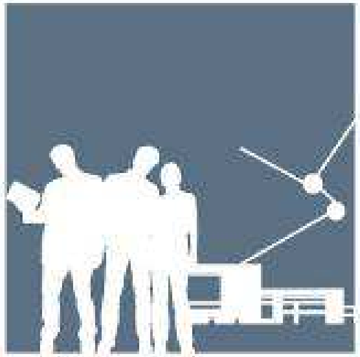


Interval SLAM for underwater robots

Fabrice LE BARS

Introduction

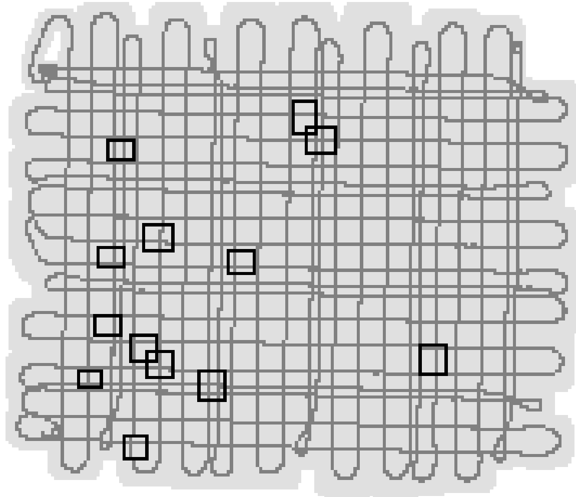
- Given an autonomous submarine covering an area with several unknown objects on the sea floor, how can we
  - Get the position of the objects
  - Get the robot's trajectory as accurately as possible
  - Validate the submarine navigation system

SLAM problem

- **SLAM** = Simultaneous Localization And Mapping : **localize** in an **unknown environment** using **marks**
- A submarine robot knows
  - Its **initial position** (GPS when at surface)
  - Its moving model (**state equations**)
  - Navigation data (**depth, orientation, speed**)
  - Data related to its environment (**sonar images**)
- Its position estimation errors increase with time due to the uncertainties : the robot is getting lost

SLAM problem

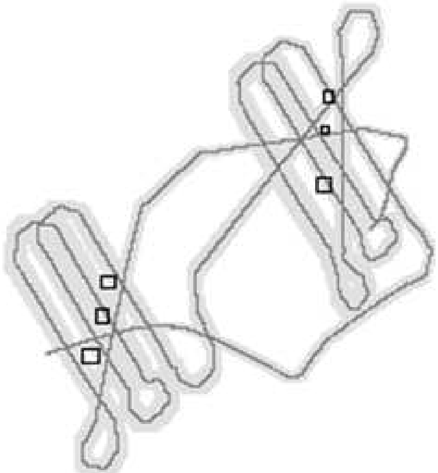
- SLAM idea
  - Localize marks from a known position
  - Use them to localize when we are lost
  - Alternate these 2 steps

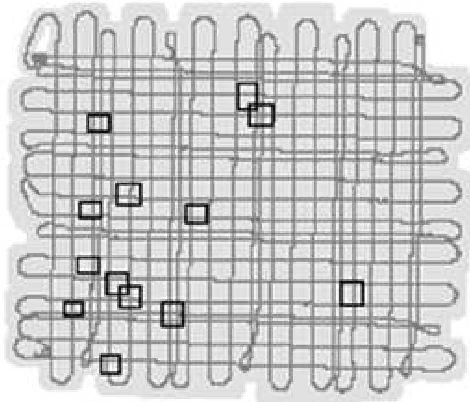


- In our case
  - **Localization** part corresponds to get the **robot's trajectory**
  - **Mapping** part corresponds to get the absolute **positions of the objects** (that will be taken as marks)

