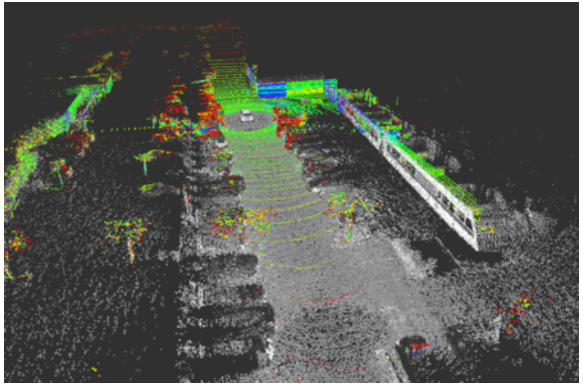
W4. Perception & Situation Awareness & Decision making

- 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)

Dynamic Probabilistic Grids (DP-Grids): *Objective*

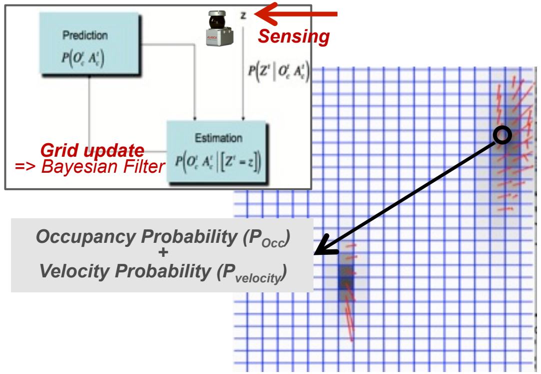
- **Perceive dynamic environment** using various imperfect sensors data *(noise, uncertainty …)*
- **Interpret data** through **Spatial Occupancy & Motion** representations
- **Perform real-time analysis** *=> usable on **embedded devices** for Mobile Robots & Intelligent Vehicles*
- **Allows conservative Collision Risk analysis** *(at DP-Grid level)*



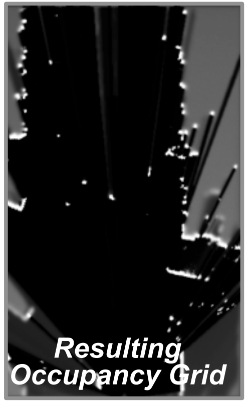
Bayesian Occupancy Filter (BOF): *Outline*

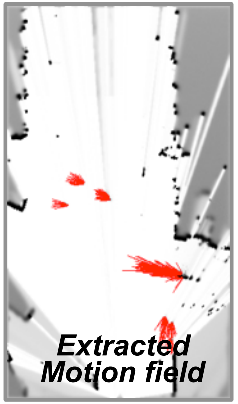
Main features:

- Estimate **Spatial occupancy**
- Analyze **Motion Field** *(using Bayesian filtering)*
- **Without object segmentation** *(i.e. at DP-Grid level)*



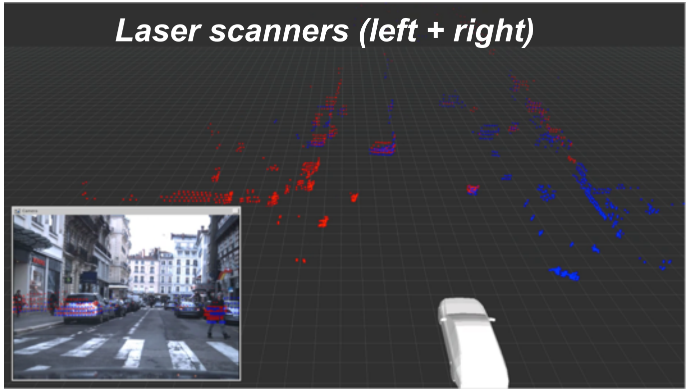
Sensors data fusion
+
Bayesian Filtering

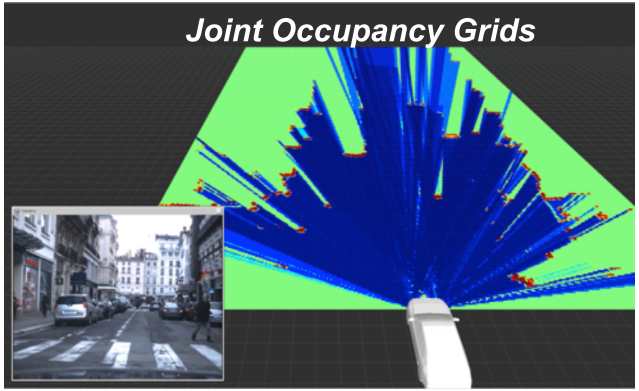




Data fusion: *The joint Occupancy Grid*

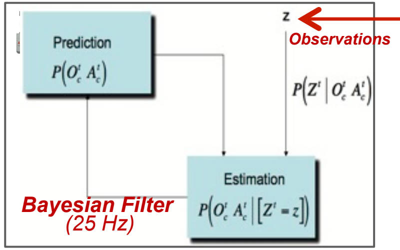
- **Observations Z_i** are given by each sensor *i* *(Lidars, cameras, etc)*
- For each set of observation Z_i , **Occupancy Grids are computed:** $P(O \mid Z_i)$
- Individual grids are **merged into a single one:** $P(O \mid Z)$



