

Robot registration

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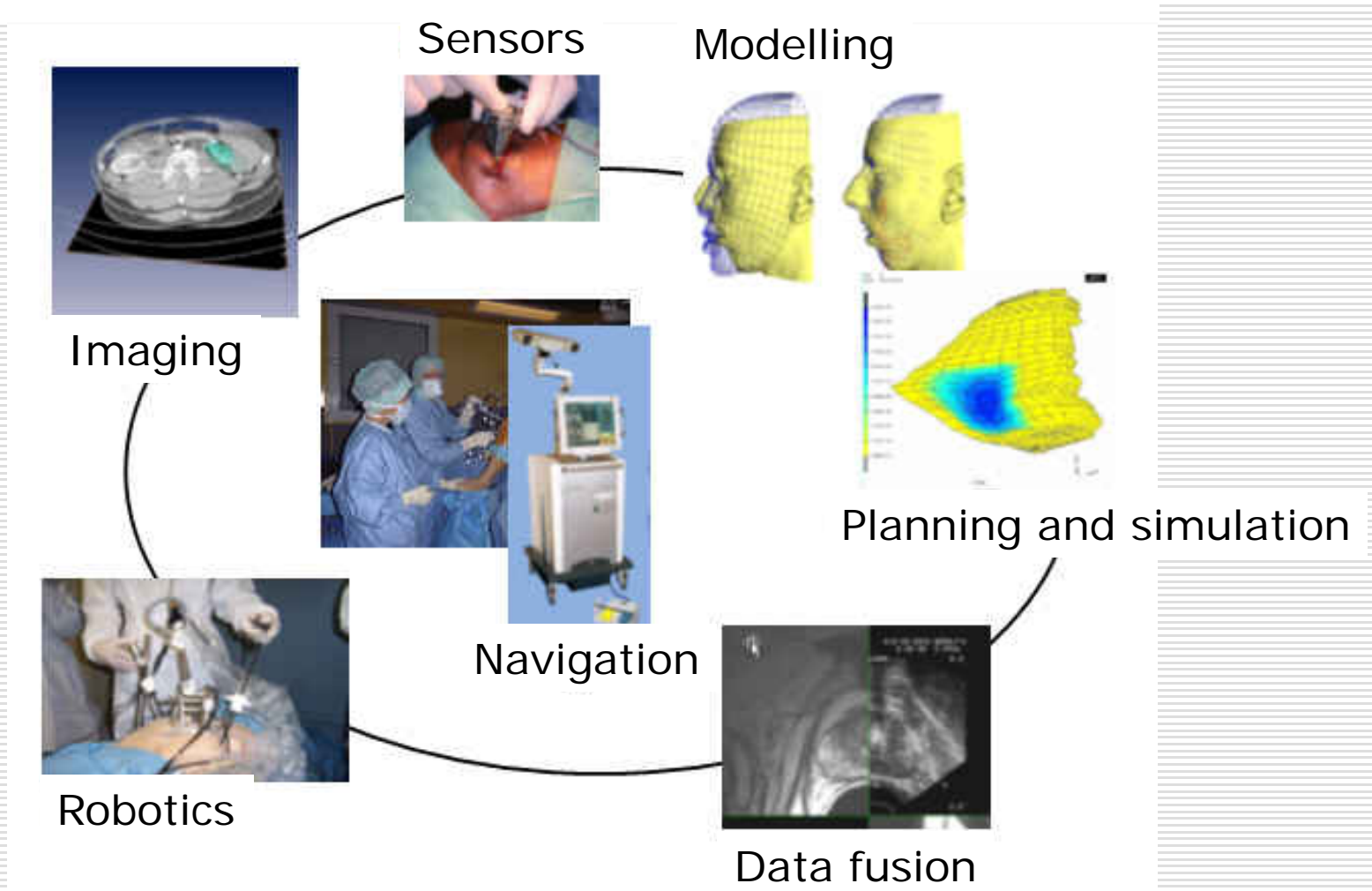
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Grenoble GMCAO (CAMI) team

- ❑ Created in 1985 by Philippe Cinquin
- ❑ Headed from 1996 by Jocelyne Troccaz
- ❑ Strong connection to Grenoble Hospital
- ❑ About 40 people

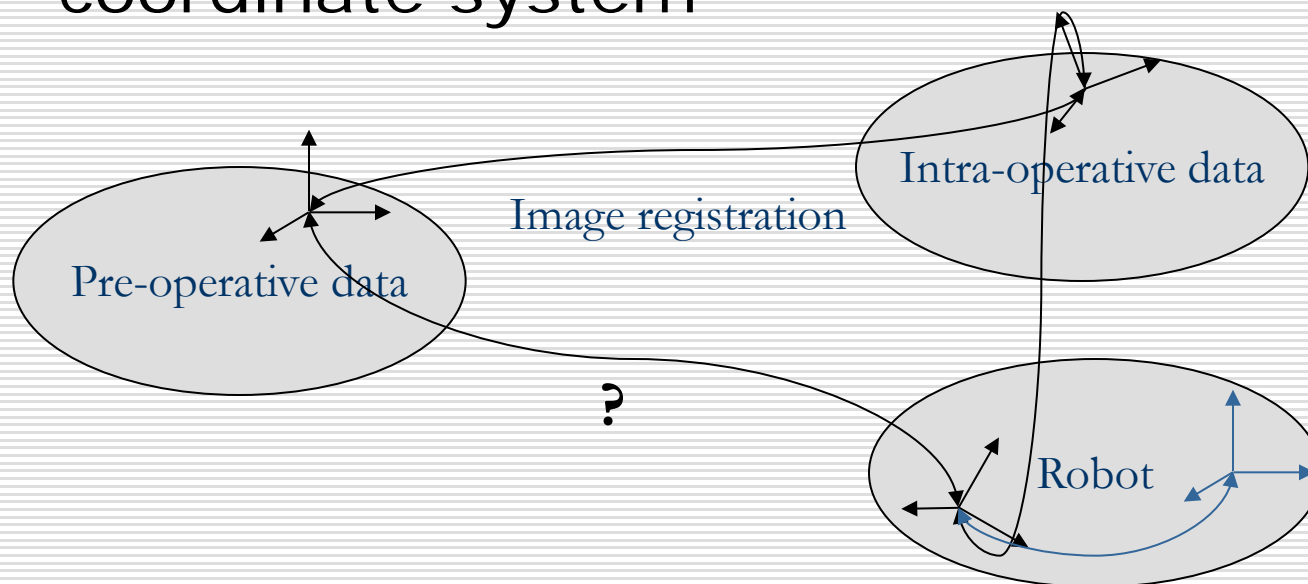


Research topics

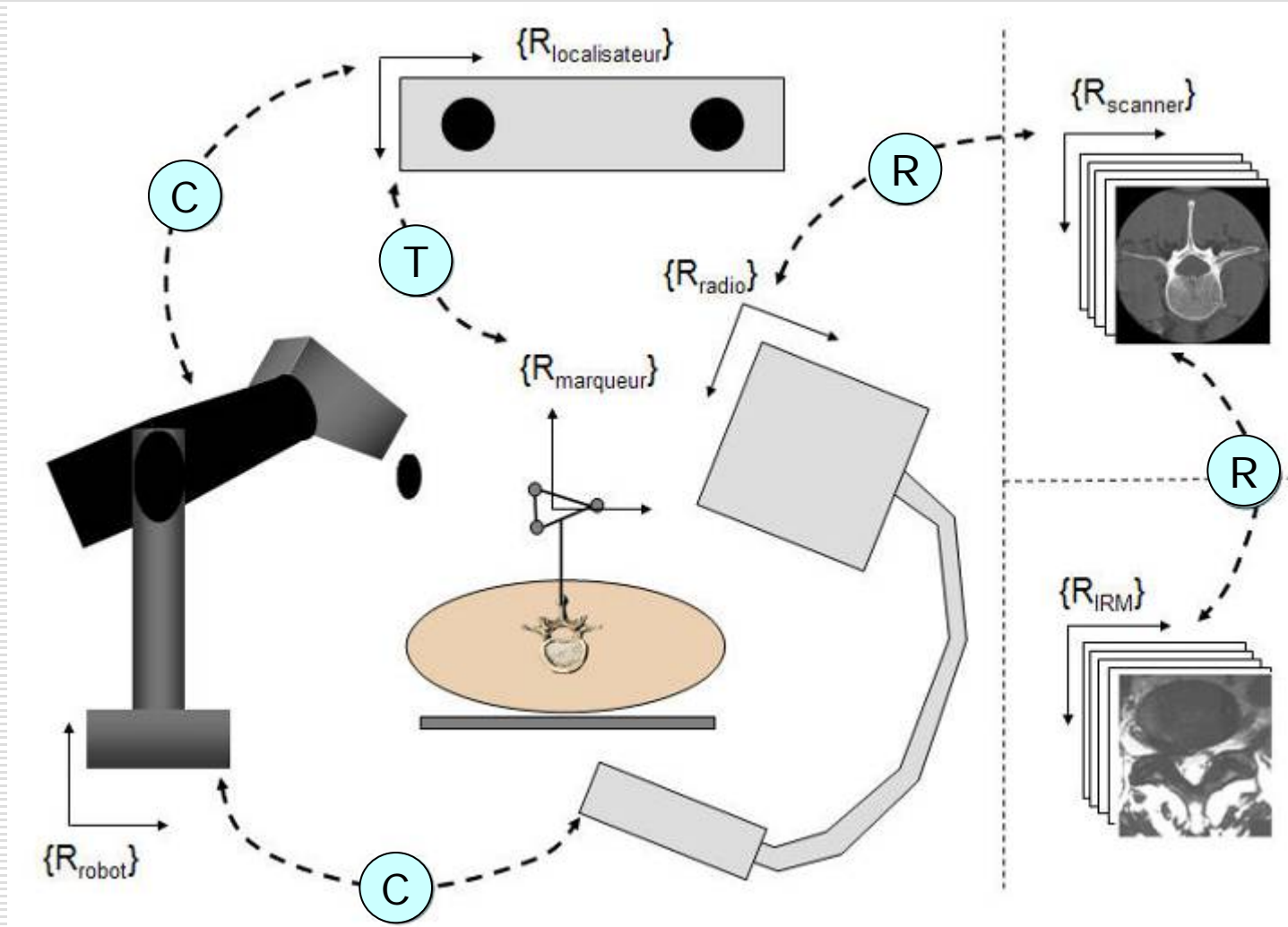


What is it?

