Medical Imaging
Application to guided surgery

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Summary

- ✓ Introduction to Medical Imaging and application to a particular case
- ✓ Image-guided Systems and Segmentation
- ✓ Medical tools tracking

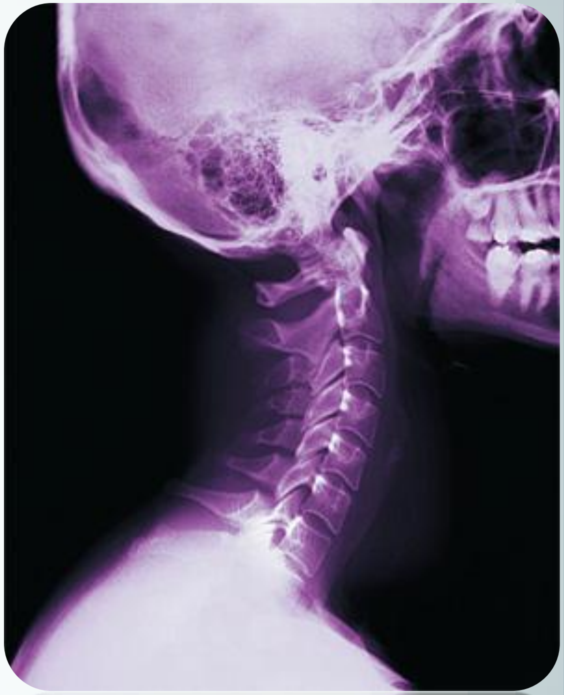
Introduction to Medical Imaging

- ✓ Radiography
- ✓ Magnetic Resonance imaging
- ✓ Nuclear medicine
- ✓ Ultrasound

Radiography

Visualization of the internal parts of the body using x-ray techniques

It is used to diagnose or treat patients by recording images of the internal structure of the body to assess the presence or absence of disease, foreign objects, and structural damage or anomaly.

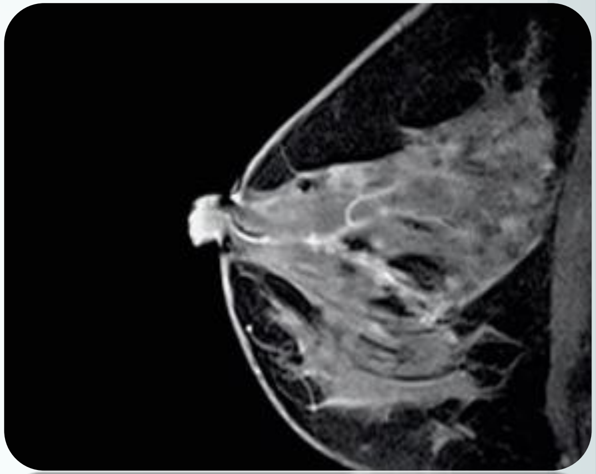


http://www.independent.co.uk

MRI

MRI is now used for many clinical indications.

The focus areas are the central nervous system, the device musculoskeletal, oncology, cardiovascular system and pediatrics

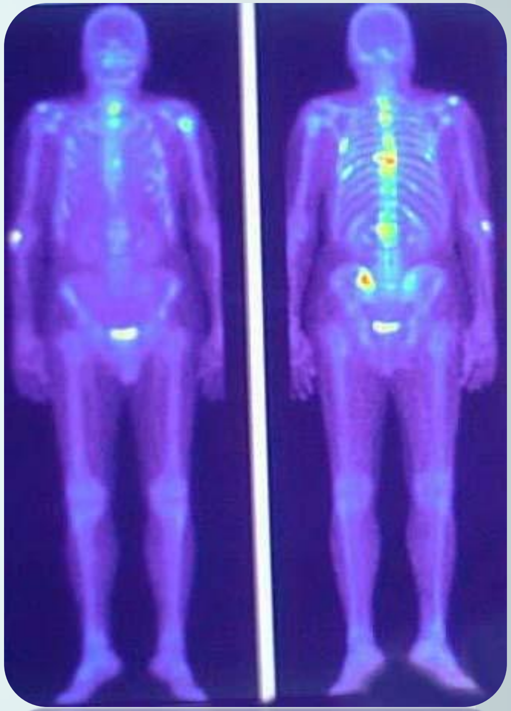


http://www.medical.siemens.com/

Nuclear Medicine

Nuclear medicine is the medical specialty that involves the use of radioactive isotopes in the diagnosis and treatment of disease.

In isotope scanning, a radioisotope is introduced into the body, usually by means of intravenous injection. The isotope is then taken up in different amounts by different organs. Its distribution can be determined by recording the radiation it emits, and through charting its concentration it is often possible to recognize the presence, size, and shape of various abnormalities in body organs.



http://www.nmimaging.com

Ultrasound

Ultrasonography is an ultrasound-based diagnostic imaging technique used to visualize subcutaneous body structures including :

- -Tendons
- -Muscles
- -Joints
- -Vessels
- -internal organs

for possible pathology or lesions.

Obstetric sonography is commonly used during pregnancy.

http://www.sanchopancho.com/

Breast Conservative Therapy

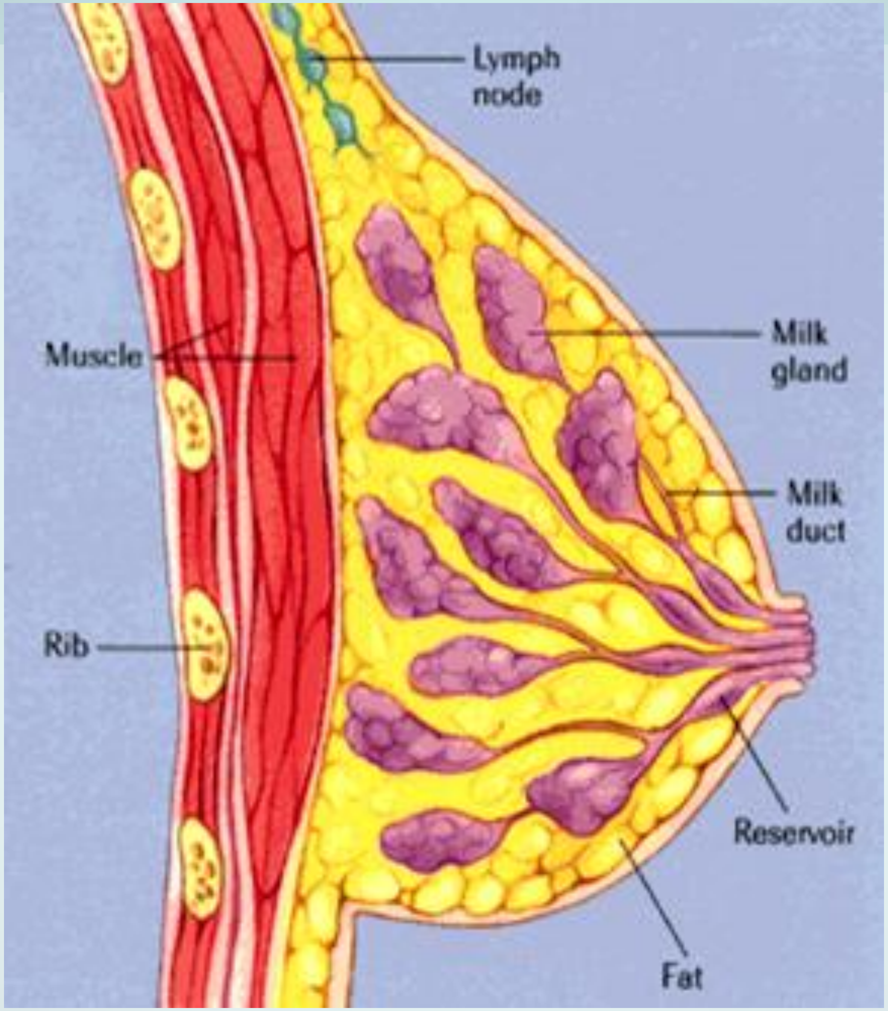
Anatomy of the breast

Development of breast tumor :

- Invasive tumor
  - Invasive ductal carcinoma (IDC)
  - Invasive lobular carcinoma (ILC)
- In situ tumor
  - Ductal carcinoma in situ (DCIS)
  - Lobular carcinoma in situ (LCIS)

Breast Conserving Therapy surgery

Anatomy of the breast



http://www.plasticsurgerycostaricaaftercarefacility.com/

Breast Cancer

→ a malignant tumor that has developed from cells in the breast. Usually breast cancer either begins in the cells of the lobules or the ducts.

In situ breast cancer : a cancer that is still within the milk duct and/or lobules of the breast.
The cancer has not invaded through the walls of the milk ducts or lobules.
Invasive breast cancer : cells that have grown through the walls of the milk ducts and glands into the normal fatty tissue of the breast.
The cells continue to grow causing a lump or thickening. They can then metastasize through the blood stream or lymphatic vessels to other parts of the body.

The major types of invasive breast cancer are:

- Invasive ductal carcinoma (IDC)
- Invasive lobular carcinoma (ILC)

Invasive Ductal Carcinoma

The most common type of breast cancer.

About 80% of all breast cancers are invasive ductal carcinomas.

