

# W1. Objectives, Challenges, State of the Art, Technologies

- Socio-economic context
- Technological evolution of Robotics & State of the Art
- New challenges for Robotics in Human Environments
- Decisional & Control Architecture for Autonomous Mobile Robots & IV
- Sensing technologies: Object Detection
- Sensing technologies: Robot Control & HRI
- **Basic technologies for Navigation in Dynamic Human Environments**
- Intelligent Vehicles: Context & State of the Art
- Intelligent Vehicles: Technical Challenges & Driving Skills

# Problem formulation

The objective is to achieve  
**Goal oriented navigation in Open, Dynamic, and Uncertain environments populated by Human beings**

- *Traditional Motion Planning approaches cannot be directly applied*
- *New Models & Algorithms have to be designed*



# Problem formulation

## Sub-problems & Solutions

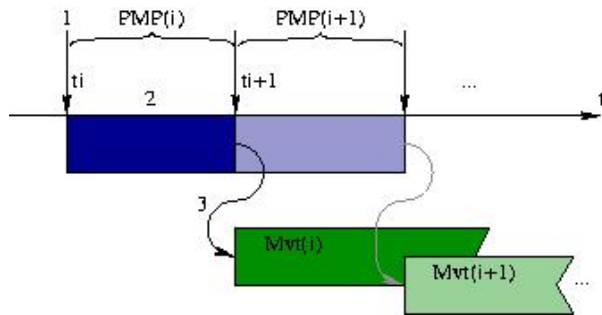
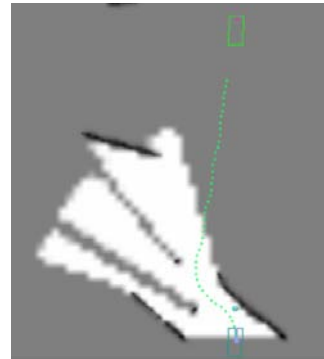
- Static environment is unknown & partially observable  
→ *Construct a Digital Map : SLAM + Hidden zones model + Uncertainty*
- Moving obstacles are not known ... but they follow typical patterns  
→ *Learning typical patterns through observations (sensors)*
- Moving obstacles behaviors cannot be directly observed  
→ *Detection & Tracking of Mobile Objects + Motion Prediction*
- Navigation Decisions in Dynamic & Uncertain environment  
→ *Iterative planning decisions + Time Horizon + Search guided by "Collision Risk"*
- Human Aware Navigation  
→ *Concept of Social Filter*

# Paradigm 1: Partial Motion Planning (PMP)

Repeat until the goal is reached:

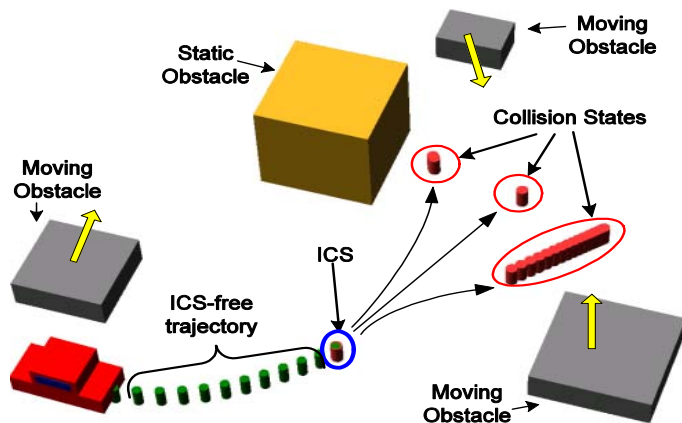
1. Get model of the future (*Observation & Prediction*)
2. Built tree of partial motions towards the goal
3. When time  $\delta_c$  is over, Return “**Best partial motion**” (*e.g. closest & safest*)

- $\delta_c$  value depends on the dynamicity of the environment
- Predictions are performed in a given “time horizon”  $H$
- Various search algorithms can be used (e.g. RRT)



# Paradigm 2: Inevitable Collision States (ICS)

- Avoiding instantaneous collision is not enough !  
→ *We also have to avoid states leading to “Inevitable Collisions” in the near future (ICS)*
- Doing nothing may also be dangerous !

