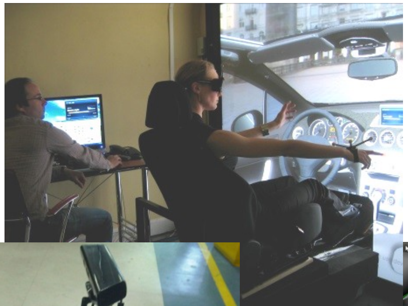
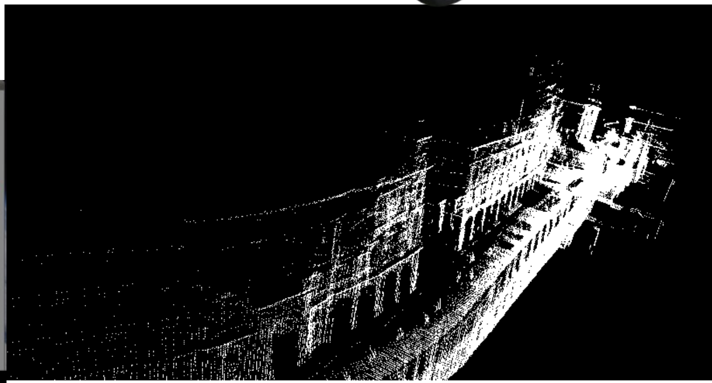
# Intelligence artificielle & véhicule autonome

Prof. Arnaud de La Fortelle









# Baseline

- Autonomous driving is arriving
  - First elements are being deployed
  - Large scale deployment is highly disruptive
  - But pace is slower than announced

- To better understand the challenges
  - We need a clearer of picture: research but not only
  - Autonomous cars are robots:
    robotics, AI, Big data, smart cities...
  - Governance? Stakeholders?

- Technology is a tool!

# Outline

- Presentation of some challenges
- MINES ParisTech's Center for Robotics
- A (partial) scientific picture
- Autonomous driving & Society

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# Some challenges

- Autonomous driving will kill insurance

- Said another way:
  - Safety: There will be no more crashes
  - Ownership: Car will be operated
  - Who pays what?

# Some challenges

- Artificial Intelligence will kill jobs

- Said another way:
  - AI will tell customers their needs
  - More accurate than human (?)
  - This is true in all sectors

# Some challenges

- Robots will supplant humanity

- Said another way:
  - Ethics: can robots kill people?
    - The famous trolley problem
  - Technically: can we control robots?
  - Singularity, transhumanism...

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# About MINES ParisTech

- MINES ParisTech
  - One of the top scientific university in France
  - Small, but 2 Nobel prizes
  - Deep links with the industry

- Center for Robotics
  - 15 professors, 50 persons
  - Theoretical and experimental approach
  - Investing a lot in platforms (~200 k€/year)
  - Tight links with the industry

- Good ground for industry-academy collaboration

# Center for Robotics

- 3 axes: teaching, science, innovation
- Scientific themes :
  - Control
  - Virtual reality and interactions
  - Logistics
  - 3D modeling of the environment (mobile mapping)
  - Mobile robotics and software tools
  - Perception & Machine learning

# A few examples

- Corebot mobile robot:
- twice French competition winner
- Technology transfer:
    - Mobile robotics
    - SLAM
    - Communication


# The Chair *Drive for All*

- An international research Chair
  - Sponsors: PSA, Safran & Valeo
  - Partners: Berkeley, EPFL, Shanghai Jiao Tong
  - Coordinator: MINES ParisTech – Prof. Arnaud de La Fortelle

- Objectives:
  - Understand necessary techniques for future autonomous driving
  - Identify best way to integrate into vehicles
  - Validate the techniques by experimenting with vehicles in Europe, America and Asia

- Facts
  - 3.7 M€ budget
  - 3 autonomous cars
  - 5 years: 2014-2019
  - A dozen of PhDs

# Sponsors

« Cette chaire s'inscrit pleinement dans la stratégie d'innovation de Valeo dont la conduite intuitive est un des axes majeurs. Cette collaboration entre industriels et partenaires universitaires d'excellence va permettre un développement accéléré de la conduite autonome et connectée. » **Jacques Aschenbroich, Directeur Général du groupe Valeo**

«Ce partenariat entre PSA Peugeot Citroën, MINES ParisTech, Valeo et Safran, offrira des conditions exceptionnelles de recherche pour faire avancer les connaissances sur la conduite automatisée à un niveau mondial. Par son soutien à cette chaire, PSA Peugeot Citroën réaffirme son ambition de développer des véhicules autonomes en phase avec les usages de demain » **Gilles Le Borgne, Directeur de la Recherche et Développement PSA Peugeot Citroën**

