Master in Computer Vision
Barcelona

Module: Video Analysis

Lecture 6: Bayesian tracking (III)

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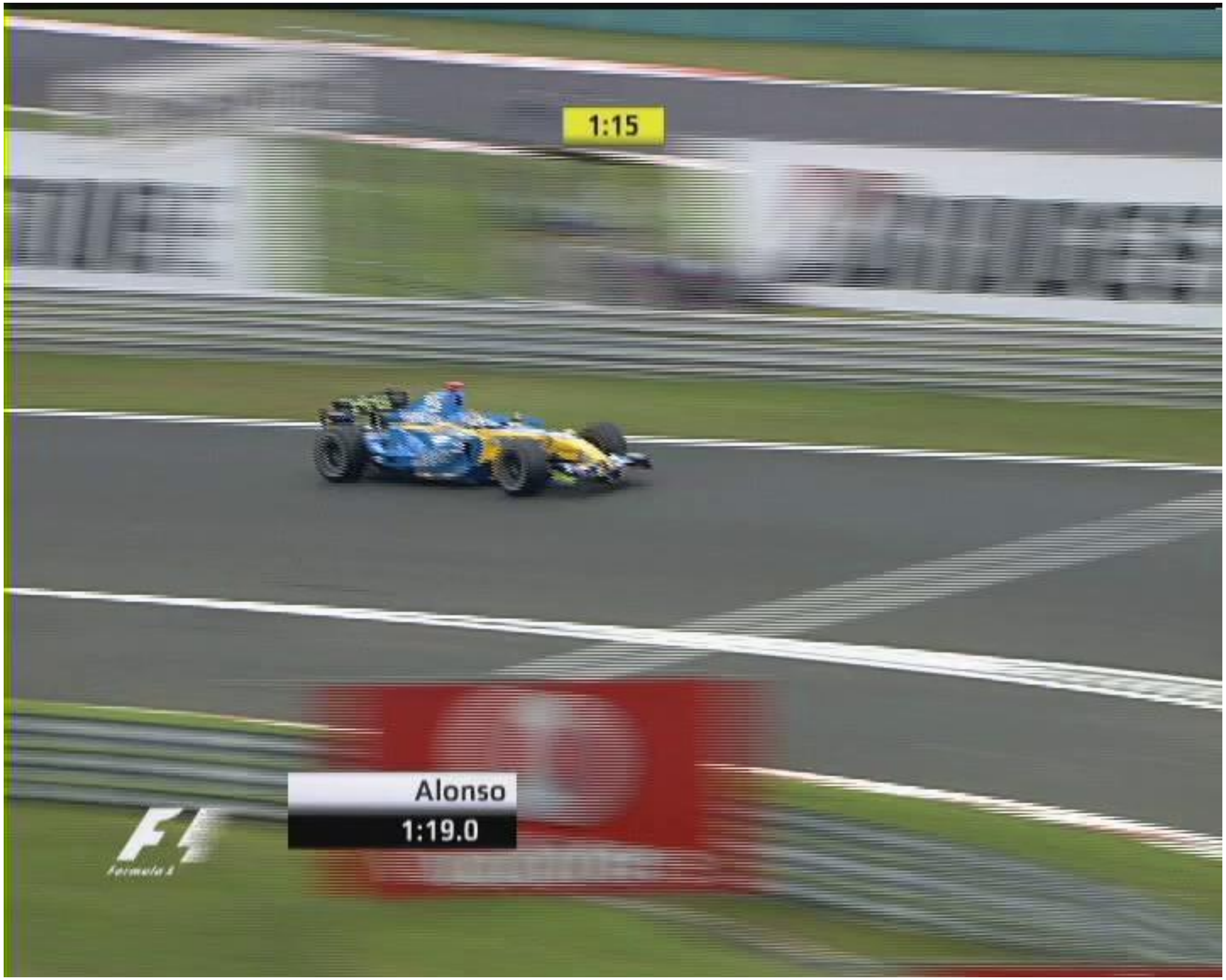
Slides: David Varas

Presentation Outline

- Introduction
- **Problem statement: F1 car tracking**
- **Application: F1 car tracking**
- **References**