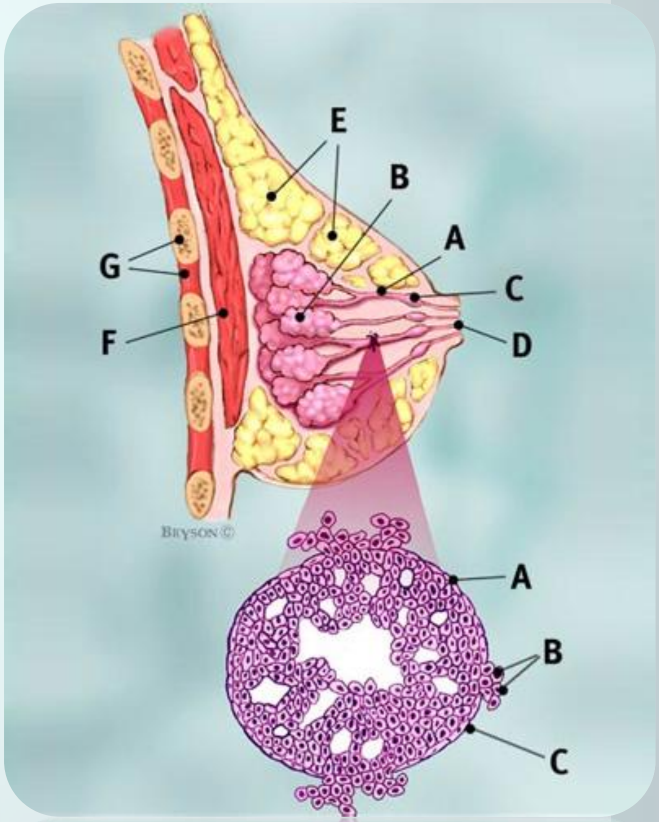
Key :

Breast profile:

A Ducts
B Lobules
C Dilated section of duct to hold milk
D Nipple
E fat
F pectoralis major muscle
G Chest wall/rib cage

Enlargement

A Normal duct cell
B Ductal cancer cells breaking through the basement membrane.
C Basement membrane



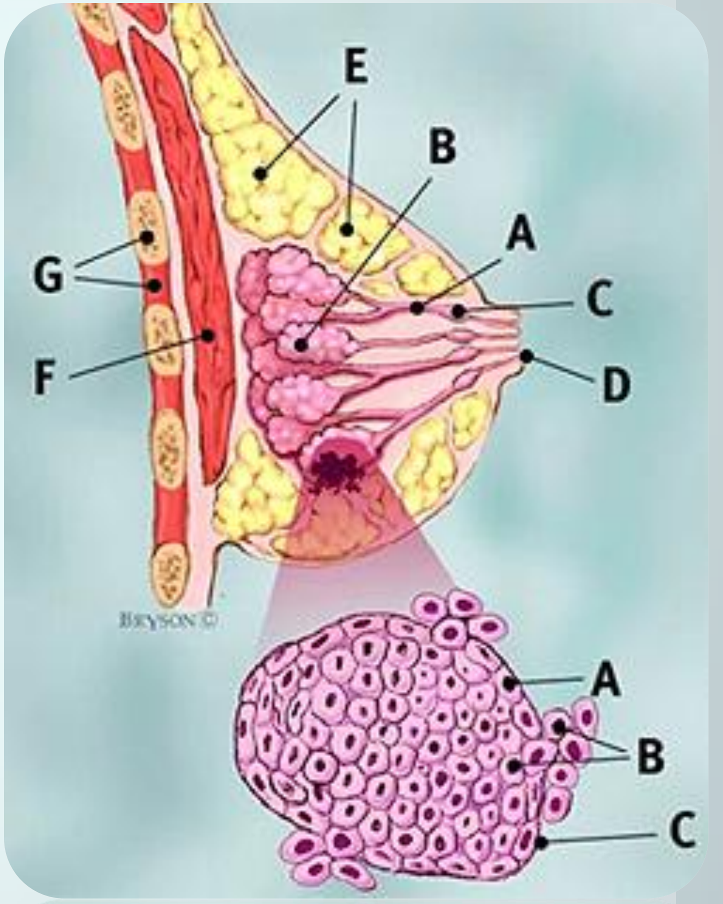
http://www.breastcancer.org/

Invasive Lobular Carcinoma

Second most common type of breast cancer after IDC (10 %) and difficult to diagnose on mammogram.

Slightly higher risk of being in both breasts and are usually estrogen receptor positive.

Key
Breast profile:
A: ducts, **B:** lobules, **C:** dilated section of duct to hold milk, **D:** nipple, **E:** fat, **F:** pectoralis major muscle,**G:** chest wall/ rib cage
Enlargement:
A: normal cells, **B:** lobular cancer cells breaking through the basement membrane, **C:** basement membrane



http://www.bccancer.bc.ca/

Breast Conserving Therapy

Surgery used in the Methodist Hospital , in Houston, Tx.

Five steps

- Localization of the tumor
- Insertion of a needle guide inside the breast
- Breast surgery
- Analysis of the tissue
- Radiotherapy

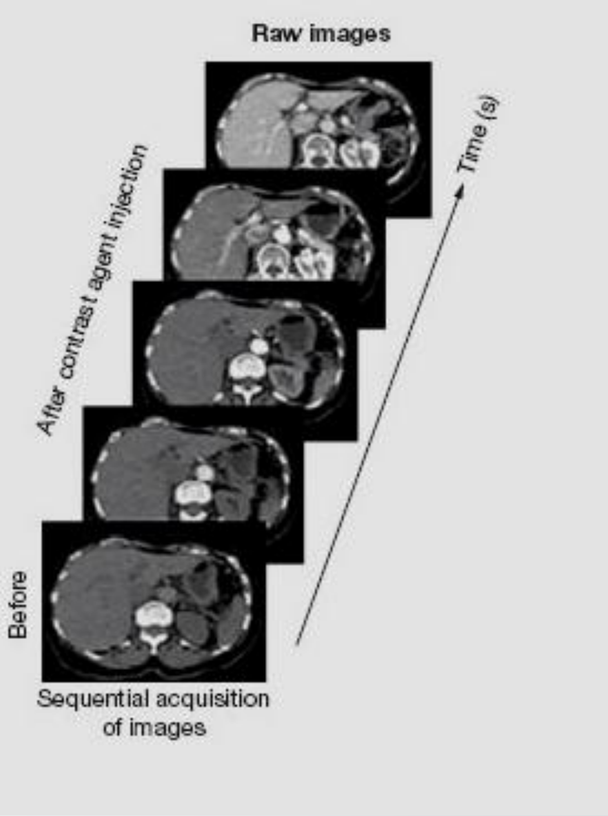
Localization of the tumor

Localization of the tumor with different MRI acquisitions :

- Once time without a contrast enhancer

- After the injection, 4 or 5 times with a contrast enhancer with a time step of 1 minute

The MRI gives the values t1 and t2.

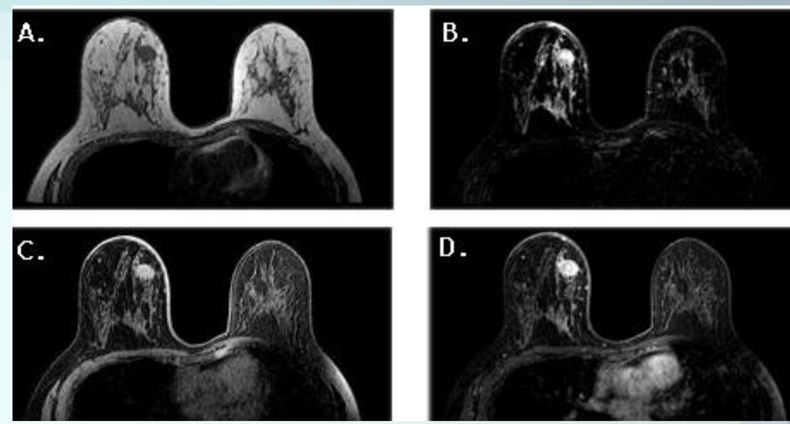


img.medscape.com

Localization of the tumor

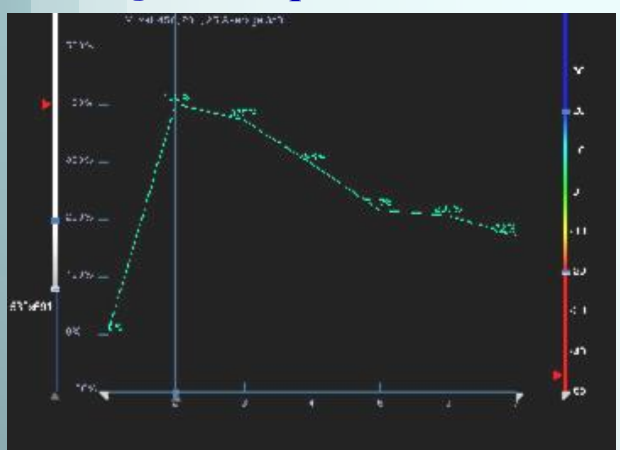
With the curve of the values of t1, at different times, we can distinct the breast tissue

- Tumor : the curve is a plateau
- Undetermined breast tissue - the curve grows up and down
- Healthy tissue - the curve grows up.



Different MRI views of the breast

A - Axial T1 pre-contrast
B - Axial T2 fat saturation
C – Axial T1 fat saturation pre-contrast
D – Axial T1 fat saturation post-contrast

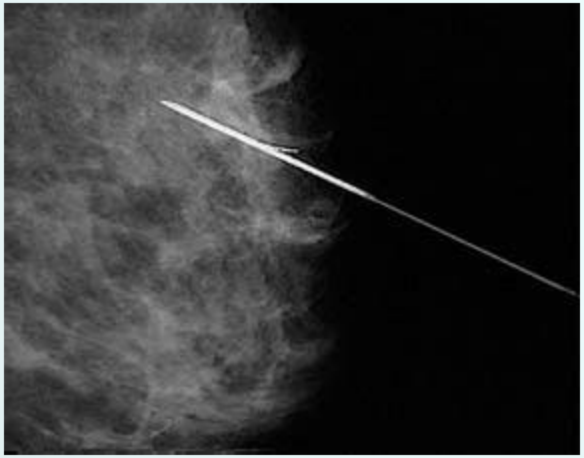


Curve of t1 : here an undetermined tissue

Breast-cancer-research.com

Insertion of a needle guide inside the breast

Once the radiologist has detected the localization of the tumor with the MRI data, he places a needle guide inside the breast in order to localize the tumor, that is not visible only with the eye.