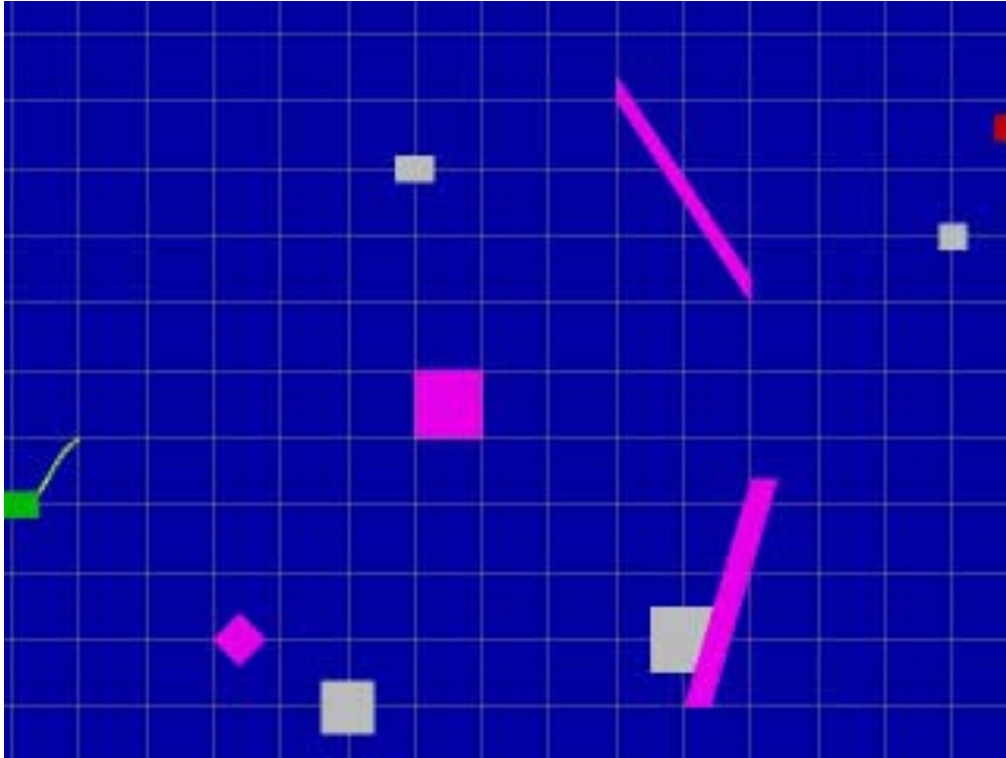


□ **PMP + ICS**



*ICS-Check [Martinez 08], ICS-Avoid [Martinez 09],  
Prob-ICS [Bautin 09]*

## *Paradigm 2: Inevitable Collision States (ICS)*

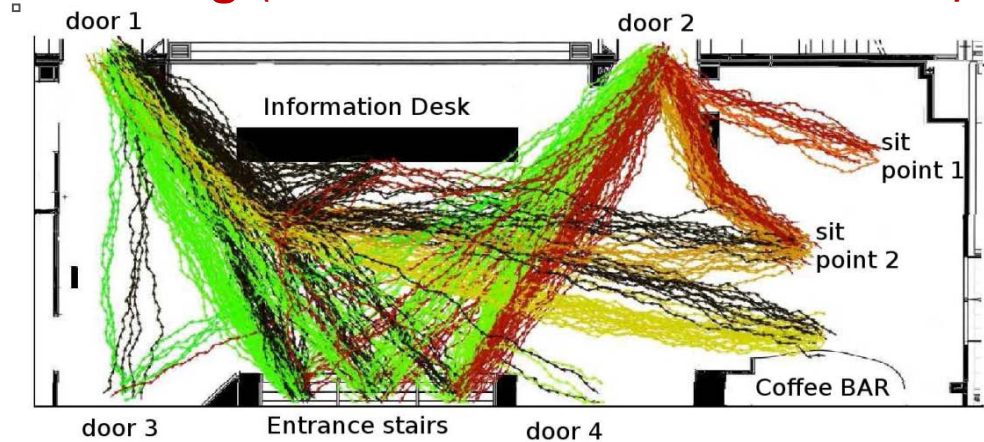


# Paradigm 3: Risk-Based Navigation (*Risk-RRT*)

- **Function 1: *Observation & Learning*** (*Environment structure + Motion patterns*)



