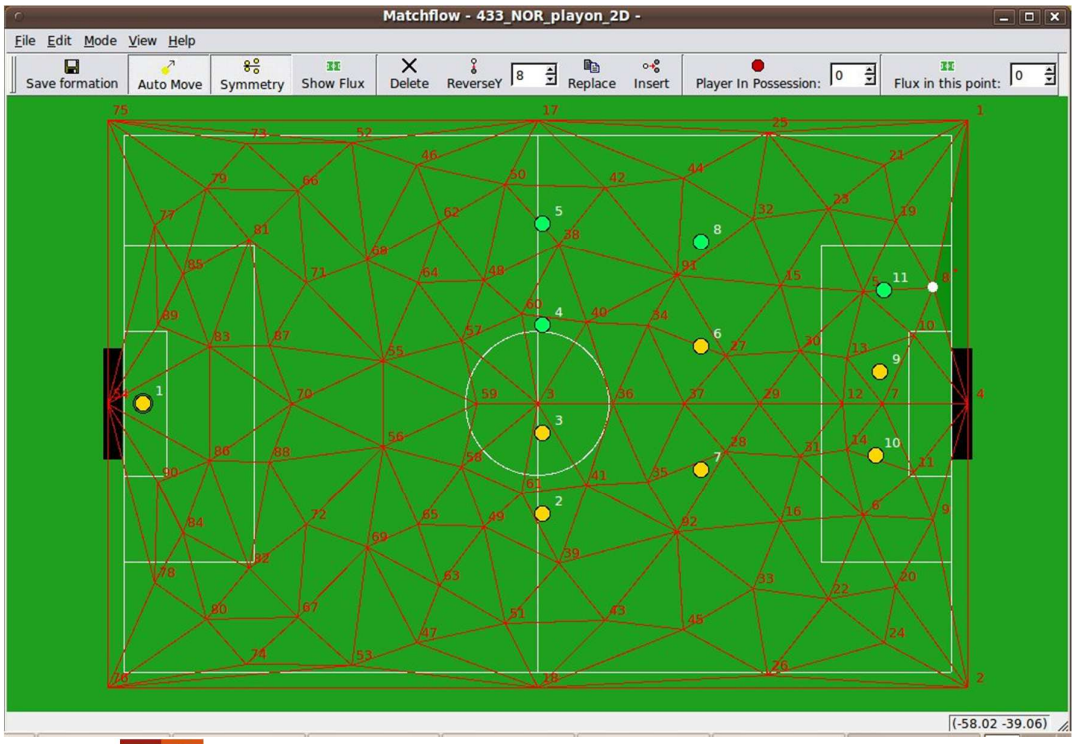


SBSP with Delaunay Triangulation

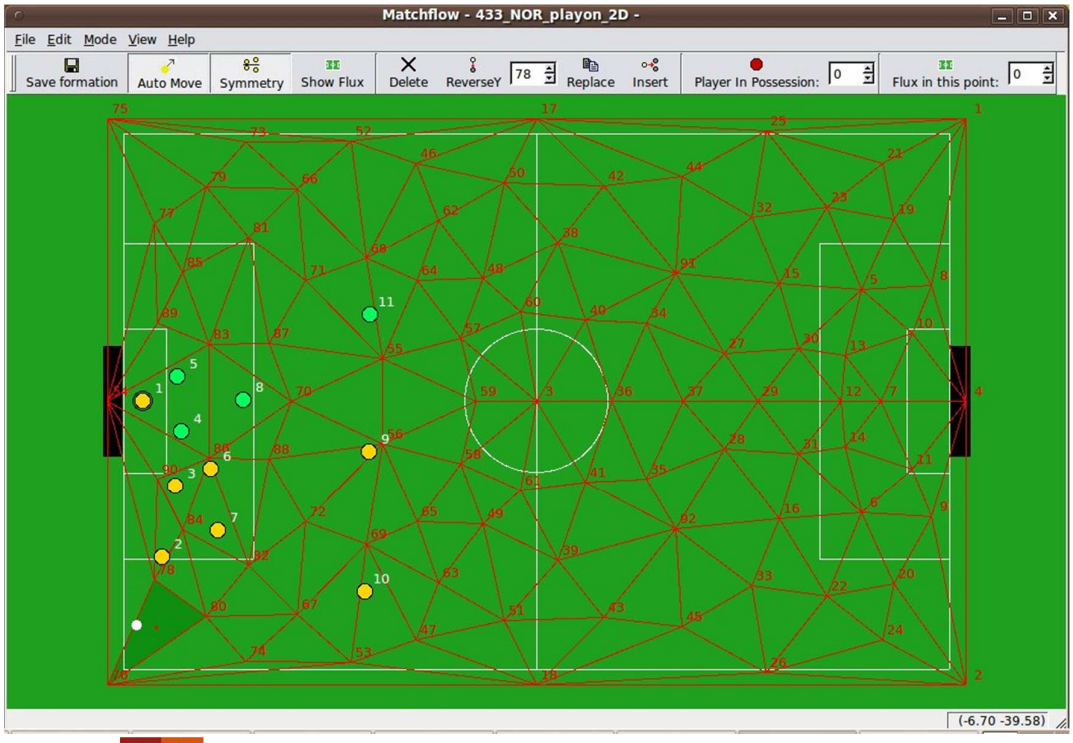


Based on Akiyama, 2007

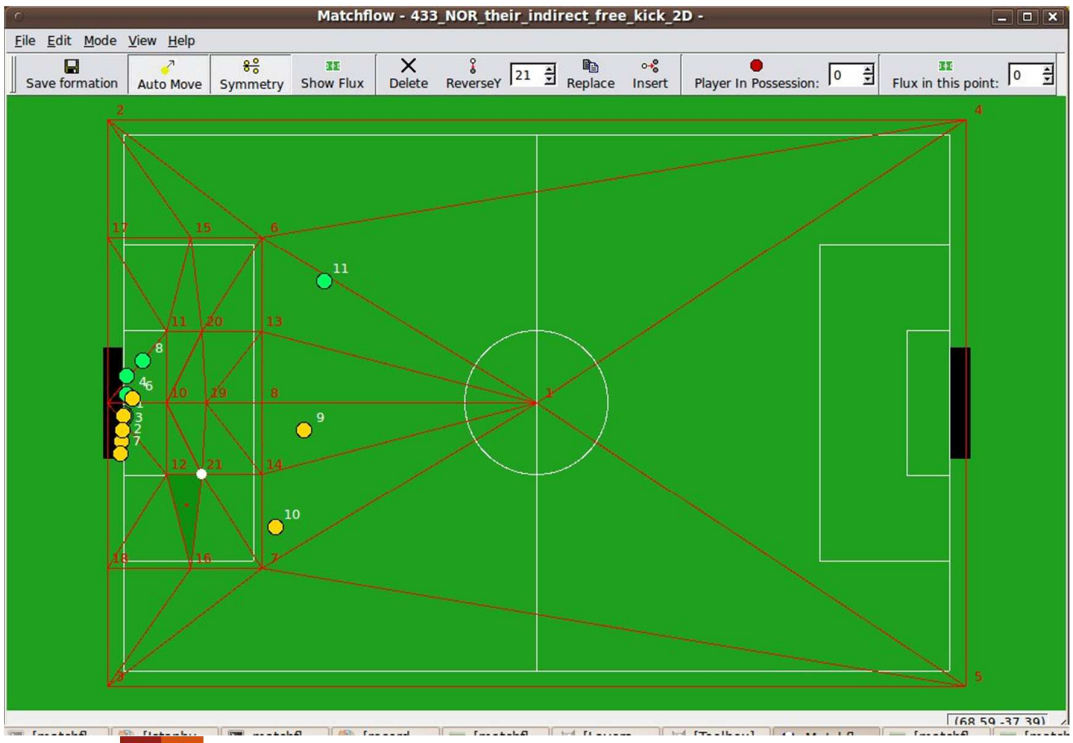
SBSP with Delaunay Triangulation



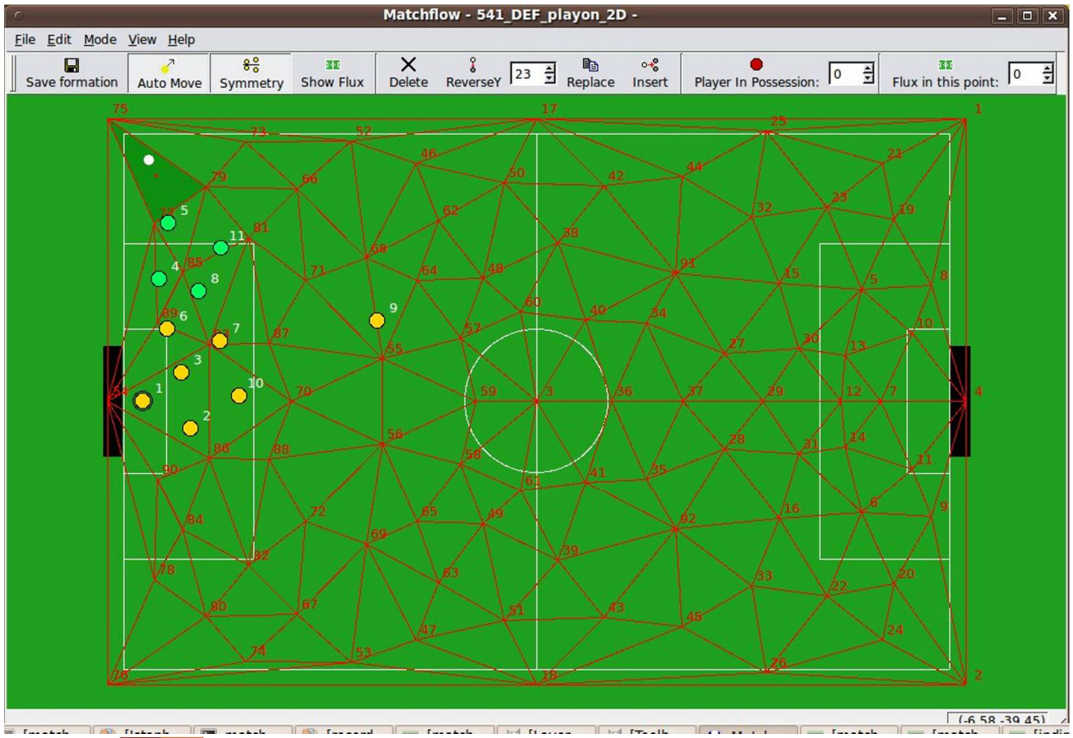
SBSP with Delaunay Triangulation



SBSP with Delaunay Triangulation



SBSP with Delaunay Triangulation



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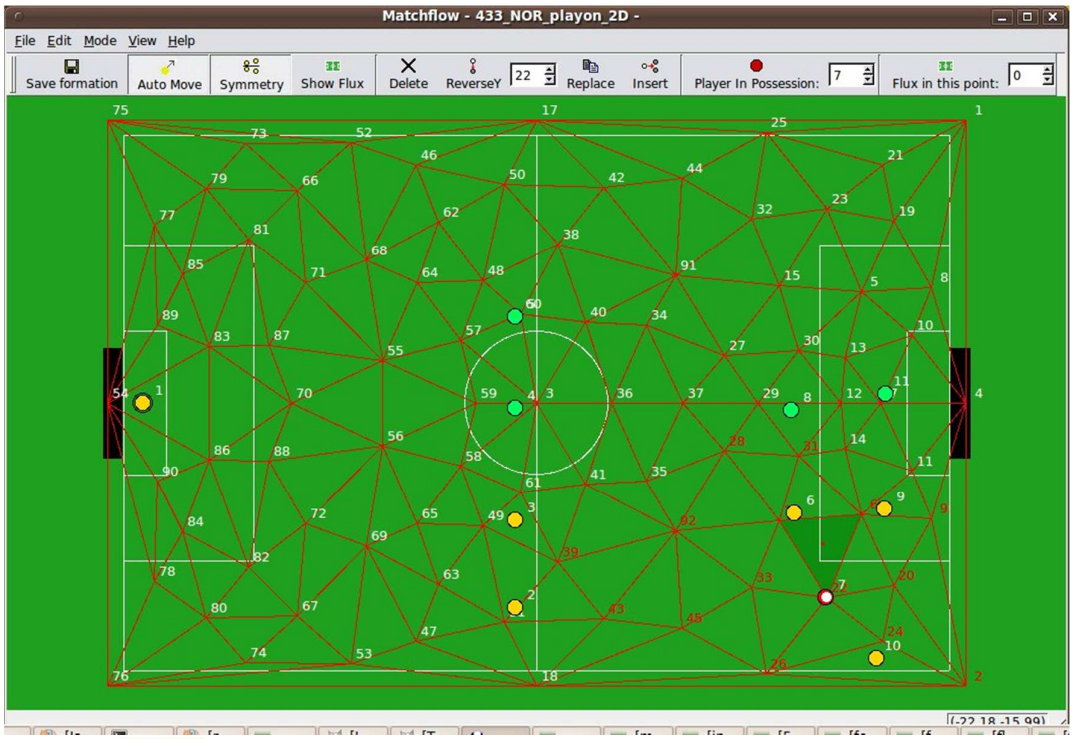
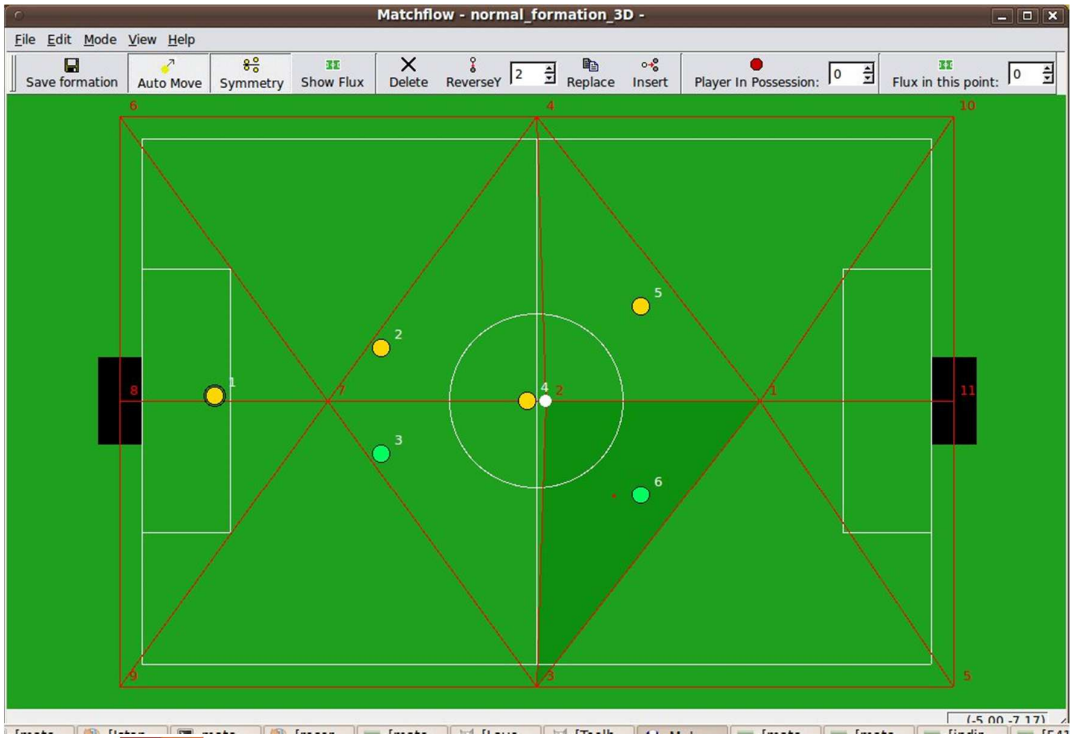
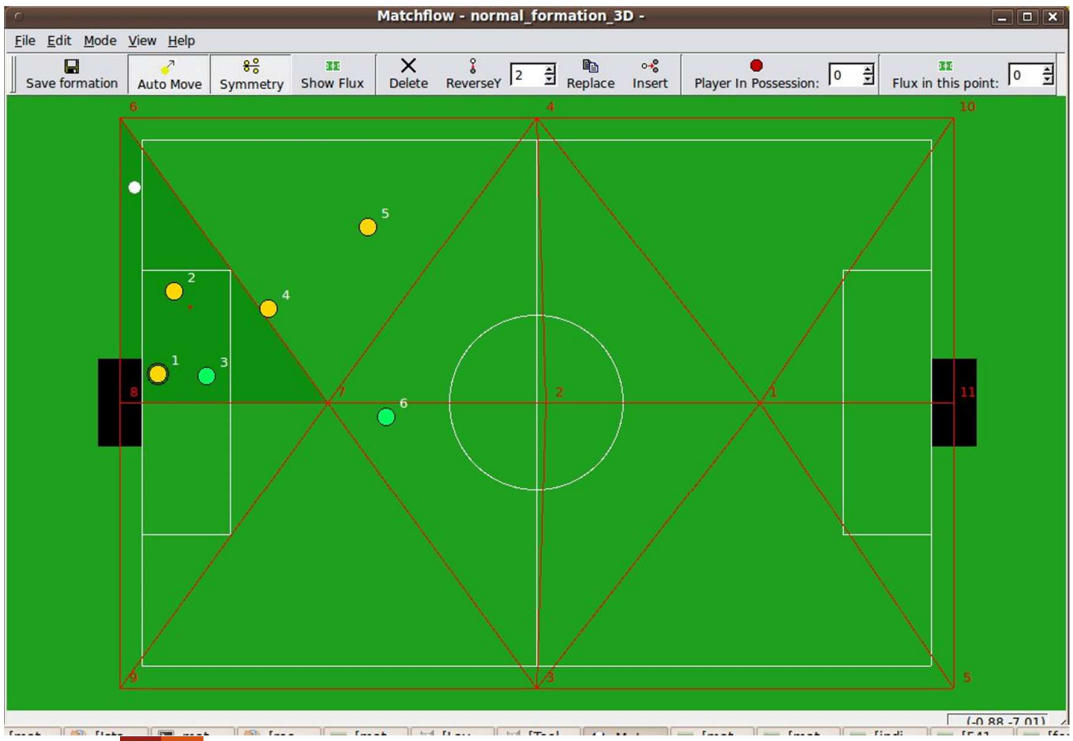


SBSP with Delaunay Triangulation



SBSP with Delaunay Triangulation



Formations in the MSL

Videos

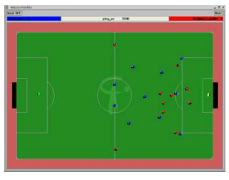
Formations in the MSL

SBSP with Flux

