Medical Robotics
Lecture 19
Medical Imaging, Registration, and Processing
Nov 1st

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Outline

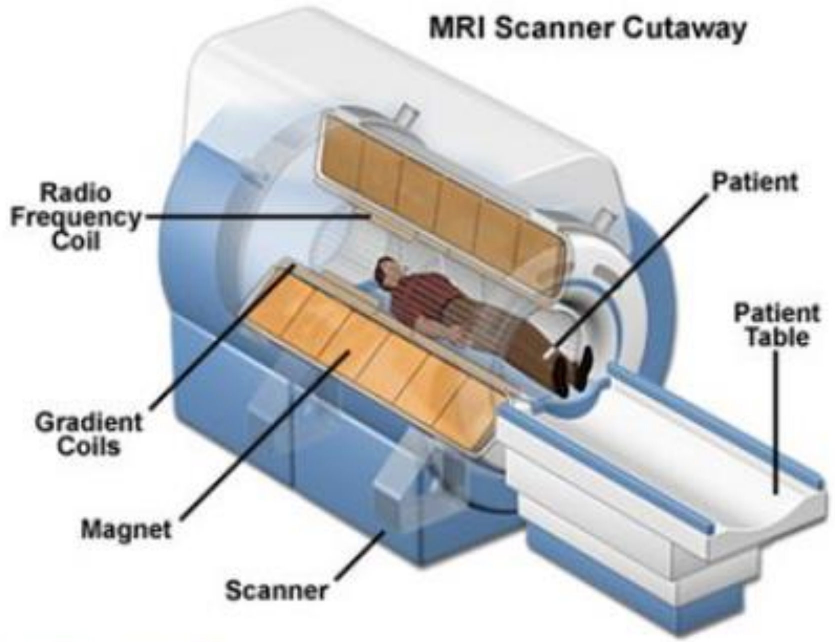
- MR Imaging
- Medical Imaging Standards (DICOM)
- Coordinate Frames
- Image Registration
- Image Processing
- 3D Slicer Demonstration

MRI – Magnetic Resonance Imaging

- Physics: Magnetic Resonance of Hydrogen
- History: Developed 1973 by Dr. Peter Mansfield and Dr. Paul Lauterbur (Nobel Price 2003)

The MRI is comprised of 3 main components:

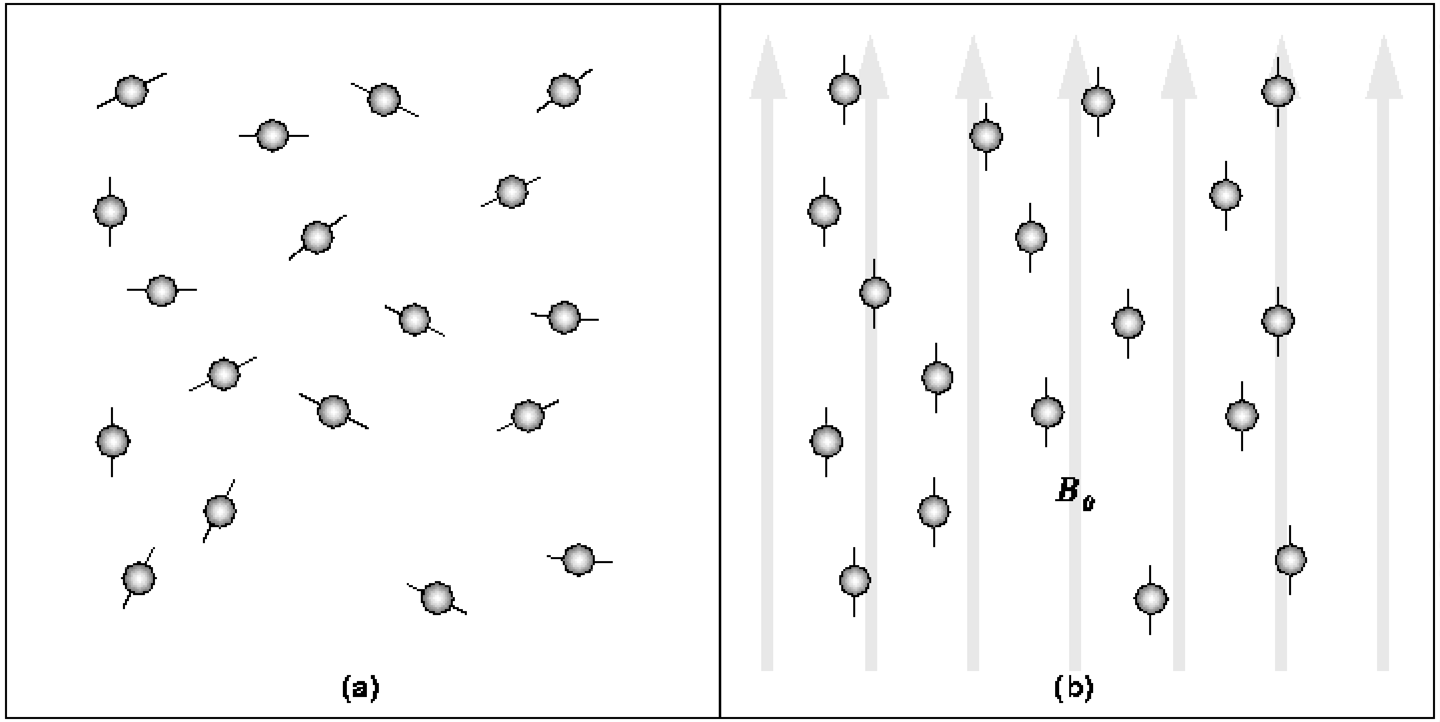
- A superconducting primary magnet
- 3 magnetic field gradient coils
- RF transmitter and receiver



Taken from
https://wiki.engr.illinois.edu/display/BIOE414/Team+4+-+MRI+Radio+Frequency+Coils

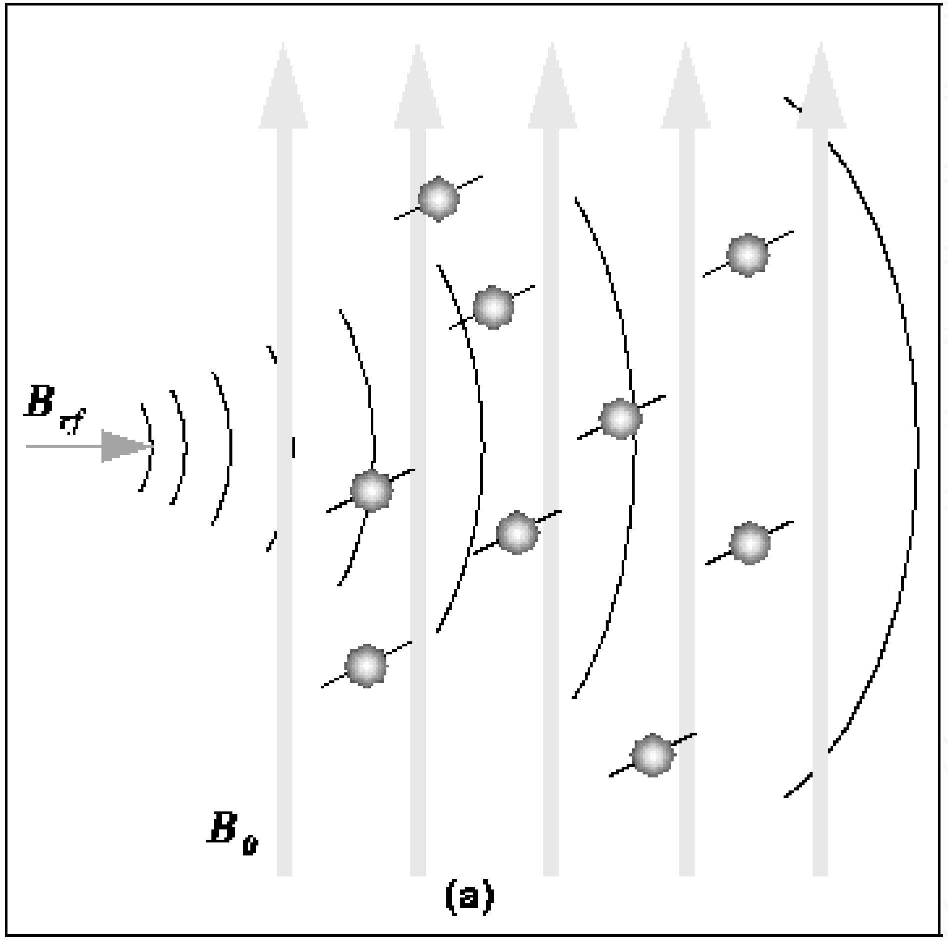
MRI – Principle

- Step 1: Strong magnetic field aligns the magnetic moments (spins) of hydrogen molecules
- 0.5-12 Tesla (~10k stronger than earth magnetic field)



