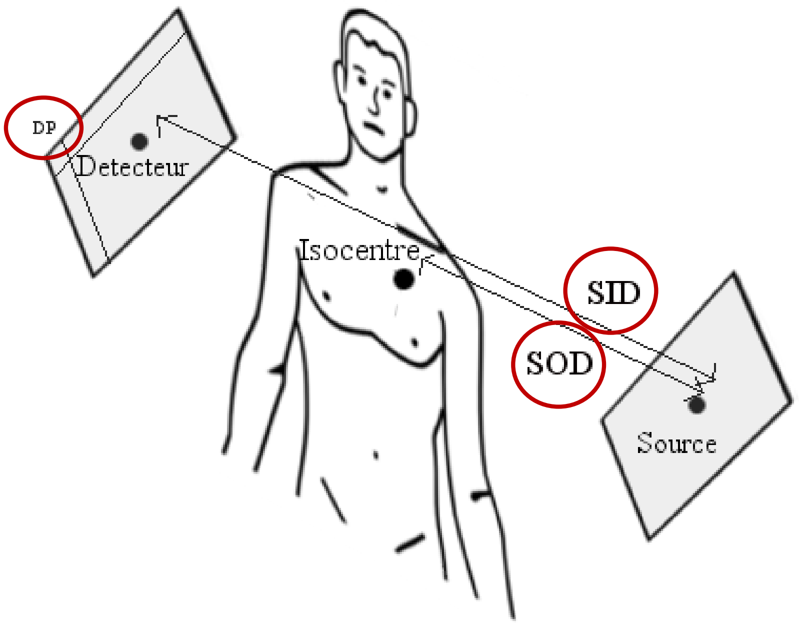
LAB2 - 3D Reconstruction of Coronary Arteries by Angiography