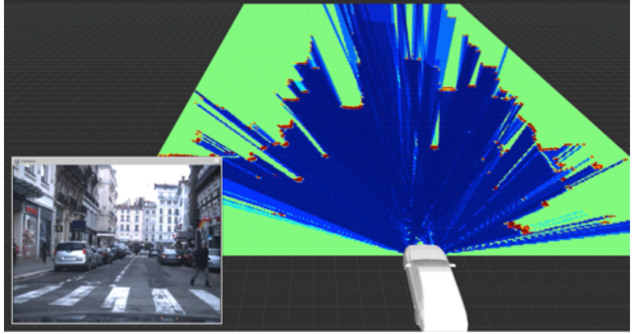


From instantaneous grids to a *Filtered Occupancy Grid* *(Bayesian filtering)*

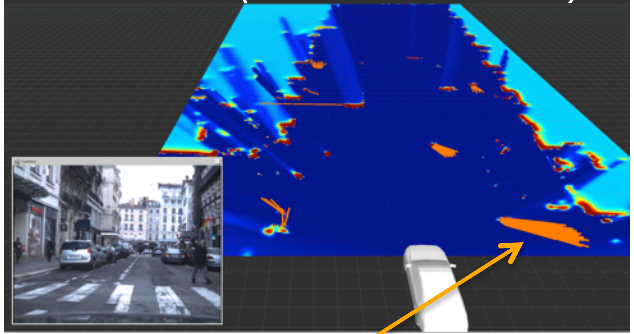
- **Filtering** is achieved through the ***prediction/correction loop (Bayesian Filter).*** It allows to take into account grid changes over time
- **Observations** are used to update the environment model
- **Update is performed in each cell in parallel** *(using BOF equations)*
- **Motion field** is constructed from the resulting filtered data



Instantaneous OG



Filtered OG (includes motion field)



Motion field is represented in orange color

Bayesian Occupancy Filter – *Formalism*

- **Features to be assessed** are represented by *Random Variables*

  ex : X1, X2, X3, …

- **Dependencies between the variable distributions** are made explicit using *Bayesian expressions*

