Applications of Image Analysis: Breast Image Analysis

Michael A. Wirth, Ph.D.
University of Guelph
Computing and Information Science
Image Processing Group

Breast Cancer Screening

- Breast cancer, or carcinoma of the breast, is the most frequently diagnosed form of cancer.
  - Mammography is currently the best method for the early detection of breast cancer.
  - 10-30% of women who have breast cancer and undergo mammography have negative mammograms.
  - In approximately two-thirds of these false-negative mammograms, the clinician failed to detect a cancer that was evident retrospectively.
  - 10-20% of masses referred for surgical biopsy are actually malignant.

Breast Cancer Screening

- The early detection of breast cancer is the key to successful treatment. If cancer is detected a woman is usually required to undergo further testing which may include:
  - an ultrasound of the breast
  - fine core needle aspiration – using a local anaesthetic cells are drawn up through a needle that is inserted through the skin of the breast into the suspicious lesion
  - core biopsy – using a local or general anaesthetic a sample of tissue is taken from the suspicious area of the breast
  - diagnostic open biopsy – a diagnostic (surgical) biopsy performed with a needle localization technique

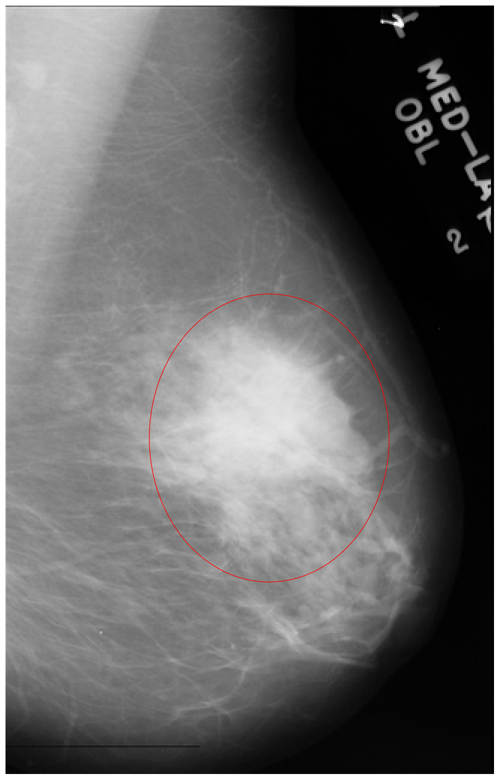
Abnormalities

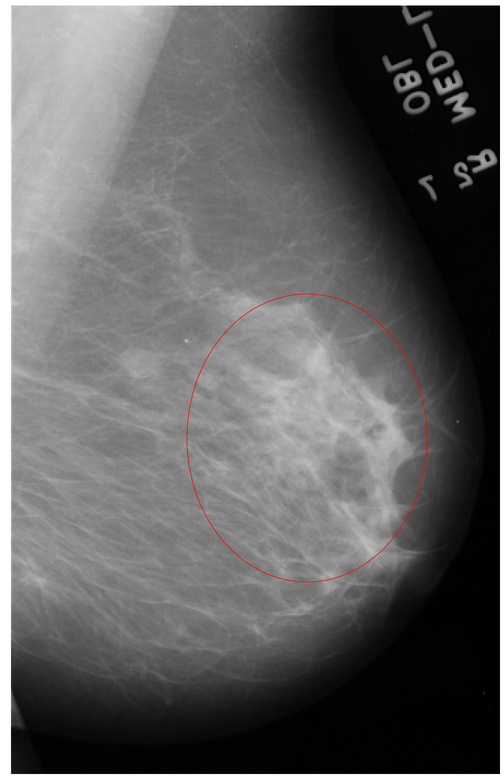
- Abnormalities can be classified as benign or malignant:
  - Cysts are tiny (round) accumulations of fluid.
  - The most common benign tumours are called fibrodenomas.
  - 90% of breast cancers arise in the cells lining the ductal system of the breast → ductal carcinomas
  - Tumours confined to the ducts themselves → in-situ carcinomas
  - If the tumour extends beyond the ductal system, the term invasive carcinoma is applied.

Abnormalities: Asymmetry

- Breast asymmetry exhibits as breast tissue that is greater in volume or denser in one breast than the other. This may be the result of either a greater volume of fibroglandular tissue on one side, or asymmetrically dense breast tissue.
  - The morphology of the two regions is similar except that there is an increase in the tissue density in the mammogram involved.
  - Variations may be the result of natural differences between corresponding left and right breasts or decreased density in one of the mammograms as a result of the surgical removal of breast tissue. The vasculature of the breast is generally symmetrical in size and distribution, therefore an asymmetrically large vein may also indicate the presence of an abnormality.

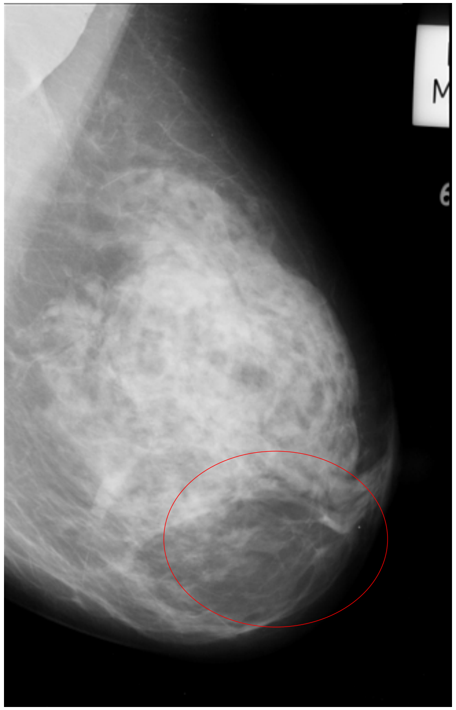
Abnormalities: Asymmetry





Abnormalities: Architectural Distortion

- Architectural Distortion
  - The structures of the breast, comprising the glandular tissue, ie. lobules, ductules, lobes and ducts converge toward the nipple. Disturbances in this symmetrical flow, ie. pulling of structures toward a point eccentric from the nipple, is the sign of a potential abnormality.



Abnormalities: Masses

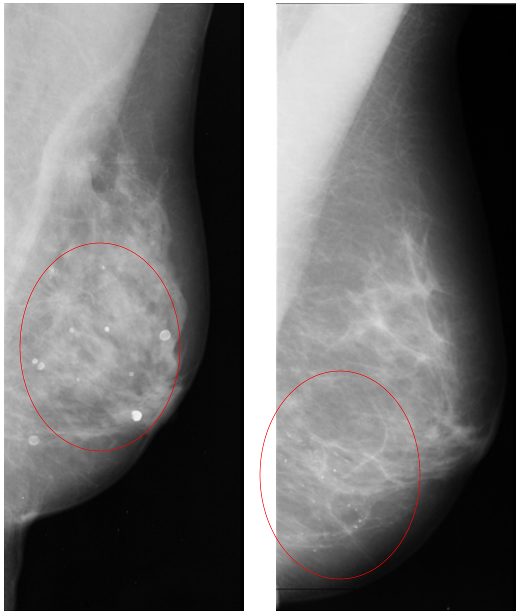
- A mass is defined as a three-dimensional dense region with margins distinguishing it from the surrounding parenchyma.
  - Masses are classified by a number of properties including: location, density, size, shape (round, ovoid, lobulated) , and margins (circumscribed, ill-defined, stellate, or spiculated).

Abnormalities: Microcalcifications

- Microcalcifications are tiny granule-like deposits of calcium frequently associated with malignant findings.
  - They have varying characteristics and may be punctate, branching, linear, spherical, fine, coarse, cylindrical, smooth, jagged, regular in size and shape or heterogeneous.

Abnormalities: Microcalcifications

- Calcifications are analysed as to:
  - their location, individual shapes and distribution pattern



Breast Image Analysis

- Modalities used in breast image analysis:
  - mammography
  - magnetic resonance breast imaging
  - ultrasonography
  - positron emission mammography

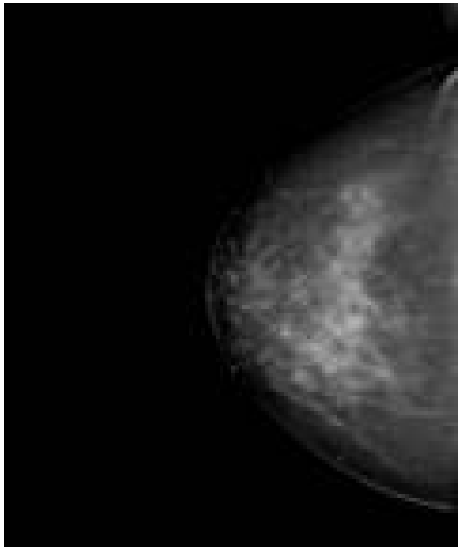
Mammography

- The term mammography refers to the x-ray examination of the mammary glands, or breasts.
  - A mammogram is a soft-tissue x-ray projection of the three-dimensional structures of the breast.
  - Mammography has a sensitivity of about 90%
  - i.e. about 10% of all carcinomas are not detected initially by mammography
  - 25-35% of carcinomas become apparent between screening examinations → interval carcinomas

Mammographic Views

- The breasts are based along the curvilinear chest wall and as such it is not possible that all the breast parenchyma be included on a single mammogram.
- There are two primary views in a mammograhic examination:
  - Medio-lateral oblique (MLO): compression is applied sidewise from the centre of the chest wall (medio) toward the outer surface of the breast (lateral) position at an angle of between 45 and 60 degrees.
  - Cranio-caudal (CC): compression is applied from the top of the breast toward the caudal (inferior) surface

Mammographic Views



CC

MLO

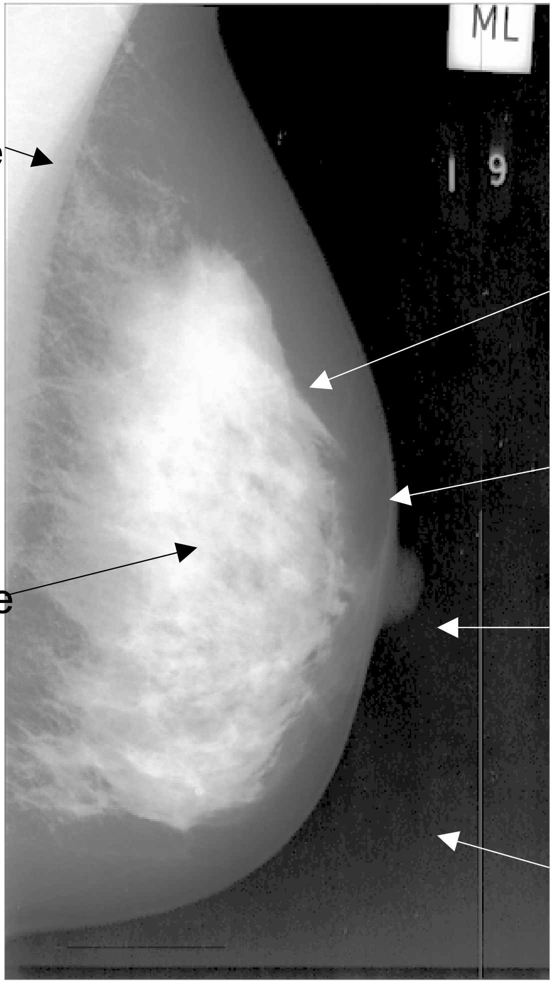
Breast Anatomy

- The breasts are mammary glands composed of glandular, fibrous connective and fatty (adipose) tissue surrounded by skin.
  - They are separated from the chest wall (pectoral) muscles (ie. pectoral muscle) by connective tissue. The glandular tissue, or parenchyma , consists of 15 to 20 lobes, with varying numbers of ducts and lobules, arranged radially about the nipple.
  - The skin generally forms a smooth convex surface, surrounding the parenchyma, and separated from it by a variable layer of subcutaneous fat.