« Safran croit en la fécondation croisée des technologies de l'aéronautique et de l'automobile. Les systèmes de conduite automatisée des véhicules terrestres de l'avenir et le vol non piloté d'aéronefs dans des espaces civils partagent des problématiques communes et verront leur développement accéléré par les travaux de la chaire » **Jean-Paul Herteman, Président-directeur général de Safran**

# Academic partners

# Cooperation rules

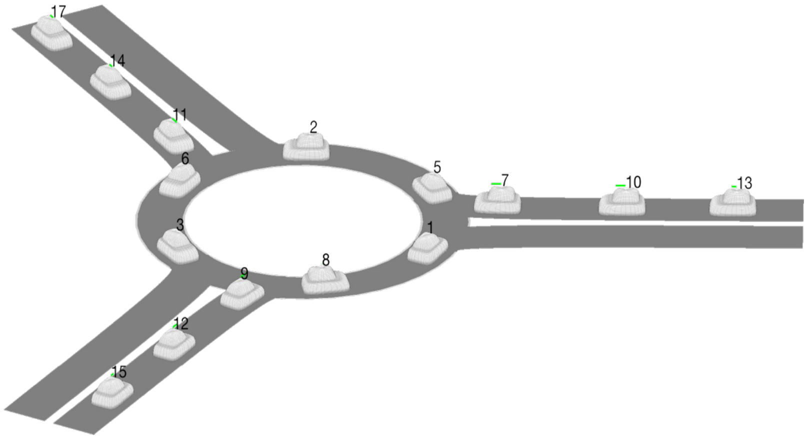
- The Chair activity is public
  - A requirement due to sponsorship
- Sponsors participate
  - They can only orient the research (*not order*)
- Academics are free
  - But are motivated to collaborate

# Some example of the research

- Cooperative planning
  - Do I decide (autonomy)?
  - Do the other decide (cooperation)?
  - How to combine individual and collective?

- What information is necessary to cooperation?
  - How to disseminate it?

# Research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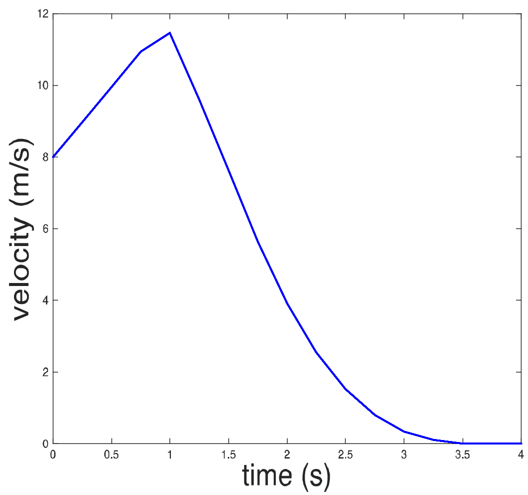
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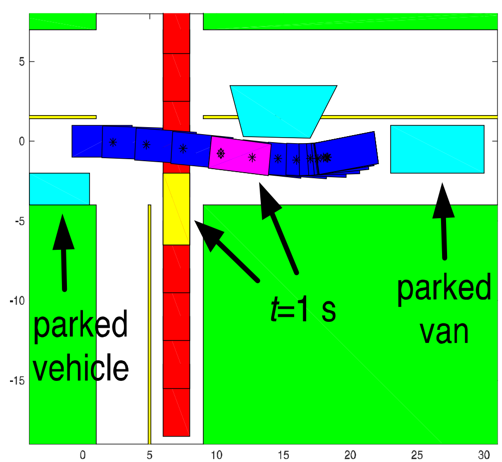
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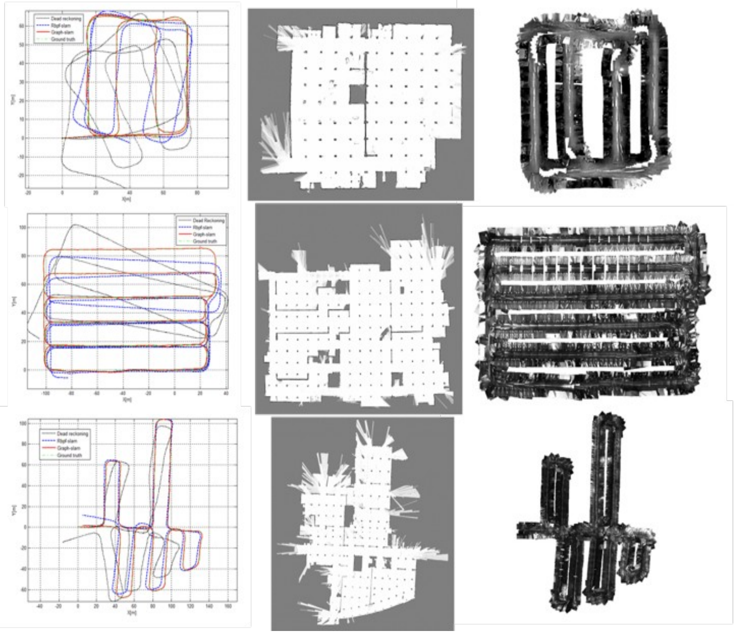
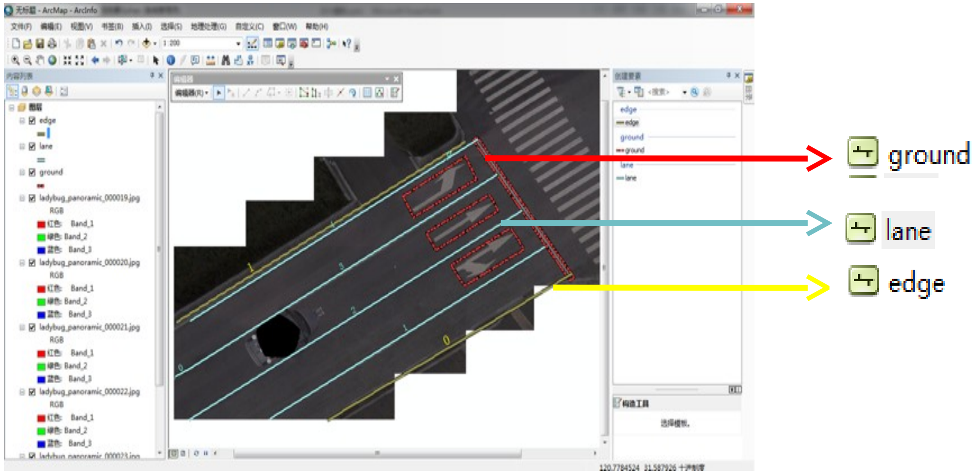
# Research






