A model-based approach for tool tracking in laparoscopy

Potential applications and evaluation challenges

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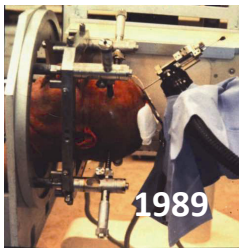
A few words about the TIMC-IMAG CAMI team

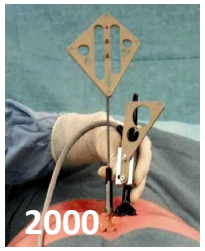
Grenoble University Hospital

TIMC-IMAG CAMI

Start-Ups in the CAMI field

Development of generic innovations
Applications to several clinical fields for the past 20 years





CAMI team activities in laparoscopic surgery

- CAMI team activities in laparoscopic surgery:
  - Robotics
  - Multimodal navigation
  - Modeling of the surgical expertise

- Tool localization / tracking is an essential brick:
  - Tool localization can « augment » robotic commands
  - Tool localization can be useful for multimodal navigation
  - Tool localization can help understand surgical expertise

Talk outline

- Presentation of our tool localization method
- Presentation of a few applications
- Evaluation of the approach

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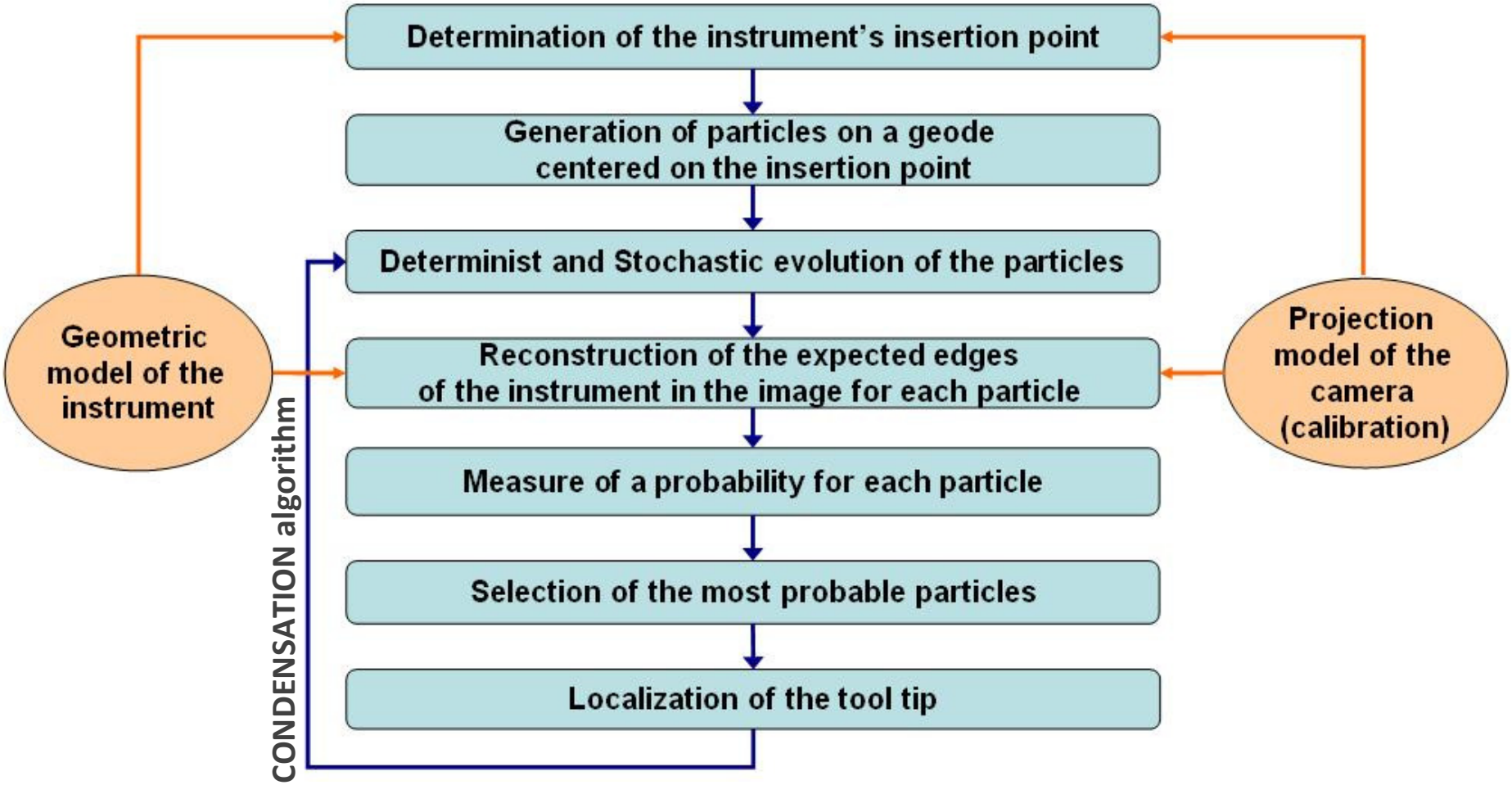
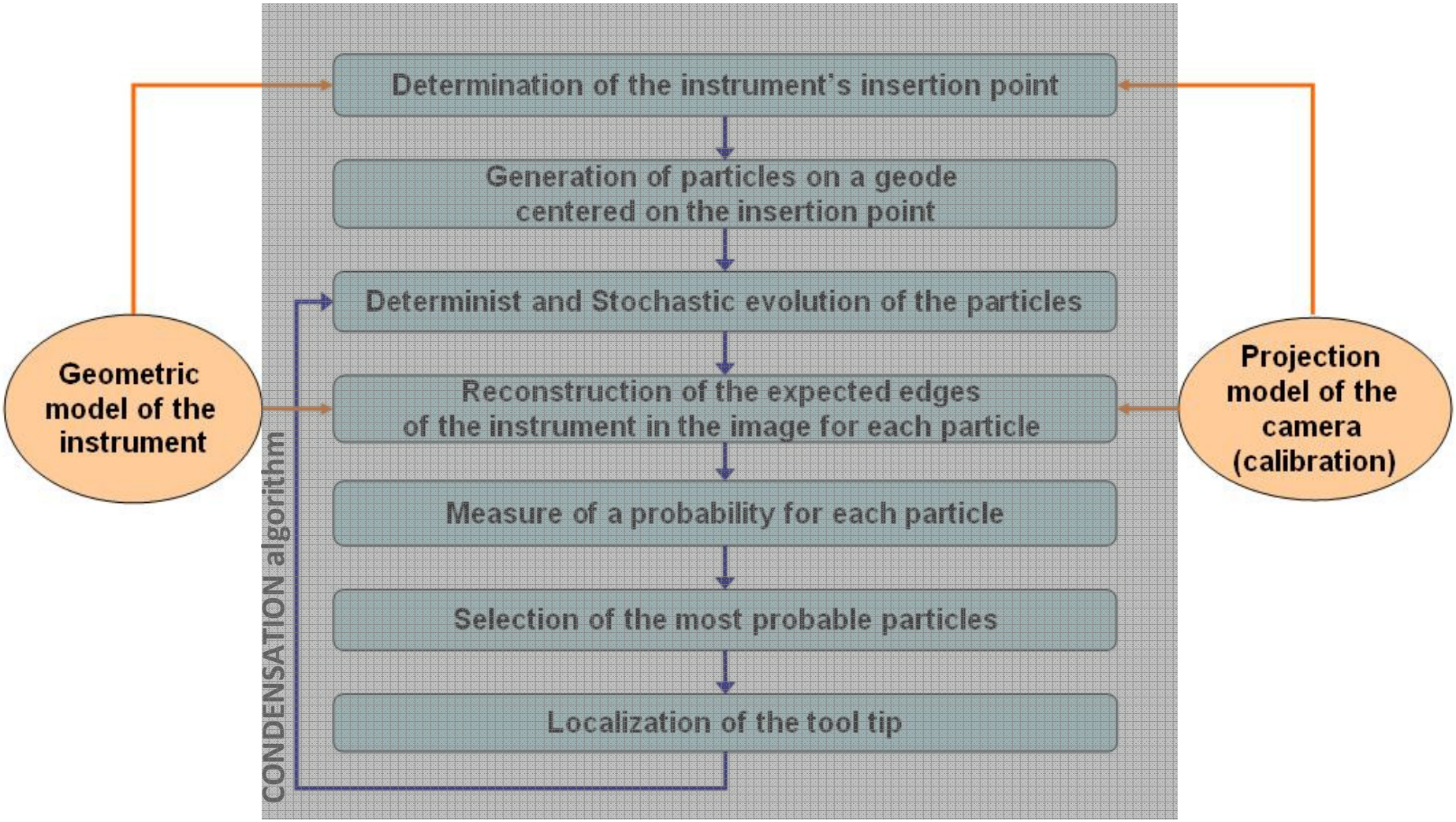
Tool localization: general framework



