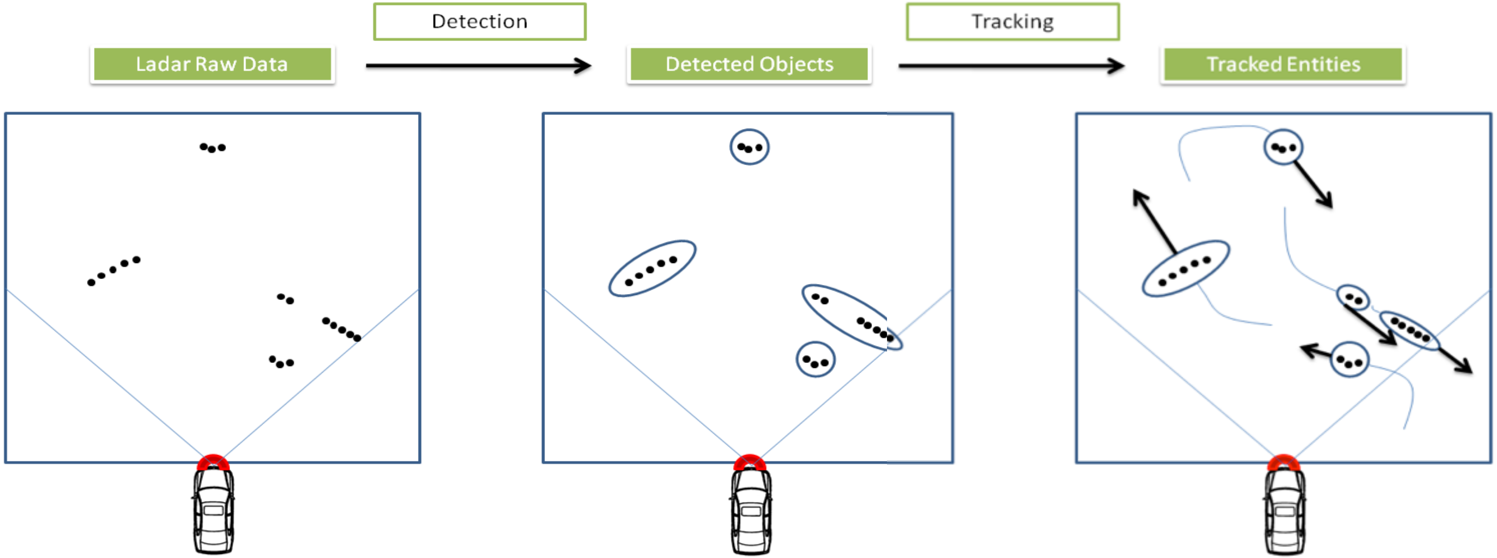
W4. Perception & Situation Awareness & Decision making

- 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)

DATMO : Intuitive definition (reminder)



Detect objects (e.g. clustering of Lidar data)

&

Track over time the moving entities (using previous detections)

Coutesy F. Nashashibi

Tracking moving objects – *What is it about?*

- **Question 1: What is moving objects tracking?**

  Intuitive definition: *Estimates how objects move in the observed dynamic scene*

- **Question 2: Why to track moving objects?**
  - **Decision** for driving assistance *(e.g. trajectories predictions, risk assessment, avoidance strategies…)*
  - Confirm the **existence of the moving objects** in the scene & **Characterize their motion parameters** *(to update the objects models)*
  - **Compute over time** the dynamic data of the scene

Tracking moving objects – *Outline*

Tracking = *Estimating over time the **states of multiple moving objects**, by using sets of observations (detection is done)*

- **Data association**
  - *Single-Scan - Global Nearest Neighbor (GNN)*
    Joint Probability Data Association (JPDA) *[Fortman 83]*
  - *N-Scan - Multiple Hypotheses Tracking (MHT)* *[Reid 78]*