- ❑ 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

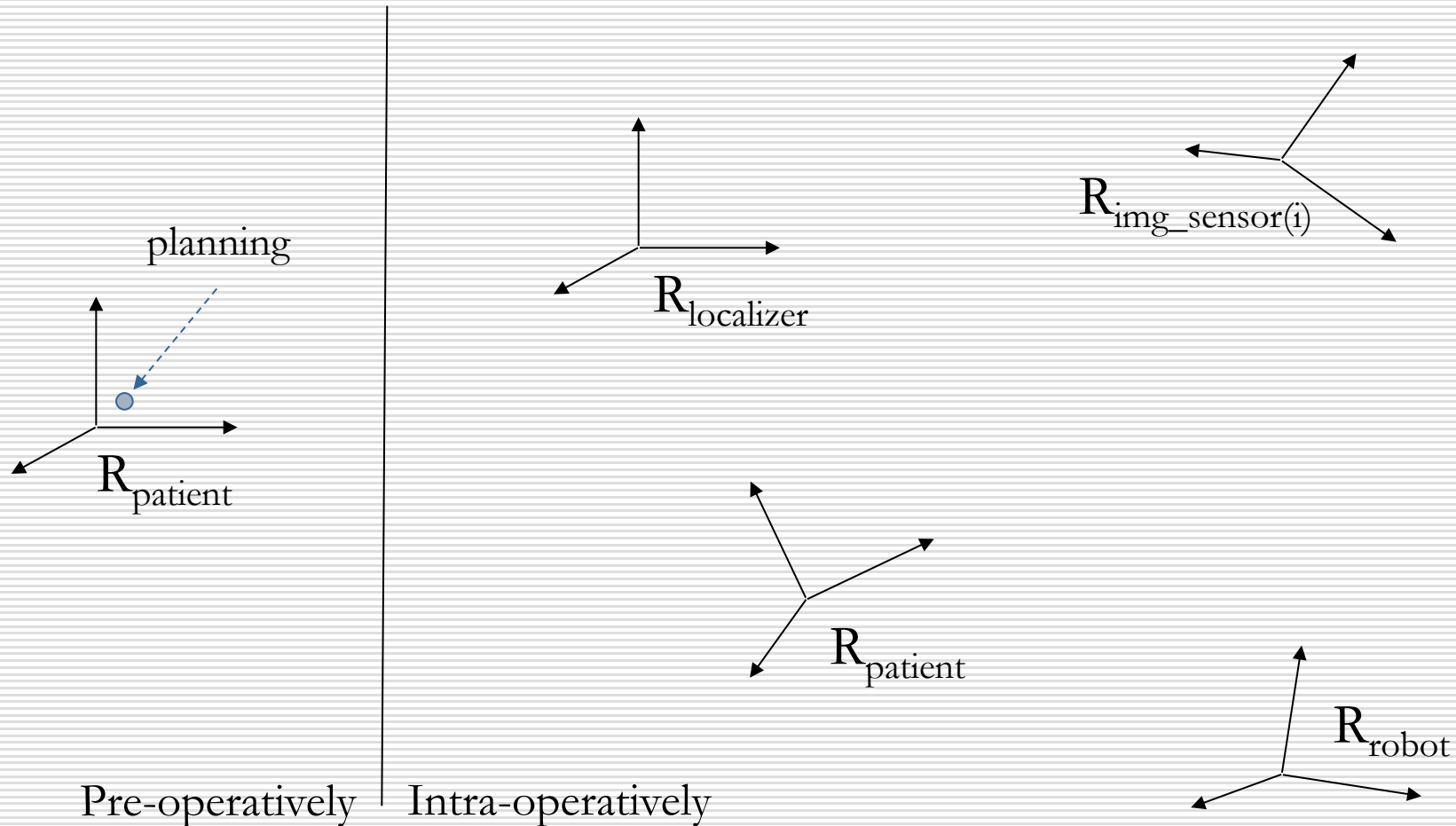
Requires

- ☐ Intrinsic robot calibration

Contents

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

Possible reference frames of interest



Hardware examples

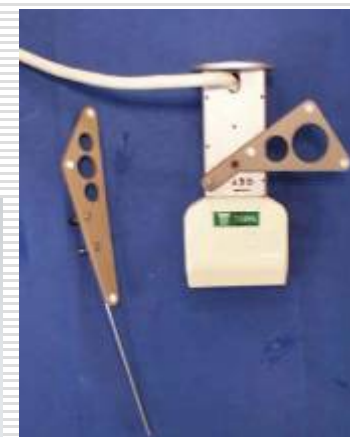
□ Localizers:

- Optical, US, magnetic, mechanical arm

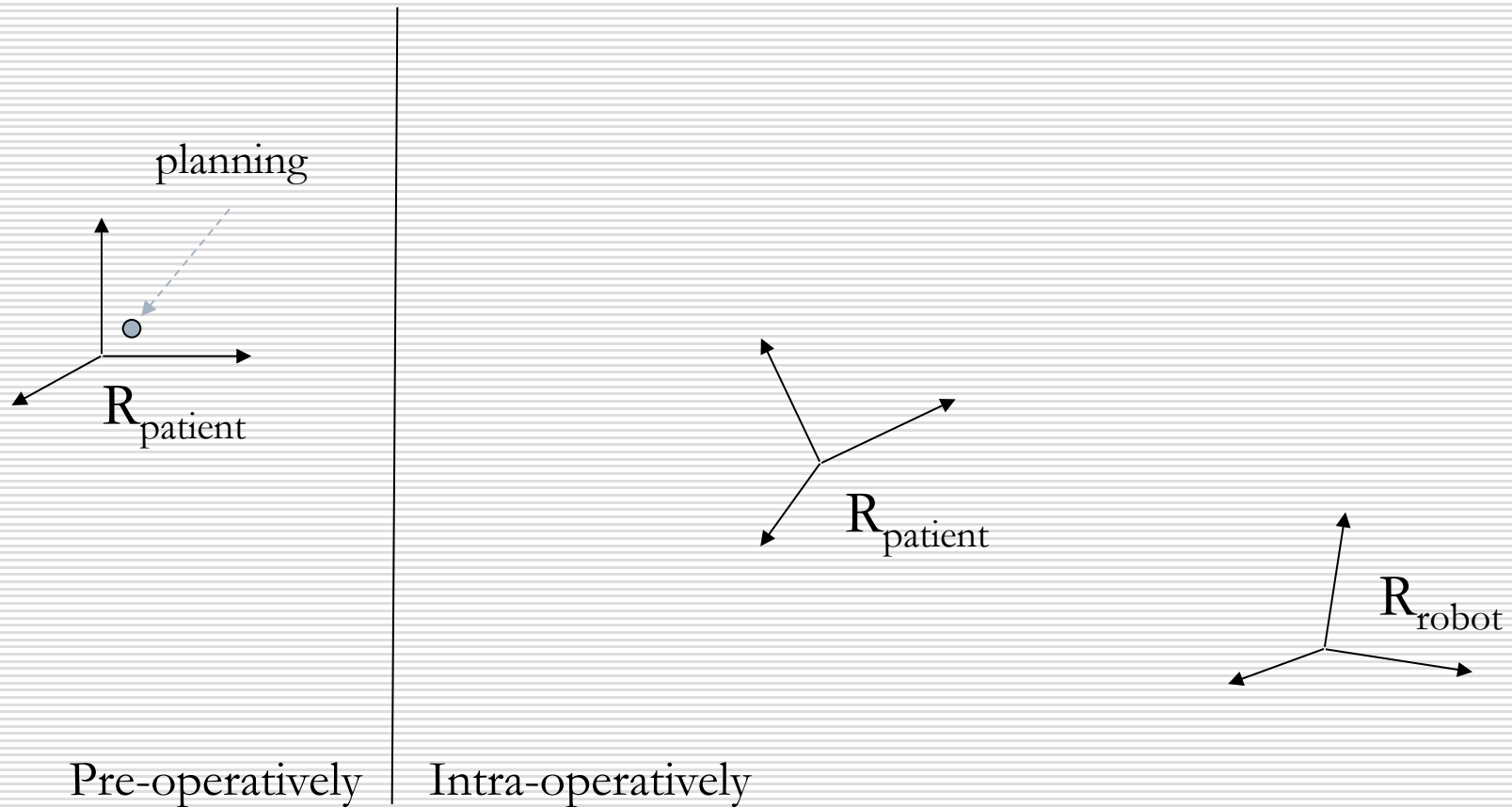


□ Imaging sensors:

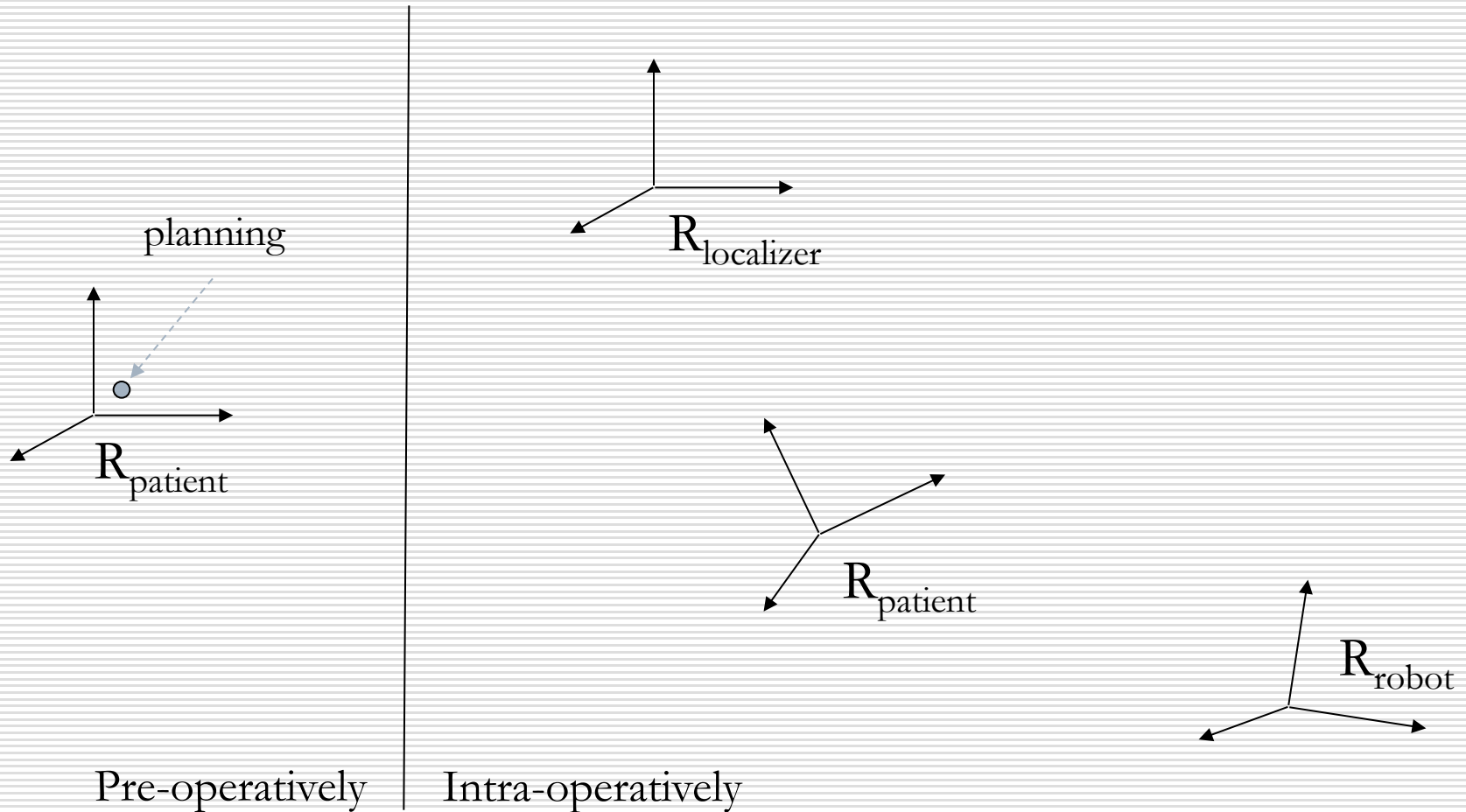
- Fluoroscopy, digital X-Ray, ultrasound



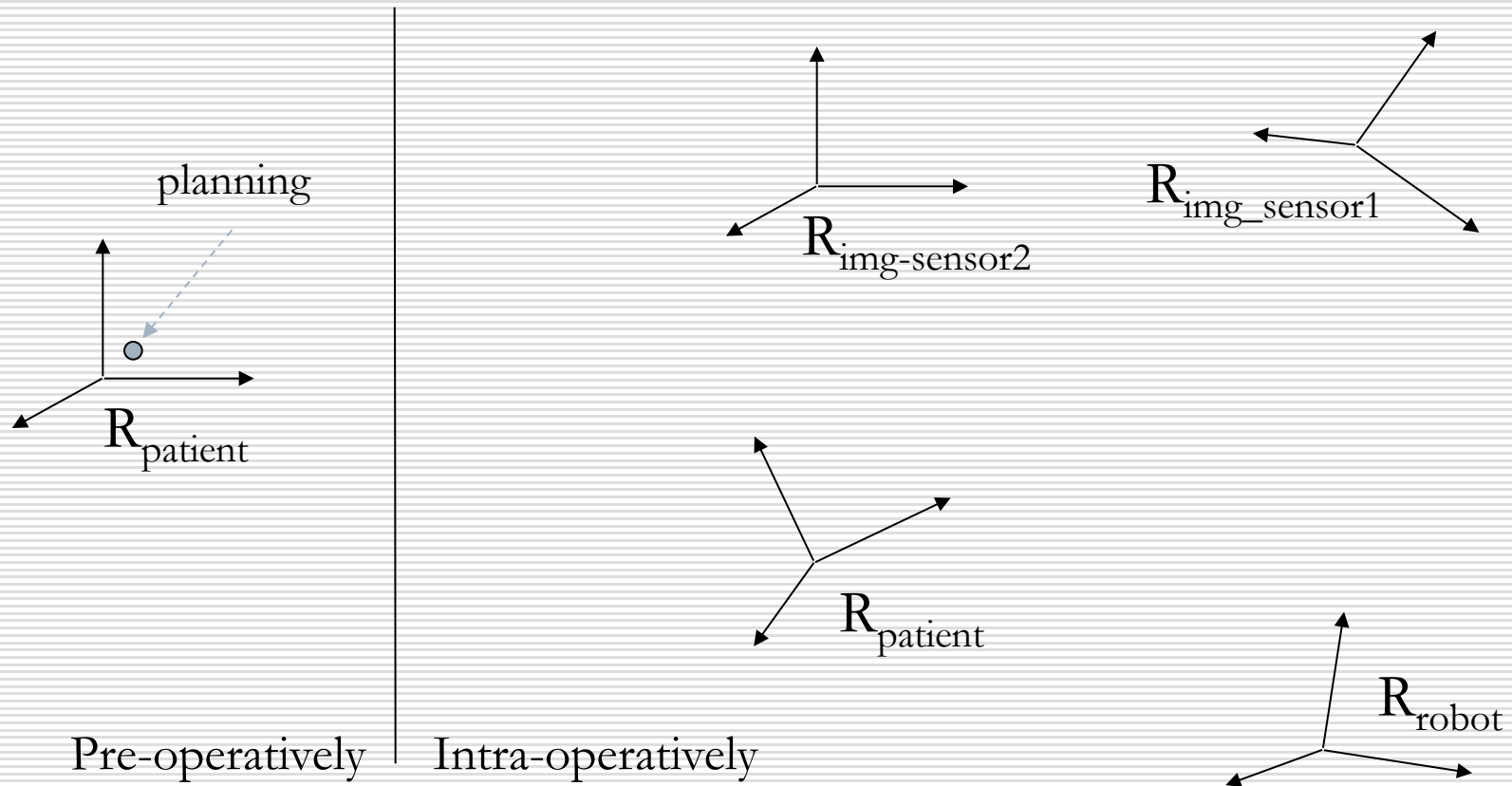
Examples A: Robodoc, ACRobot, (CAD-Implant)