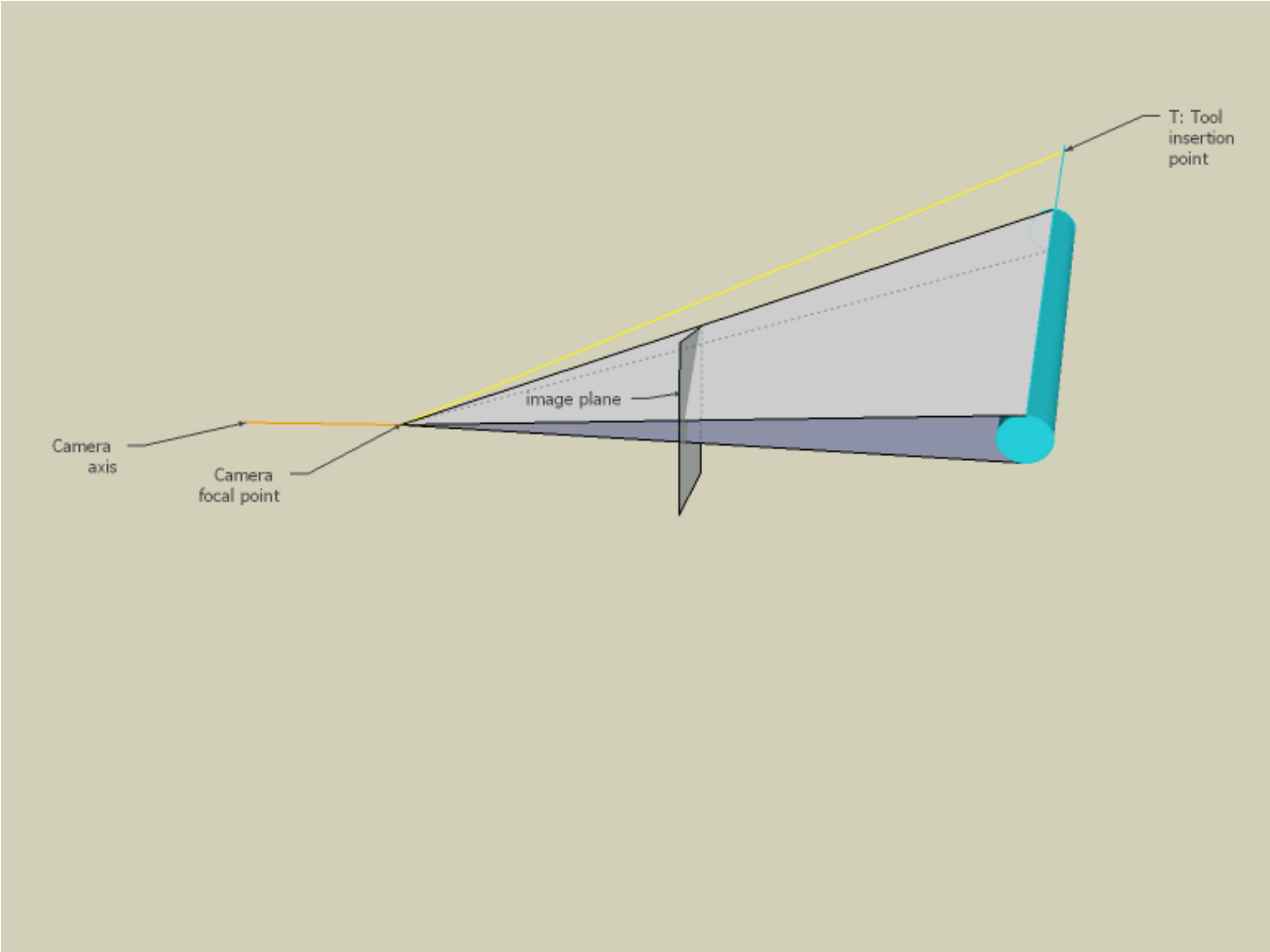
Hypothesis for now: the camera is fixed

Tool localization: general framework



Hypothesis for now: the camera is fixed

Tool localization: geometric model

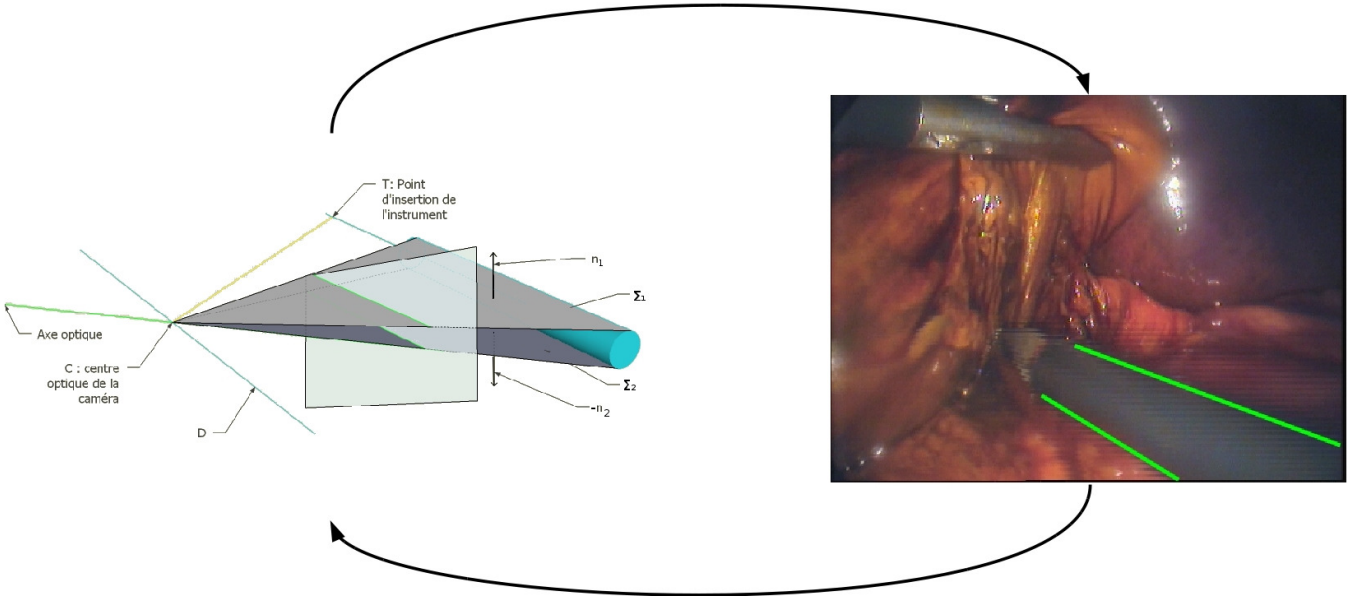


T : 3D insertion point of the tool

Tool = cylinder of known diameter and length

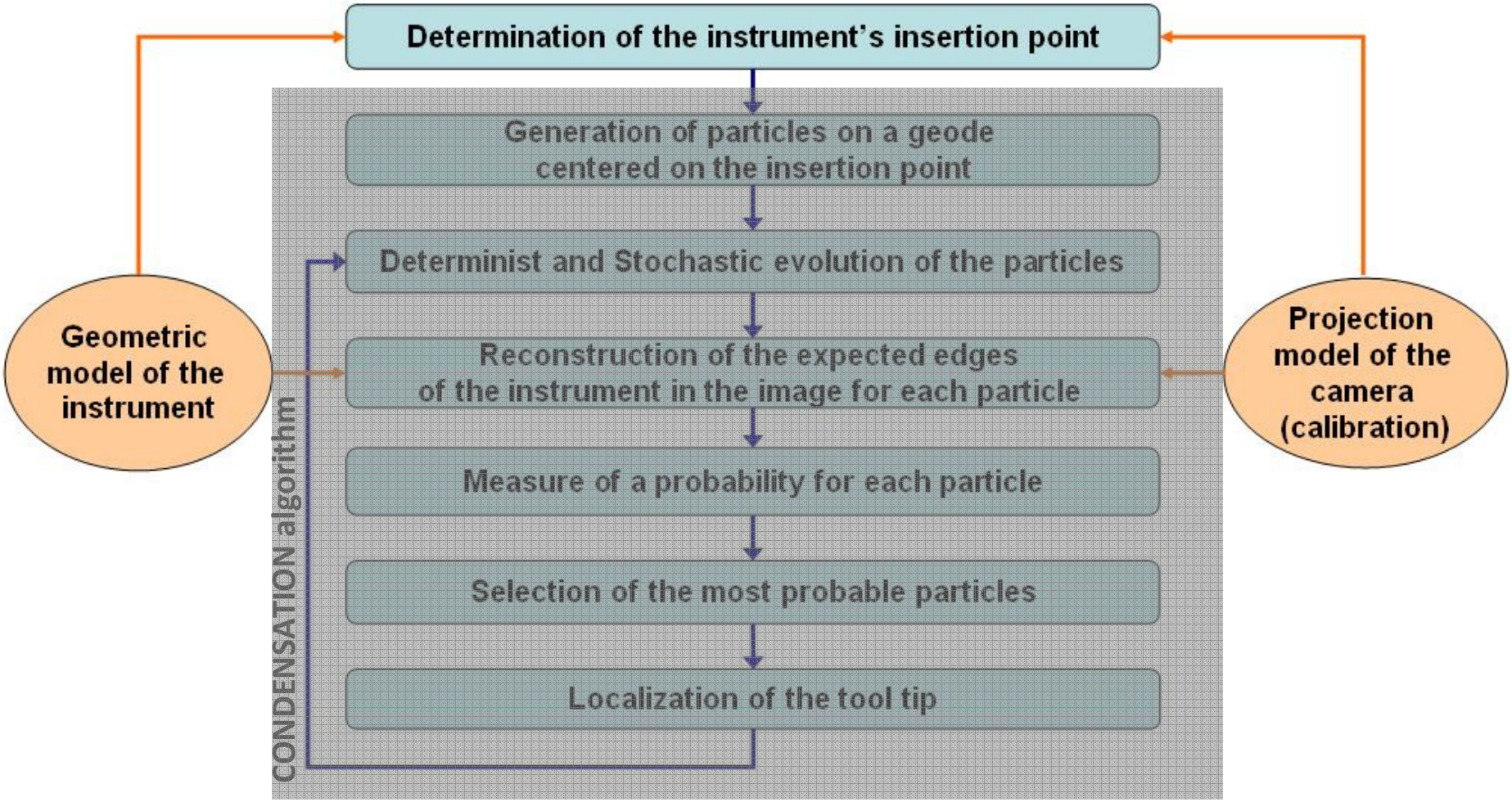
Tool localization: camera calibration

- Provides the relationship between the tool model and the tool edges in laparoscopic images



