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

Luís Paulo Reis
lpreis@dsi.uminho.pt

Member of the Directive Board of LIACC – Artificial Intelligence and Computer Science Lab.
Associate Professor at School of Engineering, University of Minho, Portugal
President of the Portuguese Society for Robotics

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.”

**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

Robotic Competitions - RoboGames

Videos

AI and Robotics | Coordination of RoboCup Teams | Intellwheels Project | Robot Dancing Project | Conclusions

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

Human-Robot Intelligent Cooperation, Luis Paulo Reis, ICINCO 2013, Reykjavik, Iceland, July 2013
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 – Suzhou (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
RoboCup Leagues: Simulation 2D

- 1997: League Start -> Simple Play

Videos

- 1998: Simple Passing and Good Individual skills

Videos
RoboCup Leagues: Simulation 2D

- 2000: Formations and Soccer like Playing

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!
Simulation 3D – Spheres model

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

- 2008: Formations SBSP/High-level playing/Setplays!

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,
  - 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)**
- **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

Intellwheels Project | Robot Dancing Project | Conclusions
SBSP with Delaunay Triangulation

![SBSP with Delaunay Triangulation Diagram](image1)

SBSP with Delaunay Triangulation

![SBSP with Delaunay Triangulation Diagram](image2)
SBSP with Delaunay Triangulation

![Diagram 1](image1)

![Diagram 2](image2)
SBSP with Delaunay Triangulation
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)))))))

(set :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))))))

(set :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

Import Export

Formal Definition (Setplay framework)

SPlanner

Test

Debug Adjust

FCPortugal

RCSSMonitor 14.0.1

RCSSLogPlayer included on SPlanner
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!

<table>
<thead>
<tr>
<th>RolePasser</th>
<th>RoleReceiver</th>
</tr>
</thead>
<tbody>
<tr>
<td>PassFlag ← TRYING_TO_PASS</td>
<td>Align to receiver</td>
</tr>
<tr>
<td>Align to receiver</td>
<td>PassFlag ← READY</td>
</tr>
<tr>
<td>Kick the ball</td>
<td>Move to next position</td>
</tr>
<tr>
<td>PassFlag ← BALL_PASSED</td>
<td>Catch ball</td>
</tr>
</tbody>
</table>
SetPlays in the MSL

Videos

Flexible Strategy for Robotic Teams

Simple Example
(from FCPortugal 3D):

```c
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;
}
```

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

Results – 20 m 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

2013  
CAMBADA: 1st place in the MSL League Sc. Challenge, RoboCup 2011  
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

![Worldwide elderly population graph](image)

- **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
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

---

Human-Robot Intelligent Cooperation, Luis Paulo Reis, ICINCO 2013, Reykjavík, Iceland, July 2013
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

Wheelchair Control

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

- Efficiency
- Recognition
- Intuitiveness

Sequence of inputs $S_i$: $I(i,1), I(i,2), I(i,3), \ldots, I(i,N_i)$

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

time to select inputs  
  timeout

Total time for all the commands
$$ T_c = \sum_{j=1}^{C} t_{S_j} $$

Intuitiveness of a sequence of inputs $S_i$
$$ T_{reg} = \sum_{j=1}^{C} \text{reg}S_j $$

Maximizes the function composed by the total time efficiency, total recognition and intuitiveness
$$ \arg\max_{T_{eff}, T_{reg}, T_{int}} (\alpha T_{eff} + \beta T_{reg} + \gamma T_{int}) $$

(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 * timeVal + w_intu * intuVal
  evaluation ← evaluation + evalComm
endfor
return evaluation
**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
- **Galdardão 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
- 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**

- Active Audition
- Choreography
- Dance Motion Generation
- Audio Beat Tracking
- Rhythm & Metre
- Embodiment & Entrainment
- Live Beat-Synchronous Robot Dancing
- Action
- Perception
- audition
- Kinematics
- Embodiment & Entrainment
- Action

**Robot Dancing**

- No Live Musical Input
- Unnatural Movements
- Virtual Body
- No Robot Audition
- No Rhythmic Intelligence
- No Human Interaction
- Pre-programmed 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

Human MoCap Recording

Human MoCap Body Model

Robot NAO Body Model

Simulated Robot NAO

Robot HEARBO Body Model

Real Robot HEARBO
Beat-Synchronous Robot Dancing Demos (1)

Human Dance Motion

Beat-Synchronous Robot Dancing Demos (2)

Videos
Live Ego Noise-Robust Beat Tracking Demo

Active Audition Framework for Auditory-driven HRI
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

Luís Paulo Reis

lpreis@dsi.uminho.pt

Member of the Directive Board of LIACC – Artificial Intelligence and Computer Science Lab. Associate Professor at School of Engineering, University of Minho, Portugal President of the Portuguese Society for Robotics