- Calculates Flux, Safety and Easiness of all possible points considering the tactic in use!

DPRE - Dynamic Positioning and Role Exchange

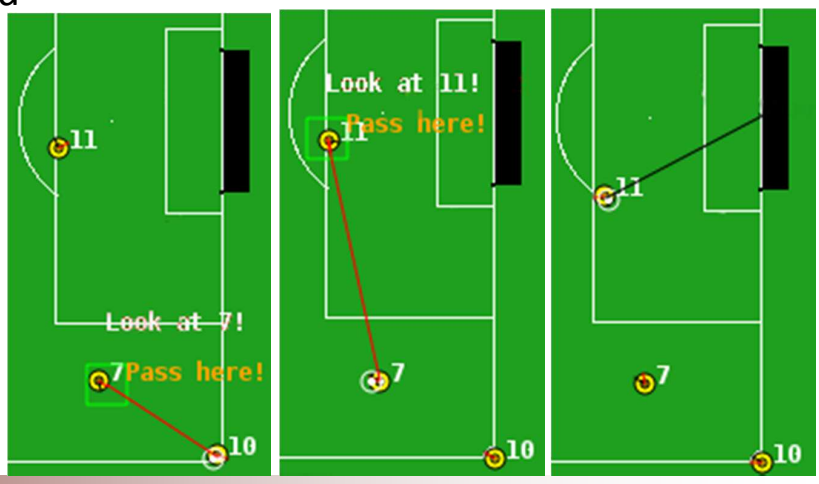
- Dynamic **Exchange of Positionings and Behaviors** based on utility:
  - Distances from players positions to their strategic positions
  - Positioning importance and adequacy of agents
- DPRE improves the robotic team collective performance
- Important against opponents with similar collective capabilities



Setplays: Concept and Definition

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

- Defined before the game by a **domain expert**
- **Human readable language** (high abstraction level)
- Selected, Instantiated and executed at run-time (text file)
- Easy to define and change