- Can be computed using Zhang's method in OpenCV

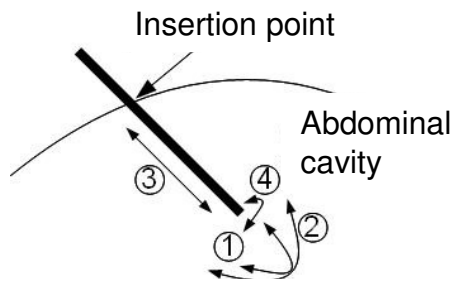
Tool localization: general framework



Hypothesis for now: the camera is fixed

Tool localization: determination of the tool's insertion point (1/4)

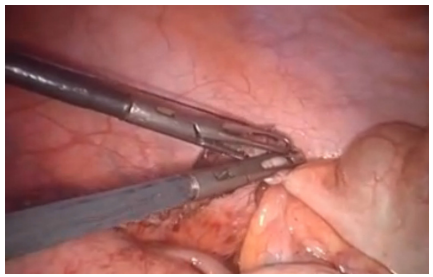
- Knowing the tool's insertion point in the camera frame reduces the number of dofs of the instrument

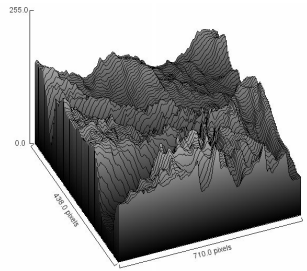


- "Pivot-like" method:
  - Detect the tool edges in the images using a non real-time method
  - Determine the corresponding 3D axis of the tool using the tool model and camera calibration
  - Use a SVD algorithm to find the best intersection point along with a RANSAC to eliminate outliers

Tool localization: determination of the tool's insertion point (2/4)

- Method for detecting the tool's edges in the image
  - Change of colorimetric space (HSV) [Doignon et al.]

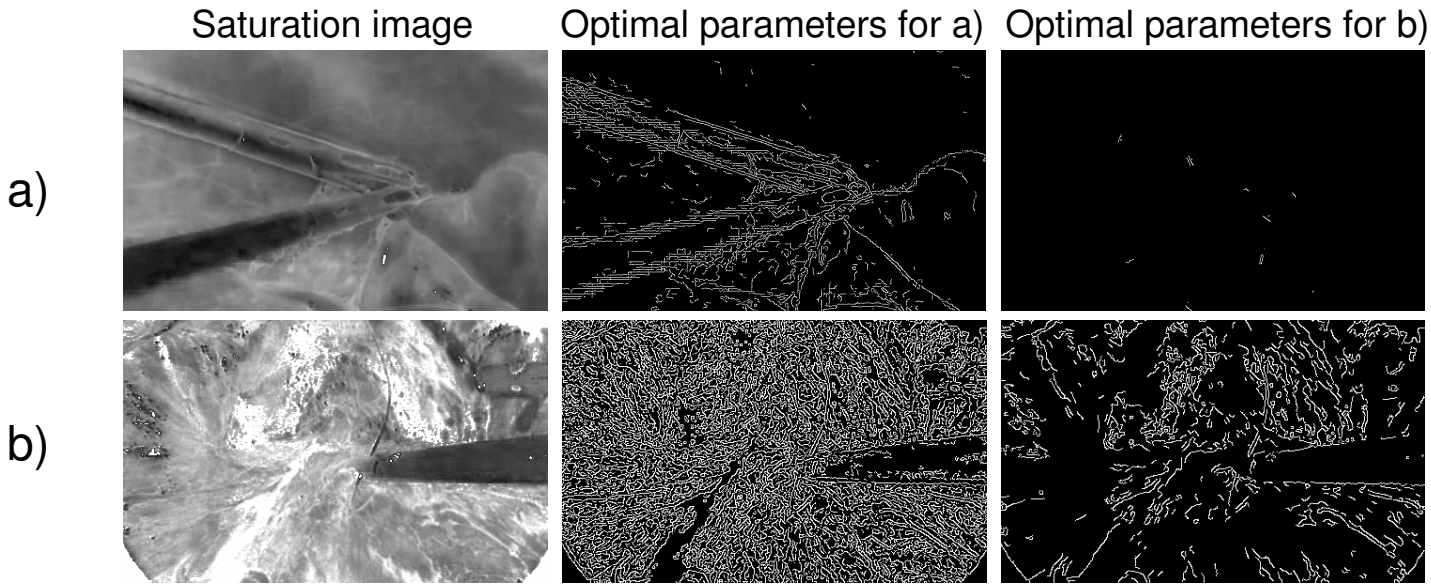




  - Non linear filtering (to keep image edges) : bilateral filter
    - a study comparing the computation time for different filters was performed
  - Canny detector to detect image edges (with bilateral filter instead of Gaussian filter)
    - The parameters of the Canny detector (filter size, low+high threshold are automatically identified)

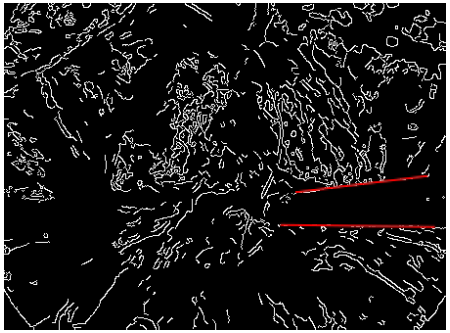
Tool localization: determination of the tool's insertion point (3/4)

- Automatic determination of the "best" Canny parameters
  - Using a typical laparoscopic image
  - Statistical approach : find the parameters with best sensitivity & specificity [Yitzhaky and Peli, 2003]

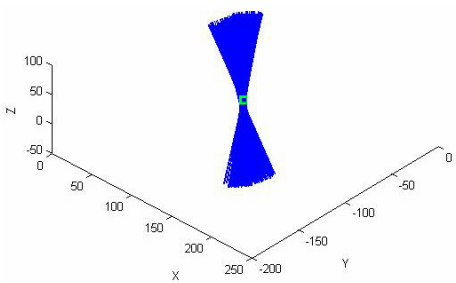


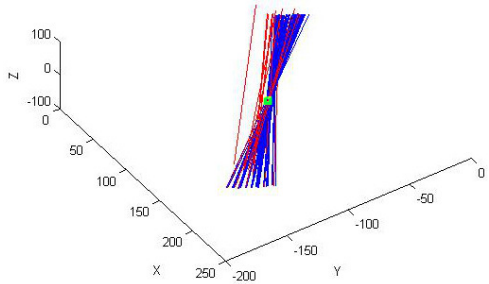
Tool localization: determination of the tool's insertion point (4/4)