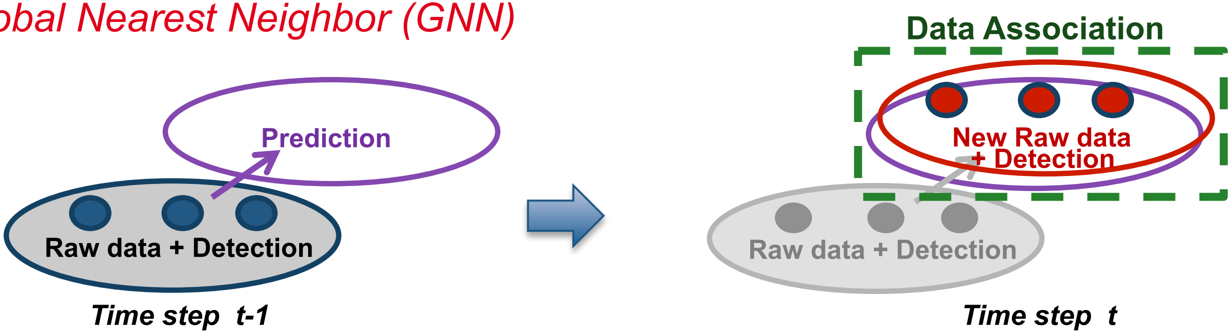
- **Filtering**
  - *Single-model - Kalman filter (KF, EKF, UKF)*
    Particle Filter (PF)
  - *Multiple-models - Interacting Multiple Models (IMM)*

- **Object representation**
  - *Point-based – JPDA + PF (Tracking people)* *[Schulz et al 01]*
    MHT + IMM (General Objects & Traffic) *[Wang 04]*
  - *Model vs Model-free*

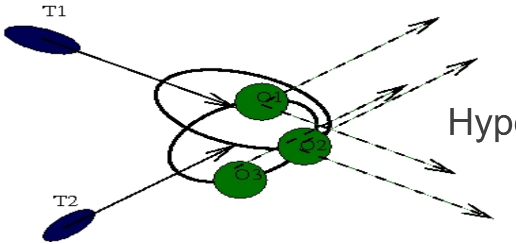
Tracking – *Data Association*

Data association = *Correspondence between the* ***observation*** *&* *the* ***predicted position*** *of a given object*