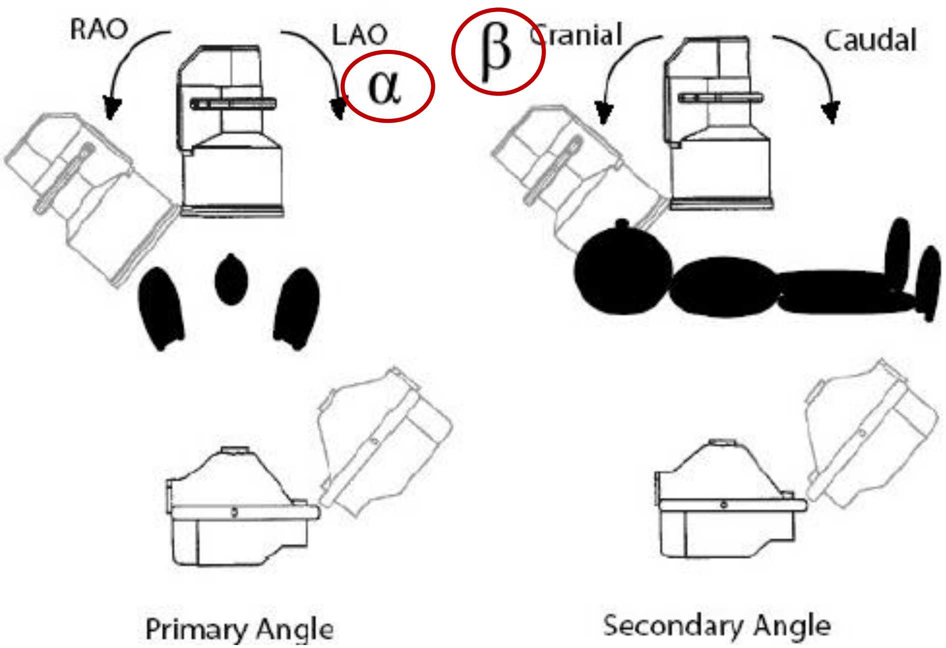
GBM6700E – Fall 2023

Context of practical assignment

C-arm at Sainte-Justine Hospital : Infinix-CFI BP by Toshiba

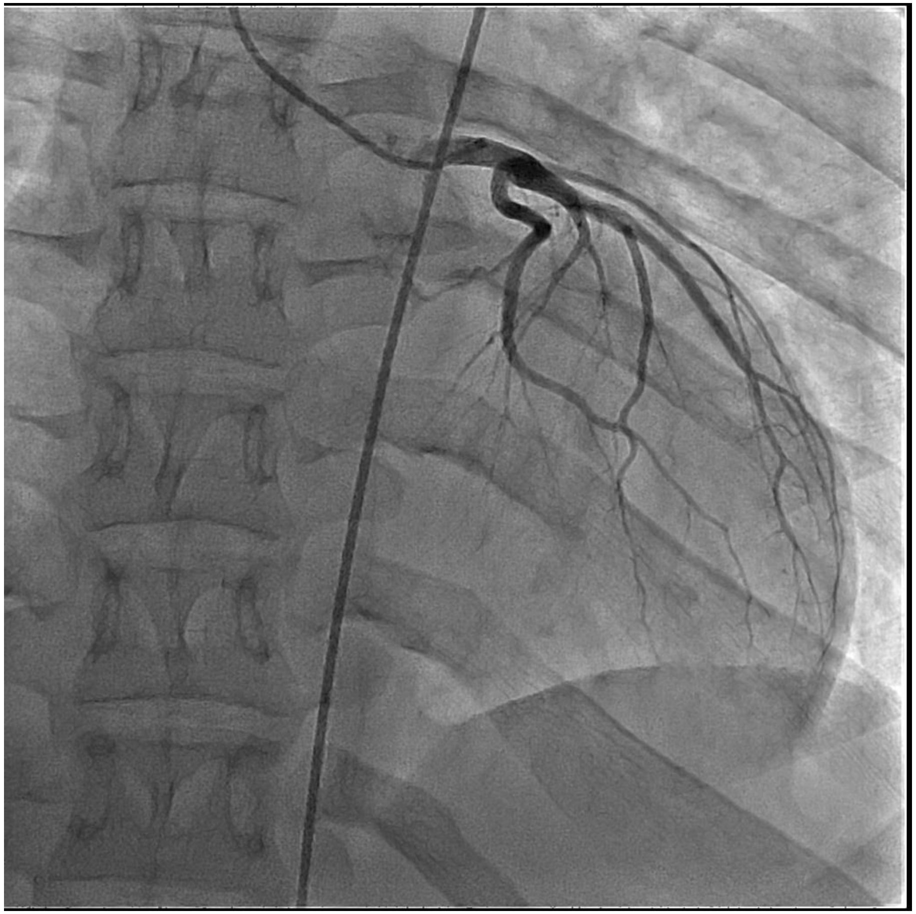
Angiographic image acquisition



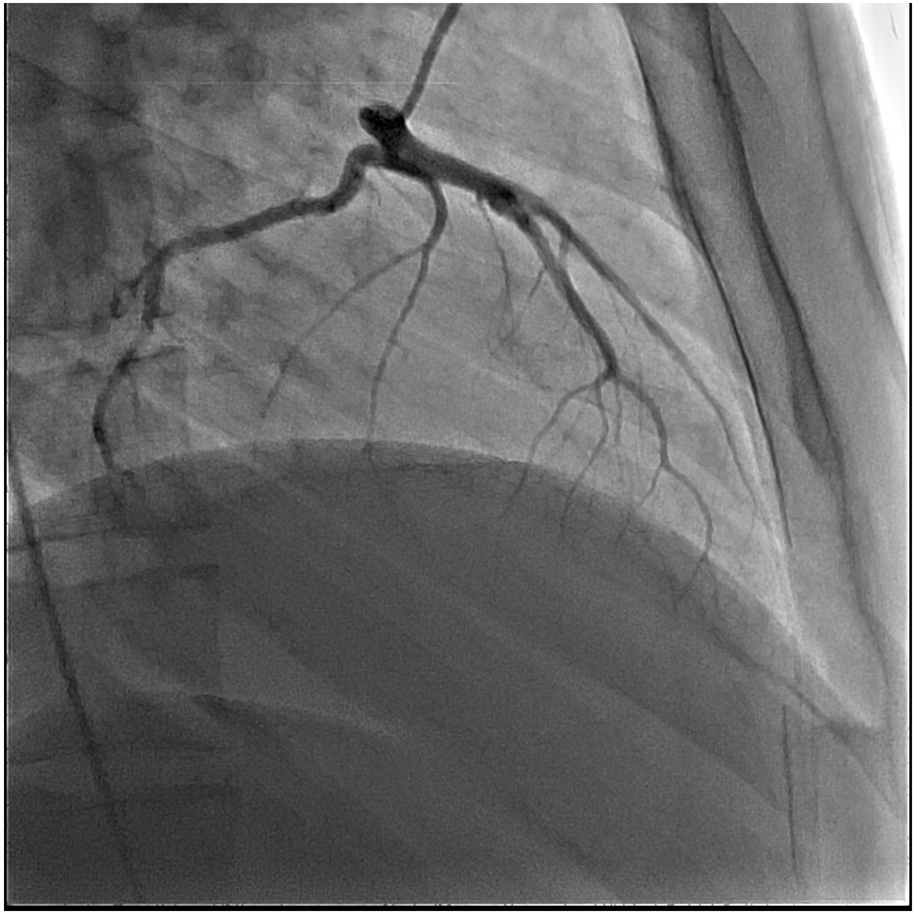


Physical meaning of the DICOM parameters

Real angio images (left coronary tree)