- Probabilistic Hough transform to find the tool's edges

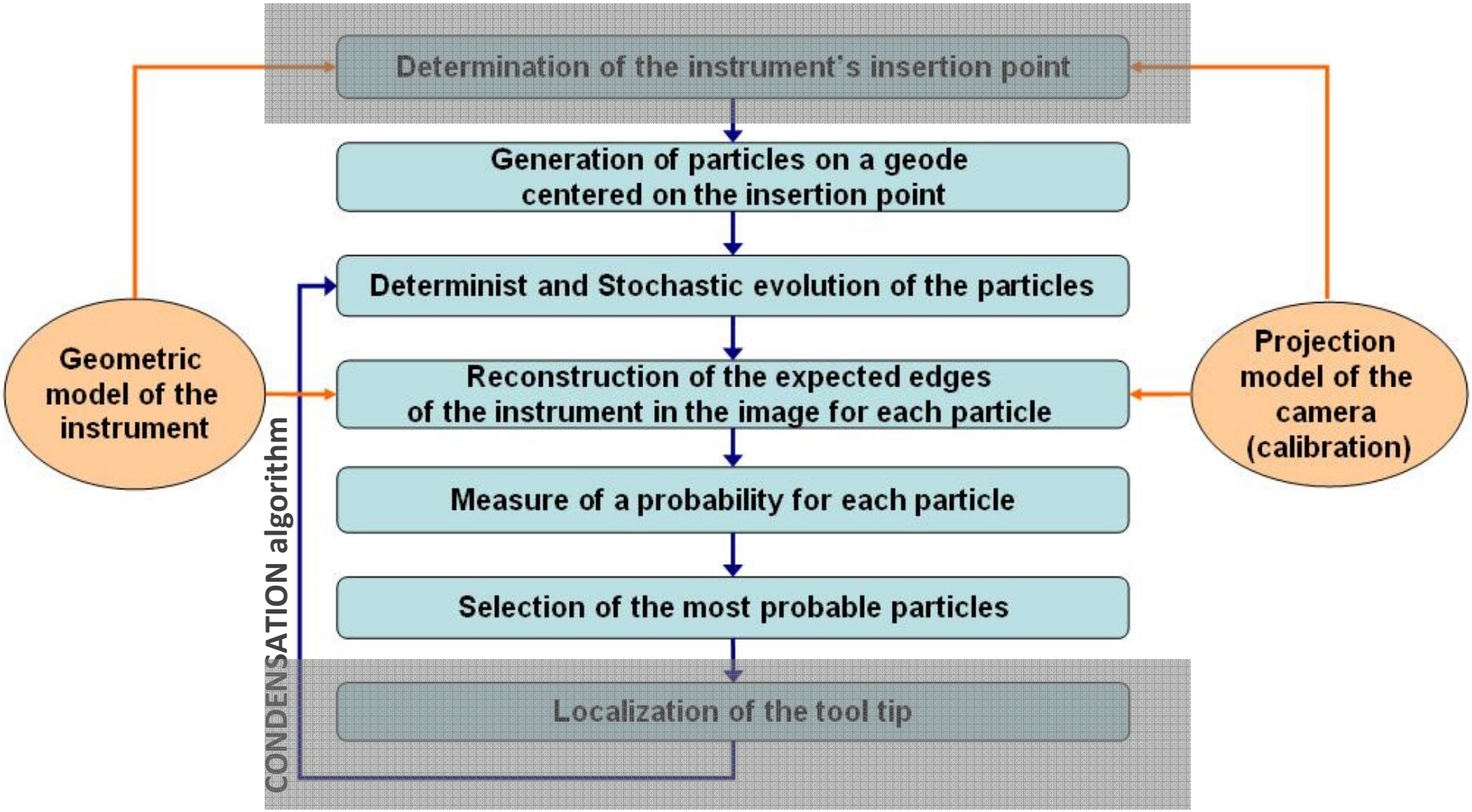


- Reconstruction of the tool's 3D axis for several positions
- Tool's axes intersections (SVD) + outliers removal (RANSAC)





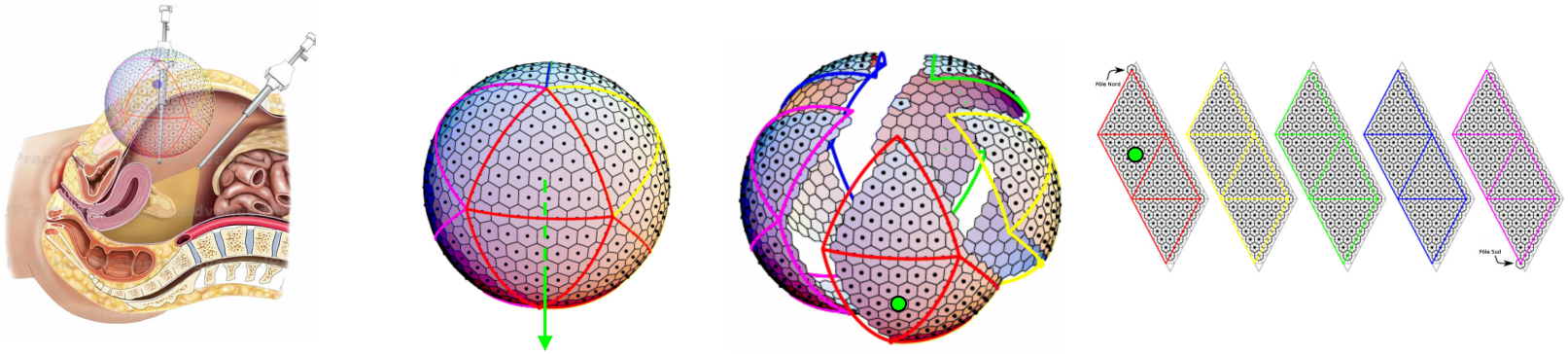
Tool localization: general framework



Hypothesis for now: the camera is fixed

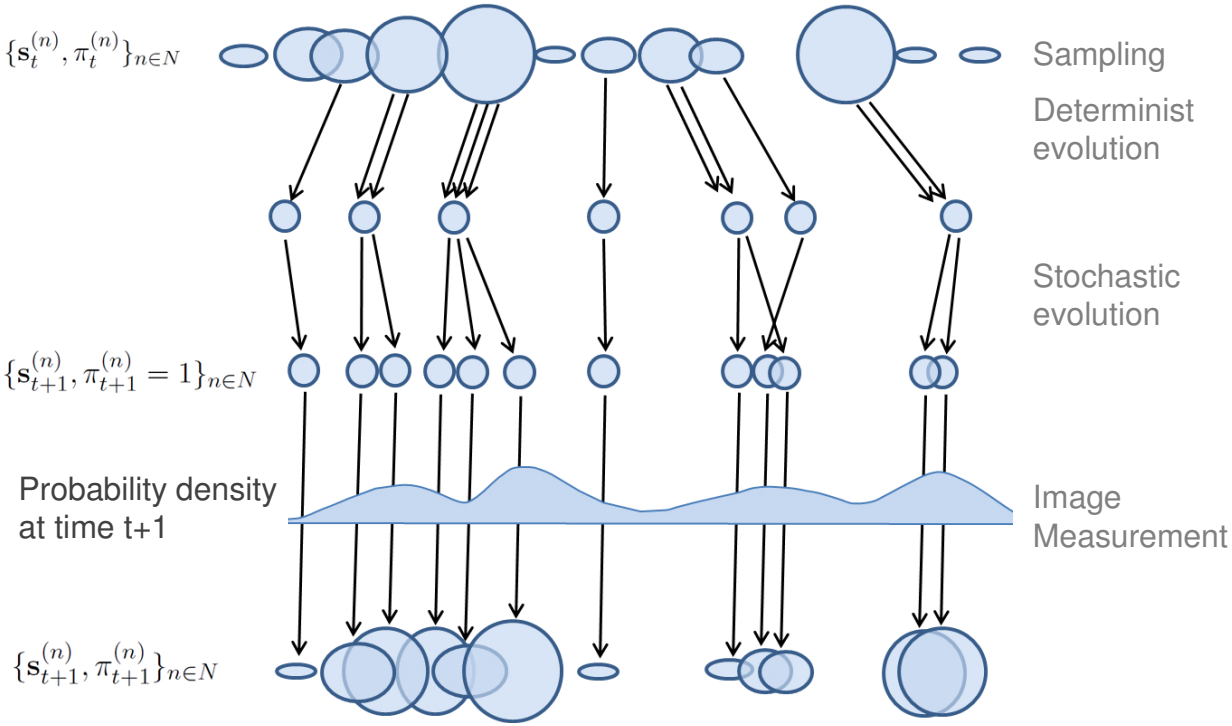
Tool localization: search for the tool's 3D orientation (1/2)

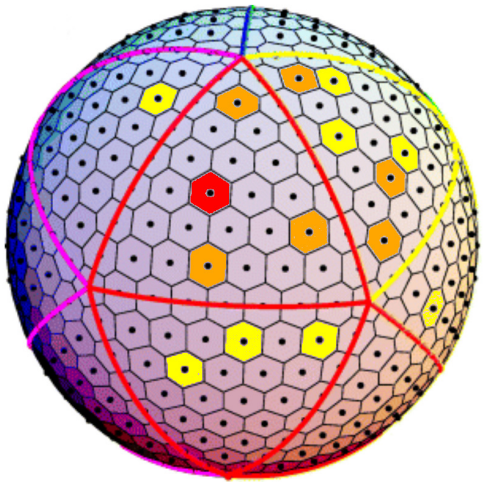
- Geode centered on the insertion point
  - A possible tool orientation corresponds to a cell on the geode
  - Easy discretization using geodesic grids



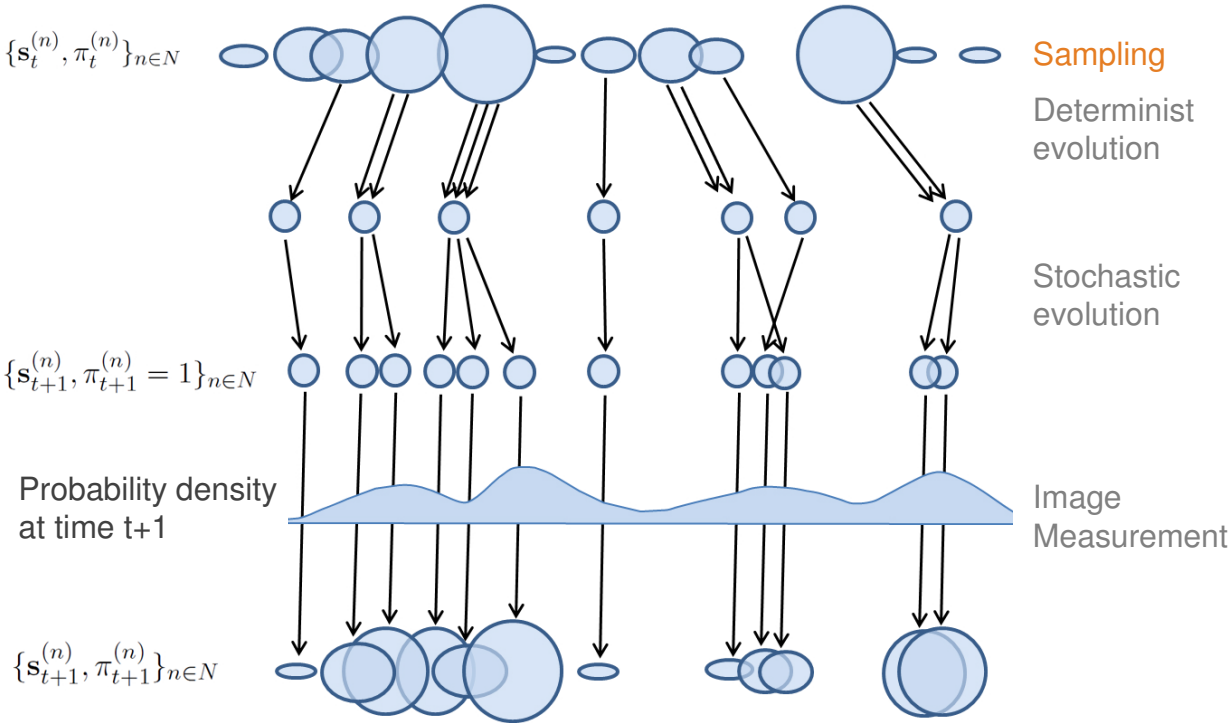
- Reduction of the search space using the Condesation Algorithm [Isard and Blake, 95]