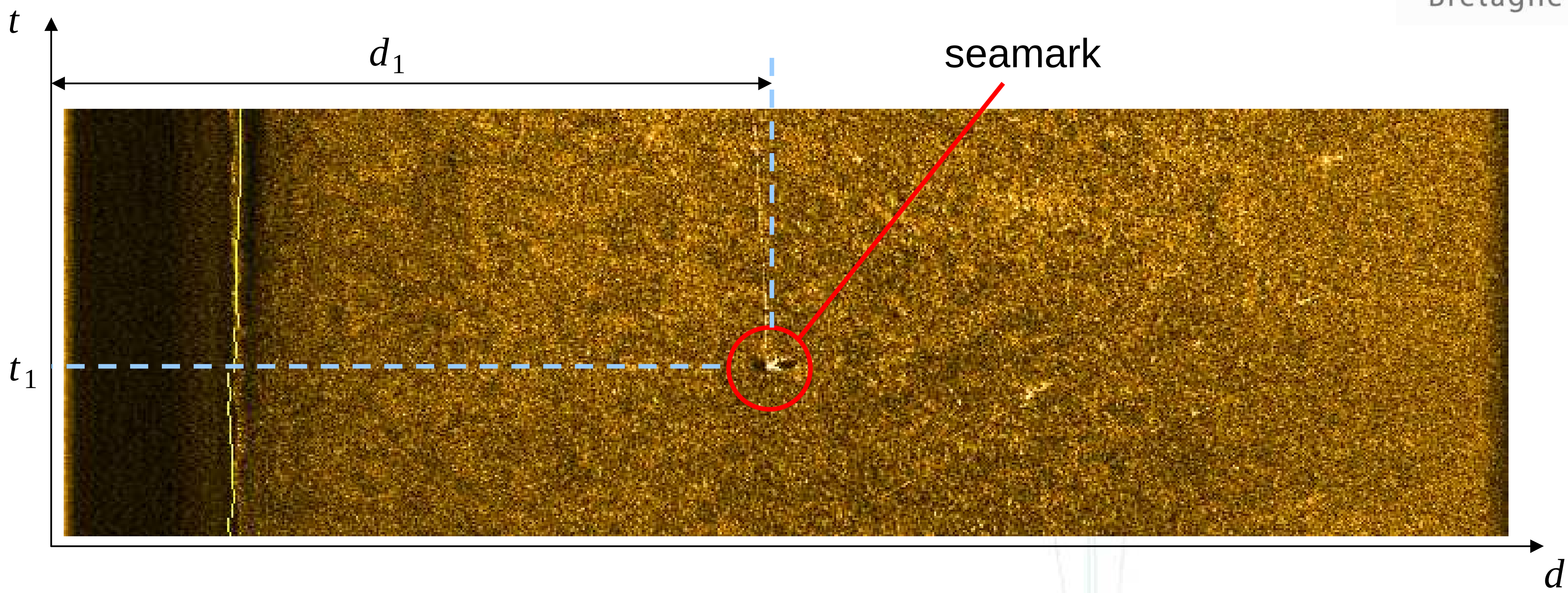
Submarine SLAM with fleeting data

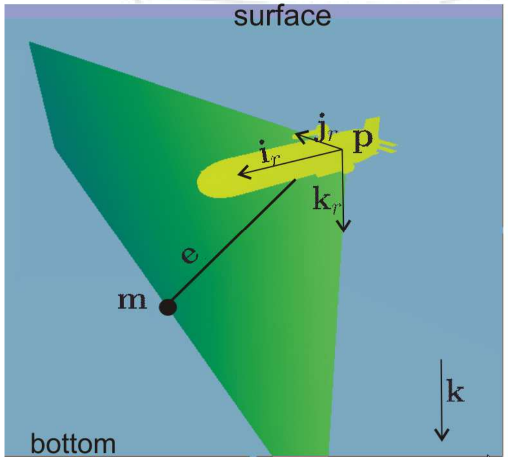
- Experiments with Daurade and Redermor submarines