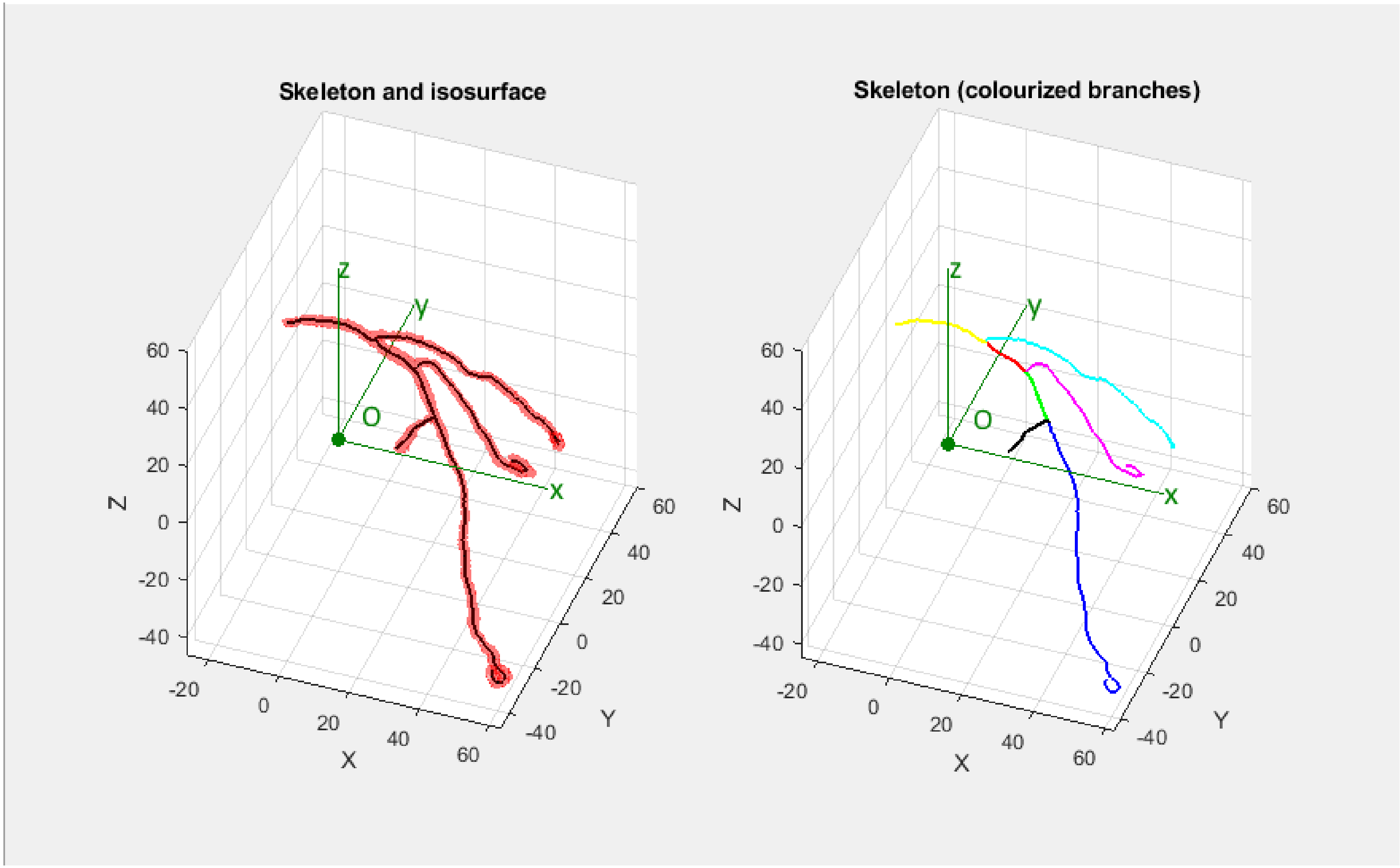


PA0 View



LAT View

Reference CT Volume



Part A

Questions 1 and 2

Question 1

Simulate two angiographic views:

- Choose 2 combinaisons of angles (α,β) based on Appendix B
- Use function BuildViewGeom.m
  - Calculate viewing geometry
- Display the results (generated images)

❖ To choose viewing angles: think of important criteria given the context of real clinical task.

Question 1 (cont'd)

Calculate fundamental matrix F :

Two methods:

a) By exploiting known system parameters

b) By using corresponding feature points and the 8-point algorithm.

Recall Calibration (LAB1)

- Projection matrices for each view
- Compute intrinsic and extrinsic parameters :

  - c_u , c_v
  - u_o , v_o

$$K = \begin{bmatrix} c_u & 0 & u_0 \\ 0 & c_v & v_0 \\ 0 & 0 & 1 \end{bmatrix}$$

  - X_o , Y_o , Z_o

$$T = -R.[X_o \;\; Y_o \;\; Z_o]^t$$

  - R

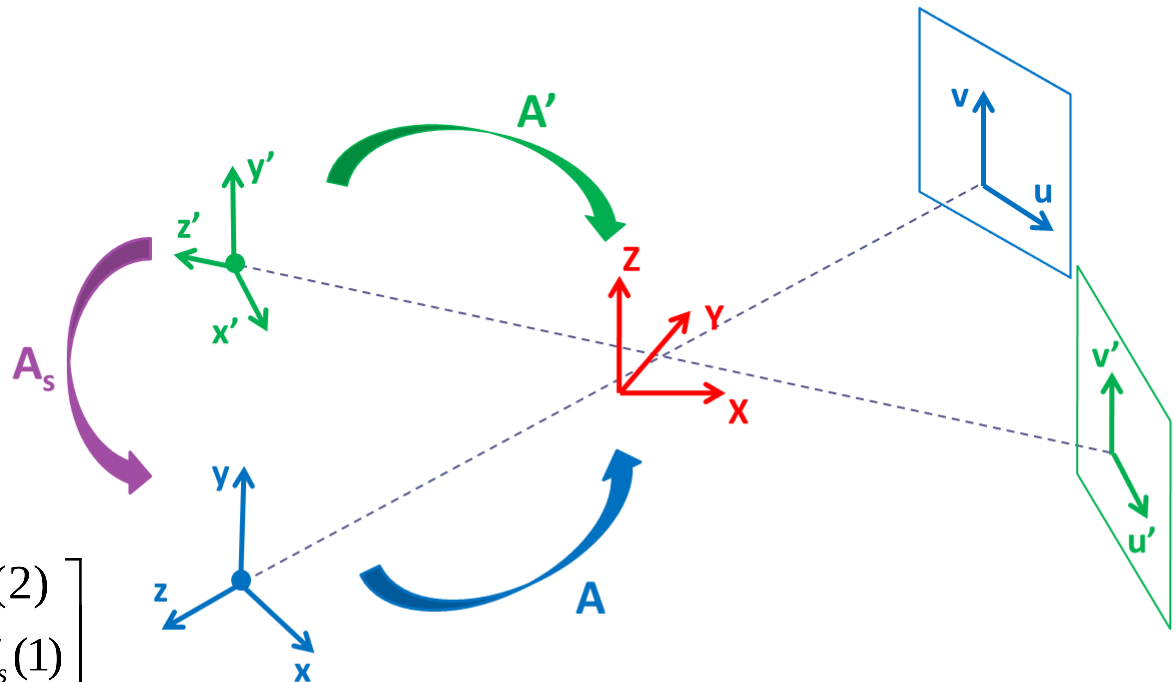
$$\boxed{\begin{bmatrix} wu \\ wv \\ w \end{bmatrix} = K.[R \mid T].\begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}}$$

Fundamental Matrix (1) *

- $A = [R|T]$
- $A' = [R'|T']$
- $A_s = A'.A^{-1}$
- $A_s = [R_s|T_s]$
- $E = [T_s]_x.R_s$

$$[T_s]_\times = \begin{bmatrix} 0 & -T_s(3) & T_s(2) \\ T_s(3) & 0 & -T_s(1) \\ -T_s(2) & T_s(1) & 0 \end{bmatrix}$$

- $\boxed{F = (K'^{-1})^t.E.K^{-1}}$



*** See next slide for explanation of notations**

Fundamental Matrix (2)

- F allows to go from View 1 to View 2
- A, R, T, K are associated to View 1
- A', R', T', K' are associated to View 2

(note that the prime (') here does **not** mean the transpose operator).

