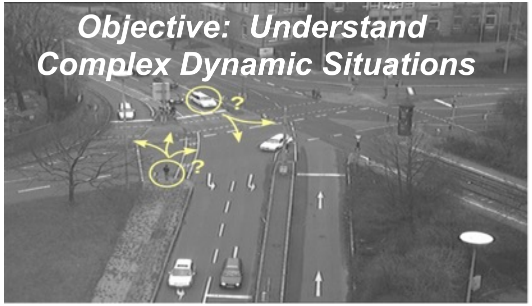
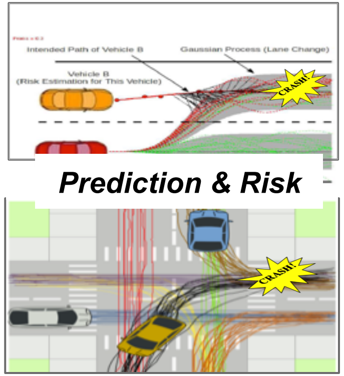
W4. Perception & Situation Awareness & Decision making

- Robot Perception for Dynamic environments: Outline & DP-Grids concept
- Dynamic Probabilistic Grids – Bayesian Occupancy Filter concept
- Dynamic Probabilistic Grids – Implementation approaches
- Object level Perception functions (SLAM + DATMO)
- Detection and Tracking of Mobile Objects – Problem & Approaches
- Detection and Tracking of Mobile Objects – Model & Grid based approaches
- Embedded Bayesian Perception & Short-term collision risk (DP-Grid level)
- **Situation Awareness – Problem statement & Motion / Prediction Models**
- Situation Awareness – Collision Risk Assessment & Decision (Object level)

Situation Awareness – *Problem statement*





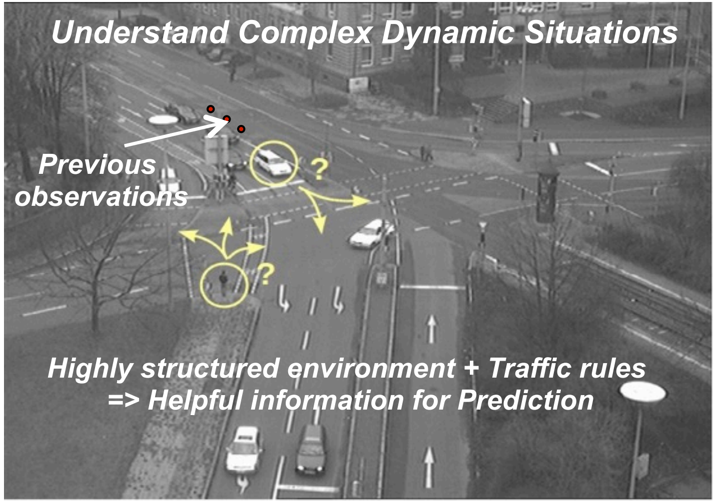
- **Main difficulties**

  Uncertainty, Partial Knowledge, World changes, Human in the loop + **Real time**

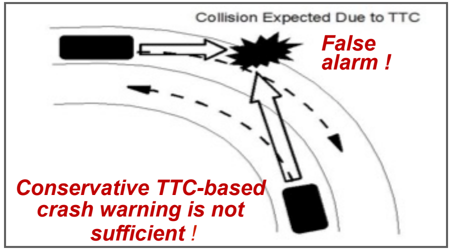
- **Approach**: *Prediction + Risk Assessment + Bayesian Decision*
  - Reasoning about **Uncertainty & Contextual Knowledge**
    => History & Prediction
  - **Avoiding pending & future collisions**
    *=> Probabilistic Collision Risk at **horizon t+δ***
  - **Decision making** by taking into account the **predicted behavior of the other traffic participants** *(cars, cycles, pedestrians…)*

Collision Risk Assessment at Object level

Increasing time horizon using Semantics & Motion models



- *More complex than **conservative short-term Collision Risk** (e.g. TTC)*
  - ⇒ *Understand the **Current Situation** & its **likely Evolution***
  - ⇒ *Evaluate the **Risk** of future Collision for **Safe Navigation Decision***



