Breast cancer is one among the most common and deadly cancers, affecting nearly one in ten women. Standard Film Mammography is an important type of medical imaging used to uniquely screen healthy women for small curable breast cancers. Currently, it is the “gold standard” in breast cancer detection. Controlled medical studies have shown that mammography can lead to decreases in death due to breast cancer sufficient to measurably lengthen life. The reported cancer free 5 year survival for cancer detected by mammography is 92%, with 96% overall 5 year survival [1], [2].

To construct a system for automatic detection of abnormalities in mammographic images, it is important to have some basic medical knowledge in the area. It is also important to investigate how an expert radiologist works. Hence a medical point of view of mammography is presented in this section.
3.1 Anatomy of the female breast

The breast is a complex organ consisting of different types of tissue (see figure 3.1). The female breast contains milk-producing glands called lobes or lobules. These glands vary in size during the menstrual cycle due to the difference in hormone levels, and regress after menopause [156]. The lobules are linked together by tiny tubes called ducts through which the milk is transported from the lobules to the nipple. The surrounding fatty tissue and ligaments, called parenchyma, supports the lobules and ducts. The structure of the breasts of different women varies much, but usually the two breasts of the same woman are much alike.

There are also blood vessels and lymphatics, small thin channels that collect and carry tissue fluids, present in the breast. Breast tissue fluid drains through the lymphatics into axillary lymph nodes, located in the underarm. They filter the lymph fluid and serve as a barrier to the further spread of cancerous cells or bacteria that may
have entered the lymph fluid. Lymph nodes are not completely effective in filtering out cancerous cells and despite their presence, once cancerous cells have gained access either to lymph channels or blood stream they have the potential to spread to any part of the body, particularly bone, lungs, liver and brain [157].

3.2 Malignancy in the breast

Cancer is a disease in which abnormal, mutated cells in some organs grow out of control [158]. Healthy cells reproduce themselves continuously throughout life, growing new tissue and replacing old or damaged ones, which is a normal, controlled and orderly process. However, sometimes this orderly process is disturbed and cells begin to reproduce in an abnormal way building a tumor.

A tumor may refer to both benign and malignant growth. Benign tumors remain similar to the tissue of their origin and generally do not invade surrounding tissues or produce metastasis [156] and their growth is usually slow. Malignant cells appear in many different forms. Some remain similar to the surrounding tissue and are referred to as well-differentiated. Cells bearing very little similarity to surrounding tissue are referred to as undifferentiated or anaplastic. These are usually more aggressive in their growth and behaviour than well-differentiated malignancies [156]. Metastasis occur when cancerous cells break away from the primary tumor, and travel through the body via blood or lymphatic channels to other organs where they grow and form new tumors.

A cancerous cell has characteristics that differentiate it from normal tissue cells with respect to the cell outline, shape, structure of nucleus and most importantly, its ability to metastasize and infiltrate. When this happens in the breast, it is commonly termed as ‘Breast Cancer’. Cancer is confirmed after a biopsy (surgically extracting tissue samples) and pathological evaluation.

The majority of breast cancers begin in either lobules or ducts [158]. Breast cancer is classified as either invasive (infiltrating) or non-invasive (in-situ). Invasive cancer has the ability to spread to other parts of the body, whereas in-situ cancers does
not spread to other parts, but may develop and become invasive and should therefore be removed.

Since breast cancer grows close to lymphatic channels, detection, diagnosis and treatment of the cancer in an early stage is important. According to Greshon [157] a tumor may be considered early, not because it is small or because it is believed to have existed for a short time, but because it has not metastasized. Few palpable tumors can be thought of as early [157]. The most important tool for early detection is the use of mammography in mass screening programs [156], [157], [159]. Clinical examination and self-examination are the other methods of finding breast cancer.

The exact cause of breast cancer is not known. However, studies show that a woman's chance of getting breast cancer increases with age, personal and family history and certain genetic alterations. Also, breast cancer occurs more often in white women than in African or Asian women.

3.2.1 Symptoms & Diagnosis

Early breast cancer usually does not cause pain. In fact when breast cancer first develops, there may be no symptom at all. As the cancer grows it can cause changes that women should watch for. Some of them are:

1) A lump or thickening in or near the breast or in the underarm area.

2) A change in the size or shape of the breast.

