AI challenges for Automated & Connected Vehicles

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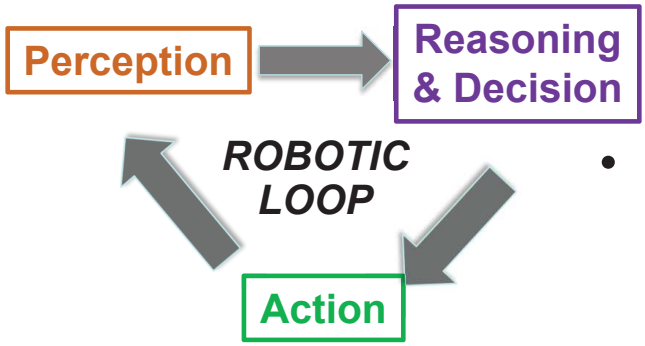
Outline

- **Introduction: Artificial Intelligences**
- AIs for Automated Vehicles
- AV current state of development
- Major remaining challenges for AV

What is (human) intelligence??

- **Intelligence = reasoning?**
  or Intelligence = adaptation?
- **In fact, MANY DIFFERENT TYPES OF INTELLIGENCE**



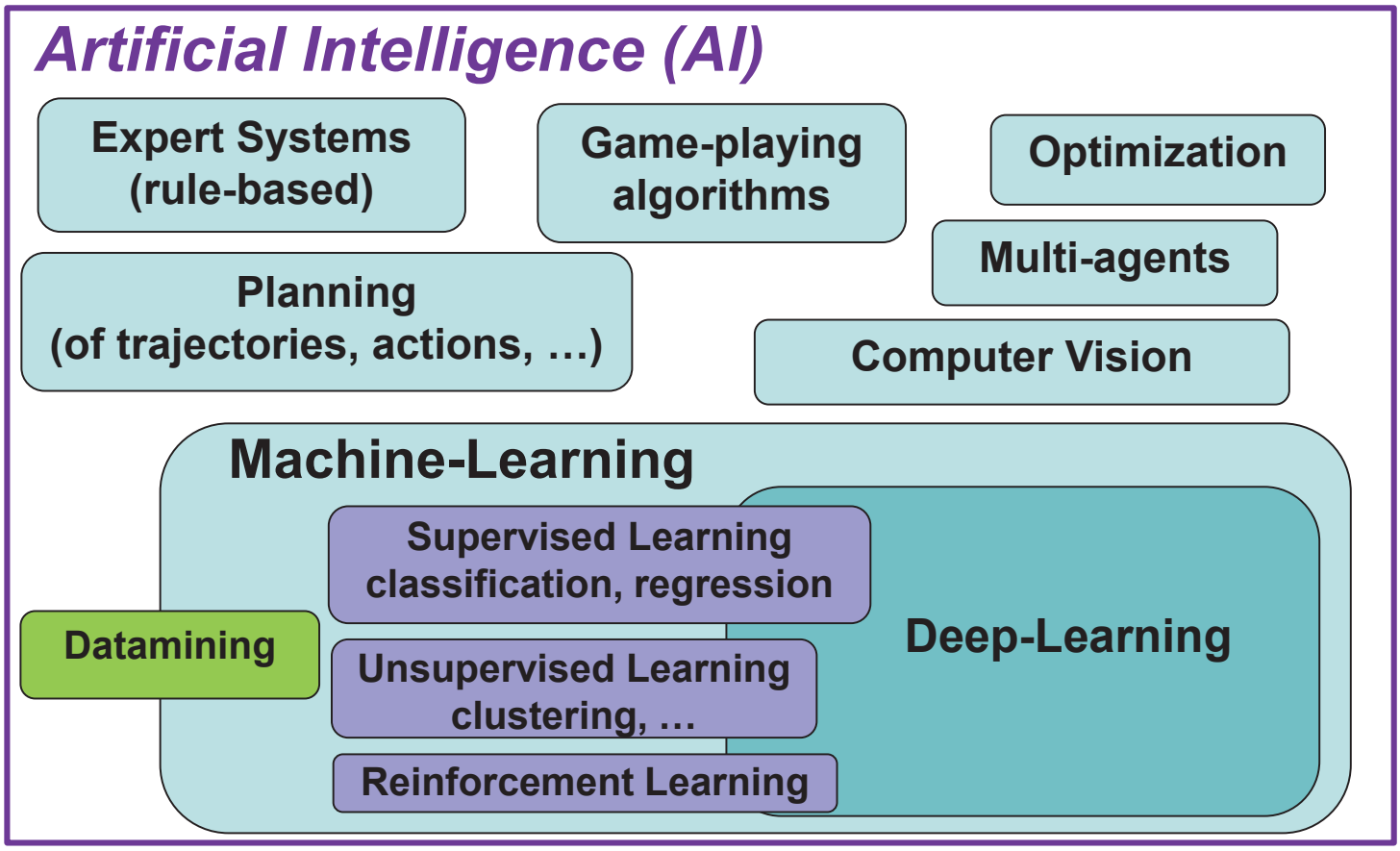
- **A possible typology:**
  - ***Perception*** **Intelligence**
  - ***Prediction*** **Intelligence**
  - ***Reasoning*** **Intelligence**
  - ***Behavior*** **Intelligence**
  - ***Interaction*** **Intelligence**
  - ***Curiosity***

What is AI?