  ex : $P(XYZ) = P(X)\ \ P(Y \mid X)\ \ P(Z \mid Y)$

- The **distributions** are updated *according to sensors observations*

- **Interpretation** is achieved *using the obtained distributions*

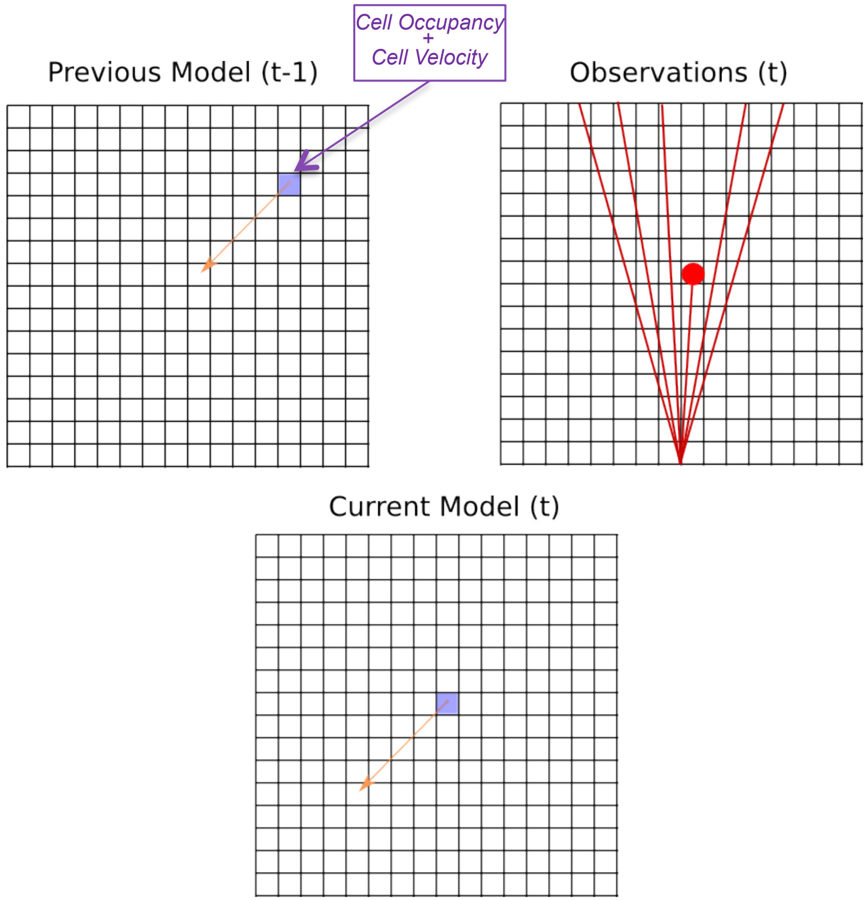
Bayesian Occupancy Filter – *Formalism*

Variables:

- *C : current cell*
- *A : antecedent cell, i.e. the cell from which the occupancy of the current cell comes from*
- *O : occupancy of the current cell C*
- *O^{-1} : previous occupancy in the antecedent cell*
- *V : current velocity*
- *V^{-1} : previous velocity in the antecedent*
- *Z : observations (sensor data)*

Objective:

- *P(O V | Z C) : probability of occupancy & velocity, knowing the cell location & the observations*



Bayesian Occupancy Filter – *Formalism*

Variables:

- ***C* : *current cell*** *(time t)*
- *A : antecedent cell, i.e. the cell from which the occupancy of the current cell comes from*
- *O : occupancy of the current cell C*
- *O^{-1} : previous occupancy in the antecedent cell A*
- *V : current velocity*
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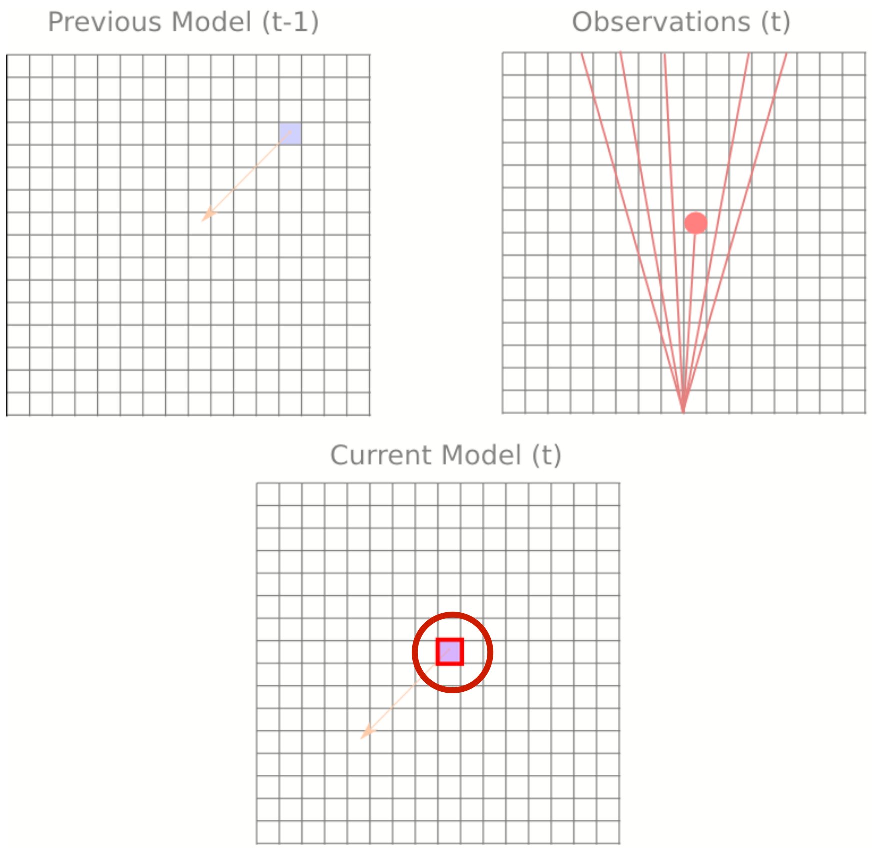