Context & Semantics

=> History & Space geometry & Traffic rules

+

Behavior Modeling & Prediction

=> For all surrounding traffic participants

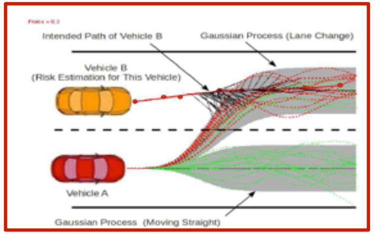
+

Probabilistic Risk Assessment

Collision Risk Assessment –*Two classes of Approaches*

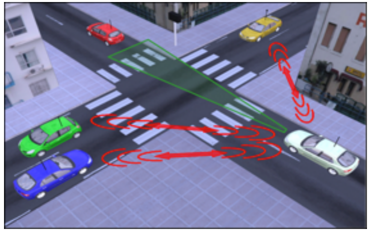
- **Trajectory Prediction & Probabilistic Collision Risk**
  - Behaviors Modeling & Learning, *e.g. using Hierarchical HMM*
  - Trajectories Prediction, *e.g. using Layered HMM + Gaussian Processes*
  - Probabilistic Risk Assessment, *e.g. GP & MC simulation*

  [Tay 09] [Laugier et al 11]



- **Cooperative Safety by reasoning on Drivers Intentions & Expectations** *(taking into account interdependencies)*
  - Exchanging vehicles states information
    using V2V communications and/or Perception
  - Estimating Drivers Behaviors using States information & Traffic rules
  - Comparing "Drivers Intentions & Expectations"
    e.g. using Dynamic Bayesian Network

  [Lefevre et al 11-12]



[Handbook of IV 2012, (chap. 54)]

Why Motion & Prediction Models ?

Motion & Prediction models are necessary in order to :

- **Estimate** the current traffic situation from data (tracking)
- **Predict** the evolution the current traffic situation (prediction)
- **Make decisions** according to current & future traffic situation (decision making)

Motion & Prediction Models – *Outline*

Motion Models can be classified in three main classes:

- **Physics-based motion models** are the simplest models. They consider that the motion of vehicles *only depends on the **laws of physics***
- **Maneuver-based motion models** are more advanced as they consider that the *future motion of a vehicle also **depends on the maneuver** that the driver intends to perform*
- **Interaction-aware motion models** take into account the *interdependencies between vehicles' maneuvers*

  ➔ *Only a few examples of such advanced representations may be found in the literature*