# Added value

- Sponsors:
  - Have direct contact to top research teams
  - Can attract talents (PhD…)
  - A dialog that sustains their own research

- Academics:
  - Experiment with the support of industry
  - Big potential to transfer technology
  - Challenge of others' vision

# A bientôt sur la route !

# Outline

- Presentation of some challenges
- MINES ParisTech's Center for Robotics
- A (partial) scientific picture
- Autonomous driving & Society

# Facts

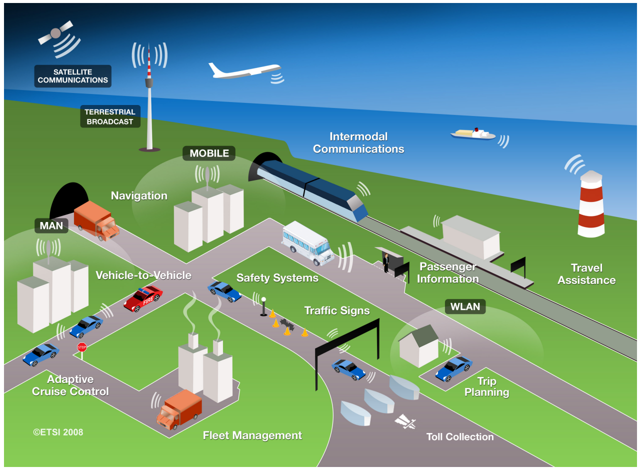
- Car is useful
- We can do better

# What to do better?

- Driving itself
  - ADAS, up to autonomous driving
- Traffic management
  - Static: road construction
  - Dynamic: traffic lights, re-routing, etc.
- Mobility
  - People
  - Goods (logistics)

# Autonomous & cooperative?

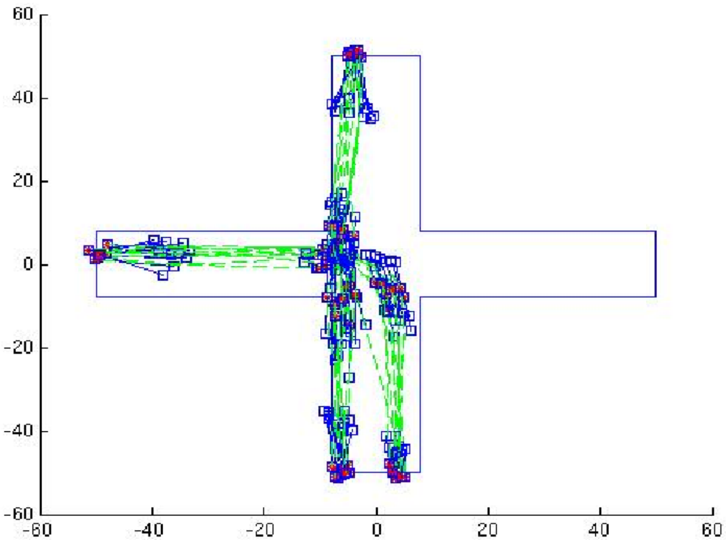
- Paradox:
  - Autonomous = independent
  - Cooperative = dependent
- Question of vision (criteria)




| Criteria that l | | |
|---|---|---|
| Safety | | |
| Planning | | |
| Centralized | | |
| | | |
| | | |