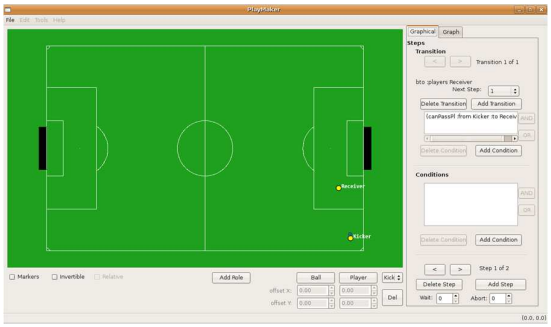


Setplay Definition

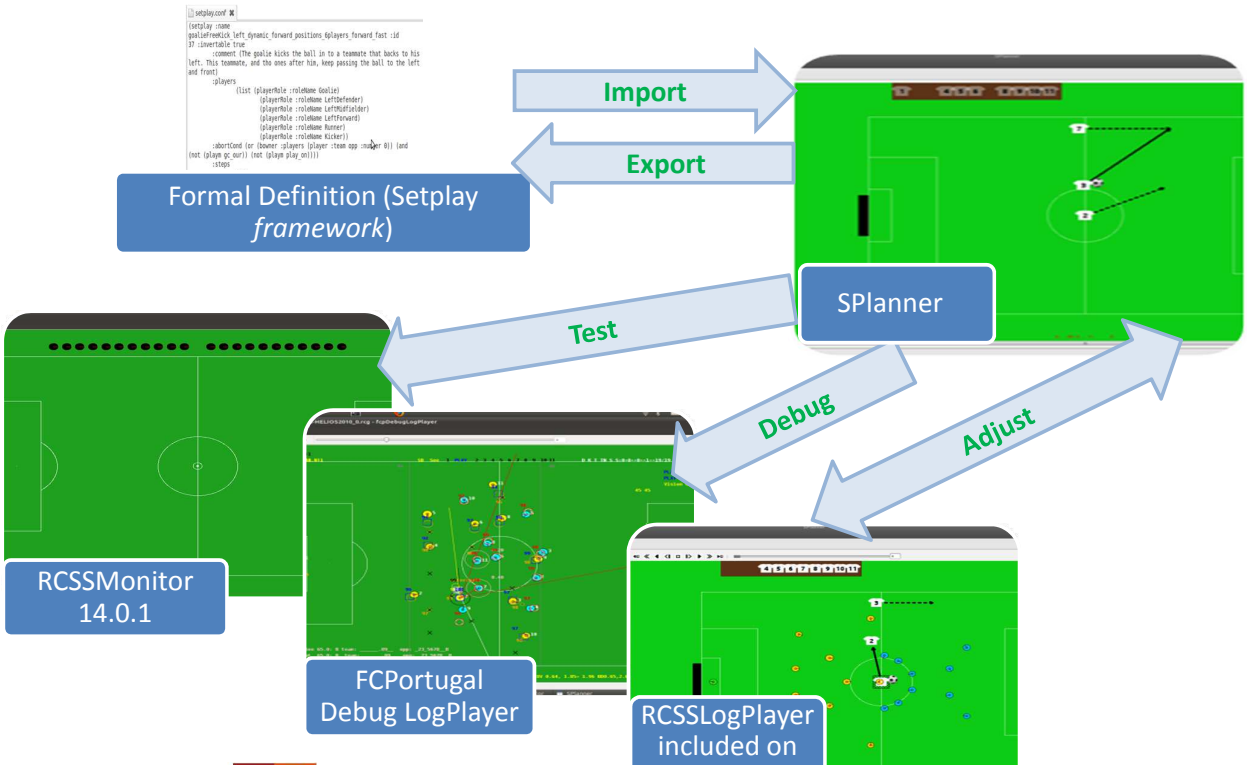
```
(setplay :name simpleCorner
    :players (list (playerRole :roleName CornerP)
    (playerRole :roleName receiver)
    (playerRole :roleName shooter))
:steps (seq (step :id 0 :waitTime 15 :abortTime 70
:participants
    (list (at CornerP (pt :x 52 :y 34))
        (at receiver (pt :x 40 :y 25)) (at 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))))))
(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))))))
```

Usage/Interest of Setplay Library

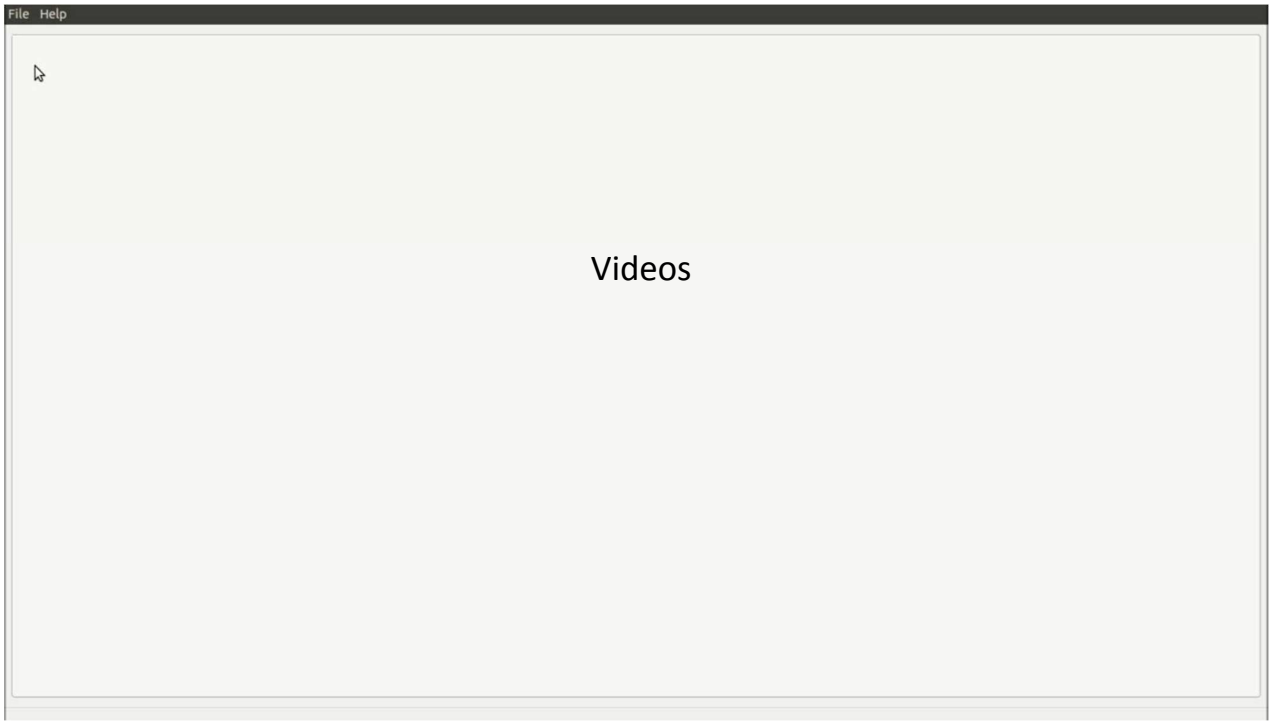
- Setplay Definition/**Graphical application**
- Implement **Conditions and Actions**
- Deal with **low level Communication**
- Decide Setplay start: CBR/ML
- Great flexibility: Application to all RoboCup leagues:
  - Simulation 2D, Simulation 3D, Middle Size, MR League, SPL)



Setplays: Graphical Definition



Setplays: Graphical Definition

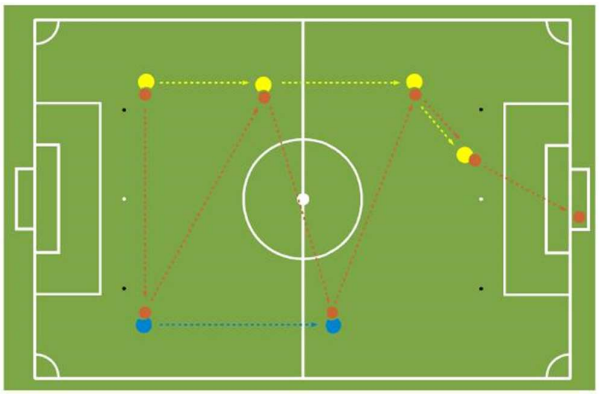


Setplays in the MSL

Passes

- Essential for teamplay
- 3 phases
  - Preparation/Alignment
  - Pass
  - Catch ball
- Used by CAMBADA in
  - Playoff
  - Free Challenge 2008
  - Also on Playon!

RolePasser	RoleReceiver
PassFlag ← TRYING_TO_PASS	
Align to receiver	Align to Passer
	PassFlag ← READY
Kick the ball	
PassFlag ← BALL_PASSED	
Move to next position	Catch ball



SetPlays in the MSL

Videos

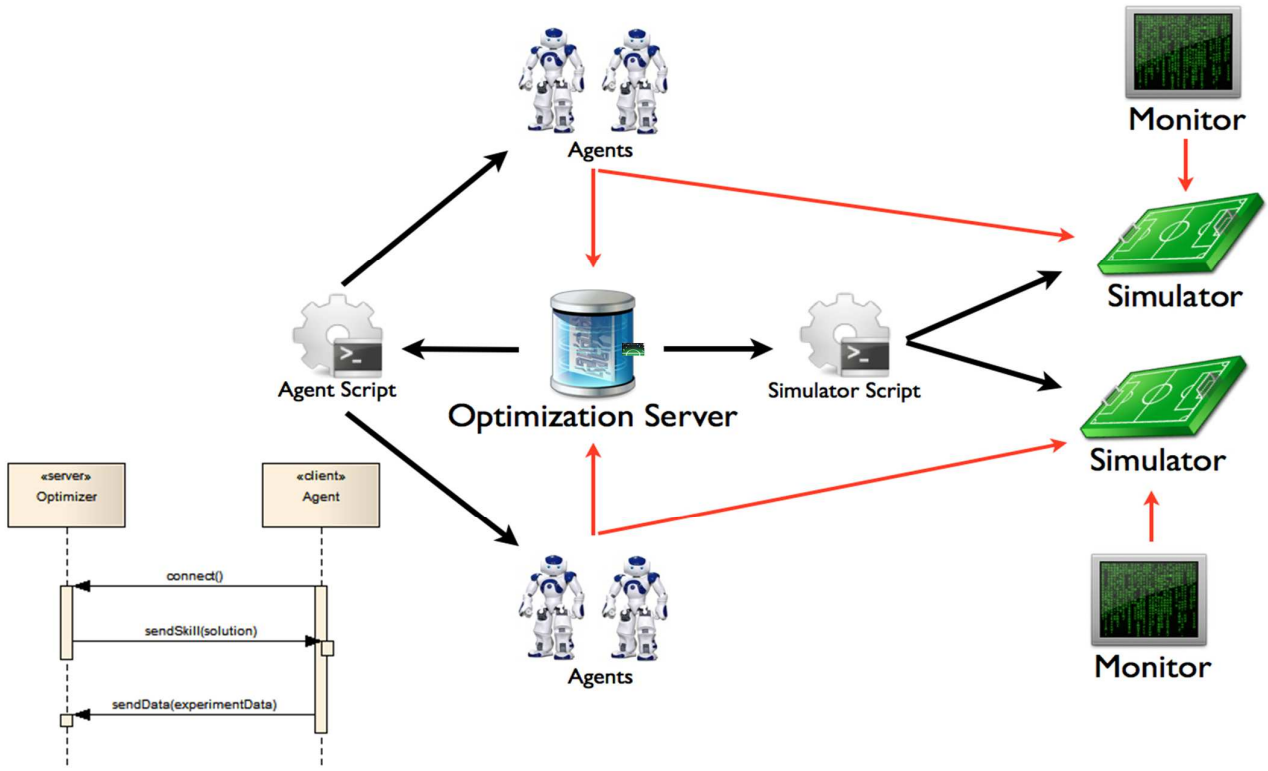
Flexible Strategy for Robotic Teams

Simple Example (from FCPortugal 3D):