Bayesian Occupancy Filter – *Formalism*

***Variables**:*

- *C : current cell*
- ***A : antecedent cell** (time t-1), **i.e. the cell from which the occupancy of the current cell C** (time t) **comes from***
- *O : occupancy of the current cell C*
- *O^{-1} : previous occupancy in the antecedent cell A*
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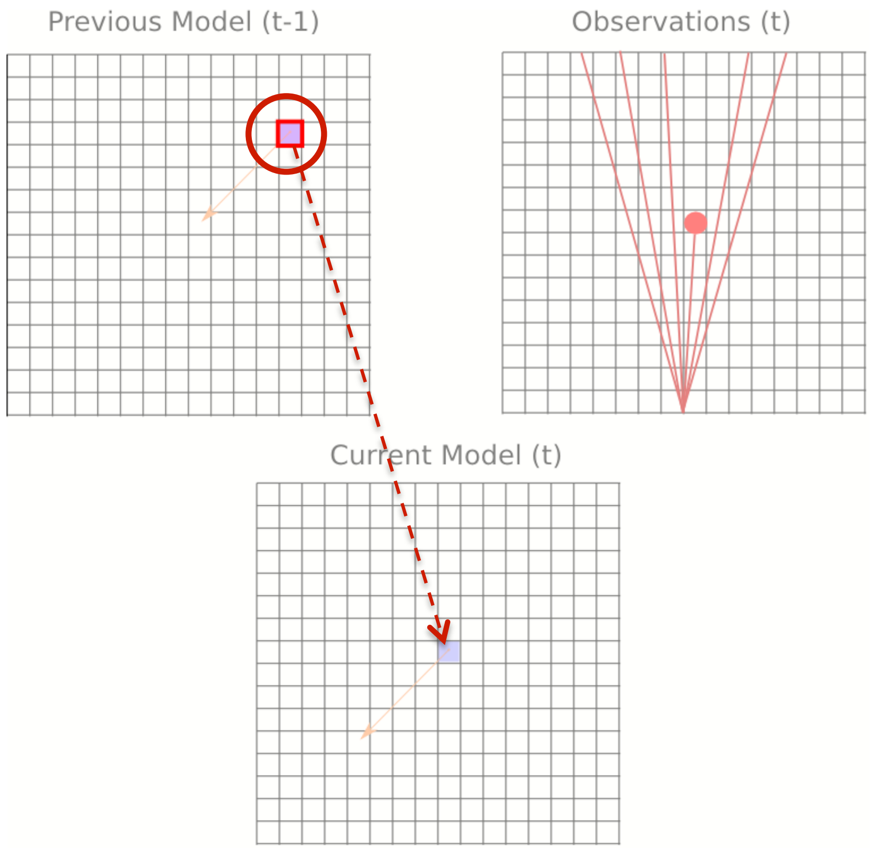

***Objective**:*

- *P(O V | Z C) : probability of occupancy & velocity, knowing the cell location & the observations*

Bayesian Occupancy Filter – *Formalism*

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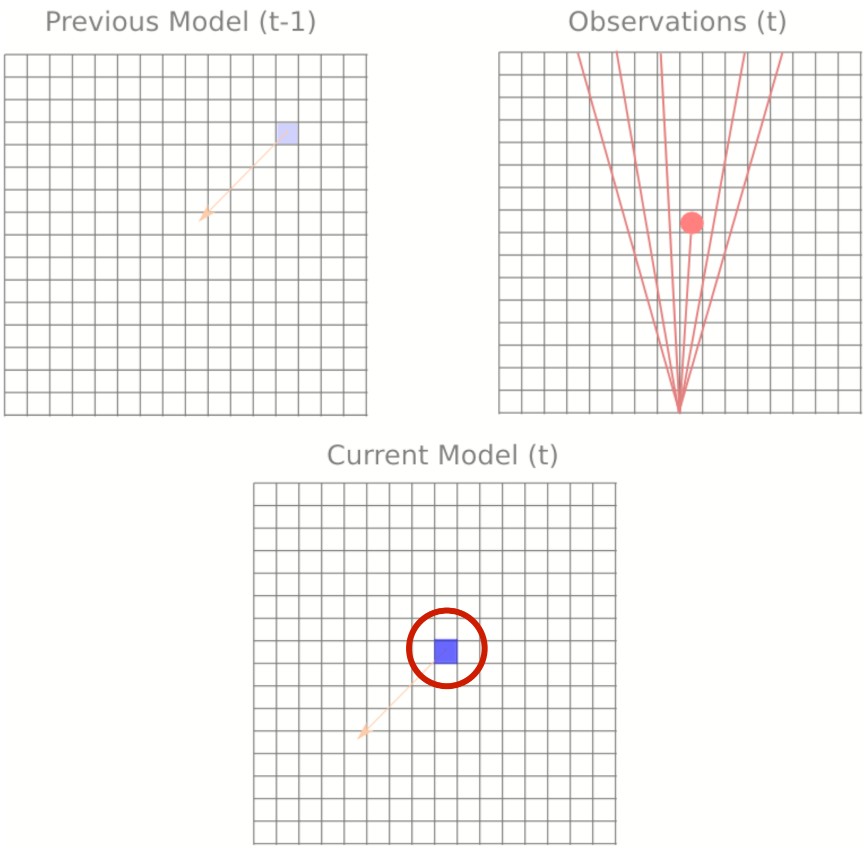