Breast Anatomy

– It is supplied by a network of vasculature and is supported in the subcutaneous fatty tissue by connective-tissue structures known as Cooper ligaments. The breast can vary greatly in form, size and composition, converges toward the nipple, and is generally symmetrical in shape.

Mammographic Anatomy



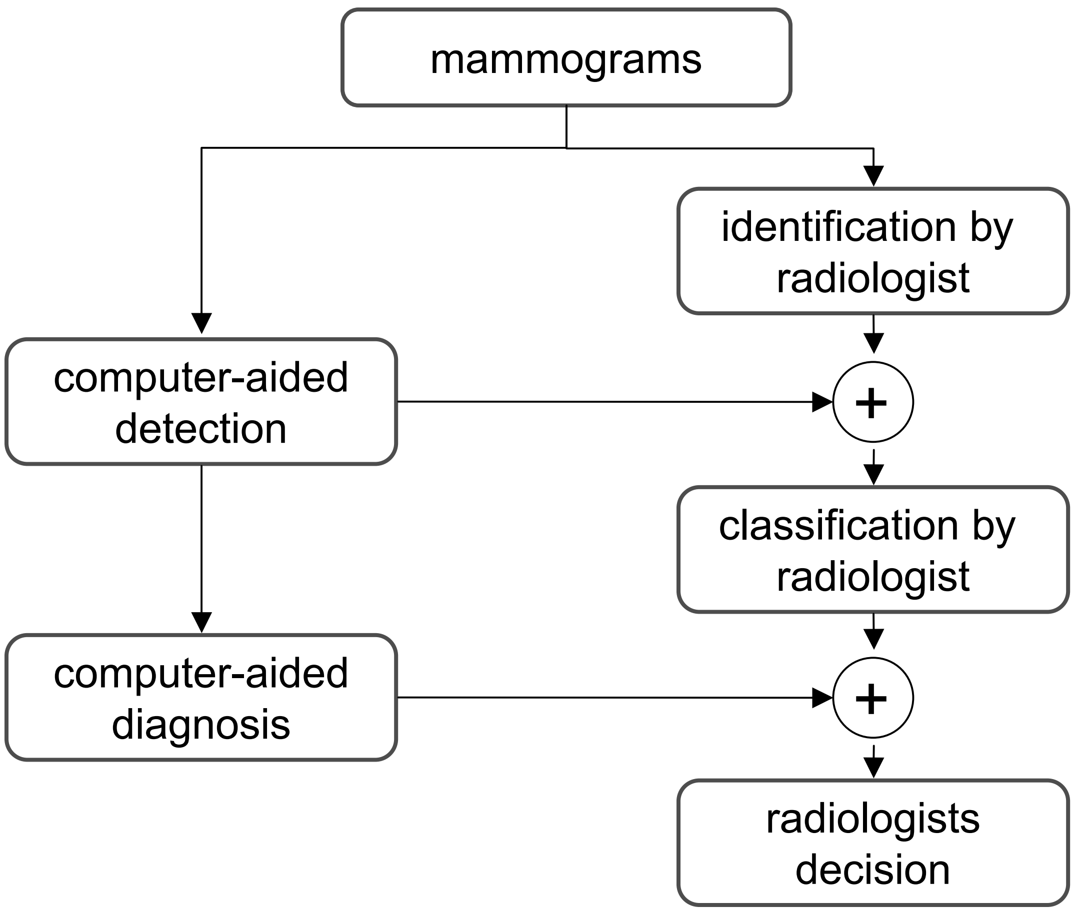
Computerized Analysis of Mammograms

- Computerized analysis of mammograms is used as a "second opinion" in detecting abnormalities and making diagnostic decisions.
  - The final diagnosis is rendered by the clinician.
  - Sometimes known as computer-aided interpretation, or computer-aided mammography
  - Improves consistency by providing a standardized approach to mammogram interpretation

Computerized Analysis of Mammograms

- Computerized analysis of mammograms has two components associated with it: detection and diagnosis.
  - Detection relates to the identification of abnormal entities, whilst diagnosis deals with the classification of identified abnormalities.
  - These techniques serve as an aid to augment the initial interpretation, allowing the final decision on the significance of identified regions to be left to the radiologist.

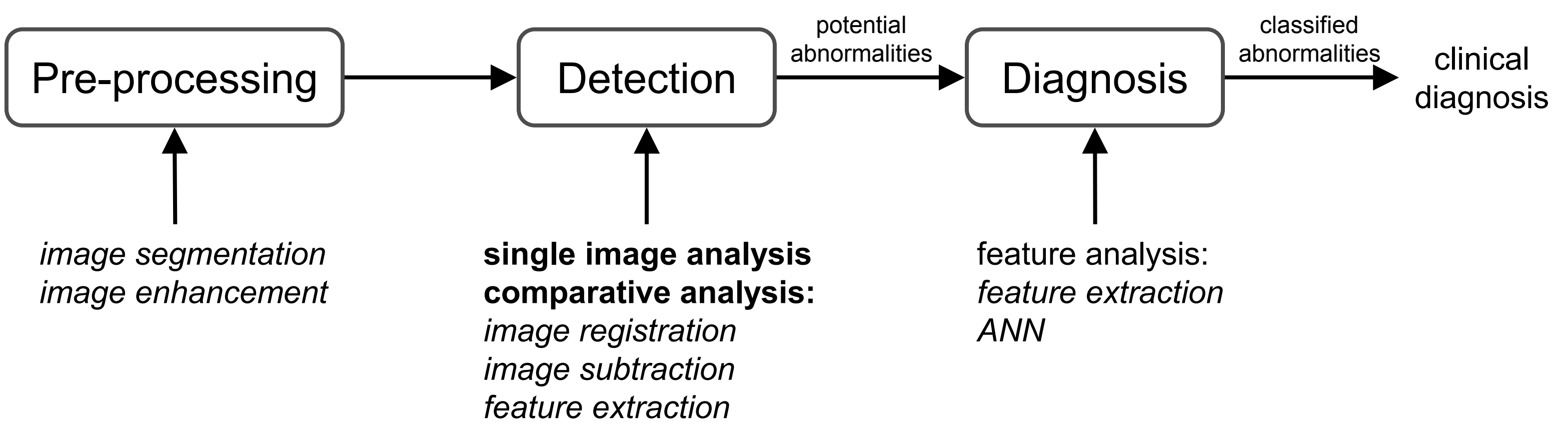
Computerized Analysis of Mammograms



Computerized Analysis of Mammograms

– A useful detection technique may have no use in diagnostic evaluation, and conversely a diagnostic technique is not useful until an abnormality is detected. Therefore detection must precede diagnosis.

Computerized Analysis of Mammograms



Detection

- Detection is the ability to find abnormalities, classifying regions of a mammogram as positive or negative.
  - Known as Computer-Aided Detection (CADe)
  - The aim of computer-aided detection is to increase the efficiency and effectiveness of screening.
  - Computerized detection involves the *isolation* of the breast region of the mammogram, *identification* of regions containing possible masses and the *analysis* of the features contained within these suspicious regions in order to reduce the detection of false-positive (normal) regions.

Detection

- Two general approaches have been explored in the detection of potential abnormalities in mammograms: single-image analysis and comparative analysis.
  - Single-image analysis relates to techniques which analyse a single mammogram for evidence of suspicious regions.
  - Comparative analysis consists of techniques which compare various corresponding mammograms.

Diagnosis

- Diagnosis is the ability to characterise a detected abnormal entity as being either benign or malignant.
  - Known as Computer-Aided Diagnosis (CADi)

Mammogram Enhancement

- A mammogram is a 2D projection image of a 3D structure:
  - The result is an x-ray image, which unlike most other x-ray or CT images has an inherent fuzzy or diffuse appearance. This is due to the superimposition of the densities from hundreds or thousands of 1mm diameter breast lobules, together with the ductal structures.

Mammogram Enhancement

- The contrast enhancement of mammograms increases the ability to recognize structures in a mammogram.
  - Image sharpness is determined by motion blur (caused by patient motion and less pronounced by arterial pulsation) or geometric blurring (occurs in structures farther away from the film).
  - Image noise can interfere with the clarity of detail and can interfere with the perception of slight differences in density and extremely fine structures.

Mammogram Enhancement

- e.g. Breast region histogram equalization
  - Equalization of the grayscale values near the periphery of the breast in order to correct for the increased density due to the reduced breast thickness.
  - This selectively enhances the peripheral region of a mammogram to visualize the central breast and the skin-line regions without low in contrast.

Mammogram Segmentation

- The global segmentation of mammograms refers to the separation of a mammogram into two visually distinct regions; namely the breast and the non-breast regions.
- Local segmentation refers to further successive division of the breast region into distinct, diagnostically meaningful regions:
  - pectoral muscle; fibroglandular tissue; fatty tissue

Global Segmentation

- In order to limit the search region during the process of detection, the breast tissue region is segmented:
  - The largest single feature on a mammogram is the skin-air interface, or breast boundary.
  - The extracted breast contour should adequately model the soft-tissue/air interface and preserve the nipple in profile. This is made difficult by the tapering nature of the breast, such that the nipple lies in between the soft-tissue and the non-breast region.