# Planning

- Planning in robotics
  - Applied intention: ***See – Plan – Act***
  - General recipe: optimized trajectory
- Multi-criteria optimization
  - Ideal Perception
  - Ideal Actions
  - Often poorly reactive



# Control

- Execute planned actions
  - In a feed-back loop
  - Constant progress in automation


# Challenge of cooperative control

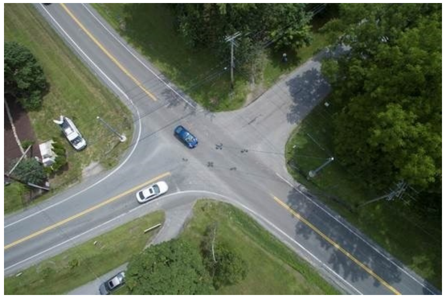
- Drive and take others into account?
  - A critical social skill
- Plan or React?
  - Both!
  - How?

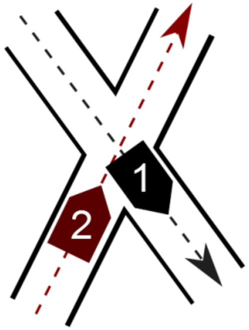
# A simple case

- What does each car see?
- How does it plan?
- Action?
- Reaction?

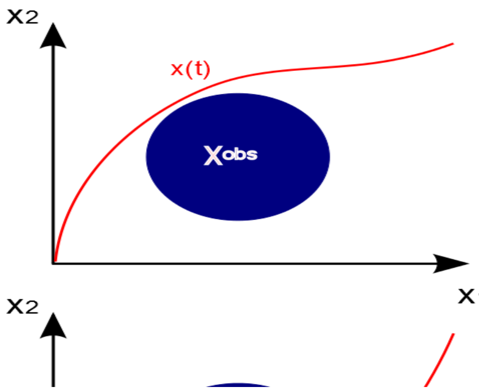
# Simple case: binary choice

- Pass before OR after
- All trajectories are so
  - Homotopy classes: 2 (binary)
  - Notion of priority






Trajectory in real space




**Trajectory** in coordination splace

$$2 \succ 1$$

**Priority** relation

# Theories

- Planning: anticipation
  - Fixed decision (even if we can re-plan)
- Reaction: without anticipation
  - More robust to uncertainty
  - Distributed systems, swarm, multi-agents…
- Game theory
  - Very difficult to model the other

- Practically: MPC + rules

# Can we have guaranties?

- Best-effort approach is efficient
  - But without guaranties
- Learning
  - Learns only what has been shown

Collisions

Congestion and gridlocks

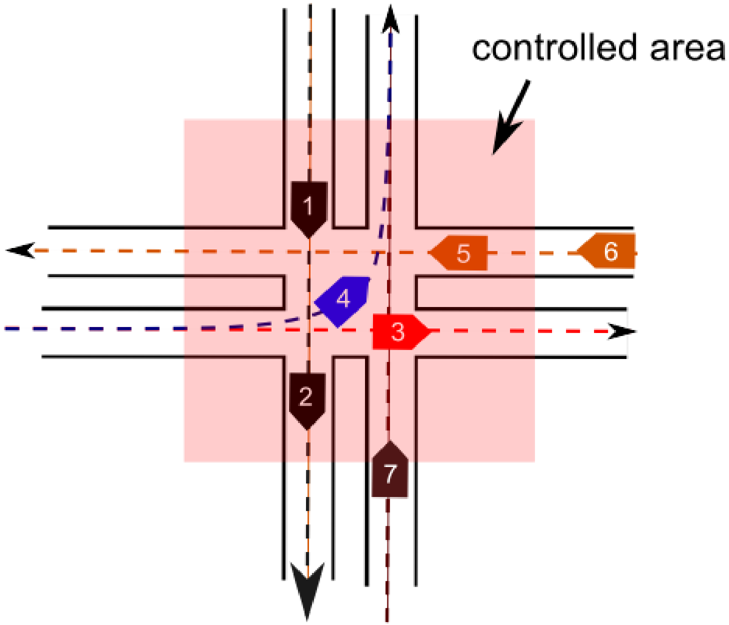
# Mathematical guaranties

- It relies obviously on strong hypothesis
  - Give knowledge of invariants
  - Teach us how to do: design
  - Complementary to a systemic approach