Problem Statement: F1 car tracking

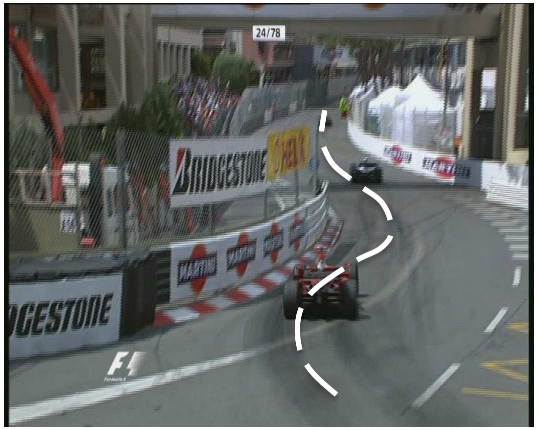
Motivation



Problem Statement: F1 car tracking

Problem statement

- Dynamics of a F1 car



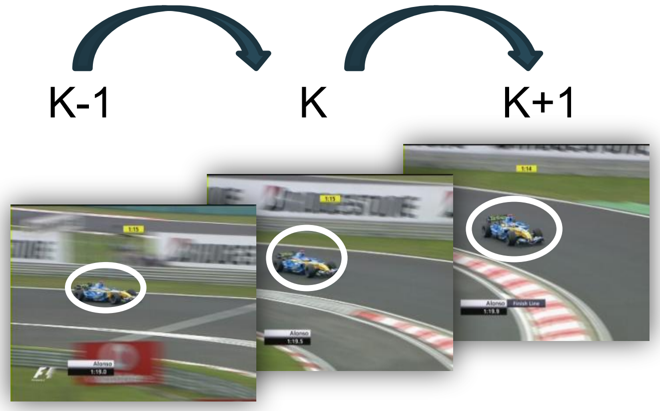
- “Correct” path is defined by a curve
- Abrupt trajectory changes (Other cars, colisions, …)
- Camera movement

Linear dynamic models may not hold!

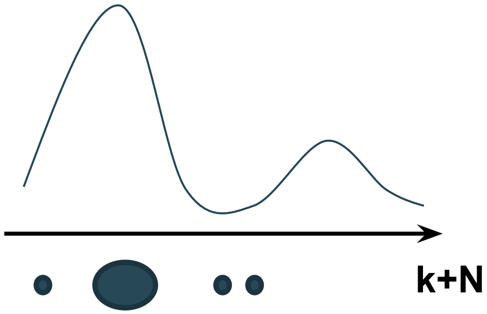
Problem Statement: F1 car tracking

Problem statement

- Recursively estimate the position of a F1 car along a sequence



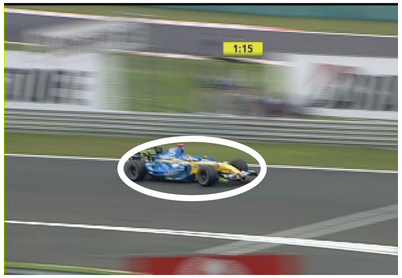
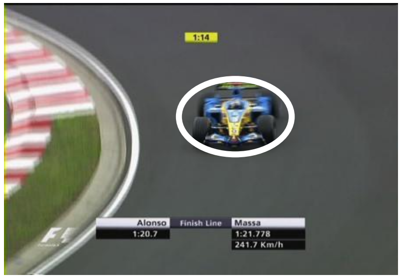
- The Degeneracy Problem appears due to this recursivity



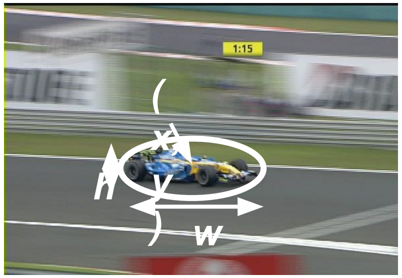
Application

F1 car tracking

- **Objective:** Track a car along the sequence using an ellipse


- **State Vector and Measurement Vector**
  - **State** of the system represents the parametrization of an ellipse tracking the real object
  - The noisy **measurement** is the input **image** received at each time instant.