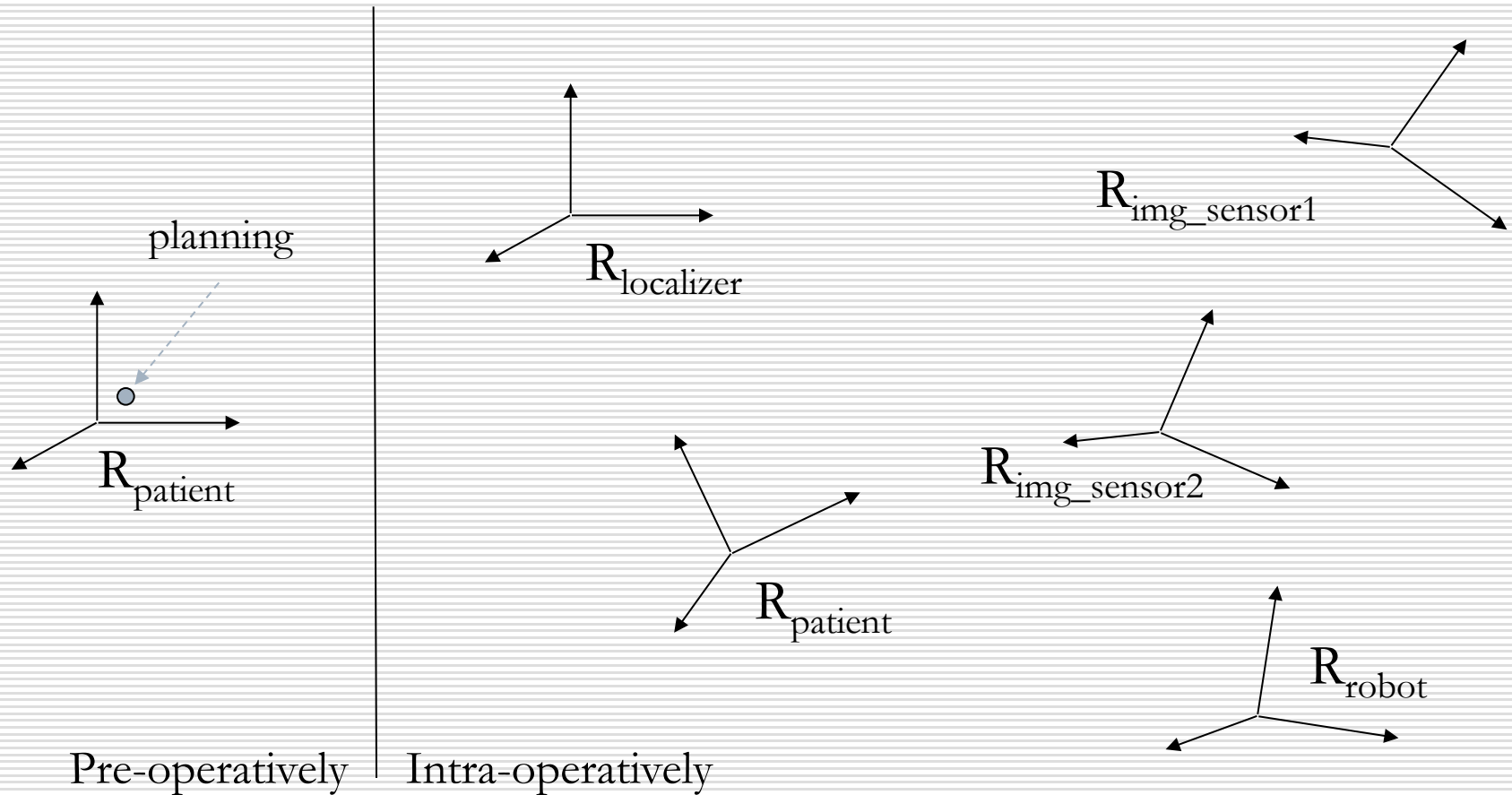
Examples B: CASPAR



Examples C: Speedy, Cyberknife, MARS



Example D: Cyberknife+Synchrony



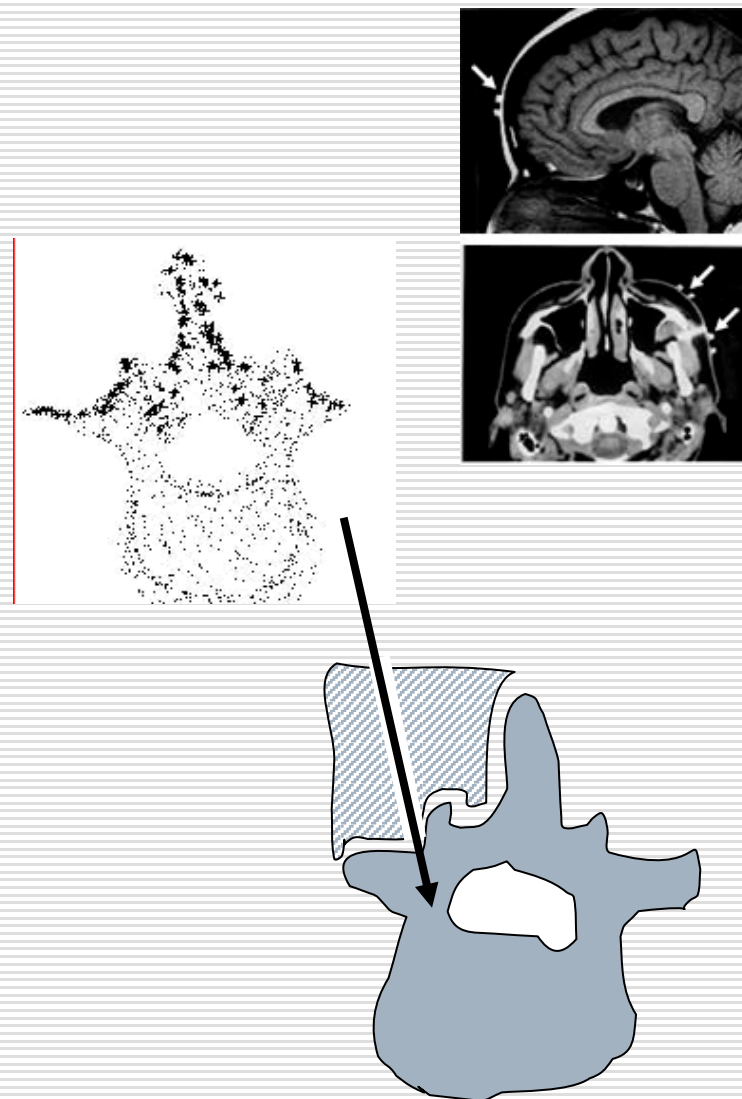
Registration basics

- Two reference frames R_A and R_B and a transform T_A^B 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 T_A^B such that the similarity is maximum (or distance minimum)

$$T_A^B = \arg \min d(F_A, T_A^B(F_B))$$

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)

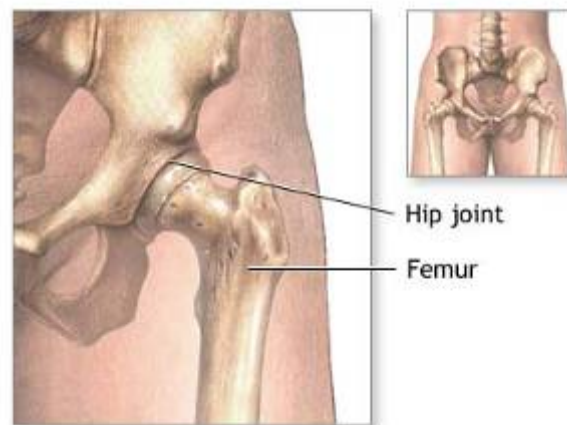


Examples A

- ❑ 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



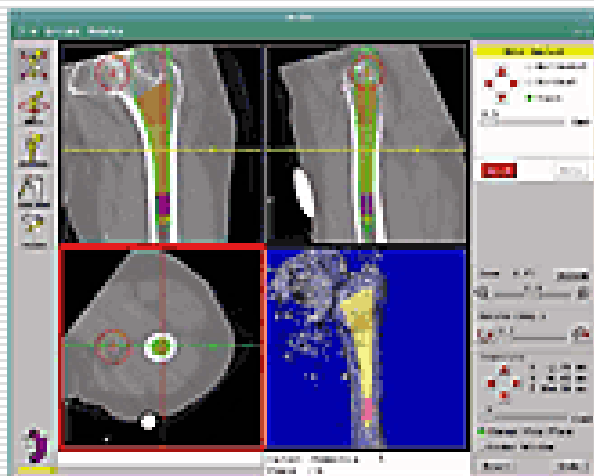
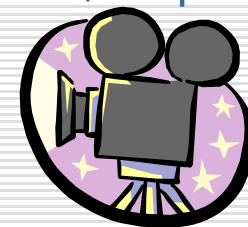
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A metal ball and stem are inserted in the femur and a plastic socket is placed in the enlarged pelvis cup



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Robodoc [Taylor et al.]



1. *Planning:* Orthodoc

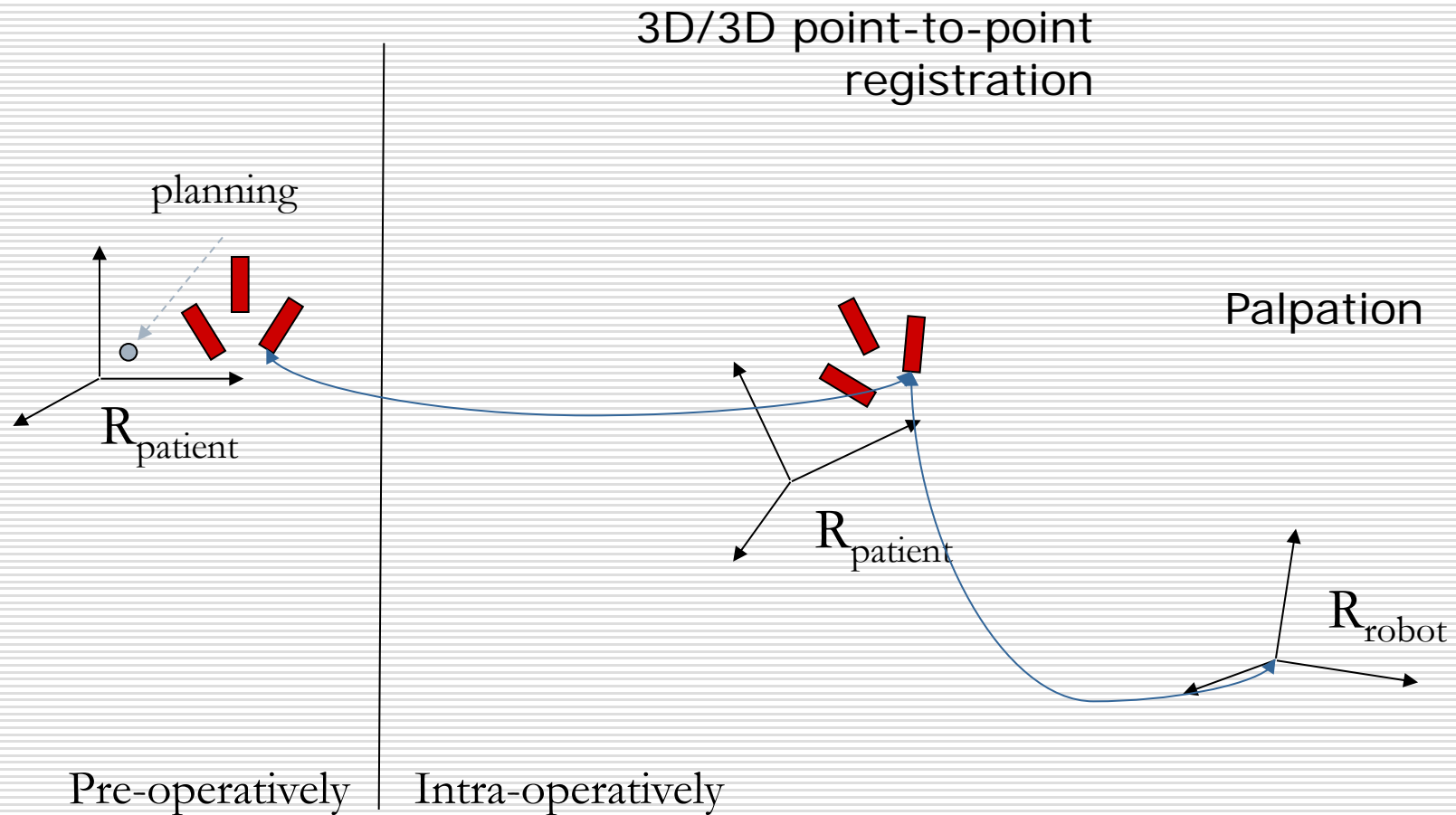
6D force sensor

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



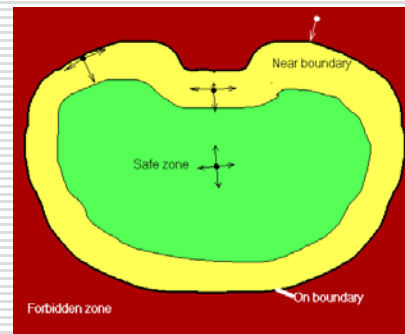
3. *Intra-operative bone milling* procedure using Robodoc (based on the IBM scara robot)