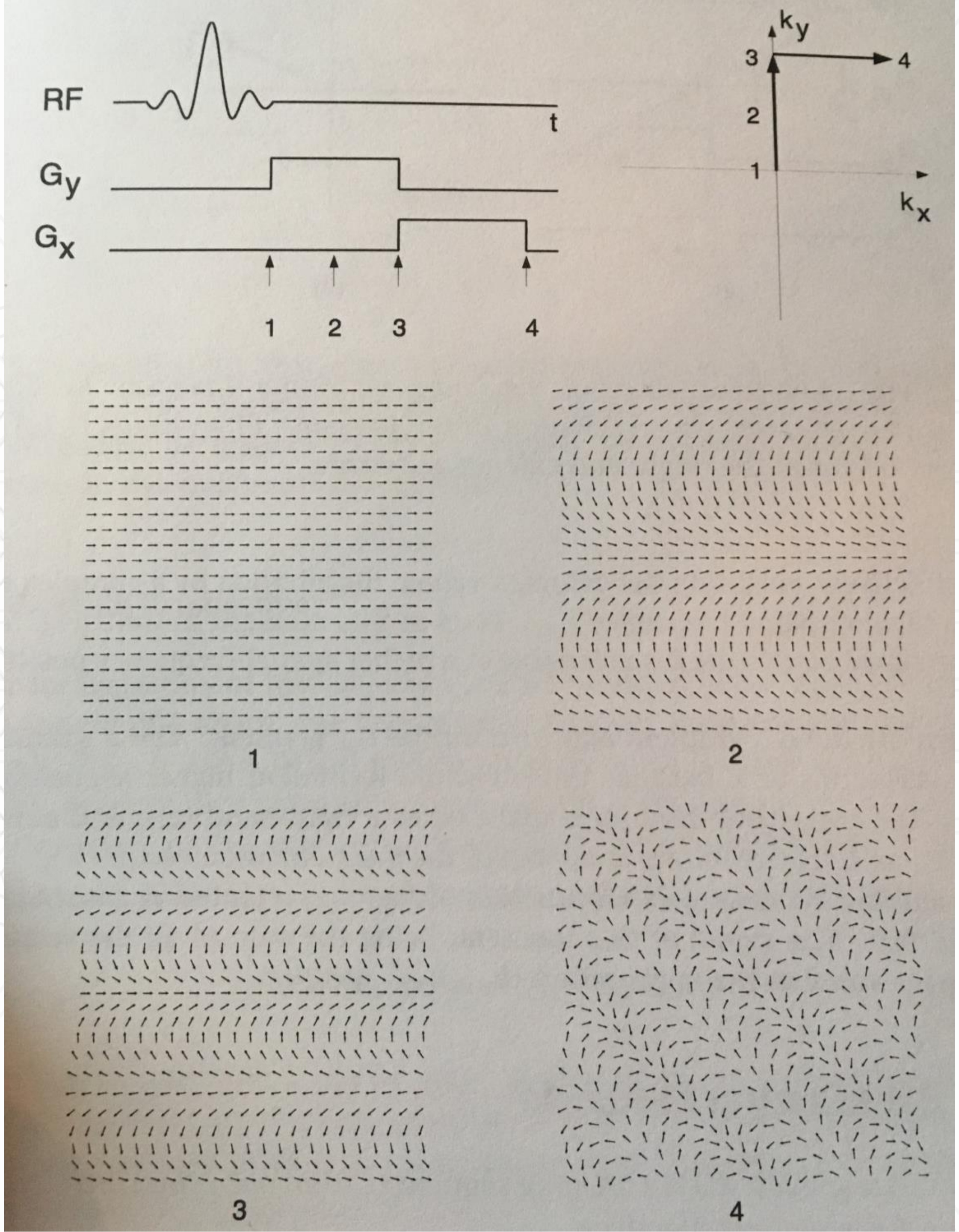
MRI – Principle

- Step 2: An Radio Frequency Pulse is applied that causes the hydrogen spins to flip and rotate with a frequency proportional to the magnetic field strength



MRI – Principle

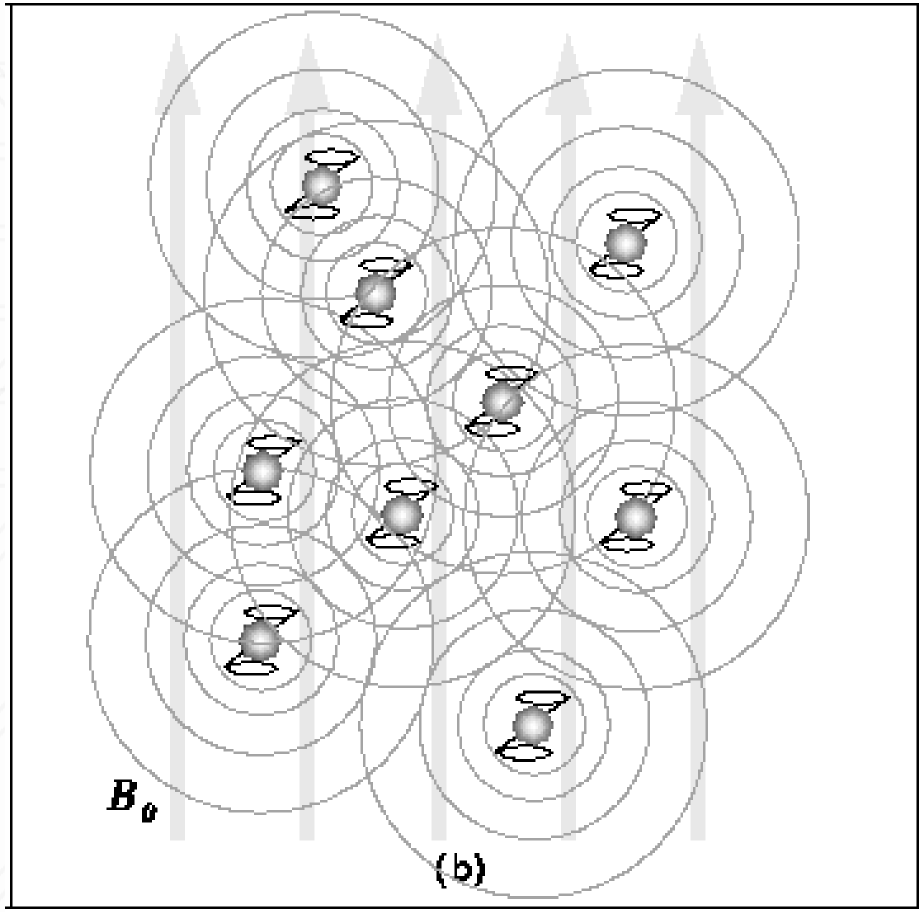
- Step 3: Linear Gradient magnetic fields are applied along x,y, and z to encode spatial information into the frequency and phase of the rotating hydrogen spins.



Nishimura, Magnetic Resonance Imaging

MRI – Principle

- Step 4: The RF signal is removed and the spins slowly re-align with the magnetic field, emitting an RF signal that is measured by imaging coils



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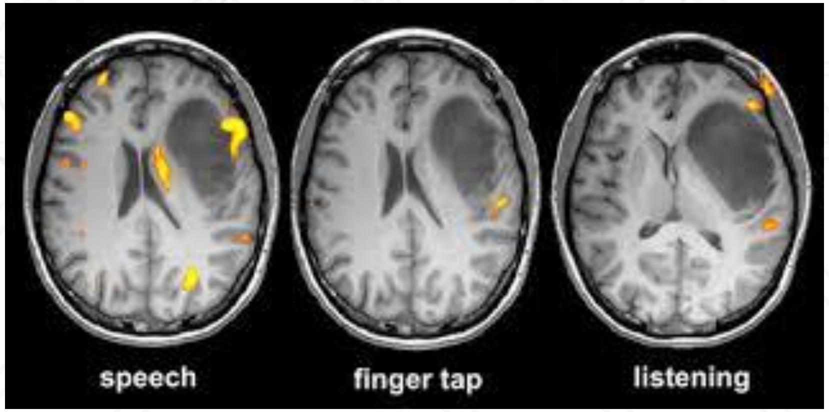
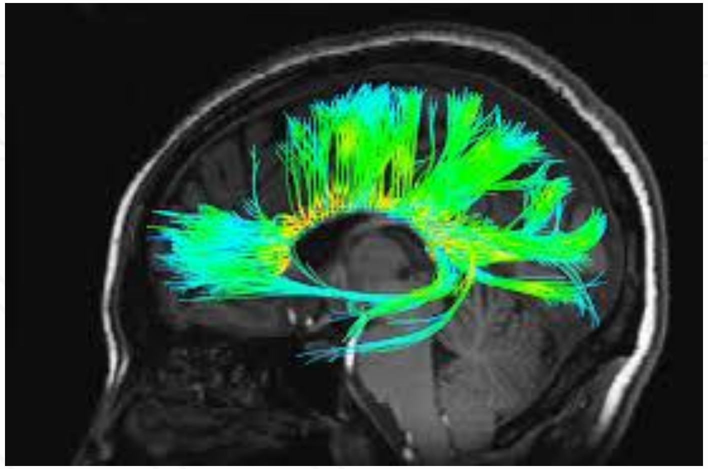
MRI – Properties

- Excellent soft tissue contrast e.g. brain and prostate tumor imaging, ligaments
- No ionizing radiation
- Image contrast based on proton density and magnetic relaxation properties (T1 and T2)
- Functional imaging e.g. brain activity
- Low temporal resolution
- No bone signal