Bayesian Occupancy Filter – *Formalism*

***Variables**:*

- *C : current cell*
- *A : antecedent cell, i.e. the cell from which the occupancy of the current cell comes from*
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- *V : current velocity*
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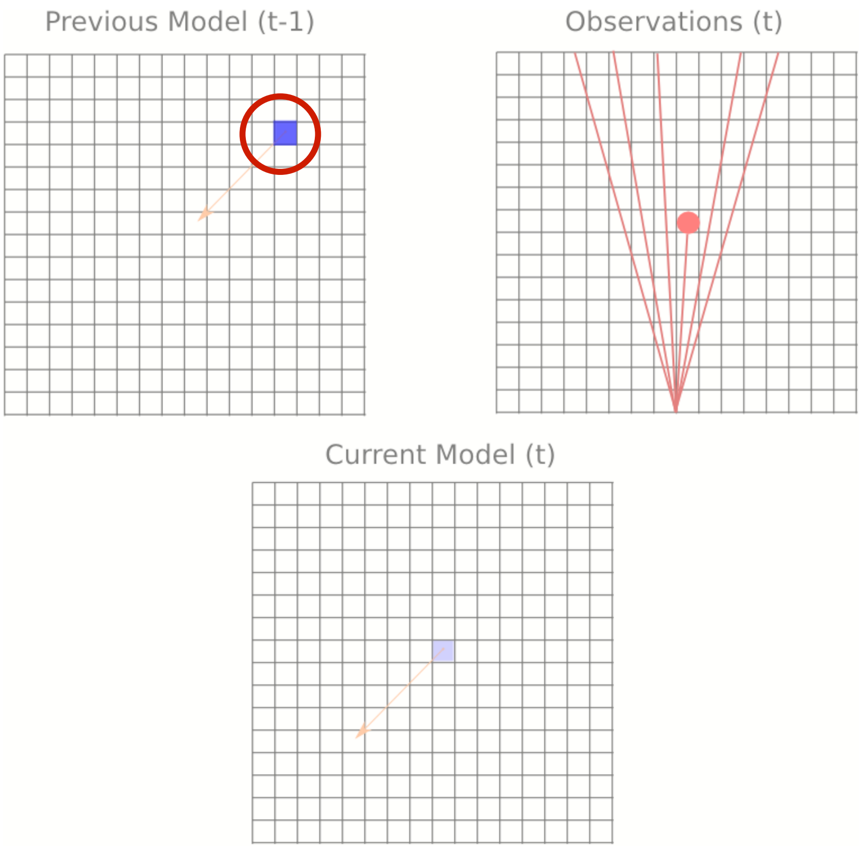

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Bayesian Occupancy Filter – *Formalism*

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- *O^{-1} : previous occupancy in the antecedent cell*
- ***V : current velocity in cell C** (time t)*
- *V^{-1} : previous velocity in the antecedent*
- *Z : observations (sensor data)*

***Objective**:*

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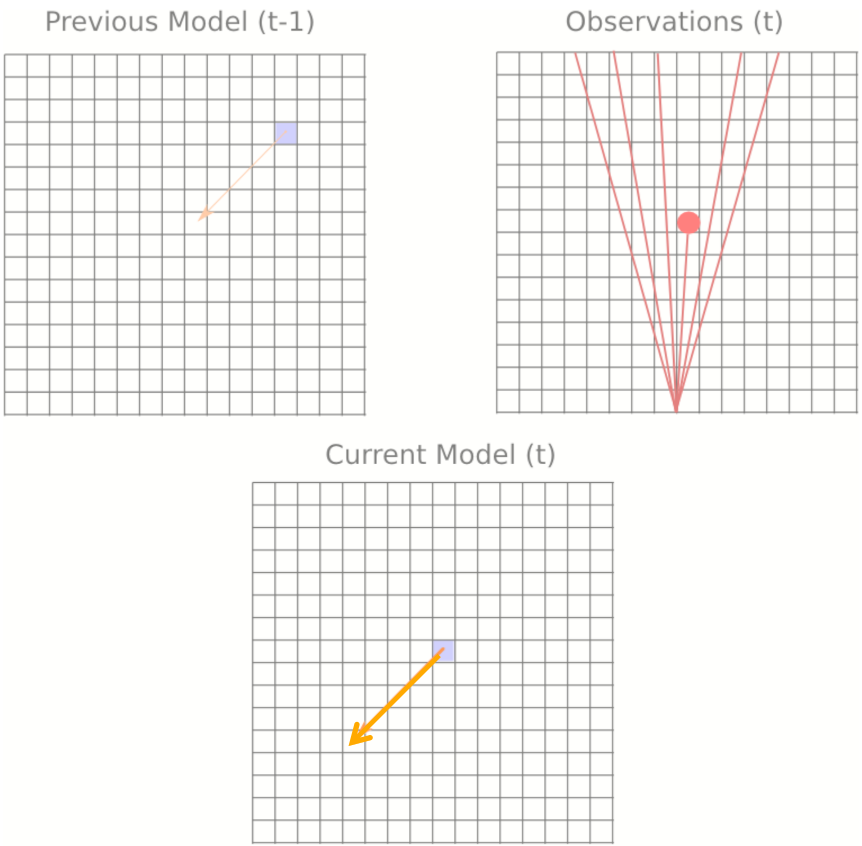

