“*e-Motion*” Project-Team

« Geometry and Probability for motion and action »

INRIA Grenoble Rhône-Alpes
&
Laboratory of Informatics of Grenoble (LIG)

Scientific leader : Christian LAUGIER (DR1 INRIA)

http://emotion.inrialpes.fr
christian.laugier@inrialpes.fr

Scientific challenge

- **Overall challenge**

Robots in Human Environments

ITS for improving safety & comfort & efficiency



Personal Assistant & House Keeping & Rehabilitation

- **Main Motivations**

  ✓ Important socio-economic perspectives *=> Transport, Aging society, Medical care & Rehabilitation, Human assistance, Intelligent home …*

  ✓ Increasing interest of industry *=> Automotive industry, Robots, Health sector, Services …*

  ✓ Challenging research topics *=> Dynamic world, Robust perception, Safety, Human Aware Motion, Complex Human-Robot interactions …*

  ✓ *Robotics state-of-the-art* & Progress in *ICT Technologies (computers, sensors, micro-nano technologies, energy …) make this challenge potentially reachable*

Required breakthroughs & Approach

- **Required breakthroughs**
  - ✓ Motion autonomy in Open & Dynamic environments
  - ✓ Safe & Understandable Human-Robot interactions
- **Main difficulties**
  - ✓ *World & Task complexity*
  - ✓ *Reactivity & Real-time constraints*
  - ✓ *Incompleteness & Uncertainty*
  - ✓ *Human in the loop*
- **Scientific approach**
  - ✓ Revisit traditional approaches not fully adapted to the processing of Human environments
  - ✓ Design new models & algorithms for *"Perception & Decision & Action & Interaction"* in *Complex & Highly Dynamic environments populated by Human beings*
  - ✓ Focus on *Robustness & Efficiency & Safety*

Our approach: *Combining Geometrical & Probabilistic approaches*

Outline of the Scientific Project

- **Scientific positioning**
  - ✓ Field of Probabilistic Robotics & Cognitive Systems
  - ✓ Pioneer work on Bayesian Programming & Motion Planning in dynamic environments
- **Research objectives**
  - ✓ Dynamic world Perception & Understanding
  - ✓ Motion planning & Autonomous Navigation in the Real World
  - ✓ Bayesian approach to Cognitive Systems

Main Achievements

✓ Technological transfers with our start-up "Probayes" (ProBT library, BOF software)
Industrial applications in Robotics (Toyota, Denso, Hitachi) and in some other domains such as Finance, Plant maintenance, Video games, or Threat evaluation

✓ Perception & Interpretation of dynamic environments using Sensor Fusion and Bayesian Reasoning. *Application to probabilistic "Risk Assessment" (in particular with Toyota)*

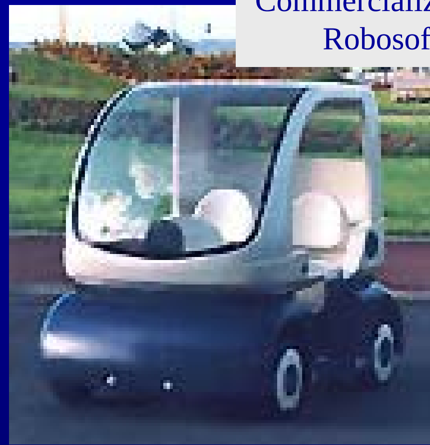
✓ Concepts of PMP & ICS for Motion Planning in Dynamic environments

✓ Bayesian models for some Human SMS *(e.g. perception of shape from motion, colliculus)*

Robotics Experimental Platform

Parkview

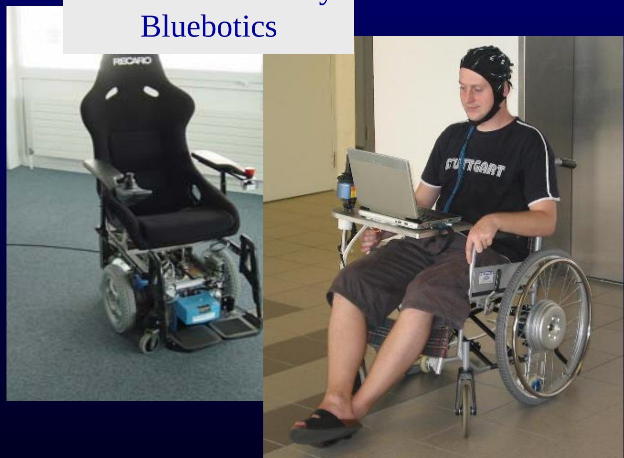
Commercialized by Robosoft



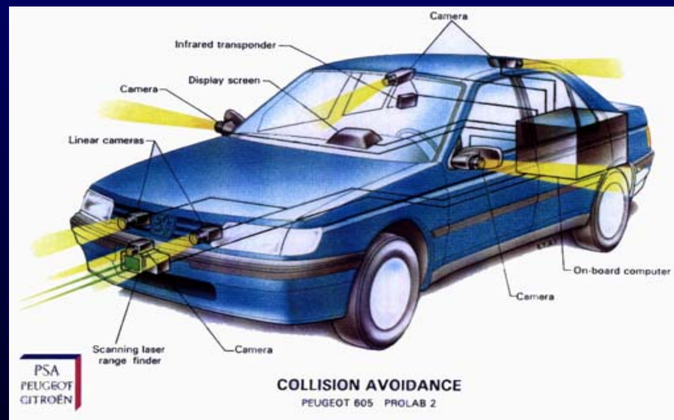
Cycab & Simulator

Koala

Commercialized by Bluebotics



Autonomous Wheelchairs



Industrial Experimental Vehicles
(soon a Toyota Prius vehicle)

Personnel

	Misc.	INRIA	CNRS	University	Total
DR / Professors		1	1		2
CR / Assistant Professor		2		2	4
Permanent Engineer			0.5		0.5
Temporary Engineer		4			4
PhD Students	4	~~6~~ 5		~~1~~ 0	~~11~~ 9
Post-Doc.		1			1
Total	**4**	**14**	**1.5**	**3**	**22.5**
External Collaborators	4		1		5
Visitors (> 1 month)	2	2			4

- **Permanent staff (6.5)**
  - 3 INRIA Researchers: *Christian Laugier (DR1), Thierry Fraichard (CR1), Agostino Martinelli (CR1)*
  - 1 CNRS Researchers: *Pierre Bessiere (DR2)*
  - 2 Associate Professors: *Olivier Aycard (UJF), Anne Spalanzani (UPMF)*
  - 0.5 Permanent Engineer: *Amaury Negre (CNRS, shared with EPI Prima)*
  - **2 Leaving:** *Emmanuel Mazer (CEO Probayes), Sepanta Sekhavat (Iran)*

- **Attractivity evidences**
  - Recruitment of *Agostino Martinelli* in 2006 (Italian, previously Ass. Researcher at EPFL)
  - Average of *2 Visitors & Invited professors* per year (from Spain, Germany, USA, Mexico, Israel, Singapore)