GE Healthcare



Functional brain activity



Diffusion tensor imaging, Frank, UCSD

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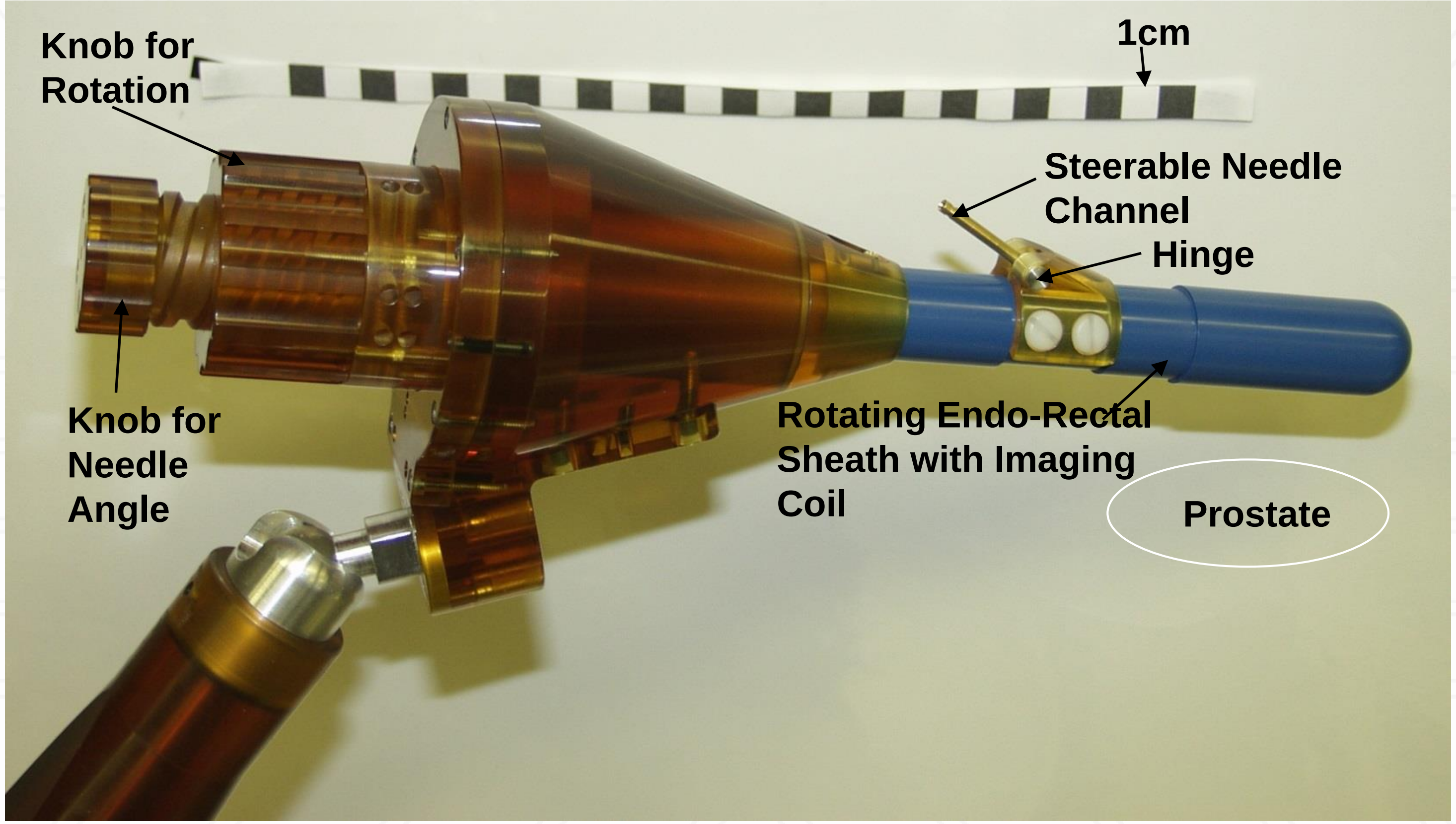
MRI – Example: MRI Prostate Robot: Manipulator



Krieger A, Susil RC, Ménard C, Coleman JA, Fichtinger G, Atalar E, Whitcomb LL. Design of a novel MRI compatible manipulator for image guided prostate interventions. *IEEE Transactions on Biomedical Engineering* 2005 Feb;52(2):306-313.

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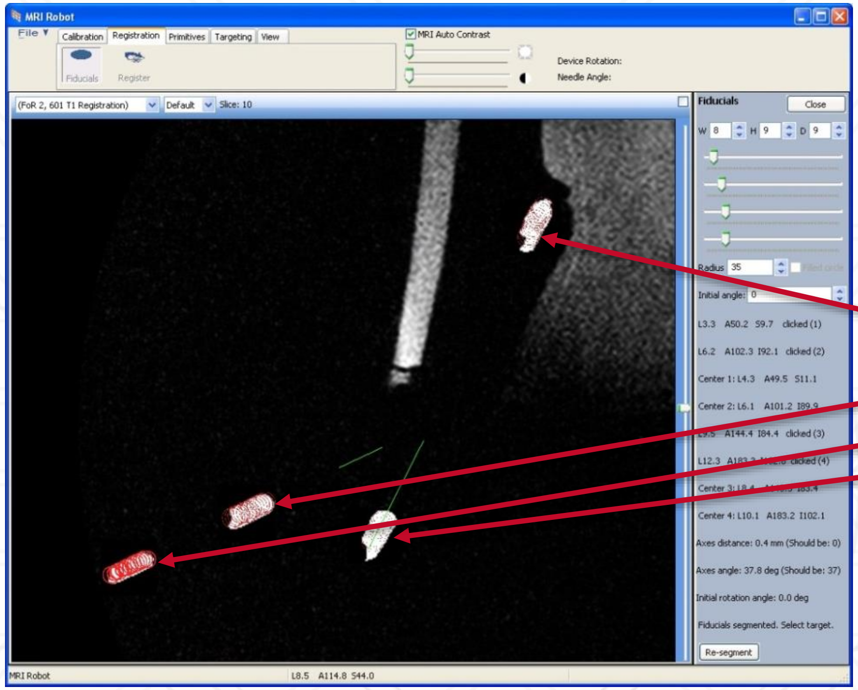
MRI – Example: MRI Prostate Robot: Registration



Four markers for registration of robot to MRI images: Robot axis and needle axis.

- Software automatically segments markers and calculates initial position of the device.
- Software displays necessary needle angle, rotation and needle depth to reach selected targets in prostate.

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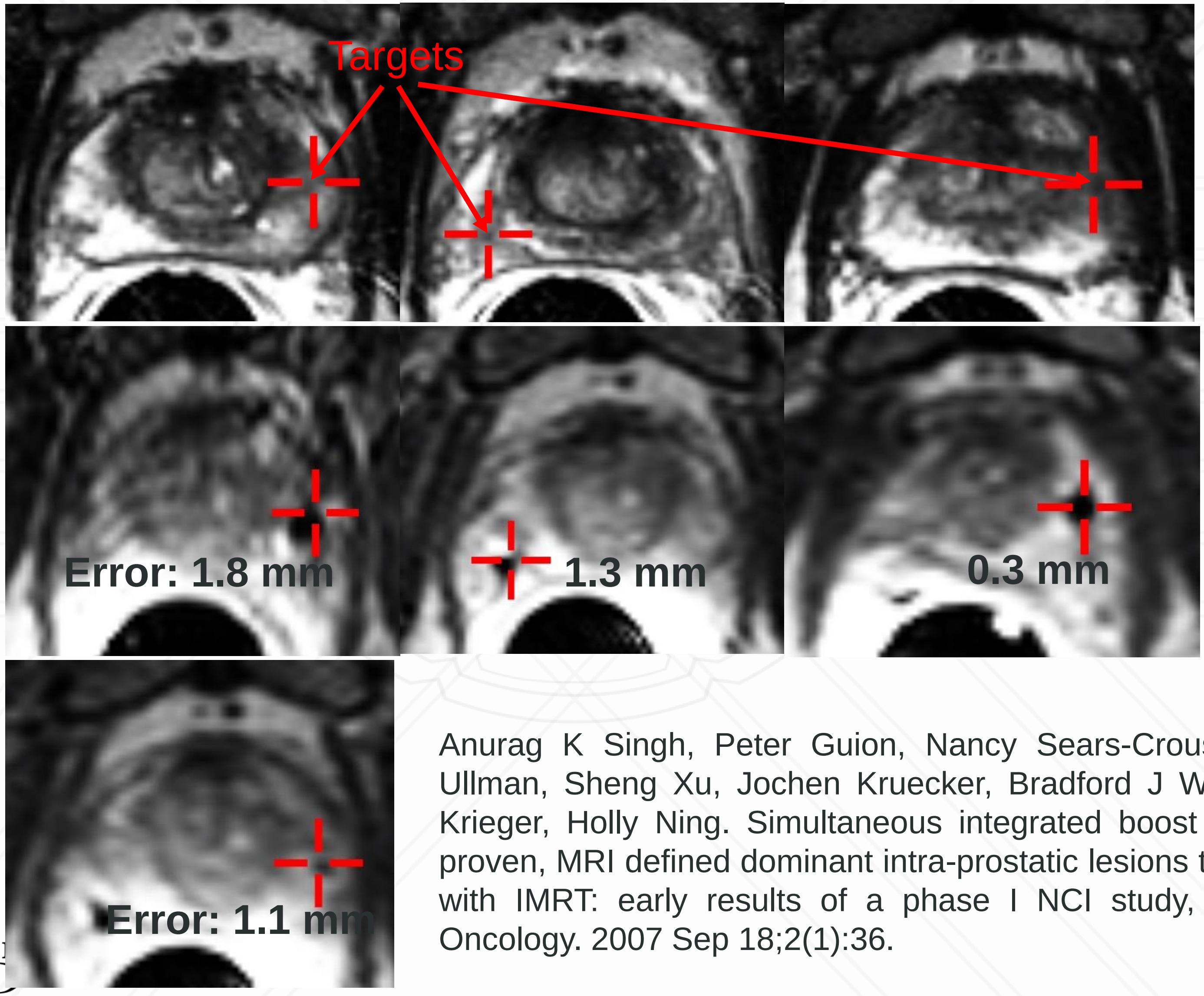
MRI – Example: MRI Prostate Robot: Clinical Case



Anurag K Singh, Peter Guion, Nancy Sears-Crouse, Karen Ullman, Sheng Xu, Jochen Kruecker, Bradford J Wood, Axel Krieger, Holly Ning. Simultaneous integrated boost of biopsy proven, MRI defined dominant intra-prostatic lesions to 95 Gray with IMRT: early results of a phase I NCI study, Radiation Oncology. 2007 Sep 18;2(1):36.