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

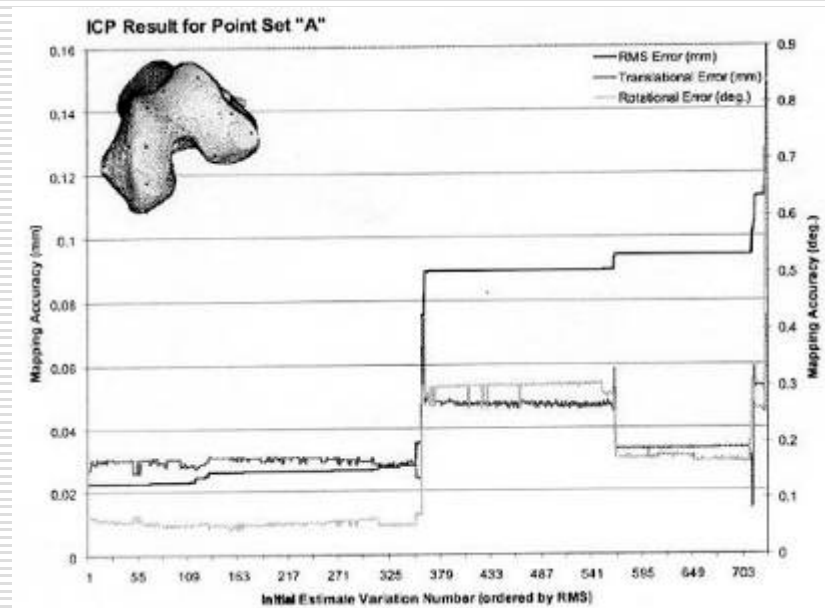


ACRobot registration tests

- ❑ 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

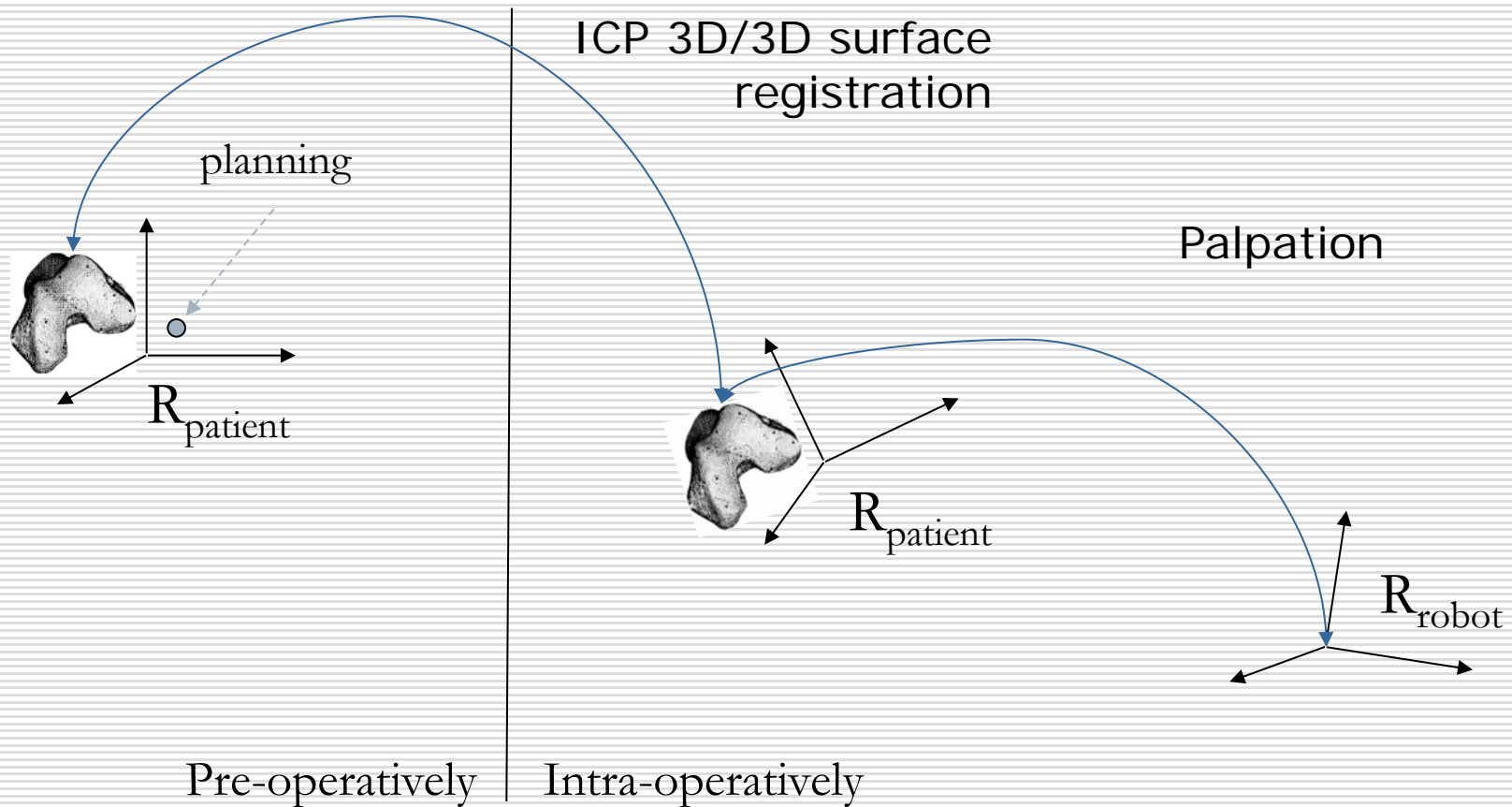
ACRobot: results

- 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



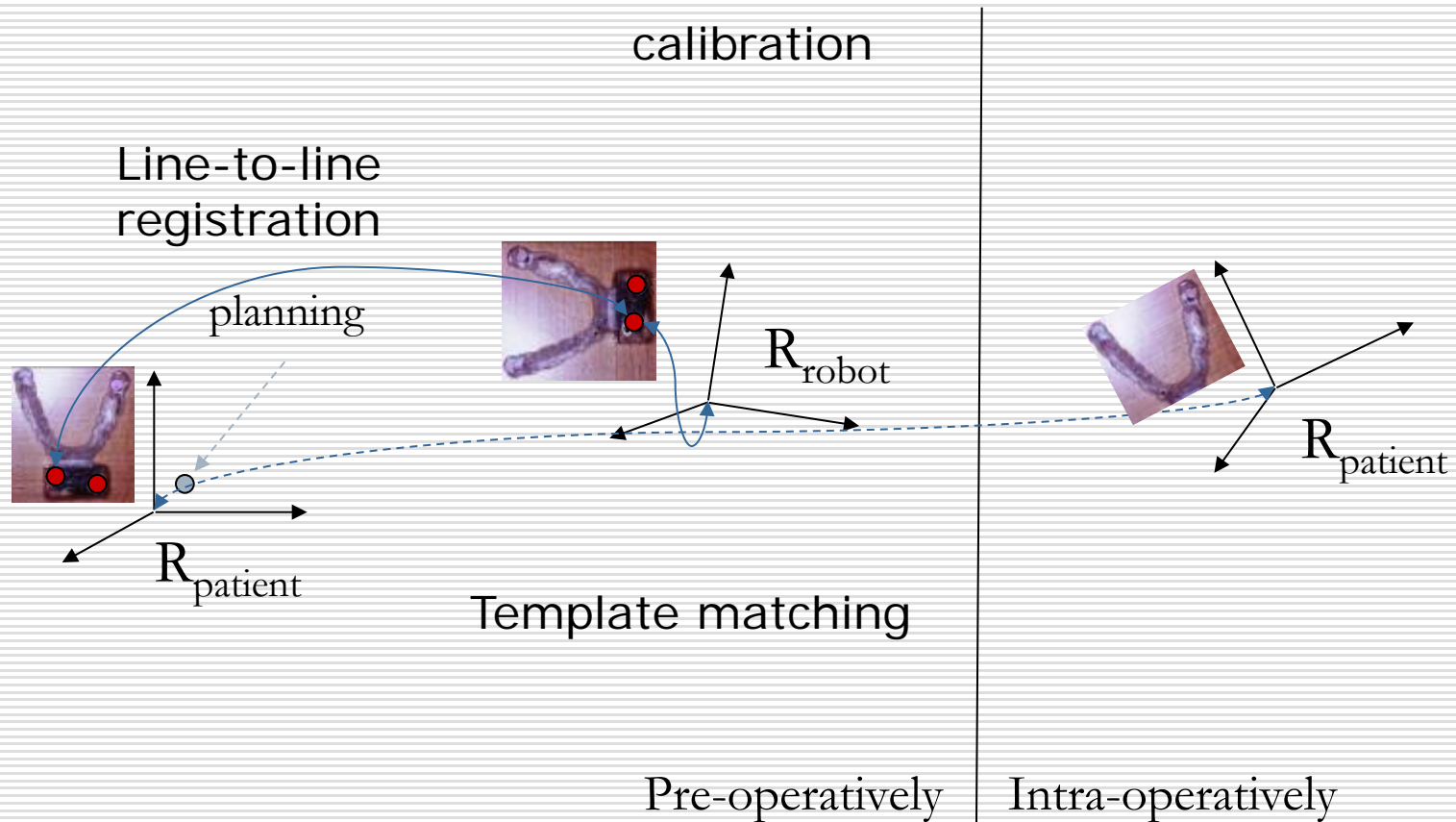
CAD-Implant

[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

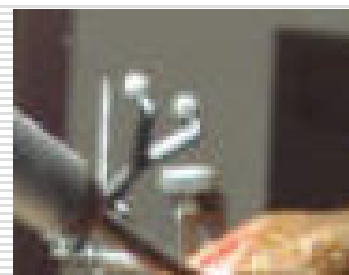


Example A.3: CAD-Implant

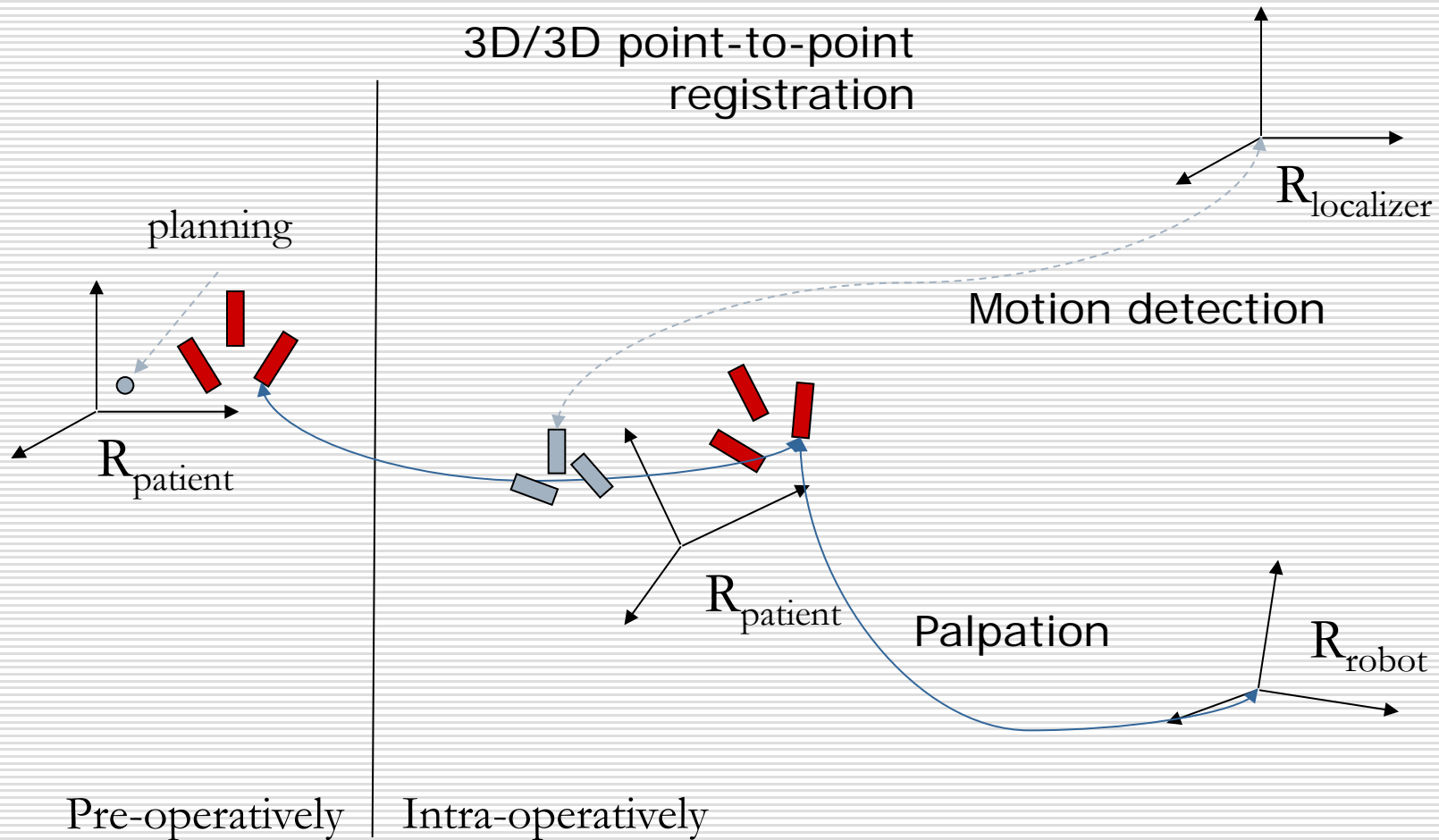


Example B