3) Nipple discharge or tenderness or the nipple pulled back into the breast

4) Ridges or pitting of the breast

5) A change in the way the skin of the breast, aerola or nipple looks or feels like warm, swollen, red or scaly.

To find the cause of any sign or symptom, a doctor does a careful physical examination and analyses family and personal medical history. In addition the doctor may do one or more of the following examinations:
Clinical Breast Examination: The doctor can tell a lot about a lump by carefully feeling it and the tissue around it. Benign lumps often feel different from cancerous ones. The doctor can examine the size and texture of the lump and determine whether the lump moves easily.

Mammography: X-rays of the breast can give the doctor important information about a breast lump.

Ultrasonography: Using high frequency sound waves, ultrasonography can often show whether a lump is a fluid-filled cyst (not cancerous) or a solid mass (which may or may not be cancerous). This examination may be used along with mammography.

Based on these tests the doctor may decide whether further tests are needed or treatment is necessary. In such cases, the doctor may need to check the woman regularly to watch for any changes.

Biopsy

Often fluid or tissue must be removed from the breast so that the doctor can make a diagnosis. This is done by:

Fine needle aspiration: A thin needle is used to remove fluid and/or cells from a breast lump. If the fluid is clear, it need not be checked in a lab.

Needle biopsy: Using special techniques, tissue can be removed with a needle from an area that looks suspicious in a mammogram but cannot be felt. Tissue removed in a needle biopsy goes to a lab to be checked by pathologists for cancerous cells.

Surgical biopsy: In an incisional biopsy, the surgeon cuts out a sample of a lump or suspicious area. In an excisional biopsy, the surgeon removes all of a lump or suspicious area and an area of healthy tissue around the edges. A pathologist then examines the tissue under a microscope for cancerous cells.
3.3 Mammography

A mammogram is a specialized X-ray examination of the breast. It is an effective non-invasive means of examining the breast, searching for breast cancer. Two types of mammogram studies are commonly performed: screening mammography and diagnostic mammography.

A screening mammogram is performed on women who have no current symptoms or breast problems while a diagnostic mammogram is performed specifically to evaluate a breast problem or revisit a previous abnormal finding. Mammograms are done using two different positions for each breast, the details of which are given in table 3.1. This allows more thorough evaluation of breast tissue. A compression paddle is used to spread out the breast tissue and obtain more uniform thickness. This greatly improves detail and image quality, making it possible to see very small abnormalities. At the same time the amount of X-rays needed for the examination are significantly reduced.

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Projection/Position</th>
<th>Direction of the X-Ray</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>Cranio-Caudal</td>
<td>Direction from head (cranium) to the feet (caudal)</td>
</tr>
<tr>
<td>MLO</td>
<td>Medio-Lateral Oblique</td>
<td>X-ray direction is from medial (inner) to lateral (outer) aspect and the orientation of the breast is at an angle (Oblique)</td>
</tr>
</tbody>
</table>

Table 3.1: Positioning on performing mammograms

When a mammogram of the breast is taken, the different forms of tissue appear as different shades of gray depending on the level of absorbed radiation. Skin and fat tissue absorb very little radiation and does not usually show. Glandular tissues normally appear in medium or light gray shades. The pectoralis muscle located behind the glandular tissue covering the ribs is visible as a white area in a normal mammogram.

X-ray images depend on differences in x-ray stopping power (attenuation) of separate tissues. In general, a clear separation between normal functioning tissue and
abnormal cancerous tissue is not possible since their attenuations are very similar. However, both functional tissue and cancerous ones can be separated from fatty storage tissue, which normally surround active breast tissue, even in lean persons. This is due to a substantially lower attenuation caused by fat.

In older women, the functional glandular tissue diminishes leaving only thin supporting tissues clearly outlined by fatty tissue. Mammography in these "mature" breasts is very effective since even small cancers are well outlined by fat. In addition, many cancers develop calcium deposits that strongly stop X-rays and are easily seen on mammograms.

Since mammography cannot separate normal gland tissue from tumors, it is much more effective when gland tissue diminishes with age. Many women retain glandular tissue as they "mature" and it camouflages tumors until they are large. The young women's breast normally contains more active tissue that again interferes with detection of small cancers.