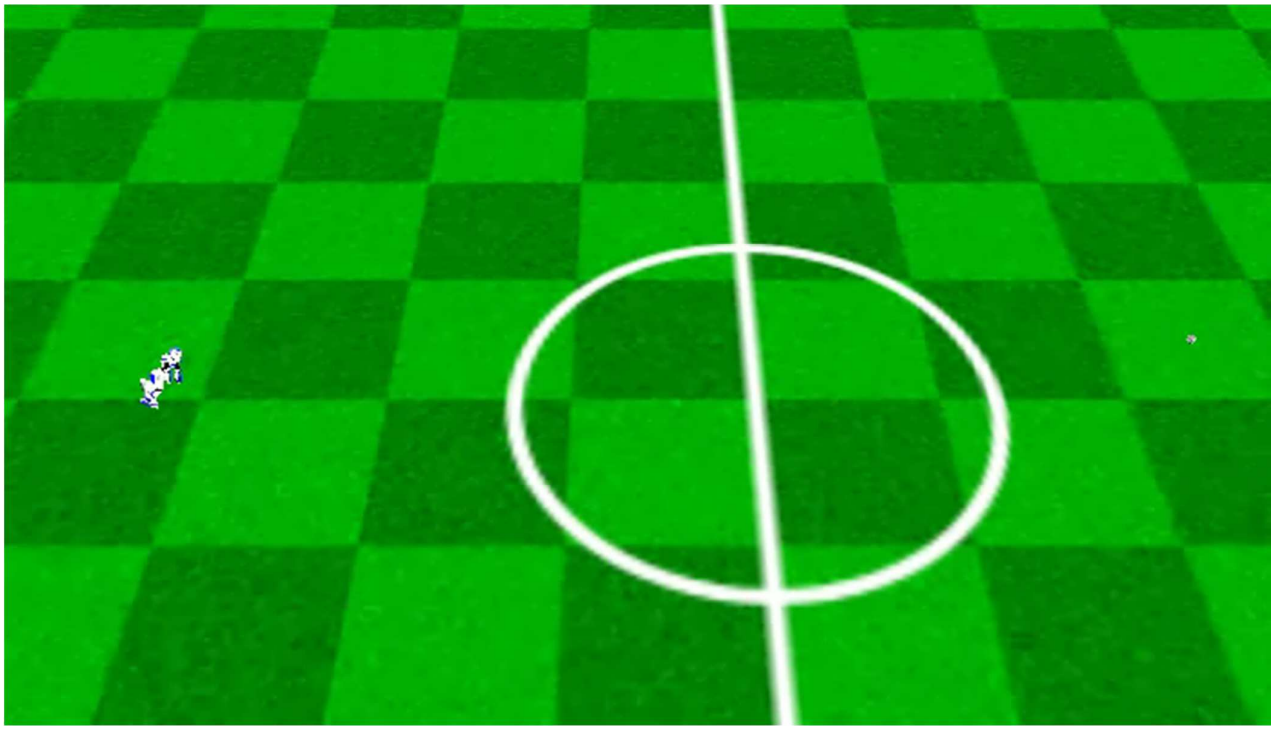
STWorldState <- FillInWSforStrategy();
Actions <- CallStrategy(STWorldState);
ExecuteActions(Actions);

```
void FCPAgentH::FillInWSforStrategy() {
    WorldState& world = SWorldState::getInstance();
    strategy->WS_GameTime = world.gTime;
    strategy->WS_Result = world.game->ourGoals- world.game->opponentGoals;
    strategy->WS_BallPos = world.ball->position.to2d(); /
    strategy->WS_BallOwner = world.->ball_owner;
    strategy->WS_BallIntPos = world.ball->finalPos.to2d();
    strategy->WS_MyNumber = world.me->unum;
    strategy->WS_MyDir = world.me->orientation;
    for (int t = 1; t <= strategy->ST_NUM_PLAYERS; t++) {
                strategy->WS_TeamPos[t]= world.getFCPortugalPlayer(t)->position.to2d();
                strategy->WS_OppPos[t] = world.getOpponentPlayer(t)->position.to2d();
                strategy->WS_TeamConf[t] = world.getFCPortugalPlayer(t)->conf;
                strategy->WS_OppConf[t] = world.getOpponentPlayer(t)->conf;
    }
    strategy->WS_PlayMode = world.game->playmode;
}
```

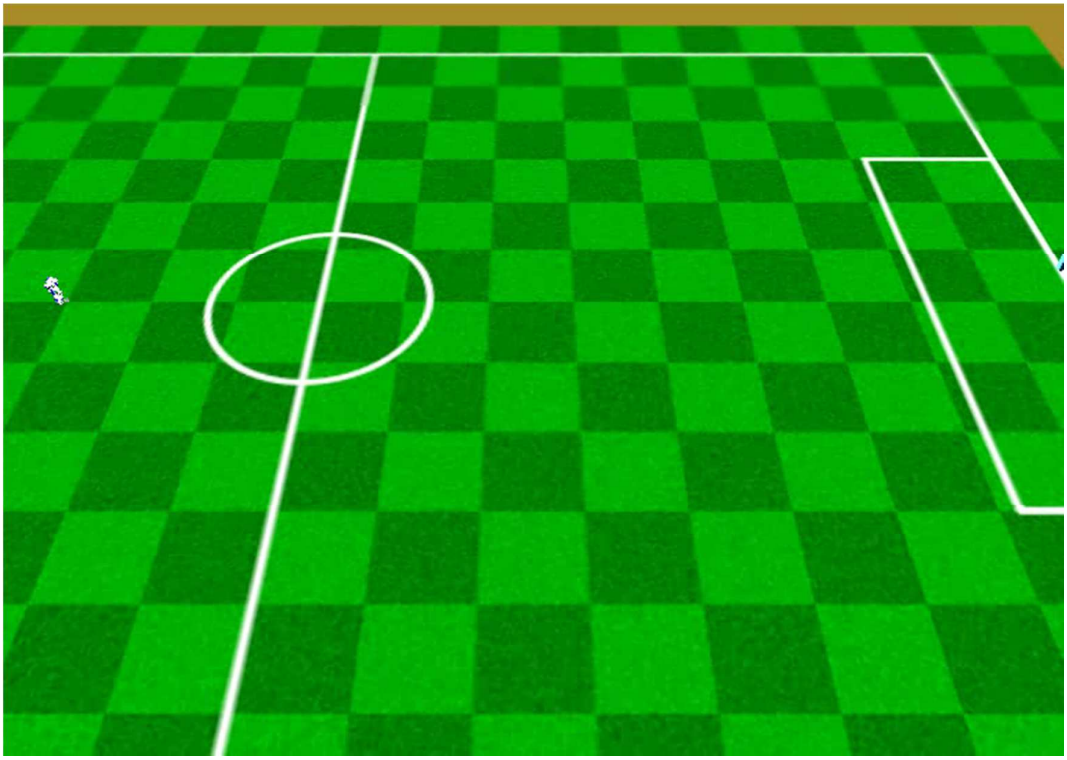
Generic Optimization



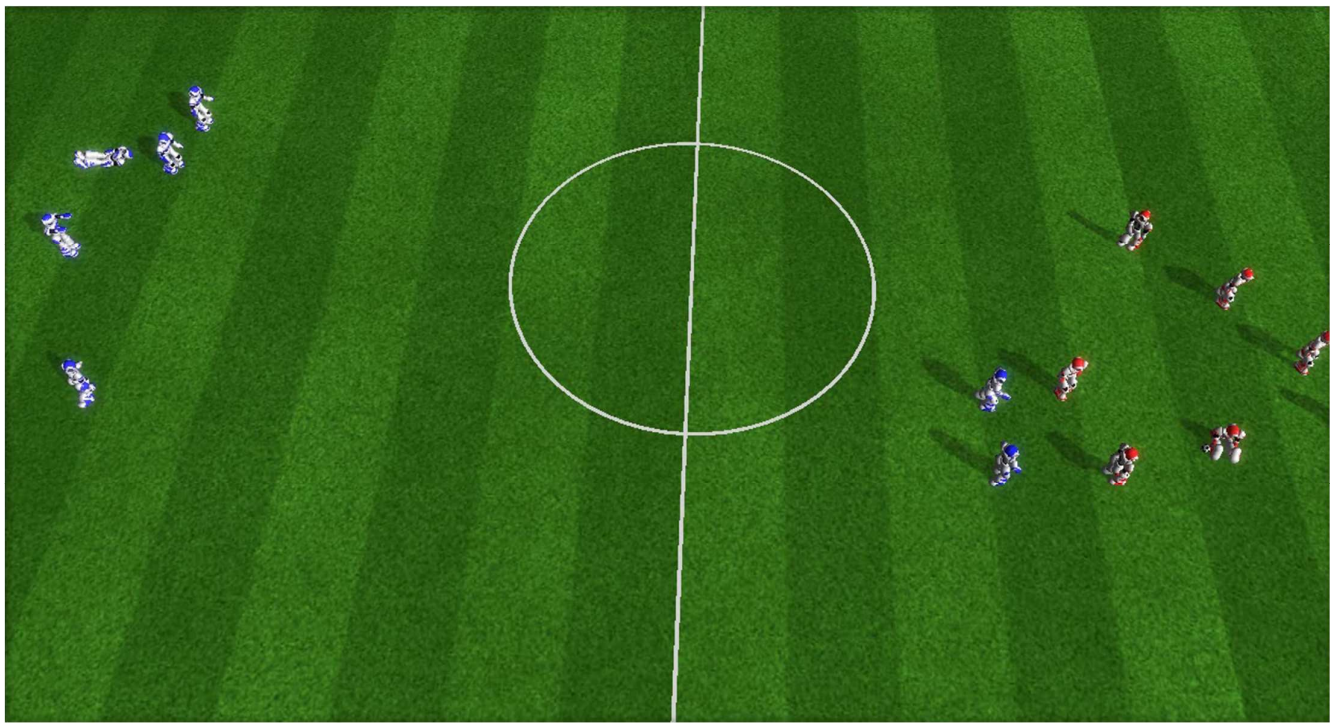
Results – 20 m Kick!!!



Results – Formation and Kick



Results – Formation and Kick



Results – 20 m Kick!!!

Selected Results: FC Portugal

Competition Results: FCPortugal

2000	1st place in the 2D Simulation League, European 2000
	1st place in the **2D Simulation League**, **RoboCup 2000**
2001	3rd place in the 2D Simulation League, RoboCup 2001
	1st place in the 2D Simulation League, European (GO) 2001
2002	**1st place** in the **Coach Competition**, **RoboCup 2002**
2003	2nd place in the Coach Competition, RoboCup 2003
2004	2nd place in the Coach Competition, RoboCup 2004
2006	**1st place** in the **3D Simulation League**, **RoboCup 2006**
	2nd place in the Small-Size League, RoboCup 2006
	1st place in the 3D Simulation League, European 2006
	1st place in the **Rescue Sim League**, **European 2006**
	2nd place in the 2D Simulation League, European 2006
2007	**1st place** in the **3D Simulation League**, **European 2007**
	2nd place in the 2D Simulation League, European 2007
	2nd place in the **Physical Visual. League**, **RoboCup 2007**

Selected Results: FC Portugal

Competition Results: FC Portugal

2009	3rd place in the 3D Simulation League, European 2009
	3rd place in the 2D Simulation League, European 2009
2010	3rd place in the 3D Simulation League, European 2010
	3rd place in the 2D Simulation League, European 2010
2011	2nd place in the 3D Simulation League, European 2011 (GO)
	2nd place in the 2D Simulation League, European 2011 (GO)
2012	**1st place in the 3D Simulation League, European 2012 (DO)**
	3rd place in the 2D Simulation League, European 2012 (DO)
	2nd place in the Rescue Simulation League, European 2012 (DO)
2013	**1st place in the 3D Simulation League, European 2013 (GO)**
	3rd place in the 3D Simulation League, RoboCup 2012
	1st place in the 3D Sim League, Scientific Challenge, RoboCup 2013
	1st place in the 2D Sim League, Scientific Challenge, RoboCup 2013