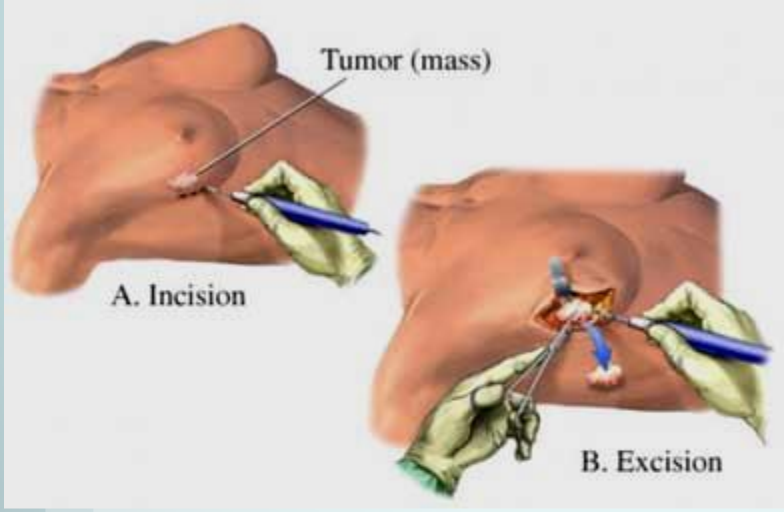
X-ray view of a breast needle localization

beasurvivor.com

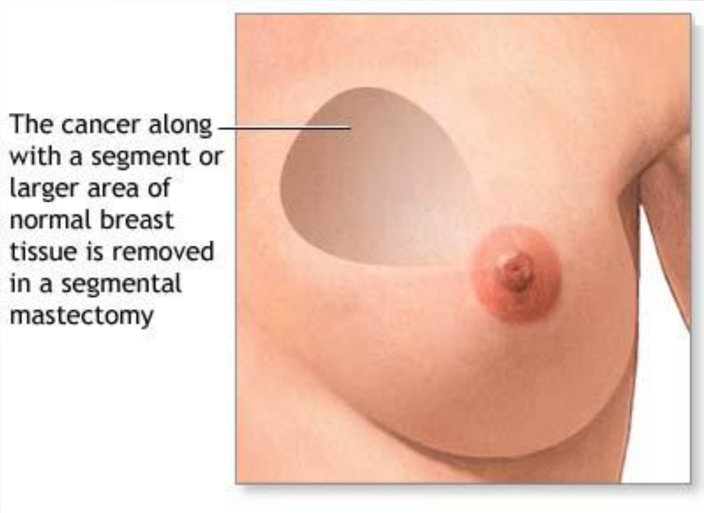
Breast surgery

The surgeon removes the breast tissue around the needle guide, plus a margin of surrounding normal tissues.

This surgery holes the breast, but the structure of the breast remains intact. The more the breast is big, the less the effect of the breast surgery is visible.



aurorabaycare.com

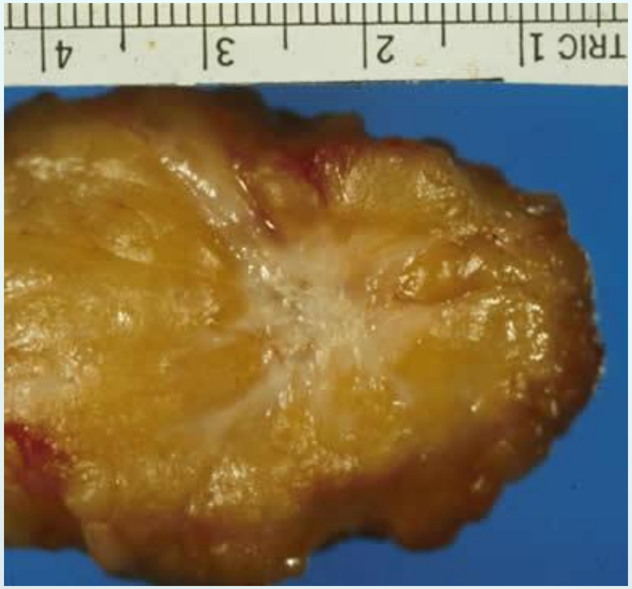


Walgreens.com

Analysis of the tissue

All this tissues will be studied under a microscope in order to check that the surrounding tissues are healthy.

In case not, an other surgery will remove the cancer tissues left in the breast.



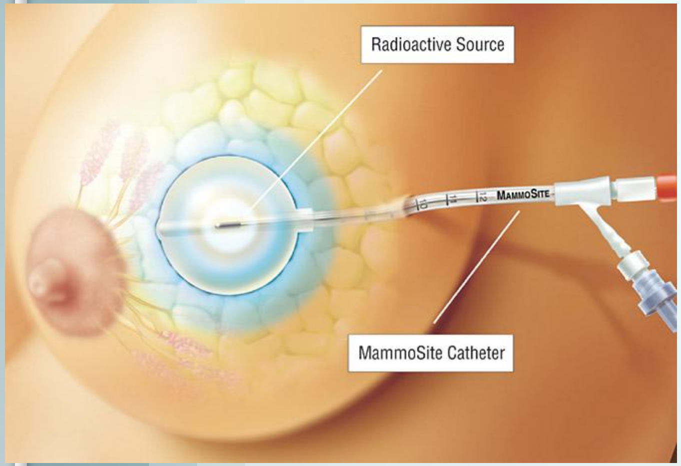
Breast cancer tissue

Cancerquest.org

Radiotherapy

Finally, a mammoSite device is placed in the lumpectomy cavity and connected to the high dose rate remote afterloaded.

The radioactive source is temporarily placed within the balloon to deliver the intended radiation dose to the targeted breast tissue that immediately surrended the balloon.



Diagrammatic representation of a MammoSite device in the lumpectomy space.

bcaction.org

Image guided Surgery and Segmentation

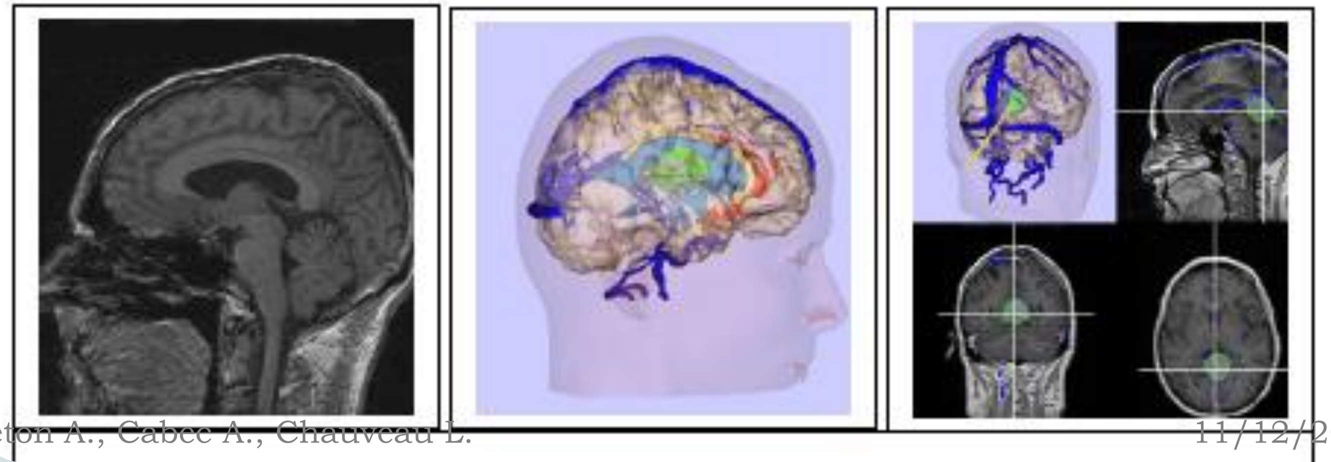
Image-guided systems : goal

¤ They integrate all information sources and used them to provide guidance to the physician

¤ Augment and complement the physician's ability to understand the spatial structure of the anatomy by integrating medical images and other sources of information

Image-guided surgery

- ¤ Acquisition of a set of medical images (RMI, CT…)
- ¤ Segmentation yelding a 3D patient-specific model
- ¤ Registration of the model
- ¤ Surgical instruments are tracked relative to the patient and the model



Segmentation

Converts standard medical imagery into information that more directly reflects patient anatomy

→ Labelling each voxel of the image with the associated tissue type

→ Agglomerating adjacent voxels with common labels into connected structures

Two categories of algorithms :

→ where the user can explicitly specified the desired segmentation

→ where the specification is implicit

First category of segmentation

Interactive process where the user is provided with real-time feedback and directly modifies the segmentation until satisfactory results are obtained

Hard task : images are often noisy, organ boundaries may be diffuse ...