- The notation [R|T] means the concatenated matrix:

$$\begin{bmatrix} r_{11} & r_{12} & r_{13} & t_1 \\ r_{21} & r_{22} & r_{23} & t_2 \\ r_{31} & r_{32} & r_{33} & t_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Question 1 (cont'd)

- Real-world situation: we don't know the system's geometric parameters !
  - Exploit information in images: corresponding points between the two views.
  - Feature points: can use **bifurcations**
  - Use function `FMatNorm8.m` *(8-point algorithm)*
  - Try with minimum number of points
  - Try with all available points

Question 2

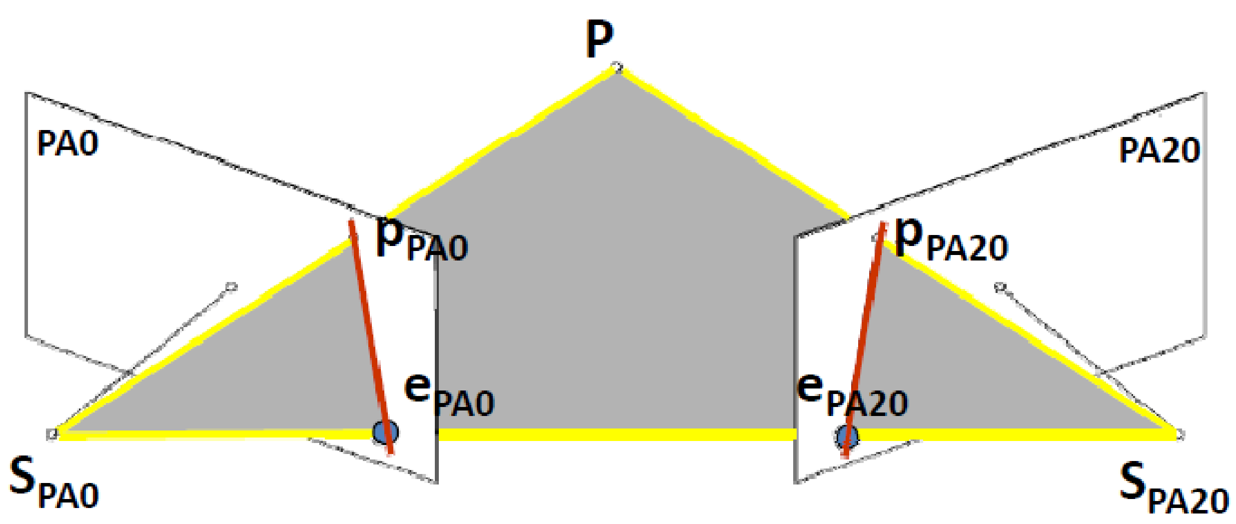
Correspondence (feature matching) of vessels between the 2 views

Main steps:

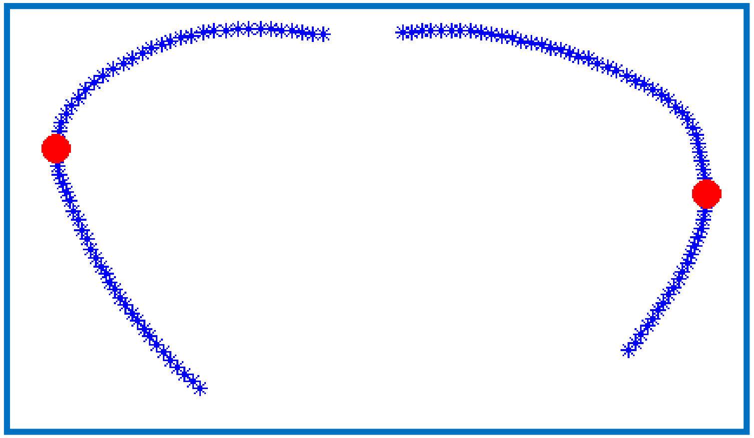
1) Select one image at View 1 and one as View 2
2) Resample branches in View 2 (to higher density) using function Interpole_Discretise.m
3) Use epipolar constraint to find correspondences in View 2 to points in View 1

Properties of the fundamental matrix

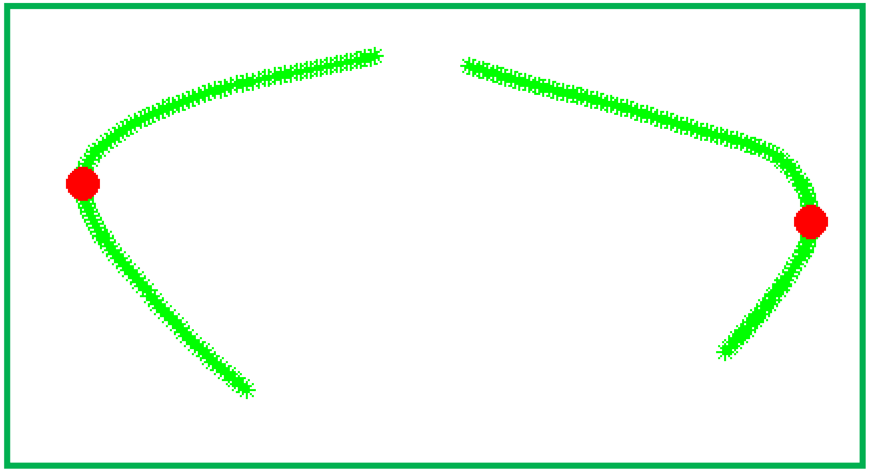
- $F.P_{View1}$ is the epipolar line associated to P_{View1}, in View 2
- $F^t.P_{View2}$ is the epipolar line associated to P_{View2}, in View 1
- $F.e_{View1} = 0$ and $e^t_{View2}.F = 0$.
- F is singular.