State Vector

$$x_k = [x, y, w, h]$$

Measurement Vector

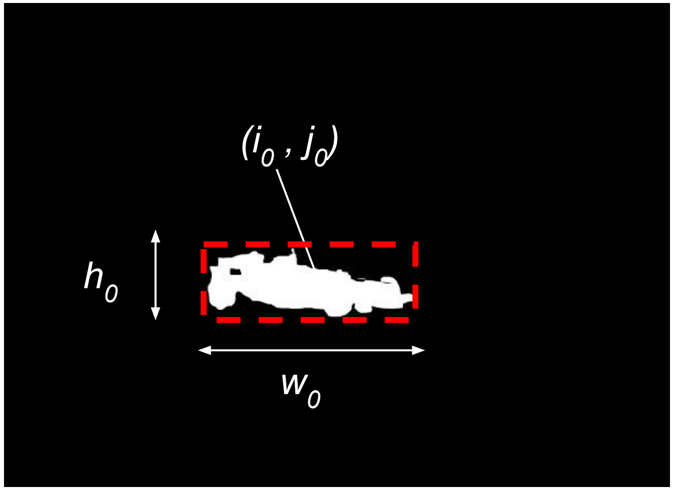
$$z_k$$

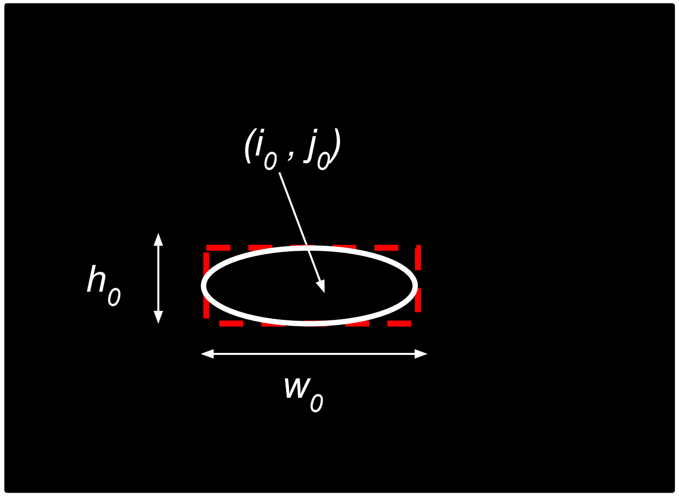
Application

F1 car tracking

- Initial state of the system x_0

SEGMENTATION OF THE OBJECT ➔ -Manually
-Detection algorithms





Application

F1 car tracking

- **Object model**

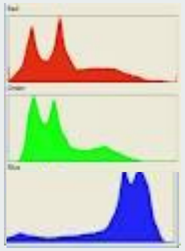
The algorithm must know what to track. Several ways to **characterize objects** in images.

- Characterization of the target
  - Color features
  - Texture features
  - Movement features
  - …

Normalized Histogram of the object

-Scale invariant

-Rotation invariant



Application

F1 car tracking

- Iteration of the algorithm (N_s = 8 particles)

▪FOR $i = 1{:}N_s$
  I. Draw $x_k^i \sim p(x_k | x^i_{k-1})$ — Propagate
  II. Calculate $w^i_k = p(z_k | x^i_k)$ — Evaluate
▪END FOR

▪Calculate total weight: $t = \mathrm{SUM}[\{w^i_k\}_{i=1:Ns}]$

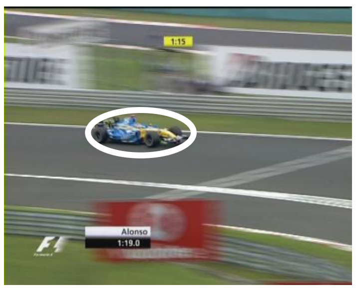
▪FOR $i = 1{:}N_s$ — Normalize
  I. Normalize $w^i_k = t^{-1} w^i_k$
▪END FOR

▪Resample — Resample

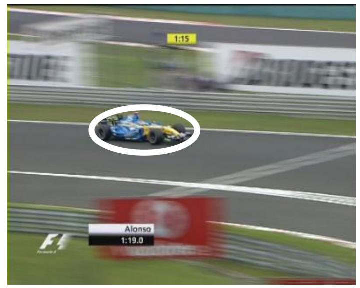
Application

F1 car tracking

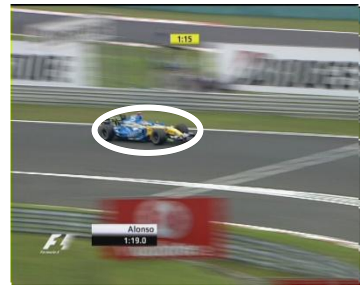
- Initialization (k = 0)



$w^1_1 = 0.125$



$w^2_1 = 0.125$



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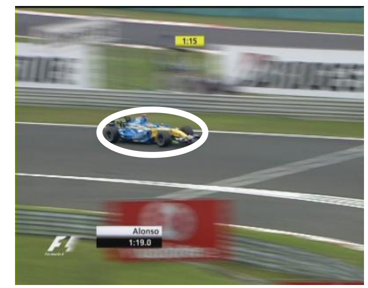