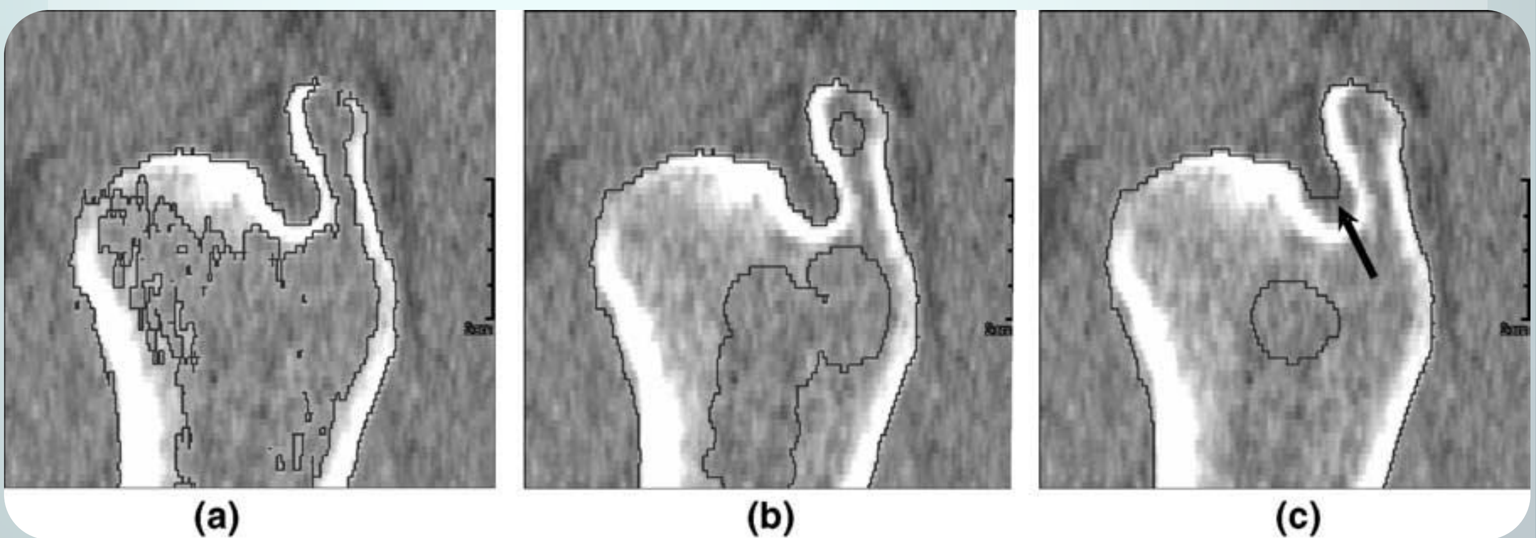
2 types of algorithms :

- manual segmentation
- user steered segmentation

Manual segmentation

Example : Interactive 3D editing tools for image segmentation
(Yan Kang, Klaus Engelke , Willi A. Kalender)

⟶ the user edits the segmentation results by selecting a volume of interest and then either applying mathematical morphology operators, local thresholding or directly manipulating the surface to achieve the desired segmentation



Algorithm steering

→ based on real-time interaction between the user and algorithm, where the user views the segmentation results and explicitly steers the algorithm to a desired segmentation

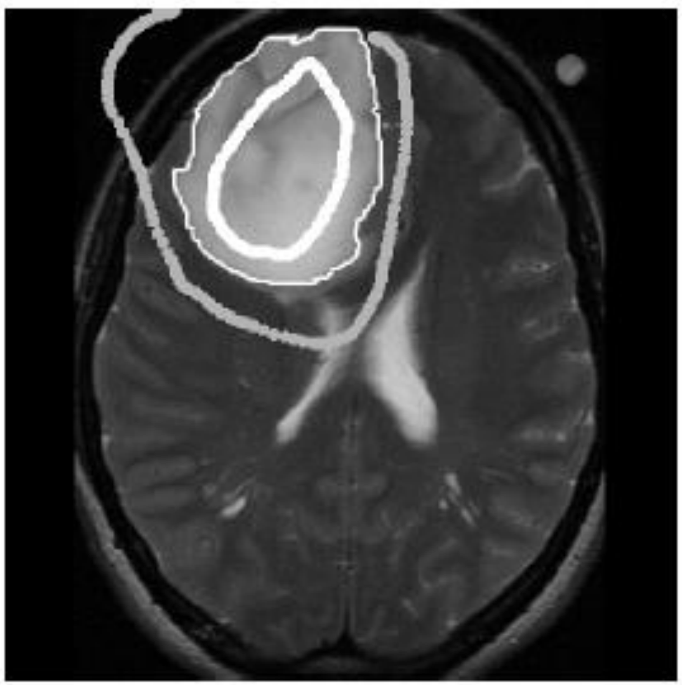
Example : the livewires family of algorithms for 2D and 3D segmentation

Principle : They produce a piecewise optimal boundary representation of the object, by viewing the image as a weighted graph and finding the shortest path between consecutive user specified boundary points.

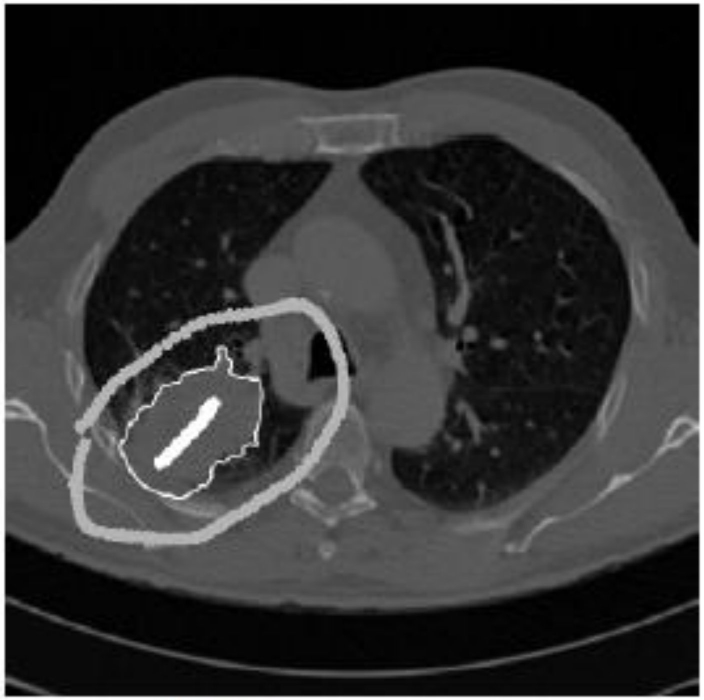
Algorithm steering

Random Walks for Interactive Organ Segmentation in Two and Three Dimensions: Implementation and Validation

Leo Grady, Thomas Schiwietz, Shmuel Aharon, and Rudiger Westermann



(a) Brain tumour



(d) Lung tumour

Second category of segmentation

The vast majority of segmentation algorithms fall into this category :

-edge based methods

-region based methods

- markov random fields

- level set methods

- atlas based methods

Using anatomical knowledge

Given an instance of the anatomical structure in one modality the goal is to segment it in another modality. Once the model is registered it defines the segmentation.

When the model is patient specific :

Example : a CT based vertebral model is registered to an X-ray image

Segmentation results are ranked according to the current registration estimate and an incremental registration update is computed based on the segmentation.

Using anatomical knowledge

The patient specific model can be replaced with an atlas (mainly for brain structures)

The atlas is registered to a new patient specific data set, producing a segmentation. As the model is generic, registering it to patient specific data requires the use of curved (deformable) transformations.

Atlas + curved transformations → segmentation of structures

Using anatomical knowledge

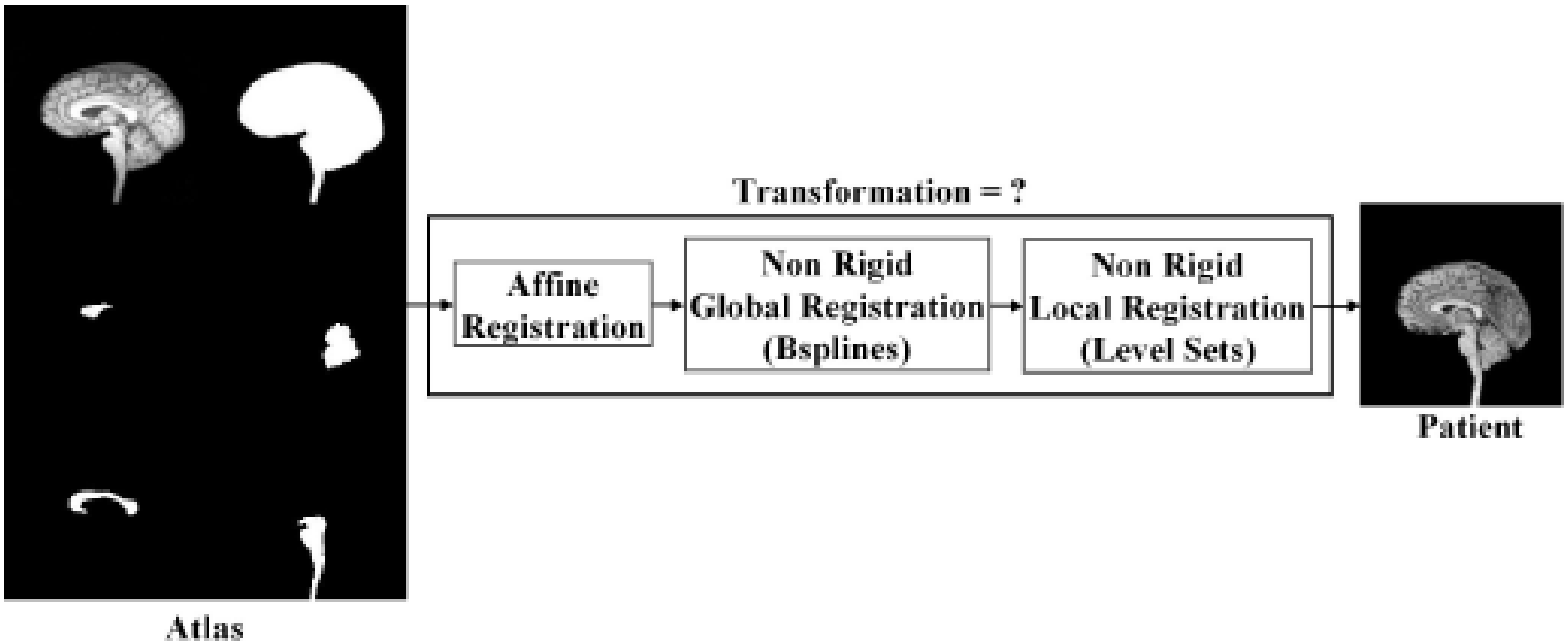


Fig. 1. Atlas-based segmentation process.

Using anatomical knowledge

Other model : Statistical models of appearance
(encode variations in shape and intensities)

- Active Shape Models (ASM), encoding the objects boundary

- Active Appearance Models (AAM), encoding the boundary and intensities inside the object

Using anatomical knowledge

ASM and AAM are constructed using a set of training images with corresponding landmark points marked on each of the images.

Shape and intensity parameter spaces are described by the modes of variation obtained by principle component analysis of the training data.