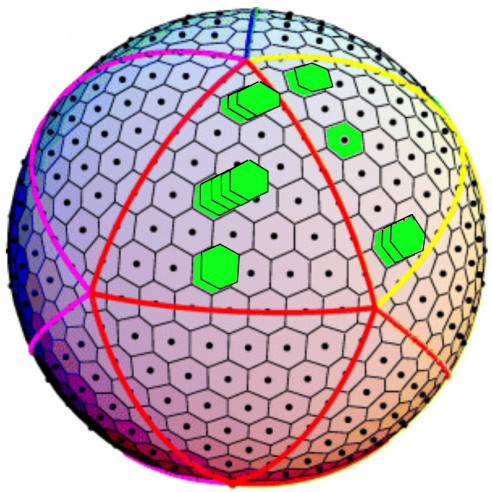
Tool localization: search for the tool's 3D orientation (2/2)





Tool localization: search for the tool's 3D orientation (2/2)





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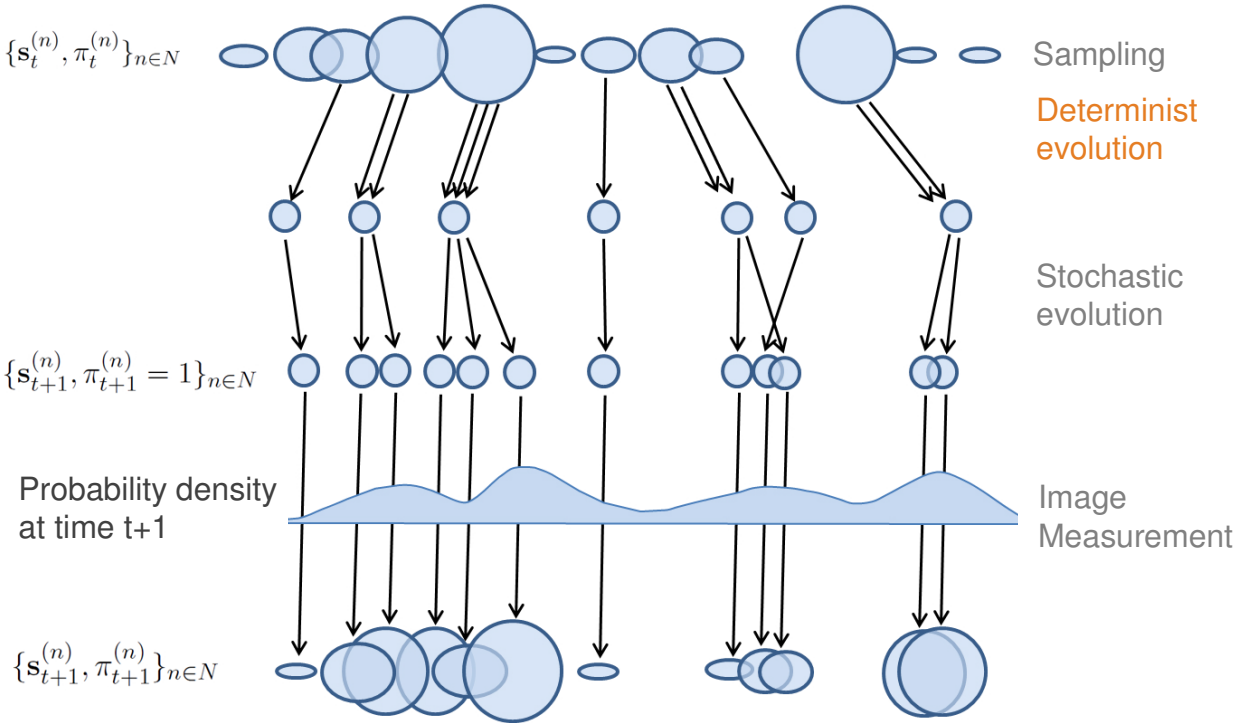
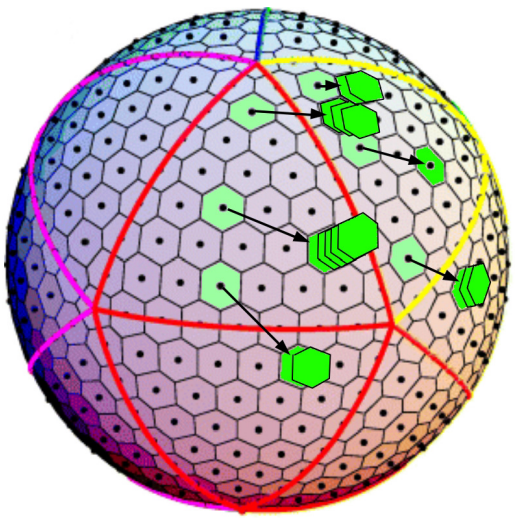
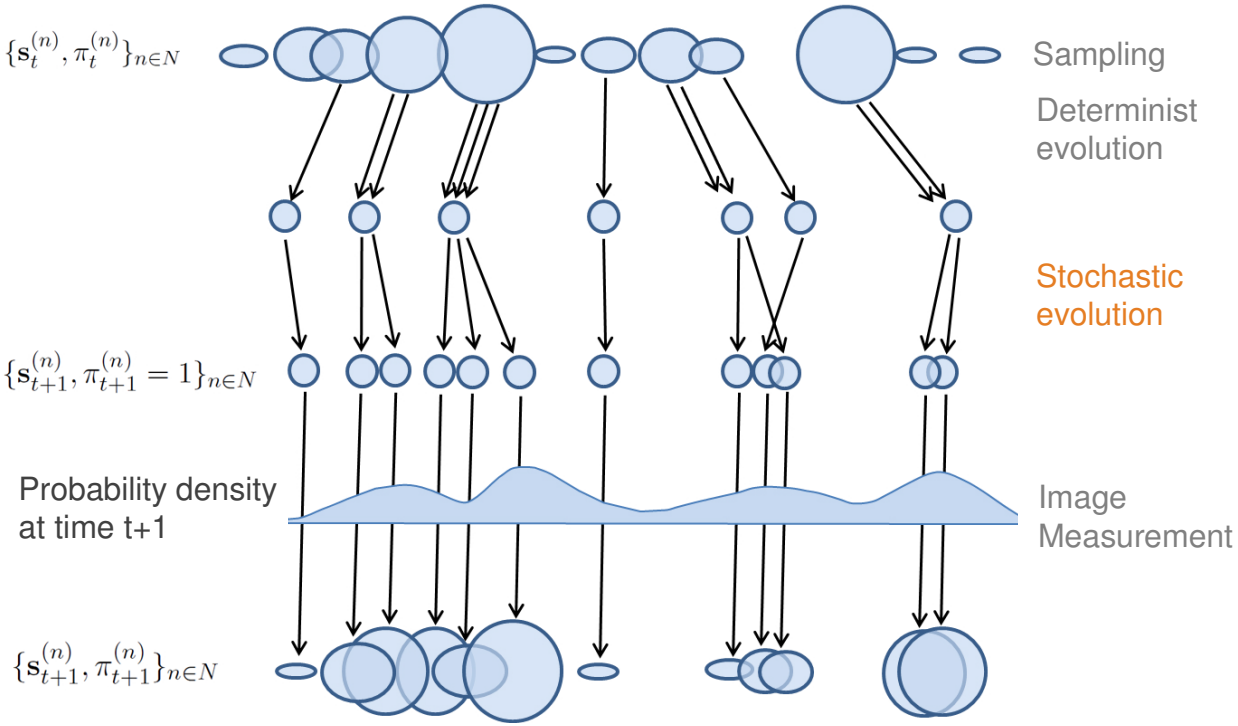
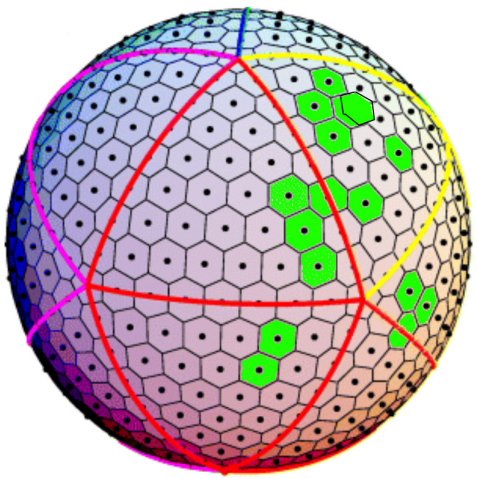