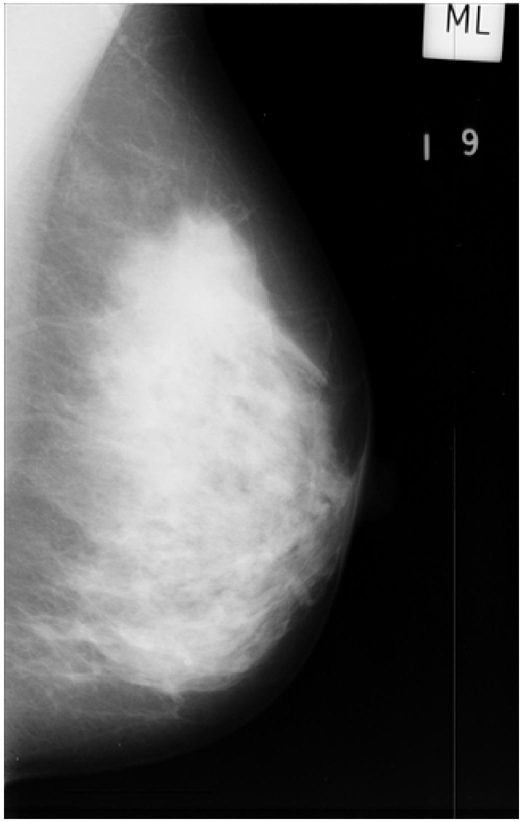
Global Segmentation

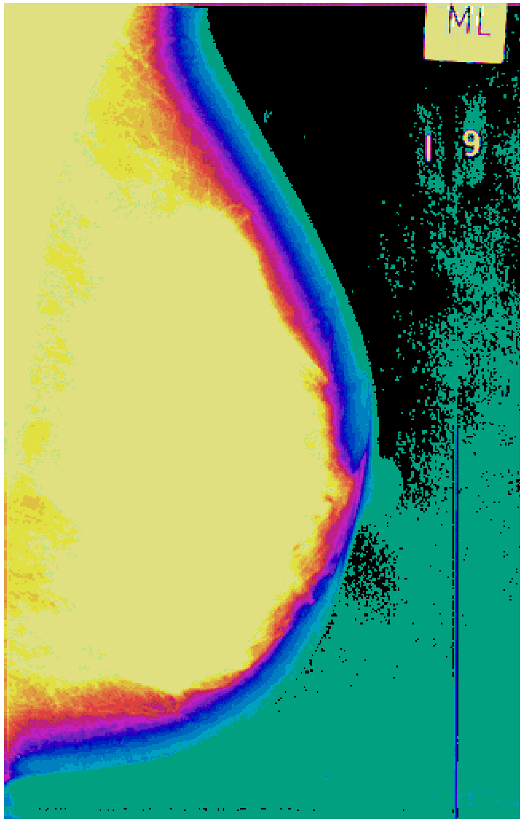
- Breast contour segmentation involves three phases:
    1. Modelling the non-breast region of the mammogram by a polynomial of degree *n*.
    2. Subtracting the modelled image from the original image to yield a difference image.
    3. Thresholding the difference image to produce a binary, labelled image consisting of the breast and non-breast regions, from which the breast contour can be extracted.

Global Segmentation

- The intensities which comprise the non-breast (background) region of a mammogram $I_t(x,y)$, are spatially continuous and usually occupy a band of low values on the closed interval $[0,b_m]$.
- As there is a distinct change in intensity at the breast, it might seem like the easiest approach is to use global thresholding.
  - However the intensities comprising the breast and non-breast regions can, and often do, overlap.
  - Indeed, if global thresholding were used, it is very likely that neither the skin, nor the nipple, were it in profile, would be preserved.

Segmentation of the Breast Region





Initial Thresholding

- In order to properly model the background of the original image, I_o , it is first necessary to threshold the mammogram at a suitable intensity value, t to produce a thresholded image I_t .
  - This serves to give an approximation of the non-breast region.

$$I_t = \{ \ (x,y) : I_0(x,y) \leq t \ \}$$

  - The value chosen for each particular mammogram is twice the estimate of the knee on the cumulative curve

Modeling the Non-Breast Region

- A 2D polynomial is then fitted to the values of the pixels in I_t
  - The x and y coordinates of all pixels are normalized to the interval [0,1]
  - Let $P_n(x,y)$ represent the polynomial of degree n given by:

$$P_n(x,y) = \sum_{i=0}^{n} \sum_{j=0}^{i} c_{ij} x^j y^{i-j}$$

such that:

$$P_n(x,y) = I_t(x,y)$$

Modeling the Non-Breast Region

– The derived polynomial $P_n(x,y)$ is then evaluated using all pixels in I_o to yield the model image, $I_m(x,y)$.
– As n increases, the model image increasingly assumes the contours of the breast.

Subtracting the Modeled Image

- The model image, I_m , is then subtracted from the original image, I_o , to yield the difference image, I_d , as given by:

$$I_d(x,y) = \begin{cases} 0 & \text{if} \quad (I_0(x,y) - I_m(x,y)) < 0 \\ I_0(x,y) - I_m(x,y) & \text{if} \quad 0 \le (I_0(x,y) - I_m(x,y)) \le 255 \\ 255 & \text{if} \quad (I_0(x,y) - I_m(x,y)) > 255 \end{cases}$$

with the subtraction truncated at either end.

Thresholding the Difference Image

- Once a difference image has been obtained, the final step involves identifying the two primary regions and removing inclusions of either in the other.
  - The result is a labelled binary image from which the contour of the breast can be extracted.
  - This may lead to a region of the background, contiguous with the breast having non-zero values. To exclude this region of the background, a final threshold, *k*, was chosen such that all background pixels contiguous with the breast had values less than of equal to *k*.
  - If *k* is too large, then portions of the skin (and nipple if it is in profile) would be thresholded out as well.

Thresholding the Difference Image

– When the difference image I_d is thresholded at the value k, the result is a binary image, I_b , in which pixels of value less than or equal to k in I_d are black (0) and others are white (255) such that:

$$I_b(x,y) = \begin{cases} 0 & \text{if } I_d(x,y) \le k \\ 255 & \text{if } I_d(x,y) > k \end{cases}$$

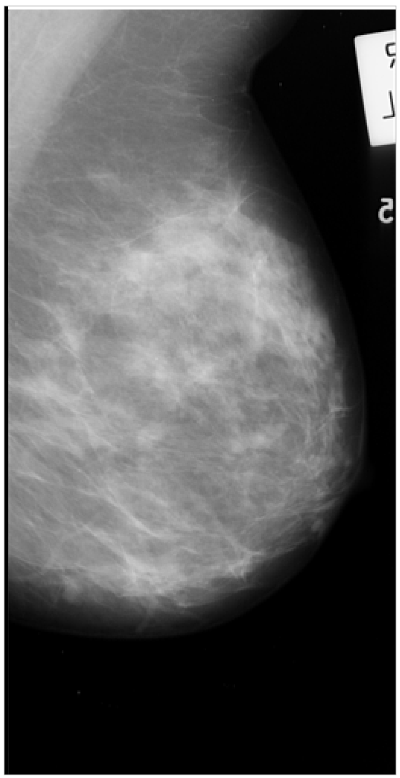
– The value for k is chosen interactively and is normally either 0 or 1.

Labelling the Binary Image

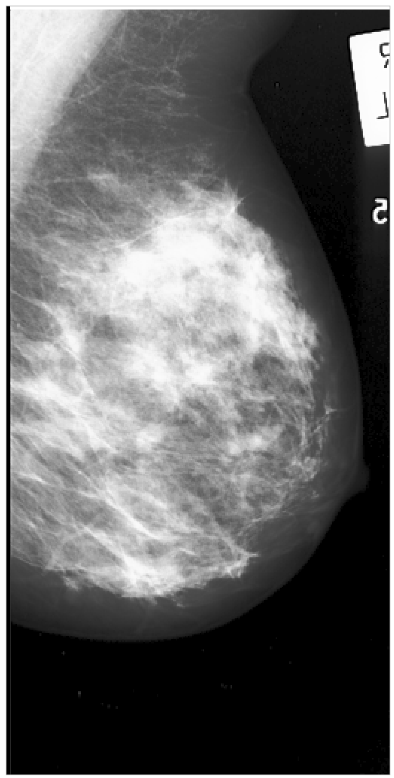
- After a morphological erosion operation is performed to remove image artifacts (classic erosion), a closing operator is performed on I_b. This has the effect of removing spurious regions.
- A connected-component algorithm is then used to label the separate regions in I_b yielding a new labelled image, I_l.
- The breast region is subsequently identified as the largest non-zero component. After a final morphological dilation of the labelled image to smooth irregularities in the shape of the breast contour, a simple 8-connected contour-tracing algorithm is used to obtain the breast contour.