Registration

defined as the alignment of multiple data sets into a single coordinate system such that the spatial locations of corresponding points coincide.

Evaluation of the suitability of a registration for image-guided procedures with three factors:

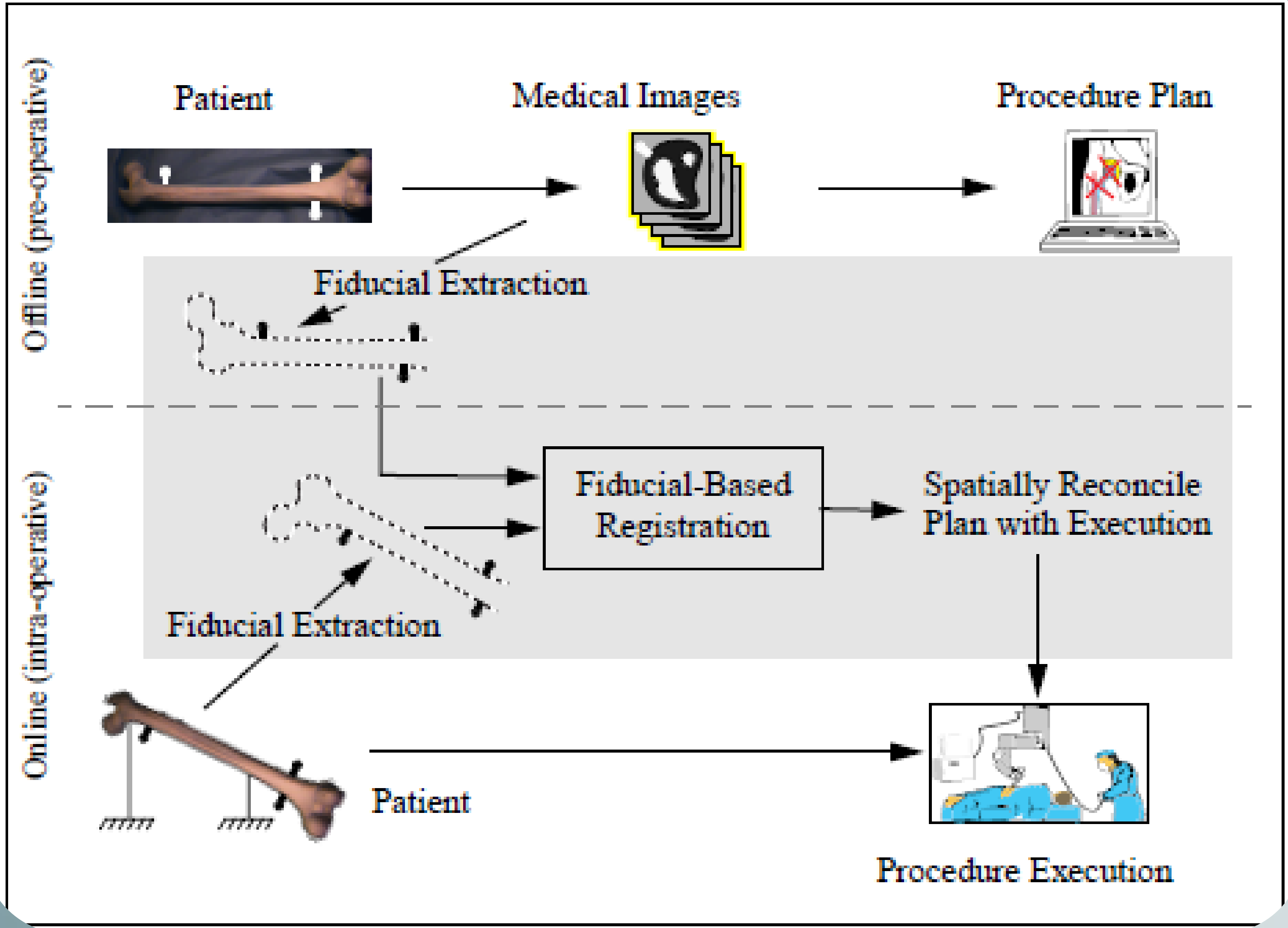
- Accuracy
- Speed
- Robutness

Registration

The most popular and mature registration methods used in image-guided surgery are based on paired point registration where the pairing is either known or computed.

Example : Fiducial based Registration

Registration



Medical Tools Tracking

Medical tools tracking

- Purposes:
  - Determine Pose and orientation of tools
  - Combine with Medical images
  - Real time system
  - Display relevant information to surgeons

Tools tracking

- Ideal tracking system :

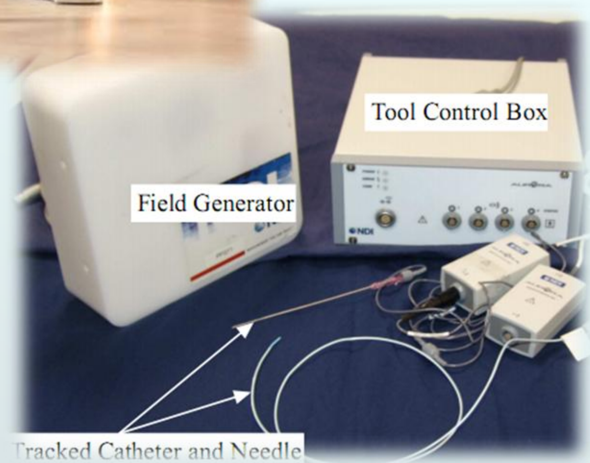
Small (unobtrusive)	**Accurate**
Fast	**Robust**
Concurrent (several tools)	**Inexpensive**
Easy to use	**Stable**

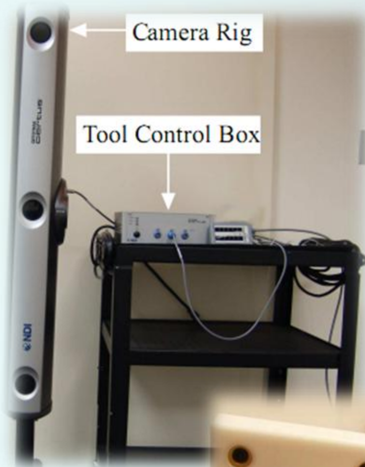
Tools tracking

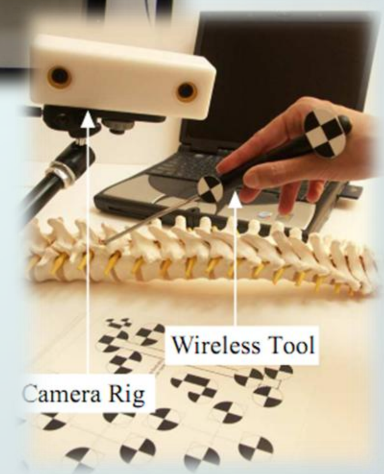
- Existing Technologies:
  - Fiber optic based devices
  - Video tracking
  - Electromagnetic tracking
  - Ultrasound tracking
  - Mechanical tracking

Tools tracking

❖ Existing Technologies:

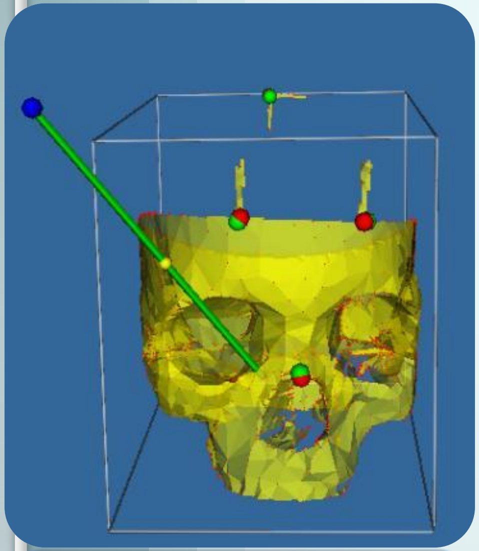






Example of Tracking System

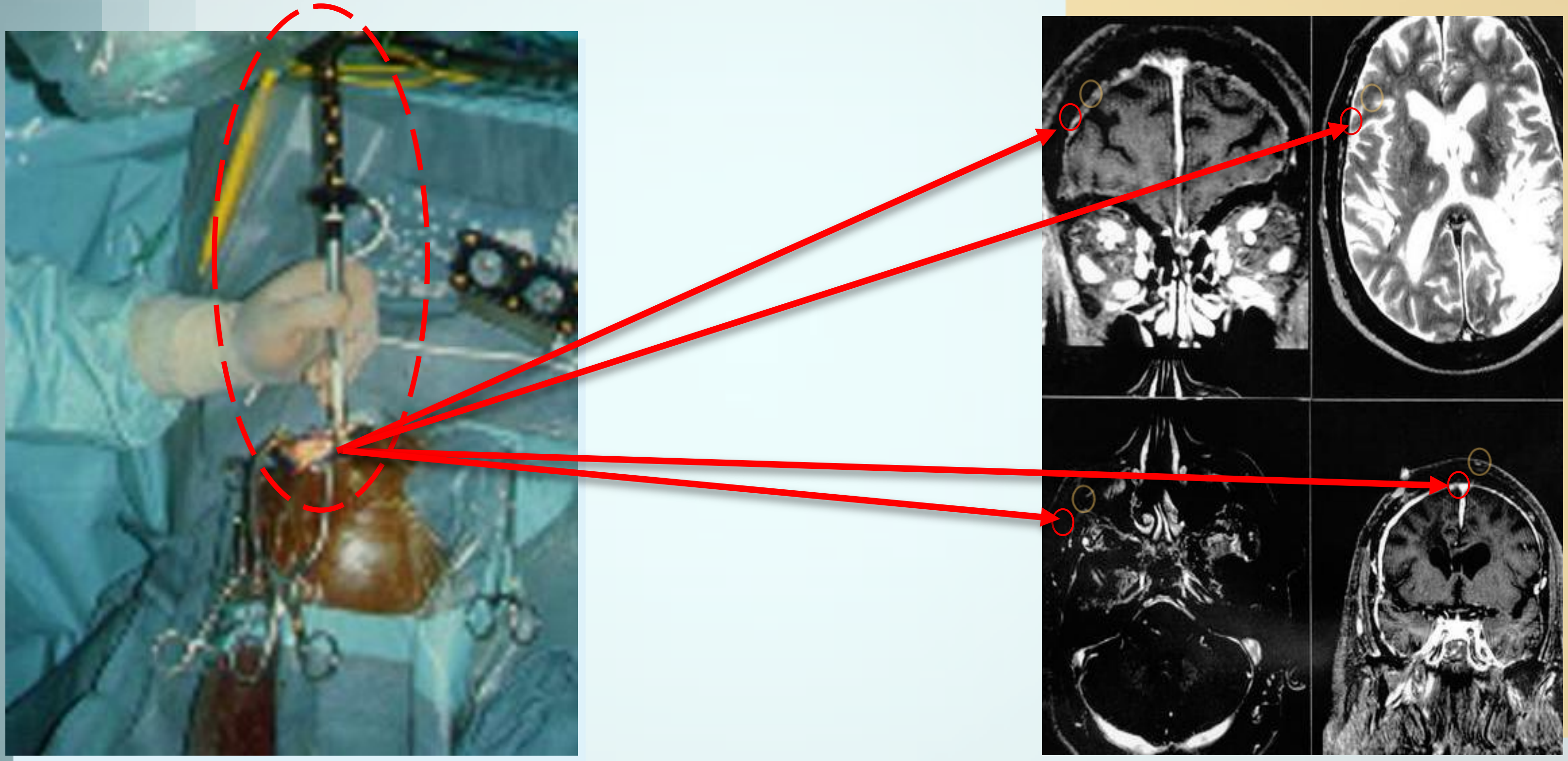
- Real Time Vision-Based Image Guided Neurosurgery
- CVIP Lab, University of Louisville