3.3.1 The Mammography Machine

The first dedicated mammography machine was developed in 1966 [160]. Until then, mammographic images had been produced using standard X-ray machines. They have a reciprocating grid to reduce scatter radiation, thus avoiding fog and blurry images. A 0.03 mm molybdenum filter is generally used to make the beam hard and more penetrable.

The second-generation design introduced in 1980's reduced the exposure time significantly. The machine also provided increased resolution and accuracy and used more advanced type of film to provide better detail. Film processing is done under specific conditions. Depending on the type of film used, standard processing or extended processing techniques are employed to develop an exposed film [161]. The Films used for mammography are single emulsion fast films, which enhance image sharpness by eliminating geometric distortion. Films commonly used are Kodak Min-
The screens consist of a rare earth phosphor called terbium activated gadolinium oxysulfide. Screens have to be compatible with the film. The newest film-screen combination is responsible for dose reduction by 30 - 50%.

The technique used for mammography is low Kilo-voltage Peak (KvP) of about 24 to 30. The milli-Ampere-seconds (mAs) vary depending on breast tissue density. When the photo timer cells are used, it provides the optimum mAs for the tissue to be imaged. This technique results in mammograms with a high film contrast, making it easier for the radiologist to read.

The design of mammography equipment has progressed rapidly over the last four decades. In developed countries, dedicated mammography units are used. A whole range of manufacturers, GE, Bennett, Lorad, Siemens, Fischer, Phillips, etc. make these machines. In 2000 GE introduced the first full field digital mammography system the Senographe 2000D [160]. A digital mammography system uses essentially the same system as conventional mammography, but it is equipped with a digital receptor and a computer instead of a film cassette.

3.3.2 Breast Composition Determination

Because mammographic screening procedures are applied to all persons at risk, millions of mammograms and hundreds of thousands of biopsies must be preformed. To minimize the natural anxiety and inconvenience, mammographic procedures must be quick and accessible and every effort must be made to inform, counsel and support women undergoing the procedure.

Breast care involves many people, viz, personal physicians who order mammograms, radiologists who interpret mammograms and do needle biopsies, surgeons who perform incisional biopsies and curative cancer operations, pathologists who interpret biopsies, and radiotherapists who deliver radiation treatment. Patients often must function under great stress in evaluating several physician recommendations to make important treatment decisions. Hence, clear and accurate communication is
3.4 Normal Mammograms

Unfortunately, there is no "normal" appearance on a mammogram that can be memorized. What constitutes "normal" varies within a wide spectrum. In addition, the appearance of the breast differs during pregnancy and in the postpartum period. This spectrum is due to the differences in breast composition. A breast with a high composition of adipose tissue will appear darker on a mammogram than a breast with a high composition of connective tissue stroma (lighter). From a population perspective, the mammogram will appear radiographically denser in a higher percentage of younger
women than in older women. Even for an individual female, the image of breast density may vary over the years. Such changes are often gradual and the trend is generally towards a less dense (higher percentage of fat) breast tissue, but the reverse trend may happen as in the case of weight loss or hormone replacement therapy. Examples of different, entirely normal mammograms are shown in Figures 3.2 to 3.4.

Other normal variations of breast tissue include asymmetric patterns and asymmetric size. Although the breasts usually develop symmetrically, differences in the symmetry of breast tissue patterns or breast size are not necessarily abnormal. Without other indices of an abnormal process, such asymmetry may simply be a developmental phenomenon.

Figure 3.2: Normal Mammogram
Dense-glandular type
3.5 Mammographic Abnormalities

3.5.1 Microcalcifications

A microcalcification is a tiny calcium deposit that has accumulated in the tissue in the breast and it appears as a small bright spot in the mammogram. A cluster is typically defined to be at least 3 to 5 microcalcifications within a 1 square centimeter region [1], [31]. Up to 50% of malignant masses demonstrate clustered microcalcifications and in a number of cases the clusters are the only sign of malignancy [1].

Suspicious calcifications occur in about one-third of breast cancers, and may develop prior to the invasive phase of tumor growth (in situ cancer) when cancers are most curable. Calcium deposits are easy to be seen in X-rays because they are much denser (have higher X-ray stopping power) than all types of soft tissues in the breast. Calcifications associated with cancer are usually very small. However calcifications
commonly occur in benign breast processes, where they may be confused with cancer. Figure 3.5 shows snippets of mammograms containing malignant and benign microcalcifications.