Selected Results: CAMBADA, 5DPO

Competition Results: CAMBADA and 5DPO

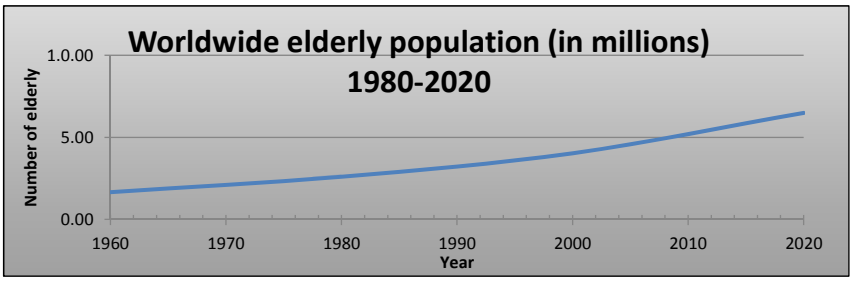
1998	**5DPO: 3rd place in the SSL League, RoboCup 2000**
2001	**5DPO: 1st place in the SSL League League, European (GO) 2001**
	5DPO: 3rd place in the MSL League League, European (GO) 2001
2002	5DPO: 2nd place in the SSL League, European (GO) 2002
2003	5DPO: 2nd place in the SSL League, European (GO) 2003
2004	**5DPO: 1st place in the SSL League, European (GO) 2004**
2006	**5DPO: 1st place in the SSL League, European 2006**
	5DPO: 2nd place in the SSL League, RoboCup 2006
2008	**CAMBADA: 1st place in the MSL League, RoboCup 2008**
2009	**CAMBADA: 3rd place in the MSL League, RoboCup 2009**
2010	CAMBADA: 2nd place in the MSL League, European 2010
	CAMBADA: 3rd place in the MSL League, RoboCup 2010
2011	**CAMBADA: 3rd place in the MSL League, RoboCup 2011**
	CAMBADA: 1ST place in the MSL League Sc. Challenge, RoboCup 2011
2013	**CAMBADA: 3rd place in the MSL League, RoboCup 2013**
	CAMBADA: 1ST place in the MSL League Te. Challenge, RoboCup 2013

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 disabiliti**
  - Cerebral palsy
  - Tetraplegia
- **Inability to control conventional electric wheelchairs**

Intelligent Wheelchair

- **Definition:**

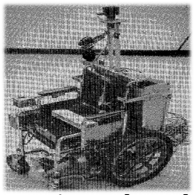
  Robotic device with sensorial and actuation systems and processing capabilities:
  - Semi-Autonomous behavior with **obstacle avoidance**
  - **Autonomous navigation** and planning capabilities
  - Flexible **Human-Machine interaction**
  - **Cooperation** with other IW and with other devices (e.g. automatic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

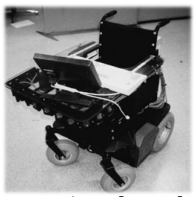
Related Work

- **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]

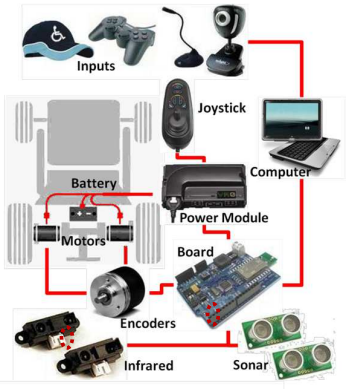

VAHM [2010]


ARTY [2012]


SDA [2012]

IntellWheels - Hardware

- **Off-the-shelf devices**
  - Human-machine interface
  - Easy to adapt to other wheelchair models
  - Powered wheelchair control
  - Sensors and Processing/interface board
- **Basic functions developed in firmware (without PC)**
  - Sensor reading
  - Pre-processing odometry
  - Obstacle avoidance

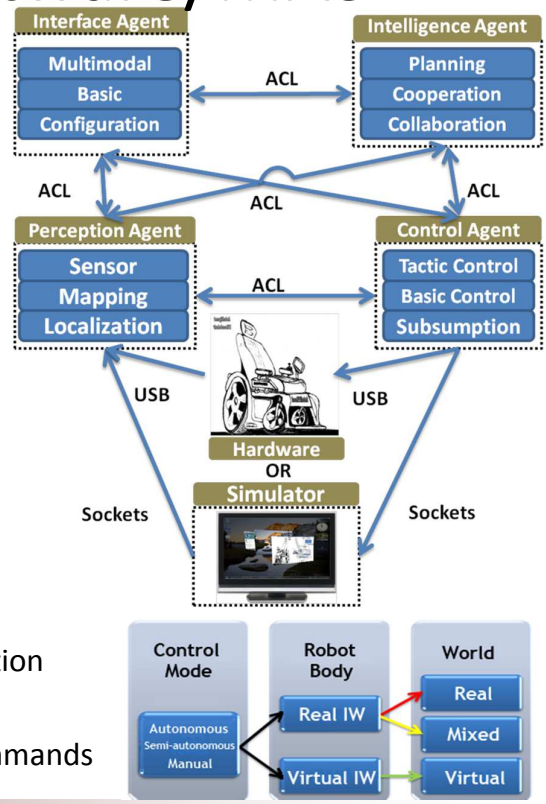


IntellWheels Software/MAS

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



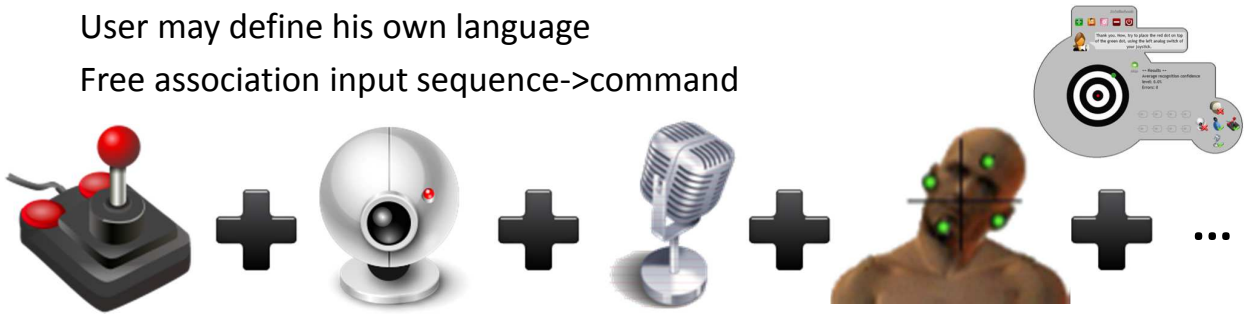
IntellWheels Multimodal Interface

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

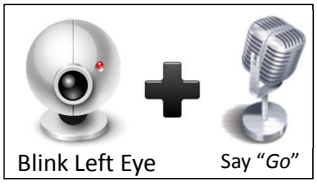
  IntellWheels combines user inputs (e.g. speech, pen, touch, gestures)

  User may define his own language

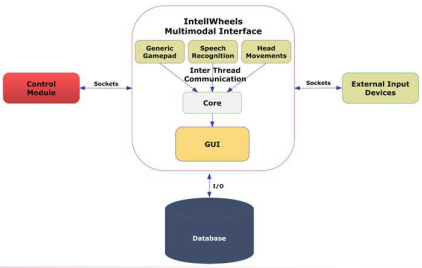
  Free association input sequence->command