Motion & Prediction Models – *Main features*

Symbolic

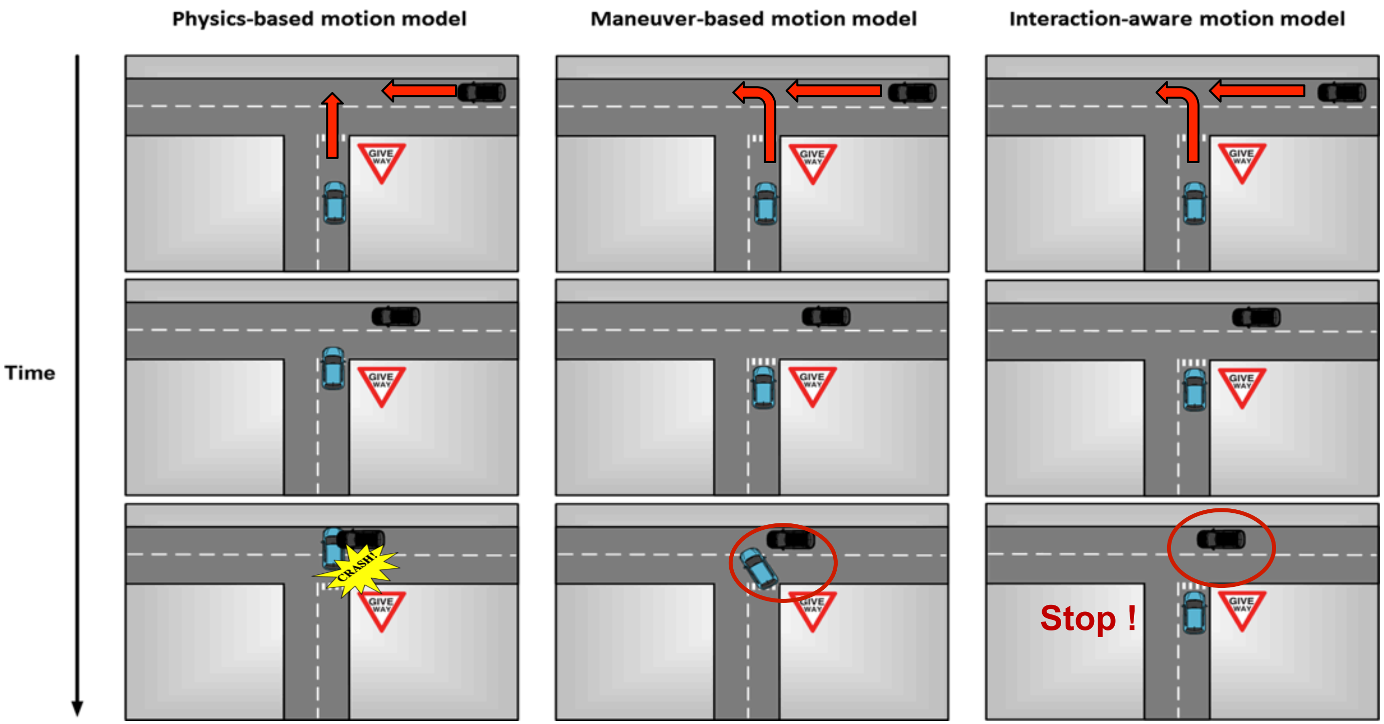
Target	Variables	Challenges	Tools
Interaction-aware models	- Social conventions. - Joint activities. - Communications.	- Detecting interactions. - Identifying interactions. - Combinatorial explosion.	- Coupled HMMs. - Dynamically-linked HMMs. - Rule-based systems.
Maneuver-based models	- Intentions - Perception - Surrounding objects and places.	- Unobservability. - Complexity of intentional behavior.	- Clustering. - Planning as prediction. - Hidden Markov Models. - Goal oriented models. - Reinforcement Learning.
Physics-based models	- Kinematic and dynamic properties	- State estimation from noisy sensors. - Sensitivity to initial conditions.	- Kalman Filters. - Monte Carlo sampling.

Metric

Classification
&
Main features

More details in [Lefevre et al 2014, Robomech journal]

Motion & Prediction Models – *Illustration*



Constant speed & orientation
=> Crash situation given byTTC

- *Black car straight*
- *Blue car turn left*

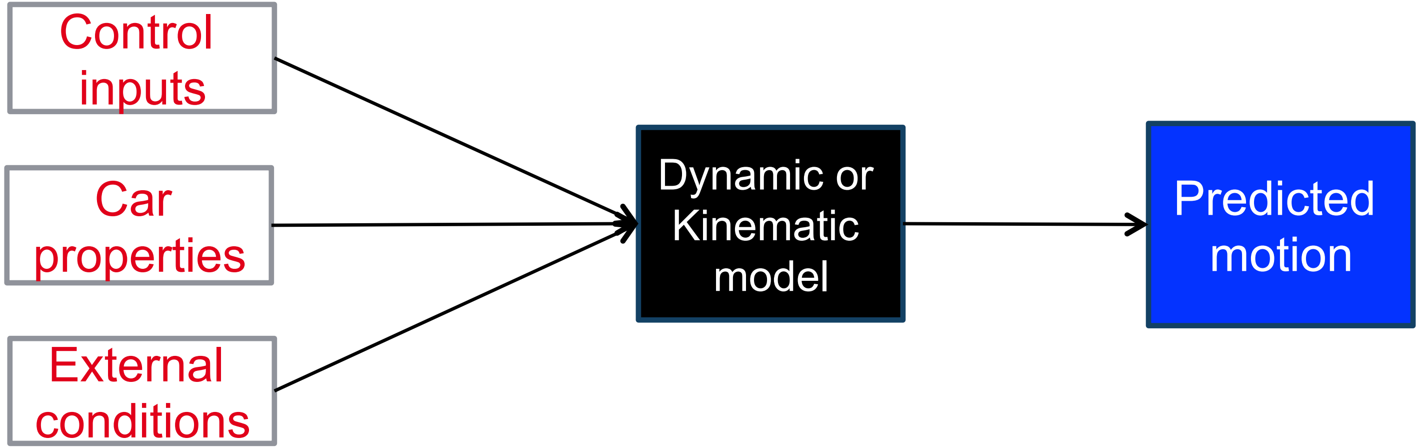
=> Crash might be avoided

- *Black car straight*
- *Blue car turn left*
- *Joint motion of cars constrained by traffic rules*