- ***Single-Scan*** **-** *Global Nearest Neighbor (GNN)*



- ***N-Scan*** **-** *Multiple Hypotheses Tracking (MHT)*

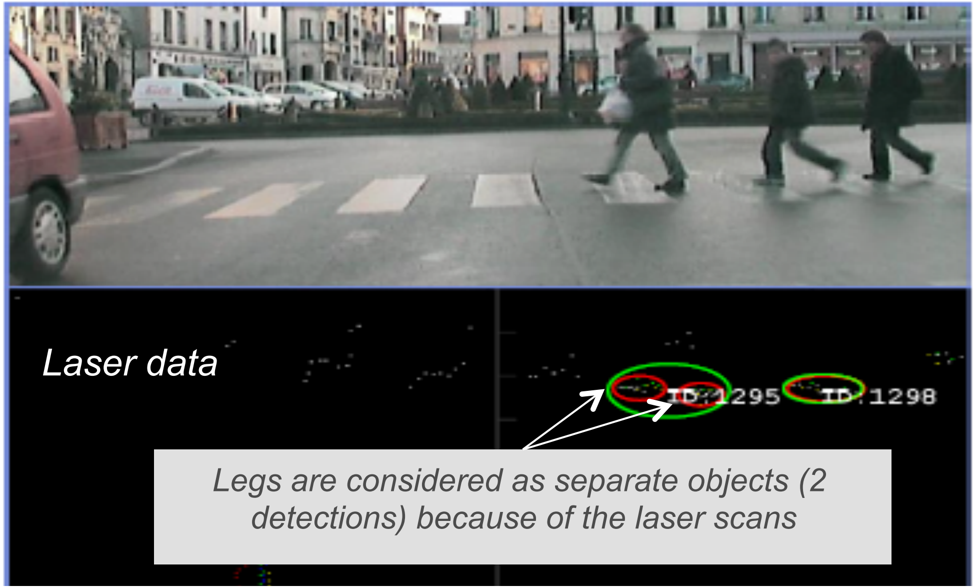


Difficulty:
Hypotheses tree management

Tracking – *Data Association*

Some well-known problems with data association methods

➔ *Ambiguity & Complexity (one object & several detections)*



Tracking – *Data Association*

Some well-known problems with data association methods

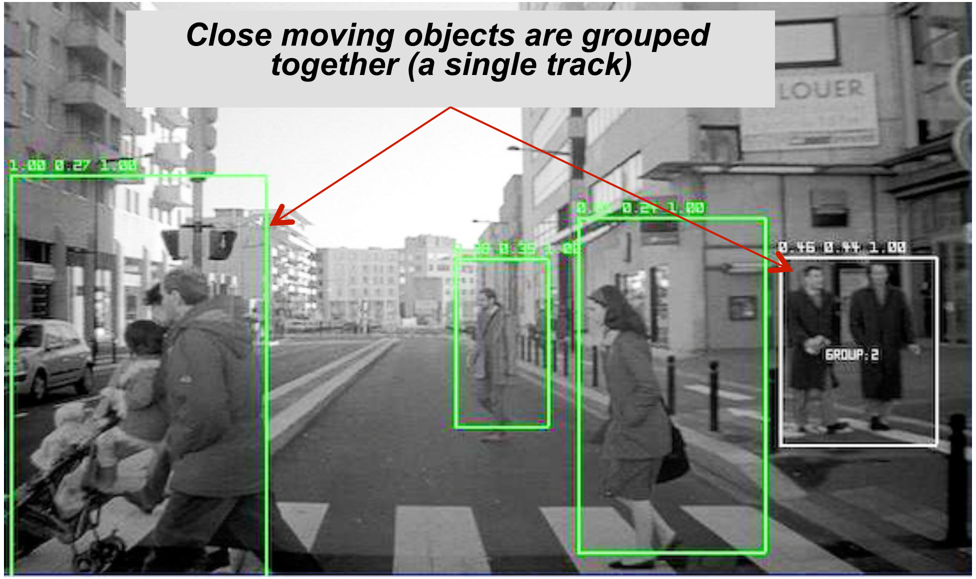
➔ *Ambiguity & Complexity (New object appearing close to an other tracked object)*

***New pedestrian** appearing in the scene, at roughly the position previously occupied by an other tracked pedestrian (highlighted by the red ellipse)*

Tracking – *Data Association*

Some well-known problems with data association methods

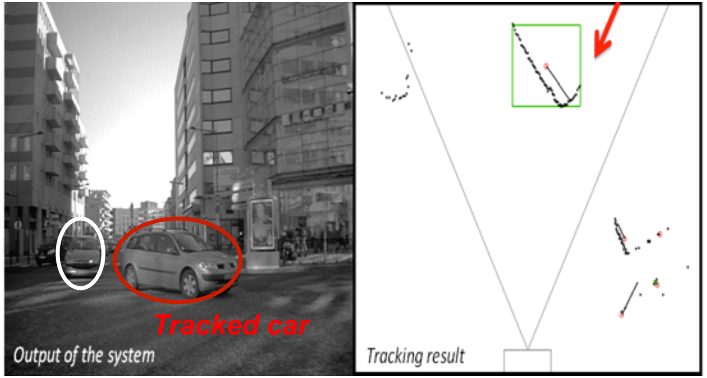
➔ *Ambiguity & Complexity (Close objects moving together)*