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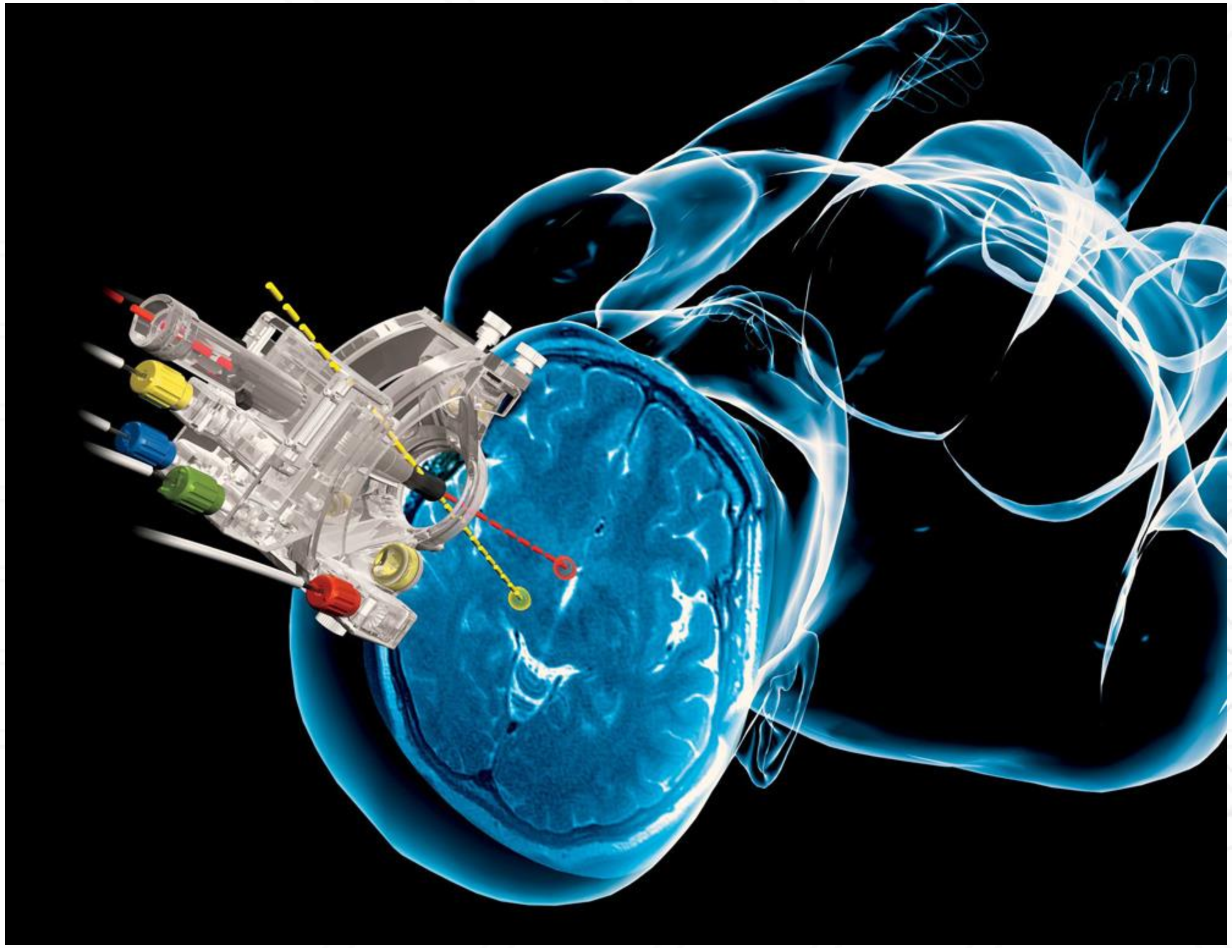
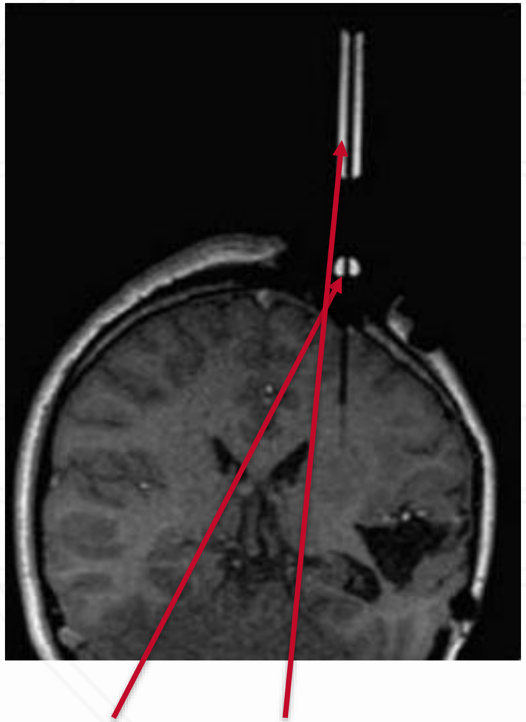
MRI – Example: MRI Guided Deep Brain Stimulation



Clear Point System
MRI Interventions



Point and Line Fiducial to
register device to images

MRI - Discussion

- what challenges might exist in performing MRI-guided robotic interventions?

MRI – MRI Guided Procedures

Challenges of MRI Environment:

- Confined space
- Material restrictions
- No standard actuators and encoders
- Shielded room
- Difficult access to patient