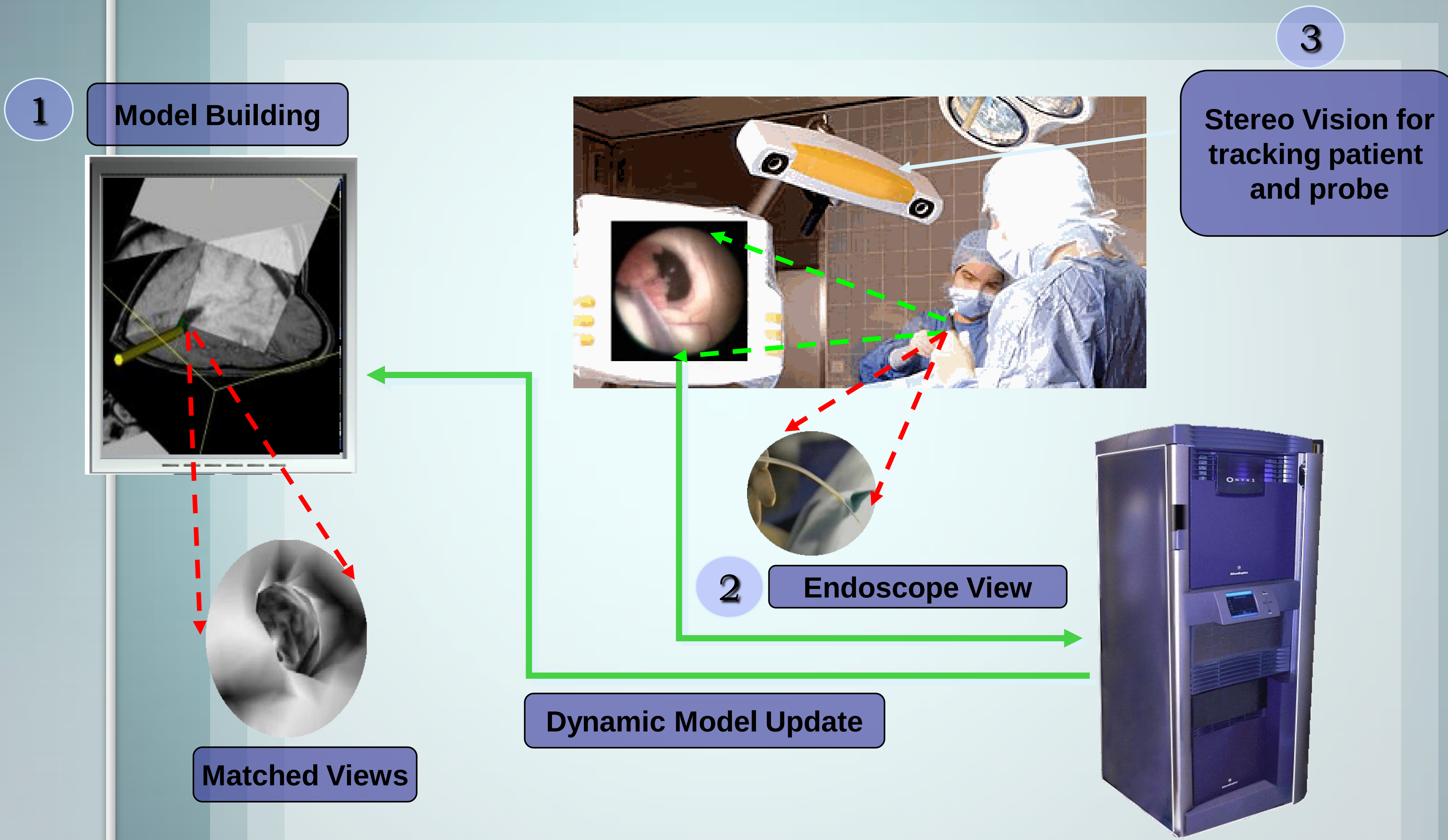
Motivations:

1. Decide which spot to make an incision
2. Find optimal path to targeted area
3. Avoid critical tissues

Example of Tracking System

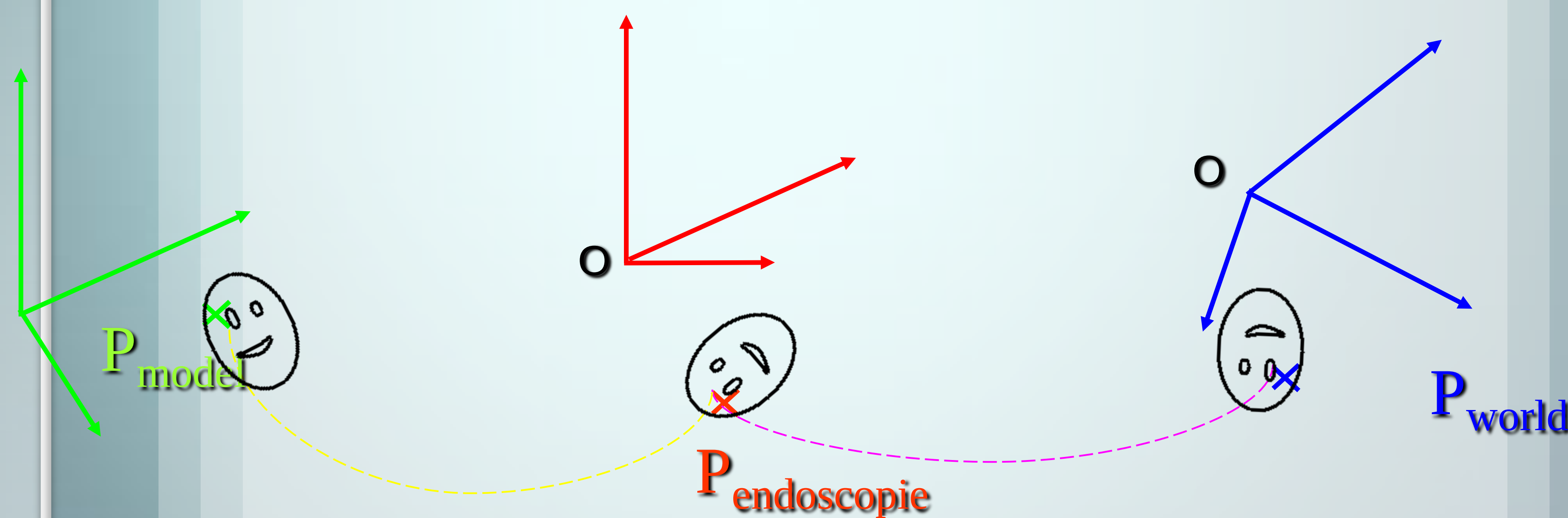


Example of Tracking System



Combining Informations

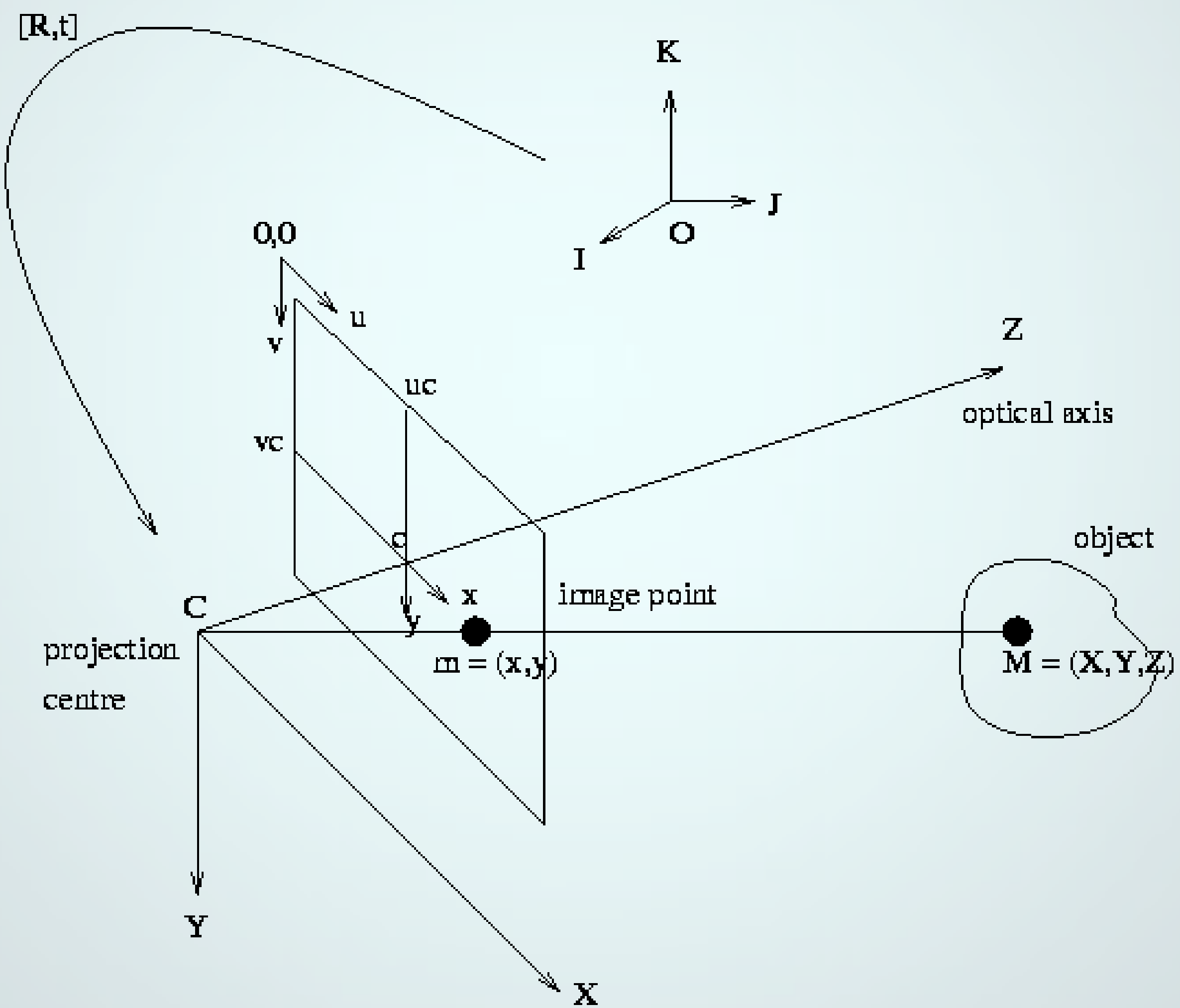
- Model information (CT, MRI….)
- Endoscopic view information
- Video Stereo information



Video Tracking

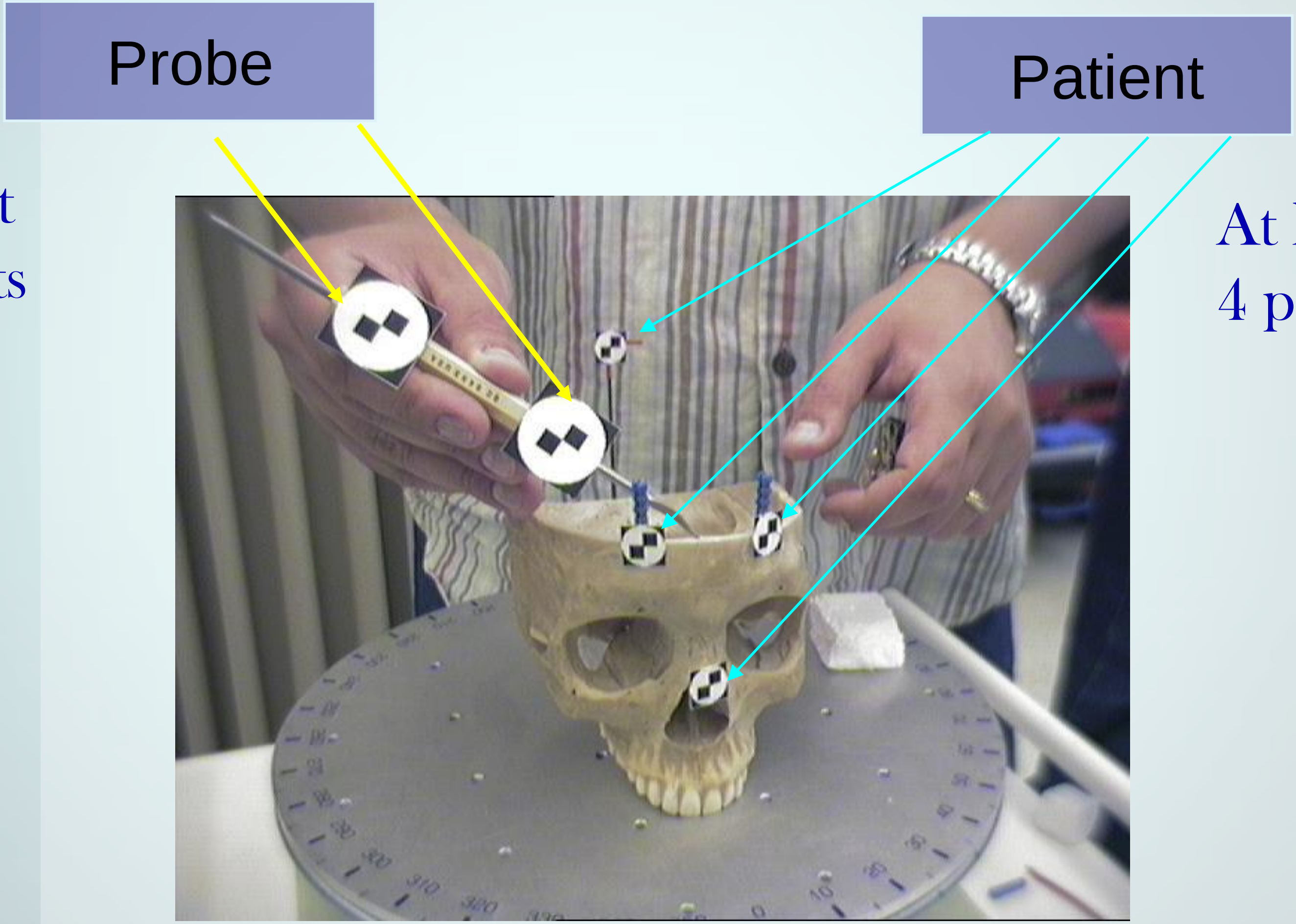
- Camera Calibration:
  - Measure intrinsic and extrinsic parameters
  - **Intrinsic:** Relations between pixels and camera normalized coordinates.
  - **Extrinsic:** Relation between 3D points in the world and camera coordinates

