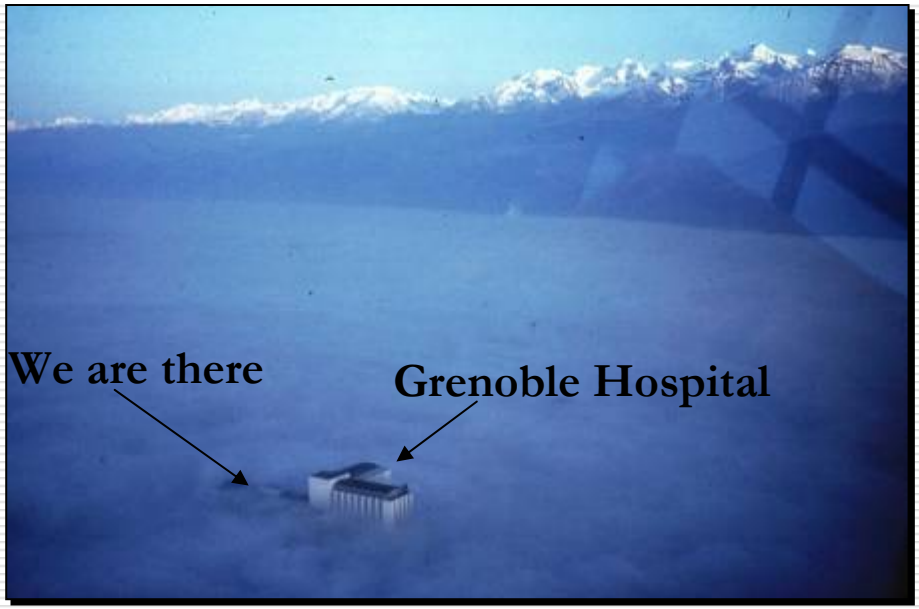
Robot registration

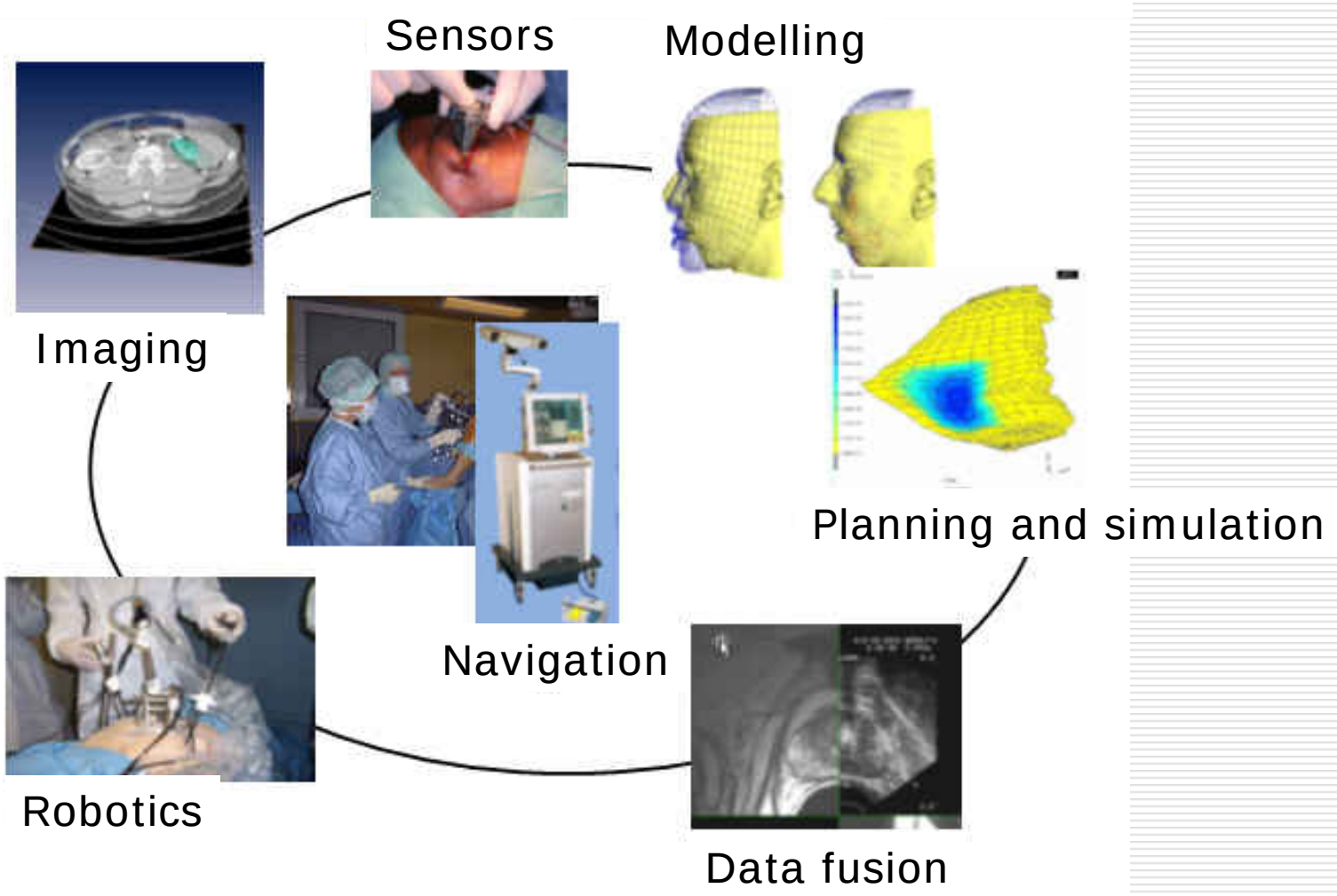
Jocelyne TROCCAZ
TIMC Lab.
jocelyne.troccaz@imag.fr
http://www-timc.imag.fr/gmcao
http://www-timc.imag.fr/Jocelyne.Troccaz

Grenoble GMCAO (CAMI) team

- Created in 1985 by Philippe Cinquin
- Headed from 1996 by Jocelyne Troccaz
- Strong connection to Grenoble Hospital
- About 35 people