=> Crash is avoided

Physics-based motion models – *Main idea*

- Represent vehicles as **dynamic entities governed by the laws of physics**



- **Dynamic models:** *Mainly based on Lagrange's equations*
- **Kinematic models:** *Most common assumptions:*
  Constant Velocity or Acceleration, Constant Turn Rate & Velocity, Constant Turn Rate & Acceleration

Physics-based motion models

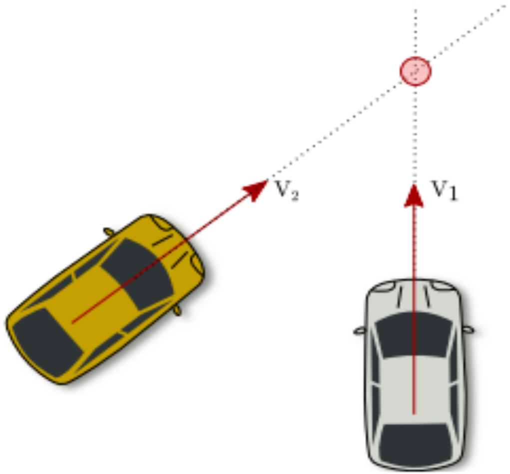
Dynamic & Kinematics Models

- **Dynamic models**
  - **Some complex models based on Lagrange's equations**, taking into account the different forces that affect the motion of a vehicle
  - **Some simpler models** based on the "bicycle" assumptions
  - Typically used for **advanced control applications**

- **Kinematic models**
  - Much simpler that dynamic models, represent the **mathematical relationship between the parameters of the movement,** without considering the forces which affect the motion
  - Most common assumptions / models:
    Constant Velocity, Constant Acceleration, Constant Turn Rate & Velocity, Constant Turn Rate & Acceleration