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

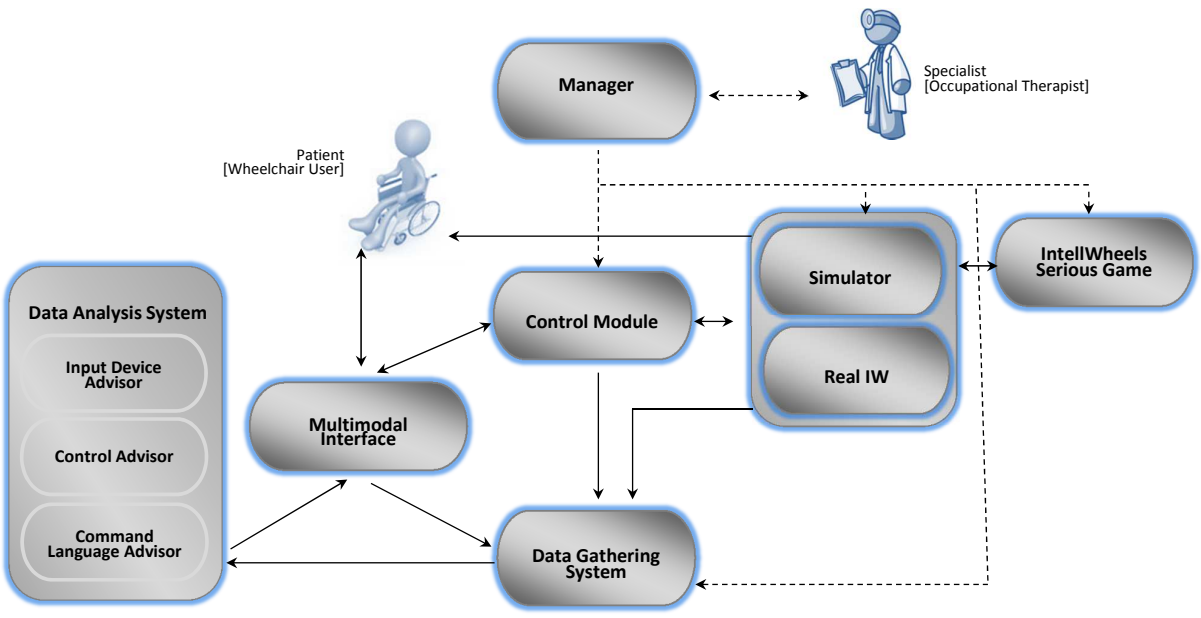


Action: Wheelchair goes to Room A



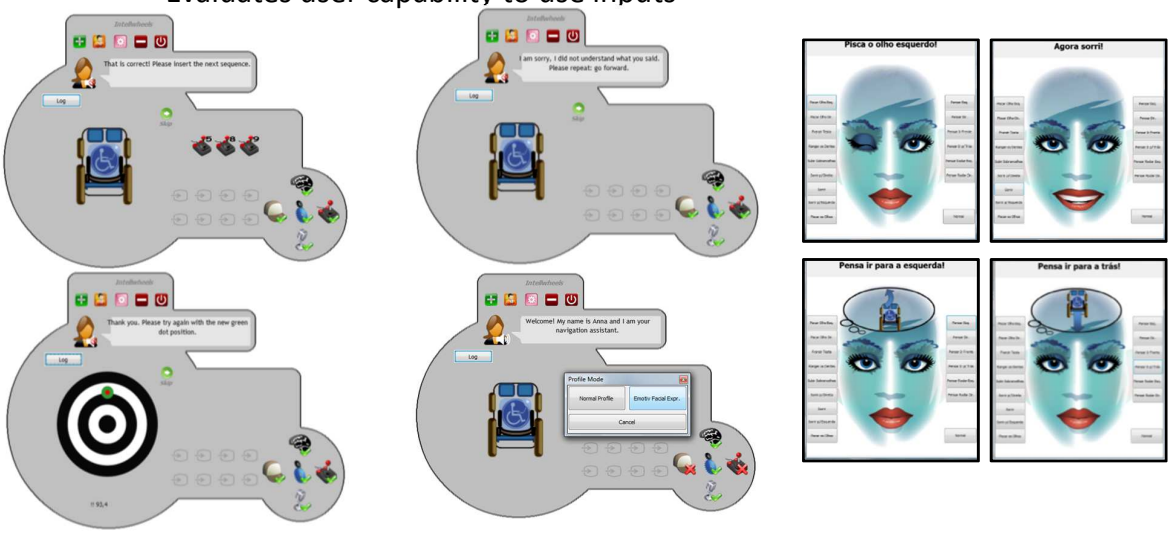
Real Wheelchair Prototype

System Architecture

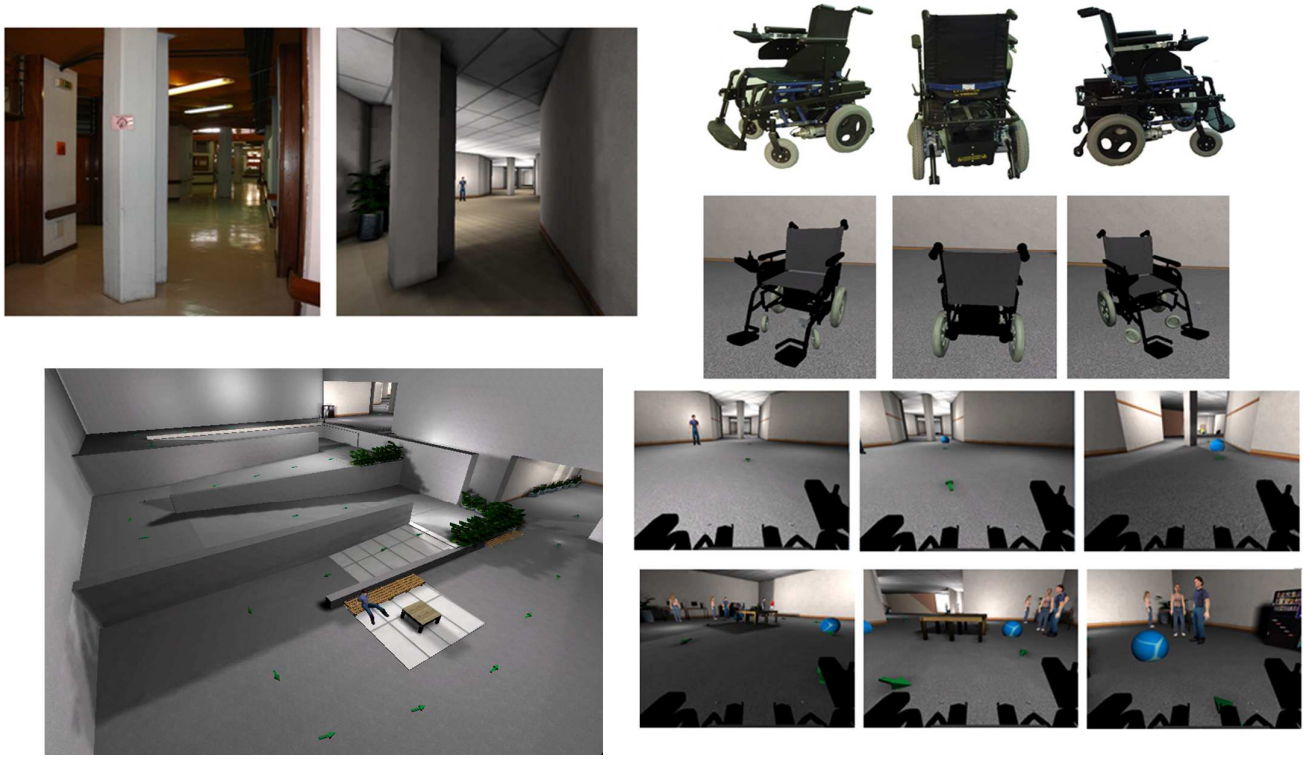


Multi-Modal Interface User Profiling

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

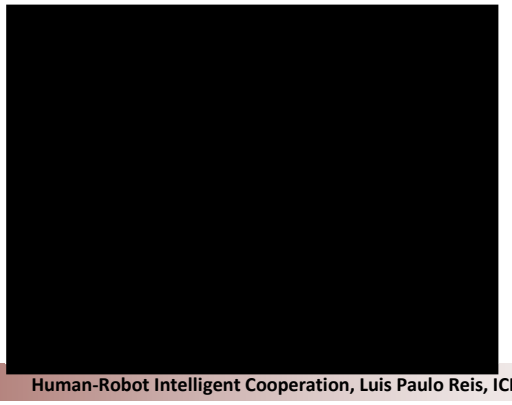


Simulated Environment and Wheelchair



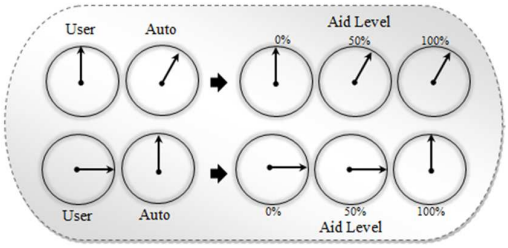
IntellSim – Tests With Cerebral Palsy Patients

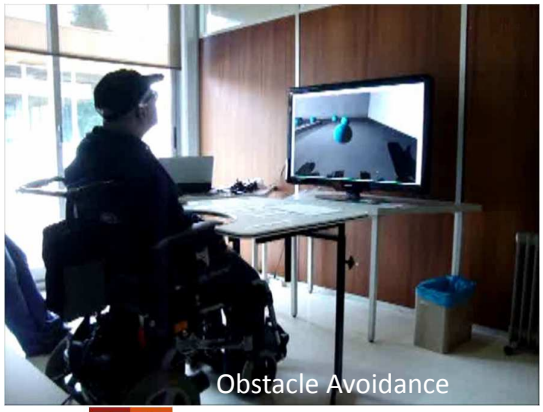
Videos



Wheelchair Control

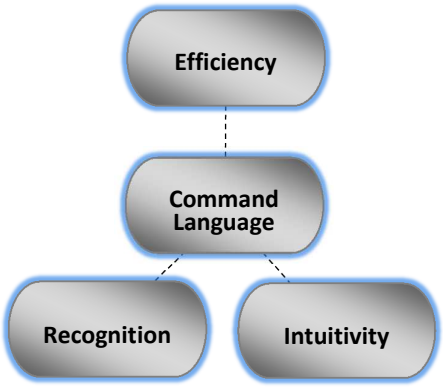
- **Shared Wheelchair Control**
  - Aid level of 100%
  - Aid level of 50%
  - Manual with obstacle avoidance





Data Analysis System

Command Language



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

Efficiency: $t_{S_i} = \sum_{k=1}^{N_i} t^{ID}_{I^{(i,k)}} + t_{timeout\,(i)}$

time to select inputs — timeout

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

$T_{C_{eff}} = \sum_{j=1}^{C_j} eff\,(t_{S_j})$

$eff : [0,+\infty[\rightarrow [0,1]$

$t_{S_i} \mapsto \frac{1}{t_{S_i}+1}$

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

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

Intuitiveness of a sequence of inputs S_i

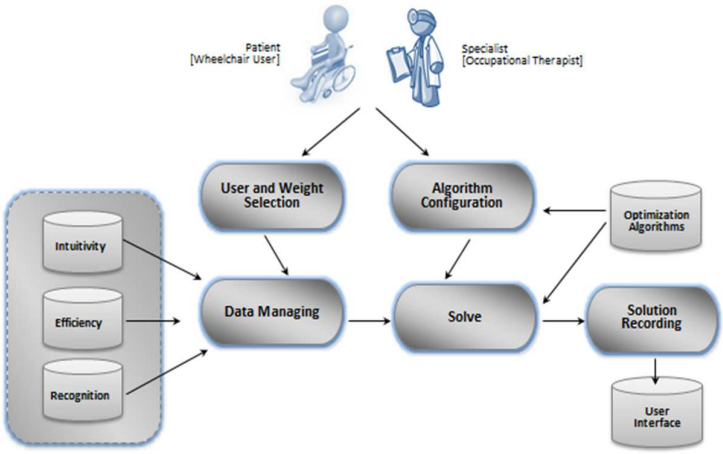
Commands	I_1 ("Go")	I_2 ("Left")	I_3 ("Right")	I_4 ("Back")	I_5 ("Stop")	I_6 ("Front")	I_7 ("Forward")
Forward	1	0	0	0	0	1	1
Left	0	1	0	0	0	0	0
Right	0	0	1	0	0	0	0
Back	0	0	0	1	0	0	0
Stop	0	0	0	0	1	0	0

Data Analysis System

Command Language

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

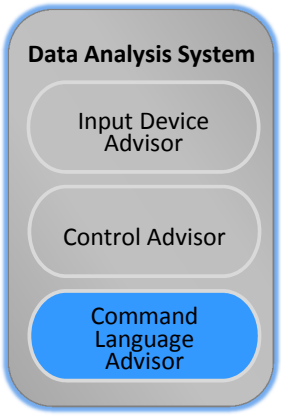
$$\arg\max_{T_{eff},T_{reg},T_{\text{int}}} (\alpha T_{eff} + \beta T_{reg} + \gamma T_{\text{int}})$$




```
(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
```

Data Analysis System

Command Language Advisor



Mean of DAS evaluation higher than mean of evaluation of the command language recommended by specialist (p value = 0.002)

Patient	Evaluation	Command Language for Patients: Forward	Left	Right	Back	Stop
P1						
Specialist	4.53	wiimote	joystick	joystick	joystick	joystick
IDAS	4.57	joystick	joystick	joystick	joystick	joystick
P2						
Specialist	4.18	joystick	joystick	joystick	joystick	voice ("stop")
IDAS	4.85	joystick	joystick	joystick	joystick	voice ("go")
P3						
Specialist	3.33	voice ("forward")	wiimote	wiimote	joystick	voice ("stop")
IDAS	4.51	wiimote	wiimote	wiimote	wiimote	voice ("go")
P4						
Specialist	4.50	voice ("forward")	joystick	joystick	joystick	voice ("stop")
IDAS	4.60	joystick	joystick	joystick	joystick	voice ("stop")
P5						
Specialist	4.14	voice ("front")	wiimote	wiimote	joystick	voice ("stop")
IDAS	4.40	wiimote	wiimote	voice ("turn")	joystick	voice ("stop")
P6						
Specialist	4.13	wiimote	joystick	joystick	joystick	joystick
IDAS	4.38	wiimote	wiimote	wiimote	wiimote	wiimote
P7						
Specialist	4.49	voice ("front")	joystick	joystick	joystick	voice ("stop")
IDAS	4.60	joystick	joystick	joystick	voice ("back")	voice ("stop")
P8						
Specialist	3.51	wiimote	joystick	joystick	joystick	joystick
IDAS	4.20	wiimote	wiimote	wiimote	wiimote	wiimote
P9						
Specialist	3.70	voice ("forward")	wiimote	wiimote	joystick	voice ("stop")
IDAS	4.75	joystick	joystick	joystick	joystick	joystick
P10						
Specialist	4.11	voice ("forward")	voice ("left")	voice ("right")	voice ("turn")	voice ("stop")
IDAS	4.80	joystick	joystick	voice ("turn")	joystick	voice ("go")
P11						
Specialist	4.29	joystick	wiimote	wiimote	joystick	joystick
IDAS	4.30	wiimote	wiimote	wiimote	wiimote	wiimote