Artificial Intelligence, is a vast and heterogeneous domain:

- **Rule-based reasoning, expert systems**
- **Algorithms for playing games (chess, Go, etc..)**
- **Multi-agents, emergence of collective behavior**
- **…**
- **Optimization, Operational Research, Dynamic Programming**
- **Planning (of trajectories, tasks, etc…)**
- **Computer vision, pattern recognition**
- **Machine-Learning**
  = empirical data-driven modelling
  (optimization, based on examples, of a parametric model)

Artificial IntelligenceS



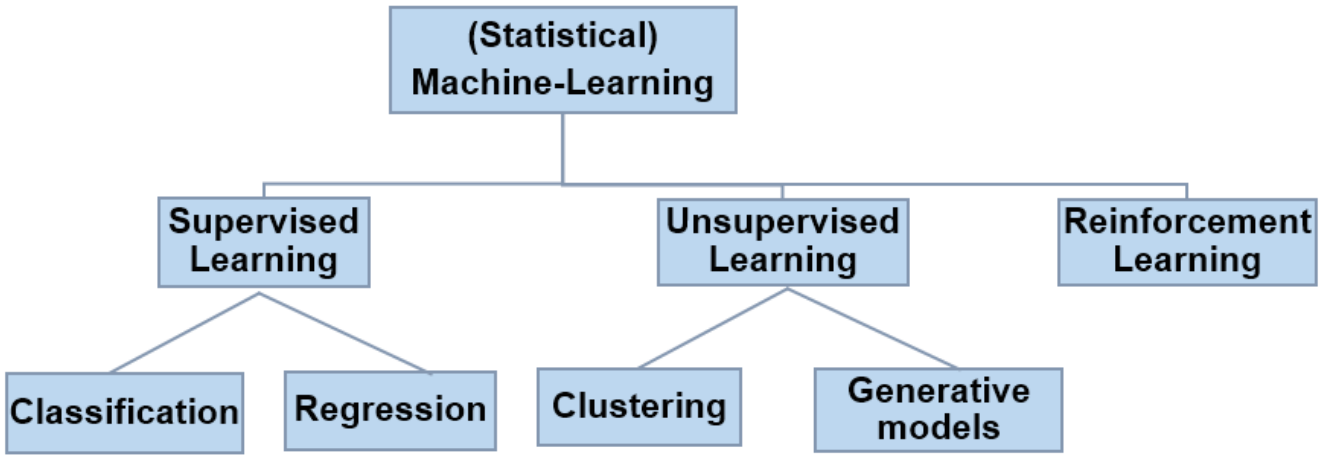
Typology of Machine-Learning (ML)

(Statistical) Machine-Learning

=

EMPIRICAL MODELING

(statistically-optimized parameterized models)



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In the beginning was Driving Assistance…

Detection & recognition of Traffic Signs (~95% OK) and Traffic Lights
[algos de MINES_ParisTech vers 2011]

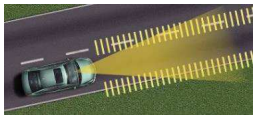
Visual Detection of vehicles and pedestrians
→ ~95% OK (cars) et ~80% OK (pedestrians)
[Algos de MINES_ParisTech vers 2009]

→ **Inform/Warn the driver (or even emergency stopping of vehicle)**

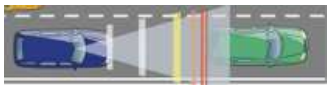
What are ADAS?

Acronym of Advanced Driving Assistance Systems = Intelligent functions for safer and/or easier driving

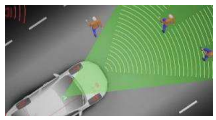
- ***Warning or Information***
  - Lane Departure Warning (LDW)



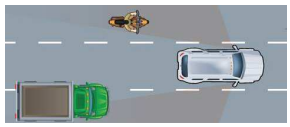
  - Forward Collision Warning (FCW)



  - Pedestrian Collision Warning



  - Blind Spot Monitoring



  - Speed Limit Assistant

  - Driver Attention Warning
  - Night vision
  - …

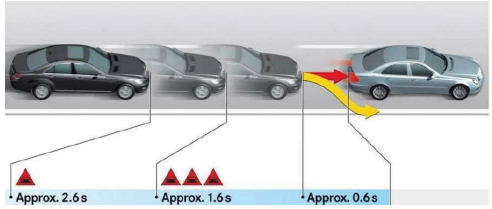
Evolution towards Active ADAS

= ADAS that ACT on the vehicle (rather than just only warn)

- ***Active systems***
  - Adaptive Cruise Control (ACC)

  - Lane Keeping (LK)