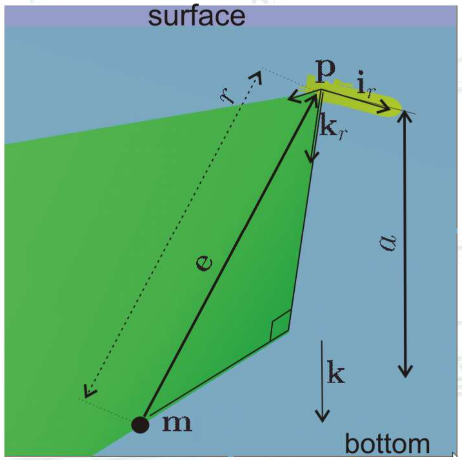


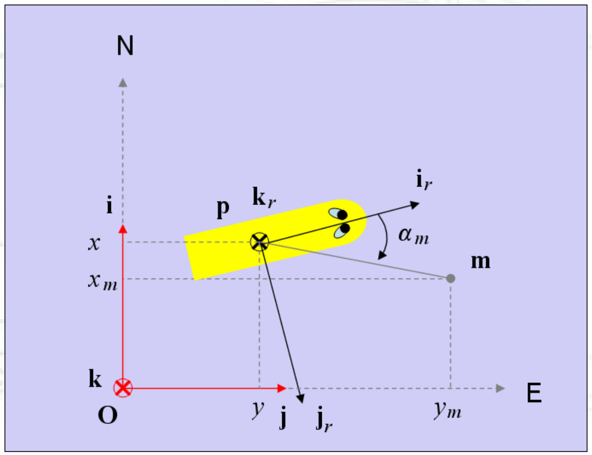


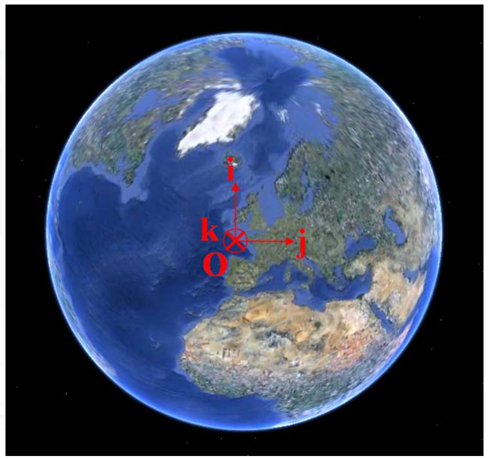
Submarine SLAM with fleeting data







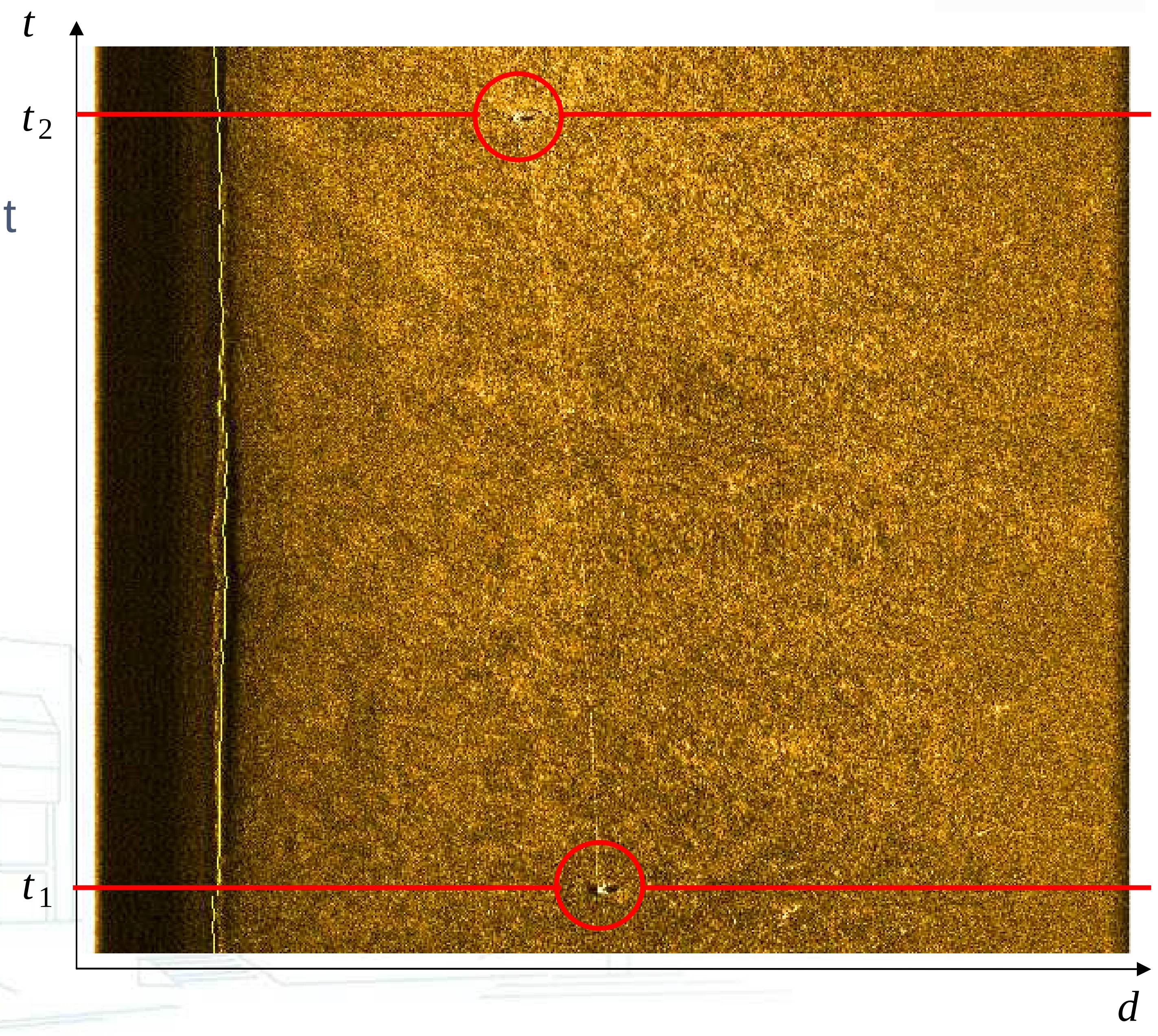




Interval SLAM for underwater robots

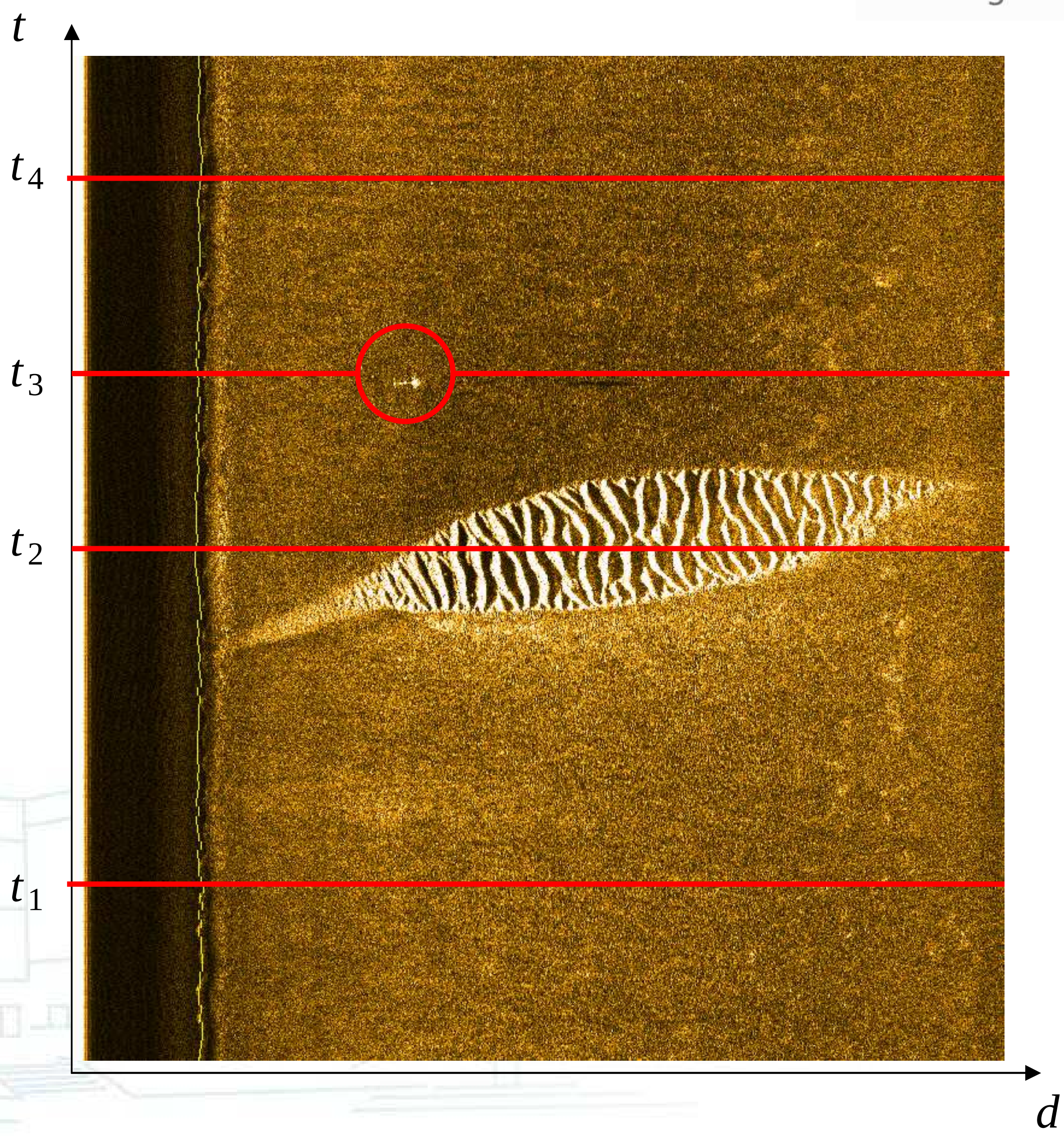
Submarine SLAM with fleeting data

- Waterfall
  - On a waterfall, it is difficult to distinguish 2 different marks