Segmentation of the Breast Region

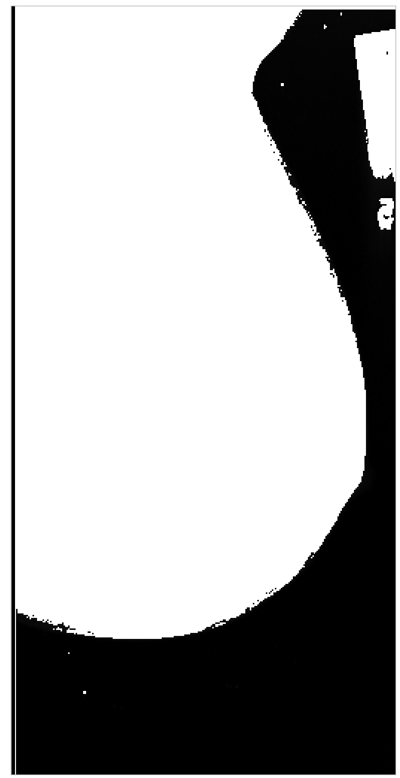
Original Mammogram
n=3



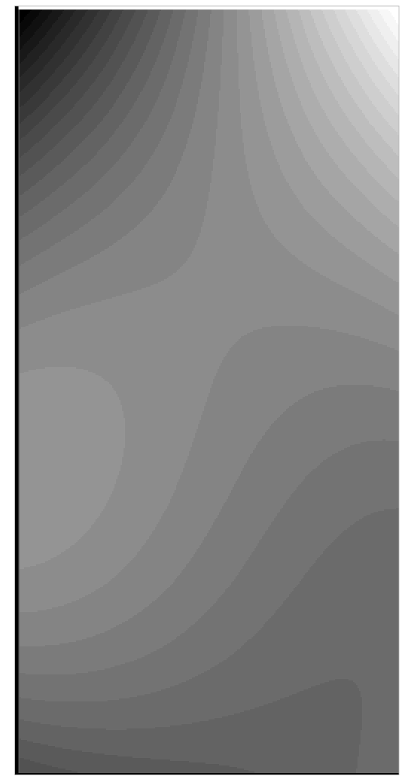
Histogram-Equalised



Initial Threshold t=12

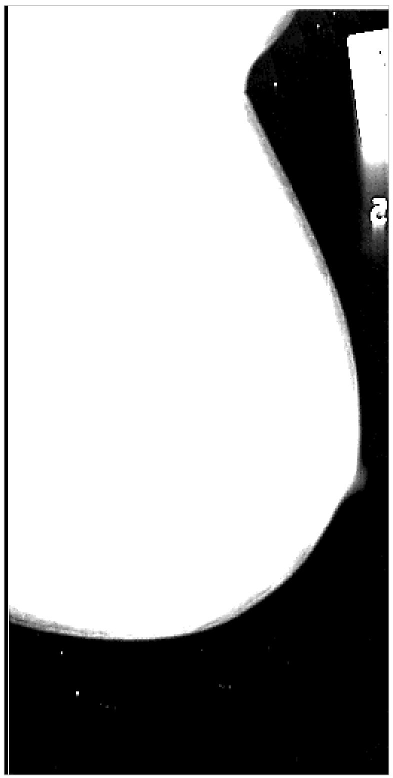


Polynomial Model

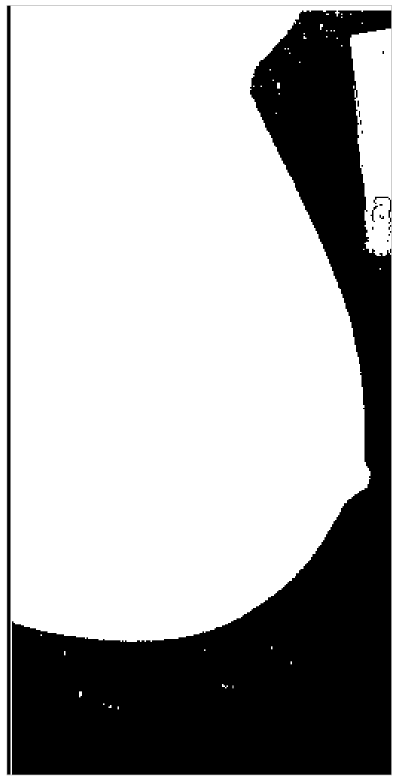


Segmentation of the Breast Region

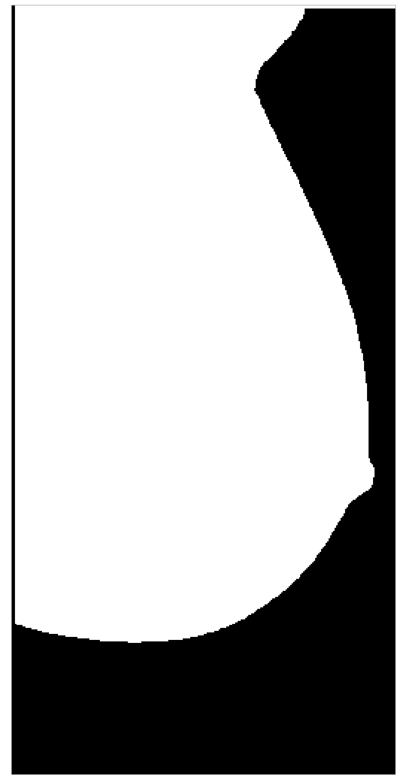
Difference Image



Thresholded difference image



Labeled binary image k=1



Extracted boundary

Comparative Analysis

- Mammograms are often analysed by comparing various corresponding mammograms of the same patient
  - Such comparative readings help to identify abnormalities and determine their clinical significance.
  - There are two principal forms of comparative analysis: temporal and bilateral
  - Spatial variations existing between corresponding mammograms significantly complicate comparative analysis.

Temporal vs. Bilateral Analysis

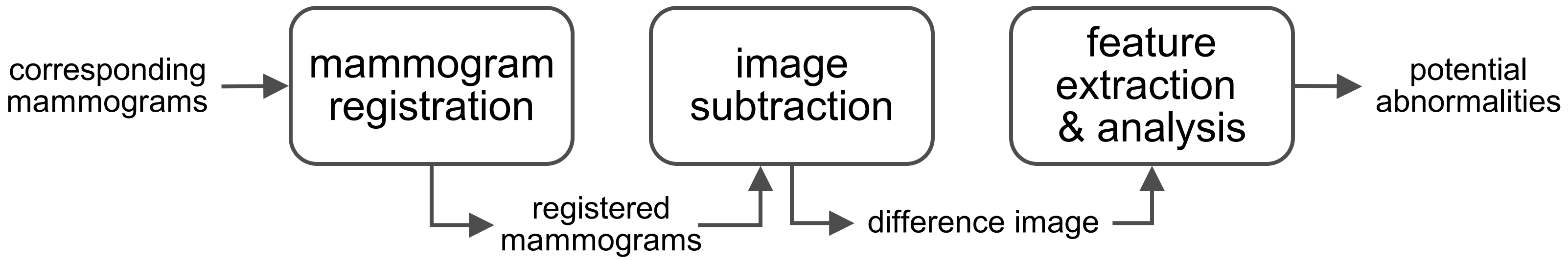
- Temporal: comparing mammograms of the same breast, representing approximately the same view, acquired at different times.
  - Detects changes indicative of a developing abnormality (changes may include an increase in the size of a mass, or the number of microcalcifications, a change in breast architecture, or the presence of a new mass or microcalcifications)
- Bilateral: comparing mammograms of the left and right breasts, representing the same view, acquired during the same screening session.
  - Left and right mammograms from the same woman tend to exhibit a high degree of symmetry. A deviation from this symmetry can indicate the presence of an abnormality.

The Process of Comparative Analysis

- Comparing a pair of mammograms by means of comparative analysis involves a number of stages:
  - Establishing a frame of reference by matching corresponding mammograms according to some criterion. This process is known as registration.
  - Obtaining a difference measure between the two mammograms and using this measure to generate an image that accentuates suspicious regions. This is achieved by subtracting the registered mammograms to generate a difference image.

The Process of Comparative Analysis

– Further analysing the difference image to delineate potential abnormalities and suppress false-positive responses using techniques such as Artificial Neural Networks (ANN). These potential abnormalities can be passed to the diagnostic phase of computer-aided interpretation where they can be classified with respect to malignancy.



Deformable Behavior of the Breast

- Mammograms are typically obtained by applying compression to the breast using two plates parallel to the image plane.
  - An exact registration must account for two-dimensional projections of three-dimensional deformations which occur largely due to changes in position and pressure applied to the breast during the screening.

Deformable Behavior of the Breast

- There are a number of factors which contribute to spatial differences between mammograms:
  - Projective nature of mammograms
  - Complexities of mammogram acquisition

    e.g. differences in the 3D positioning of the breast, and the magnitude and geometry of compression applied to it
  - Deformable behavior of the breasts

    i.e. the fact that the breast is a deformable, mobile, soft-tissue structure, which is inhomogeneous (composed of different types of tissue), anisotropic (deforms to varying degrees in different directions), and compressible
  - Motion

    i.e. the effect of respiratory, cardiac, and patient motion

Mammogram Registration

- The automated comparison of corresponding mammograms is made difficult task due to the spatial variability that is present between mammograms of the same breast taken at different times, and mammograms of contralateral (left and right) breasts.
- The process of **registration** minimizes spatial differences between corresponding mammograms.
- Mammogram registration using a *rigid model* (translation and rotation) is limited in its scope:
  - Such a registration model fails to take into account that the deformation between two corresponding mammograms is neither uniform, nor rigid in nature

Mammogram Registration

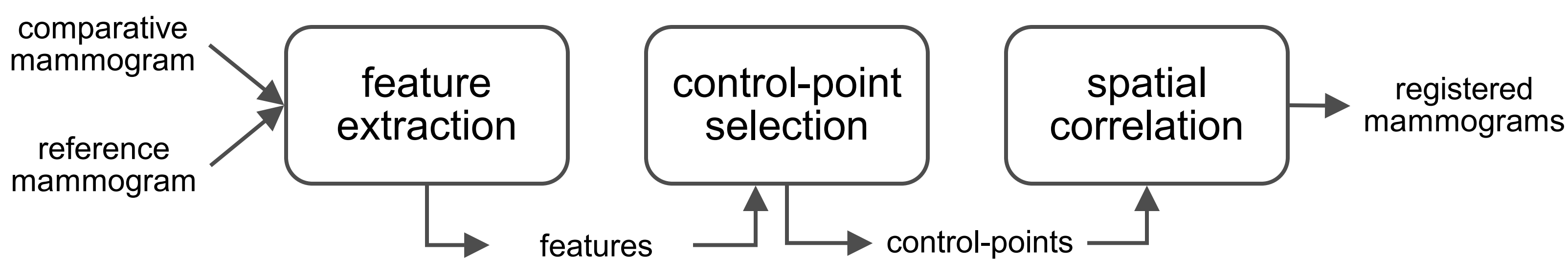
  - Structures retain their shape and form during the registration process
- Precise mammogram registration using a *realistic-model* is complex:
  - Requires modeling the nonrigid and inhomogeneous physical properties of breast tissue, how such tissue is affected by potential changes in patient positioning and pressure applied to the breast during compression.
- Explore the use of physical "elastic" and "viscoelastic" models for nonrigid mammogram registration which approximate deformable behavior.

Mammogram Registration

- When matching mammograms from one or more studies, one image is selected as the reference mammogram, and the remaining "comparative" mammograms are registered relative to this reference.
- Mammogram registration using a point-based methodology involves three tasks.
  1. **Feature extraction**: the identification of salient features, such as the breast contours, from each of the mammograms.
  2. **Control-point selection**: corresponding control-points, such as the nipple positions, are identified from amongst the extracted features. Each of the feature-points in the comparative image is then uniquely paired with the corresponding feature point in the second image.