*Inria entrance hall (ceiling camera view)*



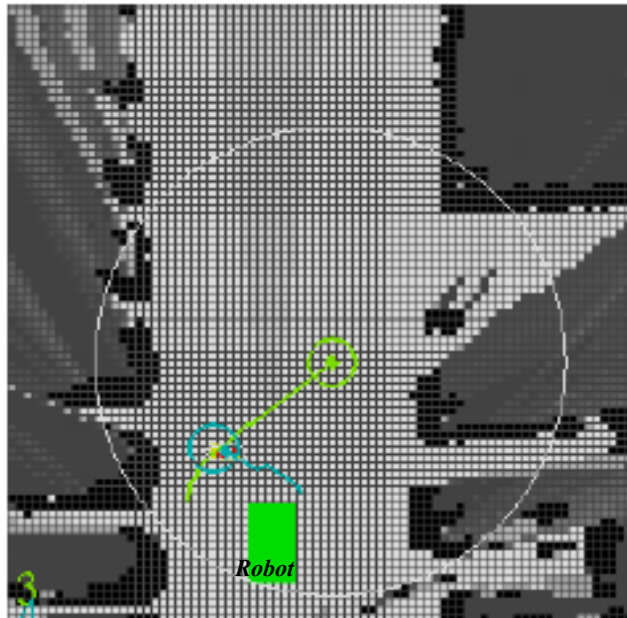
*Map + Learned motion patterns (represented by HMM)*

=> Learning process described in Week 5

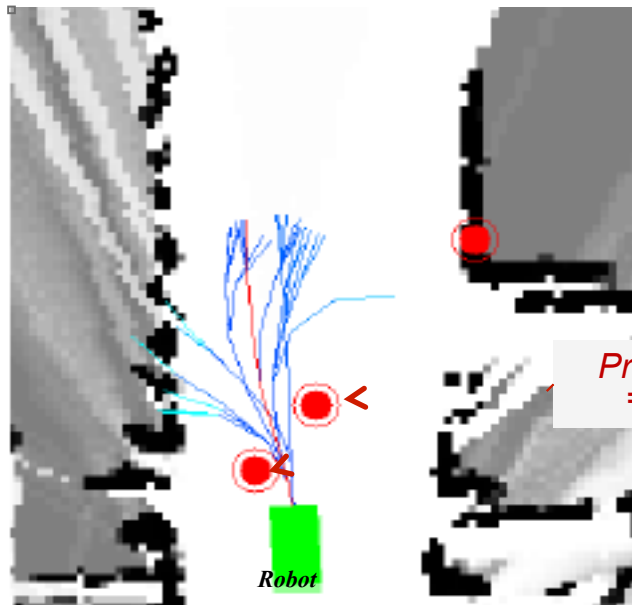


# Paradigm 3: Risk-Based Navigation (*Risk-RRT*)

- Function 2 : *Sense & Predict* + *Risk based navigation*



*Local Map + Moving Obstacle*



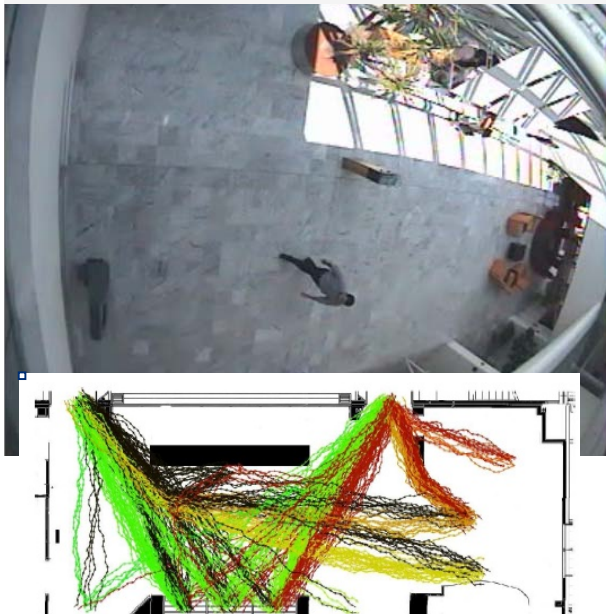
*Prediction & Risk Assessment  
+  
Iterative Motion Planning*