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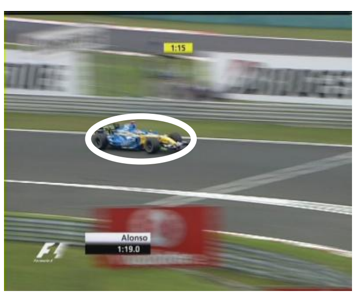
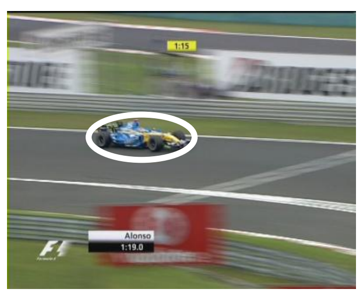
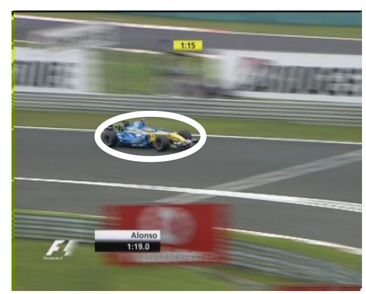


$w^5_1 = 0.125$



$w^6_1 = 0.125$



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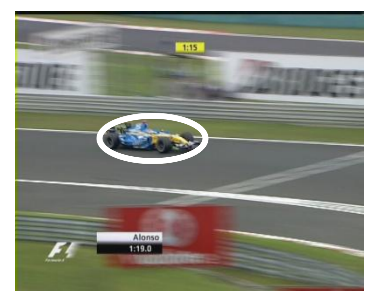


$w^8_1 = 0.125$

Application

F1 car tracking

- Propagation at k=1

▪FOR $i = 1{:}N_s$

I. Draw $x_k^i \sim p(x_k | x^i_{k-1})$ — Propagate

II. Calculate $w^i_k = p(z_k | x^i_k)$ — Evaluate

▪END FOR

▪Calculate total weight: $t = \mathrm{SUM}[\{w^i_k\}_{i=1:Ns}]$

▪FOR $i = 1{:}N_s$ — Normalize

I. Normalize $w^i_k = t^{-1} w^i_k$

▪END FOR

▪Resample — Resample

Application

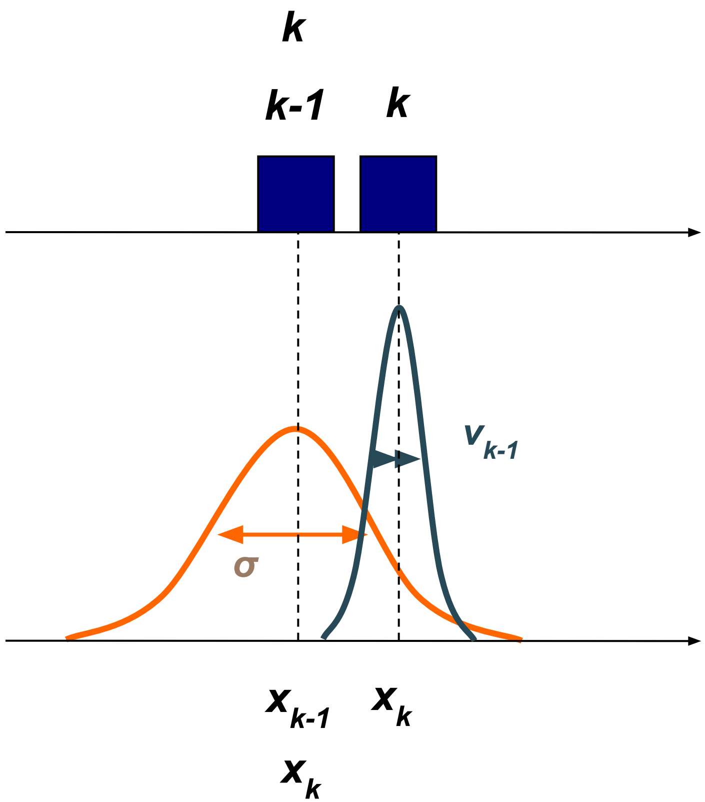
F1 car tracking

- Propagation at k=1
  - Draw ***(PREDICTION)***
    - If $\varphi(\cdot)$ is know:

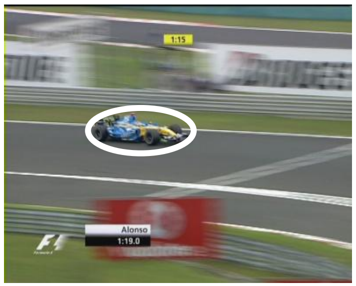
      $$\mathrm{x}_{\mathrm{k}}^{\mathrm{i}} = \varphi\left(\mathrm{x}_{\mathrm{k-1}}^{\mathrm{i}}, v_{k-1}^{i}\right)$$

    - Otherwise:

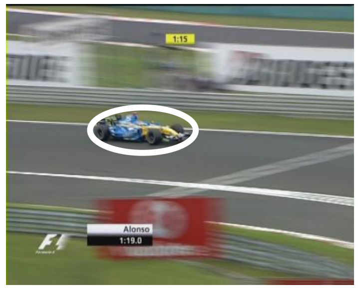
      $$x_k^i = N\left(x_{k\text{-}1}^i, \sigma\right)$$