Physics-based motion models – *Trajectory prediction*

- **Single trajectory prediction**

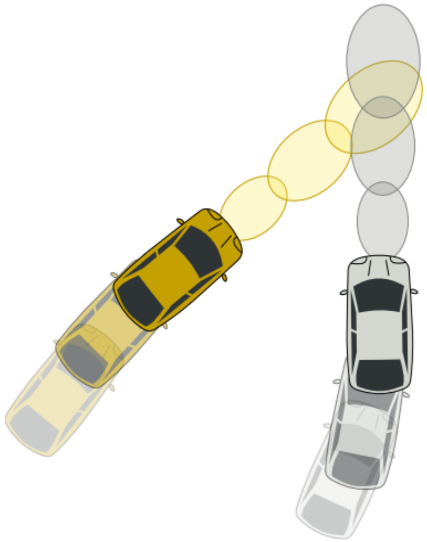


+ Computationally efficient

- Does not take into account uncertainty

Physics-based motion models – *Trajectory prediction*

- **Gaussian noise simulation**



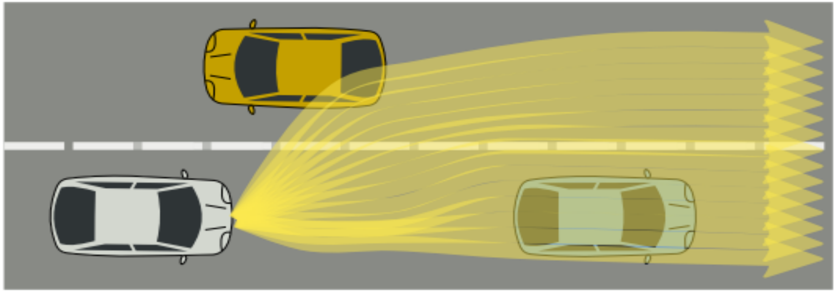
+ Computationally efficient

+ Takes into account some uncertainty

- Does not represent uncertainty on maneuver

Physics-based motion models – *Trajectory prediction*

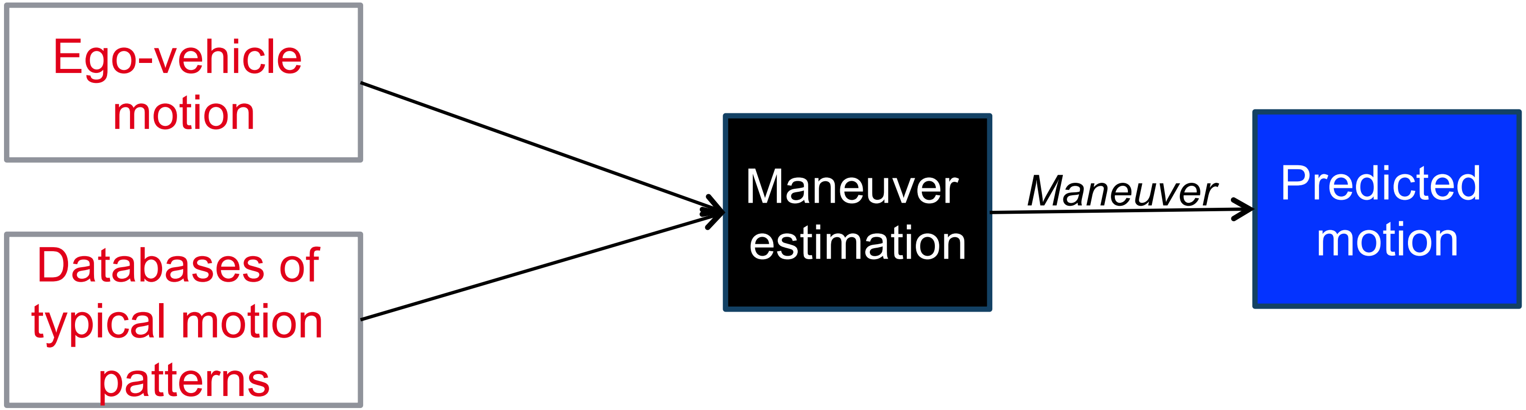
- **Monte Carlo Simulation**



+ *Takes into account uncertainty*
- *Computationally slow*

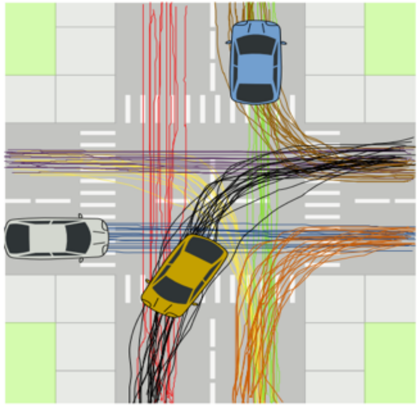
Maneuver-based motion models – *Main idea*

- Represent the motion of the vehicle as **a series of maneuvers executed independently of the other vehicles**



Maneuver-based motion models

Prototype trajectories *(for Estimation & Prediction steps)*

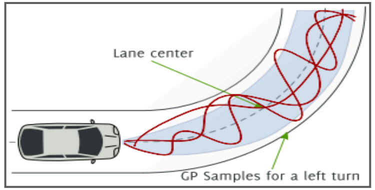


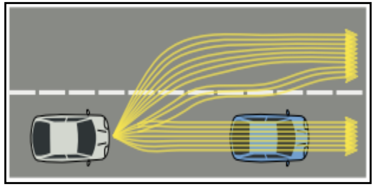
- **Step 1: Maneuver estimation**
  - Group all possible trajectories on the road in **clusters which represents maneuvers.** *Clusters are **learned from data***
  - **Match the observed partial trajectory** to the clusters **to identify the current maneuver**

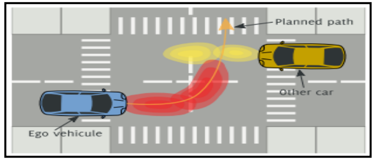
- **Step 2: Trajectory prediction**
  - ***Solution 1:*** Select **the most likely** motion pattern
  - ***Solution 2:*** Compute a **probability distribution over the different motion patterns**

Maneuver-based motion models
Two steps approach & Main methods

- **Basic idea:** *Maneuver estimation step & Trajectory prediction step are* ***performed independently***