*Previously Observed Pedestrians  
=> Position probability at  $t+dt$*

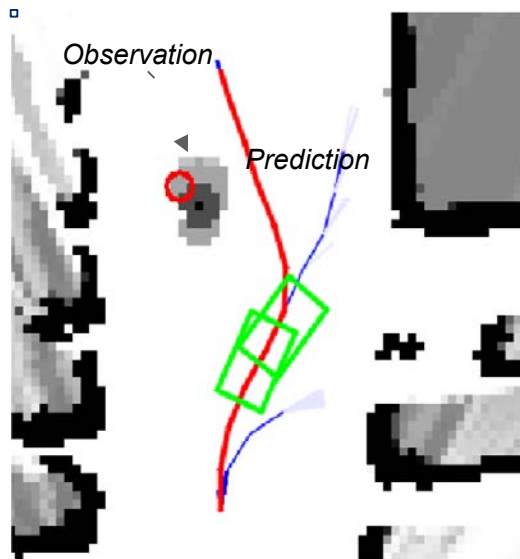


# Risk-RRT: Outline of the Algorithm

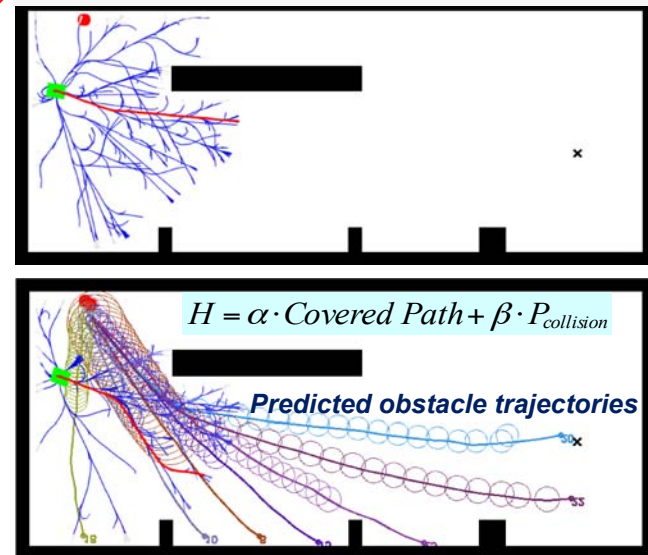
## Behaviors Modeling & Learning



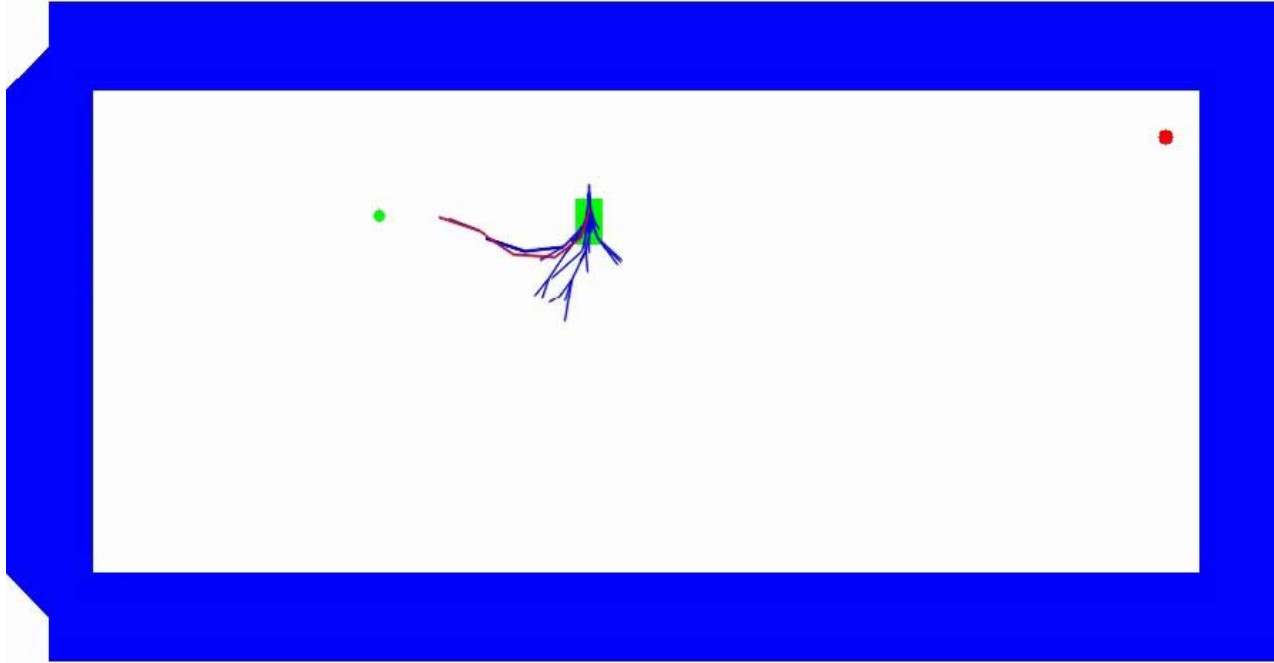
## Perception & Risk Assessment



## Risk-Based Navigation Decisions



# Risk-RRT: *Experimental Results*



- **Robot:** green rectangle
- **Assigned Robot goal:** green dot