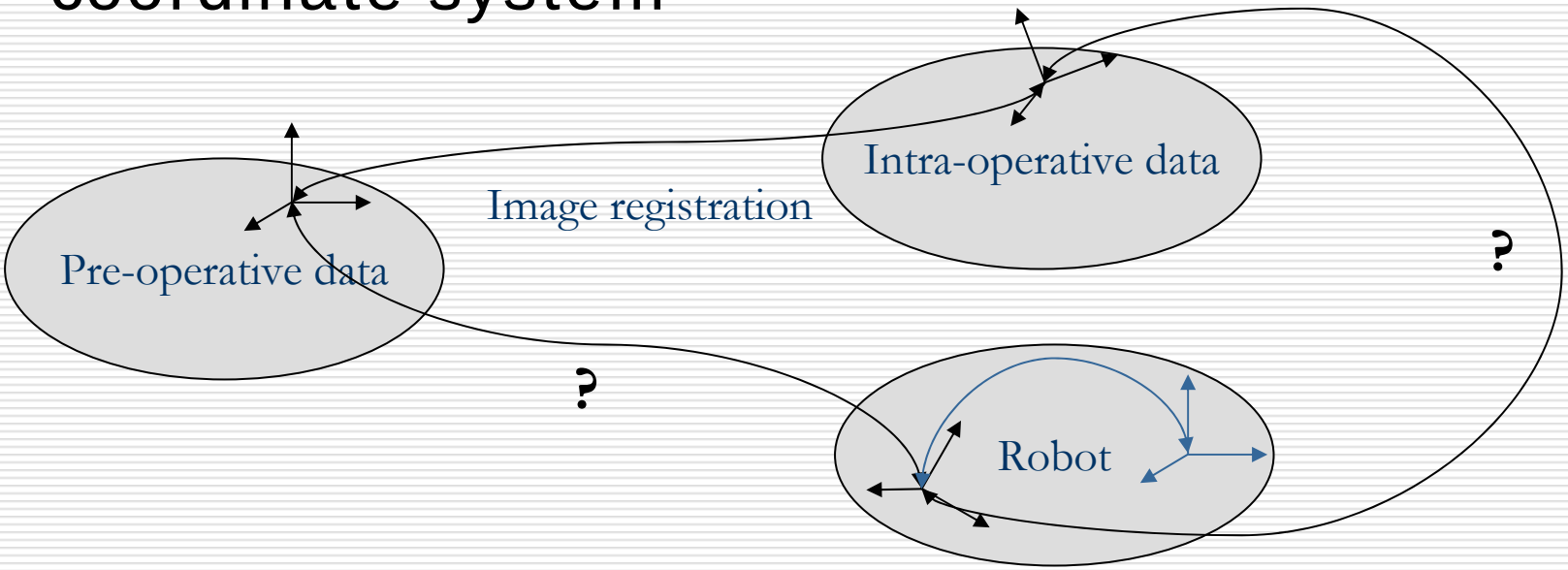


Research topics

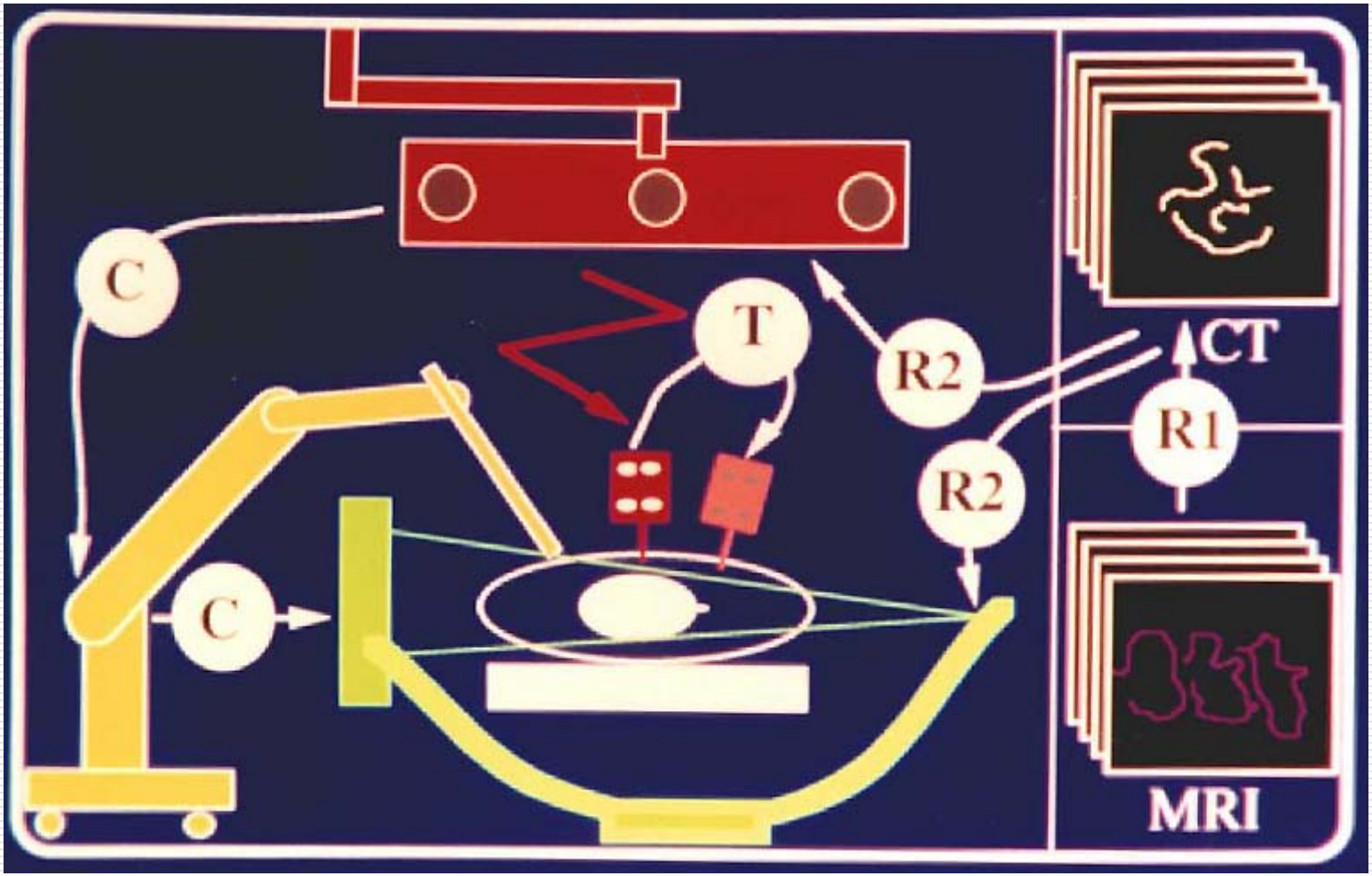


What is it?

- Registration consists in determining geometric relationships between two reference frames
- Robot registration essentially consists in transferring the planning to the robot coordinate system



Example



Tools

- Calibration
- Tracking
- Data registration

Using:

- Patients' data
- External objects

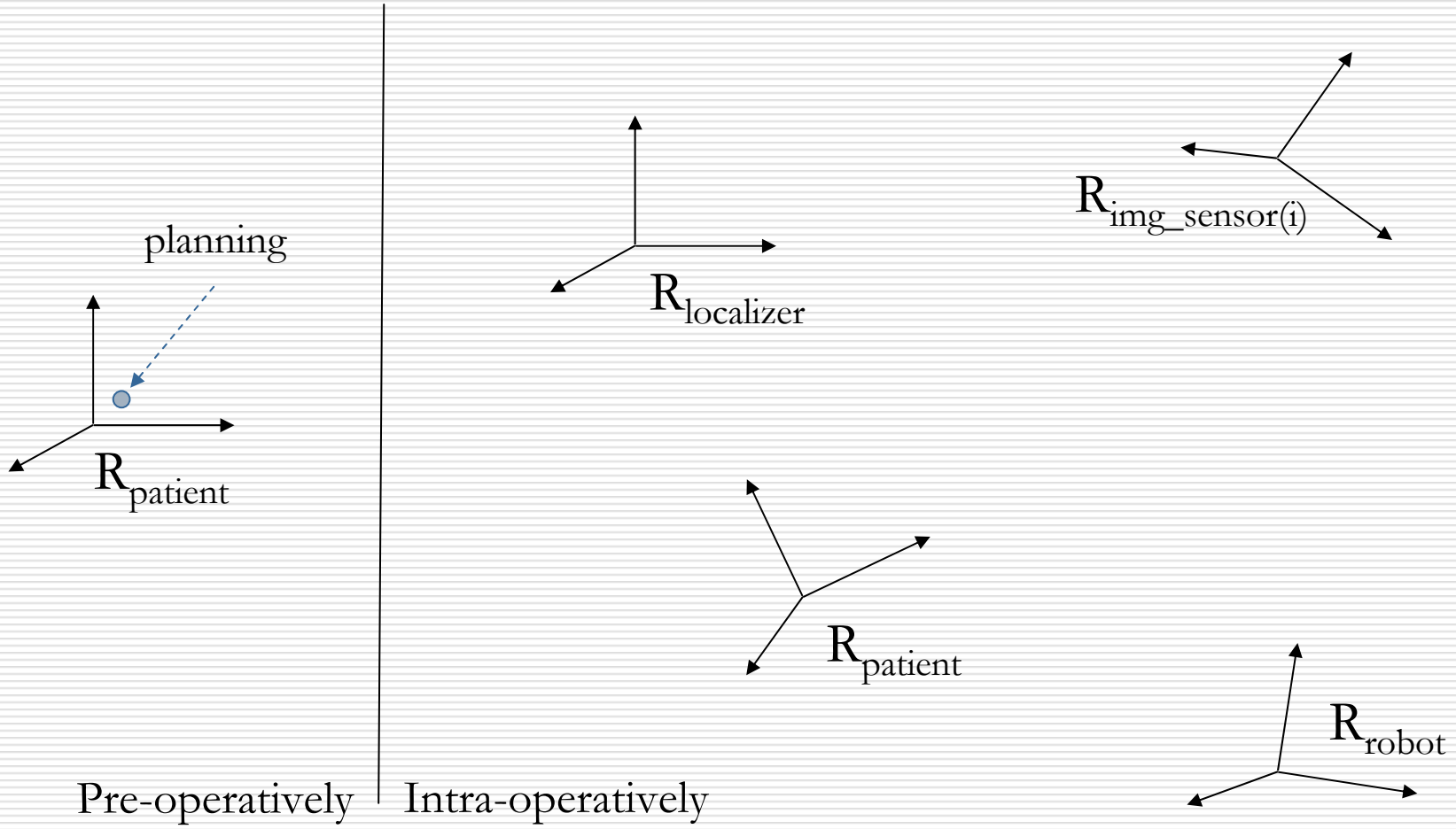
Requires

- Intrinsic robot calibration

Contents

- Introduction
- Methods
- Examples: four main situations
- Conclusion

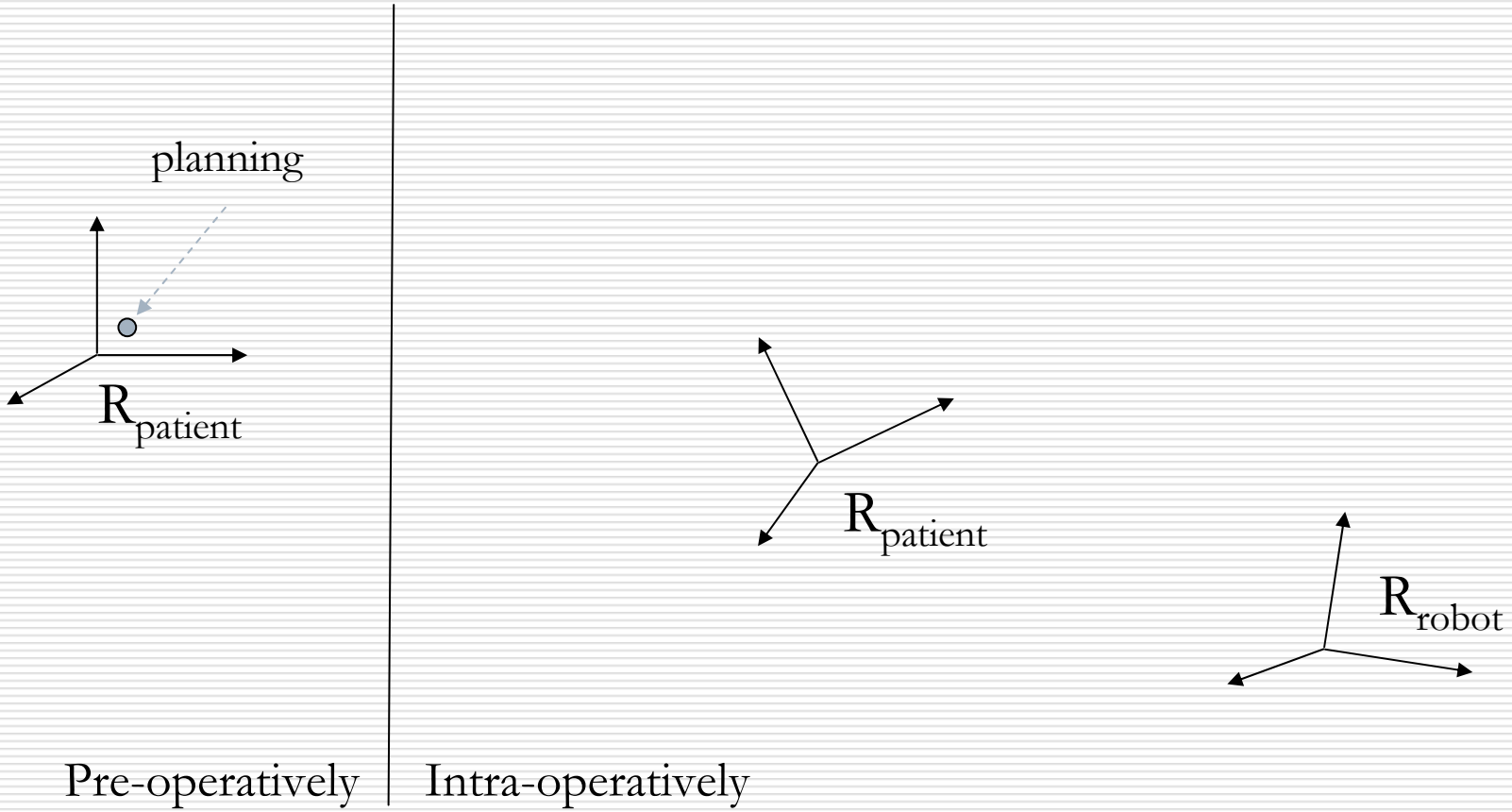
Possible reference frames of interest



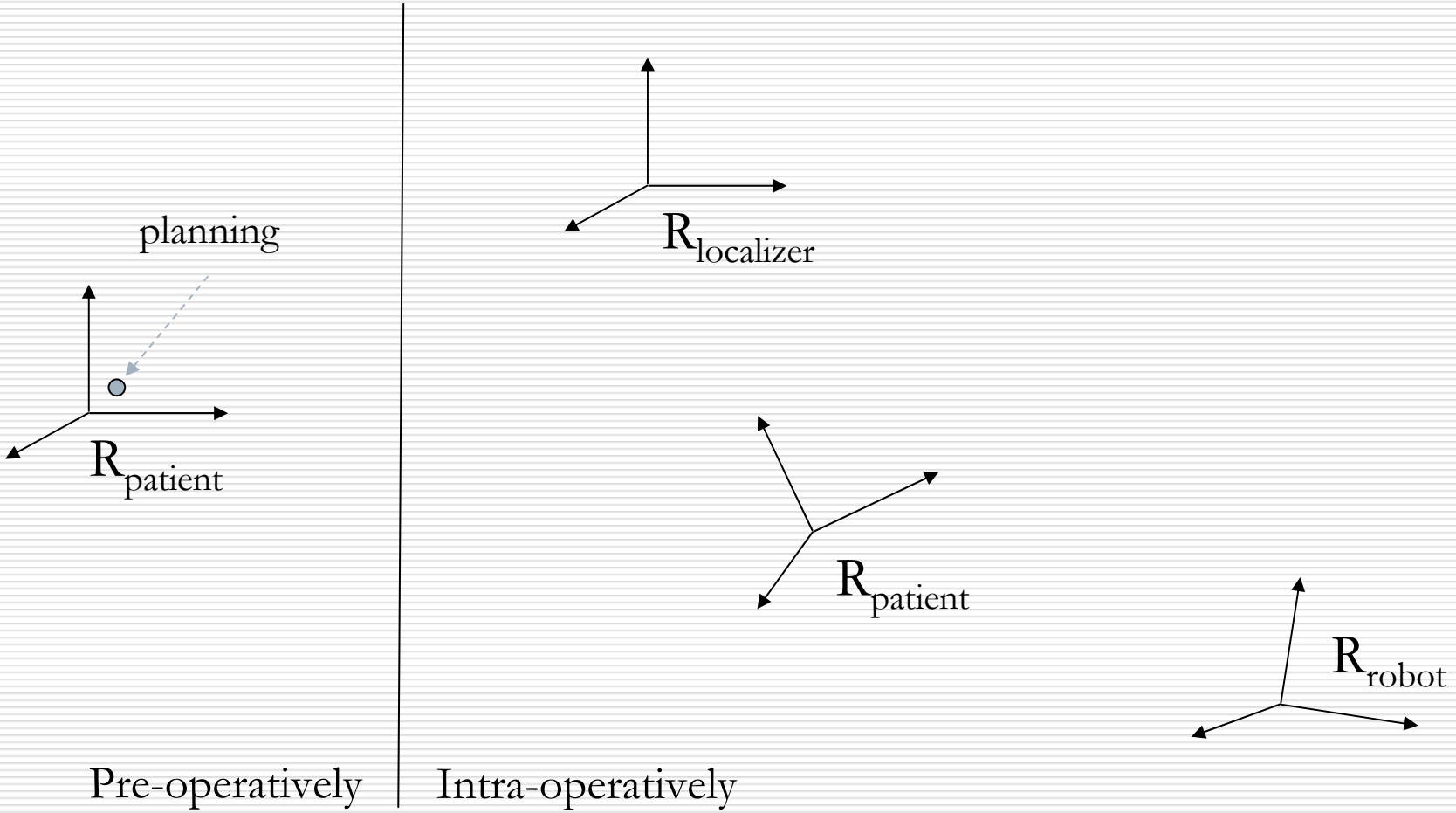
Hardware examples

- Localizers:
  - Optical, US, magnetic, mechanical arm
- Imaging sensors:
  - Fluoroscopy, digital X-Ray, ultrasound

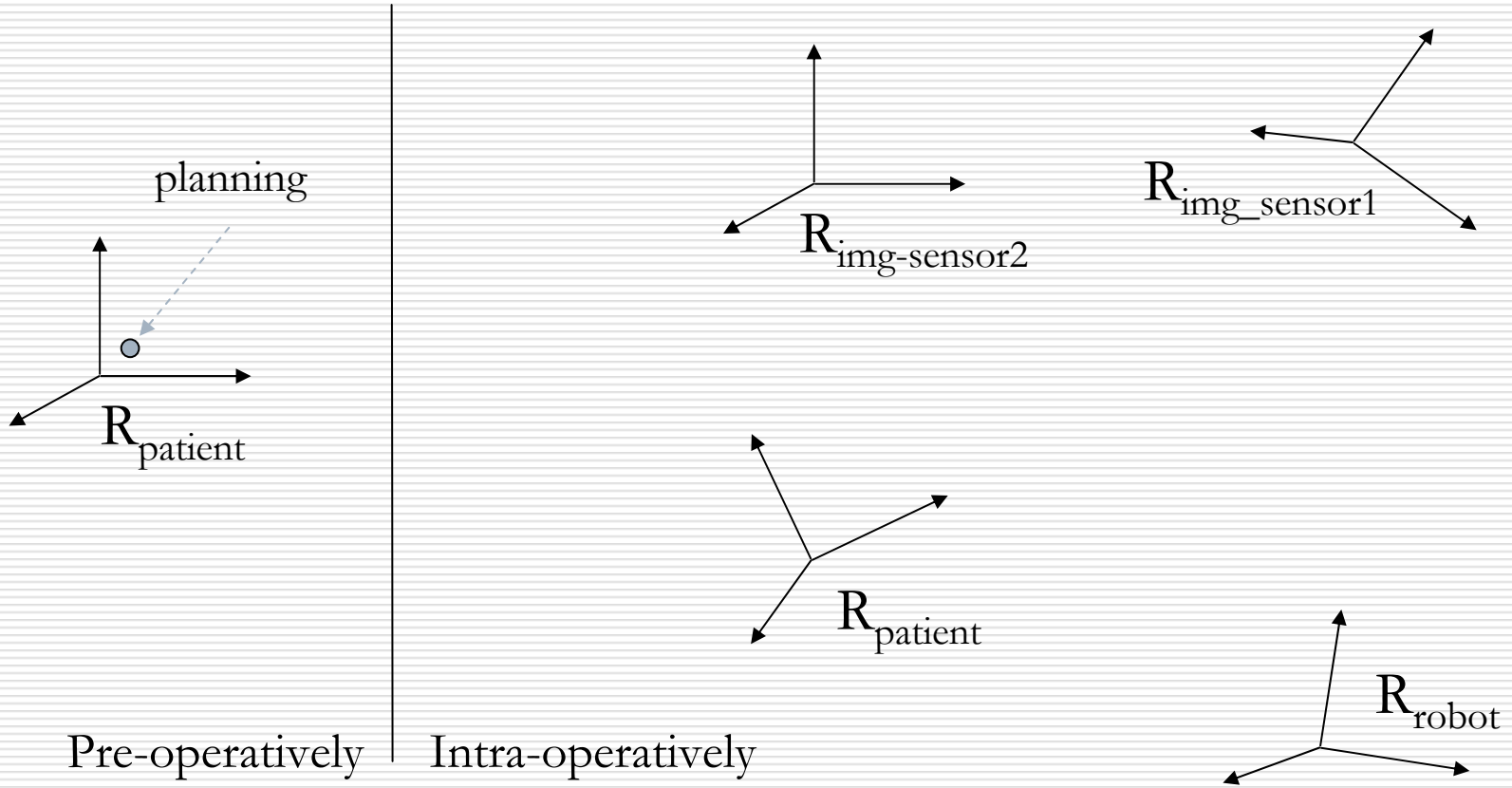
Examples A:
Robodoc, ACRobot, (CAD-Implant)