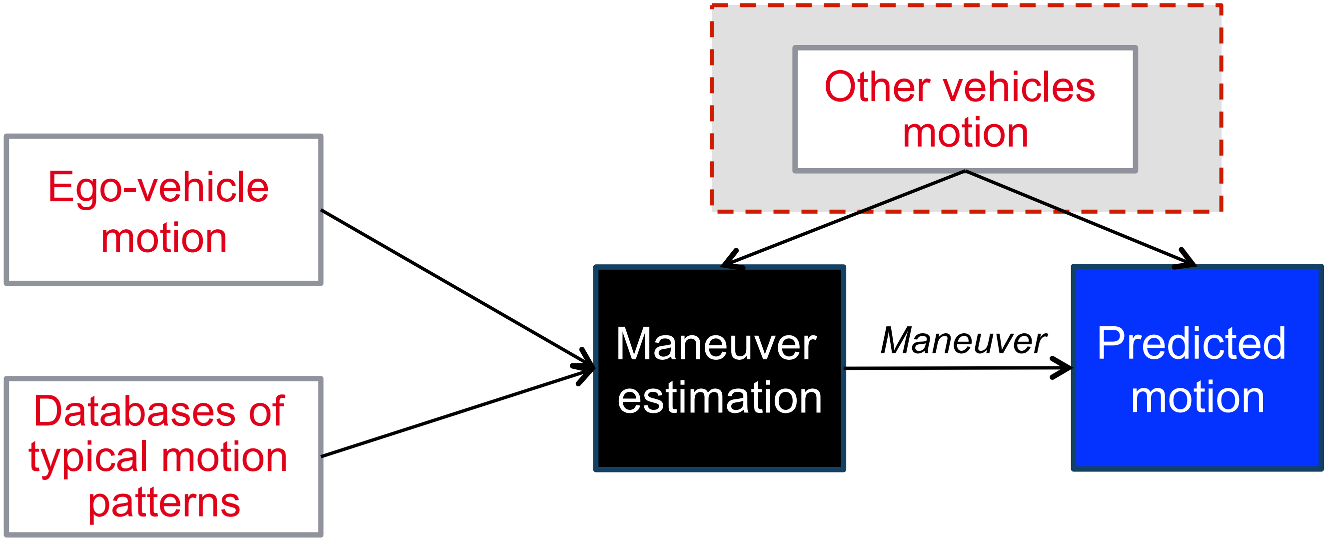


- **Common approaches for *Maneuver Estimation***
  - ***Discriminative classification approaches*** *such as Support Vector Machines*
  - ***Generative approaches*** *such as Hidden Markov Models*

- **Common approaches for *Trajectory Prediction***
  - *Gaussian Processes, Rapidly-exploring Random Tree (RRT)…*

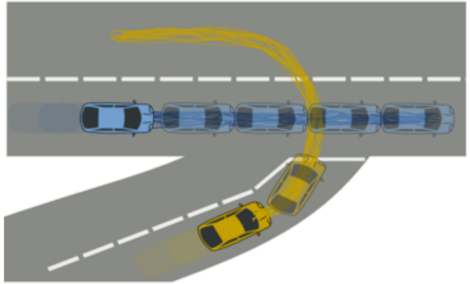
Interaction-Aware motion models – *Main idea*

- Represent the motion of a vehicle ***as a series of maneuvers***, but this time *the motion of a vehicle is assumed to be **influenced by the motion of the other vehicles***



Interaction-Aware motion models – *Approaches*

- Most approaches are based on ***Dynamic Bayesian Networks***, since the representation of **dependencies between variables** (and vehicles) is easily integrated



- *Coupled Hidden Markov Models can be used for modeling maneuvers*
- *Making use of an **explicit representation** of what a driver is expected to do, based on the maneuver intention of the other vehicles*

=> More details in the next session

Conclusion on Motion & Prediction Models

- **Physics-based motion models**
  - **Valid for short-term predictions only**

- **Maneuver-based motion models**
  - **Longer term prediction based on series of maneuvers**
  - *May result in some erroneous predictions*

- **Interaction-aware motion models**
  - **Predictions of most probable joint motion of vehicles in the scene**