- **Local search graph:** blue curves
- **Selected motion:** red curve
- **Pedestrian:** red dots

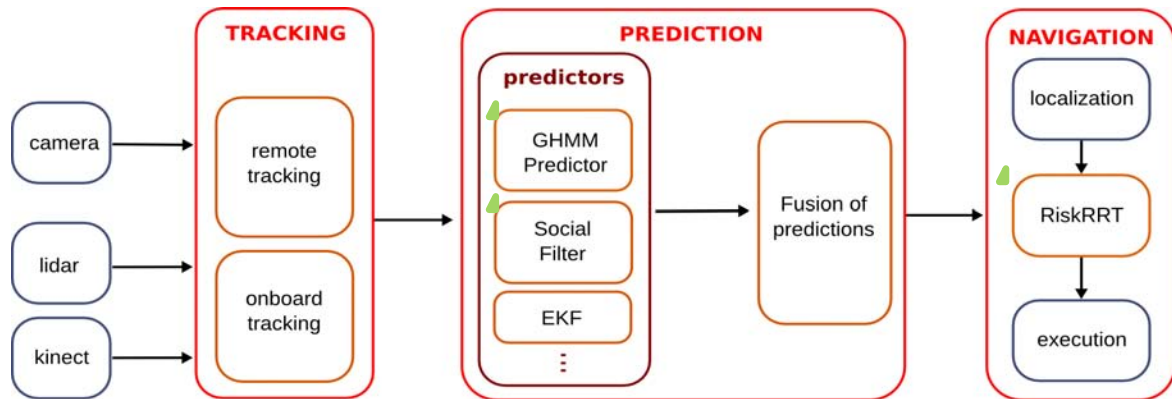
# Paradigm 4: Human Aware Navigation Paradigm

- **Problem:** *Safe & Socially acceptable Robot Motions in Human Environment*
  - => *No collision*
  - => *Robot Behavior complies with Social Conventions*



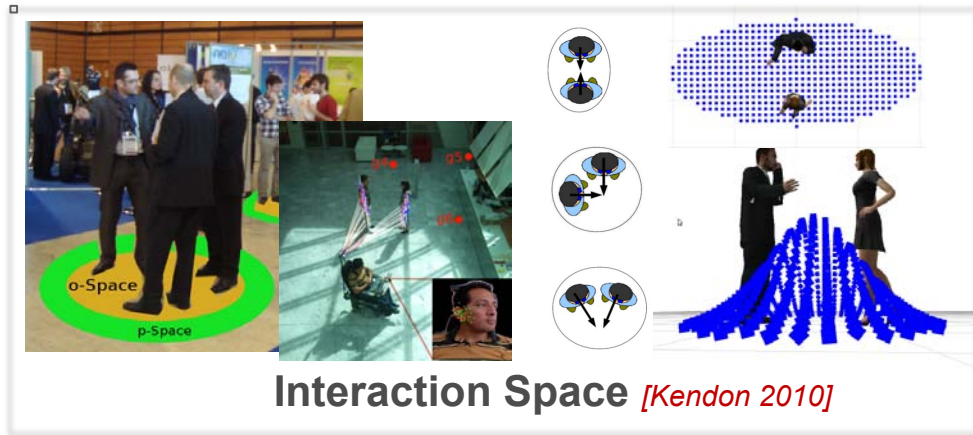
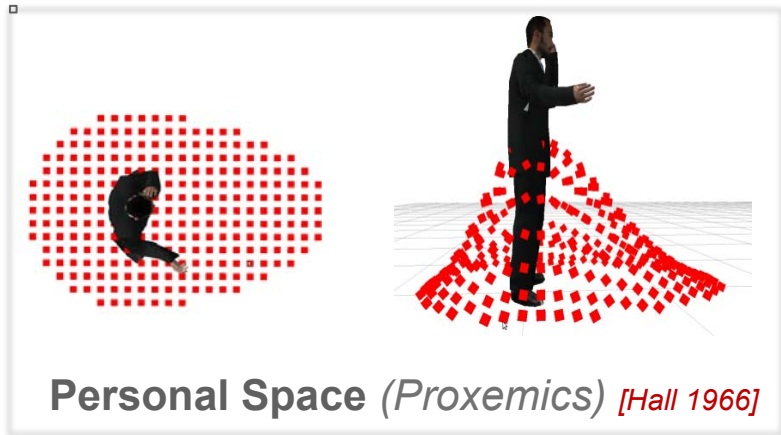
# Paradigm 4: Human Aware Navigation Paradigm