Malignant microcalcifications vary extremely in form, size, density and number. They are usually clustered within one area of the breast, often within one lobe. They are of two types: granular and casting.

**Pleomorphic or heterogeneous calcifications (Granular):** These are tiny calcifications with dot-like or elongated shape and innumerable. They are having varying size, usually less than 0.5 mm.
3.5. *Mammographic Abnormalities*

**Fine and/or branching (casting) calcifications:** These are thin, irregular calcifications that appear linear, but are discontinuous and under 0.5 mm in width.

Figure 3.6 shows examples of these types of calcifications. They are often associated with cancer and clearly merit immediate biopsy.

Figure 3.5: Snippets of mammograms containing microcalcifications
a) Benign calcifications b) Malignant calcifications

(a) (b)

Figure 3.6: Basic types of malignant microcalcifications
(a) Granular type (b) Casting type

(a) (b)
Benign microcalcifications are characterized by homogeneous shape, uniform density, sharp outline, or radio lucent density. They are usually larger than that associated with malignancy. They are coarser, often round with smooth margins and are easily seen. Some examples of benign calcifications are given in Figure 3.7.

**Skin calcifications**: These are typically dense, smooth and lucent centered (less dense in center than margin) that are *pathognomonic* (appearance is always benign). They are situated in the skin, resulting from calcium deposits in hair follicles and are more common in the center of the chest at the inner edge of the breast.

![Figure 3.7: Different forms of benign calcifications.](image)

(a) Skin calcifications  
(b) Vascular calcifications  
(c) Rod shaped calcification  
(d) Round calcifications
3.5. Mammographic Abnormalities

*Vascular calcifications:* These are parallel paired tracks or linear tubular calcifications that are clearly associated with small arteries.

*Coarse or popcorn like calcification:* Rounded groups of coarse calcifications develop in an involuting *fibro adenoma*. When completely developed the appearance is reliable, but during early phases of development calcifications in fibro adenomas may be suspicious.

*Large rod shaped calcification:* These are benign calcifications forming continuous rods that may occasionally branch. They are usually more than 1 mm in diameter and may have lucent center, if calcium surrounds rather than fills an enlarged duct. These kinds of calcifications are found in *secreatory disease, plasma cell mastitis*, and *duct ectasia*.

*Round Calcifications:* They are smooth, dense and round calcifications with size less than 1 mm.

*Spherical or lucent centered calcifications:* These are benign calcifications that range from under 1 mm to over a centimeter. These deposits have smooth surfaces, are round or oval and tend to have a lucent center. They arise from areas of *fat necrosis, calcified duct debris* and occasional *fibro adenoma* of a duct involved irregularly by breast cancer.

### 3.5.1.1 Calcification Distribution Modifiers

Breast cancer frequently spreads locally in characteristic patterns. These patterns are used as modifiers of the basic morphologic description and describe the arrangement of the calcifications. The significance of groups of calcifications is influenced by the pattern of distribution. Multiple similar groups may be indicated when there is more than one group that show similar morphology and distribution.

*Grouped or Clustered:* The term is used when multiple small calcifications occupy a small volume of tissue (less than two cubic centimeters).

*Linear:* Calcifications arrayed in a line that may have branch points.
**Segmental:** These are worrisome in that their distribution suggests deposits in a duct and its branches raising the possibility of multi-focal breast cancer in a lobe or segment of the breast. Although benign causes of segmental calcifications exist such as *secretory disease*, this distribution is of greater concern when the morphology of the calcifications is not specifically benign.

**Regional:** These are calcifications scattered in a large volume of breast tissue not necessarily conforming to a duct distribution that are likely benign, but are not everywhere in the breast and do not fit the other more suspicious categories.

**Diffuse/Scattered:** These are calcifications that are distributed randomly throughout the breast.

**Multiple groups:** Multiple groups may be indicated when there is more than one group of calcifications that are similar in morphology and distribution.

### 3.5.2 Circumscribed Masses

The presence of a localized collection of tissue represents a mass. By ACR-BIRAD definition, a mass is a space-occupying lesion seen in 2 different projections (X-ray points of view). When an apparent collection is seen in only one view, it is referred to as a mammographic "density". Although the density may be a mass, perhaps obscured by overlying glandular tissue on other views, it may be nothing more than several overlapping normal areas. When a density is seen on only one view, additional views must be done to confirm or exclude the presence of a mass.