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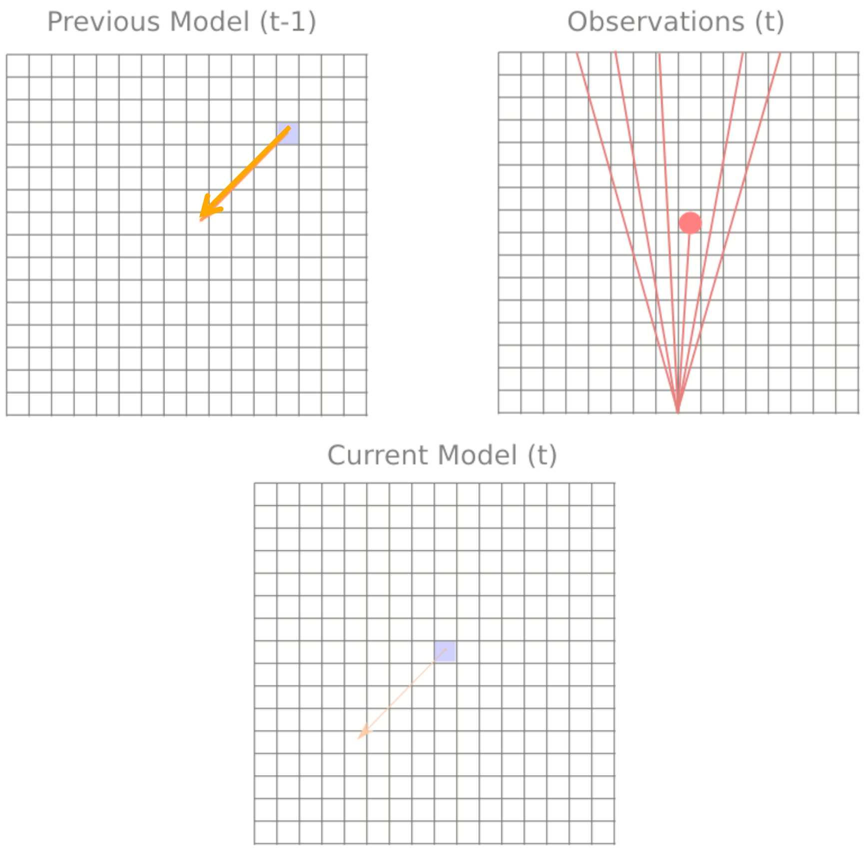