- **Problem:** *Safe & Socially acceptable Robot Motions in Human Environments*
- **Approach:**
  - ✓ **Safety issue:** *Integrating Perception (off board & on board) + Iterative Motion Planning + mid-term Motion Prediction → e.g. Risk-RRT*
  - ✓ **Social & Interaction issue:** *Detecting People Interactions & Executing Socially Acceptable Robot Motions → Social Filter*



# Social Filter: *Basic idea*

- **Approach:** *Representing “Personal Space” & “Interaction Space” as motion constraints for the robot (using Mixture of Gaussians)*



# Social Filter: *Impact of interactions on navigation*

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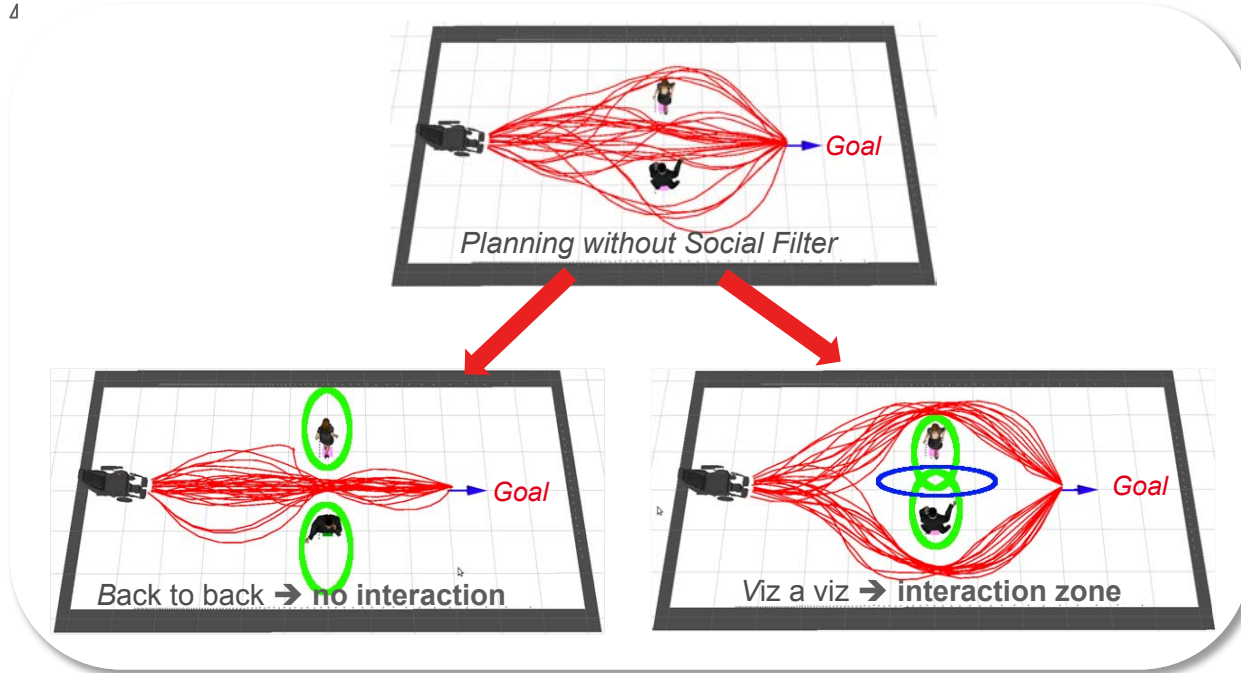
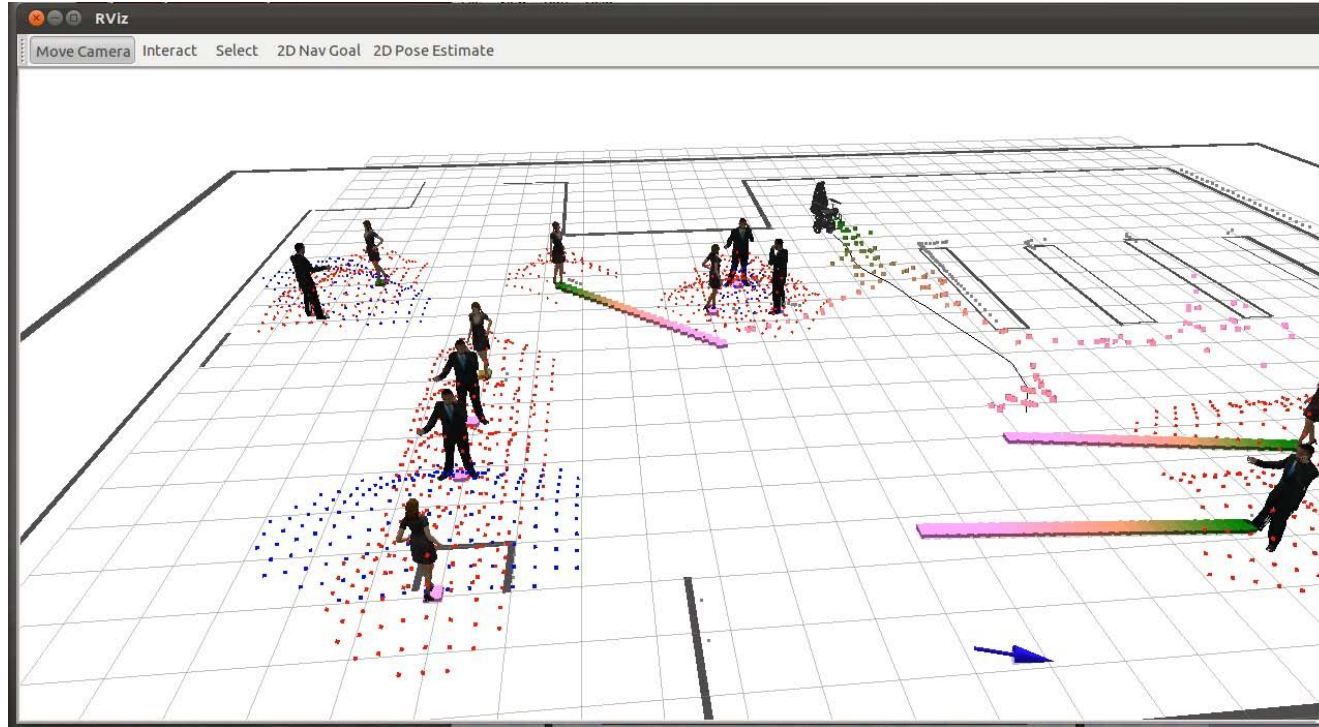


Illustration: *Back to back & Viz a Viz scenarios*

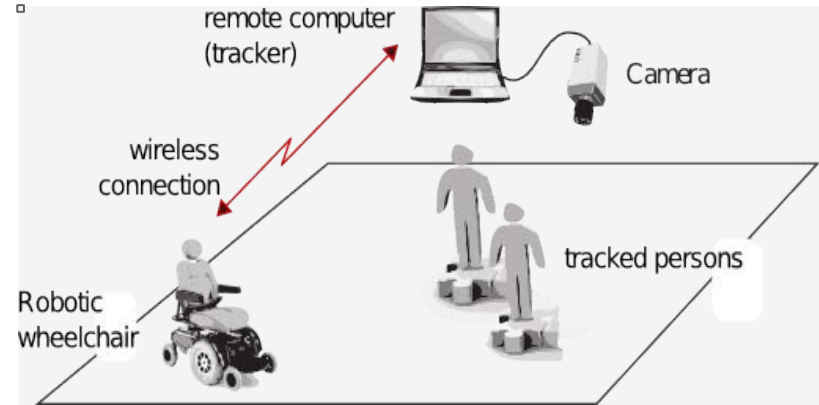
# Social Filter: *Experimental results (simulation)*