Video Tracking



Markers tracking

At least
2 points



At least
4 points

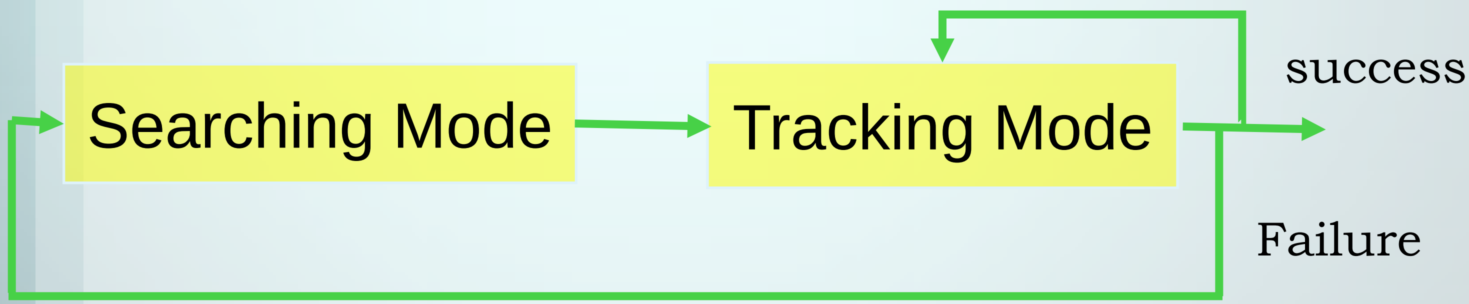
Markers tracking

Initialization

Search for first appearance of probe in scene

Tracking Mode

Track new probe position assuming smooth motion

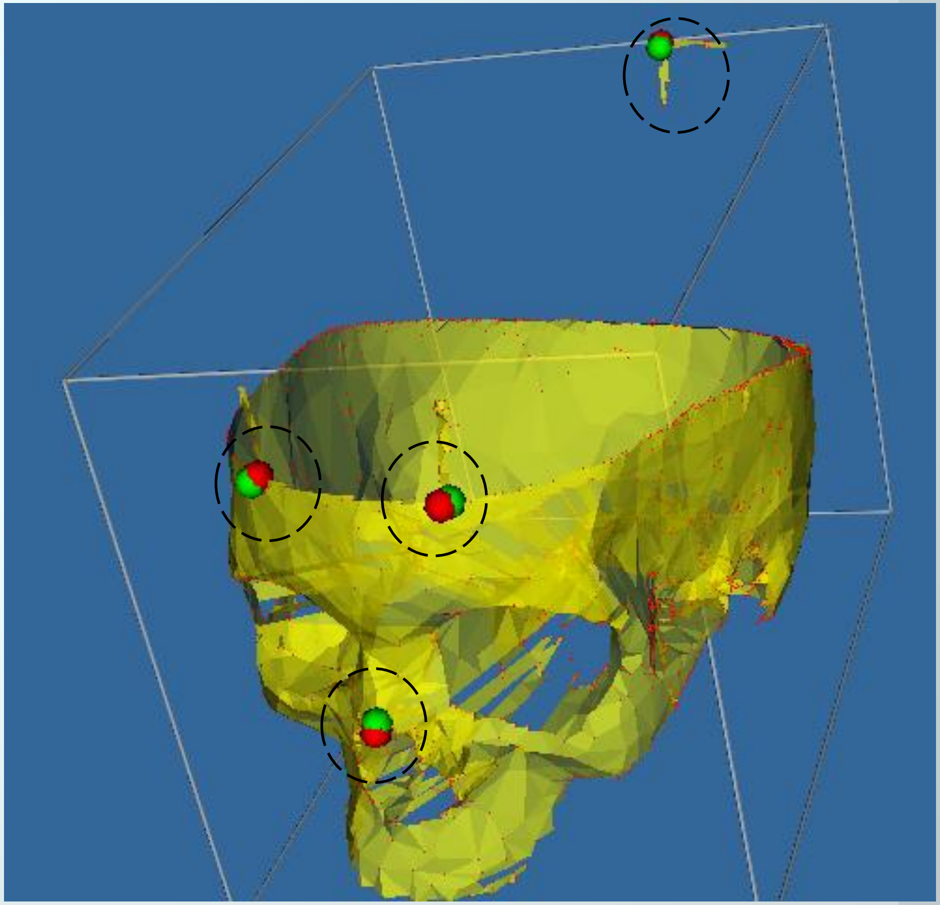


Markers tracking

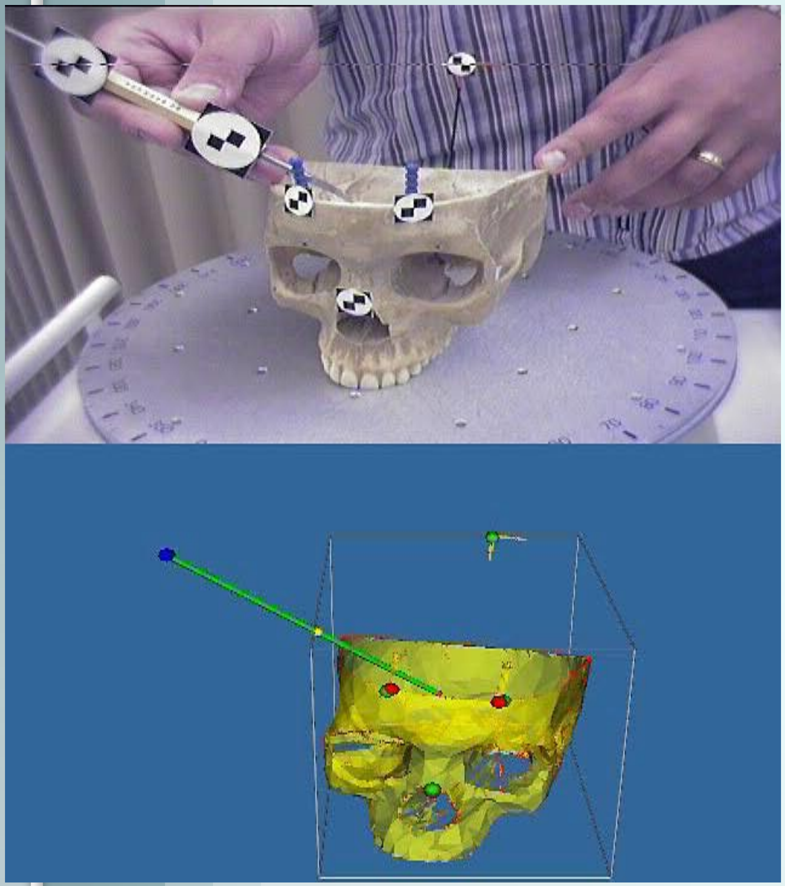
Min error between ground truth markers in RED and tracked ones in GREEN

RED markers: Ground truth markers in Model Space

GREEN markers: Tracked markers in Patient Space



Results



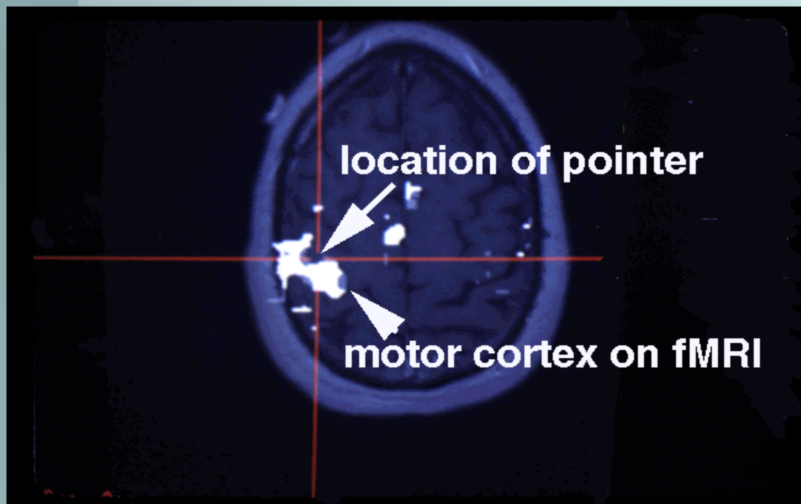
Probe Tracking System:

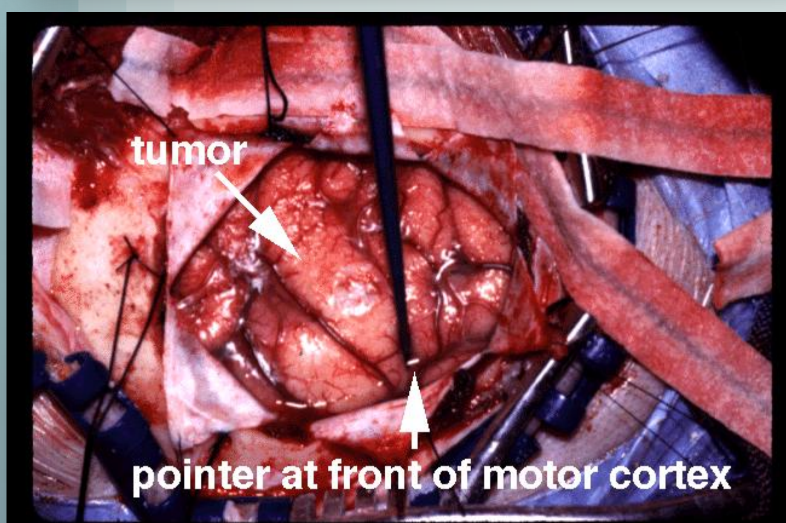
- Fast
- Cheap
- Accurate
- Robust

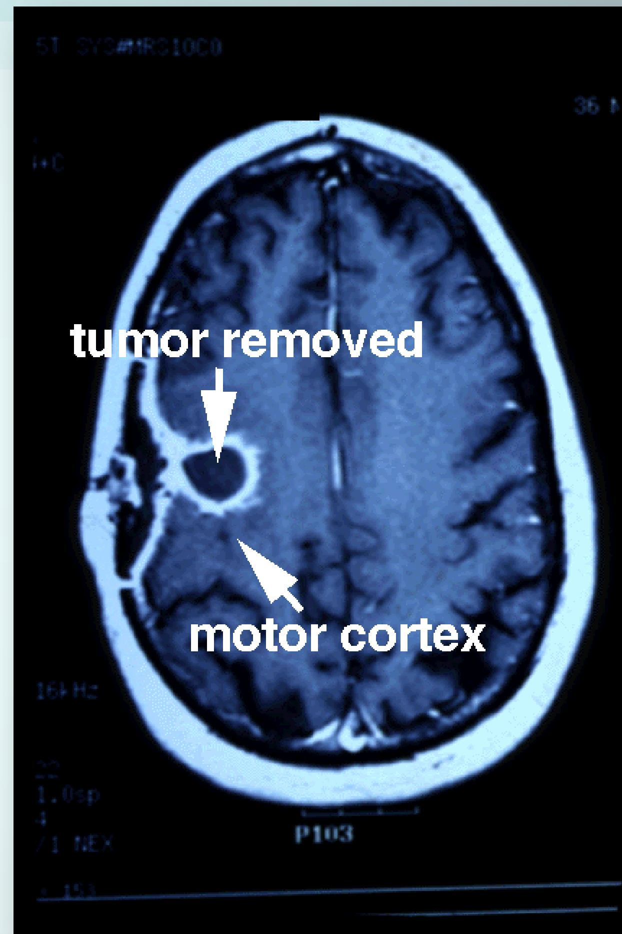
Example of guided surgery

- ***Scenario 1:***
  - 35 year old patient
  - He has a brain tumor close to motor cortex
  - Surgery is highly risky (paralyzed on left side)

Example of guided surgery







Pointer is tracked on a screen, surgeon can remove the tumor safely

Results

- Tumor is removed
- Patient is neurologically intact
- Guided surgery is very helpful in this case

Sinus guided surgery

Video example :

http://www.youtube.com/watch?v=sy8jwMjrgvs

References

www.tumorcells.net/breast.php

http://www.bccancer.bc.ca/

Essential operating principles for tumor and spheriod growth, Jesse A Engelberg, Glen EP Ropelle, C Anthony Hunt

http://wiki.chemeddl.org/images/6/63/

http://www.radiologyinfo.org

http://www.uptodate.com/

Image-Guided Procedures: A Review, Ziv Yaniv and Kevin Cleary

Segmentation of anatomical structures in chest radiographs using supervised methods: a comparative study on a public database Revised version, Bram van Ginneken, Mikkel B. Stegmann, and Marco Loog

References

Computer Vision Methods for Image Guided Surgery, Eric Grimson, Michael Leventon, Olivier Faugeras, William Wells

Medical Images Registration with a hierarchical atlas, Nawal Houhou, Valerie Duay, Abdelkarim S. Allal, Jean-Philippe Thiran

Fast and Accurate Shape-Based Registration, David A. Simon

Interactive 3D editing tools for image segmentation, Yan Kang, Klaus Engelke, Willi A. Kalender

Random Walks for Interactive Organ Segmentation in Two and Three Dimensions:

Implementation and Validation, Leo Grady, Thomas Schiwietz, Shmuel Aharon, and Rudiger Westermann

Image Guided Surgery, Eric Grimson, Michael Leventon, Liana Lorigo, Tina Kapur, Ron Kikinis