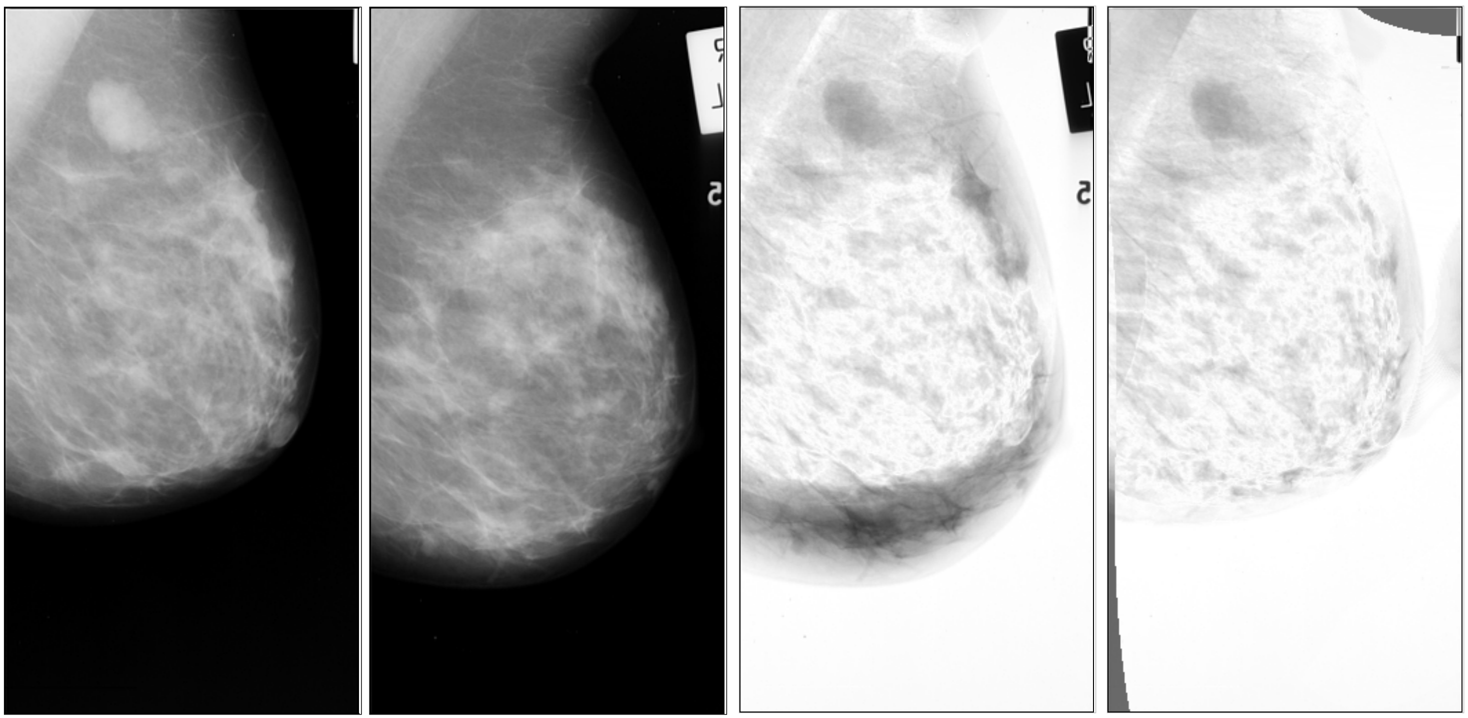
Mammogram Registration

3. **Spatial correlation**: a spatial transformation is used to mathematically represent the spatial differences between the corresponding mammograms, aligning the comparative mammogram relative to the reference mammogram.



Mammogram Registration

left mammogram   right mammogram   pre-registration difference image   post-registration difference image



Mammogram Fusion

- When a physician evaluates a medical case s/he must integrate and visualise the information provided by medical imaging in a manner which highlights regions of clinical significance.

Fusing Information

- Once registration has been performed the information contained in the breast images must be combined in such a way that it is of some clinical significance.
  - This next step in the process of comparative analysis involves integrating breast images in a manner which allows for the delineation and visualization of differences between the images.
  - The objective is to fuse, or combine the information from the different studies into a new image.

Image Fusion

- The term fusion is used to describe the mechanism by which information from two or more images is combined.
  – To achieve this it is necessary to reduce the multiple attributes per image element to a single attribute per element.
  – This can either be done by combining the original pixel values to give a new pixel value, thereby in principle retaining information from all the images involved, or alternatively by deciding which single image should contribute to the final pixel.

Information Types

- Multiparametric information exists in many forms, the two major types being complementary and synergistic information.

Complementary Information

- Complementary information means that both images provide separate but useful information.
  - Sometimes different modalities provide complementary information about non-overlapping structures. Such information may be multi-anatomical, multi-functional or functional-anatomical.

Synergistic Information

- When the fusion of two or more studies provides additional information that neither study can provide separately then the information is of a synergistic nature.
  - Integration of MR in radiotherapy treatment planning allows a more accurate delineation of the target volume and sparing of normal tissues. CT information is essential in defining abnormalities not perceivable using MR.

Subtractive vs. Additive Fusion

- The process of fusion can be broadly grouped into two categories: subtractive and additive.
- Additive fusion combines complementary information to form a better understanding of the whole. Such imaging studies are usually intermodal and involve complementary information.
  - e.g. The integration of functional FDG-Positron Emission Mammography (PEM) images with x-ray mammograms. If the colour PEM pixel is above a certain threshold it is chosen for the composite image, else the greyscale mammogram pixel is used. The result is a mammogram with regions of increased FDG uptake visible (signifying potential pathological activity).

Subtractive vs. Additive Fusion

- In subtractive fusion, the aim is to reveal subtle variations or differences amongst two imaging studies more accurately. Such studies are usually intramodal, use synergistic information and may involve the use of contrast-agents.
  - Here an initial pre-contrast reference image is acquired and contains the base information that will be subtracted from the second, comparative image after they are registered.
  - e.g. subtraction of temporal mammograms where significant changes in the contrast of a particular region of the breast signifies a pathological change.

Simple Subtraction

- An ideal difference image, calculated using corresponding breast images which have been perfectly matched, would have a uniform value of zero throughout the image were there no changes in the breast.
  - If a change occurs in one of the images, then the difference image will reflect this by a corresponding increase (or decrease) in intensity proportional in magnitude to the difference.
  - A positive difference will signify an increase in intensity in the reference image, whilst a negative difference depicts an increase in intensity in the comparative image

Simple Subtraction

- Subtracting a comparative image, I_C , from the reference image, I_R , would yield a difference image, I_D , such that:

$$I_D(x,y) = I_R(x,y) - I_C(x,y)$$

- More often than not though, the difference image is represented using the absolute difference such that:

$$I_D(x,y) = \left| I_R(x,y) - I_C(x,y) \right|$$

  – Here a value of zero implies no change and a value increasing towards 255 signifies increasing differences.
  – This representation does not differentiate in which image the change occurred.

Truncated Subtraction

- A malignant structure growing in the breast will be imaged with increased intensity as time progresses.
  - Extracting a measure of change which encapsulates only a temporal change can be achieved by subtracting the recent comparative from the previous reference image and retaining only the negative values. Such a technique is known as truncated subtraction and is given by:

$$I_D(x,y) = \min\left[\ 0, I_R(x,y) - I_C(x,y)\ \right]$$

Truncated Subtraction

- Over time fibroglandular tissue (high intensity) turns to fatty tissue which appears as a lower intensity.
- If brighter regions are identified as developing abnormalities, changes resulting from abnormal growth will be retained using truncated subtraction, whereas natural changes will be removed.
- For bilateral mammograms, either the left or right mammogram may contain abnormalities:
  - This suggests the generation of two difference images depicting both negative and positive differences.

Adaptive Subtraction

- Adaptively weighted subtraction weights the difference obtained by a value which reflects certain properties which could be used to differentiate tissues.
  - To weight the difference by a parameter which reflects the tendency for abnormal regions to have higher intensity values:

$$I_D(x,y) = \max\left[I_R(x,y), I_C(x,y)\right] \cdot \left(I_R(x,y) - I_C(x,y)\right)$$

Adaptive Subtraction

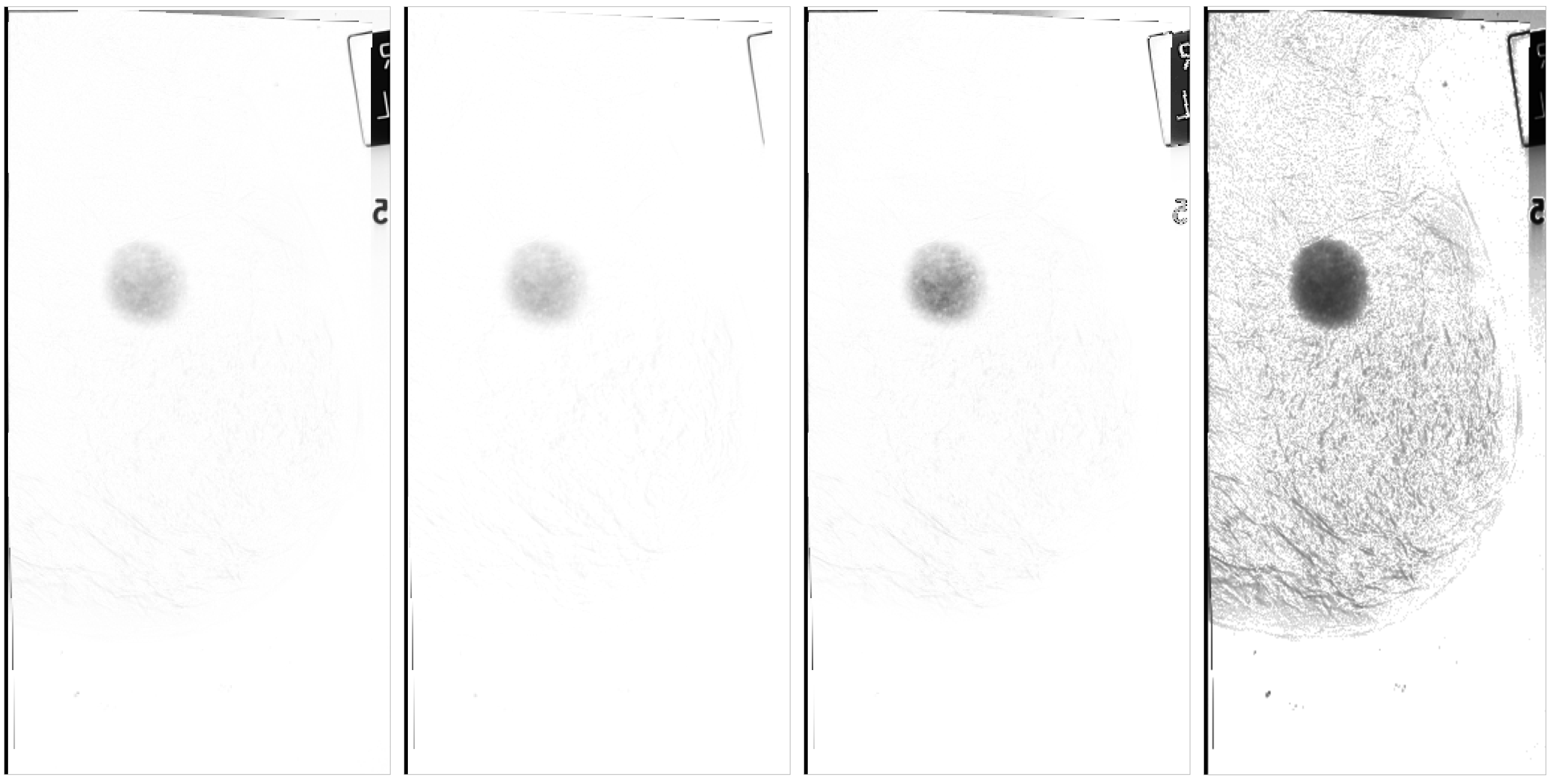
- An alternative might be to use LOG-accentuation:

$$I_D(x,y) = \log\left[I_R(x,y) - I_C(x,y)\right]$$

however LOG-accentuation does tend to accentuate background residual differences.

Comparing Subtraction

Simple Subtraction Truncated Subtraction Adaptive Subtraction LOG-Subtraction



Temporal Subtraction

- Temporal subtraction is used to provide a time-series view of a contrast agent as it passes through a particular structure.
  - The first image, the reference, is acquired prior to the introduction of the contrast agent (I_R).
  - After the contrast agent is introduced a series of post-contrast images, I_j , are acquired where j denotes the number of images which will be acquired in the sequence. In the subtraction of I_j from I_R , for all values of j, the progress of the contrast agent may be viewed temporally.