Research Objectives

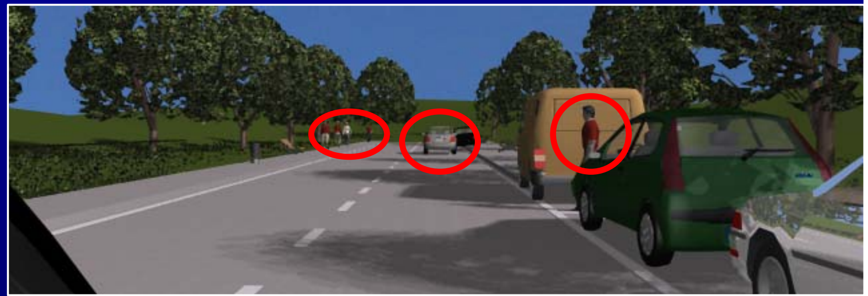
- **Objective 1: Dynamic world Perception & Understanding**
  ~ 50 % activity of e-Motion

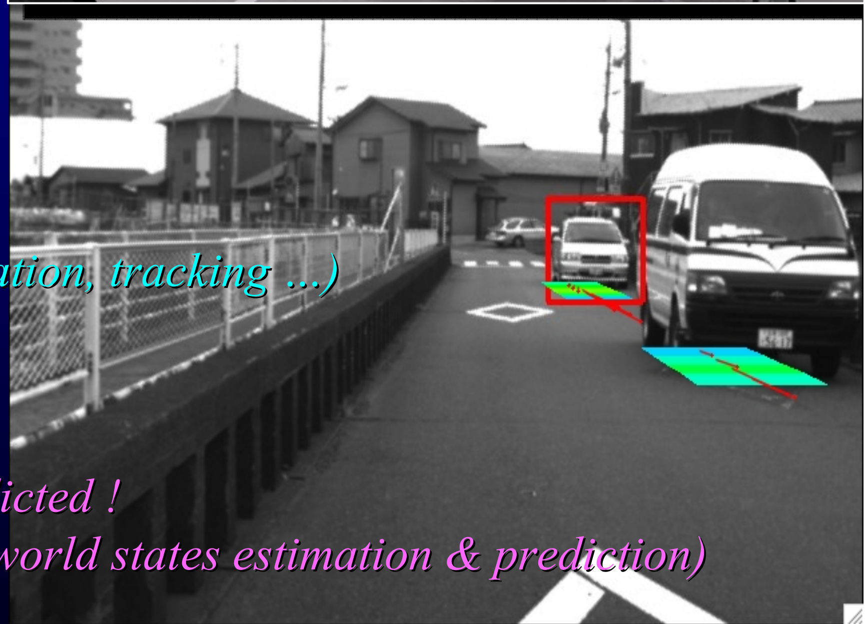
- **Objective 2: Motion planning & Autonomous navigation in the real world**

- **Objective 3: Bayesian approach to Cognitive Systems**

The addressed problem

Moving safely amidst Stationary & Moving obstacles (vehicles, pedestrians …)
in Open & Dynamic environments





- **Continuously changing environment**
  - ✓ *Continuous world modeling using sensors*
  - ✓ *Space & Time have to be considered*
  - ✓ *Real-time processing is required*
- **Sensed Stationary & Moving obstacles**
  - ✓ *SLAM + DATMO*
  - ✓ *Uncertainty is a key issue (perception, localization, tracking …)*
- **Complex partly known environments**
  - ✓ *Most probable world changes have to be predicted !*
  - ✓ *Iterative safe navigation decisions (based on world states estimation & prediction)*

Project-team positioning

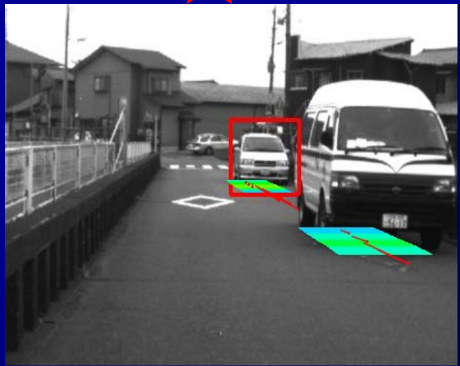
- Considerable research material exists on SLAM, Detection & Tracking, but robustness is still an issue !
- Few contributions on Prediction & Risk assessment
- Focus on Open & Highly Dynamic environments
  => Robustness & Efficiency issues

Three main topics

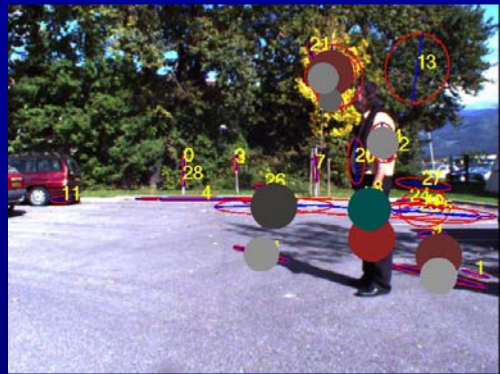
1. Robust Detection & Tracking *=> Sensor Fusion + Grid based approach in space (OG) & Space/Velocity (BOF) + Towards a unique Detection & Tracking process*
2. Localization & Mapping *=> Sensor self-calibration + Multi-modality Localization + Efficient multi-resolution 3D mapping*
3. Prediction & Risk assessment *=> Prediction of the future behavior of the observed entities + Probabilistic Risk assessment*

Main Topics & Achievements

6 PhD, 1 Book, 15 journal papers



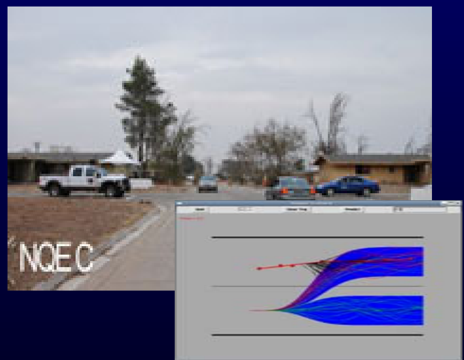
Robust Detection & Tracking
[Burlet 07][Coue 05]
(coop. Denso, Toyota, Daimler)



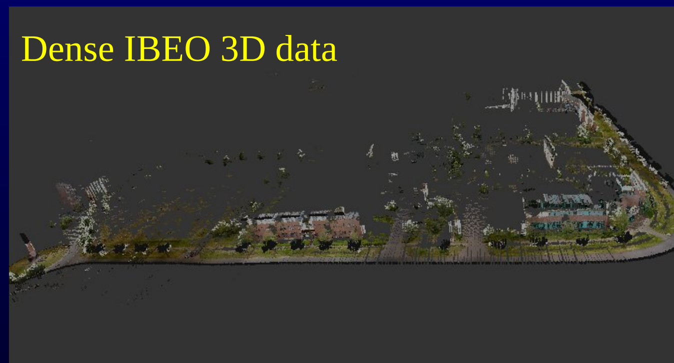
Vision based Detection & TTC
[Braillon 08][Negre 09]
(Coop. Prima)

Simultaneous calibration of Odometry & Bearing sensor
[Martinelli 08]
(Coop. ETH Zurich)

World change prediction
[Vasquez 07]
(coop. ETH Zurich)



Risk assessment using GP
[Tay PhD Thesis]
(coop. Toyota)