Bayesian Occupancy Filter – *Formalism*

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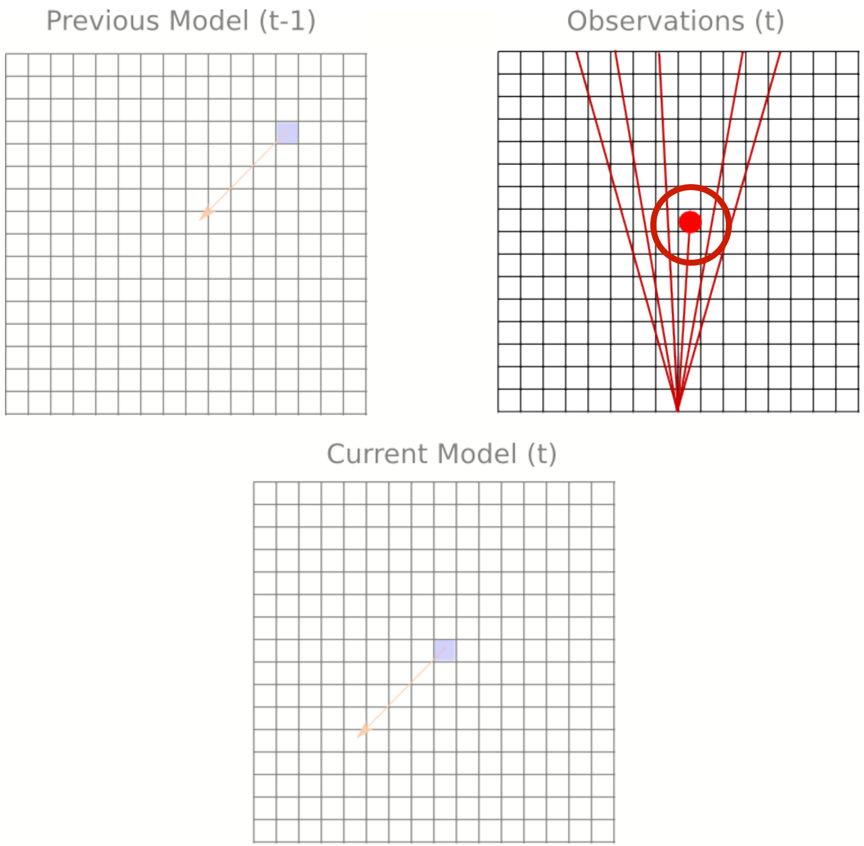
- *V : current velocity*
- *V^{-1} : previous velocity in the antecedent*
- ***Z : observations (sensor data)** at time t*

Objective:

- *P(O V | Z C) : probability of occupancy & velocity, knowing the cell location & the observations*



Bayesian Occupancy Filter – *Formalism*

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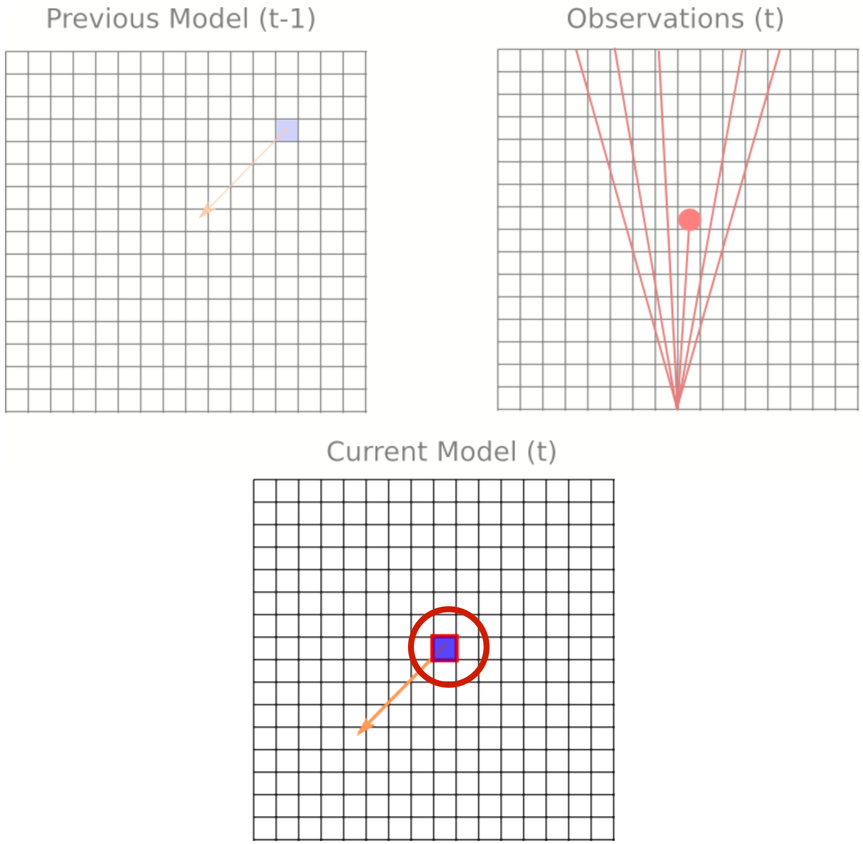

Objective:

- ***Evaluate P(O V | Z C) :** Probability of **Occupancy & Velocity** for each cell C, knowing the **observations Z** and the cell **location C** in the grid*

Bayesian Occupancy Filter – *How to theoretically compute P(O V | Z C)?*

$$P(O\,V\,|\,Z\,C)=\lambda\sum_{A\,O^{-1}\,V^{-1}}P(C\,A\,O\,O^{-1}\,V\,V^{-1}\,Z)$$