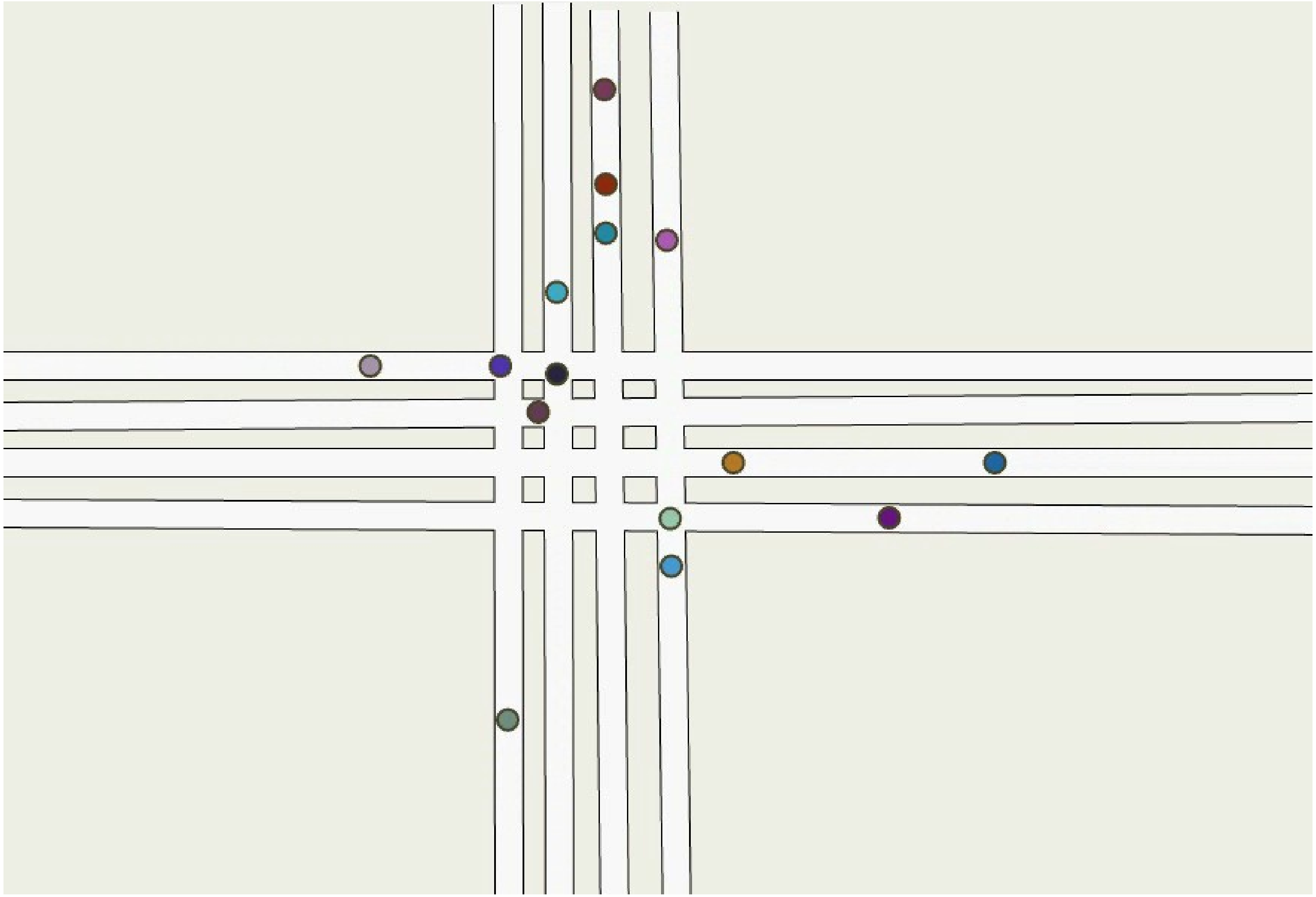
- Simplify to learn

# Our model

- Simplification
- But remains complex!