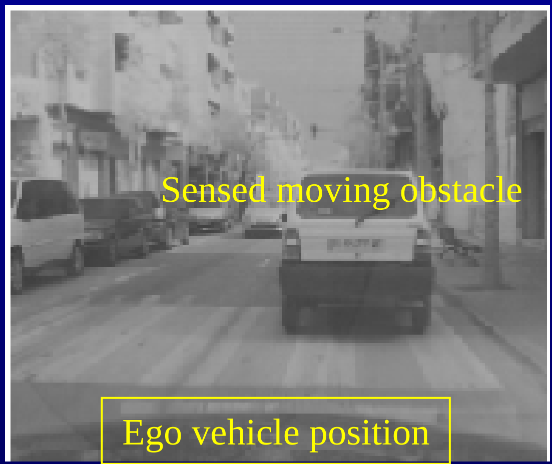


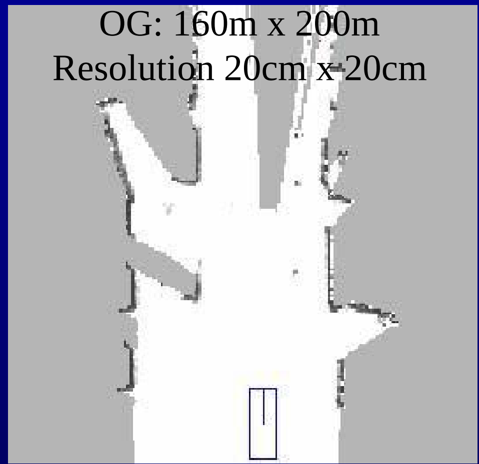
Efficient 3D Multi-resolution Mapping using "Tensor maps"
[Yguel PhD Thesis]
(coop. Perception, Ibeo)

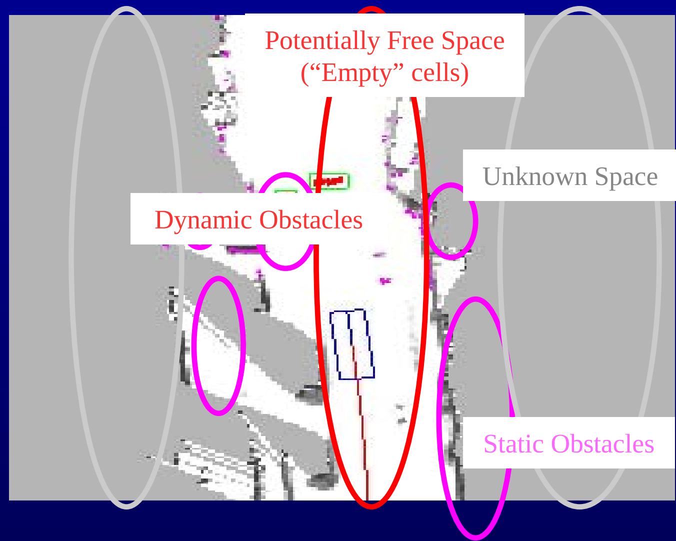
Laser based Multi-Objects Detection & Tracking

"PreVent" EU project *[Burlet, Vu, Aycard 07-08]*

• Grid-based Obstacles Detection

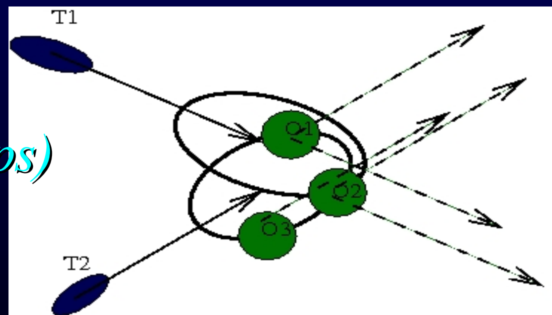






• Multi-Objects Tracking

- ✓ *Mapping & localization: Scan matching*
- ✓ *Data Association: Multiple Hypotheses (for n time steps)*
- ✓ *Filtering : Interacting Multiple Models*



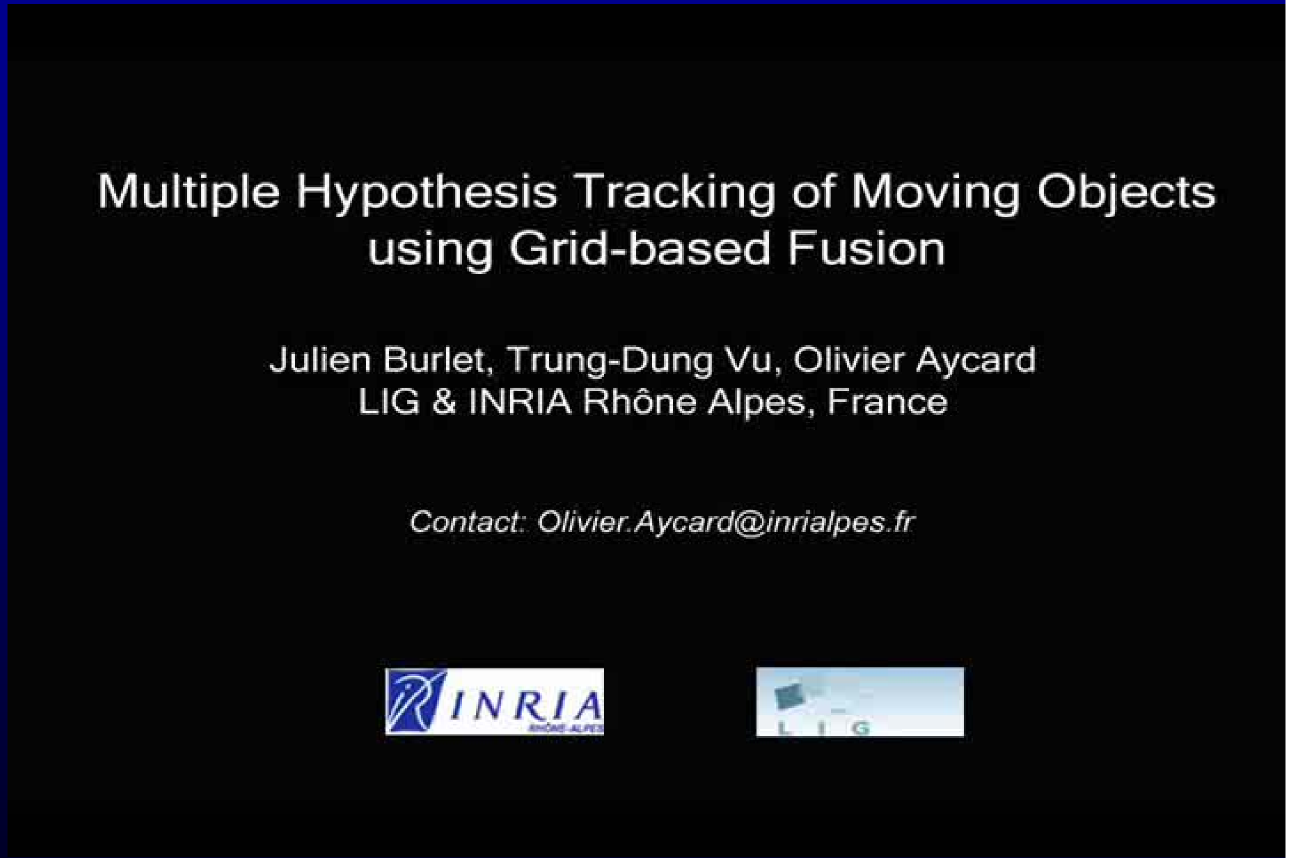
Inspired from [Blakman 98] (radar) & [Wang 04] (laser + ICP)