  - Autonomous Emergency Braking



  - Automated Parking
  - …

More detailed information: see for instance
https://mycardoeswhat.org/

Example of active ADAS : Lane Keeping

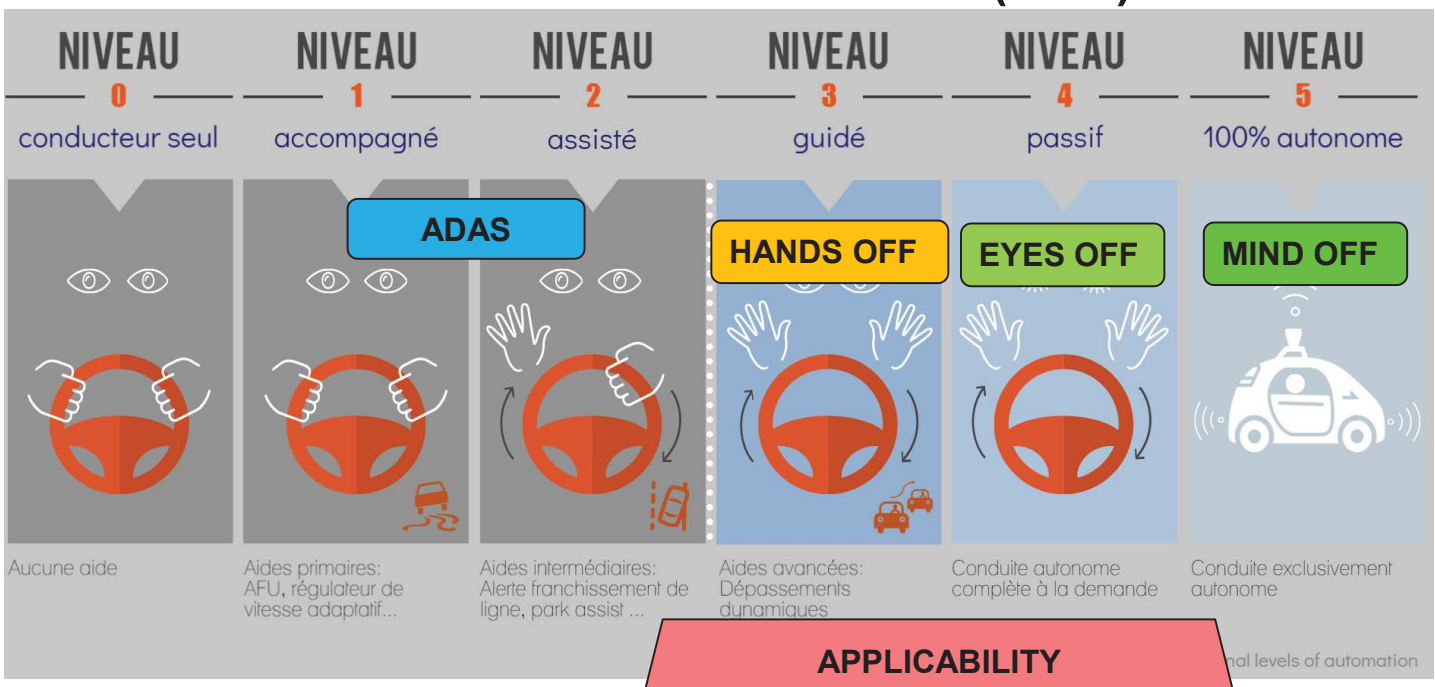
[Automated Driving experiment (on closed track) by the Center for Robotics of MINES_Paris in… 2002 !]

ESAY on simple road with good lane markings…
…and no other road users!!

On "open" roads, it is much more challenging (especially in urban area)

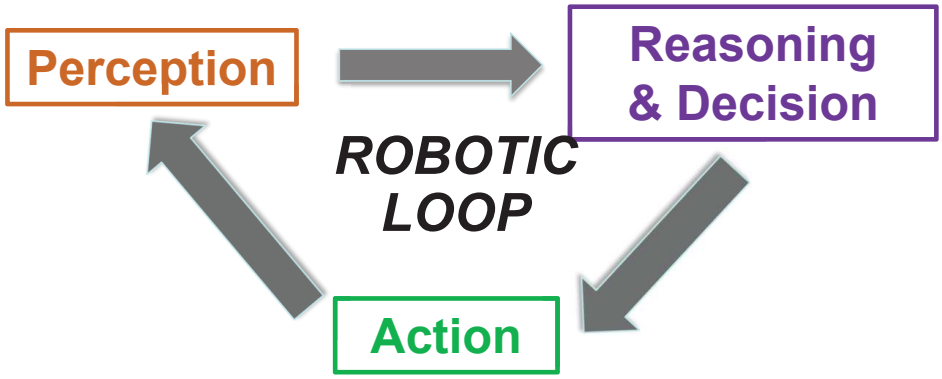
Autonomous??
Or rather *Automated* Vehicles?

The 5 levels of automation for vehicles (SAE)



APPLICABILITY CAN BE RESTRICTED TO SPECIFIC CONDITIONS (eg HIGHWAYS, …) = "Operational Design Domain" (ODD)

An Automated Vehicle is a mobile robot!



"Ingredients" of Automated Vehicle

Robot ➔ perceive (& analyze) + reason + act

An Automated Vehicle therefore needs:

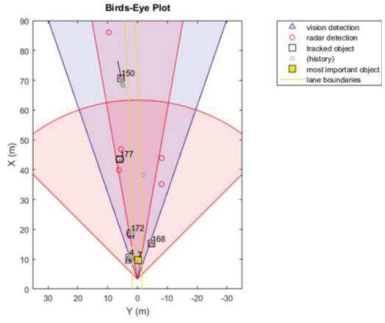
- **Sensors**
- **"Intelligent" algorithms**
  - **for perception**
  - **for trajectory planning**
  - **for control**
- **Embedded calculator(s)**
- **Actuators ("drive by wire")**

- **…and also an ergonomic Human-Machine Interface!** ***[especially for automated/manual transitions]***

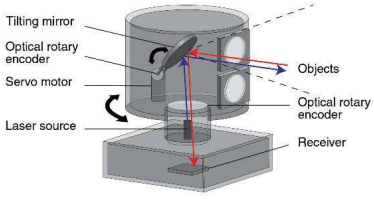
Sensors for Intelligent or Automated Vehicle

- **"classic" Cameras** ***[long range ~500m, wide field-of-view]***

- **Radar(s)** ***[intermediate range ~200m, NARROW field-of-view]***



- **LIDAR** ***[range ~100m, field-of-view ~ 120° up to 360°]***



- **Ultrasound etc…**

What types of Intelligences are needed for Automated Vehicles?

- "Semantic" interpretation of vehicle's environment:
  - Detect and categorize/recognize objects (cars, pedestrians, bicycles, traffic signs, traffic lights, …)
  - Ego-localization
  - *Predict movements of other road users*
  - *Infer intentions of other drivers and pedestrians (or policeman!) from their movements/gestures/gazes*
- Planning of trajectories (including speed)
  In a dynamic and uncertain environment
- Coordinated/cooperative planning of multiple vehicles

- For Advanced Driving Assistance Systems (ADAS) and partial automated driving (level 3-4):
  - Analyze and understand attention and activities or gestures of the "driver-supervisor"

What kind of AI algorithms for Automated Vehicle?