Submarine SLAM with fleeting data

- Waterfall
  - Hypothesis
    - On a waterfall, we detect parts where we are sure there is no mark rather than the marks
    - When there is a mark, it is seen punctually (fleeting)

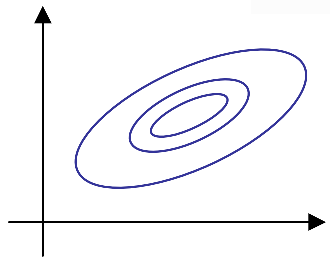


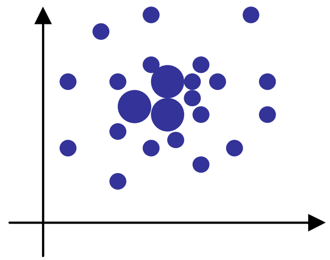
Submarine SLAM with fleeting data

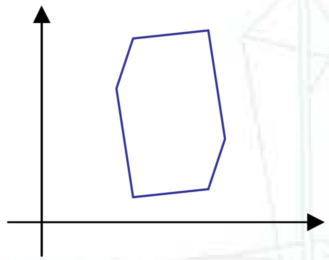
- Representations of uncertainties
  - Probabilistic methods
    - Gaussian
    - Particles

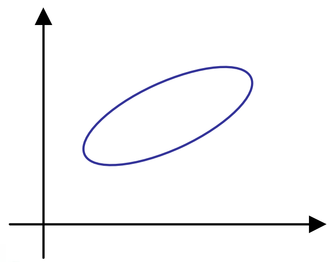
    => Try to get most probable solutions
  - Set-membership methods
    - Zonotopes
    - Ellipsoids
    - Intervals

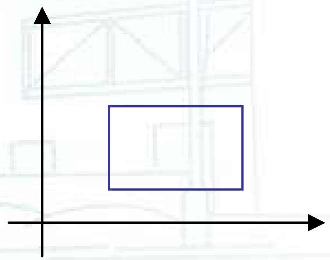
    => Try to enclose all possible solutions