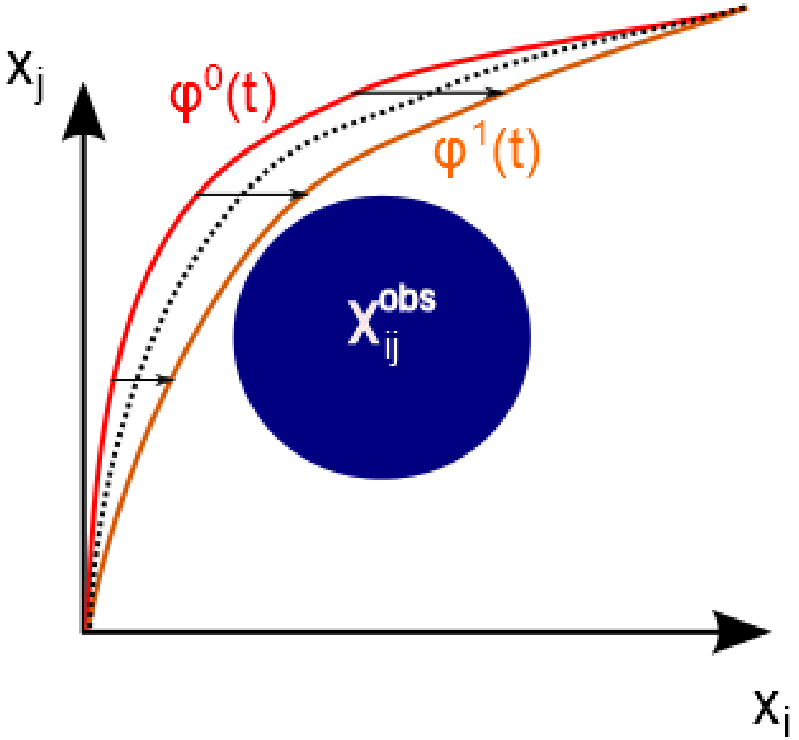


# Complexity…



# Some theory

- Binary choice → priority graph
  - Encoding of *all* trajectories
  - Invariant



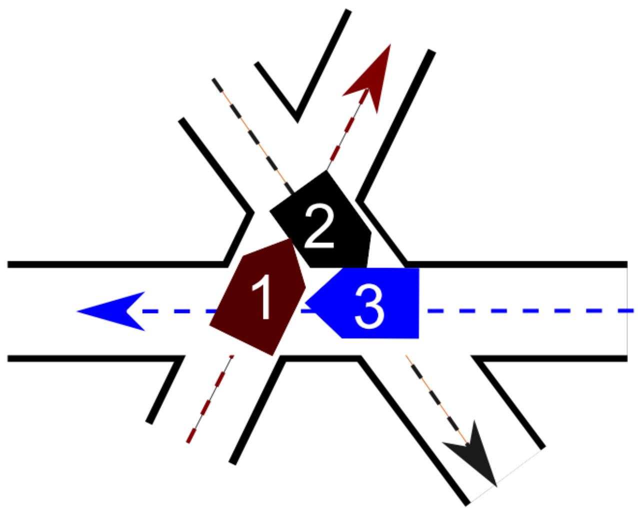

Homotopic trajectories
⇔
same priority graph

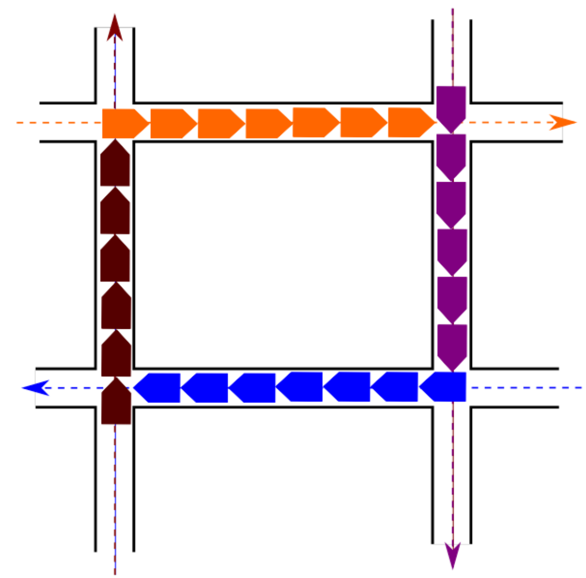
*PhD of Jean Grégoire*

# More theory

- This allows describing *all* blockings
  - Condition on the cycles of the graph

$$\bigcap_{(i,j)\in E(\mathcal{C})} \mathrm{cl}(\chi^{\mathrm{obs}}_{i\succ j}) = \emptyset$$



# Interpret theory

- We can enumerate all priorities
  - To each graph corresponds one homotopy class
  - Check if class is blocking
  - If not, perform a continuous optimization
- We learned to build an optimal trajectory
- But there are many of them:
  - Up to $2^{n(n-1)/2}$

# Re-interpret theory

- If I can build a trajectory
  - All trajectories obtained by deformation have the same priority graph
  - And this priority is *always* non-blocking

- This set of trajectories may be huge
  - So that we can even build a *control* within
  - *Priority-aware control*

# Cooperative control

- Chose a good priority
  - Problem of priority assignment
  - Combinatorial problem that is well structured
- Compute a control respecting that priority
  - New constraints
  - *Brake-safe* robust control
  - Robustness: it is always feasible to brake more without collision (pedestrian crossing, communication loss…)