Tracking – *Data Association*

Some well-known problems with data association methods

➔ *Ambiguity & Complexity (A tracked object disappeared)*



Detection & Tracking at time t-1

Detection & Tracking at time t

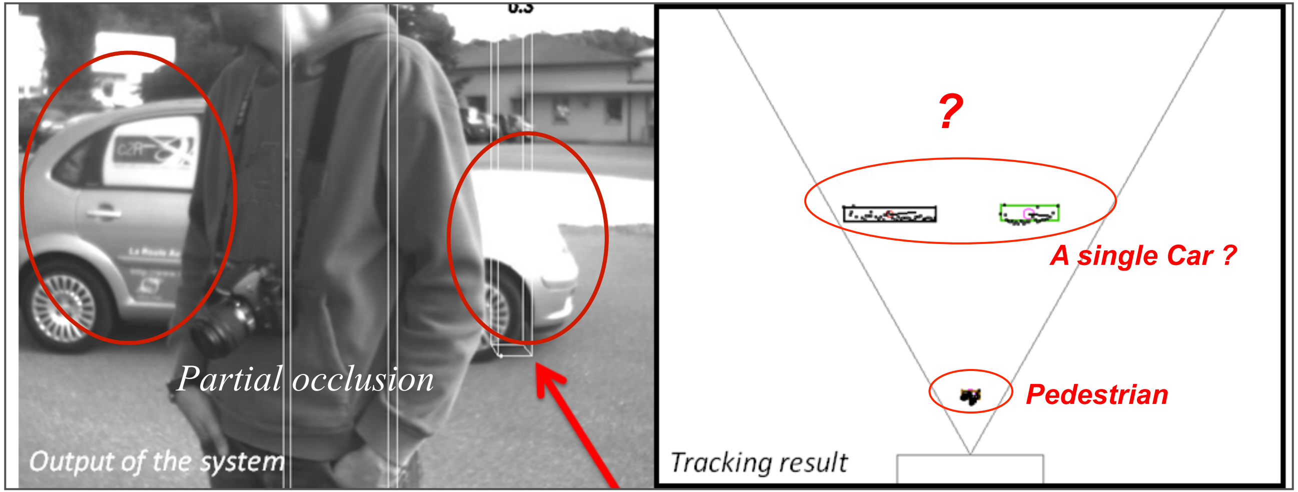
⇒ *too big change between two consecutive frames*

⇒ *the previously tracked car disappeared*

Tracking – *Data Association*

Some well-known problems with data association methods

➔ *Temporary Partial Occlusion (A tracked object is split in two parts because of temporary occlusion)*

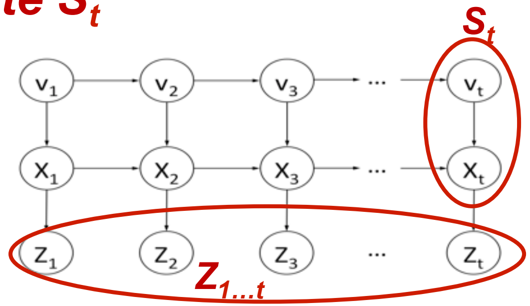


Tracking – *Filtering*

- **Filtering:** *Tracking a single object when **its observations are known over time***

Bayesian formulation: *Estimating the **belief over a state S_t** based on observations $Z_{1...t}$*

$\rightarrow$ $bel_t = P(S_t \mid Z_{1...t})$?



with:

- ***State (S_t)** = Position (X_t) + Velocity (V_t)*
- ***Markovian Hypothesis**: State at time t only depends on state at time t-1*

- **Recursive estimation**

$$bel_t = \eta \, p(Z_t|S_t) \int p(S_t|S_{t-1}) bel_{t-1} \, dS_{t-1}$$

Likelihood model ***Evolution model***

Tracking – *The filtering loop*

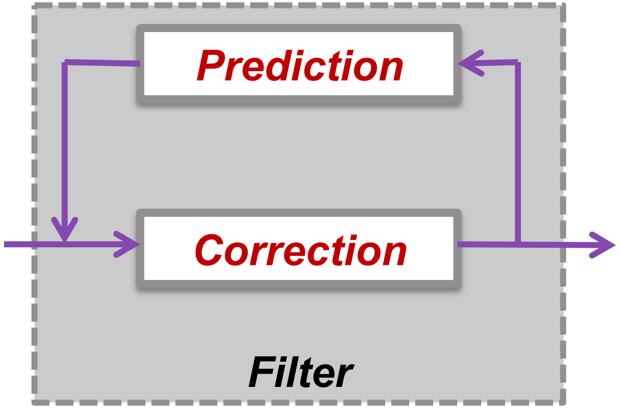
- **Prediction** *(using evolution model)*
  - Velocity model: P($\mathbf{V}_t$ | $\mathbf{V}_{t-1}$)
  - Motion model: P($\mathbf{X}_t$ | $\mathbf{X}_{t-1}$, $\mathbf{V}_t$)