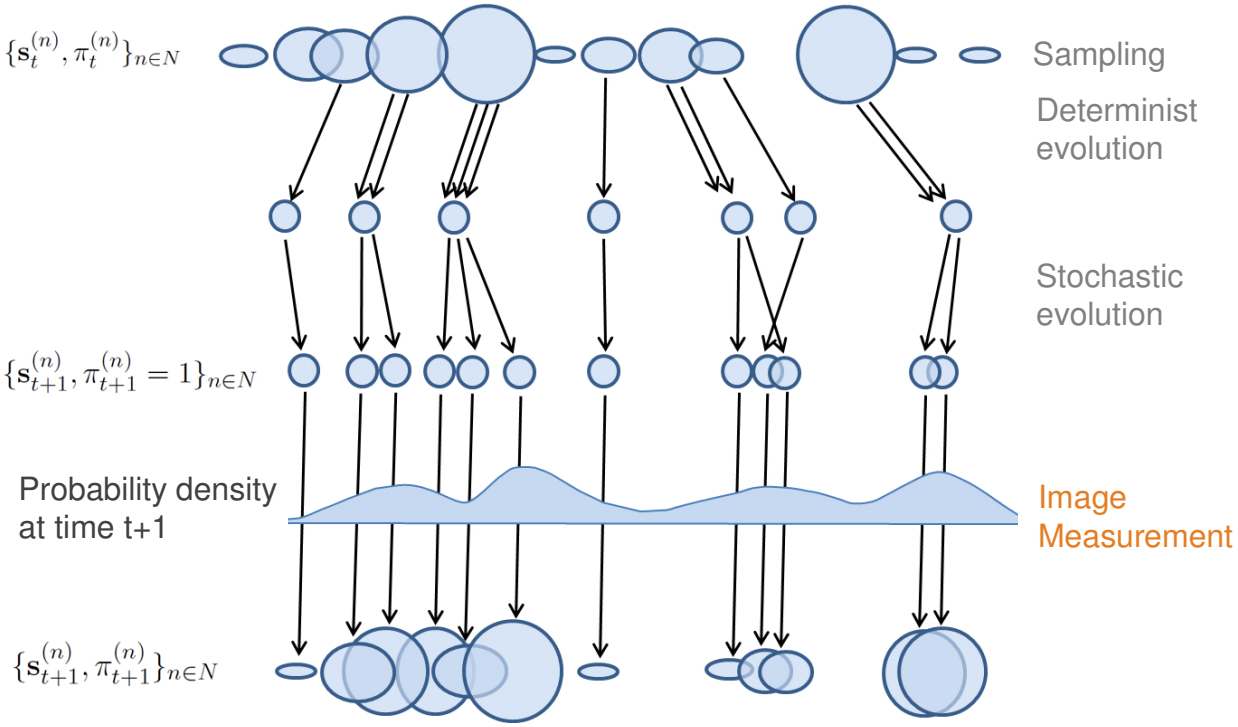


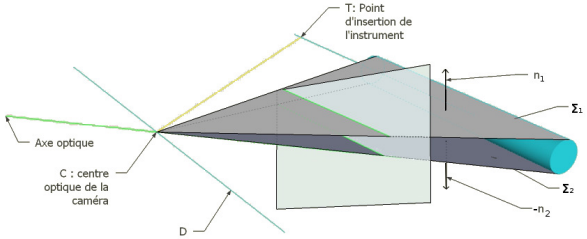
Tool localization: search for the tool's 3D orientation (2/2)

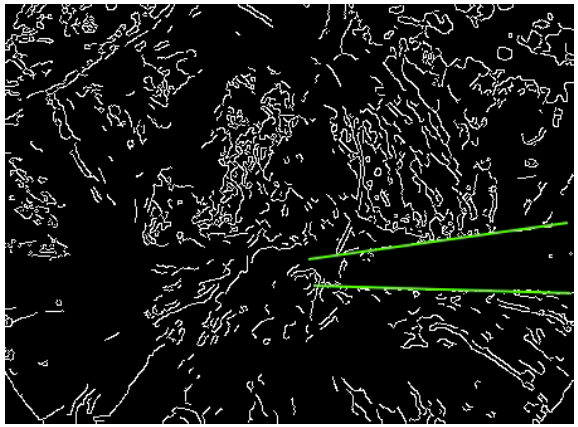




Tool localization: search for the tool's 3D orientation (2/2)

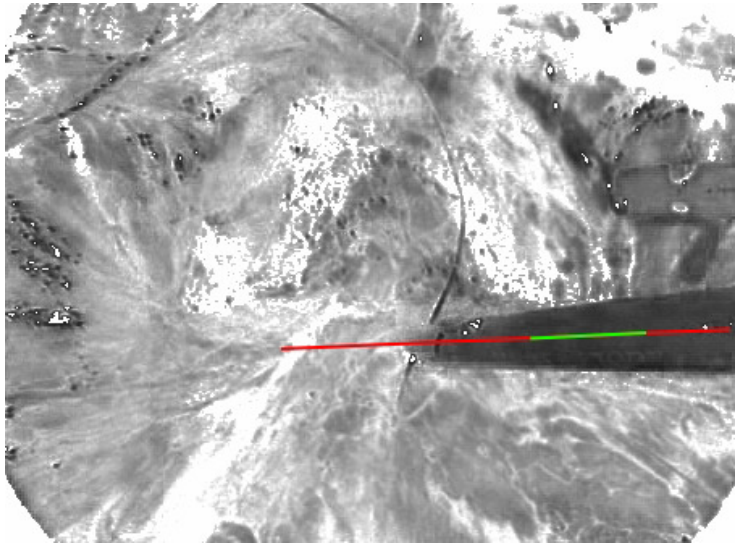


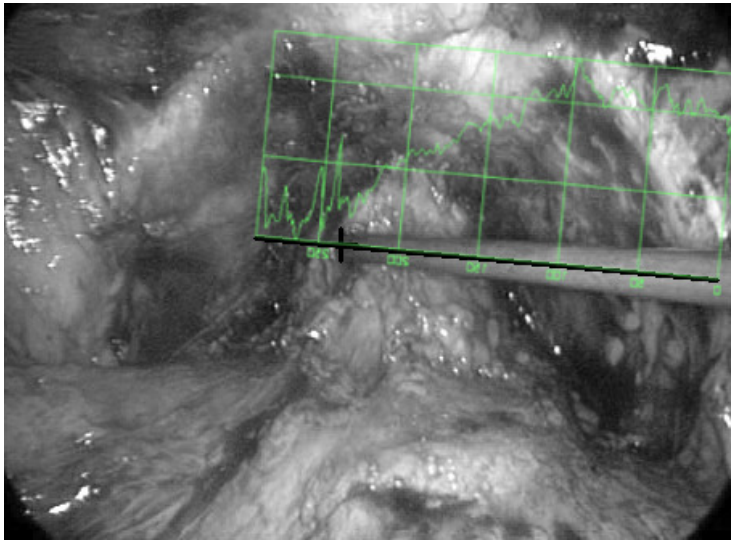




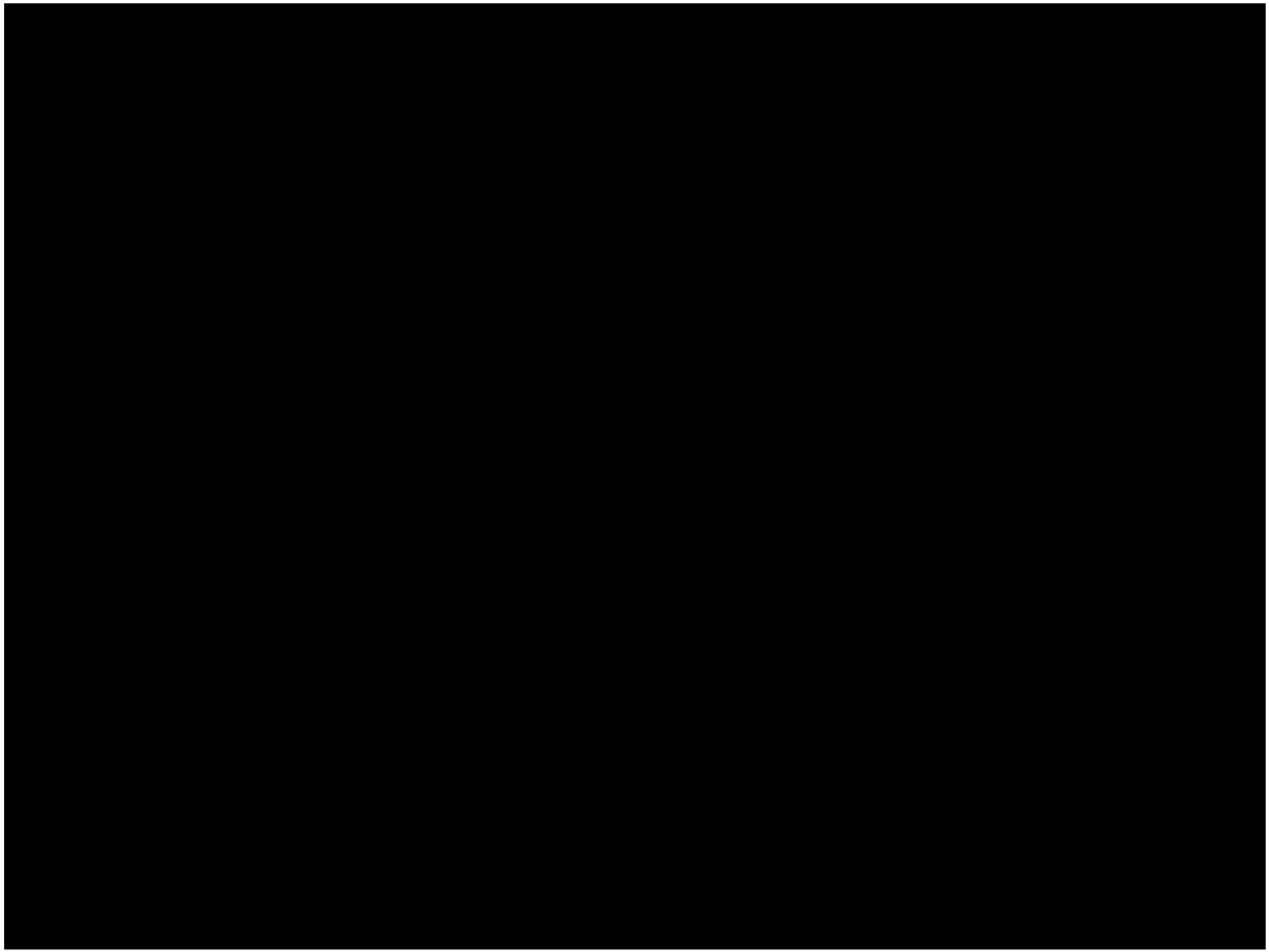
Tool localization: search for the tool's tip