Experimental validation

"PreVent" EU project, Versailles demo 2007 (Daimler-Chrysler & Ibeo test vehicle)

Mercedes E-Class 350

Computational time ~ 10 ms



Application:

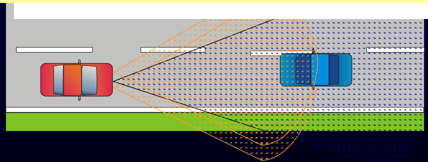
- **Pre-fire & Braking**

Sensors:

- Two short range radars
- A laser scanner ALASCA

Actuators:

- Electrical belt pre-tensioning
- Automatic braking



Also tested on a truck Volvo / Ibeo

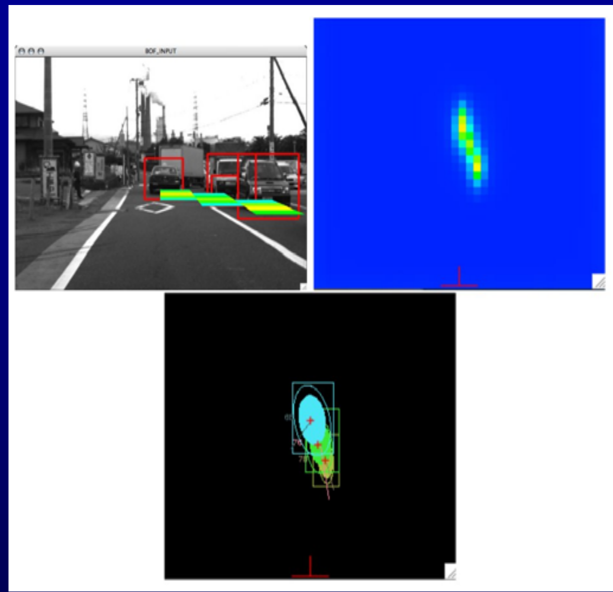
Currently under testing on a Wolkswagen / Ibeo demonstrator

Bayesian Sensor Fusion for “Dynamic Perception”

“Bayesian Occupation Filter paradigm (BOF)”

Patented by INRIA & Probayes, Commercialized by Probayes

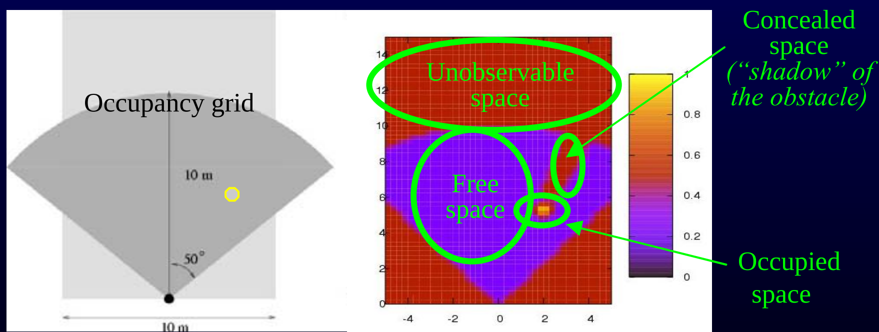
[Coué & al IJRR 05]



BOF

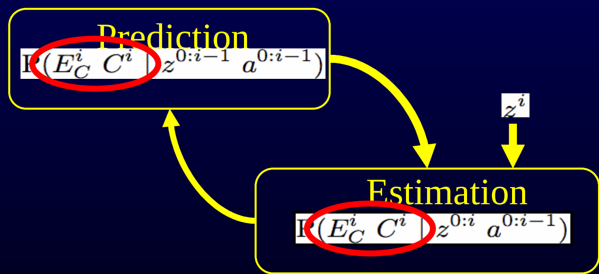
- Continuous Dynamic environment modelling
- *Grid* approach based on *Bayesian Filtering*
- Estimates *Probability of Occupation & Velocity* of each cell in a 4D-grid
- Application to *Obstacle Detection & Tracking + Dynamic Scene Interpretation*

=> More robust Sensing & Tracking + More robust to Temporary Occultation



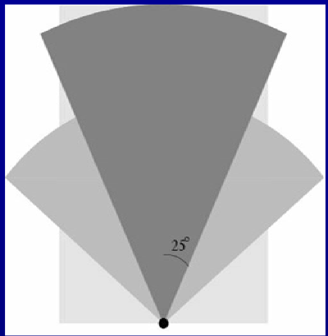
Sensed moving obstacle

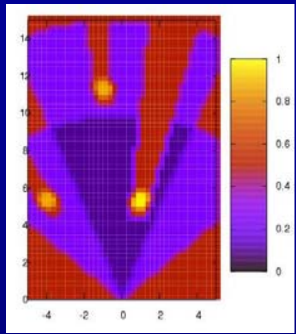
P($[O_c = occ]$ | z c)
$c = [x, y, 0, 0]$ and z=(5, 2, 0, 0)



Robustness to Temporary Occultation

Tracking + Conservative anticipation *[Coué & al IJRR 05]*





Description

Specification

- Variables :
  - V^k, V^{k-1} : controlled velocities
  - $Z^{0:k}$: sensor observations
  - G^k : occupancy grid
- $P(Z^{0:k}\ V^k\ V^{k-1}\ G^k) = \left(\begin{array}{l} P(Z^{0:k})P(V^{k-1}) \\ P(G^k \mid Z^{0:k})P(V^k \mid V^{k-1}\ G^k) \end{array} \right)$
- Parametric forms :
  - $P(G^k \mid Z^{0:k})$: BOF estimation
  - $P(V^k \mid V^{k-1}\ G^k)$: Given or learned

Question

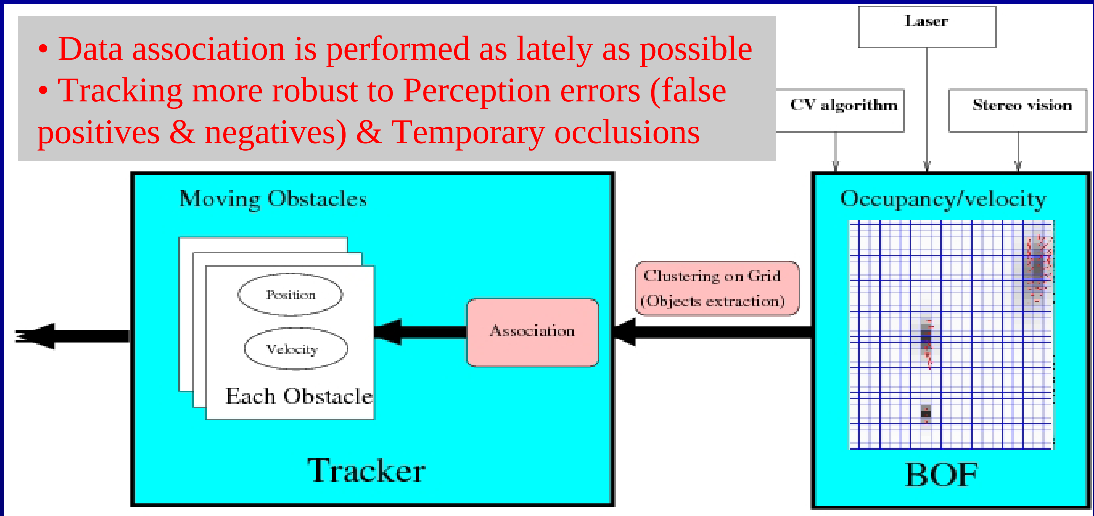
Inference

$P(V^k \mid z^{0:k}\ v^{k-1})$

Thanks to the prediction capability of the BOF, the Autonomous Vehicle "anticipates" the behavior of the pedestrian and brakes (even if the pedestrian is temporarily hidden by the parked vehicle)