# Back to practice

- How to exploit mathematical guaranties?
- Conclusions are largely valid
  - Each vehicle must pass *before* or *after*!
  - We learned to deform trajectories

    i. e. slow down or accelerate *safely*, all *together*

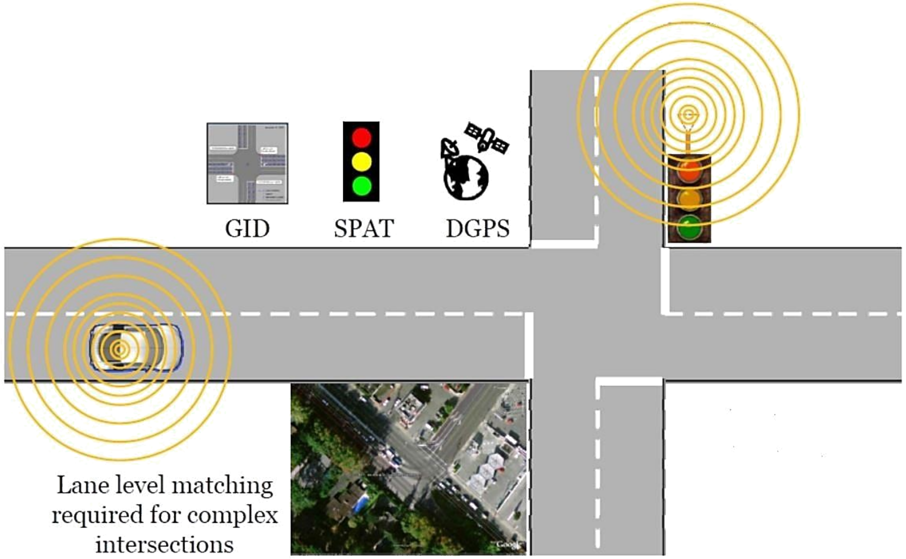
- We built the necessary information for a good cooperation = priorities

# Concretely

- MPC + rules = state of the art
  - Now we know which are the rules
  - And we know how to constraint MPC
- Control guided by a common goal
  - With a minimalistic information
  - Precious for communication

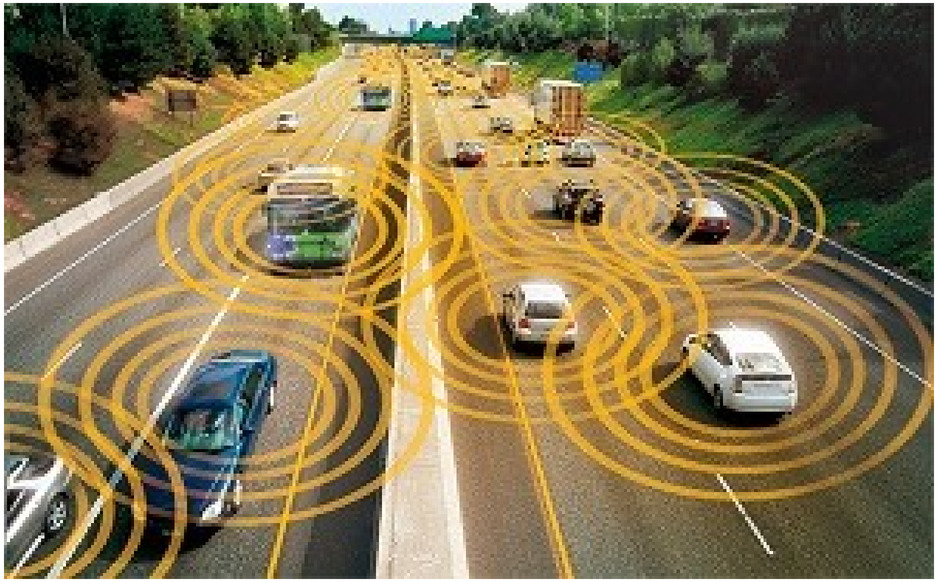
# Perspectives

- Compute an efficient priority (assignment)
  - Exact computation or heuristic
- Enlarge theory to other cases
  - Multiples lanes, roundabout…
  - Protocols