Temporal Subtraction

$$I_{Dj}(x,y) = I_R(x,y) - I_{Cj}(x,y)$$

- This results in a series of *j* difference images.

- Time Interval Difference (TID) subtraction.
  - Subtraction is performed continuously between subsequent post-contrast images:

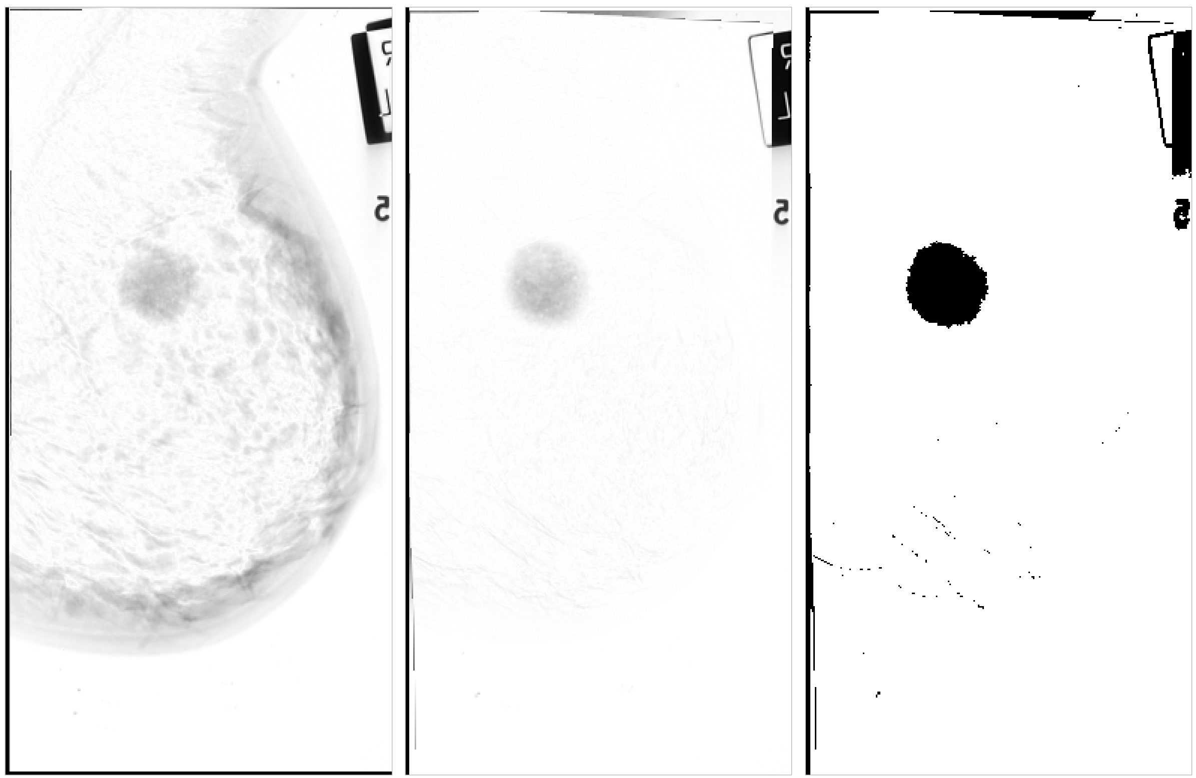
$$I_{Dj}(x,y) = I_{Cj}(x,y) - I_{Cj+1}(x,y)$$

Difference Image Analysis

- Some regions of residual change in difference images are attributable to variations in the intensities between breast images.
  - More often than not change is due to structures that appear in one breast image and not the other due to variability in positioning as well as natural aging.
  - To remove such changes and reduce false-positive results requires feature analysis.
  - Once an appropriate difference image has been generated, feature extraction and analysis techniques can be applied to extract potential abnormalities.
  - To identify regions of extreme difference it may be first necessary to apply a threshold to the difference image.

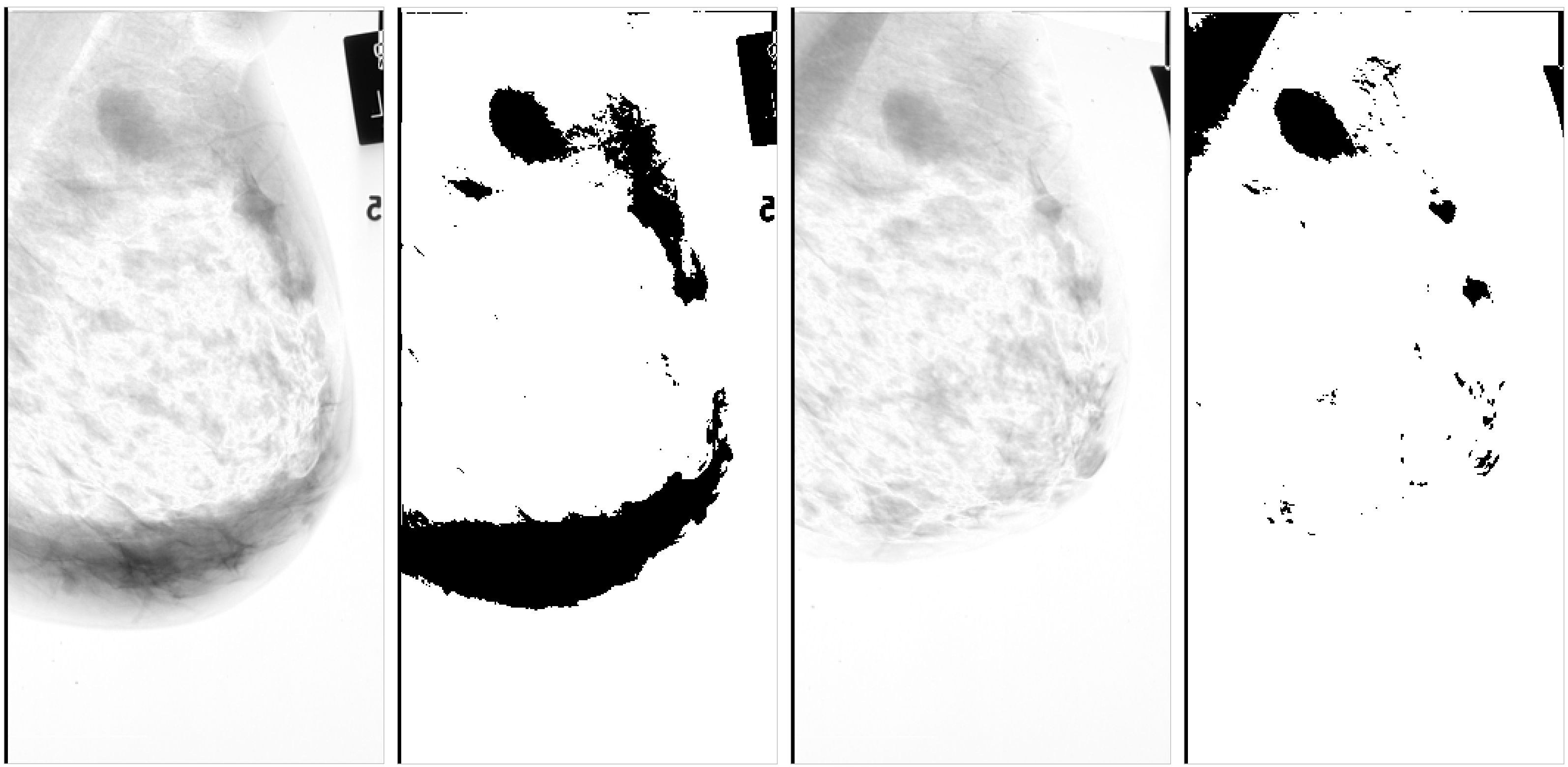
Difference Image Analysis

Pre-registration difference image | Post-registration difference image | Thresholded difference image



Bilateral Mammogram Analysis

Pre-registration difference image | Pre-registration threshold image | Post-registration difference image | Post-registration threshold image



Detection and Diagnosis

	abnormal	normal	Total
abnormal	TP	FN	TP+FN
normal	FP	TN	FP+TN

Sensitivity

- The true positive fraction gives a measure of how likely it is that a genuine abnormality will be detected:

$$TP_{fraction} = \frac{TP}{(TP + FN)}$$

- The term sensitivity is a synonym for the true positive fraction expressed as a percentage:
  - Measures the proportion of cases in which a disease is present correctly identified.

Specificity

- The true negative fraction gives a measure of the likelihood of a normal object being correctly identified:

$$TN_{fraction} = \frac{TN}{(TN + FP)}$$

- The term specificity is a synonym for the true negative fraction expressed as a percentage:
  - Measures the proportion of disease-free cases that are correctly identified.

Detection and Diagnosis

- A false-positive (FP) object is a normal object misclassified as abnormal.
- A false-negative (FN) object is an abnormal object misclassified as normal.

Detection and Diagnosis

- The FP fraction is given by:

$$FP_{fraction} = \frac{FP}{(TN + FP)}$$

- The FN fraction is given by:

$$FN_{fraction} = \frac{FN}{(TP + FN)}$$

- The TP fraction and FP fraction are sometimes called the hit rate and false alarm rate respectively.

MR Breast Imaging

- Mammography is the primary imaging modality used in the early detection of breast cancer, yet despite advances in mammographic techniques, it has a number of shortcomings:
  - The inherent 2D nature of mammograms.
  - Mammography is limited to providing anatomical information in a two-dimensional context, which makes it hard to derive a clear understanding of the 3D nature of the breast.

MR Breast Imaging

- Magnetic Resonance breast imaging, sometimes known as MR mammography is an adjunct modality to mammography.
  - Improved soft-tissue contrast, multiplanar capability, and the lack of ionising radiation

MR Breast Imaging

- MR imaging provides information on the entire three-dimensional structure of the breast, including the chest wall.
  - This 3D representation allows the visualization of structures within the breast, their size, shape, and relationships with neighboring structures.
  - One important diagnostic use of 3D imaging is the display of geometrical relationships between normal and pathological (abnormal) structures.
  - These images permit the calculation of a range of useful quantitative parameters such as the volume of a tumor.

Multiplanar Imaging

- There are three planes used in MR imaging of the breast: sagittal, axial and coronal.

A Multimode Modality

- MR imaging offers many modes of inquiry, each capable of imaging different properties of breast tissue including breast anatomy, blood supply, metabolism, and chemistry.
  - Visualization of breast vasculature is achieved through MRA (MR angiography)
  - Functional and chemical aspects of the breast may be provided by fMR (functional MR) and MRS (MR spectroscopy) respectively.
  - A new technique, MR elastography (MRE) depicts tissue elasticity, or stiffness, and may allow "palpation" by imaging.