Application to Robust Detection & Tracking

- Data association is performed as lately as possible
- Tracking more robust to Perception errors (false positives & negatives) & Temporary occlusions



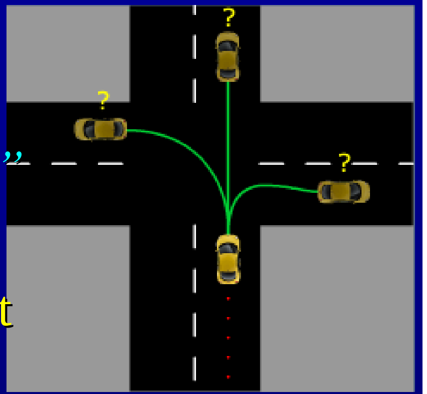
Successfully tested in real traffic conditions

- TOYOTA
- DENSO Lidar
- Current tests with IBEO Lidar

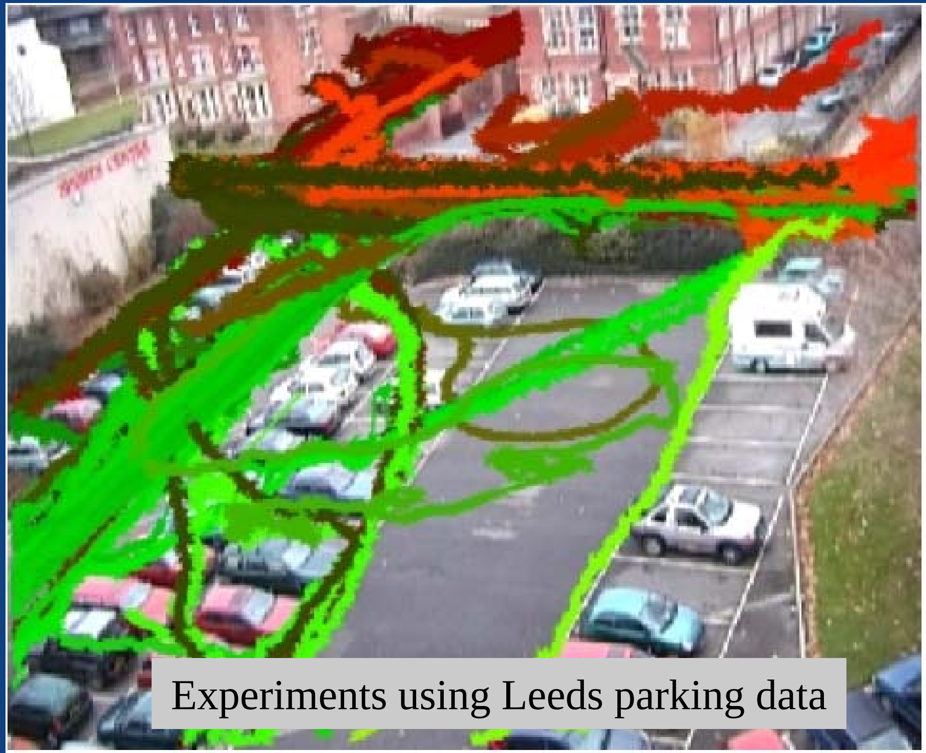
World changes Prediction

[Vasquez & al 05, 06, 07, 08]

- Risk assessment requires to both *Estimate the current world state* & *Predict the most likely evolution of the dynamic environment*
- Objects motions are driven by *"Intentions"* and *"Dynamic Behaviors"* *=> Goal + Motion model*
- Goal & Motion models are not known nor directly observable …. But *"Typical Behaviors & Motion Patterns"* can be learned through observations



Our Approach :
Continuous "Learn & Predict" using GHMM & Topological maps (SON)