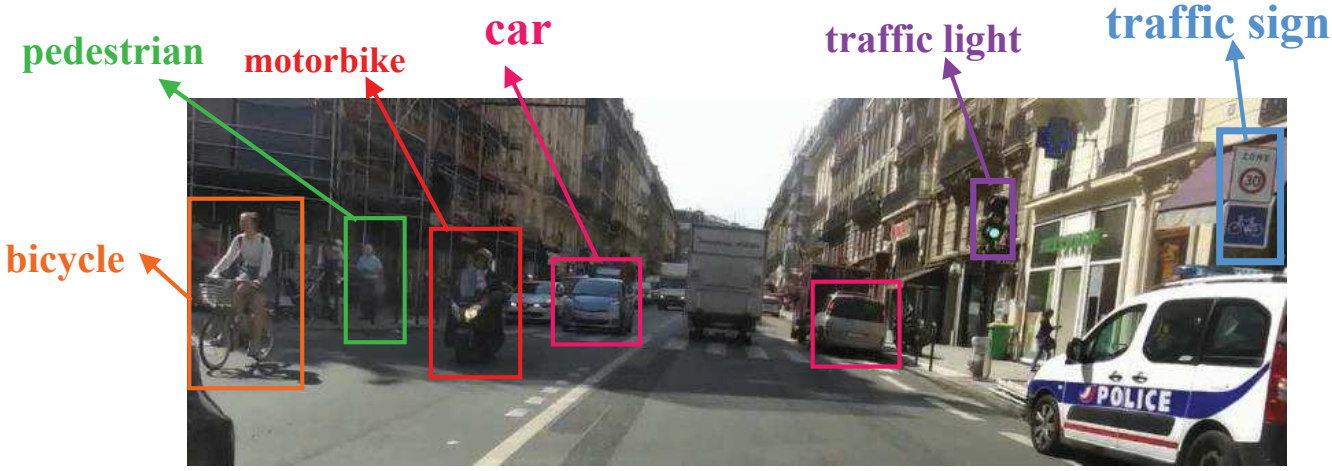
- Statistical Machine-Learning
  - on Images/videos
  - on 3D data (depth images and/or point clouds)
  - on time-series

- Planning (of trajectories, of tasks, etc…)