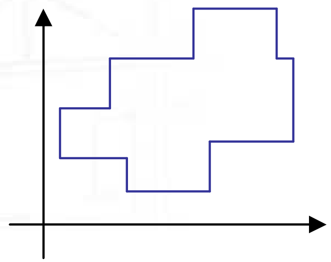






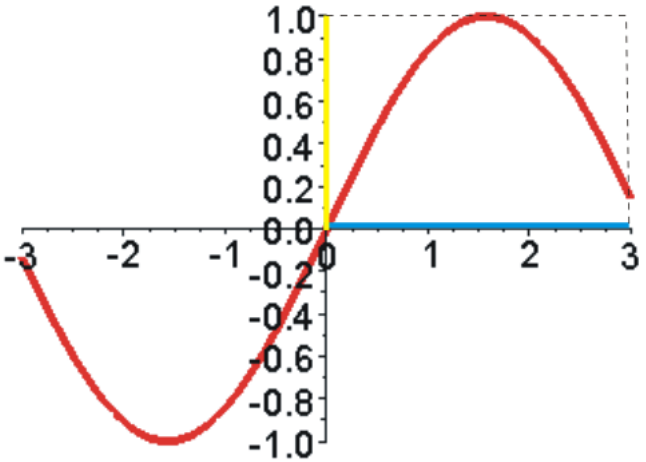






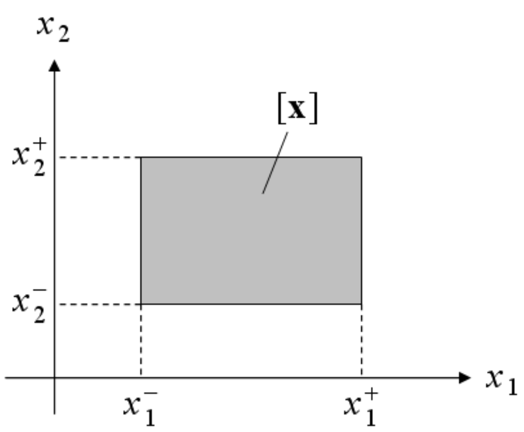
Interval arithmetic

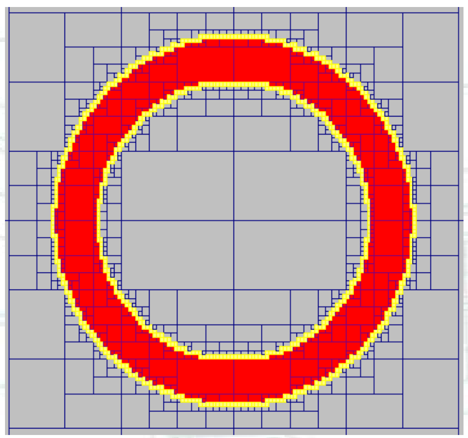
- $[-\infty, 2]$, $[-1, 4]$, $[-\infty, \infty]$ are examples of intervals
- Operations $\diamond \in \{+, -, *, /\}$
  - $[x^-, x^+] \diamond [y^-, y^+] =$ smallest interval containing the set of all possible values for $x \diamond y$
  - $[-1, 4] + [2, 3] = [1, 7]$
  - $[-1, 4] * [2, 3] = [-3, 12]$
  - $[-1, 4]/[2, 3] = [-1/2, 2]$
- Multiplication by a number, intersection, union
  - $2[-1, 4] = [-2, 8]$
  - $[-1, 3] \cap [2, 4] = [2, 3]$
  - $[-1, 2] \sqcup [3, 4] = [-1, 4]$
- Image by a function
  - $\sin([0, \pi]) = [0, 1]$