# Perspective: decision

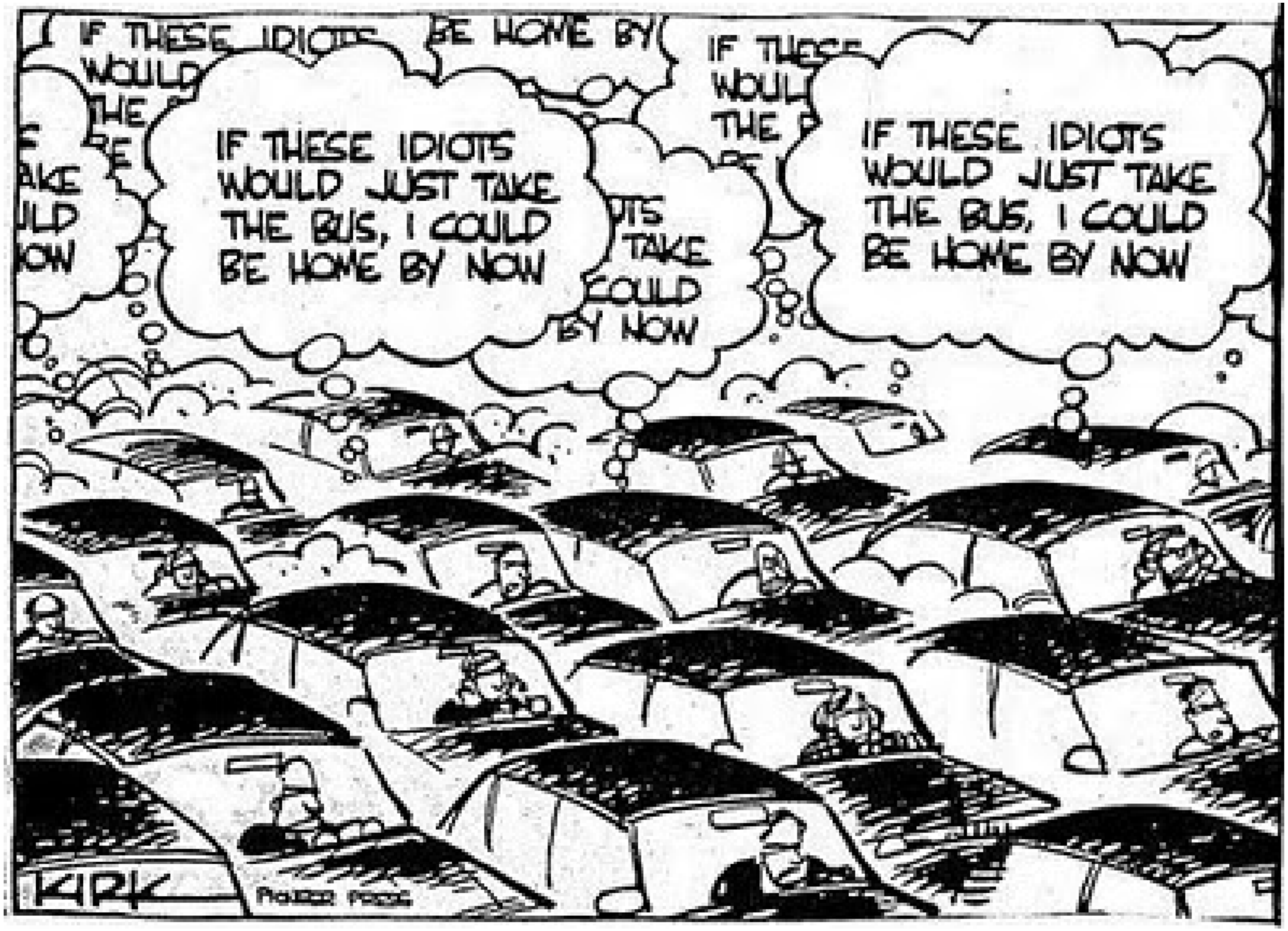
- Priority assignment = decision
  - When take the decision?
  - Neither too early nor too late
  - It depends on uncertainties



# Conclusion

- Theory substantially increases our understanding
- It is important to better understand the ties between planning, control and decision
- This also influences the rest of the system (perception, communication…)
- In a dedicated cooperative framework

# Tomorrow, the same with robots?



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# Social impacts: organization

- ICT had a huge impact:
  - Work
  - Globalization
  - Changes in society

- Technology changes → organizational changes
  - Less TV → more Internet
  - SAP, banking, retail, education, politics
  - Deep links between Internet and people

- This is happening in transport
  - Organization in information systems
  - No information → no trip
  - But technology offers more possibilities

# Social impacts: entities

- Entities have to be defined
  - Who rules cars?
  - Who rules cars+devices (connected cars)?
  - Who rules clusters of cars?
  - Who rules the roads?

- Technology tells what is feasible
  - Open doors, don't reduce liberty
  - Technology can be set aside
  - Difficulty to forecast consequences

- Governance
  - Set goals, globally and for each entity (politics)
  - Ensure means are adequate (governance)
  - There is choice

# Social impacts: decision

- For each domain, society has to decide

- Communication
  - Safety of exchanges ↔ cryptography
  - Accessibility to everybody
- Perception
  - Privacy policy ↔ privacy design
- Planning
  - Decide about goals (intentions, criteria)
  - Decide about decision making (what is allowed)
- Control
  - What are the entities to be considered

# Examples

- ADAS
  - ABS, ESP, Lane keeping, ACC...
  - Driver: HMI, supervision
  - Copilot: highly automated driving
  - Laws evolves with technology
- Automated driving
  - Technology is demonstrated
  - Laws: Vienna Convention
  - Use cases: truck platooning, campus...
- Transport systems
  - Mobility → economy, social life...
  - Consequences on city planning, environment, energy
  - New mobility schemes

# Future work

- Several names
  - C-ITS = Cooperative ITS
  - CAS = Collective Adaptive Systems
  - New mobility
  - Web 4.0...
- Cooperative ITS is not an autonomous entity
  - It is linked to many other domains
  - Consumer electronics, Internet, robotics...
- Technology seems to go fast
  - But people do not change as fast
  - Social structures and environment even slower
- Applied research!

MINES ParisTech

# Thank you!

## Questions?

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