- Optimization, Operational Research, Dynamic Programming, …

- Multi-agents, Emergent collective behaviors,
- …

Real-time scene understanding for Automated Vehicles

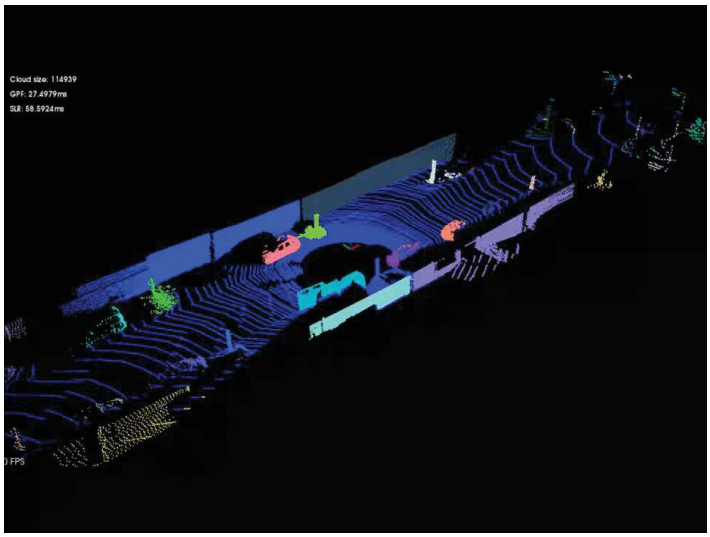


Key componant for driving assistance (ADAS) & automated driving

- **Strong real-time constraint : process at least ~15 frames/second**

Intelligent Perception for Automated Vehicles

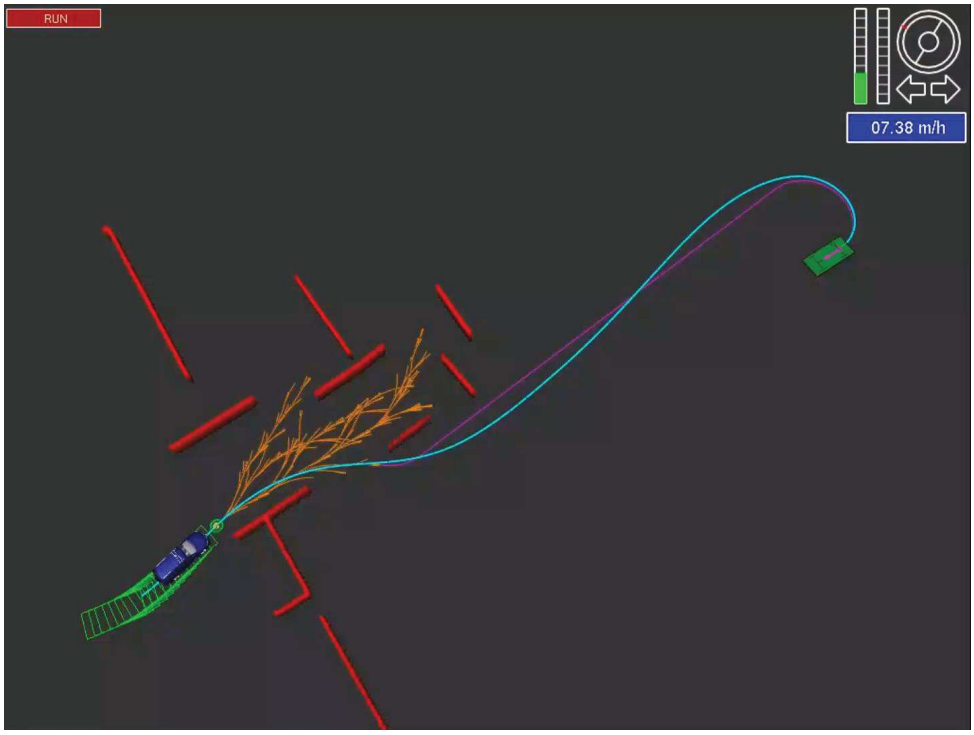
From camera



From LIDAR

Strong real-time constraint: process ≥ 15 frames/seconde

Trajectory planning



Tree search computation (A*/RRT algorithms), re-executed frequently for updating

Platooning

“Virtual hooking” of vehicles in a queue: each one follows the preceding one (e.g. using visual servoing)

Real experimentation by Volvo Trucks

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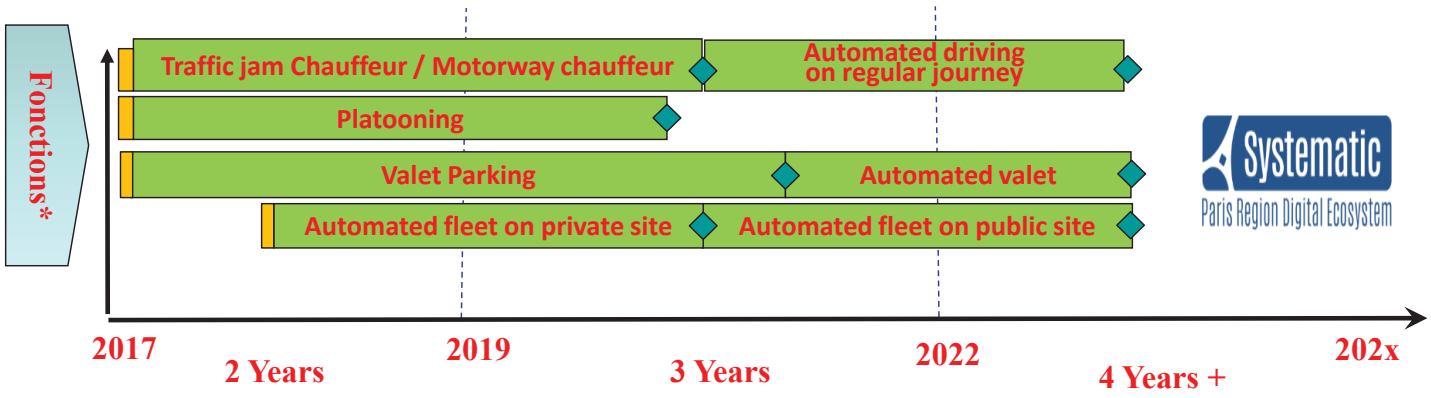
Deployment "roadmap"?

Vienna Convention (1968) modified in March 2016 to "allow automated driving systems on road, provided that they are compliant with United Nations rules on vehicles, or that they can be controlled or even disabled by driver"



Roadmap "Automated driving" du pôle System@TIC

Current development state of Automated Vehicles

➔ TESLA's auto-pilot ~ Level_3

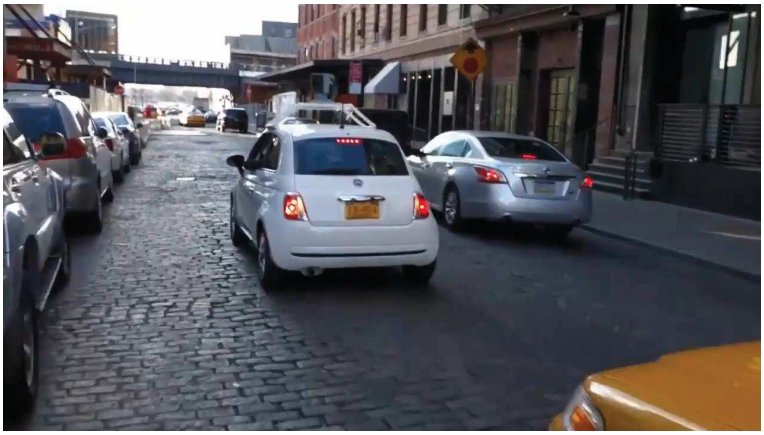
➔Automated shuttles on private site or dedicated lane ~ OK

Current development state of Automated Vehicles (2)

➔ Level_4 on motorways ***in « normal » conditions*** nearly OK except for 2 problems:

- VALIDATED robustness by redundancy of sensors and algorithms
- Lane-changing (intelligent planning, decision making for passing, etc)

➔ Many ongoing experiments (and Google/Waymo on top os leaderboard for level_4-5)



Open-roads experimentations of Automated Vehicles

Many prototypes experimented on OPEN roads (with a "safety driver") in USA and Europe

2017 **annual report of DMV on experiments in California:**

Company	Number of vehicles	Distance driven on open-road	Number of collisions	Average distance between to 2 "disengage"
Google_Waymo	75	567 000 km	3	9 005 km
GM_Cruise	86	211 910 km	22	2 018 km
Mercedes-Benz	3	1750 km	-	2 km
Bosch	3	2340 km	-	4 km

For comparison, Human driving
~500.000km between collision,
~3 millions km between injury crash,
and ~150 millions km between fatal crash