- ❑ 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

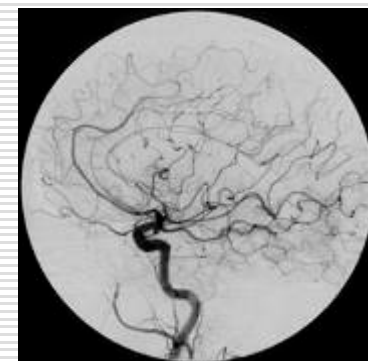


Examples C

- 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

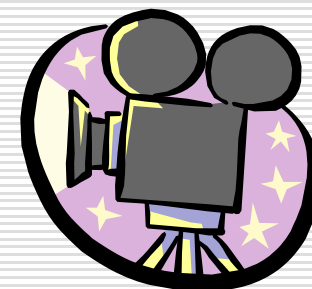
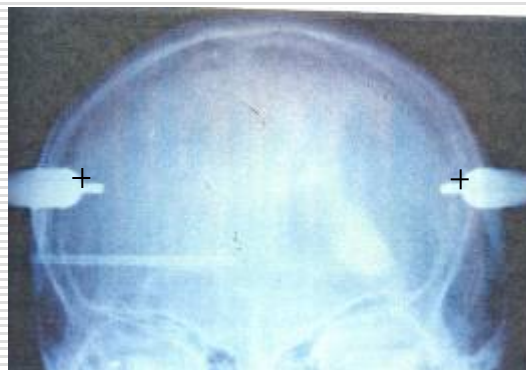
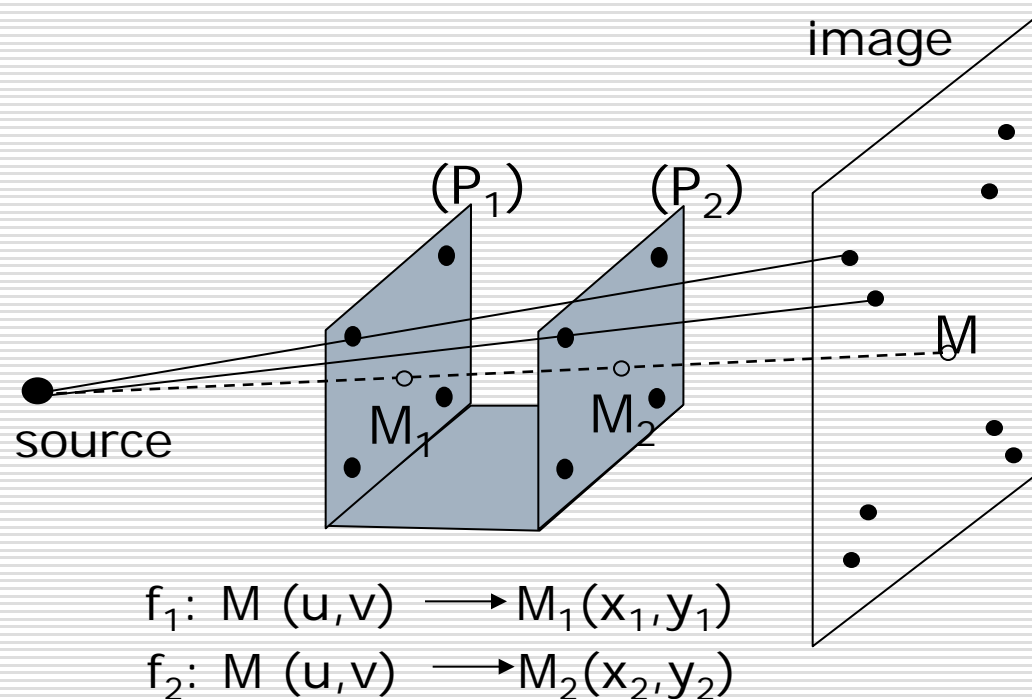
- ❑ Stereotactic neurosurgery
- ❑ Pre-operative MR or CT
- ❑ Intra-operative X-Ray (AP and lateral) – several exams
- ❑ Direct X-Ray/robot calibration →
- ❑ Manual image registration (anatomical for pre-op/intra-op and markers for intra-op/intra-op)