Sum over the possible antecedents A and their states (O^{-1} V^{-1})

The joint probability term can be re-written as follows:

$$P(C\,A\,O\,O^{-1}\,V\,V^{-1}\,Z) = P(A)\;\;P(O^{-1}\,V^{-1}\,|\,A)\;\;P(O\,V\,|\,O^{-1}\,V^{-1})\;\;P(C\,|\,A\,V)\;\;P(Z\,|\,O\,C)$$

Joint probability

=> used for the update of P(O V | Z C)

Bayesian Occupancy Filter – *How to theoretically compute P(O V | Z C)?*

$$P(O\,V \mid Z\,C) = \lambda \sum_{A\,O^{-1}\,V^{-1}} P(C\,A\,O\,O^{-1}\,V\,V^{-1}\,Z)$$

Sum over the possible antecedents A & their states (O^{-1} V^{-1}) of :

$P(C\,A\,O\,O^{-1}\,V\,V^{-1}\,Z) =$ $\boxed{\mathbf{P(A)}\ \ P(O^{-1}\,V^{-1} \mid A)\ \ P(O\,V \mid O^{-1}\,V^{-1})\ \ P(C \mid A\,V)\ \ P(Z \mid O\,C)}$

P(A) *: Selected as* ***uniform***

=> every cell can a priori be an antecedent of C

Bayesian Occupancy Filter – *How to theoretically compute P(O V | Z C)?*

$$P(O\,V\,|\,Z\,C) = \lambda \sum_{A\,O^{-1}\,V^{-1}} P(C\,A\,O\,O^{-1}\,V\,V^{-1}\,Z)$$

Sum over the possible antecedents A & their states (O^{-1} V^{-1}) of :

$P(C\,A\,O\,O^{-1}\,V\,V^{-1}\,Z) =$ $P(A)$ $\mathbf{P(O^{-1}\,V^{-1}\,|\,A)}$ $P(O\,V\,|\,O^{-1}\,V^{-1})$ $P(C\,|\,A\,V)$ $P(Z\,|\,O\,C)$

$P(O^{-1}\,V^{-1}\,|\,A)$ *: Result from the previous iteration*

Bayesian Occupancy Filter – *How to theoretically compute P(O V | Z C)?*

$$P(O\,V\,|\,Z\,C) = \lambda \sum_{A\,O^{-1}\,V^{-1}} P(C\,A\,O\,O^{-1}\,V\,V^{-1}\,Z)$$

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$P(C\,A\,O\,O^{-1}\,V\,V^{-1}\,Z) = P(A)\;\; P(O^{-1}\,V^{-1}\,|\,A)\;\; \boldsymbol{P(O\,V\,|\,O^{-1}\,V^{-1})}\;\; P(C\,|\,A\,V)\;\; P(Z\,|\,O\,C)$

$P(O\,V\,|\,O^{-1}\,V^{-1})$: *Dynamic model*

Bayesian Occupancy Filter – *How to theoretically compute P(O V | Z C)?*

$$P(O\,V\,|\,Z\,C) = \lambda \sum_{A\,O^{-1}\,V^{-1}} P(C\,A\,O\,O^{-1}\,V\,V^{-1}\,Z)$$

Sum over the possible antecedents A & their states (O^{-1} V^{-1}) of :

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P(C | A V) *:* ***Indicator function*** *of the cell* ***C*** *corresponding to the “****projection****” in the grid of the antecedent* ***A*** *at a given velocity* ***V***

Bayesian Occupancy Filter – *How to theoretically compute P(O V | Z C)?*

$$P(O\,V \mid Z\,C) = \lambda \sum_{A\,O^{-1}\,V^{-1}} P(C\,A\,O\,O^{-1}\,V\,V^{-1}\,Z)$$

Sum over the possible antecedents A & their states (O^{-1} V^{-1}) of :

$P(C\,A\,O\,O^{-1}\,V\,V^{-1}\,Z) =$ $P(A)$ $P(O^{-1}\,V^{-1} \mid A)$ $P(O\,V \mid O^{-1}\,V^{-1})$ $P(C \mid A\,V)$ $\mathbf{P(Z \mid O\,C)}$

P(Z | O C) *: Sensor model*

Bayesian Occupancy Filter – *Main properties*

- **Bayesian Filtering Method** for implementing the DP-Grid formalism
  => Occupancy probability & Velocity probability
- **Integrates raw sensor data** into a coherent model of the environment
- **Highly parallelizable** framework
- Allow to construct **Static Map** & to extract **Motion Field.** It also allow to perform conservative short-term motion prediction *=> see session 7*