Reconstruction of curvilinear structure: *example of rib pairs*

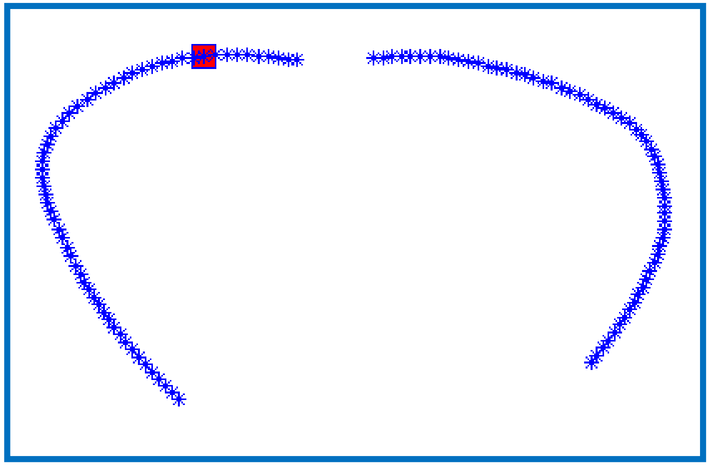


In View 1

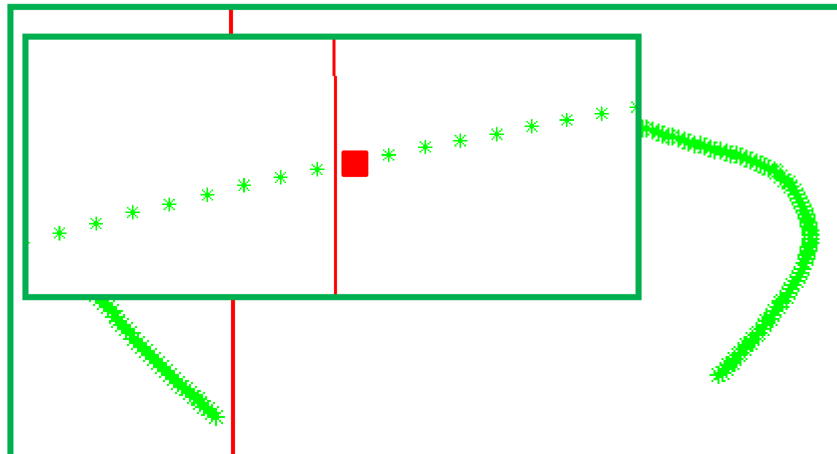


In View 2

Reconstruction of a curvilinear structure: *example of rib pairs*



In View 1



In View 2

Part B

Questions 3 and 4

Question 3

Calculate depth map of scene:

- Depth Z is approximation of 3D shape
- Z is inversely proportional to disparity
- Formula :

$$Z = \frac{f * B}{d}$$

where:

d : disparity (between pairs of points)

B : baseline = distance between the sources

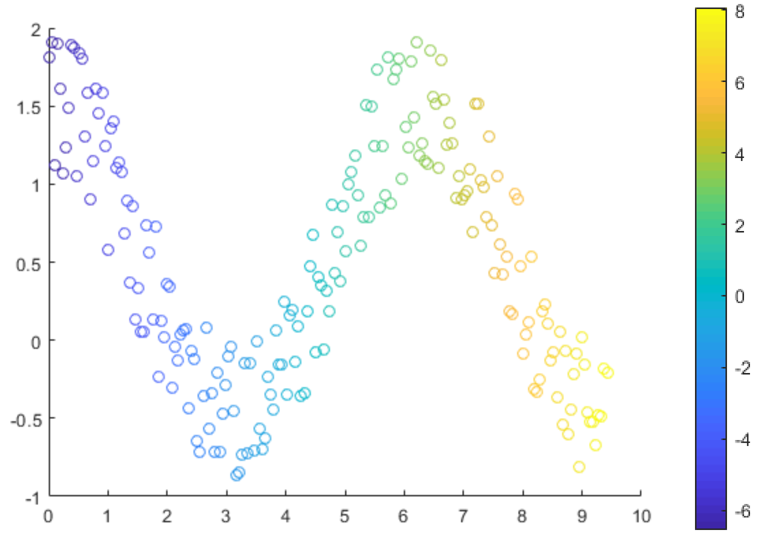
f : focal length

Question 3 (cont'd)

Display depth map of scene:

- Viewing scene from point of view of 1st source
- For plots of disparity / depth maps, can use Matlab commands: `scatter`, `colormap`, `colorbar`