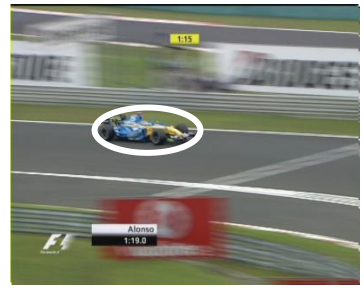
Application



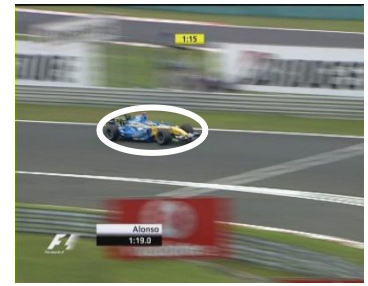
$w^1{}_1 = 0.125$



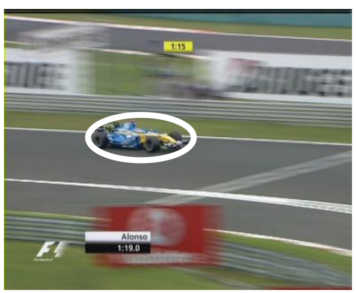
$w^2{}_1 = 0.125$



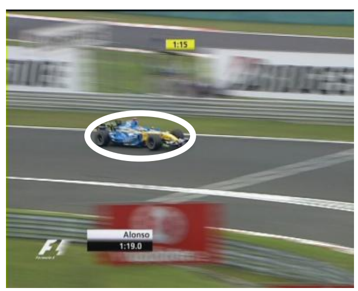
$w^3{}_1 = 0.125$



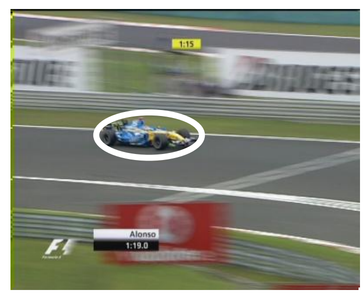
$w^4{}_1 = 0.125$



$w^5{}_1 = 0.125$



$w^6{}_1 = 0.125$



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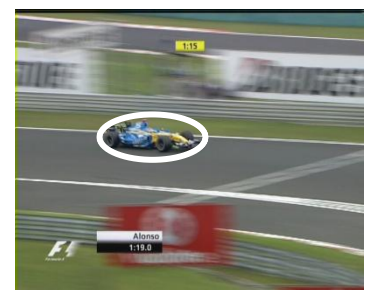
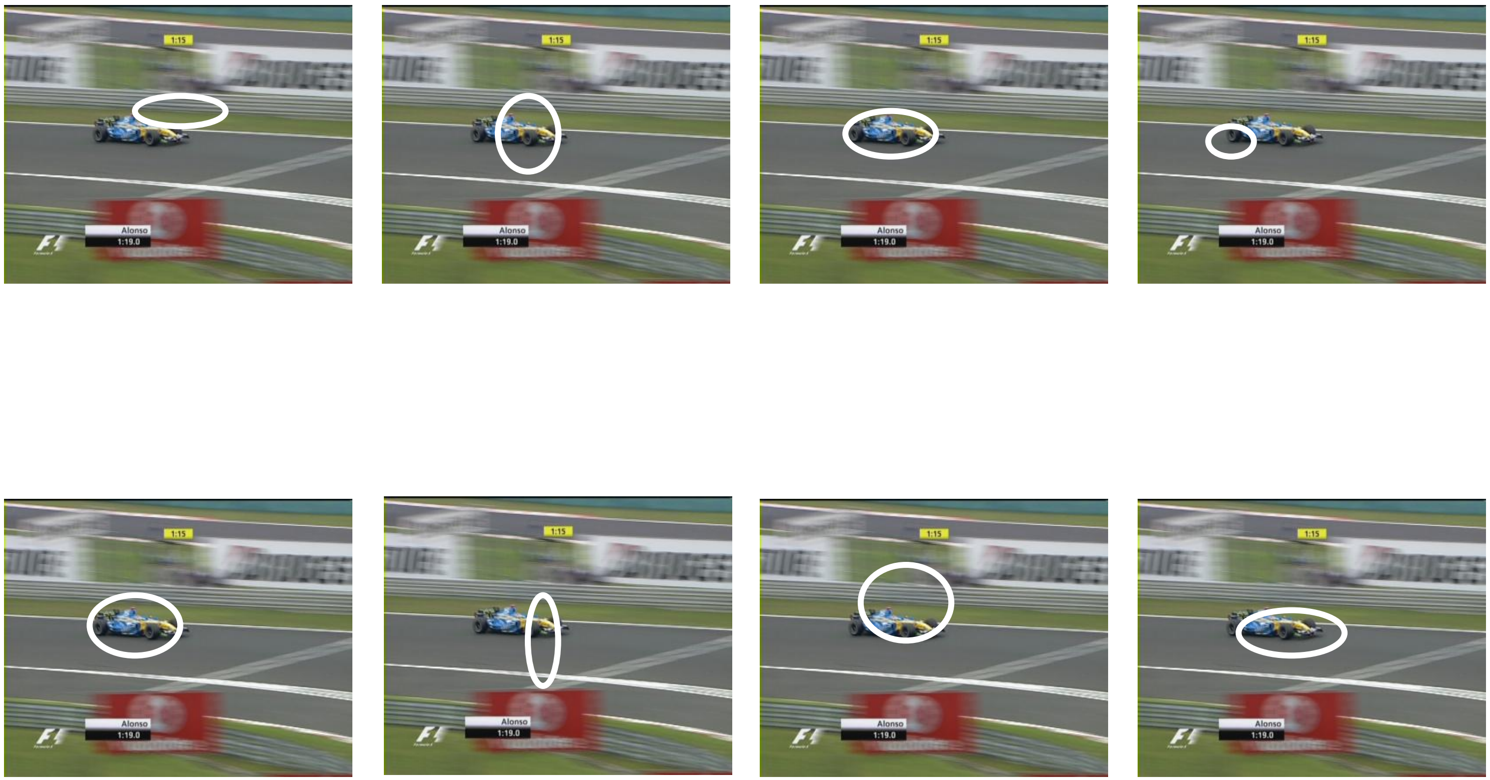