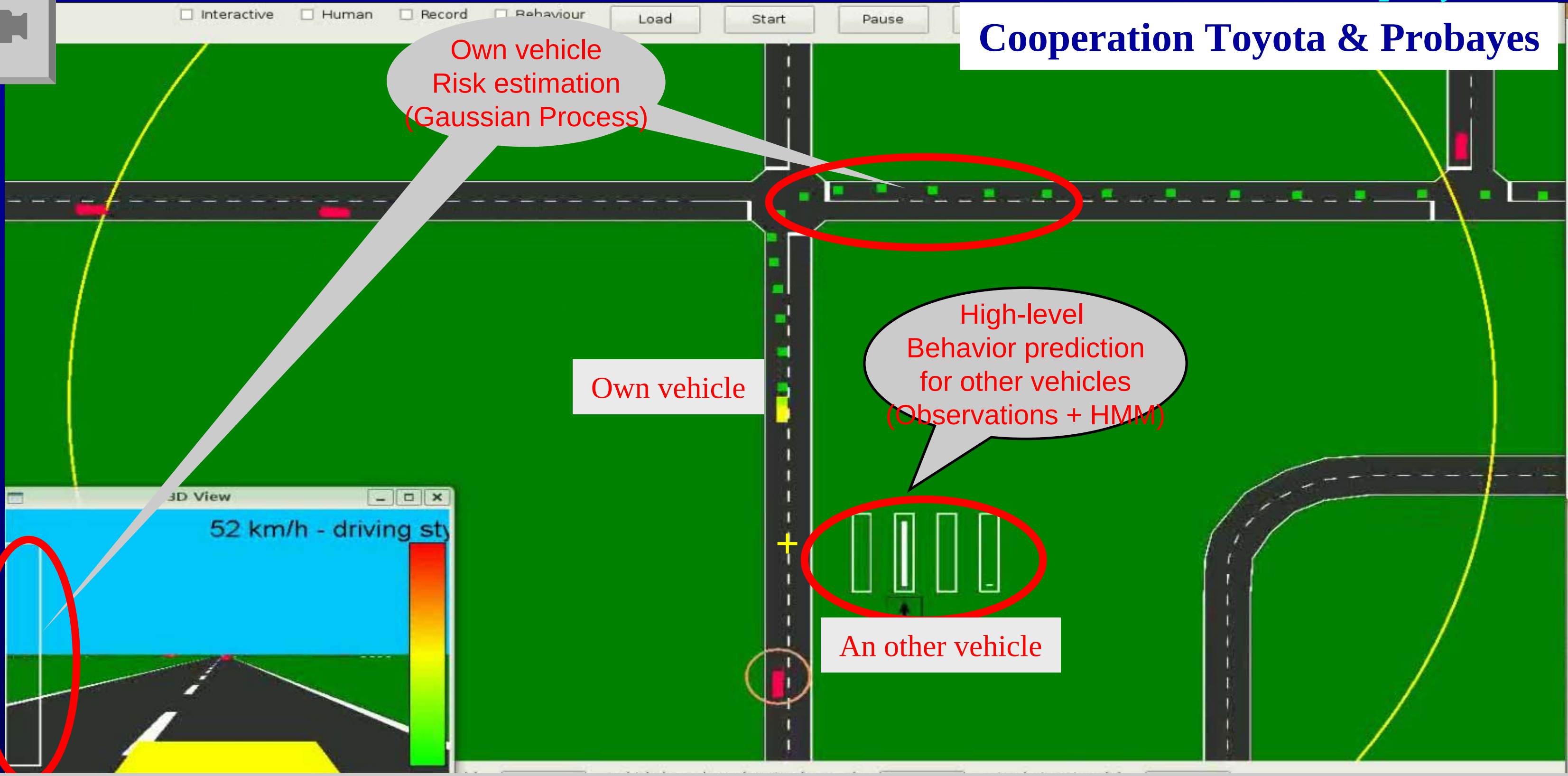


Experiments using Leeds parking data

Risk assessment for next few seconds

[Tay Thesis 09]

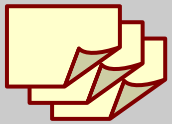
Cooperation Toyota & Probayes



Behavior Prediction (HMM)

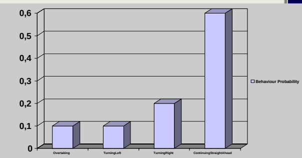
Observations

+



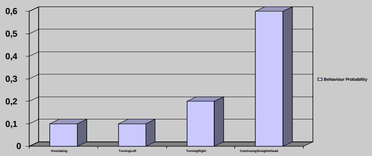
Behavior models

Prediction



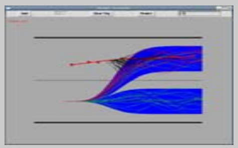
Behavior belief table

Risk Assessment (GP)



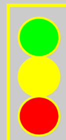
Behavior belief table for each vehicle in the scene

+



Road geometry (GIS) + Own vehicle trajectory to evaluate

Evaluation



Collision probability for own vehicle

Research Objectives

- **Objective 1: Dynamic world Perception & Understanding**
- **Objective 2: Motion planning & Autonomous navigation in the real world**
  ~25% activity of e-Motion
- **Objective 3: Bayesian approach to Cognitive Systems**

Problem statement

Objective:
Goal oriented & Safe navigation in open & highly dynamic environments

New constraints:

- ✓ *Upper-bounded decision time*
- ✓ *System's dynamics*
- ✓ *Moving Objects' future behavior*
- ✓ *Look-ahead*
- ✓ *Uncertainty*

Positioning:

- ✓ *Few contributions in the literature*
- ✓ *Taking into account all the new constraints coming from Open & Dynamic environments*
- ✓ *A new framework based on iterative safe motion decisions*
- ✓ *Focus on motion Safety*

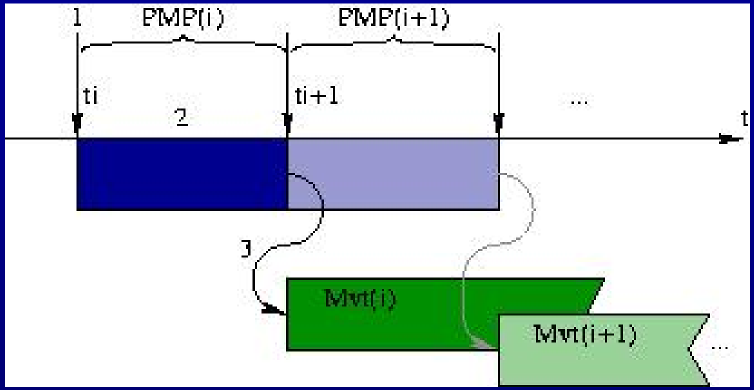
A new framework for MP in Dynamic environments

1 HDR, 1 PhD, 4 Journal papers *[Fraichard 04] [Petti 06] [Martinez 08]*

• Partial Motion Planning *(PMP)*

Repeat until goal is reached

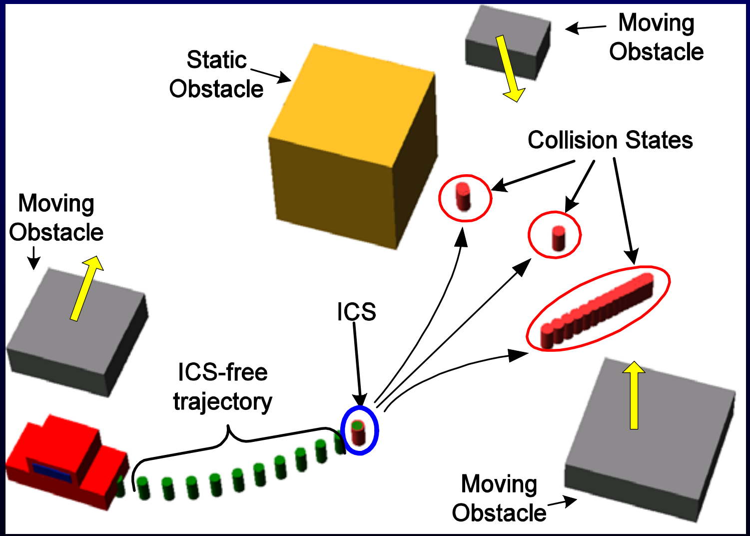
1. Get model of the future *(observation & prediction)*
2. Built tree of partial motions towards the goal
3. When time δ_c is over, Return *" best partial motion " (e.g. closest & safest)*



• Inevitable Collision States *(ICS)*

⇒ Avoiding instantaneous collision is not enough !
We also have to avoid states leading to "Inevitable Collisions" in the near future
⇒ Doing nothing may also be dangerous !

Key requirement:
Model of the future (cf. Objective #1)

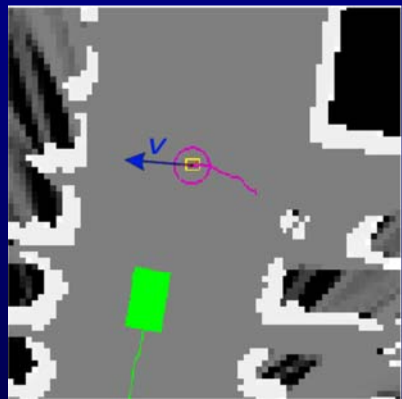


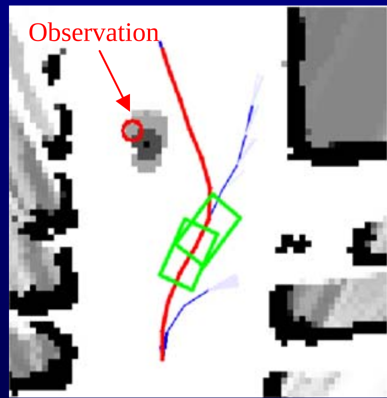
Integrating Probabilistic Uncertainty in PMP