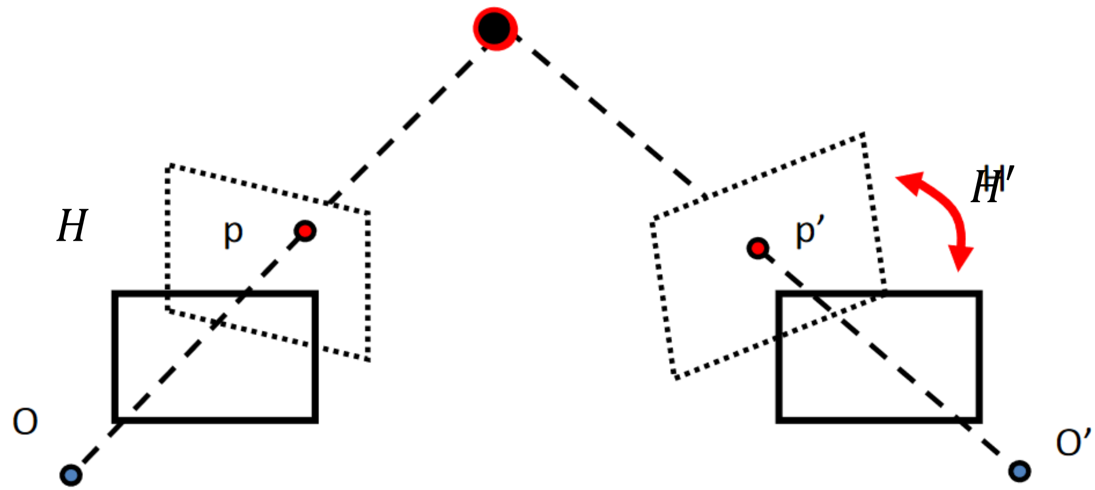
Example of How to plot results

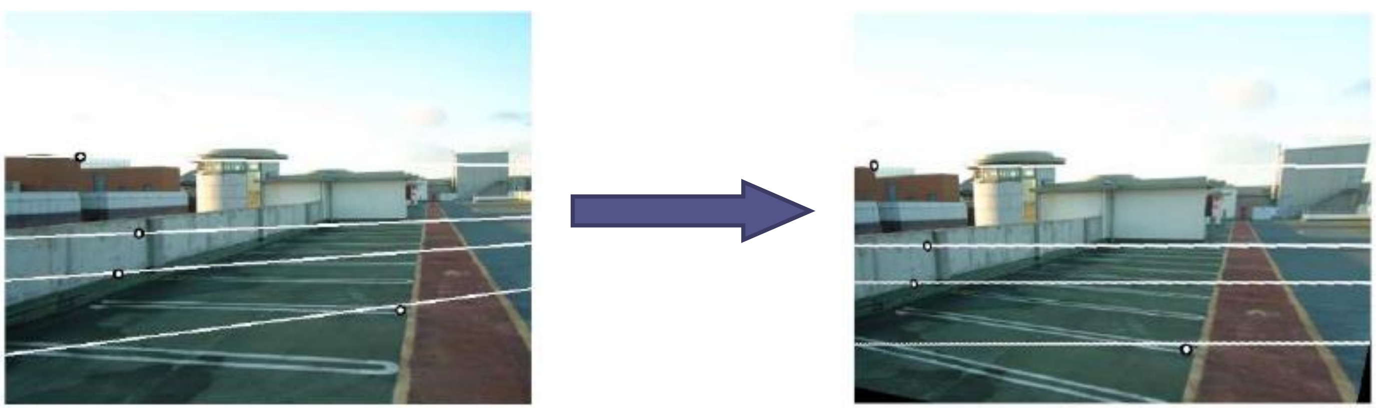


Question 3 (cont'd)

Image Rectification (reminder):

Find perspective transformations *H* and *H'*





Question 3 (cont'd)

Rectify images of View 1 and View 2:

1) Use function Rectify.m
   - Gives transformations *(H,H')* and projections matrices *(P,P')*
2) Keep correspondences from Question 2
3) Recalculate disparities
4) Recalculate depth map *Z*
5) Display new map

Question 3 (cont'd)

Construct *real* ground truth map:

1. Transform reference 3D model to coord. system of 1st source
2. *Z* coords of this 3d model : depth values
3. Plot this as a map

Compare the different maps qualitatively.

Bonus : compare the different maps quantitatively.

- examine numerical relationship between them

Question 4

Reconstruct vessels in ideal case:

- As in LAB 1 !
- Display in 3D and compare with reference: differences ?

Back-project 3D model to each view:

- How ? Go back from 3D to 2D (i.e. project) !

Compute RMS errors in ideal case (3D, 2D):

- Use formulas from LAB 1
- Are the errors = zero ?

Question 4 (cont'd)

Progressively add noise to DICOM params:

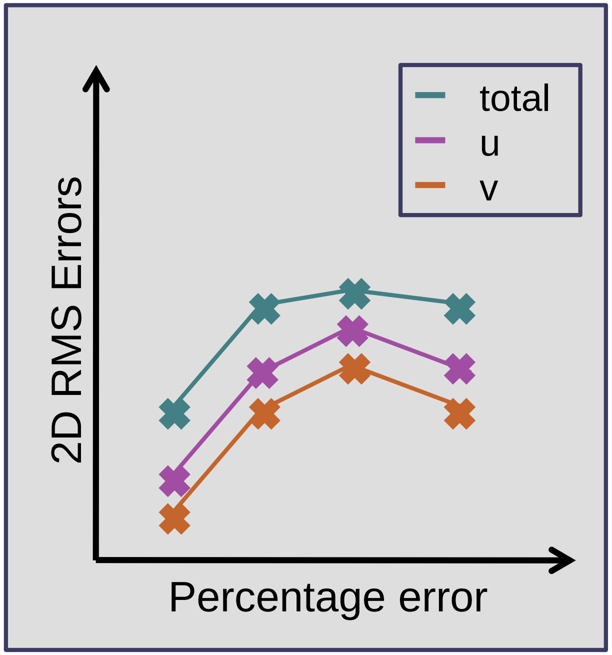
- SID, SOD, DP, alpha (α), beta (β)
- Add percentage of init. value: 1%, 2%, …, 10%
- Optional: introduce random element + average of trials

In each case:

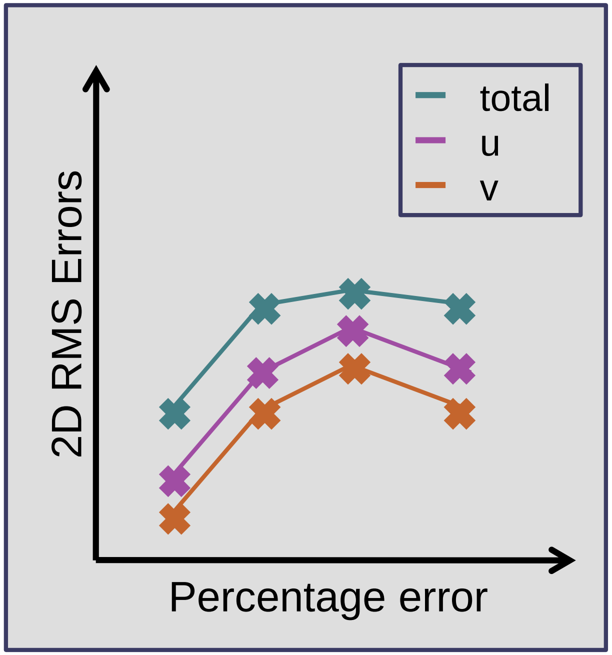
- Reconstruct 3D model of vessels
- Back-project 3D model to each 2D view
- Compute RMS errors

How do errors behave ?

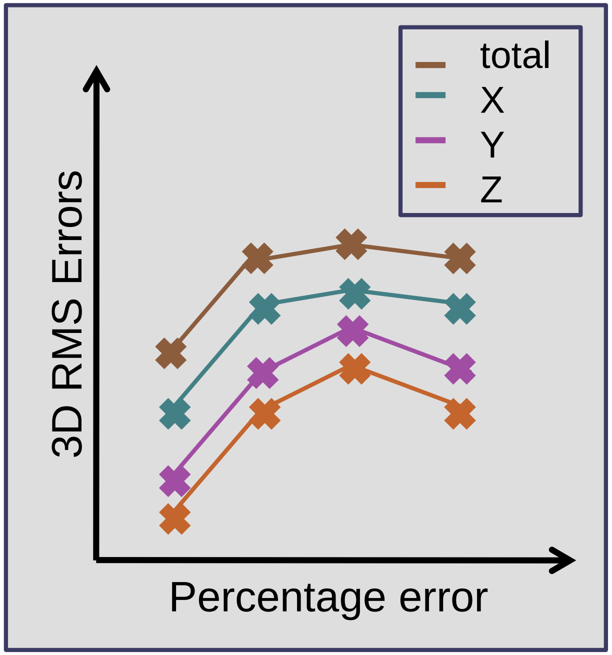
Question 4 (cont’d)



RMS plot for View 1



RMS plot for View 2



RMS plot for 3D

Part C

Questions 5 and 6

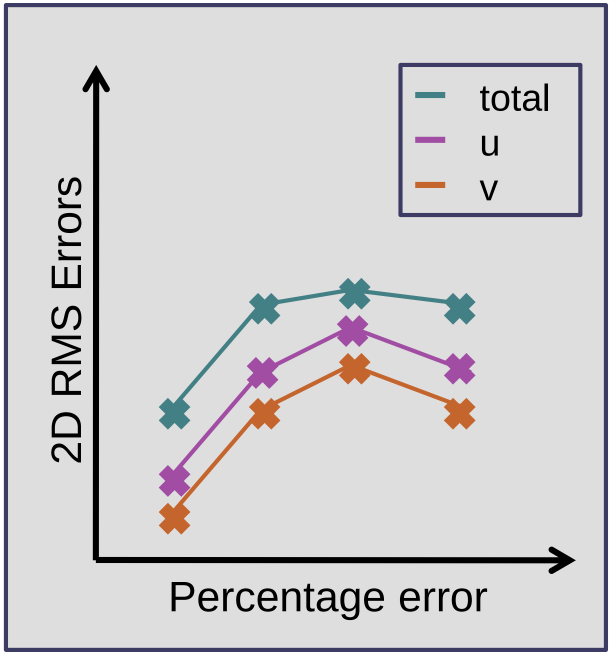
Question 5

Use self-calibration (Levenberg-Marquardt):

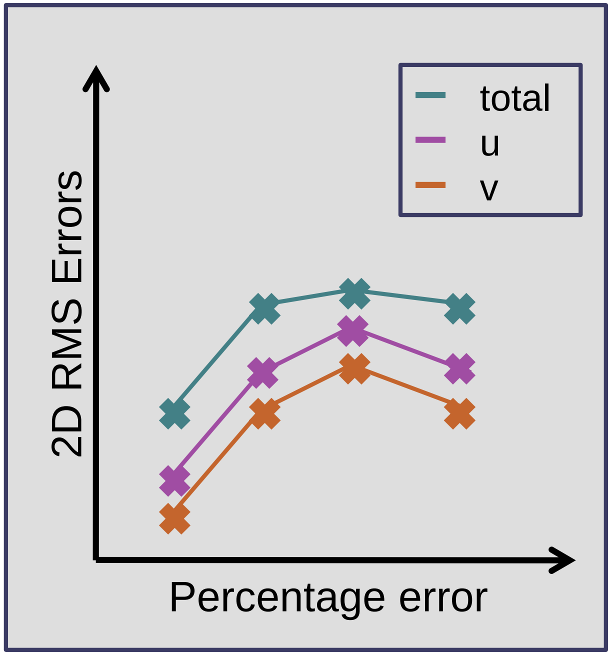
- Keep same noisy values used in Question 4
- Use provided function RefineCamParam.m
  - Read the Matlab function header carefully…
  - Separate refinement in each view
- **CAREFUL**:
  - provide *noisy* values of 3D model and calib. parameters
  - provide *non-noisy* values of 2D projections
- Effect of the correction by self-calibration algo:
  - Behaviour of 3D errors ? of 2D errors ?