$w^8{}_1 = 0.125$

Application



Application

F1 car tracking

- Evaluation at k = 1

▪FOR $i = 1:N_s$

I. Draw $x_k^i \sim p(x_k | x^i_{k-1})$ — Propagate

II. Calculate $w^i_k = p(z_k | x^i_k)$ — Evaluate

▪END FOR

▪Calculate total weight: $t = \text{SUM}[\{w^i_k\}_{i=1:Ns}]$

▪FOR $i = 1:N_s$ — Normalize

I. Normalize $w^i_k = t^{-1} w^i_k$

▪END FOR

▪Resample — Resample

Application

F1 car tracking

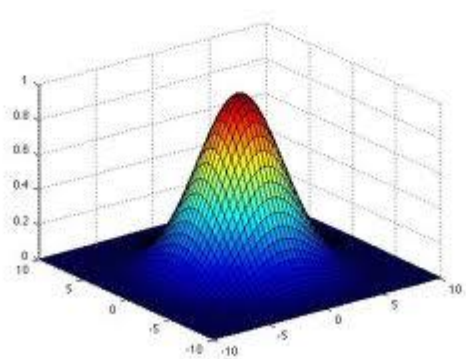
- Evaluation at k=1

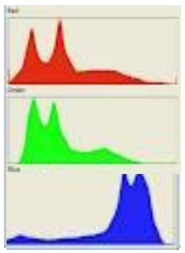
  - A new **measurement** arrives at time k = 1 ***(UPDATE)***
    We haven't made use of the image at time k = 1 yet. $w_k^i \propto p(z_k \mid x_k^i)$

  - **Likelihood measure**

$$p(z_k \mid x_k^i) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{d^2}{2\sigma^2}}$$

$$d = \sqrt{1 - \sum_{u=1}^{m} \sqrt{p^{(u)} q^{(u)}}}$$





Application

$w^1_1 = 0.08$

$w^2_1 = 0.66$

$w^3_1 = 0.81$

$w^4_1 = 0.01$

$w^5_1 = 0.72$

$w^6_1 = 0.14$

$w^7_1 = 0.45$

$w^8_1 = 0.85$

Application

F1 car tracking

- Normalization at k = 1

▪FOR $i = 1{:}N_s$
- I. Draw $x_k^i \sim p(x_k | x^i_{k-1})$ — Propagate
- II. Calculate $w^i_k = p(z_k | x^i_k)$ — Evaluate