# Social Filter: *Experimental validation scenario*

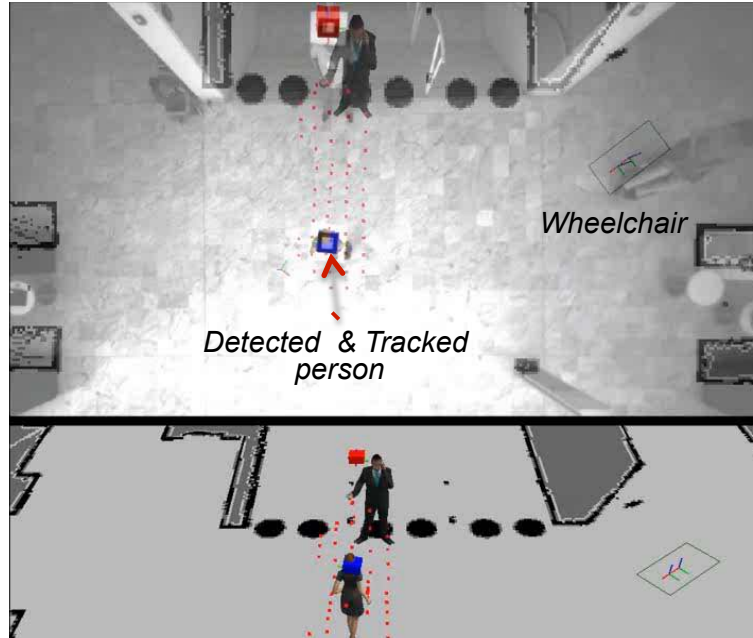
*INRIA's entrance hall + Autonomous Wheelchair*



- Markers to detect human orientation (hats)
- Experiment: Validate Social Filter + Navigation

# Social Filter: *Experimental validation (video)*

*INRIA's entrance hall + Autonomous Wheelchair*



← Camera View (persons + wheelchair)  
+  
Superimposed Wheelchair Navigation

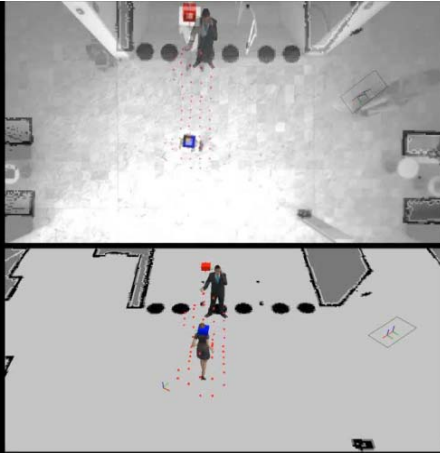
← Augmented Reality  
Interaction & Wheelchair Navigation Simulation

Video content

# Social Filter: *Experimental validation (video)*

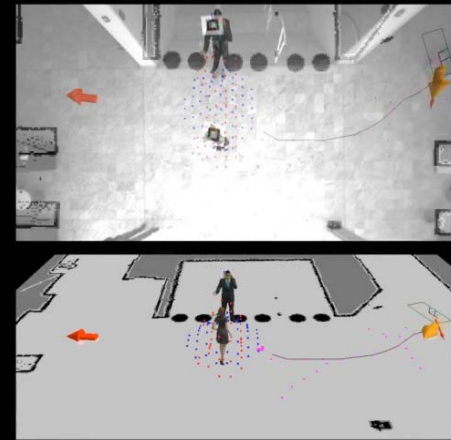
INRIA's entrance hall + Autonomous Wheelchair

***Social Filter ignored***



Camera View  
+  
Superimposed  
Navigation

***Social Filter activated***



Augmented reality  
(Simulation)

# Pictures & Movies

- p.2: © Inria
- p. 4-18: © Inria – E-Motion team