Types of MR Studies

- Breast MR imaging techniques span the spectrum from ultrafast 10-30 second dynamic acquisitions (dynamic MR images are serial 3D images acquired over a finite time period that encompasses contrast enhancement to high-resolution fat-suppressed 5-minute studies.
  - Rapid imaging may provide greater specificity, at the expense of lower resolution (2-3mm section thickness).
  - High resolution techniques (<1.5mm section thickness) such as the gradient-echo RODEO (rotating delivery of excitation off resonance) sequence provide no temporal information.
  - A compromise between the dynamic method and the high-resolution approach using a 3D FLASH (fast low-angle shot) gradient-echo images obtained every two minutes.

Clinical Studies

Invasive ductal carcinoma

fibroadenoma

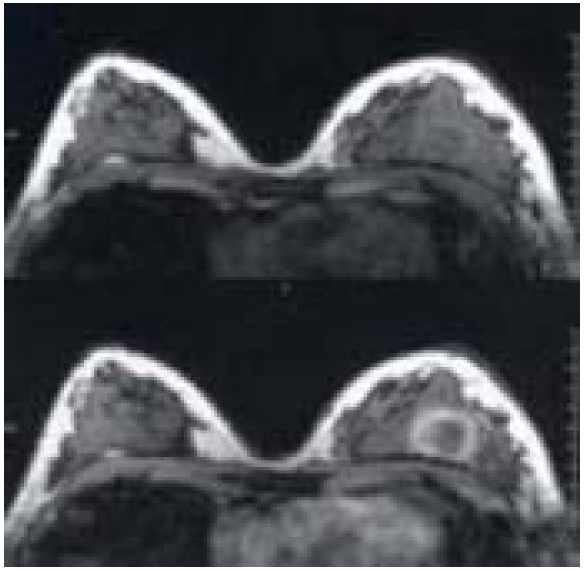
spiculated mass

Contrast Enhancement

- MR contrast enhanced (CE) imaging uses a paramagnetic contrast agent: gadolinium diethylenetriaminepentaacetic acid (Gd-DTPA).
  - MR contrast agents function through their alteration of the local magnetic environment of tissue.
  - The hypothesis is that malignancies enhance with Gd-DTPA or a similar contrast agent.
  - This is believed to a variable combination of:
    - increased vascularity
    - increased vascular permeability, and/or
    - increased interstitial space in malignant tumours compared with benign tumours

Contrast Enhancement

- The breast is imaged once before and two or more times after administration of the contrast agent.
  - Enhancing tissues are visualised as areas with signal increase.



MR Interpretation

- For the interpretation of MR breast images, the following features are considered:
  - amount of enhancement: the presence or absence of enhancement is determined by comparison of pre- and post-contrast images (quantitative evaluation)
  - morphology of an enhancing structure: enhancement can be described as irregularly shaped or well circumscribed, lobulated, oval or round.
    - diffuse enhancement (concerns enhancement of most or all of the breast tissue)

MR Interpretation

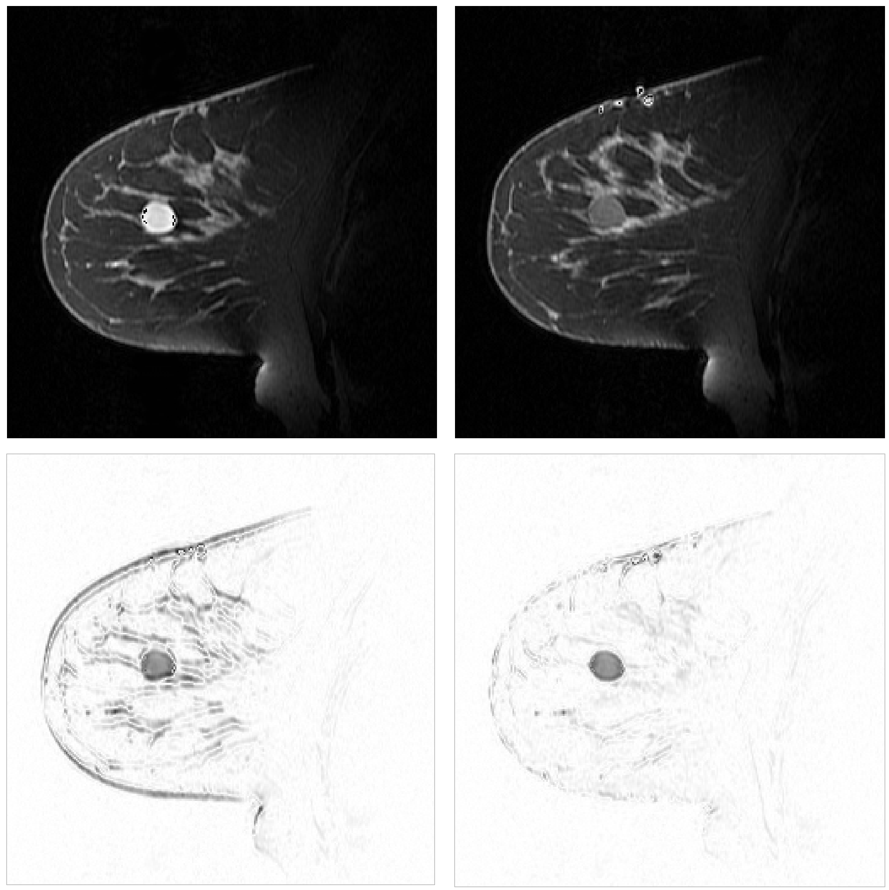
- speed of enhancement: may be estimated from the amount of enhancement on the first and second images after administration of the contrast agent.
- presence of enhancement

MR Breast Image Fusion

- The goal of comparative analysis is to quantitatively determine the existence of clinically significant differences between two corresponding MR images of the breast.
  - In MR images such differences are the result of contrast enhancement of potentially suspicious entities and associated vasculature.
  - In this instance a difference image is created by subtracting the post-contrast image from the corresponding pre-contrast image within a study.