Circumscribed Masses have a distinct border and are typically circular in shape. High-density radio opaque and random oriented masses are most likely to be malignant whereas radio lucent and radio lucent / radio opaque combined masses are almost always benign [1], [31]. Examples of benign and malignant circumscribed masses are shown in Figure 3.8. Halo and capsules are characteristics of benign masses with rare exceptions (see fig.3.9). A halo is a narrow radiolucent ring or a segment of a ring around the periphery of a tumor. A capsule is a thin, curved, radiopaque line that is seen
3.5. Mammographic Abnormalities

only when it surrounds tumors containing fat. A cyst with smooth borders and orienting in the direction of the nipple following the trabecular structure of the breast also indicates a benign lesion. Figure 3.10 shows some typical examples of different types of malignant masses. Contour, density, shape, orientation and size of the mass are important factors to be considered when analyzing a visible mass.

Figure 3.8: Snippets of mammograms with circumscribed masses
a) Benign mass b) Malignant mass

Figure 3.9: Benign masses.
a) halo b) cyst c) capsule
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General shape of a mass is relatively non-specific since both benign and malignant processes tend to arise from one spot and grow circumferentially. Round and oval shapes are associated with benign processes in part because they imply a well-circumscribed margin, a benign sign considered in the margins section.

**Round, oval, and lobular shape:** Masses in these categories imply a well-defined smooth edge and is often benign. If their margin is not smooth, their shape alone does not tend to exclude malignancy.

Fig. 3.10: Malignant masses.
(a) High density radiopaque. (b) Solid tumor with random orientation.

Fig. 3.11: Snippets of mammograms with ill-defined masses
(a) Benign mass b) Malignant mass
Irregular shape: Irregular shapes are more concerning, in part because they imply indistinct margins and are more often malignant (tumor infiltrating edges). Figure 3.11 shows typical benign and malignant ill-defined masses.

3.5.2.1 Architectural Distortion

In this class, the normal outline of tissues is distorted, sometimes with no definable mass. It includes spiculations (lines radiating from a center) and retraction (puckering) of normal connective tissue lines. It is important because cancer infiltration often occurs along normal tissue planes where it causes abnormal stiffness or contraction, which can sometimes be seen before an actual mass.

Architectural distortion occurs with healing after injury including previous biopsy and so it is critical to determine if the area has been injured. Benign causes of architectural distortion such as scarring tend to remain unchanged or improve. So in cases where previous mammograms have been performed, it is most important to compare to observe if changes have really occurred. Figure 3.12 shows typical examples of benign and malignant architectural distortions.

![Figure 3.12: Snippets of mammograms with architectural distortion](image)

(a) Benign distortion  (b) Malignant distortion
3.5.2.2 Asymmetric Breast Tissue

Breast tissue is usually very similar from one side to the other. When a greater volume or density of tissue is present on one side, concern arises even if no mass is seen. Although asymmetry does occur as an occasional normal finding, it is important to obtain detailed views, usually with small "focal compression" devices to spread tissues out and exclude a mass. Even if no mass is identified, accelerated follow-up mammogram in 6 months time is usual. If the area can be palpated (felt), biopsy must be considered. Once asymmetry is identified, it tends to remain constant over years and comparison with previous mammograms can be reassuring in such cases. Figure 3.13 shows typical examples of benign and malignant asymmetrical densities.

**Focal Asymmetric Density**: This is an area of breast density (tissue) with similar shape on two views, but completely lacking borders and conspicuity of a true mass. It must be carefully evaluated with special views to exclude findings of a true mass or architectural distortion.

3.5.3 Spiculated Lesions

Spiculated lesions appear star shaped with blurred borders (see figure 3.14). They are almost all malignant. Generally the lesion has a distinct central tumor mass with dense

![Figure 3.13: Snippets of mammograms having asymmetric breast tissue.](image)

(a) Benign (b) Malignant
spicules radiating in all directions. The spicule length usually increases with tumor size. Occasionally, translucent, oval or circular center or translucent areas within a loose structure and low-density spicules characterize benign spiculated lesions.

Figure 3.14: Snippets of mammograms with spiculated masses
a) Benign mass b) Malignant mass