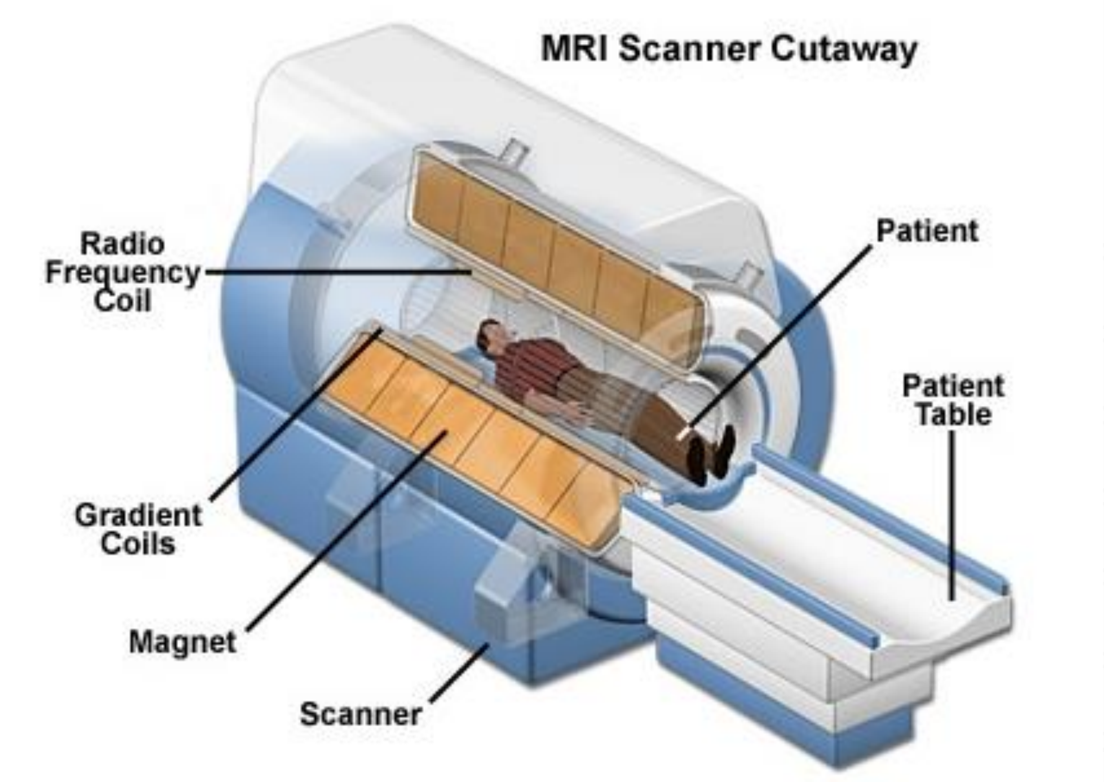


Image Credit: www.magnet.fsu.edu/education/tutorials/magnetacademy/mri/

Imaging Modalities for Image Guided Procedures

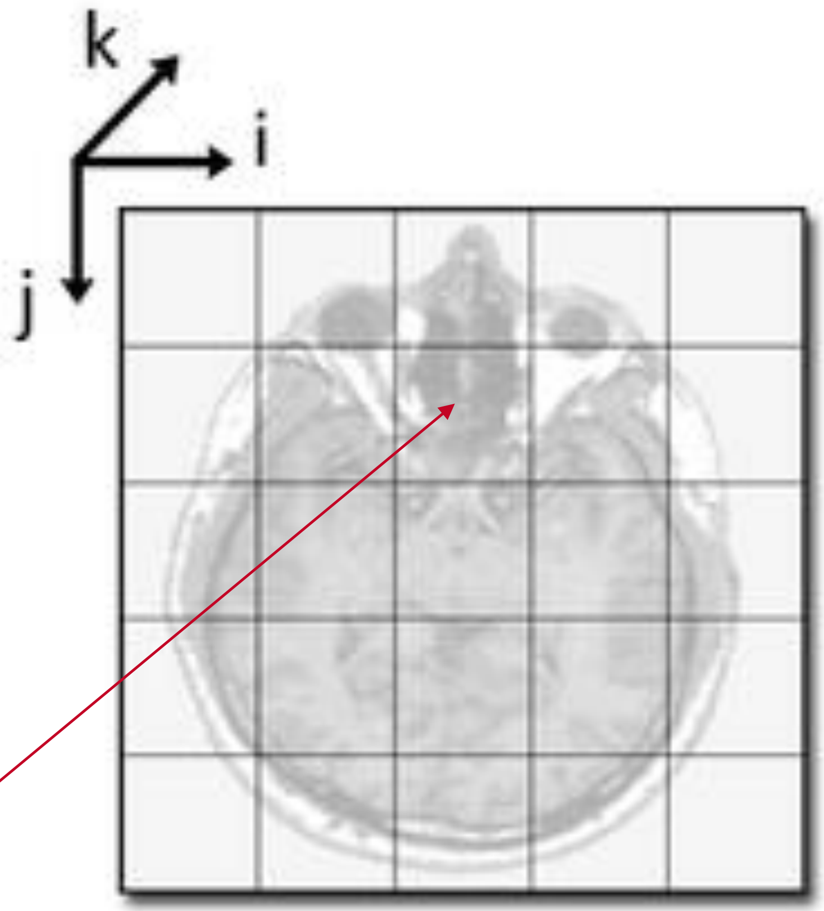
Modality	Intra-operative Availability	Accessability	Data Dimensionality
Computed Tomography (CT)	available (not widespread)	high	3D
Magnetic Resonance Imaging (MRI)	available (not widespread)	high	3D
X-ray	available	high	2D projection
functional Magnetic Resonance Imaging (fMRI)	not available	moderate	3D
Positron Emission Tomography (PET)	not available	moderate	3D
Single Photon Emission Computed Tomography (SPECT)	not available	moderate	3D
X-ray Fluoroscopy	available	high	2D projection
C-arm CT	available	low	3D
Ultrasound (US)	available	high	2D
optical imaging	available	high	2D projection

Table 1: Classification of imaging devices according to their availability for intra-operative use, their accessability to physicians around the world, the dimensionality of the data they acquire and the type of information conveyed by the images.

Source: Kevin Cleary 2006

Medical Imaging: DICOM Standard and Pixel Co-ordinates

- Digital Imaging and Communications in Medicine (**DICOM**) is a standard for storing and transmitting medical images
- Intensity values for each **voxel** in the 3D volume are stored in a three dimensional matrix
- **Pixel** or **Voxel Co-ordinates i-j-k**
- For movies, the matrix becomes four dimensional

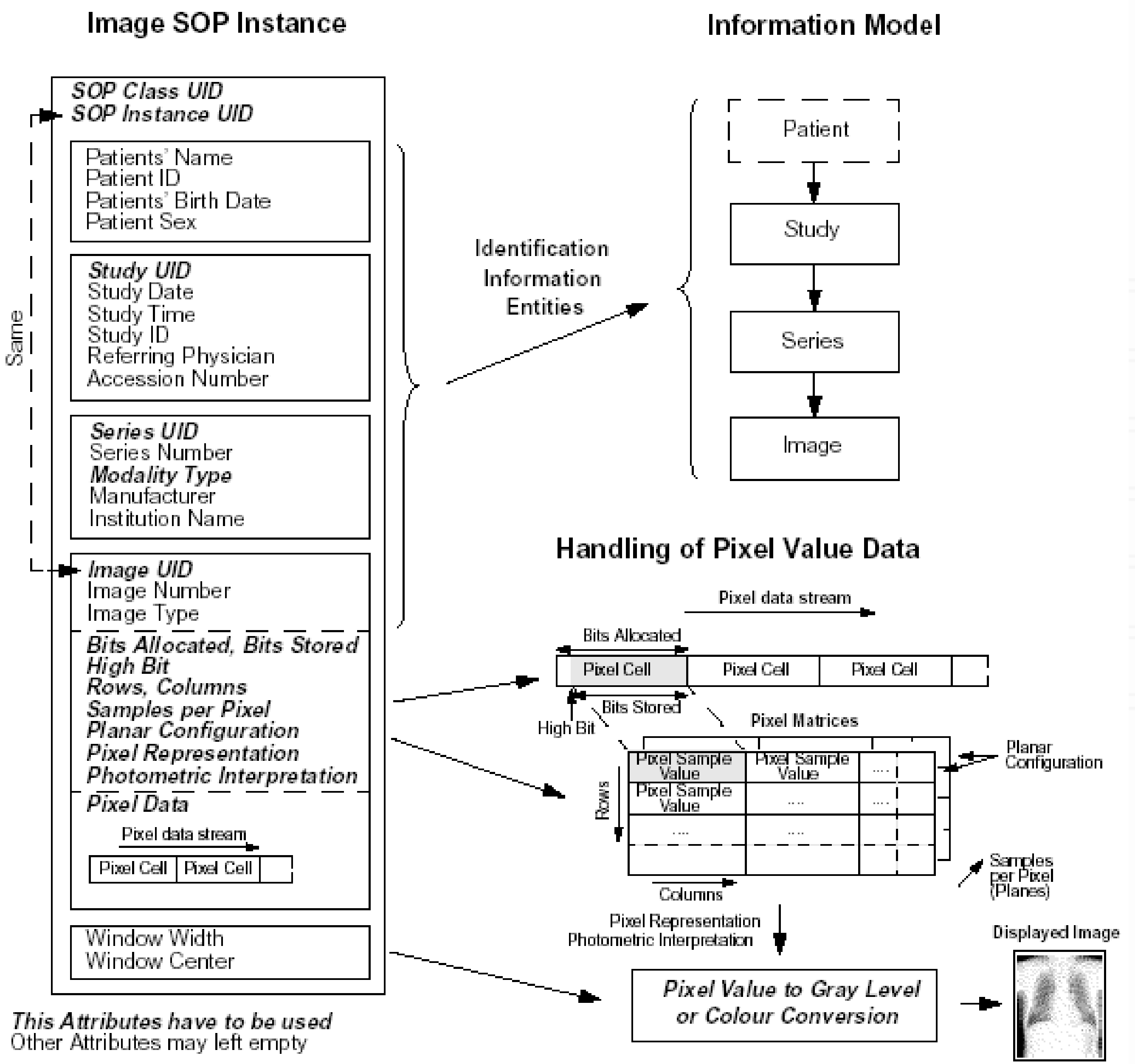


Pixel or Voxel
Co-ordinate?

Answer: 3,2,1

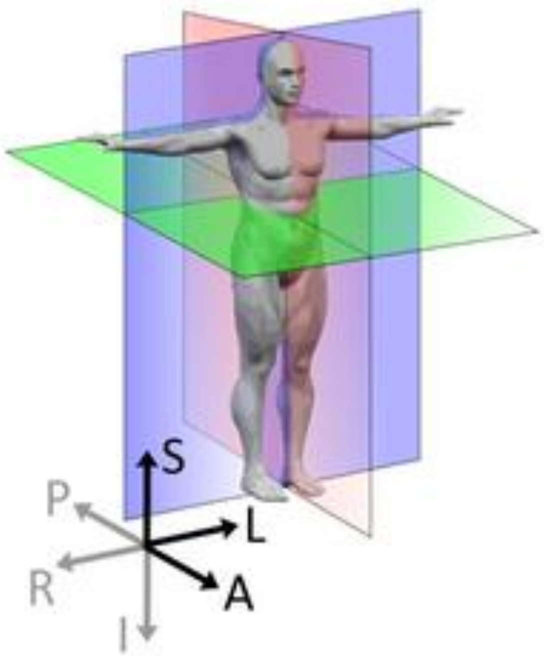
Medical Imaging: DICOM Standard and Metric Co-ordinates

- Patient, Study, Series, and Image Information are stored in the **DICOM header** (also referred as meta-data)
- FOV, Pixel Spacing, and Slice Thickness can be used to convert to **metric** cartesian **co-ordinates**
  - x = pixel_spacing_x * I
  - y = pixel_spacing_y * j
  - z = slice_thickness * k



Medical Imaging: Coordinate Frames

- Medical Images are oriented in reference to the patient position
- **Axial**, **coronal**, and **sagittal** planes/slices
- X,Y, and Z co-ordinates are now **Left-Right (LR)**, **Posterior-Anterior (PA)**, and **Inferior-Superior (IS)** (no negative signs)
- Origin of the frame is often the center of the image volume or iso-center of the scanner