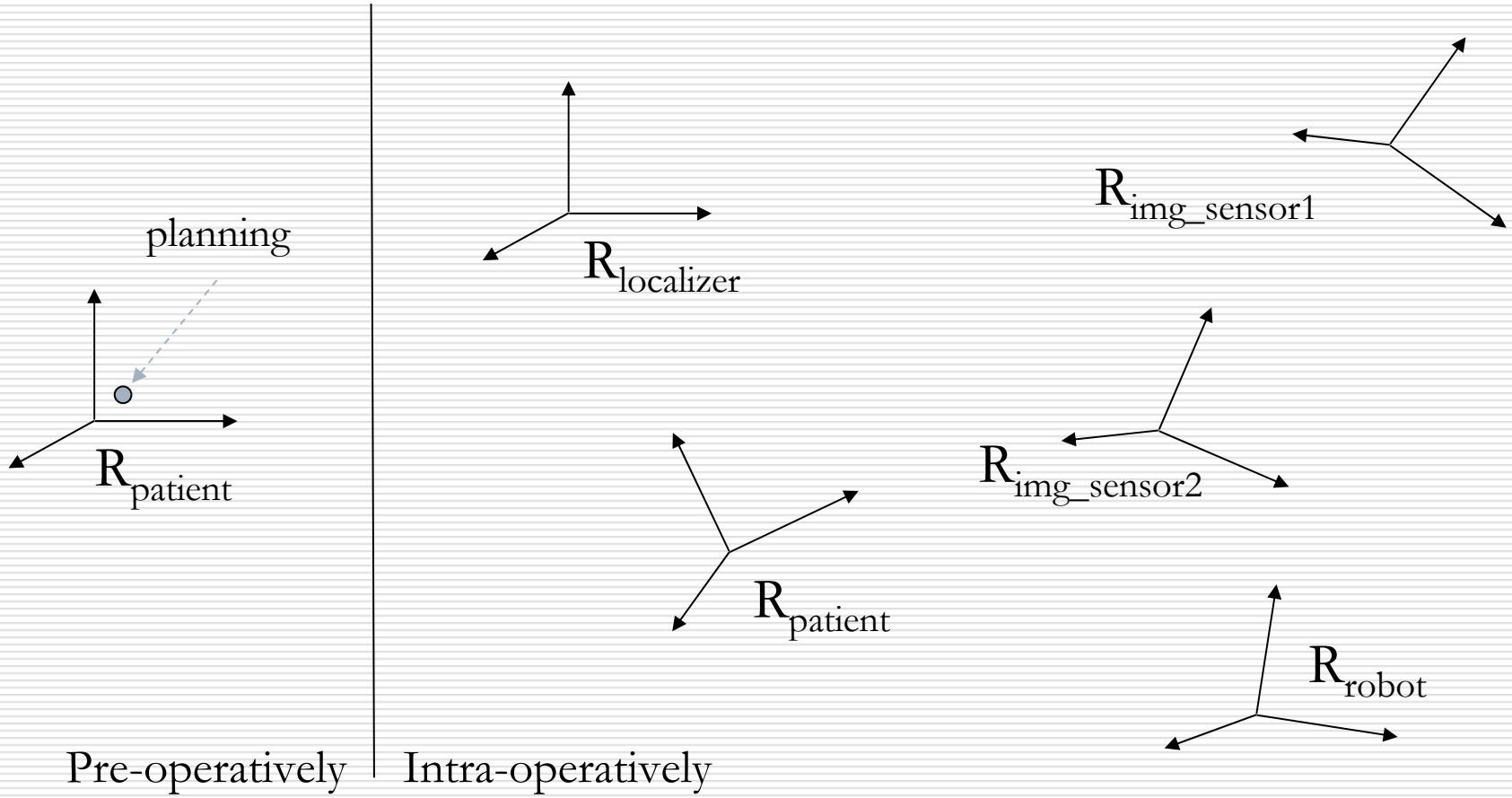
Examples B: CASPAR



Examples C: Speedy, Cyberknife, MARS



Example D: Cyberknife+Synchrony



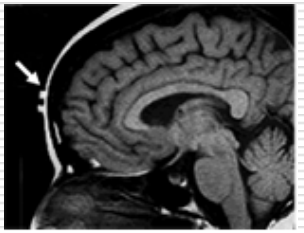
Registration basics

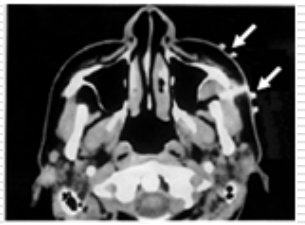
- Two reference frames R_A and R_B and a transform ${}^{B}T_{A}$ to be determined
- Selection of features F_A in R_A and F_B in R_B
- Definition of a similarity measure (or distance) between F_A and F_B
- Determination of ${}^{B}T_{A}$ such that the similarity is maximum (or distance minimum)

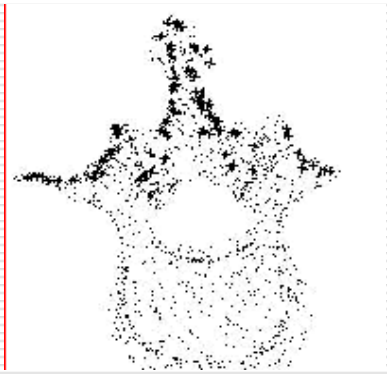
$$ {}^{B}T_{A} = \arg\min d(F_A, {}^{B}T_{A}(F_B)) $$

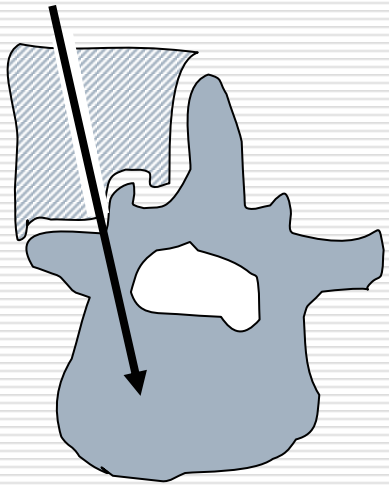
Typical 3D/3D rigid registration methods

- Point to point (Procrustes)
  - External fiducials
  - Anatomical landmarks
- Surface registration
  - Anatomical surface (i.e. ICP, chamfer matching)
  - Template [Radermacher]
- Intensity-based registration (for images only)







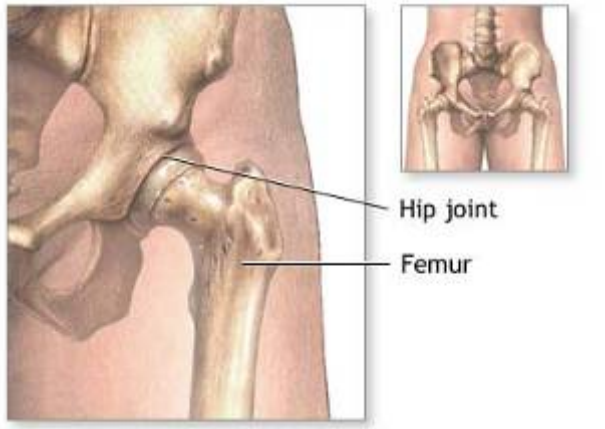


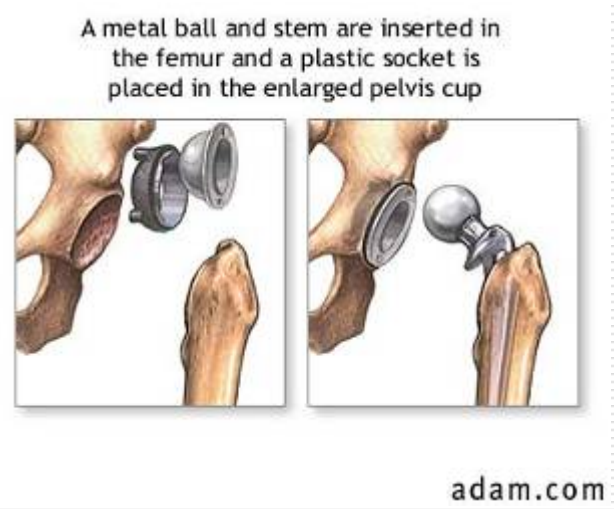
Examples A

- Pre-op: planning on CT data
- Intra-op: a robot
- Developed methods:
  - Robodoc: robot palpation of implanted fiducials
  - ACRobot: robot palpation of anatomical surface
  - CAD-Implant: fiducials+template (robot is pre-operative)

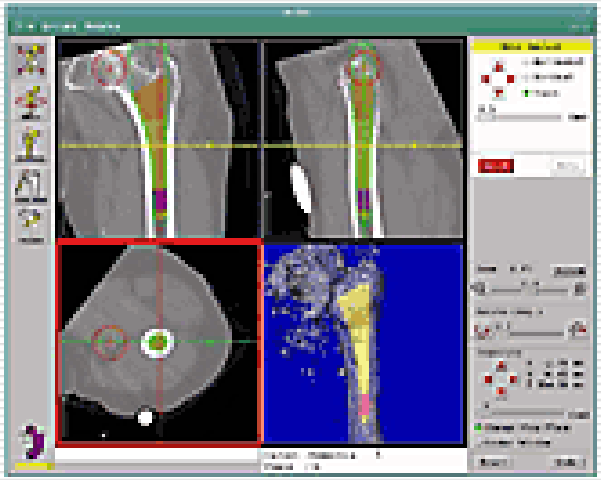
Robodoc (for hip surgery)

- Define precisely the prosthesis position (geometrical or biomechanical criteria)
- Improve the preparation of the hip cavity





Robodoc [Taylor et al.]



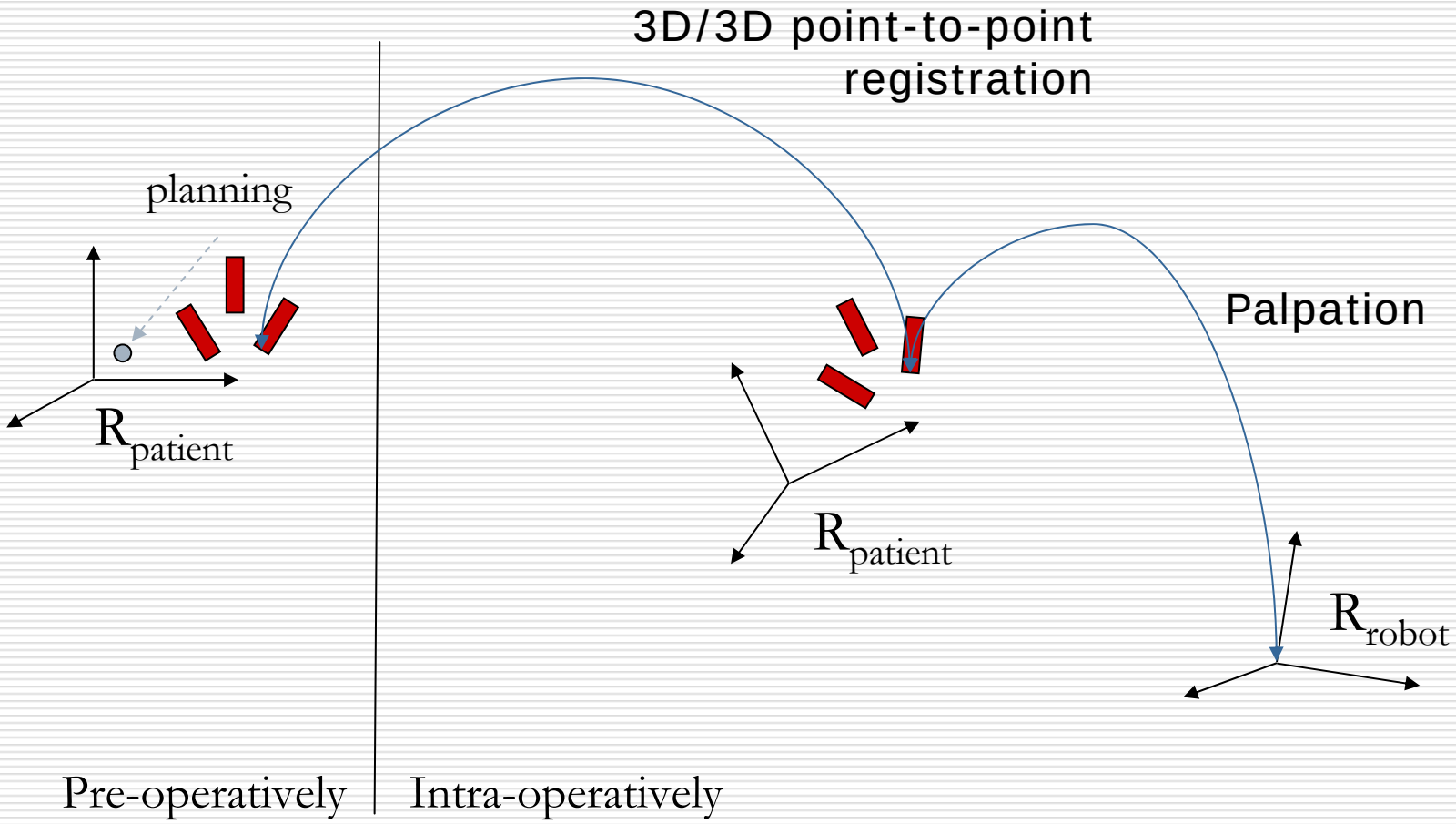
1. *Planning*: Orthodoc

2. *Pre-op to intra-op registration* using implanted titanium pins (anatomical registration in the last version)

6D force sensor

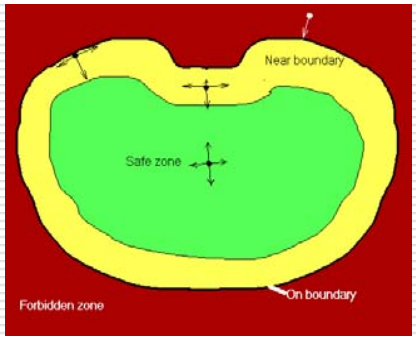
3. *Intra-operative bone milling* procedure using Robodoc (based on the IBM scara robot)

Example A.1: Robodoc



ACRobot [Davies et al.]