  e.g. constant velocity model between time t-1 and time t

  ✓ $V_t = V_{t-1}$

  ✓ $X_t = X_{t-1} + V_{X,t} \,.\, dt$

  ✓ $Y_t = Y_{t-1} + V_{Y,t} \,.\, dt$



- **Correction** *(using observation model)*
  - Observation model : *P($\mathbf{Z}_t$ | $\mathbf{X}_t$)*

Exercise:

Expressing the Filtering loop using the Kalman Filter

- $X_t = F_t X_{t-1} + B_t U_t + W_t$ ➔ Prediction step

  with: $\boldsymbol{F_t}$ *= state transition (evolution model)*

  $\boldsymbol{U_t}$ *= control*

  $\boldsymbol{W_t}$ *= processed noise*

- $Z_t = G_t X_t + V_t$ ➔ Correction step

  with: $\boldsymbol{G_t}$ *= observation model*

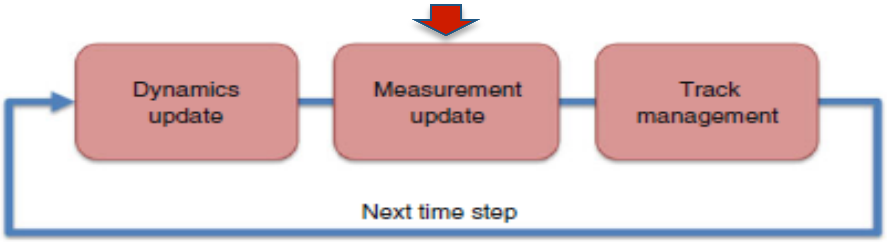
  $\boldsymbol{V_t}$ *= observation noise*

- *e.g. for constant velocity:* $F_t = \begin{bmatrix} 1 & 0 & dt & 0 \\ 0 & 1 & 0 & dt \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