- Last dof to be determined: insertion depth
  - Exploration of a sliding window on the tool's axis
  - Measure of inter-class separability [Otsu algorithm]





Tool localization: video example

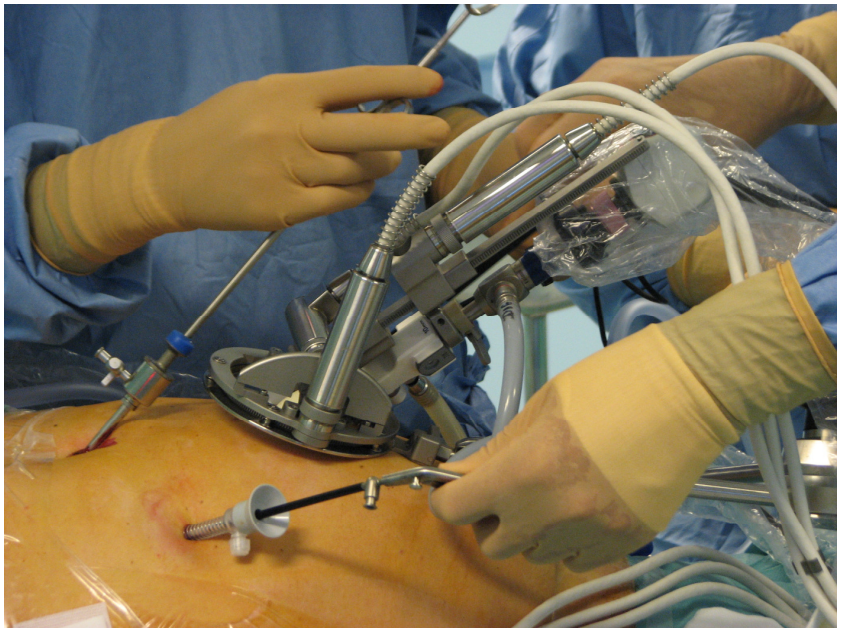


Talk outline

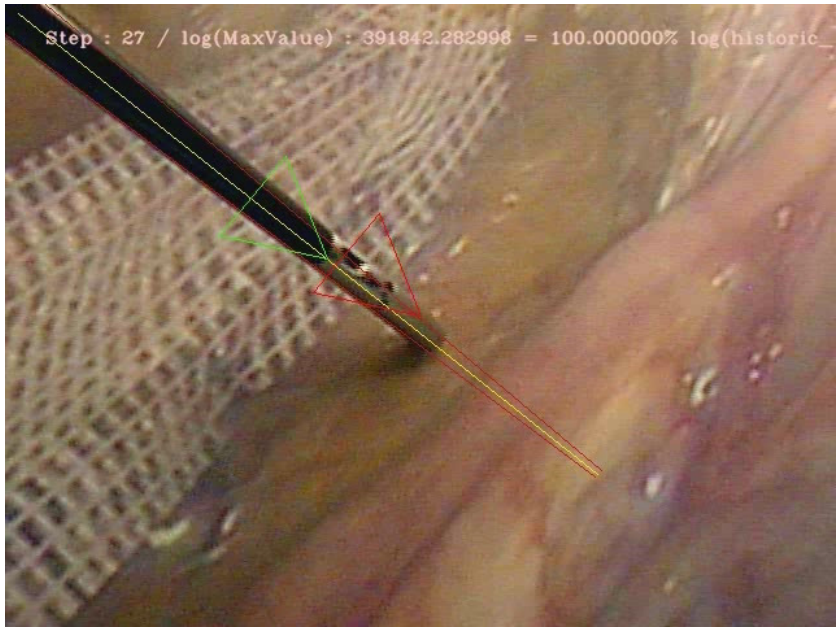
- Presentation of our tool localization method
- Presentation of a two potential applications
- Evaluation of the approach

First application: visual servoing of a robotic endoscope holder [A. Agustinos, PhD student]

- The insertion point is estimated when the camera moves thanks a the hand-eye calibration of the robot



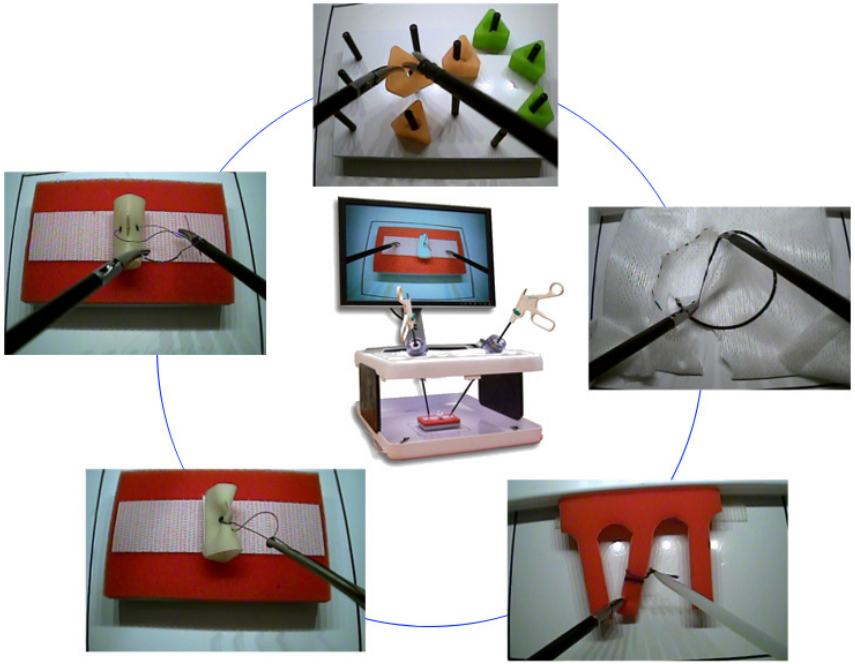
The ViKY® robotic endoscope holder (TIMC-IMAG, Endocontrol Medical)



One or two instrument(s) tracking

Second application: analysis of surgical gestures [R. Wolf, PhD student] (1/2)

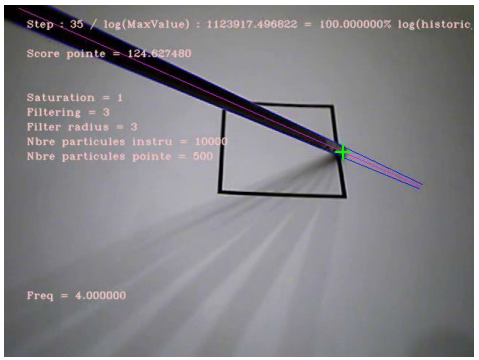
- The “Fundamentals of laparoscopic skills” based on the MISTEL testbench used to analyze the quality of execution of basic laparoscopic tasks

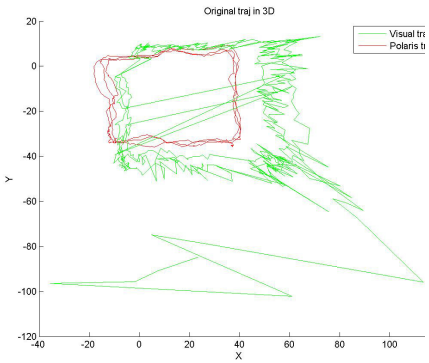


- Adopted for the evaluation of interns in digestive surgery
- Score based on execution time and gesture precision measurements
- tool localization could be used to automatize this grading
- could help acquire a finer understanding of surgical expertise

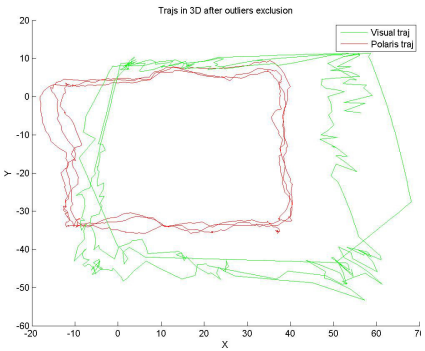
Second application: analysis of surgical gestures [R. Wolf, PhD student] (2/2)

- In this frame, data acquisition was performed for:
  - 13 Med students, 8 residents, 11 surgeons
  - Tool localization was performed offline
  - A Polaris system was used for “ground-truth” measurements (the participants were asked to not pay attention to the Polaris)
  - A systematic registration error between polaris / camera data was detected – a rigid registration was performed on the data for comparison