Conclusions

- **Many IWs prototypes are being developed:**
  - User adaptation is often neglected
  - 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
- **Automatic adaptation using user profiling**
- **Command language adapted to the user** with better evaluation than recommended by specialists
  - **Shared control** with appropriate aid level

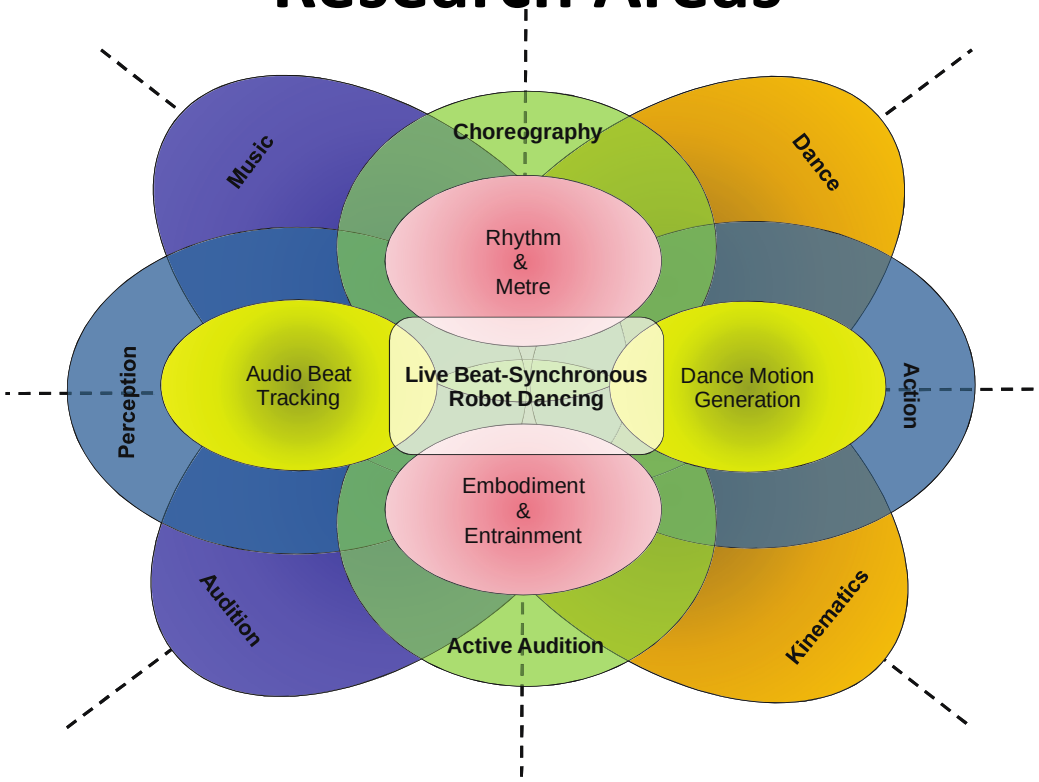
Project Awards and Divulgation

- **2nd place** at Festival Nacional de Robótica, International Competition **Freebots**, Portuguese Robotics Open, Instituto Superior Técnico, Lisbon, April 2011
- **Galardão da Inclusão at the category Applied Investigation**, Teatro José Lúcio da Silva, em Leiria, 3 de Dezembro de 2011, Dia Internacional da Pessoa com Deficiência, Centro de Recursos para a Inclusão Digital (CRID), Instituto Politécnico de Leiria (IPL)
- First Honor Mention/2nd Place at the Award **"Ser Capaz"** of Associação Salvador, Projeto Intellwheels, Espaço BES Arte & Finança, Lisboa, Portugal, 16 de Janeiro de 2012
- Honor mention, **Jaime Filipe Award**, "Projeto Cadeira de Rodas Inteligente com Interface Multimodal Flexível" - Instituto Nacional para a Reabilitação, Dia Internacional da Pessoa com Deficiência, 3 de Dezembro de 2012
- **Best Paper Award,** 13th International Conference on Autonomous Robot Systems and Competitions - Robotica 2013: "B. M. Faria, Luís Paulo Reis, Nuno Lau, "Manual, Automatic and Shared Methods for Controlling an Intelligent Wheelchair: Adaptation to Cerebral Palsy Users", April 2013
- **More than 30 TV, Radio and Newspaper reports**

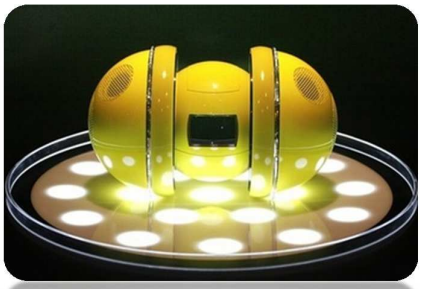
Robot Dancing Motivation

- **Inter-disciplinary area**
- **Human-robot (non-verbal) interaction**
- **Design of social intelligent robots**
- **Robotic entertainment**
- **Education**
- **Therapy**
- **Improve robot's musical and bodily cognition**
- **Improve robotic expressiveness**
- **Novel area of research**

Research Areas



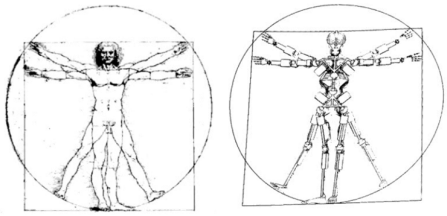
Robot Dancing



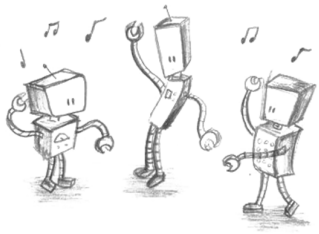
Project Objectives

Implementation of a rhythmic intelligent robot capable of dancing to live music in a real-world environment

1. Online beat-tracking to continuous music stimuli



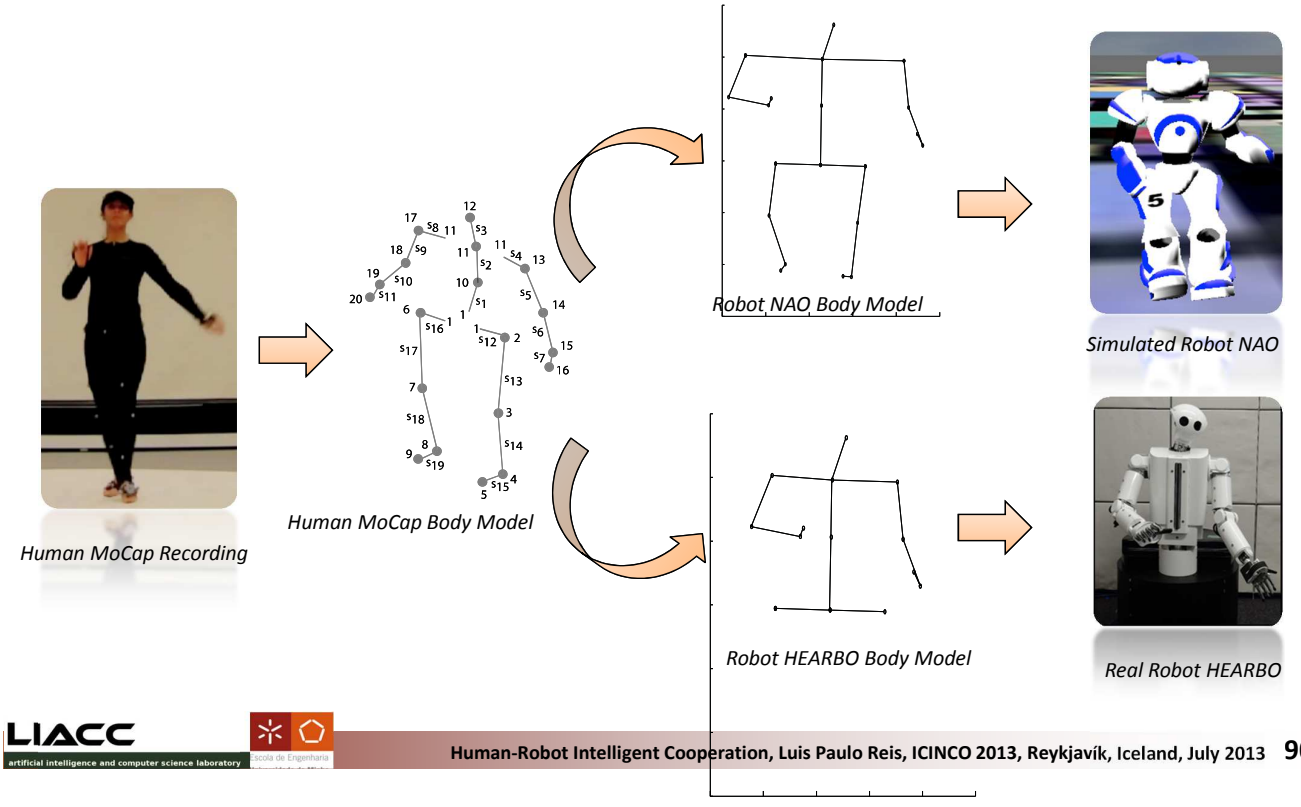
2. Representation and mapping of human dance movements onto humanoid robots



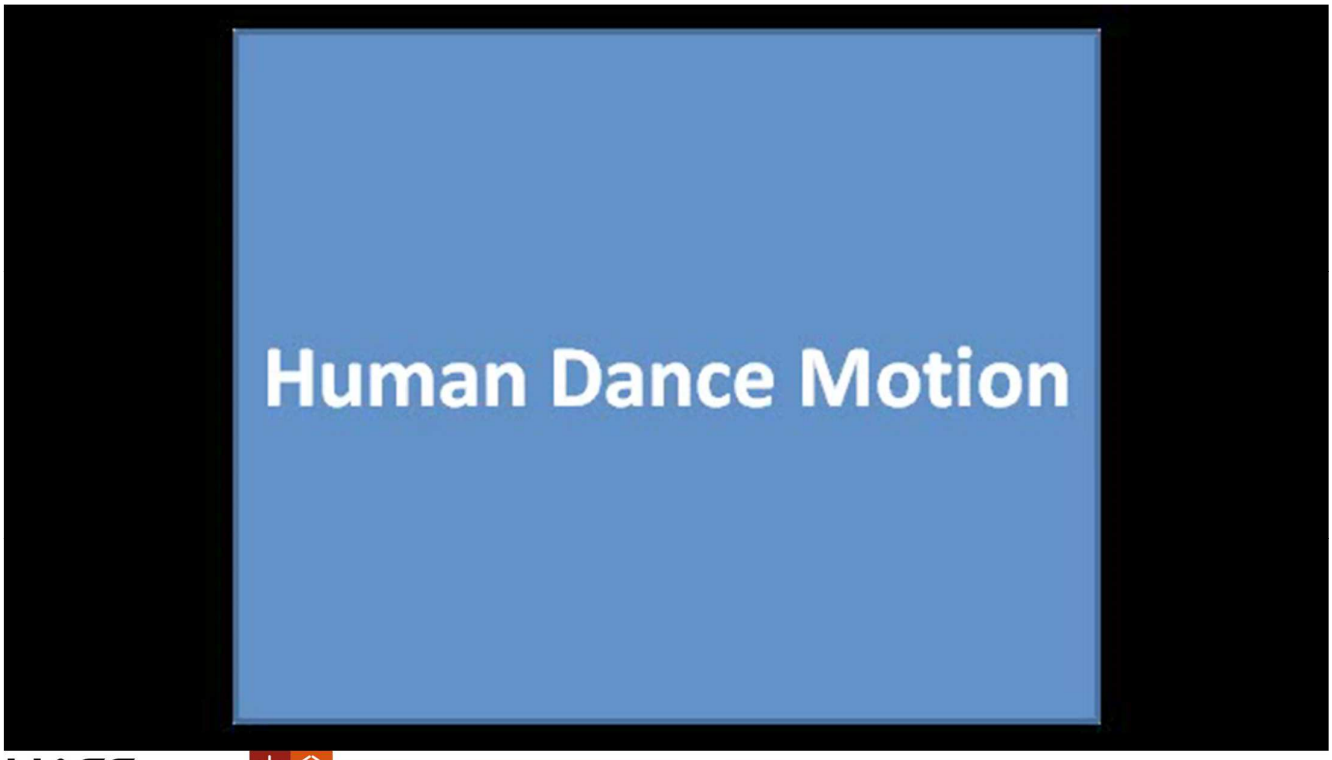
3. Online beat-synchronous robot dancing