Question 5 (cont'd)

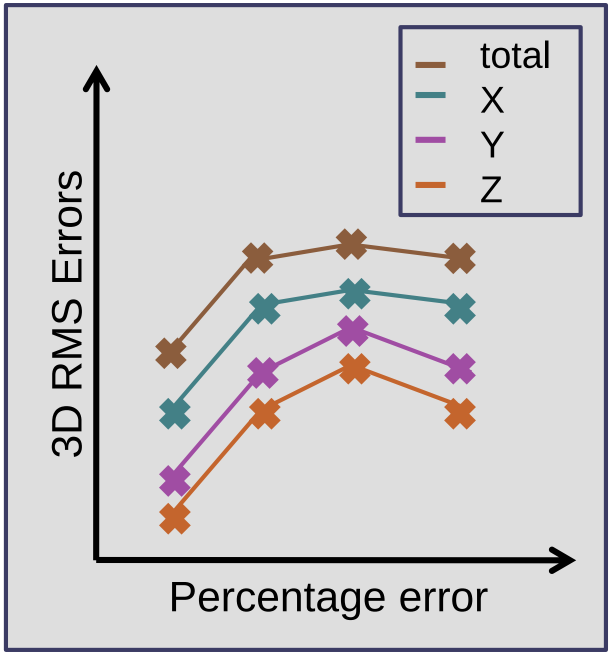
Plot resulting error curves like in Question 4:



RMS plot for View 1



RMS plot for View 2



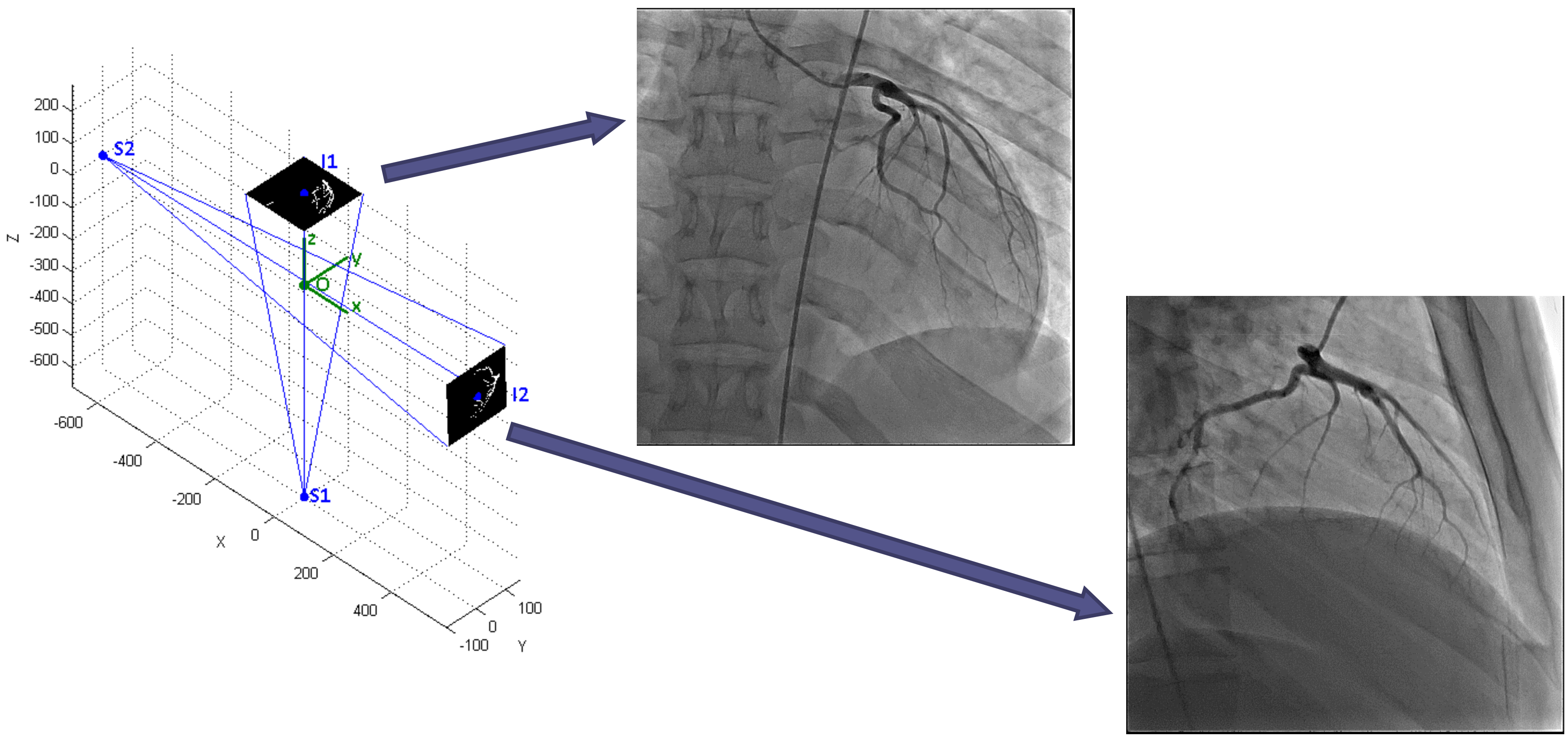
RMS plot for 3D

Question 5 (cont'd)

- Convert, in each case, refined calib. parameters back to DICOM parameters:
  - Use provided function GetDicomFromCalib.m
  - Inputs: provide nominal value of DP
- Create plots (e.g. bar charts) to compare:
  a) Nominal values
  b) Values after adding noise
  c) Values after refinement
- What happens to *SID*, *SOD*, *alpha*, *beta* after applying the self-calibration ?

Question 6

- Consider real case (PA0, LAT images provided):



Question 6 (cont'd)

- Consider real case (PA0, LAT images provided):
  - Context as described in LAB2 statement
  - Propose methodology to reconstruct 3D arteries
  - Challenges to expect in this case ?
- This is a *discussion* question:
  - Use what you learned in Questions 1 to 5
  - Can also refer to course material.