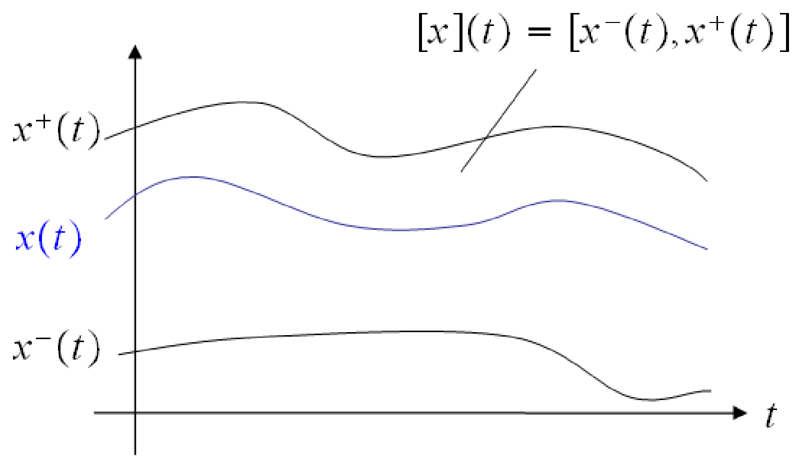


Interval arithmetic

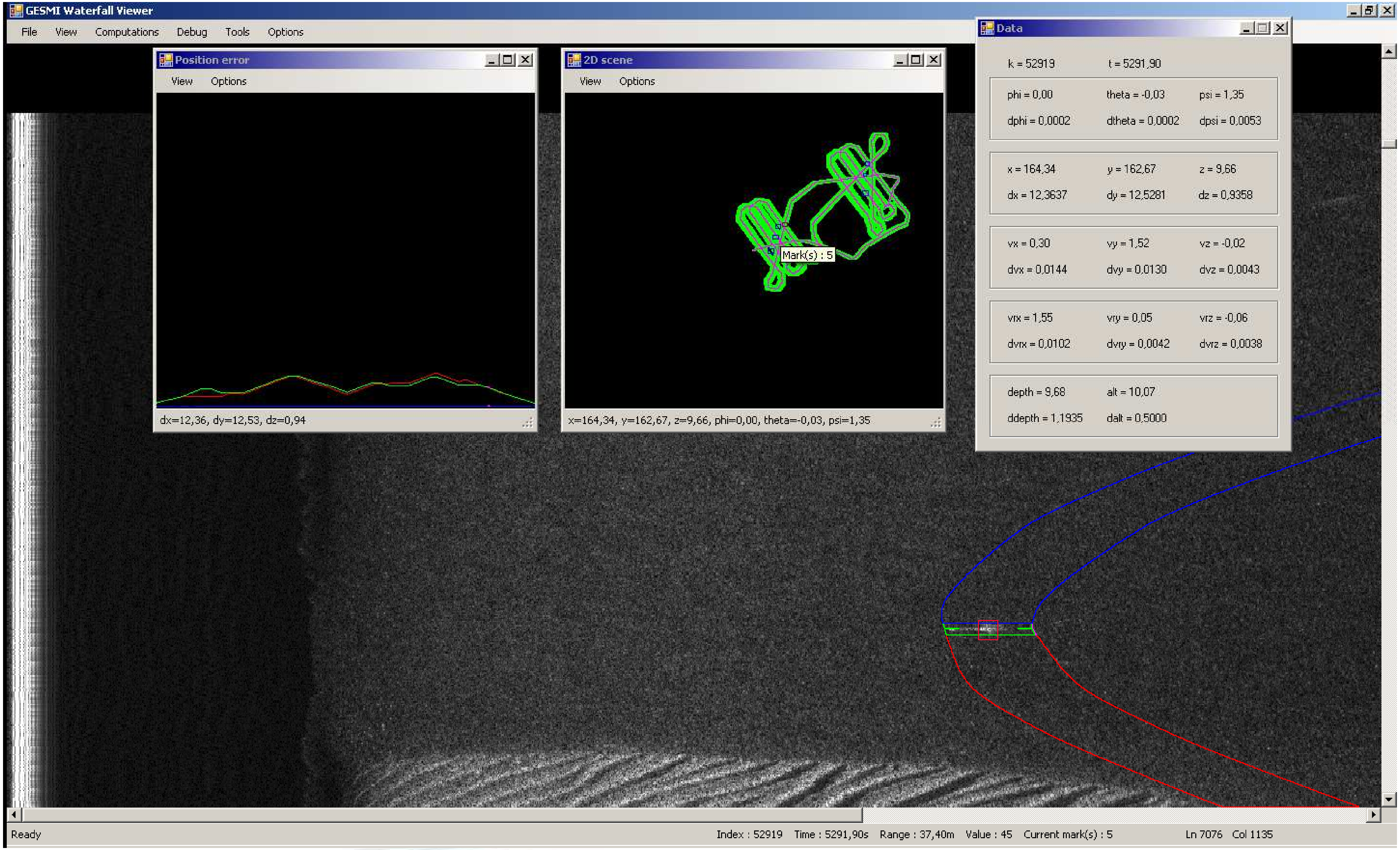
- Real-valued intervals can be generalized
  - Intervals of vectors (boxes)
  - Intervals of sets
  - Intervals of functions (tubes)







GESMI


GESMI Waterfall Viewer
File View Computations Debug Tools Options
Position error
View Options
dx=12,36, dy=12,53, dz=0,94
2D scene
View Options
Mark(s) : 5
x=164,34, y=162,67, z=9,66, phi=0,00, theta=-0,03, psi=1,35
Data
k = 52919 t = 5291,90
phi = 0,00 theta = -0,03 psi = 1,35
dphi = 0,0002 dtheta = 0,0002 dpsi = 0,0053
x = 164,34 y = 162,67 z = 9,66
dx = 12,3637 dy = 12,5281 dz = 0,9358
vx = 0,30 vy = 1,52 vz = -0,02
dvx = 0,0144 dvy = 0,0130 dvz = 0,0043
vrx = 1,55 vry = 0,05 vrz = -0,06
dvrx = 0,0102 dvry = 0,0042 dvrz = 0,0038
depth = 9,68 alt = 10,07
ddepth = 1,1935 dalt = 0,5000
Ready
Index : 52919 Time : 5291,90s Range : 37,40m Value : 45 Current mark(s) : 5
Ln 7076 Col 1135

Questions?