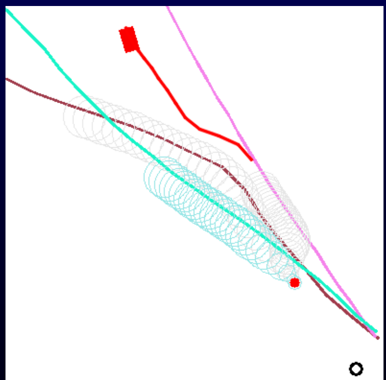
[Fulgenzi 07, 09]

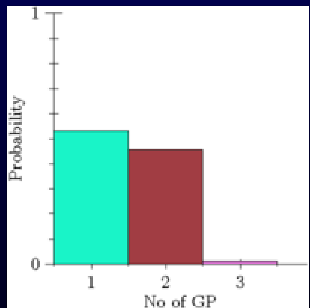
Motion Planning combined with Risk assessment

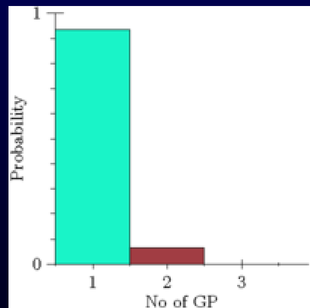
- Detection & Tracking of obstacles
- Risk assessment based on behaviors prediction *(HMM & Gaussian Process)*
- RRT search *(previously explored states are updated on-line with new observations)*

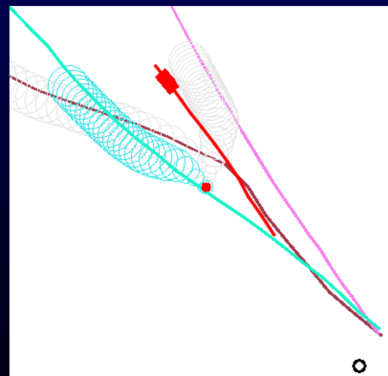












Research Objectives

- **Objective 1: Dynamic world Perception & Understanding**
- **Objective 2: Motion planning & Autonomous navigation in the real world**
- **Objective 3: Bayesian approach to Cognitive Systems**
  ~25% activity of e-Motion

Positioning

- **Basic assumption**
  - ✓ *Probability is an alternative to logic to reason with incomplete & uncertain knowledge*
  - ✓ *Probability is an emerging cognitive paradigm for "perception, action, decision and learning"*
  - ✓ *This framework can be used for modeling both Natural & Artificial systems*

- **Research topics & Achievements**
  - ✓ *Formalization of Bayesian Probability => Bayesian Programming [Bessiere 97]*
  - ✓ *Automatization of probabilistic inference & Development of industrial applications => ProBT inference engine (commercialized by ProBayes SAS)*
  - ✓ *Bayesian robot programming*
  - ✓ *Bayesian modeling of living systems*

- **Working context**
  - ✓ *Probayes SAS*
  - ✓ *European projects BIBA & BACS*
  - ✓ *Strong cooperation with LLPA Collège de France (A. Berthoz & J. Droulez)*

Main Topics & Achievements

6 PhD, 1 Book, 9 journal papers (Robotics & Neurosciences)

Robots

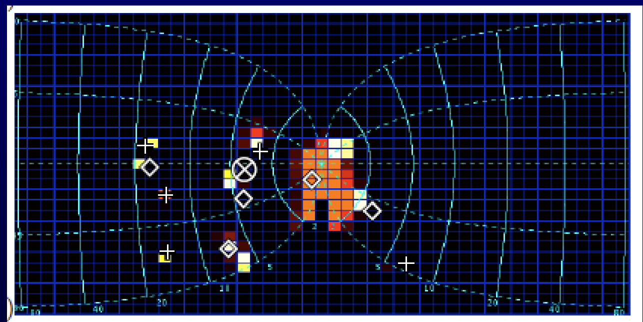
Action selection & Attention focusing
[Koike 06]

Bayesian learning
[LeHy 07] [Dangauthier 08]

Brain controlled wheelchair [Rebsamen 09]
(coop. NUS Singapore)

Living systems

Human Perception of Shape from Motion
[Colas 06] (coop. LPPA)



Bayesian models of Superior Colliculus
[Colas et al. 09] (coop. LPPA)

Sensory-motor systems & Handwriting
[E. Gillet PhD Thesis] (coop. LPN)

Human perception of shape from motion *[Colas 06]*

- **Problem addressed**
  - **Inverse problem** => *The geometry produces the stimulus*
  - **Ambiguous** => *Same optical flow for different physical situations*
  - **Uncertain** => *Ocular defaults*
  - **Brain interpretation** => *Relies on prior hypotheses (e.g. convexity, rigidity …)*

- **Bayesian model for the perception of moving planes** *(coop. J. Droulez LPPA)*

Programme / Description / Spécification

Variables Pertinentes

$X, \Upsilon, V_x, V_z, R_y, \Lambda, \vec{T}, \vec{\Omega}, \vec{\Phi}^0, \vec{\Phi}^1$ et $\vec{\Phi}^2$

Décomposition

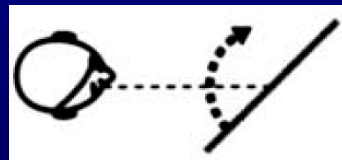
$$\begin{aligned} &P(X\ \Upsilon\ V_x\ V_z\ R_y\ \Lambda\ \vec{T}\ \vec{\Omega}\ \vec{\Phi}^0\ \vec{\Phi}^1\ \vec{\Phi}^2) \\ &= P(X\ \Upsilon) P(V_x\ V_z\ R_y) P(\Lambda) \\ &\times P(\vec{T}\ \vec{\Omega} \mid V_x\ V_z\ R_y) \\ &\times P(\vec{\Phi}^0 \mid T_x\ T_y) \\ &\times P(\vec{\Phi}^1 \mid X\ \Upsilon\ \vec{T}\ \vec{\Omega}) \\ &\times P(\vec{\Phi}^2 \mid X\ \Upsilon\ \vec{T}\ \vec{\Omega}\ \Lambda) \end{aligned}$$

Formes Paramétriques

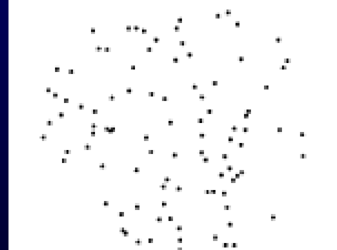
$P(X\ \Upsilon)$: uniforme en coordonnées sphériques ;
$P(V_x\ V_z\ R_y)$, $P(\Lambda)$: non spécifié ;
$P(\vec{\Omega}\ \vec{T} \mid V_x\ V_z\ R_y)$: gaussienne centrée autour de l'opposé du mouvement propre ;
$P(\vec{\Phi}^0 \mid T_x\ T_y)$: gaussienne centrée sur le flux théorique ;
$P(\vec{\Phi}^1 \mid X\ \Upsilon\ \vec{\Omega}\ \vec{T})$: *idem*;
$P(\vec{\Phi}^2 \mid X\ \Upsilon\ \vec{\Omega}\ \vec{T}\ \Lambda)$: gaussienne dont la covariance dépend de la taille du champ λ.

Identification :
Aucune.