- « Hands on » robot
- Knee arthroplasty
- 3 DOFs
- Bone surface palpated with the robot
- IEEE TRA 03: registration accuracy evaluation

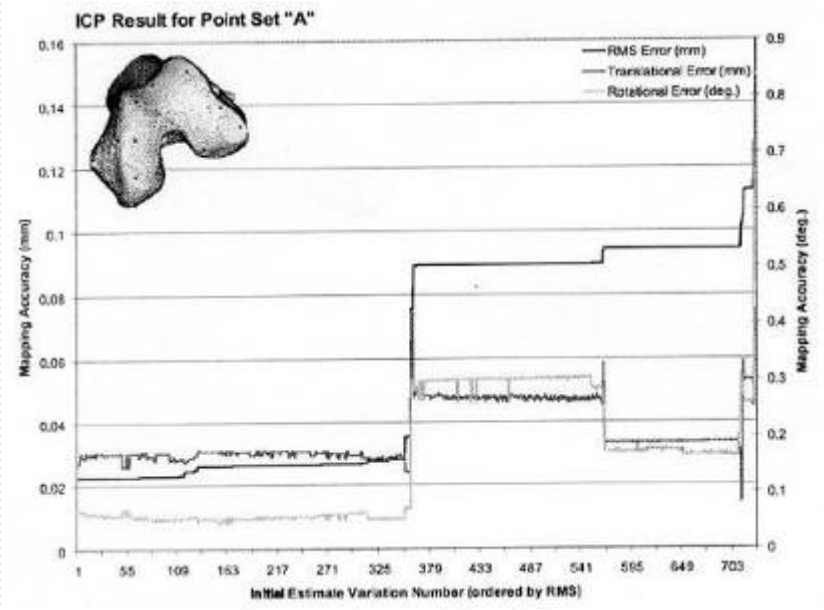


ACRobot registration tests

- Initial estimate from 4 anatomical landmarks
- ICP surface matching
- Intra-op criterion: rms distance
- Does a small rms mean a good registration?
- Experiments with phantom and artificial data:
  - Generated palpated points (10 to 100) with or without random noise added (max up to 1.5mm)
  - Initial estimates in the range of +/-10mm and 2°
  - Known translational and rotational errors

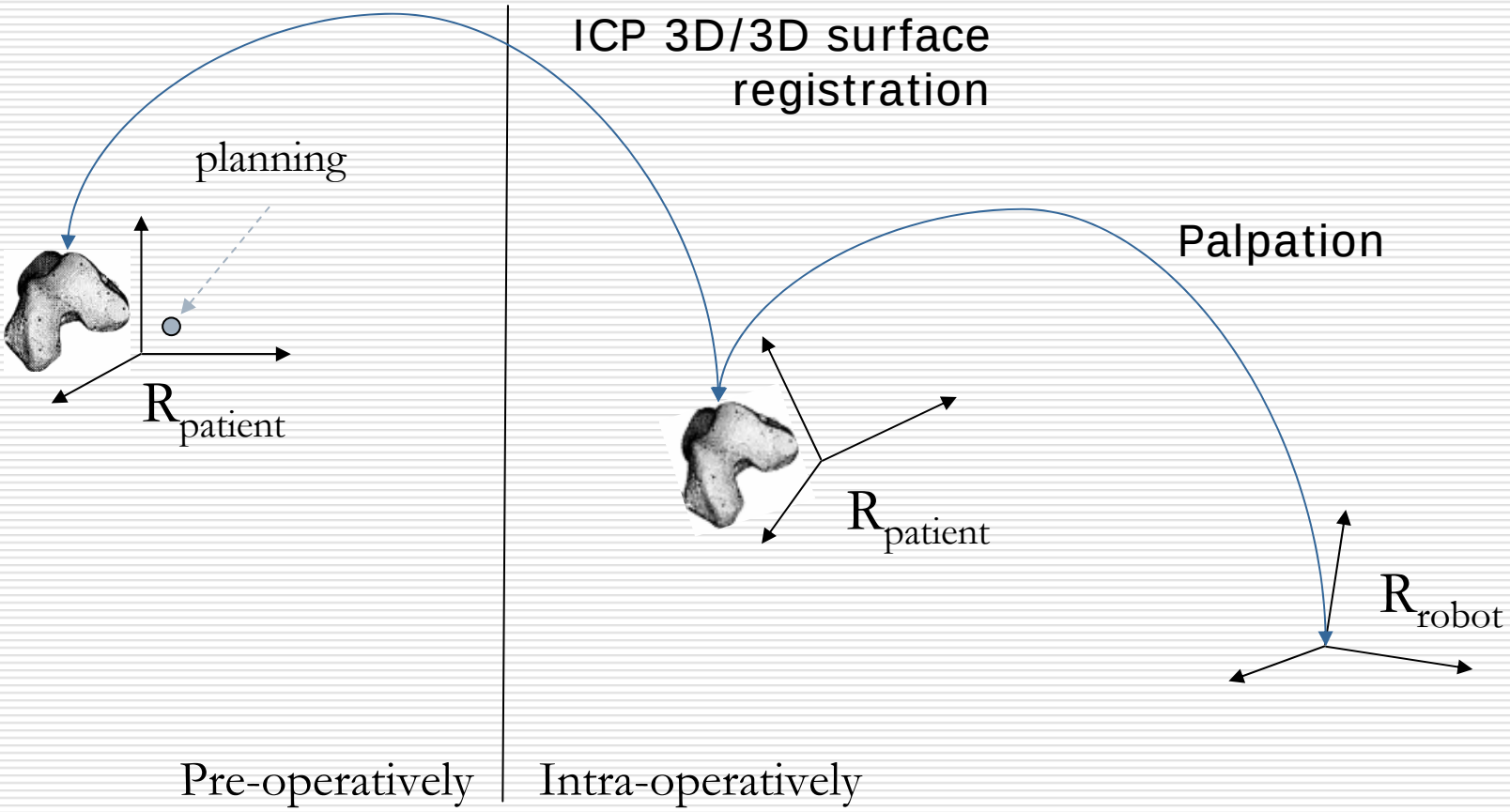
ACRobot: results

- Nb pts <70 makes ICP more problematic
- Results highly depend on the data sets
- May have a rms=0.6 with errors of 0.8mm and 2°

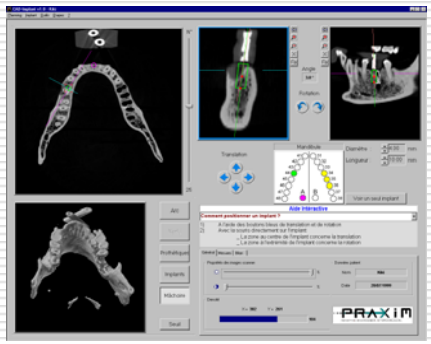


From [IEEE-TRA03]

Example A.2: ACRobot



CAD-Implant [Champleboux et al.]

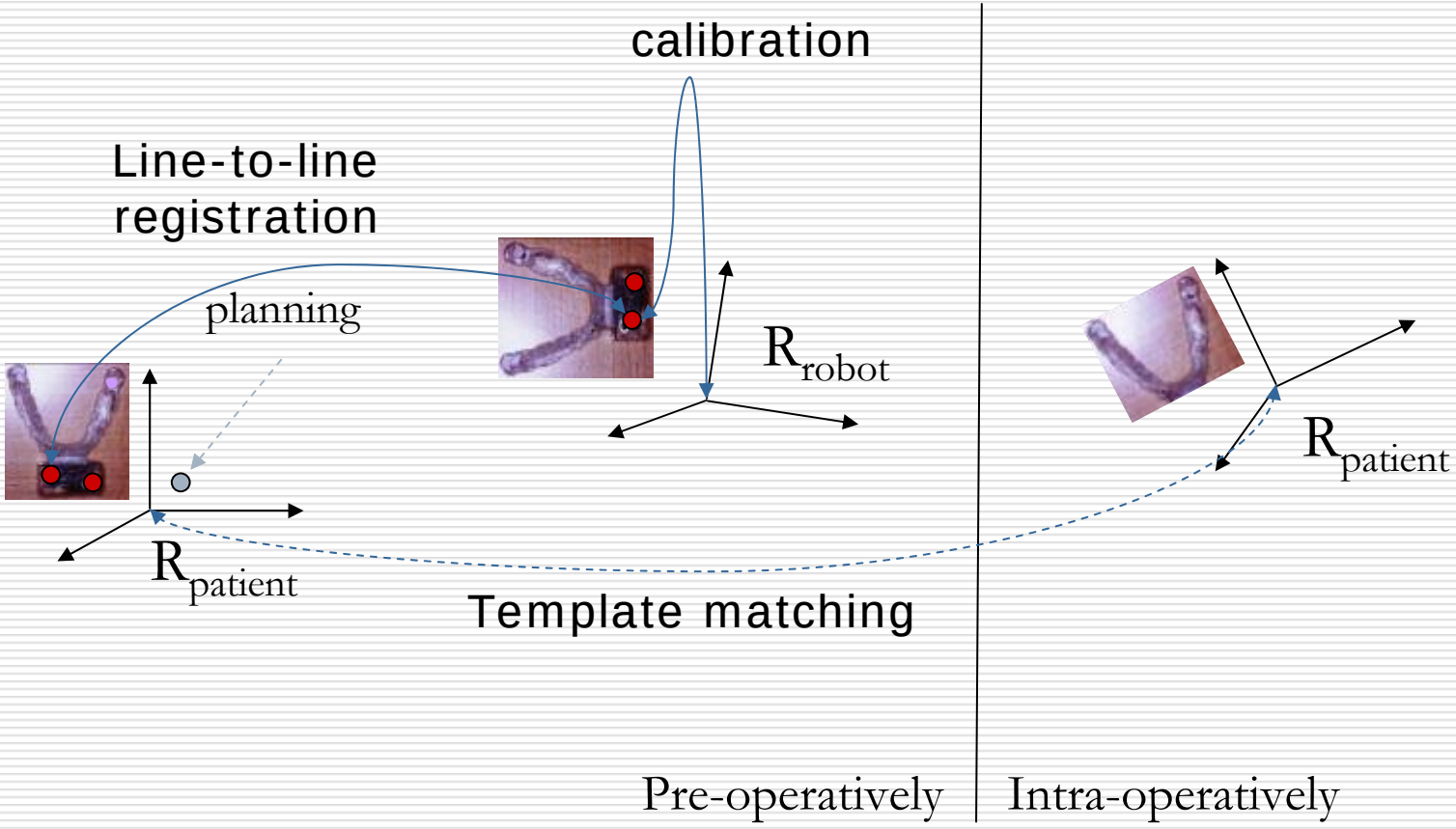


- A system for dental implant assistance
- A template associated to fiducials visible on CT