4. Robot audition for real-world robot dancing

Mapping Samba onto Humanoids

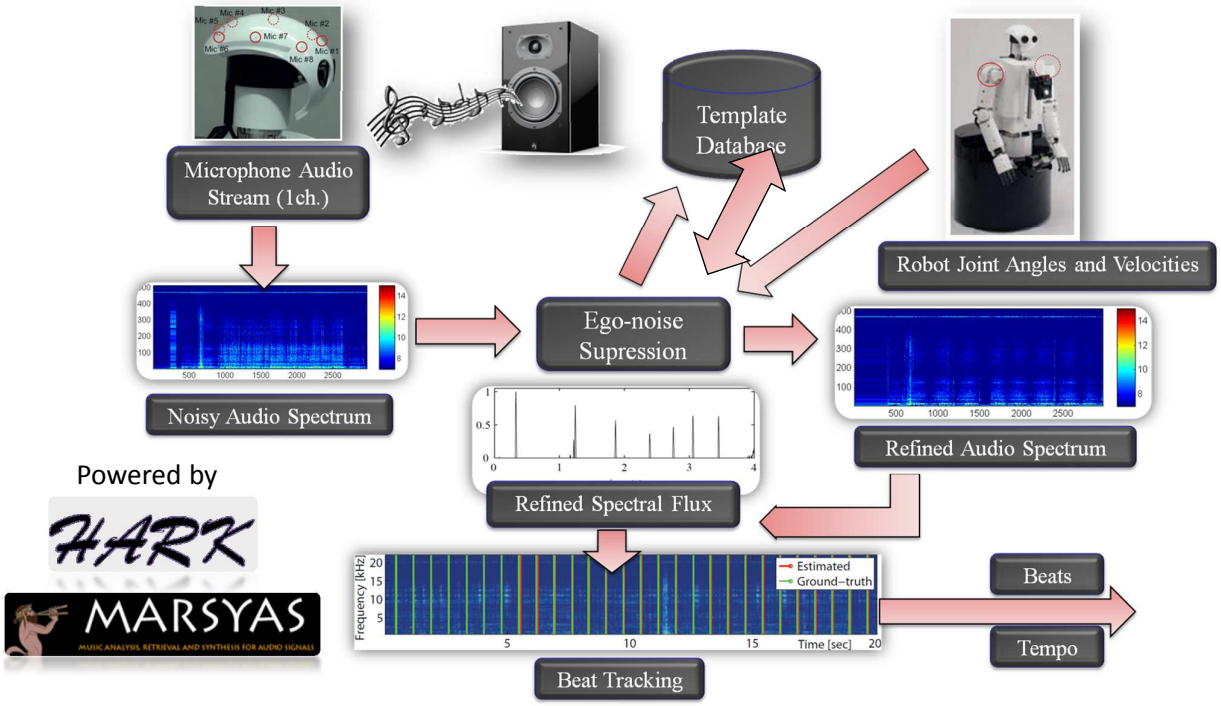


Beat-Synchronous Robot Dancing Demos (1)

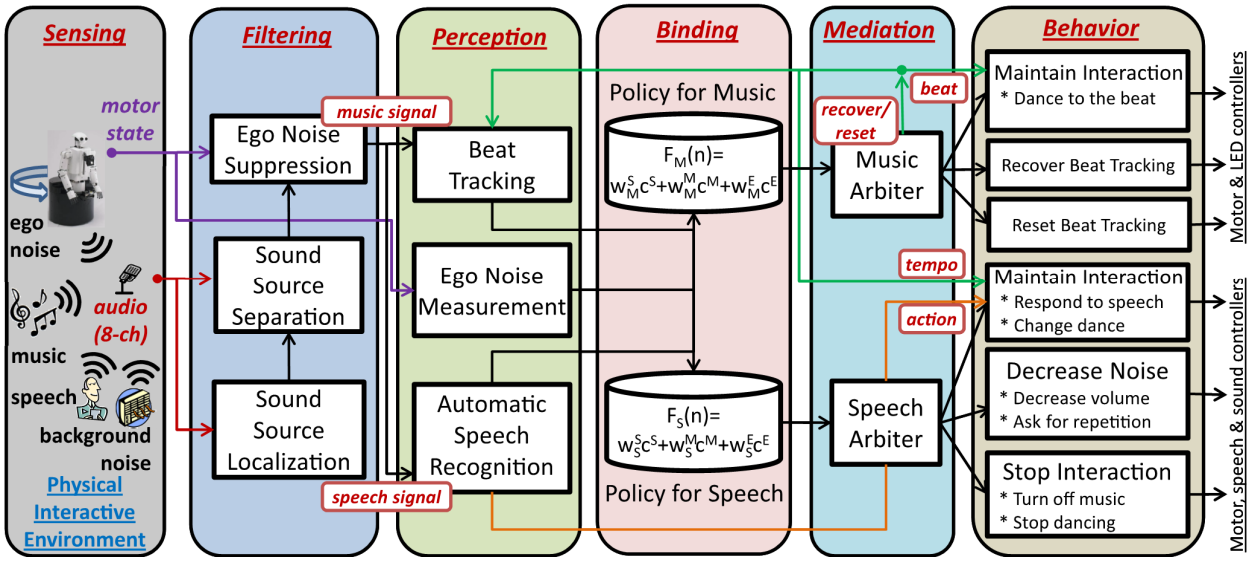


Beat-Synchronous Robot Dancing Demos (2)

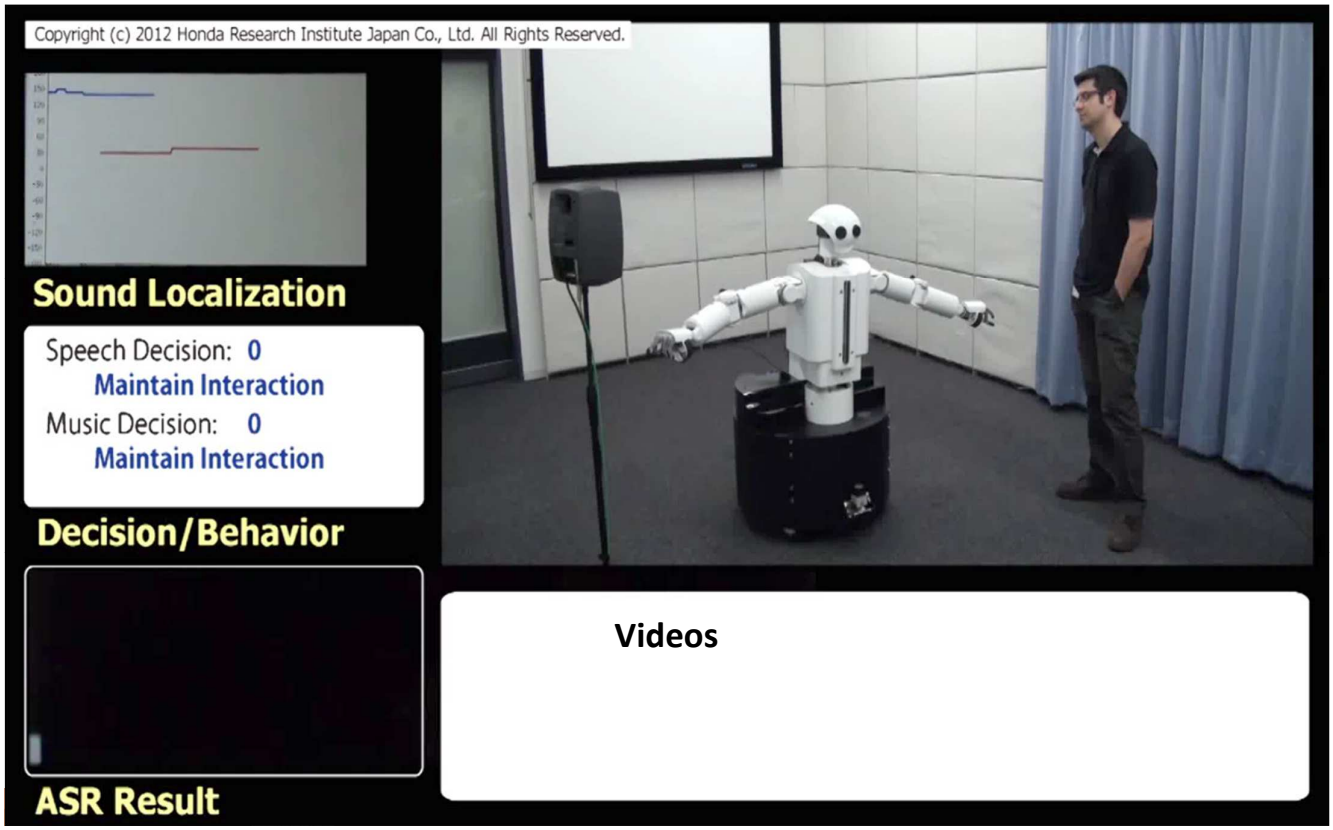
Live Ego Noise-Robust Beat Tracking Demo



Active Audition Framework for Auditory-driven HRI



Human-Interactive Robot Dancing Demo



Conclusions

- Key Issues for creating future Human-Robot Teams:
  - Sensor Fusion and Multi-Sensor Intelligent Perception
  - Multi-Robot Coordination/Flexible Strategy
  - Adaptive Strategy
  - Flexible Multimodal Interaction
  - Human Robot Cooperation - Shared Control
  - Adaptive Interaction
  - Realistic Simulation
  - Bridging the Gap between Simulation and Robotics
- More than 80 papers ISI Web of Knowledge/Scopus available about these 3 projects (*see online slides after the conference*)

Human-Robot Intelligent Cooperation: Methodologies for Creating Human-Robot Heterogeneous Teams

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