▪END FOR

▪Calculate total weight: $t = \mathrm{SUM}[\{w^i_k\}_{i=1:Ns}]$ — Normalize

▪FOR $i = 1{:}N_s$
- I. Normalize $w^i_k = t^{-1} w^i_k$

▪END FOR

▪Resample — Resample

Application

$w^{1}_{1} = 0.00$

$w^{2}_{1} = 0.18$

$w^{3}_{1} = 0.22$

$w^{4}_{1} = 0.01$

$w^{5}_{1} = 0.19$

$w^{6}_{1} = 0.04$

$w^{7}_{1} = 0.12$

$w^{8}_{1} = 0.23$

Application

F1 car tracking

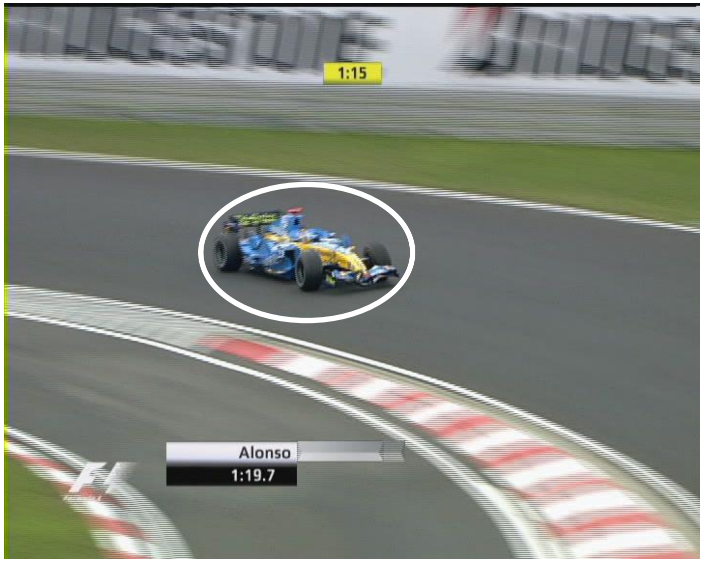
- Estimation at k=1

  - **Mean state of the system**

$$E[X_k] = \sum_{n=1}^{N_s} w_k^i x_k^i$$

$$\left\{ \begin{array}{l} \text{-Position} \\ \text{-Width} \\ \text{-Height} \end{array} \right.$$

  - Particle with higher weight



Application

F1 car tracking

- SIR Particle Filter algorithm

▪FOR $i = 1{:}N_s$

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▪END FOR

▪Calculate total weight: $t = \text{SUM}[\{w^i_k\}_{i=1:Ns}]$

▪FOR $i = 1{:}N_s$ — Normalize

I. Normalize $w^i_k = t^{-1} w^i_k$

▪END FOR

▪Resample — Resample

Application

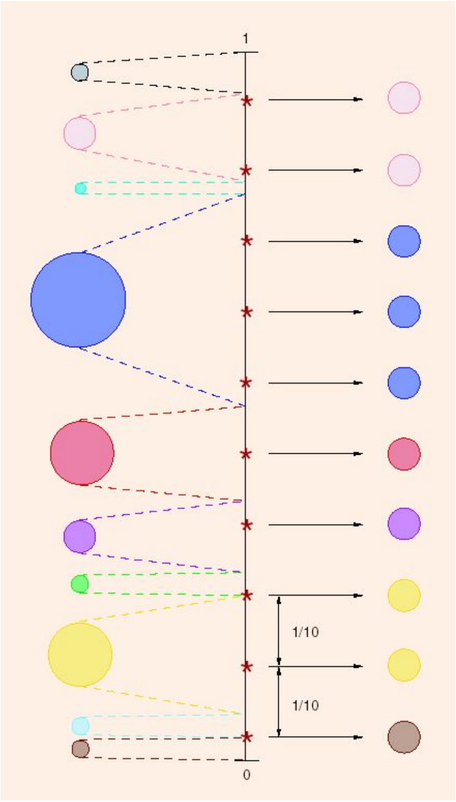
F1 car tracking

- Resampling at k=1

Algorithm 2: Resampling Algorithm

$[\{\mathbf{x}_k^{j*}, w_k^j, i^j\}_{j=1}^{N_s}] = \text{RESAMPLE } [\{\mathbf{x}_k^i, w_k^i\}_{i=1}^{N_s}]$

- Initialize the CDF: $c_1 = 0$
- FOR $i = 2: N_s$
  - Construct CDF: $c_i = c_{i-1} + w_k^i$
- END FOR
- Start at the bottom of the CDF: $i = 1$
- Draw a starting point: $u_1 \sim \mathbb{U}[0, N_s^{-1}]$
- FOR $j = 1: N_s$
  - Move along the CDF: $u_j = u_1 + N_s^{-1}(j-1)$
  - WHILE $u_j > c_i$
  - $*$ $i = i + 1$
  - END WHILE
  - Assign sample: $\mathbf{x}_k^{j*} = \mathbf{x}_k^i$
  - Assign weight: $w_k^j = N_s^{-1}$
  - Assign parent: $i^j = i$
- END FOR