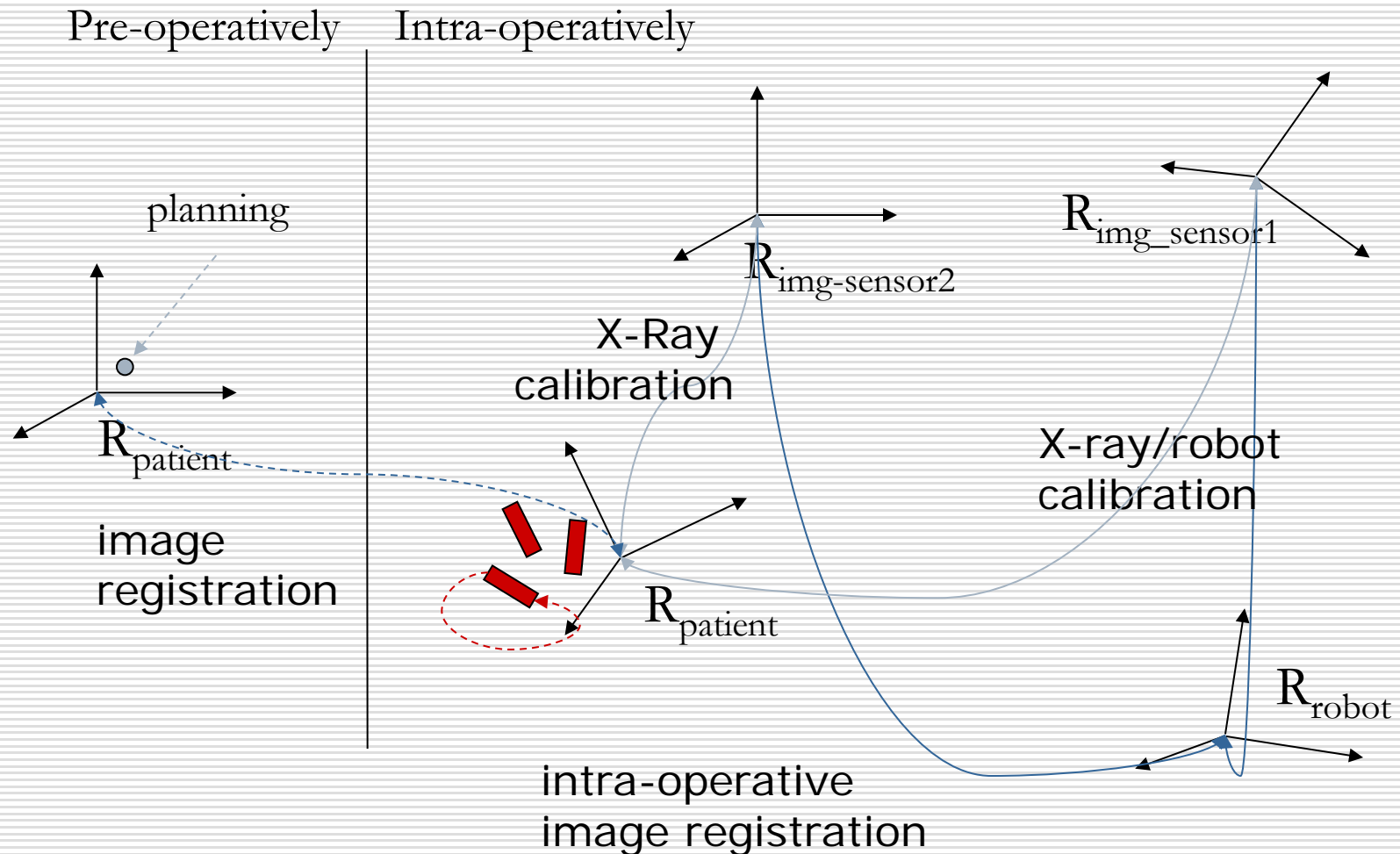
Speedy

□ X-Ray extrinsic calibration: bi-plane model

□ 2D/2D image registration fiducials



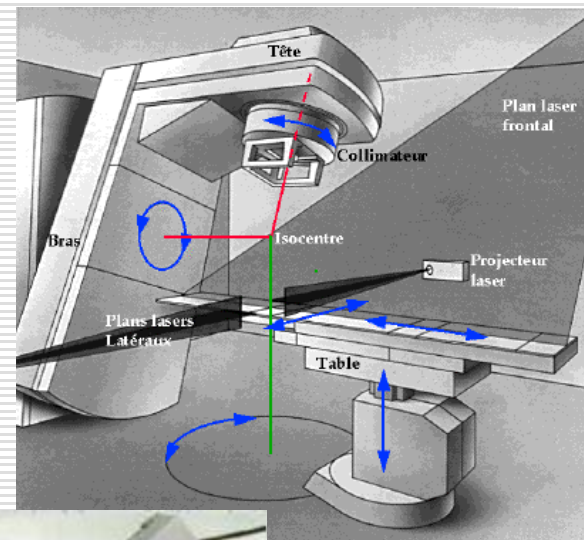
Example C.1: Speedy V1



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

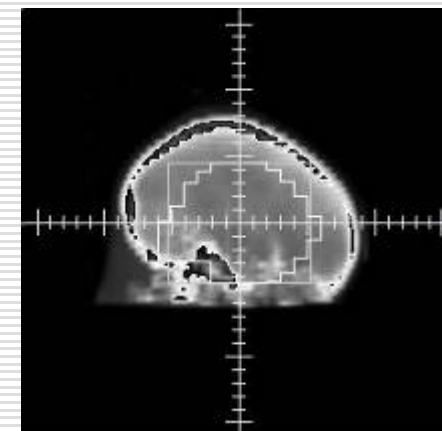
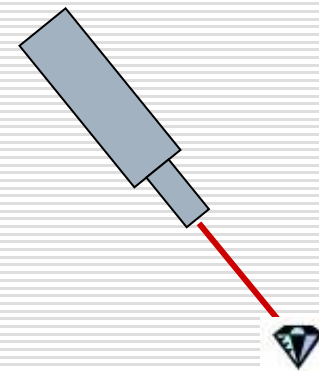


LINAC linear accelerator for stereotactic radiosurgery—the CyberKnife (TM). (C) Copyright 2000 IGL and AccuRay.



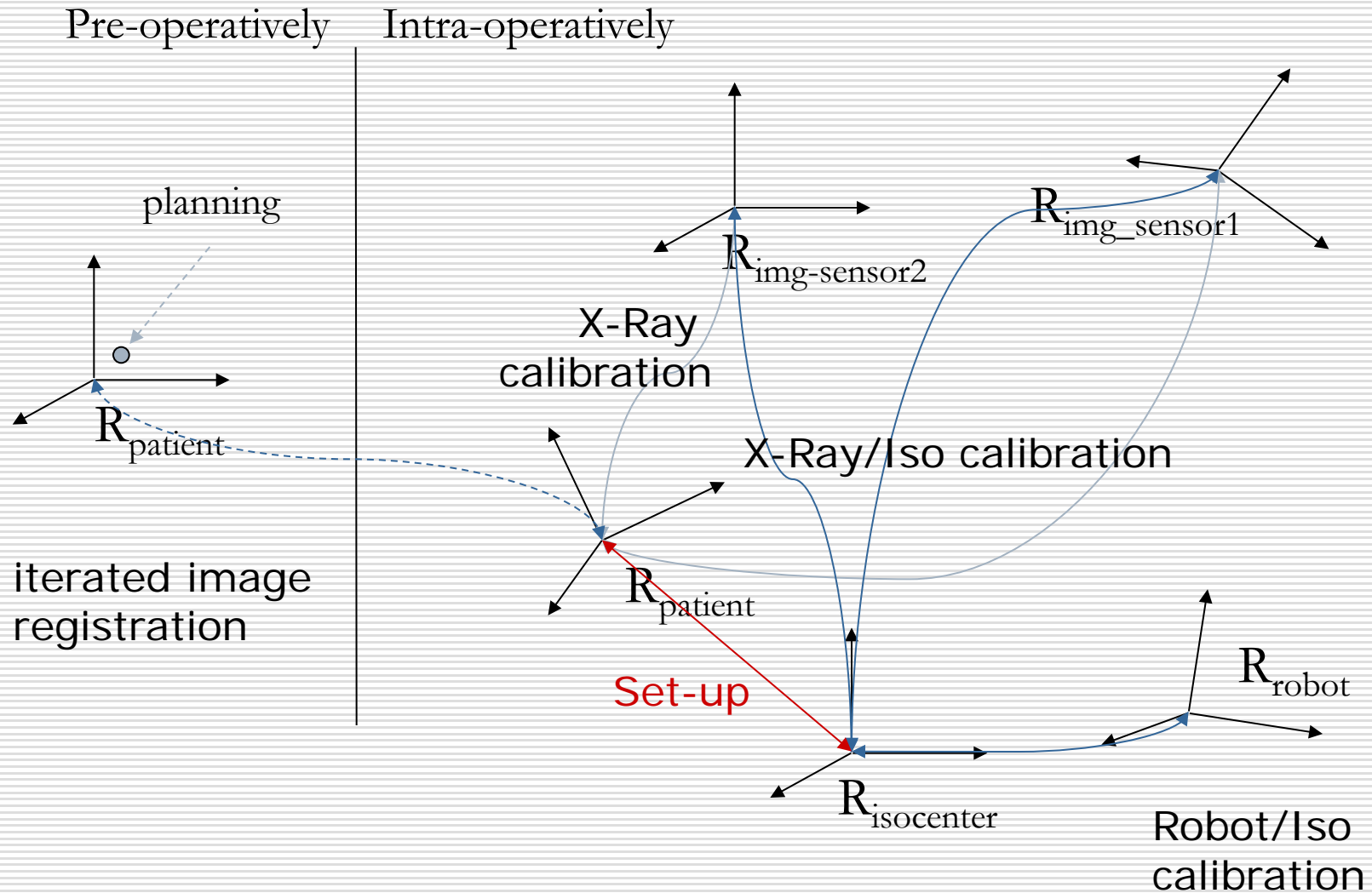
Cyberknife V1

- 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 motion compensation of head, spine, lung
 - Or fiducial-based registration plus real-time tracking for other targets moving with respiration (liver, pancreas, etc.)