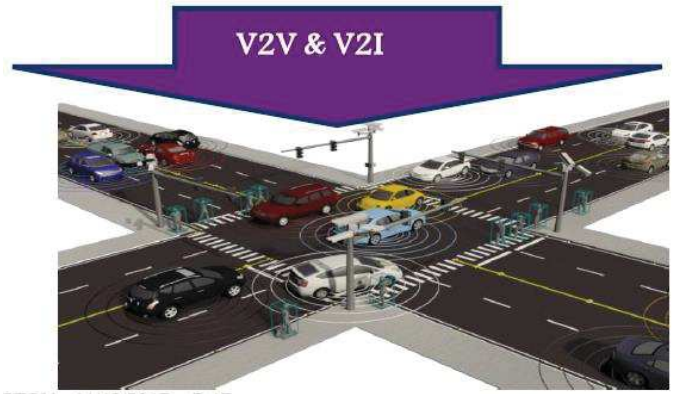
AV experimentations on open roads

- **Uber is very active (mostly in Nevada)**

- **Less publicized, but MANY experimentations in FRANCE too (by Renault and PSA)**

- **China (Baidu, Alibaba & Tancent) also "in the race"**

Communications
V2X = V2I and/or V2V



STOM - 11/10/2017 – P 17

80% of new vehicles connected by 2020

Autonomous Vehicles

The cooperation enabled by digital connectivity between vehicles and between vehicles and transport infrastructure, is expected to significantly **improve road safety**, traffic efficiency and comfort of driving.

European Commission

C-ITS
Cooperative Intelligent Transport System

C-ITS Strategy (adopted by EU the 30th of Nov 2016):

- deployment of mature C-ITS services in 2019 and beyond;
- adoption of the appropriate legal framework at EU level by **2018** to ensure legal certainty for public and private investors, the availability of EU funding for projects;
- continuation of the C-ITS Platform process;
- international cooperation with other main regions of the world.

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AI challenges for Automated (& connected) Vehicles

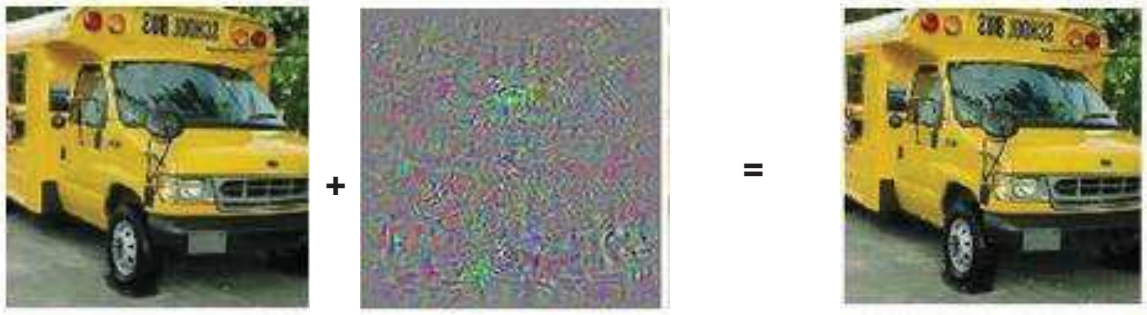
- Quantified safety validation / HOMOLOGATION??
- Intelligent and dynamic planning of trajectories
- Forecasting of road users movements/trajectories
- Inference of HUMAN INTENTIONS (pedestrians + drivers)
- Coordination/collaboration
  - between AVs (cooperative planning, etc…)
  - with Humans:
    - Non-verbal communication (gestures, movement, gaze)
    - Learning of implicit "social rules"
- Learning of adaptive BEHAVIOR

Extra challenges for CONNECTED Vehicles:

- V2X latency time, availability and bit rate
- Cyber-security!!

HOMOLOGATION?

- Still some weaknesses of Deep ConvNets…



Van diff Ostrich!!

- How to VALIDATE safety of an Automated Vehicle?
  - It can be done only STATISTICALLY!!
  - Actual driving? Would require millions of km!! And/or huge variability of configuration tests.
  - Simulations??

AVs ↔ Humans interactions

- **AVs need to:**
  - **Infer INTENTIONS of pedestrians and human-drivers**
  - **Communicate with them (cf. gesture-based and gaze-based usual "dialogues")**

Real-time posture estimation by Deep-Learning on a RGB video

AI for *Connected* Vehicles

Automated AND CONNECTED Vehicle

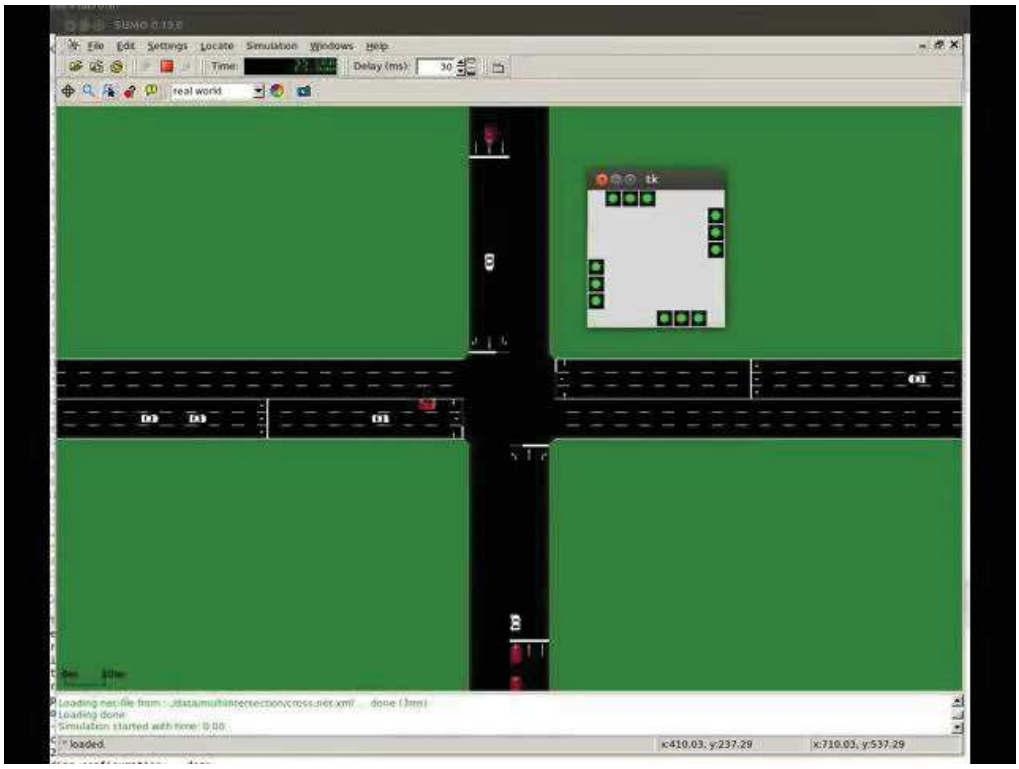
- **Platooning**
- **Automated Intersections**
- **Cooperative Manœuvres**
- **Collaborative Perception**