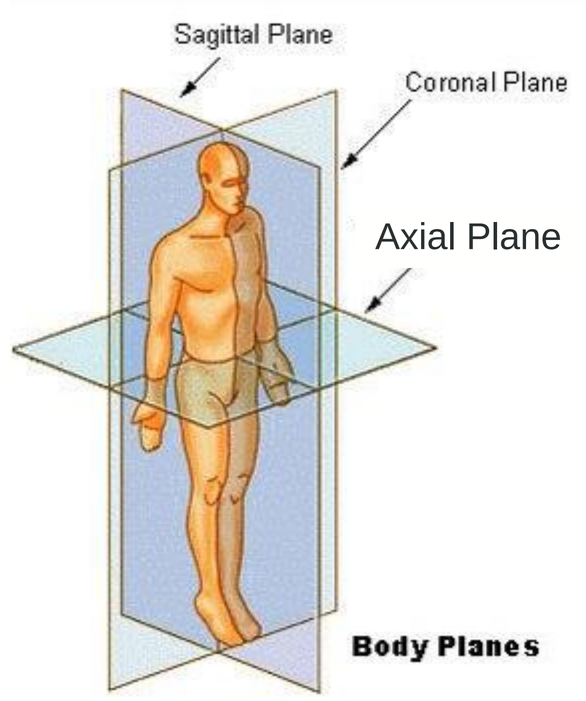
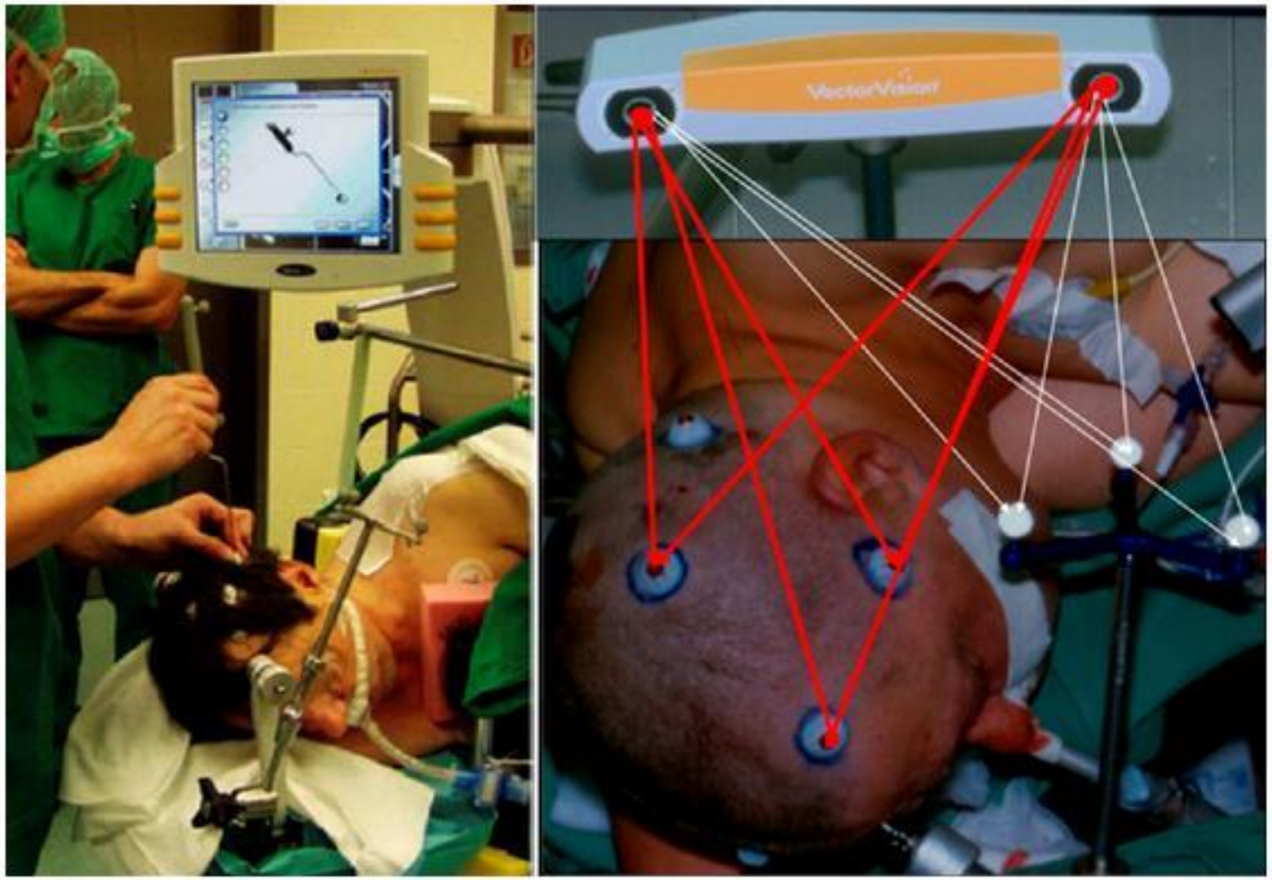


Image Registration

- **Problem:** Target an invisible location during surgery (e.g. brain tumor)
- **Solution:**
  - Register pre-operative scans (e.g. MRI) to intra-operative images (e.g. Camera)
  - Register robot or tool to intra-operative images
- **Trick:** Use **fiducials** that are visible on pre- and intra-operative scans



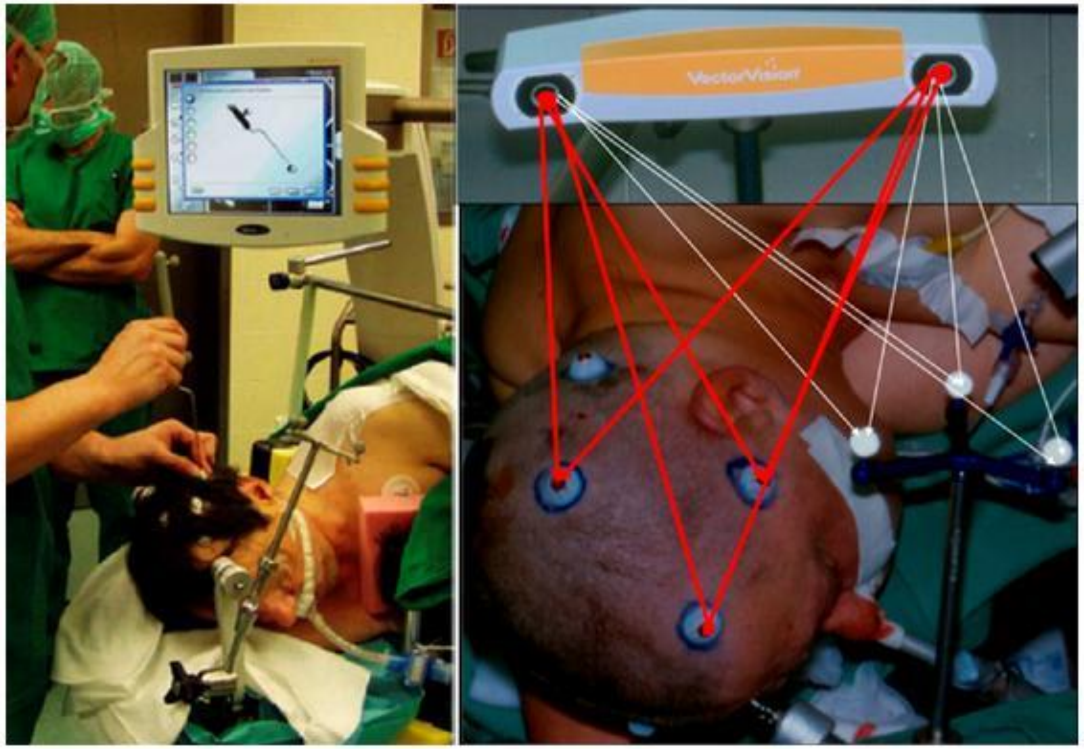
BrainLab

Image Registration

- **Steps:**

1. On pre-operative images find the target location in reference to the fiducial frame
2. On intra-operative images find the fiducial in the camera frame
3. On intra-operative images find the robot in the camera frame and calculate the transformation from robot to camera
4. Find the target location in the robot frame

Note: If target is visible intra-operatively, follow steps 3-4.

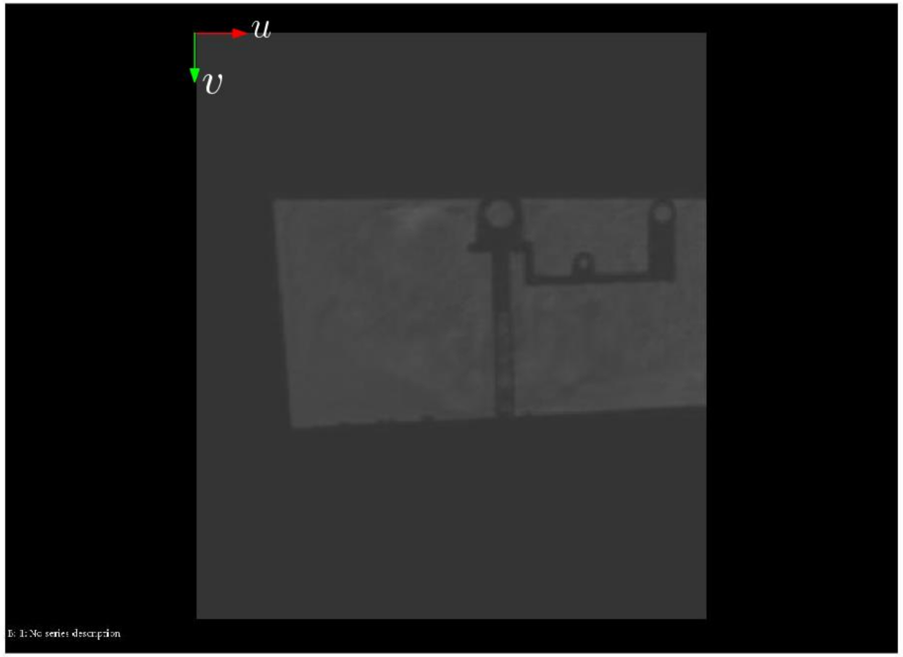


BrainLab

Image Processing:
Reading images and converting to grayscale images

- Color Images have three values RGB per pixel (image/matrix size: mxnx3). Gray Images have a single value (size: mxn)
- Image plane co-ordinate system as u-v axes, as shown in the image
- Image types can be of type uint8 [0-255], double[0-1]
- In MATLAB,

  >>img = **imread**(‘image.png');
  >>img_gry = **rgb2gray**(img);
  >>imshow(img_gry);



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Cropping Images

- Cropping can be done by detecting corners of the required window in an image
- For more accuracy and simplicity we can have a human do the cropping
- In MATLAB,