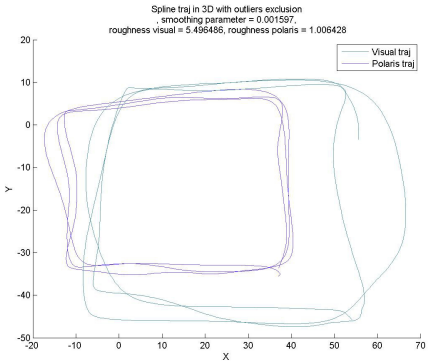




Raw measurement



After outliers removal



After spline smoothing

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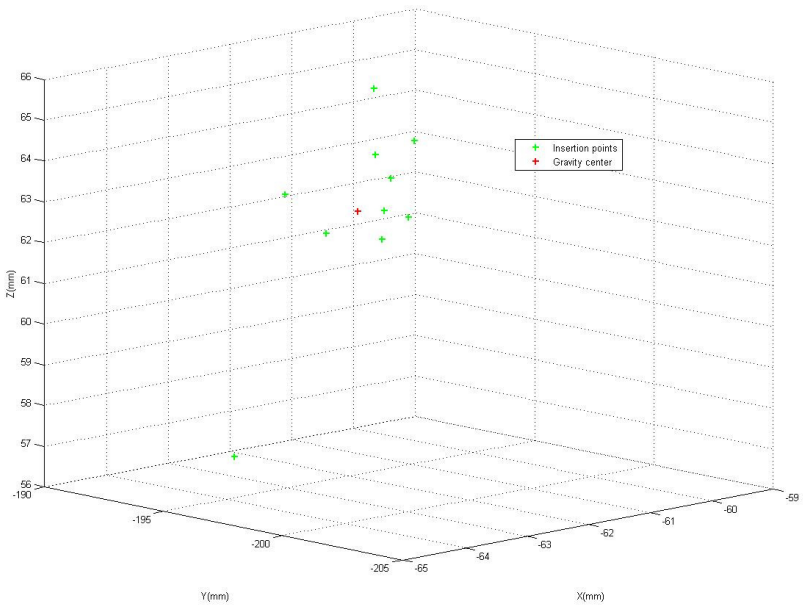
Evaluation of the approach (1/4)

- Precision of the insertion point computation



10 computations

Red circle: gravity center of the measurements

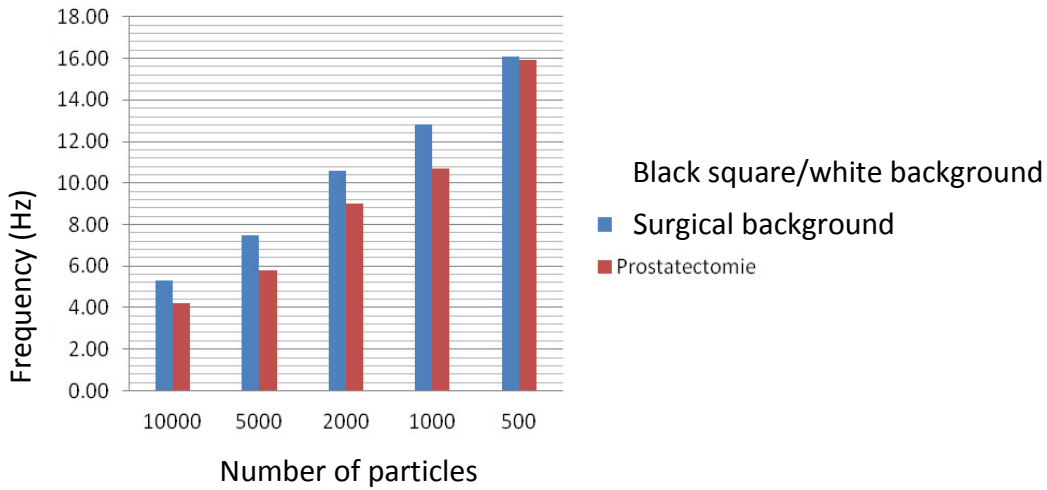
Green circles: the 10 measurements

Mean error: 6mm

In practice, we re-evaluate the insertion point during tool tracking by incorporating Gaussian noise

Evaluation of the approach (2/4)

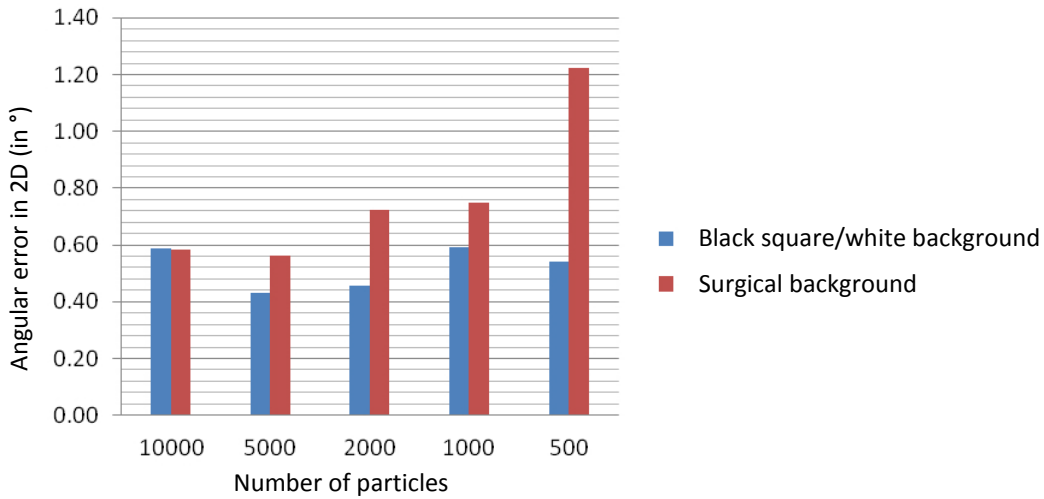
- Computation time considerations:
  - On a Intel Xeon PC 2.67 GHz, 3.48 GB RAM
  - in C++ (release mode)
  - The most important parameters is the number of particles in the Condensation algorithm



  - The geode can have a “big” resolution because it is computed only once at initialization.
  - Compromise depending on the application and required precision

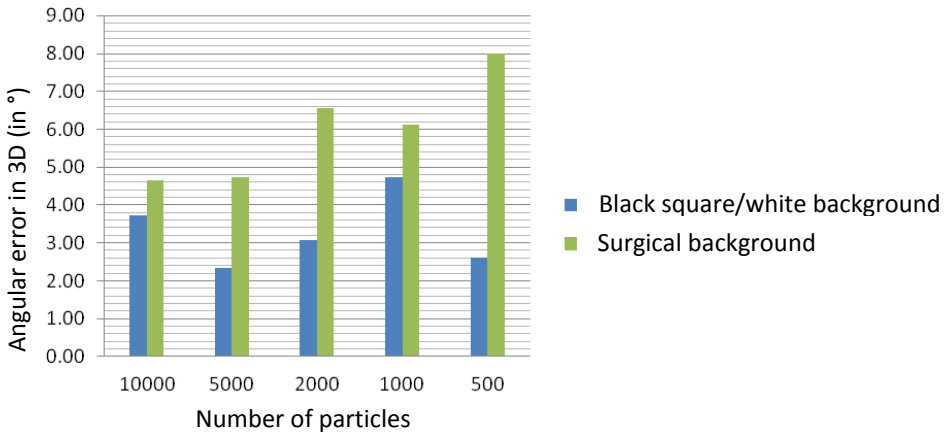
Evaluation of the approach (3/4)

- Precision considerations:
  - In theory, a ~ 650 000 cells grid allows for a resolution of 0.47 mm for a tool insertion depth of 100 mm and 1.41mm for an insertion depth of 300 mm
  - 2D tool orientation vs. manual labeling: **error <1°** with 1000 particles
  - 2D tool tip vs. manual labeling (on 20 images, with 1000 particles): **mean error of 7.6 pixels** on a 720x480 image
  - 2D tool orientation vs. Polaris (after compensation of the registration error):



Evaluation of the approach (4/4)

- Precision considerations:
  - 2D tool tip vs. Polaris (after compensation of the registration error): results not so good with an average error of 20 pixels on white background and 50 pixels on surgical background
    - Could be due to occasional confusions between tool tip and tool shaft
    - A small error in axis detection can lead to a big error at the tip
    - Our simpe thresholding method should be replaced / improved
  - 3D orientation vs. Polaris:



Errors for orientation in 3D when 2D orientation seems « perfect » due to errors along camera's optical axis

In some configurations, a 1pixel error in the image detection can lead to a >2 mm tip error in 3D

Conclusions / Perspectives

- Tool localization / tracking method
  - That can be “real-time”
  - That can (not very precisely) localize tools in 3D based on 2D image analysis
  - The 3D precision could be drastically improved with a stereo-endsocope
  - We need to improve the tool tip localization precision / robustness
- Evaluation issues:
  - Image-based measurements are good but not enough !
  - Polaris-based measurements are complicated (setup, calibration/registration issues, missing data issues: visibility of tools without changing practice ?)
  - How can we make better quantitative evaluations?
- Some example of applications
  - Our next step is to test the localization method / visual servoing during cadaver experiments

Acknowledgements

- Rémi Wolf (PhD student, CAMI team)
- Anthony Agustinos (Phd student, CAMI team)
- Members of the CAMI team
- CIC-IT, Grenoble University Hospital

- Funding from French government (ANR + FUI)

- Several types of positions open in CAMI French labs through the CAMI labex (PhDs, postdocs, visiting professor)