Must have guaranteed:

- **Safety**
  = NO COLLISION
- **Availability**
  = NO DEADLOCK

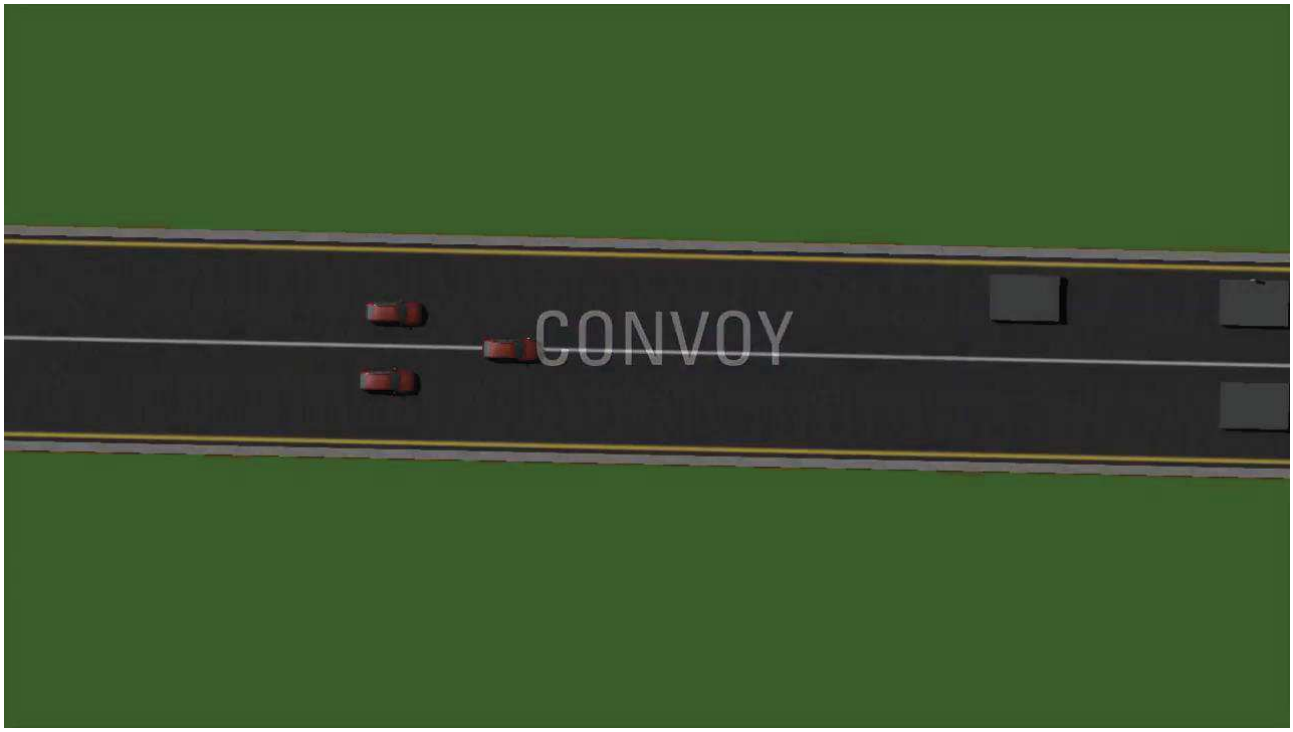
➔ ***Need intelligent algorithm for LOCAL COORDINATION***