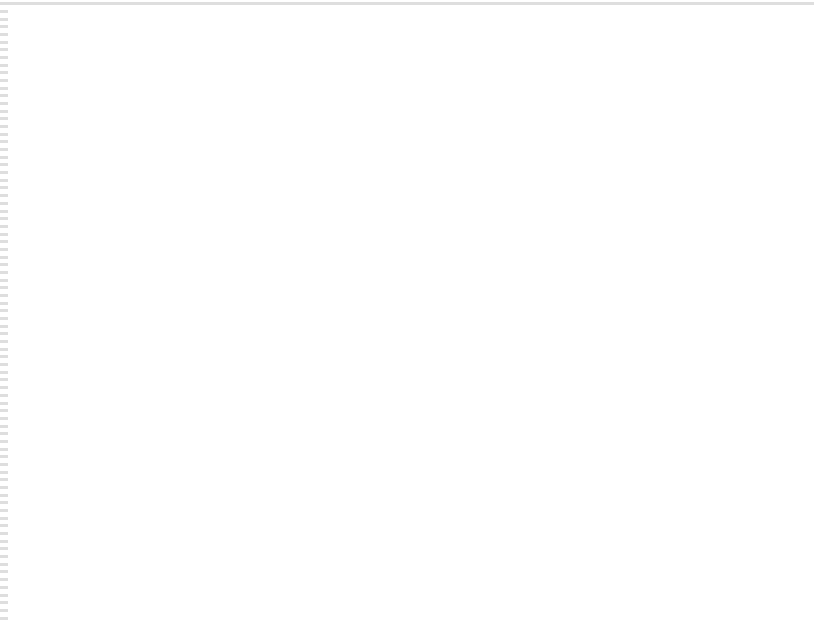
Cyberknife V2



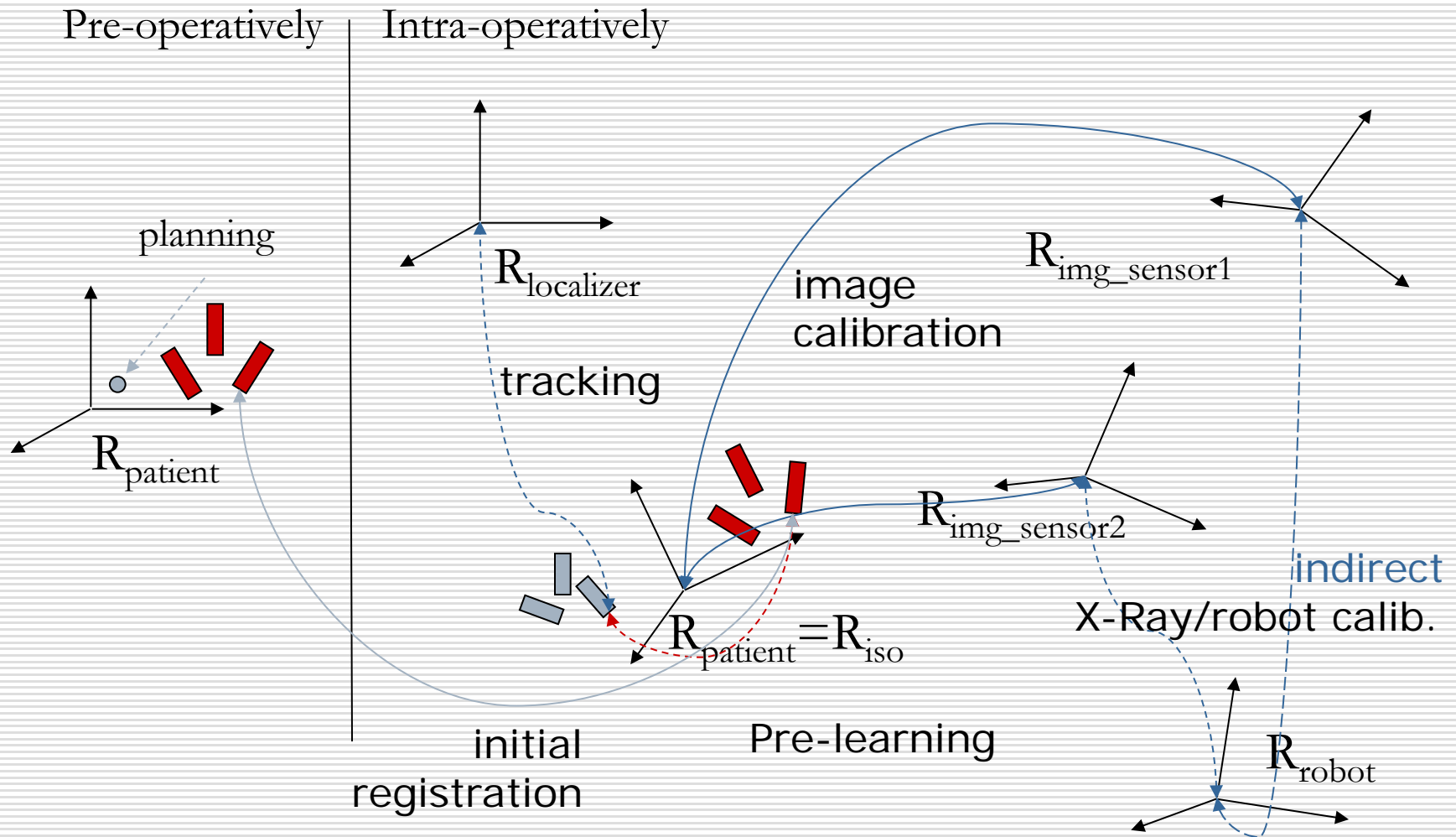
Cyberknife V3+ RoboCouch

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



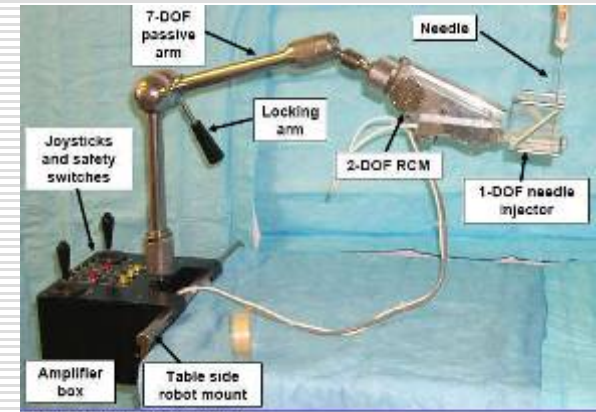
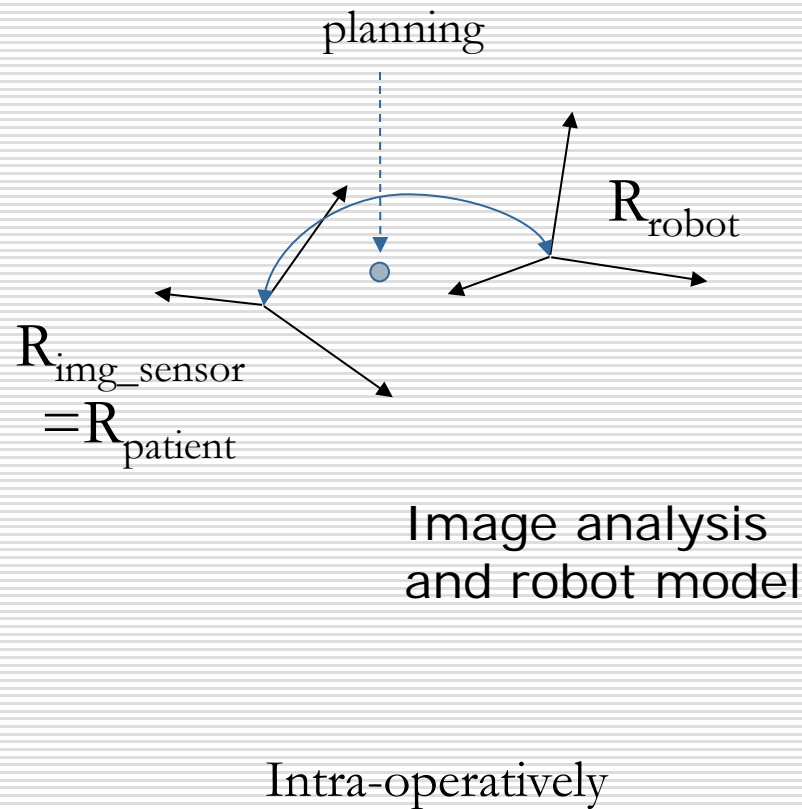
Example D: Cyberknife+Synchrony



Another type of solution (E)

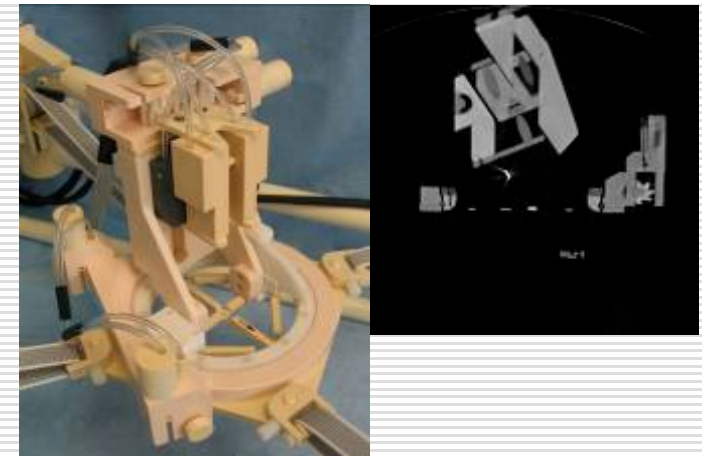
- Target defined and updated in the intra-operative imaging data
 - Indirect **visual servoing**: computing the robot position from the images
 - PAKY+RCM [Stoianovici et al.], LPR [Cinquin et al.], CT-Bot [de Mathelin et al.] etc.
 - Direct visual servoing: relating variations of the robot position to variations of the target in the images
 - From ultrasound images (see ISIR [Vitrani et al.], IRISA [Krupa et al.] for instance)
 - From endoscopic images (see ICube [deMathelin et al.], TIMC [Voros et al.], LIRMM [Poignet et al.] for instance)

Example E.1



Credit: Stolanovic, Masamune

PAKY+RCM



LPR

Example E.2

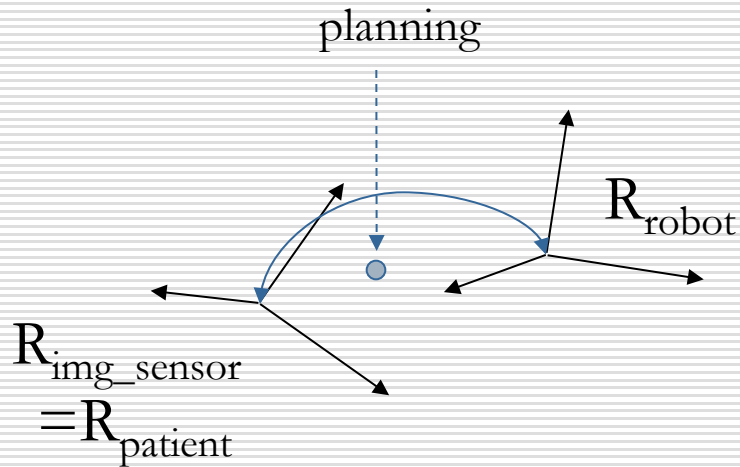
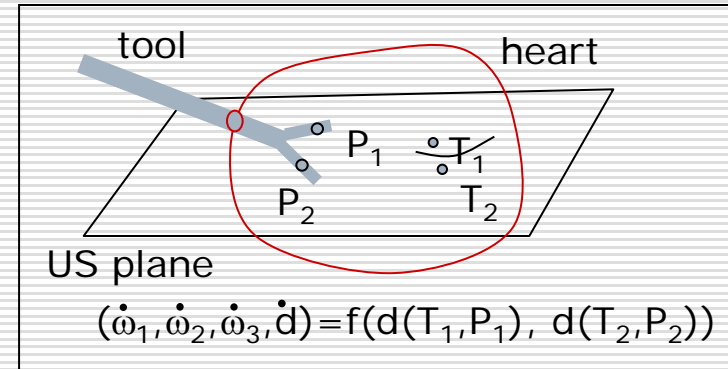


Image analysis and
Image/robot differential model



GABIE

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 recipes: depends on the application
- Some important issues
 - Intra-operative evaluation of registration accuracy
 - Safety of real-time registration