- A pre-operative robot
- Intra-operatively: no robot, no computers

- Surface registration without computers

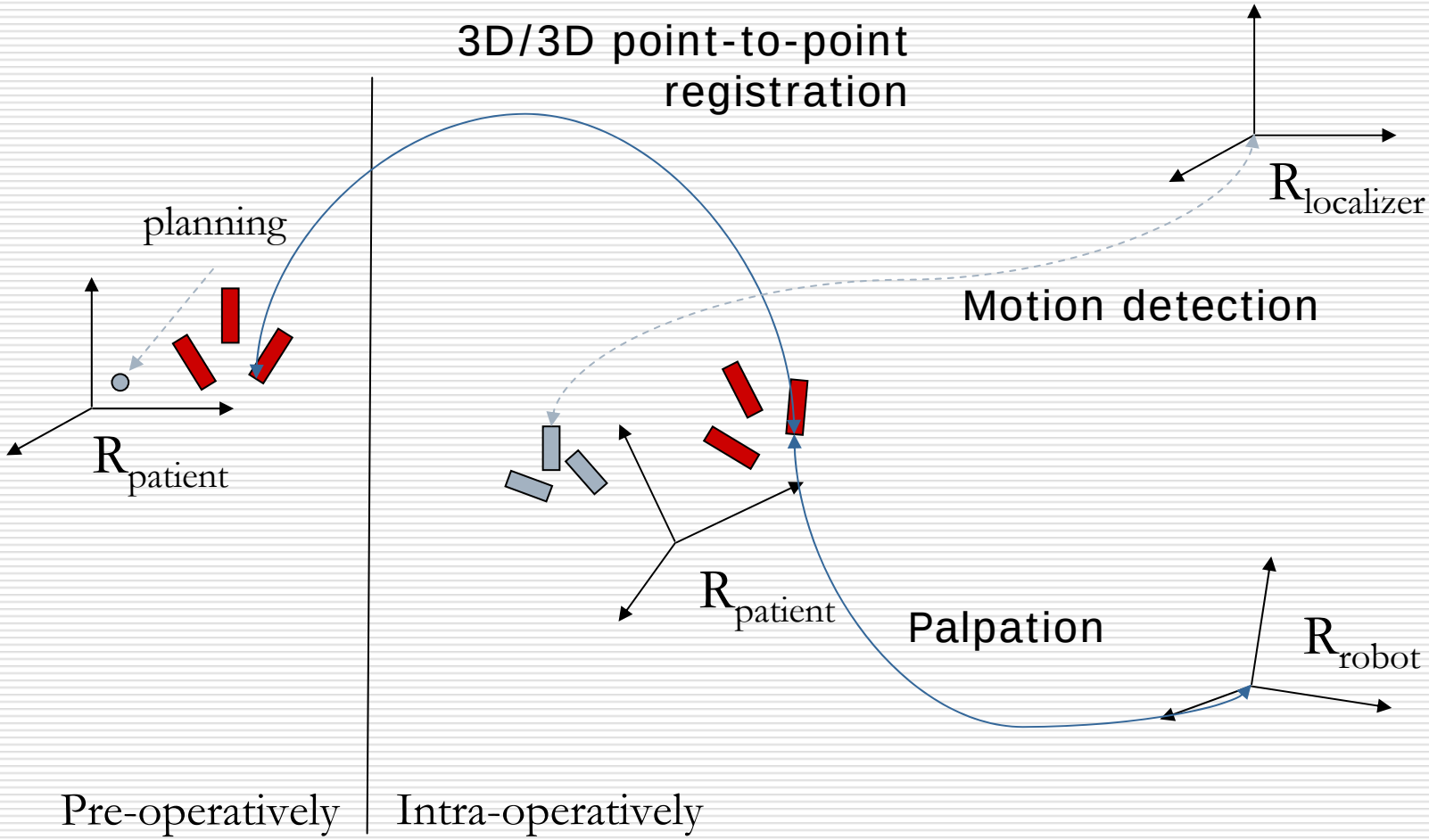
Example A.3: CAD-Implant



Example B

- Close to Robodoc
- Knee application
- Pre-op: planning on CT data
- Intra-op: a robot, a tracking sensor
- Developed method:
  - implanted fiducials S for registration
  - fiducials S' for motion detection

Example B: CASPAR

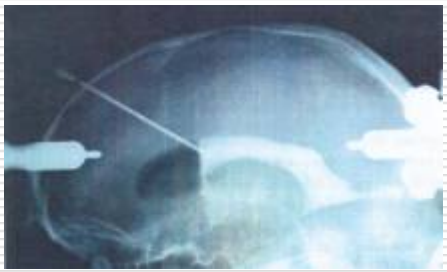


Examples C

- Pre-op: planning on CT data
- Intra-op: a robot, X-Ray sensors
- Developed methods:
  - Speedy V1 [Lavallée89]: Direct X-ray/robot calibration and manual image registration
  - Cyberknife V1 [Schweikard98]: Indirect X-ray/robot calibration and intensity-based registration

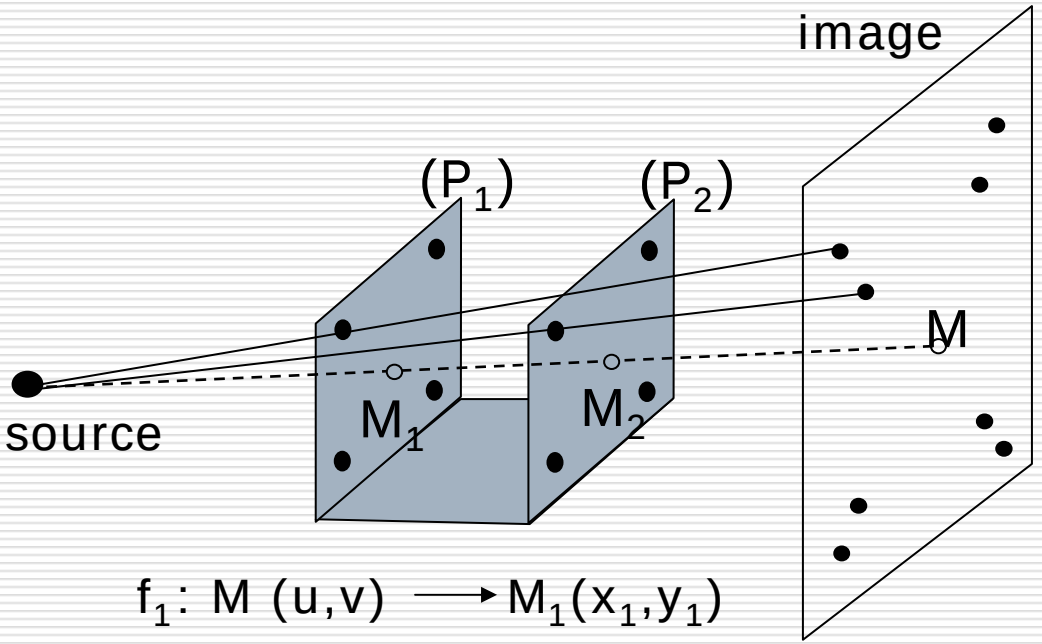
Speedy V1

- Stereotactic neurosurgery
- Pre-operative MR or CT
- Intra-operative X-Ray (AP and lateral) – several exams
- Direct X-Ray/robot calibration
- Manual image registration (anatomical for pre-op/intra-op and markers for intra-op/intra-op)



Speedy

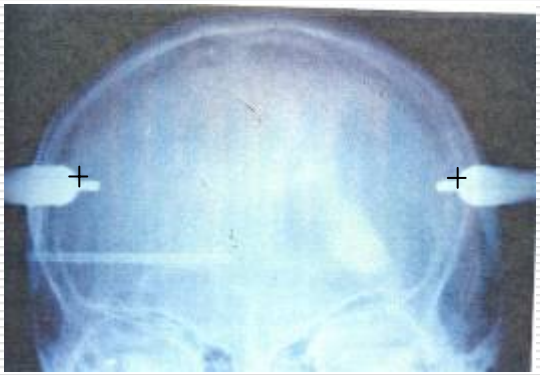
- X-Ray extrinsic calibration: bi-plane model