>> im_slice = **imcrop**(img_gry);

% Drag a rectangular window to crop

Cropped Image

Noise Removal – Image Cleaning

- Images can be affected by what is called as "salt-pepper" noise
- Easiest way to remove this is using a Median filter
- Median of the pixel intensity values in a rectangular window of odd size
- In MATLAB,

  >>img_clean = medfilt2(img,[3 3]);

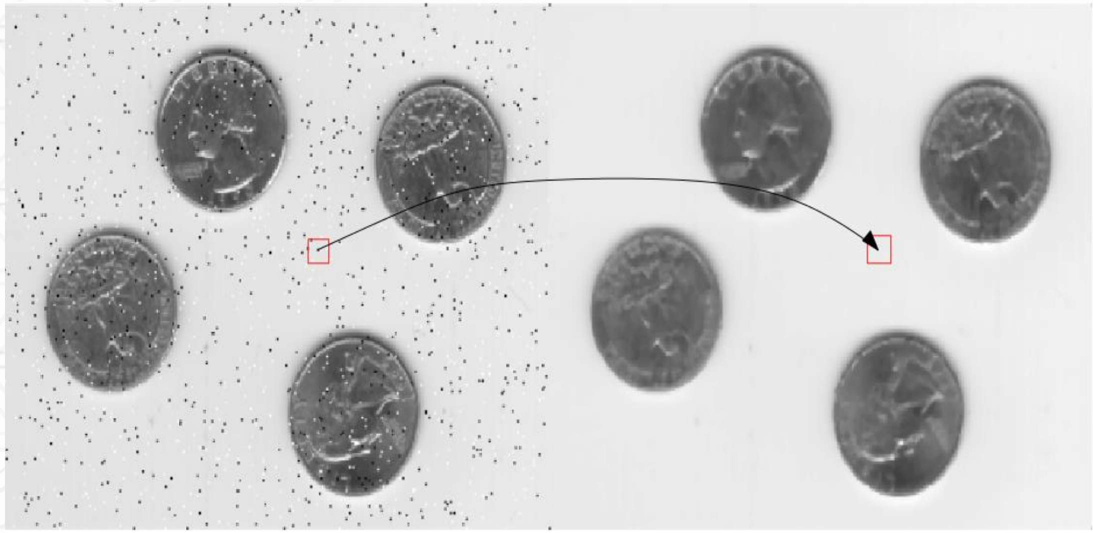
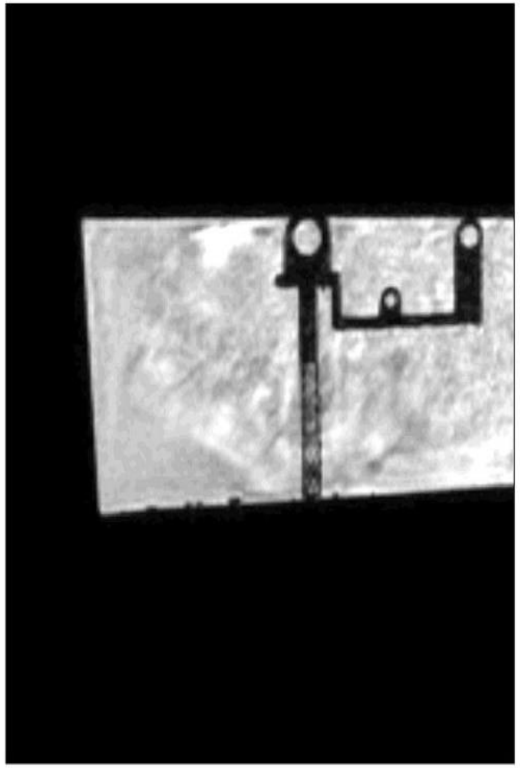


Image Reference:
https://www.mathworks.com/help/images/ref/medfilt2.html

Contrast Enhancement and Sharpening

- Thresholding can give better results if there is a good amount of difference in the intensity values.
- Sharpening the images can help in better isolating the edges and the boundaries of shapes.
- In MATLAB,

```
>>img_c = imadjust(img_g_clean);
>> img_c= imsharpen(img_c);
```



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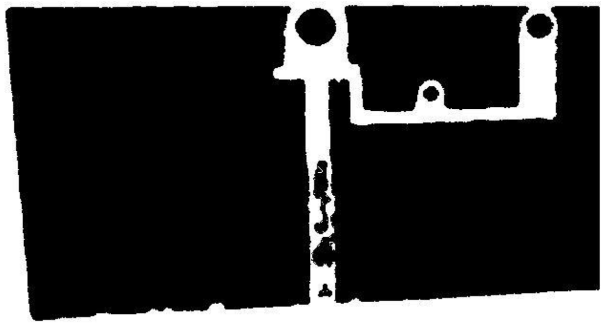
Binary Images and thresholding

- Binary Images have only two intensity values (each pixel is either 0 or 1).
- A less than greater than or equal to operator applied to an image creates a binary image
- Useful, for segmenting objects with same color intensity values
- Often done with an upper and lower threshold
- In MATLAB,

  ```
  >> bw = img_c < threshold;
  >> bw = img_c > l_thresh & img_c < u_thresh;
  ```

  Consider using imtool to query threshold value

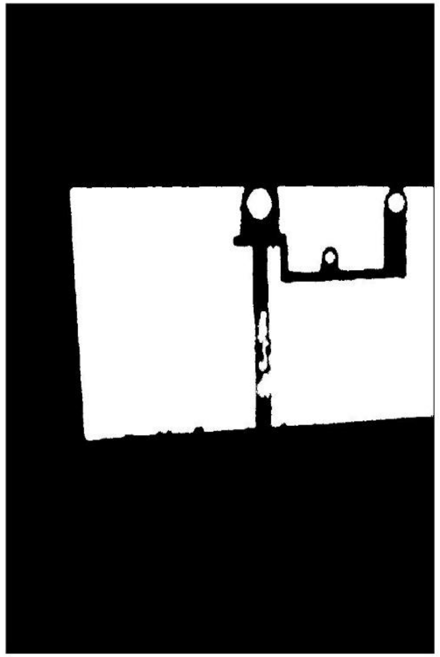


Output after thresholding on image from the last slide

Image Inversion

- Simple process of inverting the pixel values between 0 and 1
- Useful to have the regions that we want to segment as white
- In Matlab,

  >>bw_2 = 1 - bw

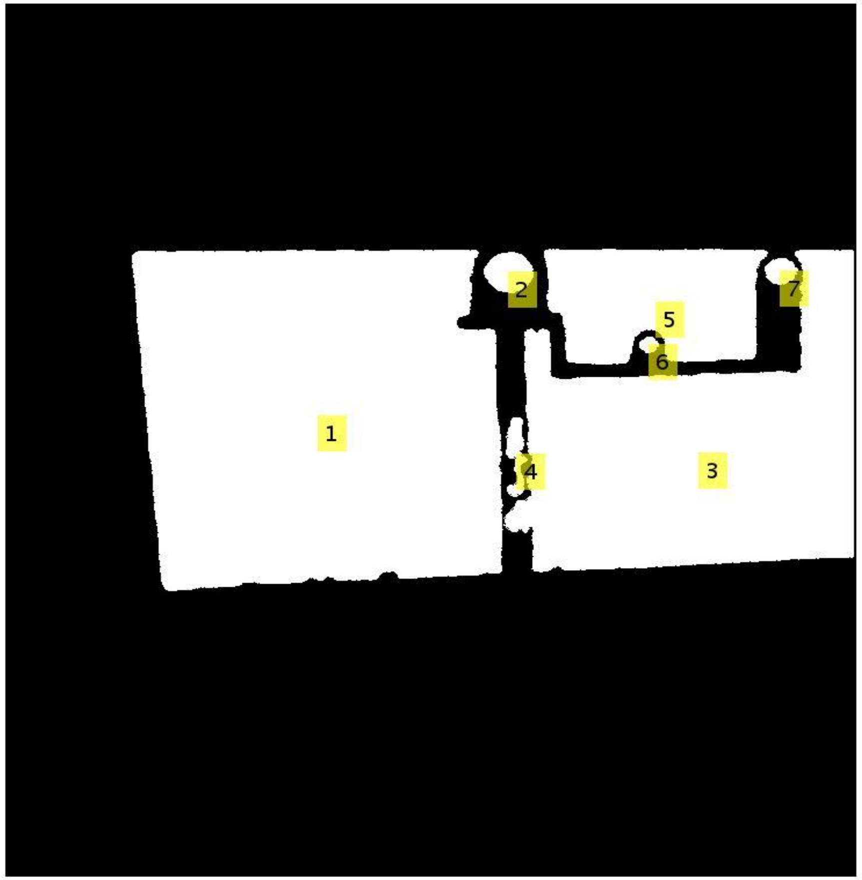


Output after inverting 0 and 1 from the last slide

Blob Analysis-I

- Blob is a set of contiguous pixels with same color (value)
- In Matlab,

  >>blob_label = bwlabel(bw)
- Label assigned to a pixel indicates which set it belongs to
- We have to isolate the blobs labelled as 2,6 and 7.
- Blobs can be queried for using different properties like Area, Centroid, Eccentricity, etc.