Sources: Arulampalam2002, Djuric2003

Application

$w^1_1 = 0.00$

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$w^3_1 = 0.22$

$w^4_1 = 0.22$

$w^5_1 = 0.19$

$w^6_1 = 0.04$

$w^7_1 = 0.19$

$w^8_1 = 0.23$

Application

$w^{1}_{1} = 0.125$

$w^{2}_{1} = 0.125$

$w^{3}_{1} = 0.125$

$w^{4}_{1} = 0.125$

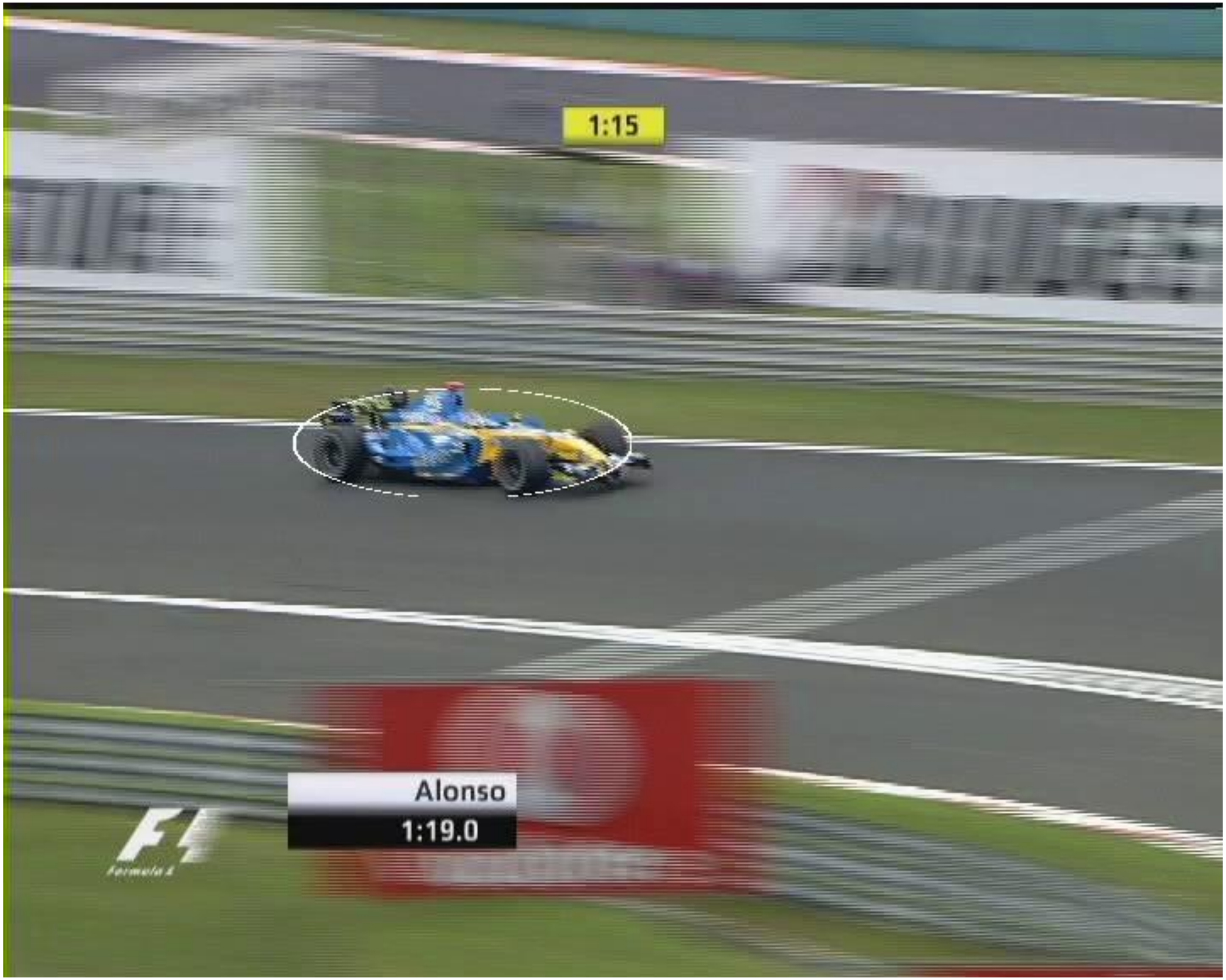
$w^{5}_{1} = 0.125$

$w^{6}_{1} = 0.125$

$w^{7}_{1} = 0.125$

$w^{8}_{1} = 0.125$

Application



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References

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