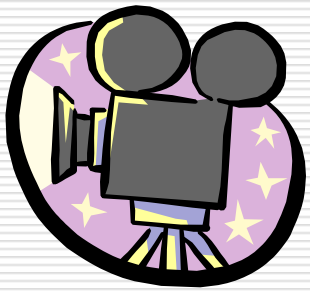


f_1: M (u,v) $\longrightarrow$ $M_1(x_1,y_1)$

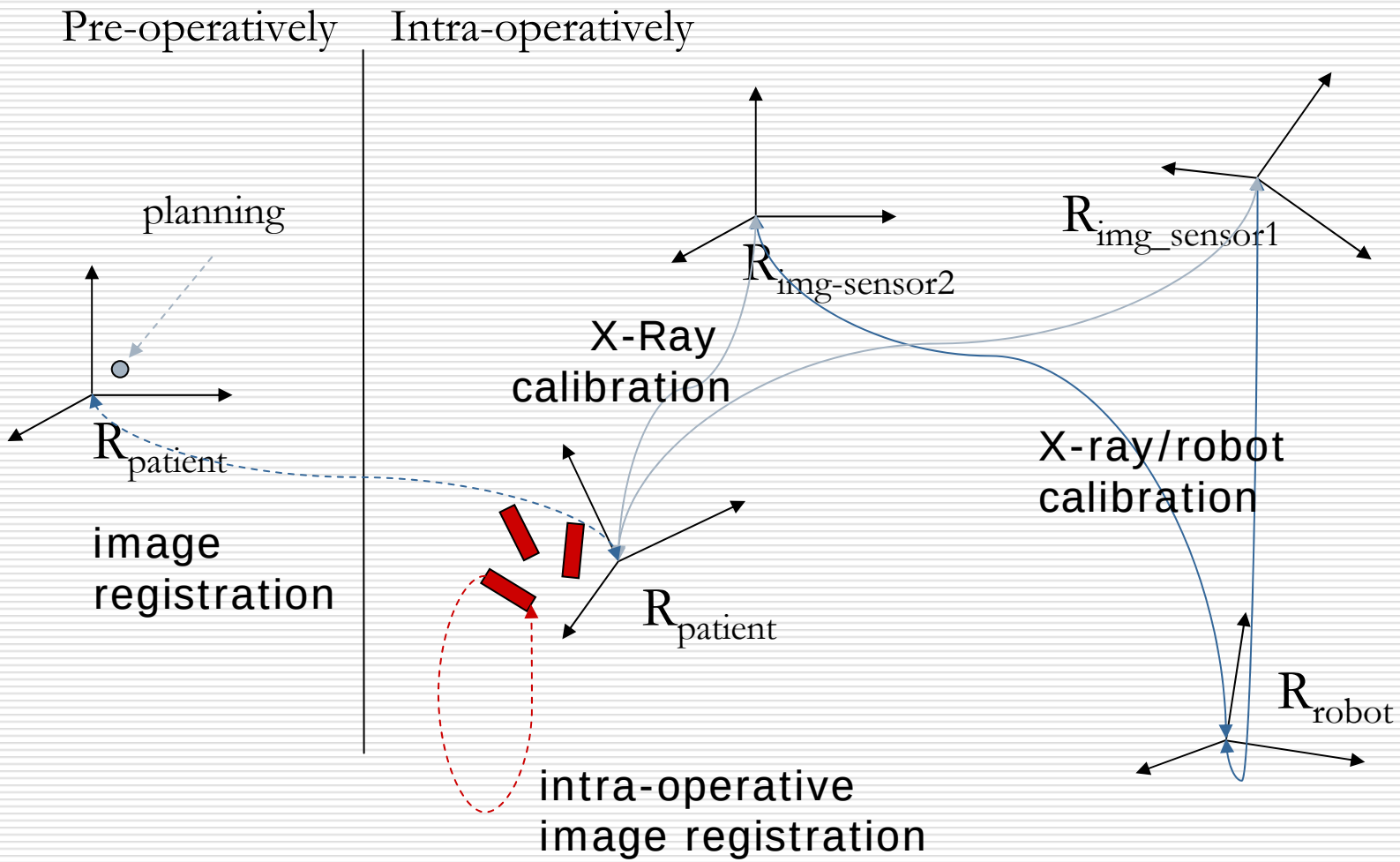
f_2: M (u,v) $\longrightarrow$ $M_2(x_2,y_2)$

- 2D/2D image registration fiducials





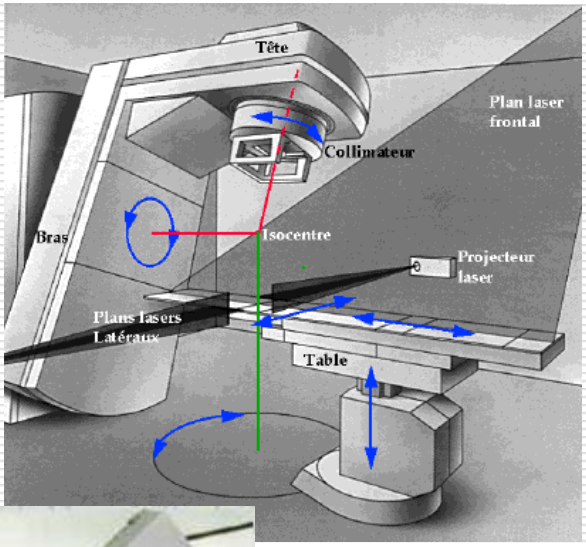
Example C.1: Speedy V1



Cyberknife V1 [Schweikard et al.]

- Radiotherapy application
- Complex trajectories for improved tumor destruction (multiple radiation ports)
- 6 DOFs required
- Very heavy tools

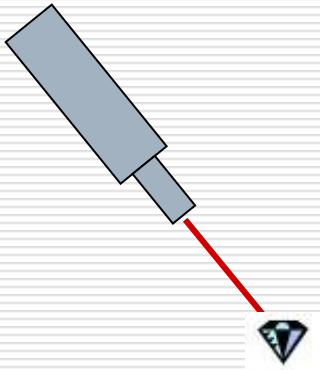
Traditional linear accelerator set-up

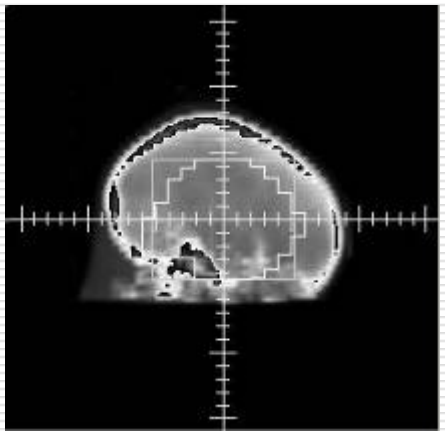


LINAC linear accelerator for stereotactic radiosurgery--the CyberKnife (TM). (C) Copyright 2000 IGL and AccuRay.

Cyberknife V1

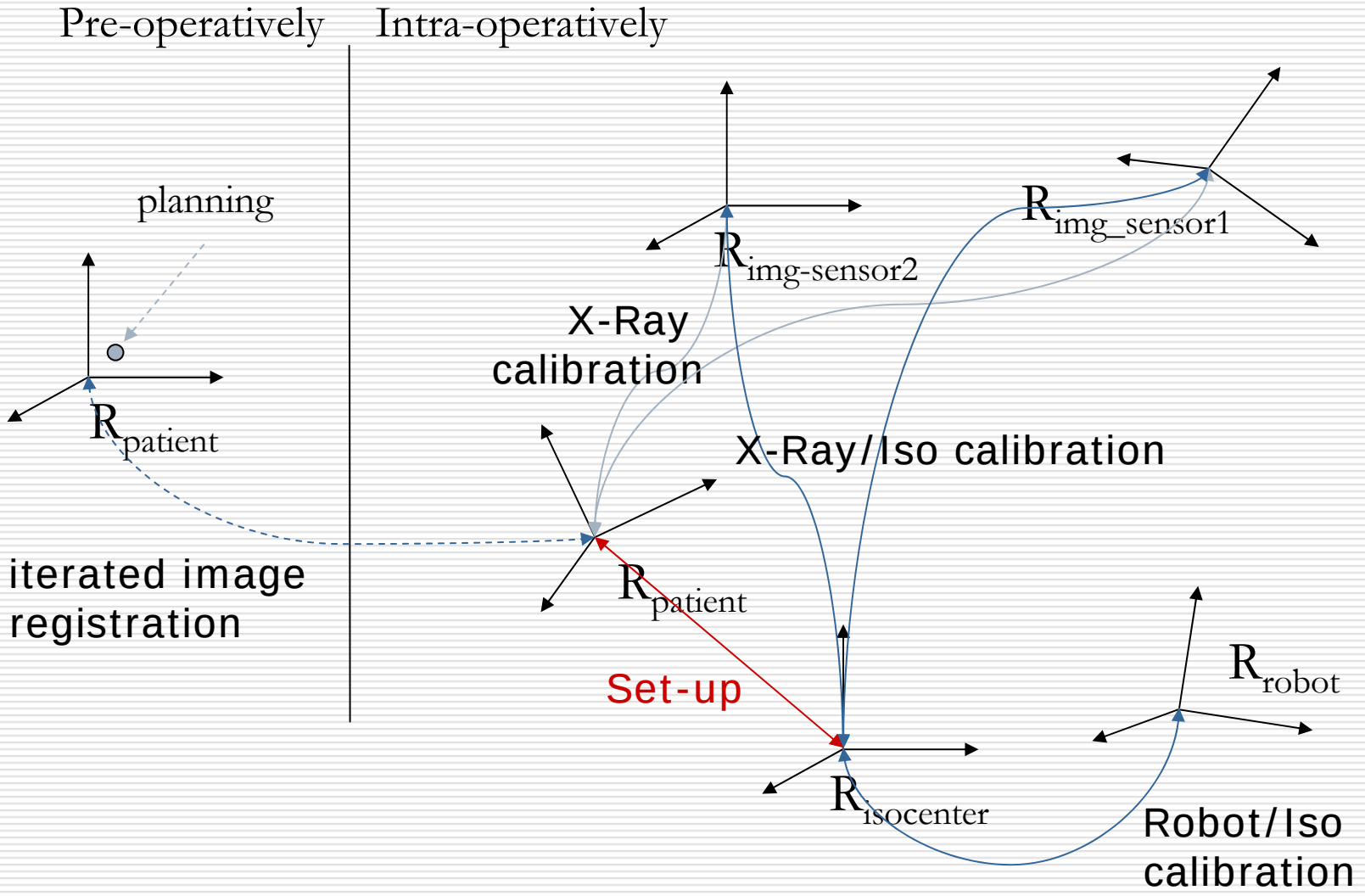
- Planning on CT data
- Intra-operatively:
  - Indirect X-Ray/robot calibration (via isocenter)
  - « X-Ray/pre-computed DRRs » intensity-based registration (before each beam activation)
  - Small motion compensation when necessary / interruption of the procedure and replanning for large motion





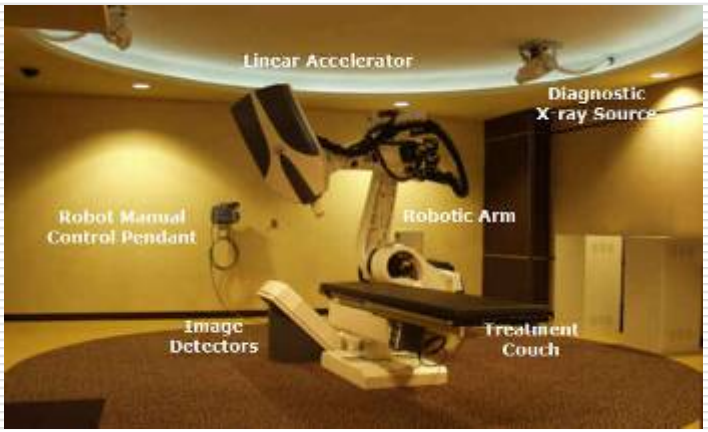
A Digitally Reconstructed Radiograph (DRR)