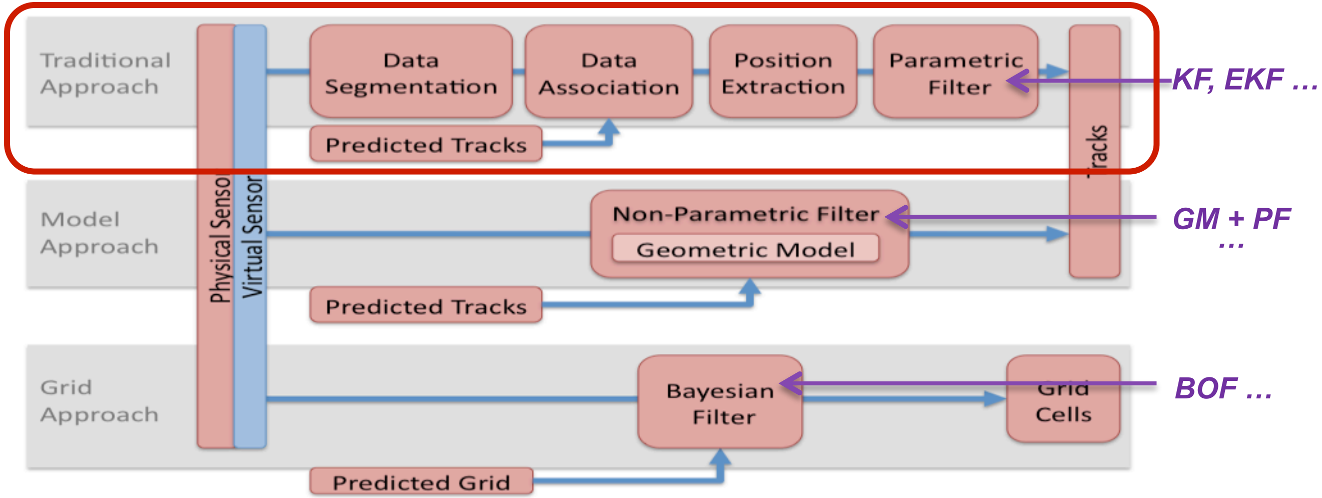
DATMO – *Outline & Main approaches*

[Handbook of IV 2012 (chap. 54)]

- Typical DATMO Pipeline

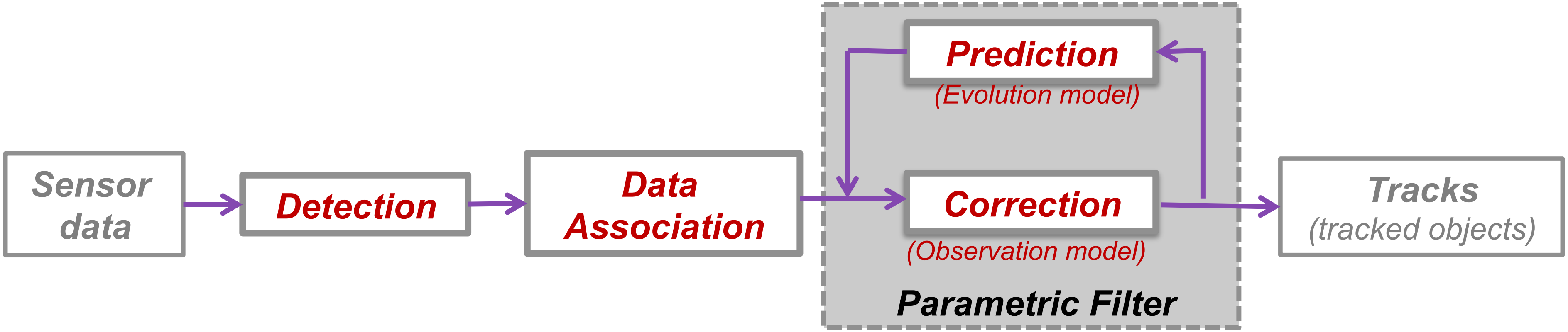


- Three main classes of DATMO Approaches



Traditional DATMO approaches – *Processing flow*

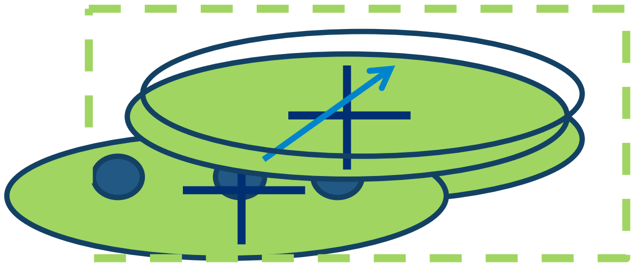
$$bel_t = \eta \underbrace{p(Z_t|S_t)}_{\text{Observation model}} \int \underbrace{p(S_t|S_{t-1})}_{\text{Evolution model}} bel_{t-1}\, dS_{t-1}$$



Traditional DATMO approaches – *Illustration*

- Raw data *(time t-1)*
- Detection
- Estimation /correction
- Prediction
- New data *(time t)*
- Detection
- Data Association
- Correction

….



Traditional DATMO Approaches – *Conclusion*

- Several possible implementations

- Works quite well on some **identified classes of problems**

  … but well-known problems with ***Laser-based Tracking*** *(point-clouds tracking)*

  & Data Association *still hold* => *Objects splitting, Appearing & disappearing targets, Errors in data associations …*

- Next session will show how to improve these approaches using "**Models**" or "**Grid Approaches**"