Intelligent (Automated) Intersections



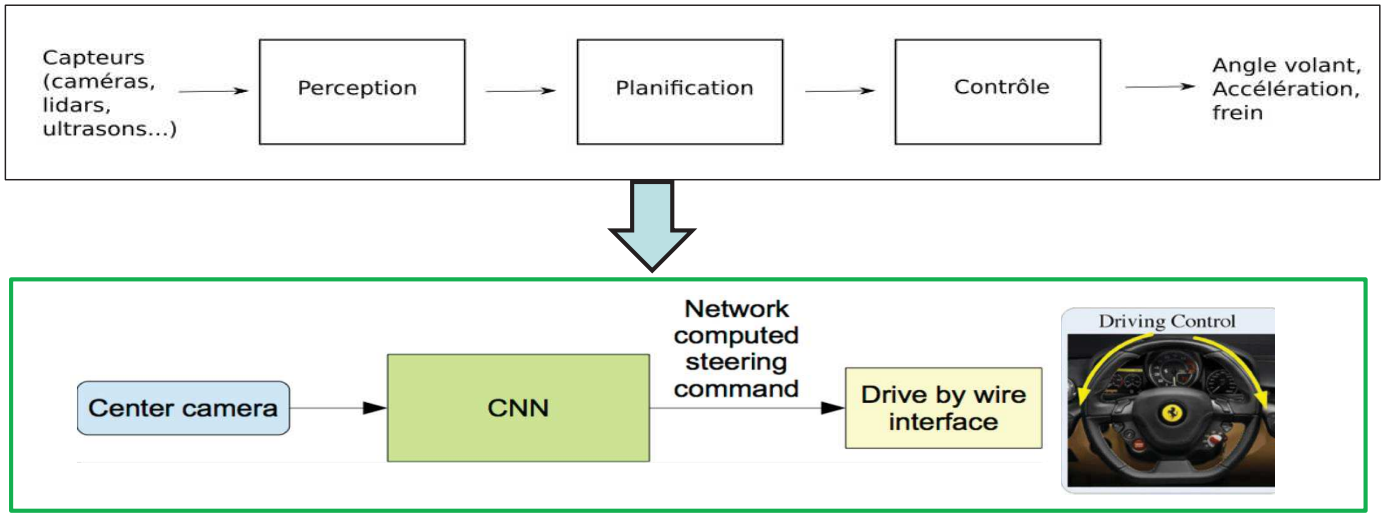
Framework designed and prototyped by Center for Robotics of MINES ParisTech, with guarantees for no-collision and no-deadlock (using *centralized* scheduling of « right of ways »)

Cooperative Driving/Manœuvres by V2V

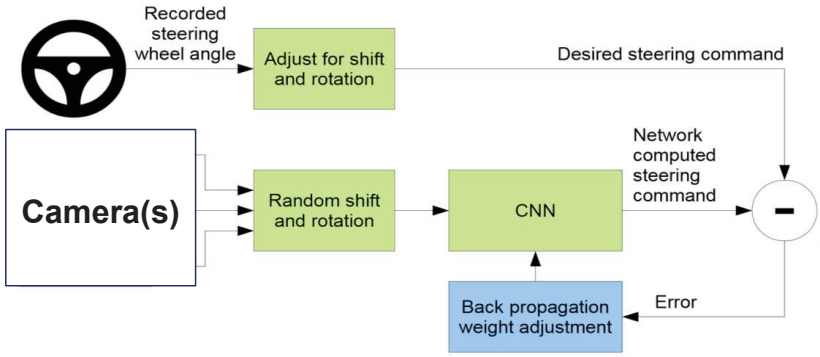


Algorithms for Cooperative Driving/Manœuvres (« convoys », merging, …), designed and prototyped at the Center for Robotics of MINES ParisTech (within European project AutoNet2030)

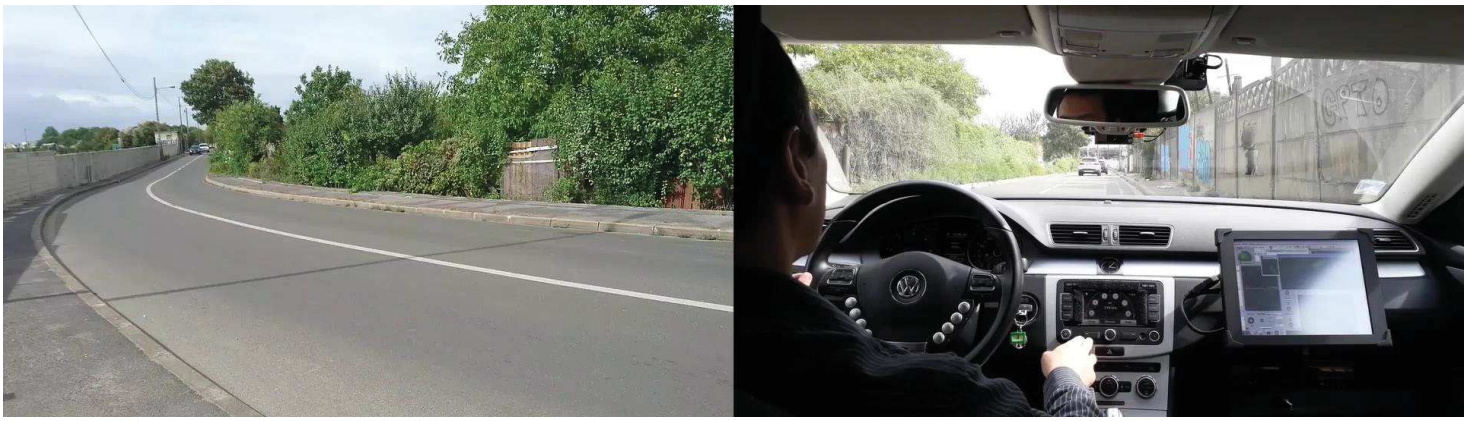
“End-to-end” Driving



- **One possible approach: “Imitation” learning (mimic human driver)**

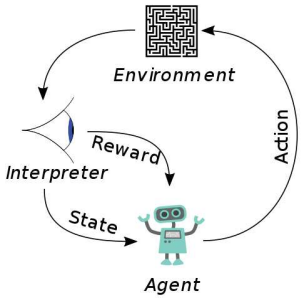


End-to-end (imitation) driving tested on real vehicle



[Work by Valeo using ConvNet trained by my CIFRE PhD student Marin Toromanoff]

Intelligent and Dynamic trajectory planning



End-to-end driving by
Deep Reinforcement Learning
[thèse CIFRE Valeo/MINES-ParisTech en cours]

Conclusions

Major current AI challenges for Automated Vehicles are related to:

- **AV-Human interactions (recognition of Human actions or behaviors, Inference of Human intents)**
- **Cooperative/coordinated planning**
- **Learning of complex adaptive behaviors**

Questions?