Example C.2: Cyberknife V1



Example D: Cyberknife+synchrony

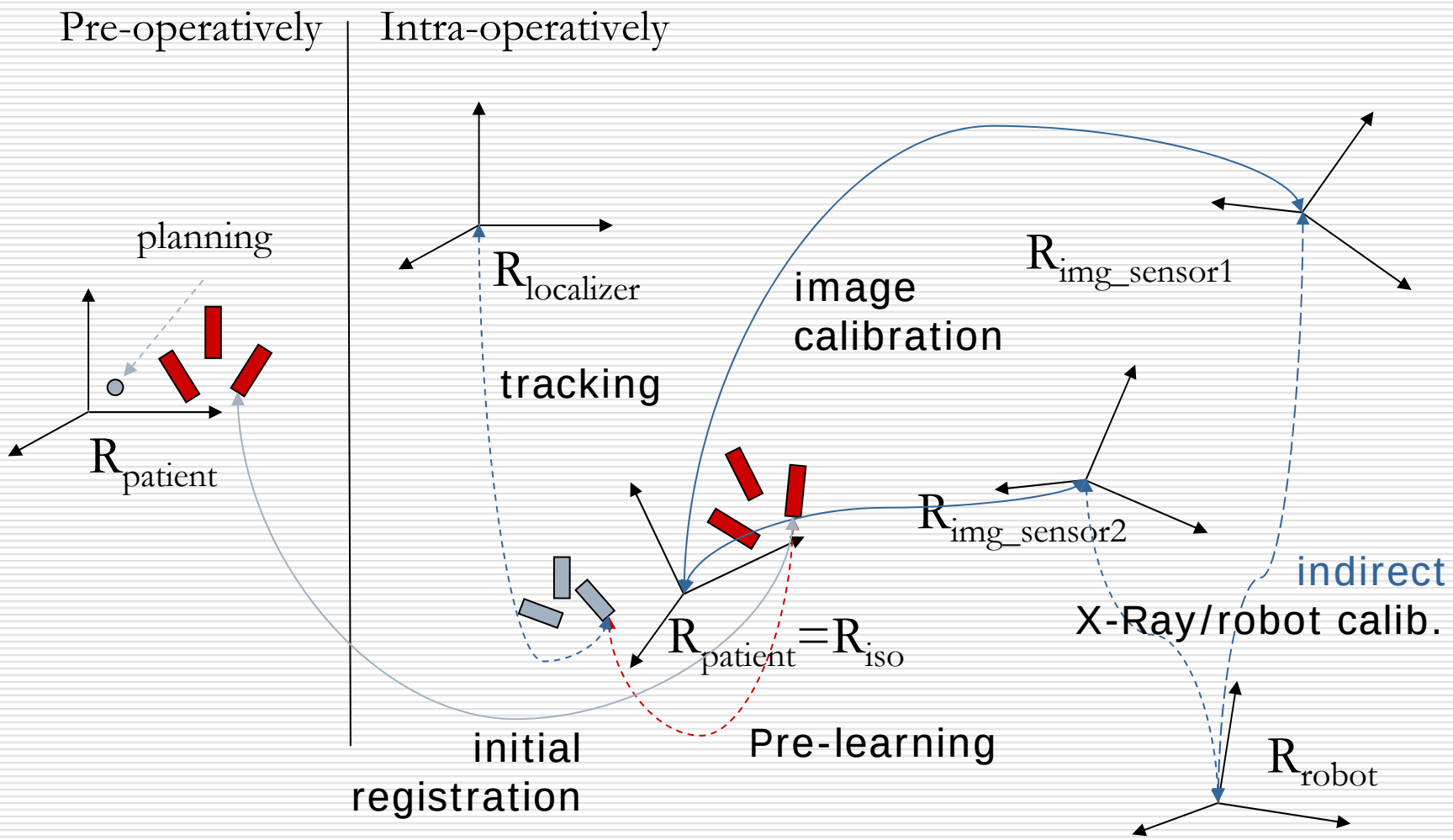
- Pre-op: planning on CT data
- Intra-op: a robot, two X-ray sensors, a localizer
- Developed methods:
  - X-Ray/robot calibration
  - X-Ray/DRR registration for head motion compensation
  - Or fiducial-based registration plus real-time tracking for targets moving with respiration



Real-time registration

- Large motion tracking [Schweikard05]
  - Internal fiducials (gold seeds) for initial registration
  - External fiducials (IR diodes) for respiration tracking
  - Learning internal/external fiducials relationship

Example D: Cyberknife+Synchrony

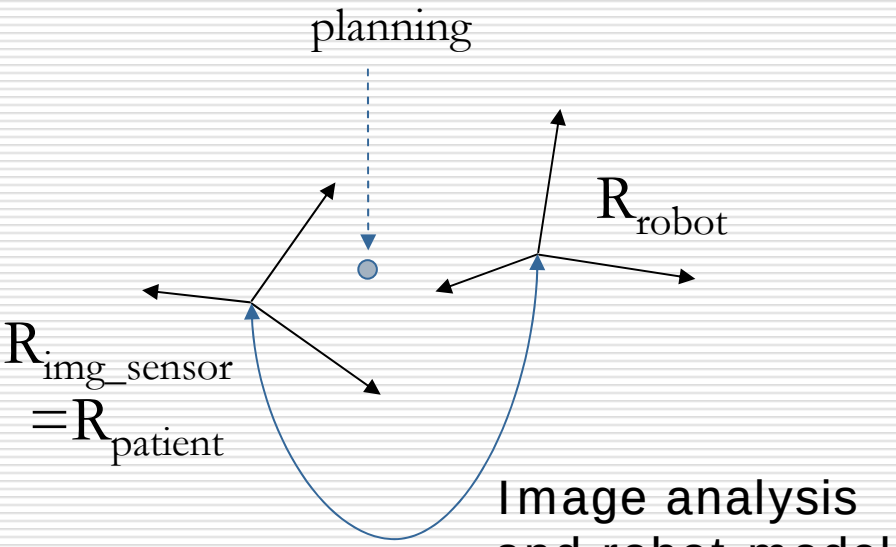


Another type of solution (E)

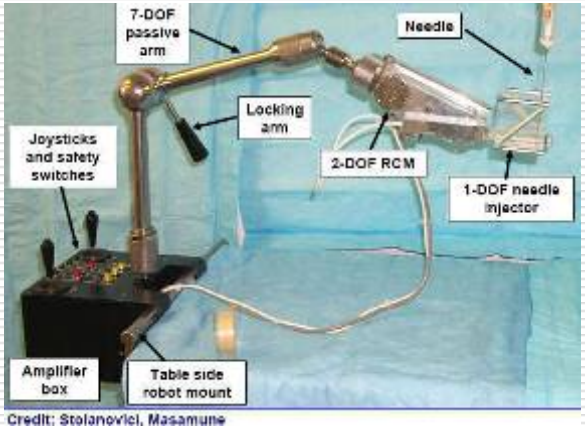
- Target defined in the intra-operative imaging data*
- Examples
  - Indirect visual servoing: computing the robot position from the images
    - PAKY+RCM [Stoianovici et al.], LPR [Cinquin et al.], etc.
  - Direct visual servoing: modeling variations of the robot position to variations of the target in the images
    - GABIE [Morel], ZEUS [deMathelin], etc.

*if pre-operative planning: need for pre-op/intra-op registration

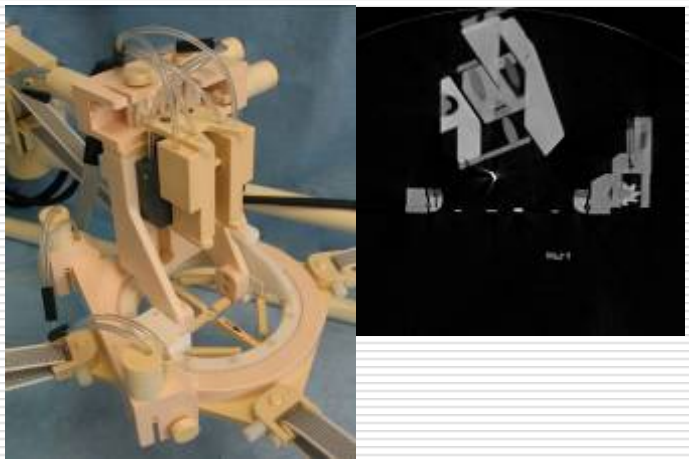
Example E.1



Intra-operatively

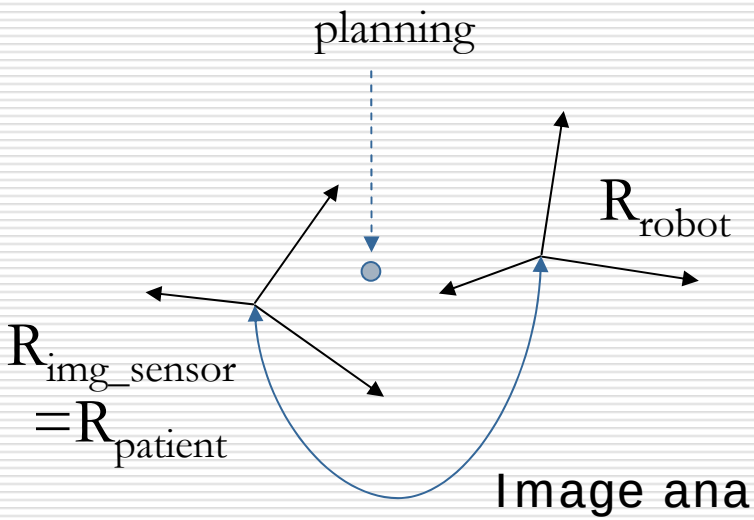


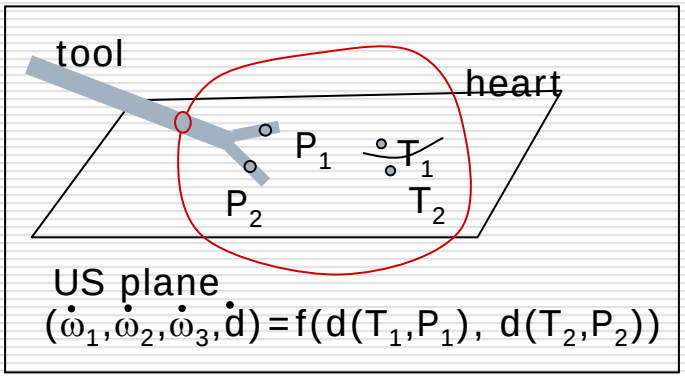
PAKY+RCM



LPR

Example E.2





GABIE

Image analysis and
Image/robot differential model

Intra-operatively

Discussion

- Modus operandi: many solutions
  - Palpation (fiducial, anatomy): easy, invasive
  - Imaging (anatomy): more difficult, less or non invasive
  - Template: easy, limited to few applications
  - Need for updated or real-time registration?
    - No motion
    - Motion detection
    - Discrete motion detection and compensation
    - Continuous motion detection and tracking

Discussion (cont'd)

- No universal recipies: depends on the application
- Some important issues
  - Intra-operative evaluation of registration accuracy
  - Safety of real-time registration