Output of Blob Extraction with bwlabel

Blob Analysis-II

- Select blobs with correct size and eccentricity
- In MATLAB,

Size:

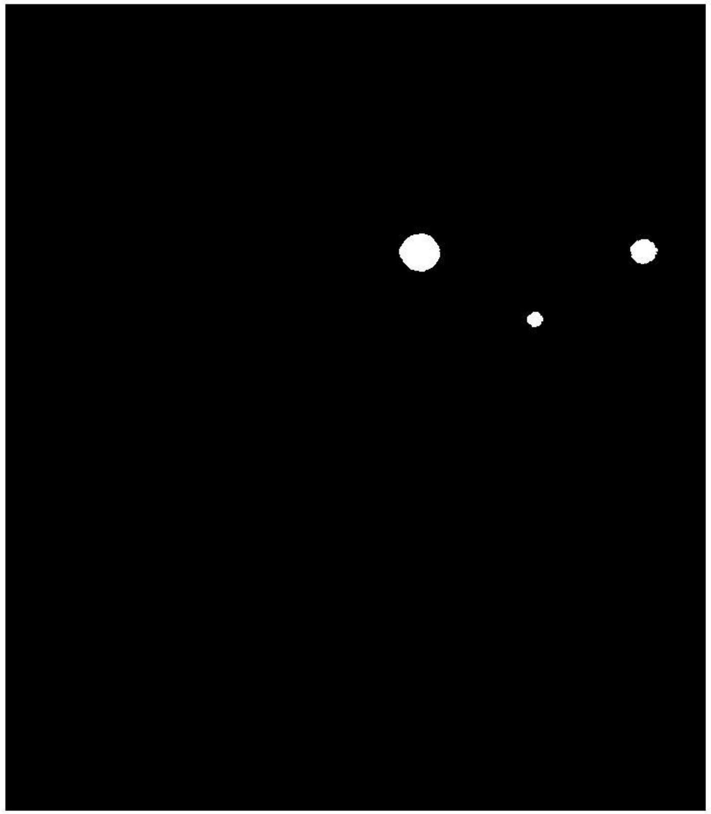
```
>>bw_2 = bwareaopen(bw, area)
```

Allows to remove blobs less than a particular area (in pixels)

Eccentricity:

```
>> [m,n] = size(im_slice);
>>label = bwlabel(bw_2);
>> stats = regionprops(logical(bw_2), 'Area', 'Centroid', 'Eccentricity');
>> bw_3 = false(m,n);
>> for i = 1 : length(stats)
      if stats(i).Eccentricity < value
           bw_3(label == i) = 1;
     end
 end
```

Check this link for more:
https://www.mathworks.com/help/images/ref/regionprops.html



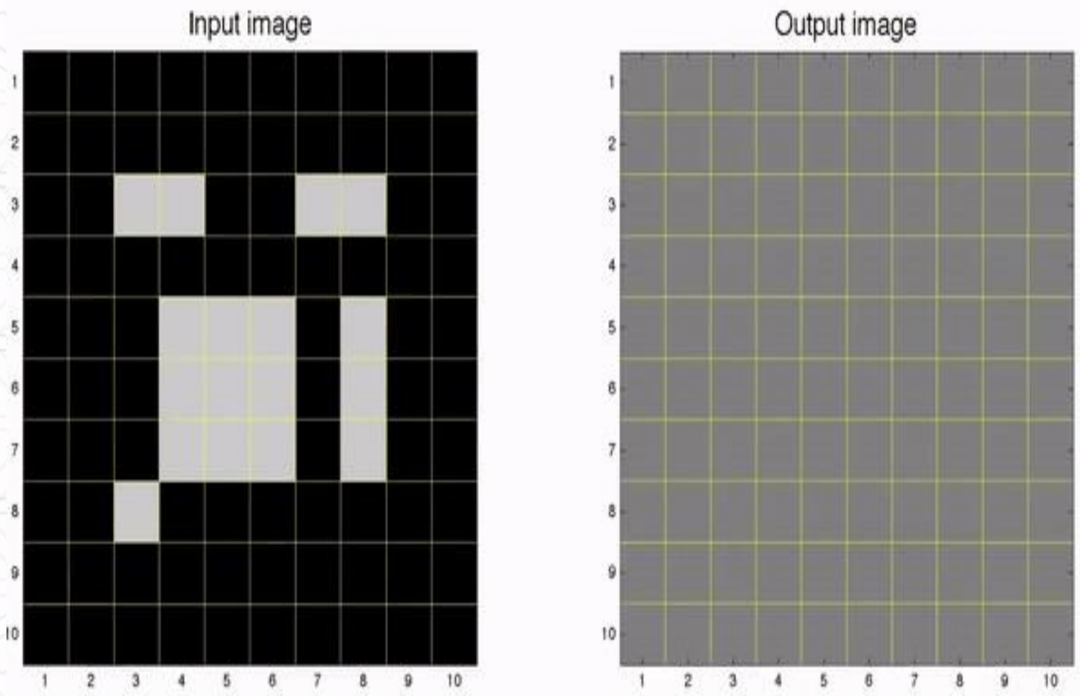
Isolating only the circular rings

Morphological Cleaning -I

- Further, morphological operations to clean the shape of the blobs.
- Structuring Element chosen like a square, disk, etc.
- Erosion operation. Output is true only if all the elements within structuring element are true
- In MATLAB,

    \>>structelem = strel(‘square',sz);

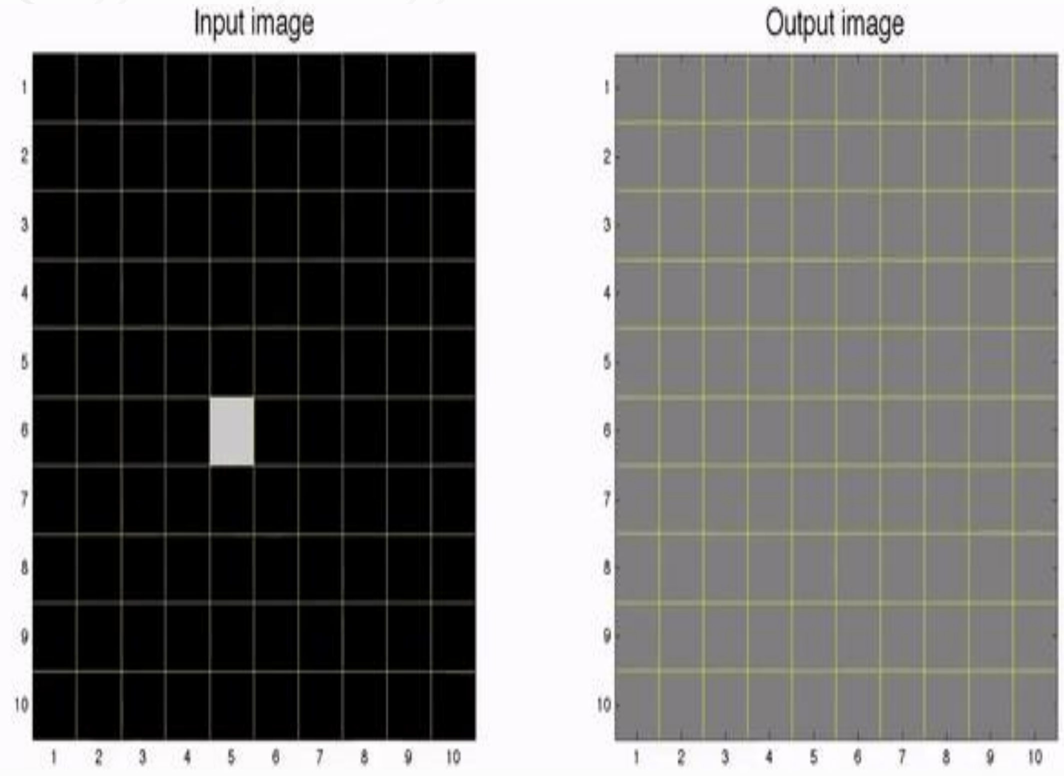
    \>> out = imerode(bw_3, structelem);



Reference animation – Prof. Peter Corke

Morphological Cleaning -II

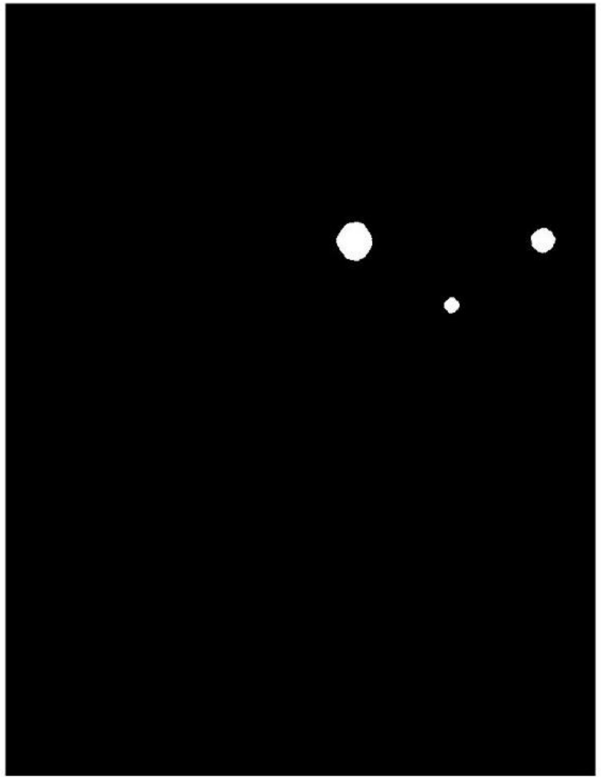
- Opposite to Erosion is Dilation
- Output is true if any of the pixels inside structuring element is true
- In MATLAB,
  - >> structelem = strel(‘square',sz);
  - >> imdilate(bw_3,structelem);
  - Also, investigate imopen and imclose



Reference animation – Prof. Peter Corke

Dilation applied to our original image

```
>>structelem = strel('disk’,sz);
>>bw_4 =
imdilate(bw_3,structelem);
```



The circular blobs were dilated with Disk structure element

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