Question :
$P(X\ \Upsilon \mid \vec{\phi}^0\ \vec{\phi}^1\ \vec{\phi}^2\ v_x\ v_z\ r_y\ \lambda)$



Fixed or moving observer



Moving visual points

The same Bayesian model has produced identical perception results than 5 psychophysics experiments (for the perception of planes & motions)

Objectives for the next four years (1)

- Continuing to work on the three current research themes of e-Motion

- Improving our key technologies, with the objective to transfer some of them to the automotive industry. *Context : ADT ArosDyn & Toyota & Probayes*

- Experimental tests in real traffic conditions *=> Toyota Prius experimental vehicle*

- More integration between objectives 1 & 2 & 3. *Context: AEN -INRIA "Personally Assisted Living"*

- More emphasis in objective 3 on the study of living systems *=> Cooperation with our neurophysiologist partners*

Toyota Prius (future experimental vehicle)

Autonomous Wheelchair

Objectives for the next four years (2)

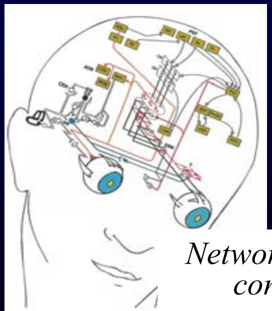
- **Objective 1 : Dynamic world Perception & Understanding**
  - ✓ Improved grid-based Bayesian filtering *=> Models + GPU + SOC with CEA*
  - ✓ Robust Detection & Tracking *=> Specialized fusion based Detectors + Better integration of Detection & Tracking (using classification & models)*
  - ✓ Accurate and Efficient Localization & Mapping *=> Efficient 3D multi-resolution models & Hybrid maps*
  - ✓ Risk assessment *=> Generalization to more complex traffic scenes + Learning behaviors + Integration with MP (objective 2)*

Preliminary results using Data-Driven MCMC for Spatial-Temporal search [Vu 09]

Objectives for the next four years (3)

- **Objective 2 : Motion Planning & Autonomous Navigation in Real World**
  - ✓ Probabilistic ICS => *Taking into account uncertainty*
  - ✓ Coupling PMP & ICS => *Focus on safety guarantees*
  - ✓ Coupling PMP & Risk assessment => *Real sensor & GIS data + Risk factor in PMP*

- **Objective 3 : Bayesian approach to Cognitive Systems**
  - ✓ Bayesian robot programming => *Focus on modeling & learning sensory-motor skills*
  - ✓ More emphasis on Bayesian modeling of Living systems => *Behavioral level & Central nervous system (new prospective issue)*



Network of physiological structures contributing to saccadic eye movements [Berthoz 97]

Cooperation

- **Cooperation inside INRIA**
  - Robotics: *Imara (common PhD students), Lagadic, Arobas, more recently Coprin*
  - Other domains: *Prima (common PhD students), Perception, more recently Galaad*
  - Future AEN "Personally Assisted Living"

- **International cooperation**
  - *Large participation to European projects (NOE, IP, Streps)*
  - *Formal cooperation agreements (Singapore, Mexico)*
  - *Coordinator ICT-Asia NOE on ITS (Singapore, Korea, China, Japan, France)*

- **Industrial cooperation**
  - *4 Start-up (ITMI, Getris Image, Aleph Technologies, Probayes)*
  - *Long-term industrial collaborations with Probayes, Toyota, Denso*

Knowledge dissemination

- **Software**
  - ✓ *ProBT & BOF (patented), Robot simulator, ColDetect, Markov models toolbox*
- **Valorization**
  - ✓ *Start-up Probayes & Several common R&D projects (Toyota, Denso, Hitachi …)*
  - ✓ *ProBT inference engine & BOF => Used in several industrial applications (Car safety, Finance, Plant maintenance, Video games, Threat evaluation)*
- **Teaching**
  - ✓ *Engineer schools, Master, International Tutorials, Summer schools (SSIR)*
- **Visibility**
  - ✓ *General chair & Program chair of some major international conference (IROS'97, IROS'00, IROS'02, IROS'08, FSR'07, IV'06)*
  - ✓ *Organization of focuses workshops + Publications of Books & Journal special issues (STAR, IJRR, JFR, IEEE ITS, IJVAS)*
  - ✓ *Invited talks & Keynotes (SRG'04 Singapore, ICARCV'08, FSR'09, ISRR'07 …)*
  - ✓ *Steering committees (IROS, IEEE TC on ITS), Editorial boards (IEEE TRO, IEEE ITS, RIA …), NOE coordination (ICT-Asia)*

Publications

	year1	year2	year3	year4
PhD Thesis	4	2	4	4
H.D.R (*)		1		
Journal	5	2	7	9
Conference proceedings (**)	14	27	22	22
Book chapter				
Book (written)				1
Book (edited)			1	4
Patent		2		
Technical report	7	13	4	2
Deliverable				

(*) HDR Habilitation à diriger des Recherches
(**) Conference with a program committee
+ 9 invited talks

Remark: The four first journals of the list are considered as journals of rank A by the GDR Robotique.

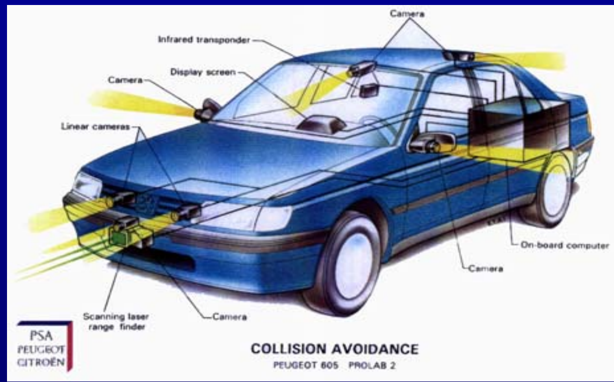
1. International Journal of Robotics Research (IJRR, IF=1.318) (1)
2. IEEE Transactions on Robotics (IEEE TR0, IF=1.976) (1)
3. IEEE Transactions on Intelligent Transportation Systems (IEEE ITS, IF=1.689) (1)
4. Autonomous Robots (IF=1.413) (3)
5. Field Robotics (IF=0.960) (1)
6. Robotics and Autonomous Systems (RAS, IF=0.633) (3)
7. Advanced Robotics (IF=0.504) (4)

Remark: The five first conferences of the list are considered as conferences of rank A by the GDR Robotique.

1. IEEE International Conference on Robotics and Automation (ICRA, 42%) (18)
2. IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS, 47%) (20)
3. International Symposium of Robotics Research (ISRR) (2)
4. IEEE International Symposium on Intelligent Vehicle (IV, 29% + posters) (10)
5. Robotics Science and Systems (RSS, 25%) (1)
6. International Symposium of Experimental Robotics (ISER) (4)
7. International Conference on Field and Service Robotics (FSR, 44%) (8)
8. IEEE International Conference on Intelligent Transportation Systems (ITS, 57%) (4)

Other journals: *Biological Cybernetics, Machine Vision & Applications, Medical Image Analysis, RIA, Autonomous Vehicles …*

Other conferences: *NIPS, World congress of Psychophysiology, CogSys, SYROCO, ICCV, ICARCV, RFIA, European Robotics Symposium, …*



Thank You !
Any questions ?

http://emotion.inrialpes.fr/laugier
christian.laugier@inrialpes.fr