$$D = I_{precontrast} - I_{postcontrast}$$

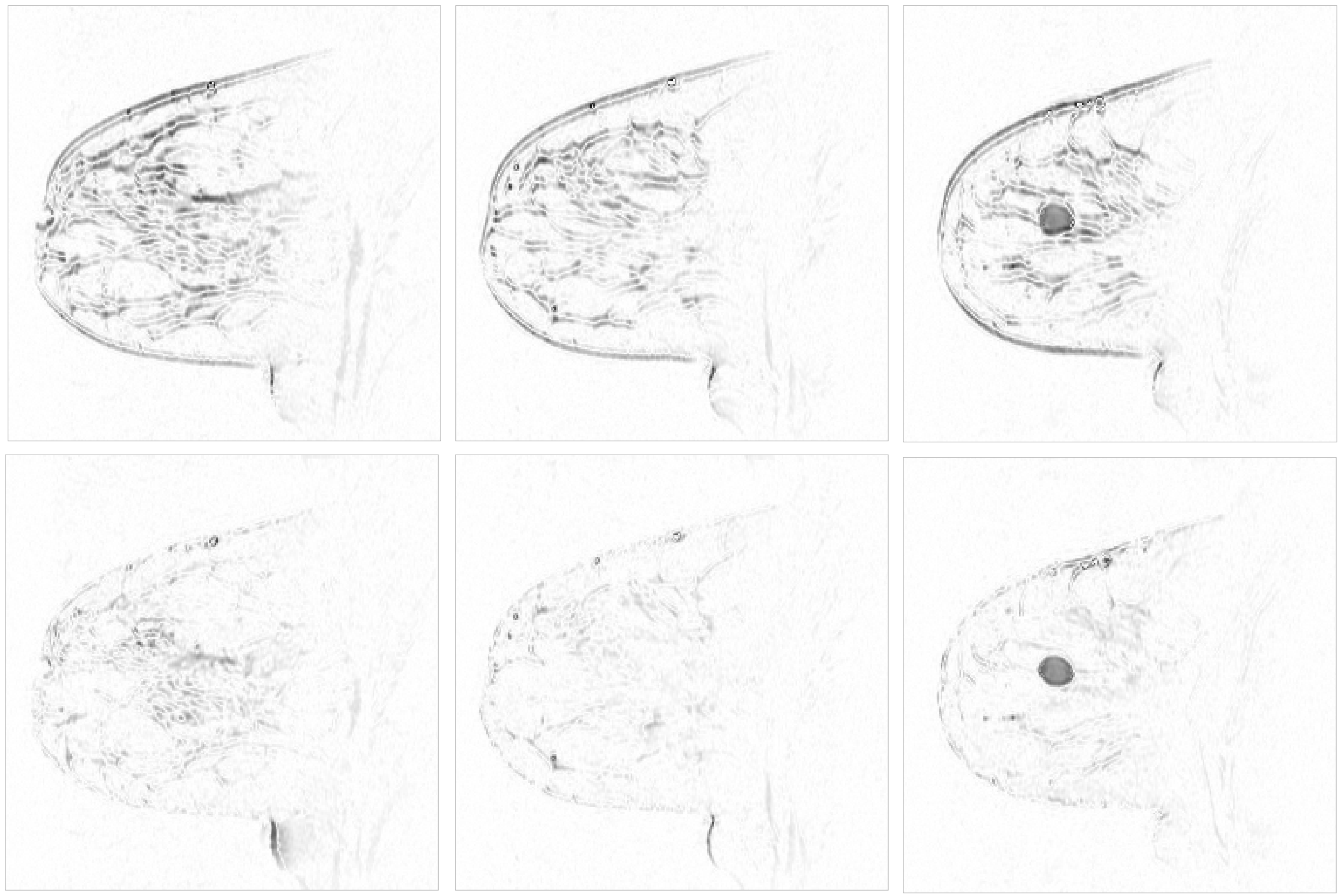
Pre-Post Contrast MR Images



Pre-Post Contrast MR Images

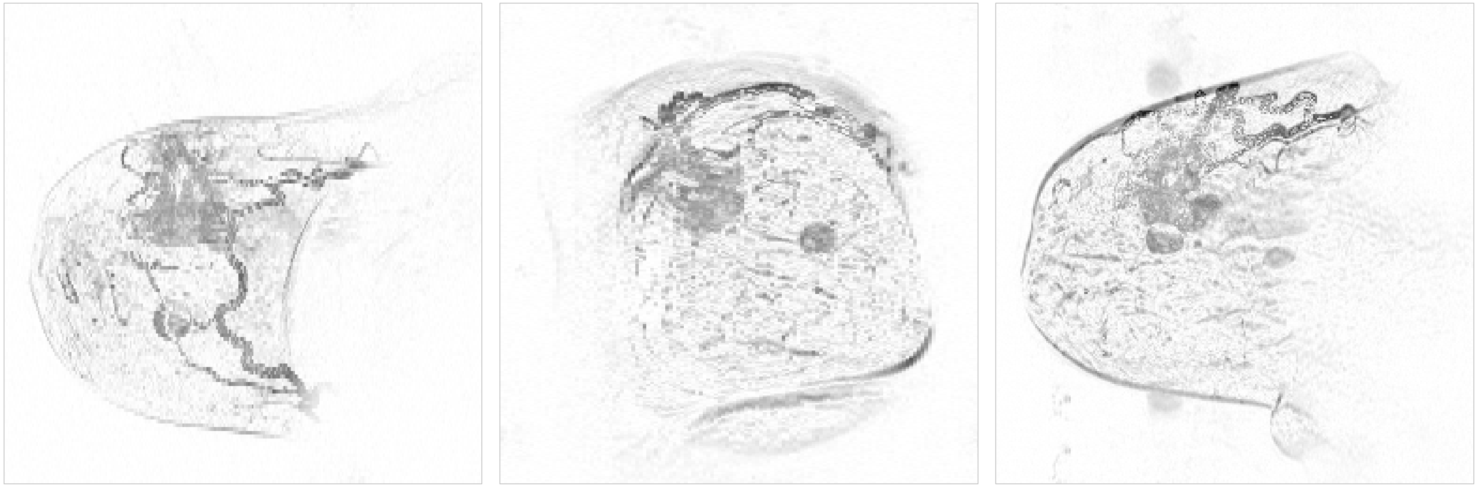
Pre-registration difference images

Post-registration difference images



MIP Fusion

- A Maximum Intensity Projection (MIP) is a 2D projection image of a 3D MR image



Axial
Coronal
Sagittal

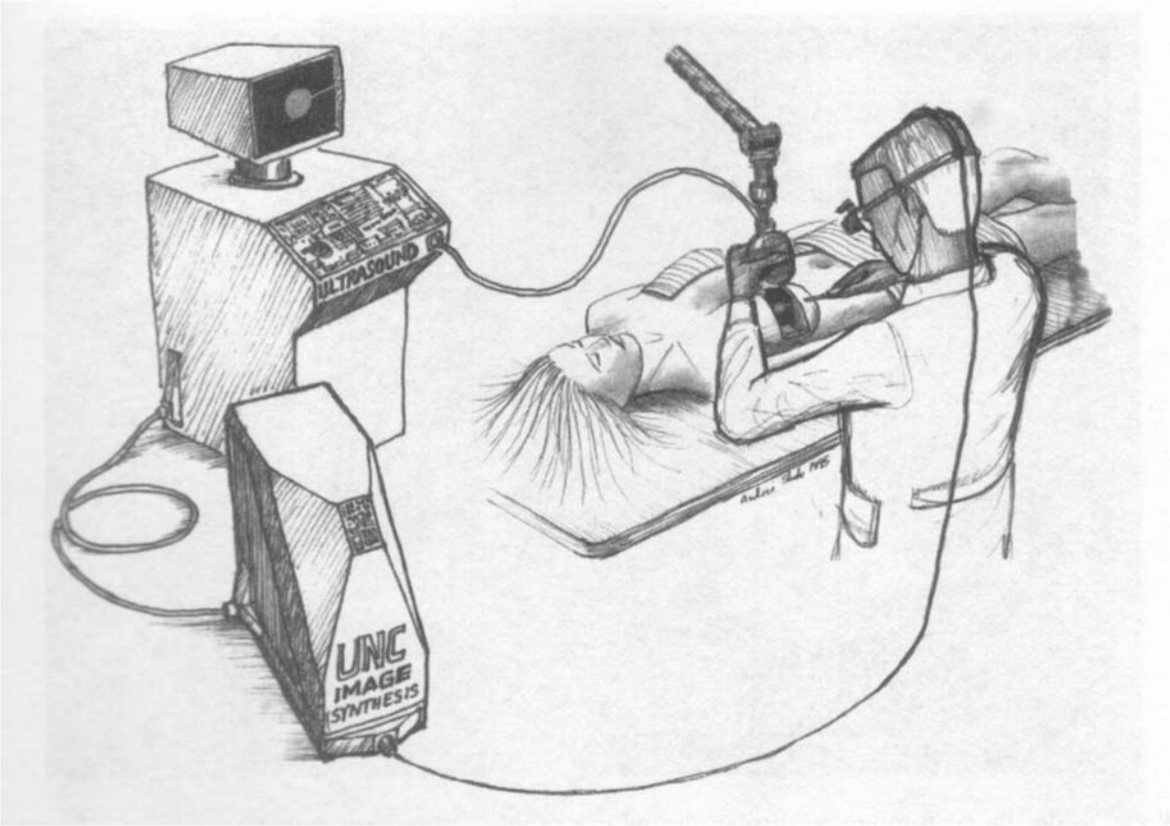
Augmented Reality

- With emphasis on the use of synergistic imaging in the intraprocedural realm, particularly in breast surgery and image-guided procedures, there will be an increasing need to develop real-time fusion techniques.
  - This includes augmented-reality fusion whereby information from preprocedural images of the breast, such as Magnetic Resonance, can be fused dynamically with intraprocedural images such as video, real-time MR and US to facilitate techniques such as image-guided needle biopsy.

Augmented Reality

– As an example of this consider the augmented-reality model for image guidance in breast cancer surgery. Here a 3D tumour model derived from real-time 3D US images is superimposed on live video images of the patients breast. This allows a surgeon to perceive the exact 3D position and shape of a tumour as if it were visible through the breast skin.

Augmented Reality

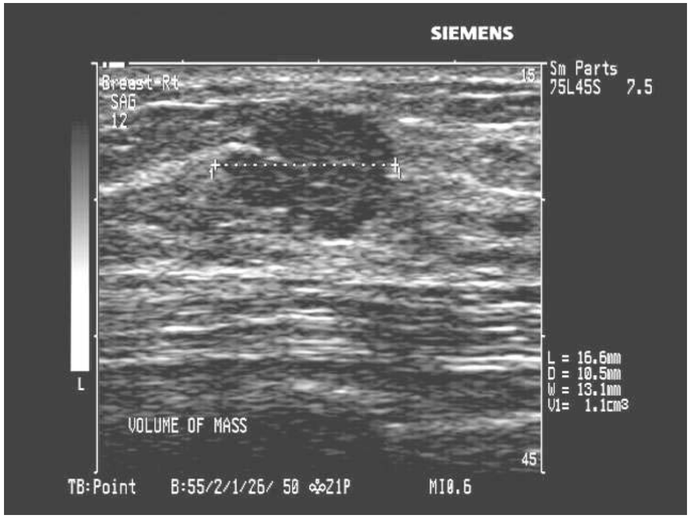


Breast Ultrasound

- Breast Ultrasound
  - Breast ultrasound, also known as sonography, or ultrasonography, is used to evaluate breast abnormalities found with mammography.
  - Most useful in distinguishing between dense masses (an increased density of solid tissue) and cysts.
  - Ultrasound is also useful in helping guide a biopsy (tissue sampling).
  - Ultrasound has excellent contrast resolution (e.g. an area of normal tissue and a cyst are easy to differentiate), but has poor spatial resolution, Ultrasound is also unable to image microcalcifications.

Breast Ultrasound

circumscribed, slightly lobulated fibroadenoma



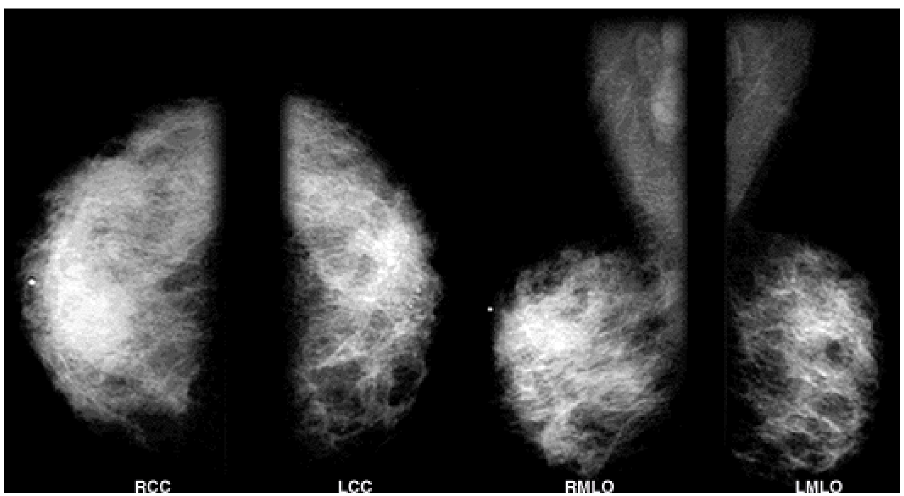
breast cyst

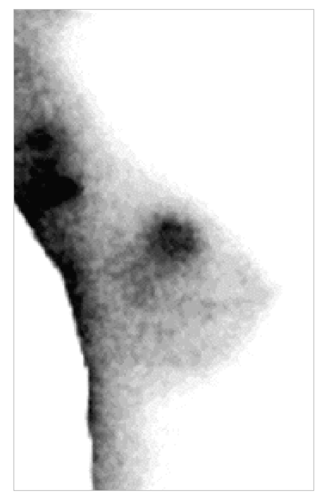
Computerized Thermal Imaging

- Computerized Thermal Imaging
  - Uses thermal imaging (thermography) to acquire images based on heat radiating from the body.
    - represents breast tissue temperature.
  - Uses heat patterns to differentiate between different tissue types.

Positron Emission Mammography

- Sestamibi Nuclear Medicine Breast Imaging
  - Known as scintimammography
  - Radionuclide is technetium sestamibi

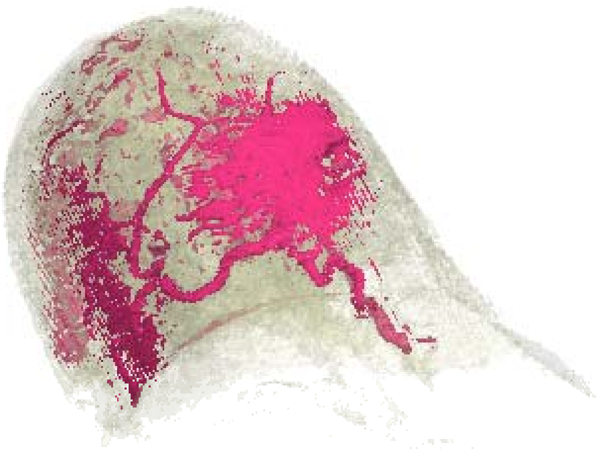




Electrical Impedance Imaging

- Electrical Impedance Imaging (EIS or T-scan)
  - The T-scan measures low level bioelectric currents to produce real-time images of the electrical impedance (EI) properties of breast tissue.
  - Electrical impedance is a measurement of how electricity travels through a given material. A material with a low EI conducts electricity much better.
  - Malignant tissue conducts electricity differently than healthy tissue, and as such show up on the resulting images as bright white spots.
    - Malignant (low EI), normal tissue & benign tumours (high EI)

3D: The Final Frontier



3D: The Final Frontier