Imaging Science: Introduction

- Highly Compelling: To understand the basic processes of life
- Highly Compelling: To understand conditions that influence and endanger healthy living
- Has energized molecular and structural biologists, functional genomists, and biomedical engineers
- Visual senses - most powerful to understand and interpret images, scenes and objects, with the aid of modern imaging technology
Biological Organisms

- Continuous supply of fluids is critical - supply nutrition and carry away waste to/from tissues
- Such movements controlled by voluntary and involuntary musculature (walking, heart beat, respiration)
- Physical function, in turn, controlled by muscle cells that produce the needed forces/torque that produce these movements.
- Cells: defined by their atomic constituency, biochemical and metabolic properties, geometric arrangements - changes in 3D configuration in the anatomic structures they are embedded in.
- Improved understanding of normal and patho-physiological processes depends on accurate visualization and measurement of anatomical structures and their function, across the biological scale.
Need for Biological Imaging

■ Function and interaction of bodily organs and tissues are affected by their physical intervention into their working environment.

■ Direct measurement techniques are preferred, that minimize morphological and physiological disturbance.

■ Non-Invasive: Use of radiant energy based transmission (x-rays, gamma, radio waves, ultrasound) through the body produces images that does not affect the function, nor produce subjective sensations at low dosage levels.

■ A beam of radiation is absorbed and scattered to varying degrees, depending on composition of structures and beam intensity.

■ It is this differential absorption that creates images, and useful direct recording of internal, unseen structures.
Imaging Science: Historical Perspectives

X-Rays (1895)

- Rontgen (1895): Discovery of the invisible ray; observations of fluorescence in CRTs.
- Rontgen’s ray renamed x-ray; potential for medicine and biology recognized.
- Can see into the body in a painless, non-destructive way (without surgery)
- Potential for a new medical diagnostic technique.
- Modest risk (ionizing radiation) outweighed by ability to visualize structure when indicated by illness/symptoms
X-Rays (Rontgen, 1895)

Figure 1.1 First radiograph of hand made by W. C. Röntgen on December 22, 1895. Historical notes suggest it is the hand of Röntgen's wife. Note the ring on the third finger. Original plate is in the Deutsche Museum, Munich, Germany.
X-Rays (Mayo Clinic, 1995)

Figure 1.2 X-radiograph of patient’s hand made in 1995 at Mayo Clinic. Note improved quality by comparison to Figure 1.1. This is due primarily to improvement in X-ray film, not improvement in basic methodology or procedure, 100 years old at the time this X-ray was taken.
Historical Perspectives (contd)

- Fluoroscopic Imaging (Late 1940s): With image intensifier
- Coupled with video monitors, provides dynamic x-rays
- Contrast(Cine) Angiography: radiopaque dyes used to highlight blood vessel geometry
- 1950s and 1960s: Nuclear Medicine Tomography and Ultrasonography were important developments in biomedical imaging.
- 1970s: Epoch Making development similar in magnitude to "Rontgen’s ray": Tomographic Imaging
Limitations of X-Ray Imaging Techniques

- Small differences (1-2%) in x-ray attenuation not detectable, due to:
  - Low signal to noise ratio.
  - Film sensitivity.
  - Superposition problem.
X-Ray Computed Tomography (Early 70s)

- Innovated by Radon (1915)
- Mathematically rigorous inversion formula for object reconstruction from its projections
- Greatly eliminated the superposition problem
- Revolutionary impact on diagnostic imaging
- Combines highly collimated x-ray imaging and computer based image reconstruction techniques
- Unambiguous cross-sectional images, excellent discrimination of tissue differences
CT, MRI, Vascular Ultrasound Images

Example Biomedical Images
CT Technology Drivers

- Success primarily based on power and speed of computers
- Several new developments in CT and applied science principles
- 1979 Nobel price in physiology and Medicine: Allen Macleod Cormack and Geoffrey Hounsfield, for X-ray computer assisted tomography (CAT) or Computed Tomography (CT).

- Bracewell (1950s) - Practical reconstruction of an object from its projections (earlier work by Radon).

- Cormack (50s): Determination of distribution of attenuation constants in tissues, for radiation treatment planning.
  - X-Ray views at different angles can be used to solve the problem.
  - Led to a mathematically sound reconstruction solution.
CT Technology Drivers (contd)

■ Hounsfield (1960s):
  o Independently worked on the reconstruction problem
  o Theoretical calculations led to conclude that the quantitative tomographic technique could produce 100 times more accurate measurements.


■ 1972: Clinical data presented.

■ 1973-Classic publications by Hounsfield, Ambrose:
  o Hounsfield developed a numerically stable implementable mathematical solution to the reconstruction problem.
  o Organized electrochemical and x-ray technology into a precisely engineered instrument, resulting in a successful clinical scanner.
CT Technology Drivers (contd)

- 1976: More than 20 companies producing x-ray scanners, but quickly down to a few major manufacturers.

- 1980s: Many clinical hospitals with CT scanners, wealth of published data, new clinical applications.

- Disadvantages of CT (ionizing radiation) leads to new 3D CT technologies, such as MRI, PET.

- 90s: Multi-modality imaging - multiple images of the same tissue (objects) could be combined to provide a synergistic picture of body structures and function.
Current Issues/Trends

- Multimodality Imaging: Driven by new developments in scanning technologies and dynamic scanning of functional parameters.
- 3D imaging provides excellent anatomic detail, but need for measurement of cellular function, tissue composition and organ behavior.
- Other technologies (MRI, PET) need to be brought in.
- Significant options for the clinical physician for 3D biomedical imaging.
- But the extraction of objective and quantitative information from tomographic images - developments needed.
- Significant advances in microelectronics (and hence, the computational power of the desktop) liberates software developers to be more creative, without compromising on accuracy or functionality (ITK, VTK).
- Dynamic growing field of biomedical visualization.
Definitions

- **Goal of Biomedical Imaging and Visualization**: Use imaging science to acquire, transform, present and interact with multi-dimensional biomedical datasets.

- **3D imaging**: Acquisition of digital samples of objects in 3-space; generalized to include processing, display, analysis

- **Multimodal Imaging**: Use different imaging systems (CT, MRI, etc) to image same structure (spatio-temporal fusion)

- **Real-time Imaging**: Acquisition at video rates (30 fps)

- **Interactive Visualization**: High response time and repetition rate, in response to user initiated requests/events.

- **3D Visualization**: Transformation, Display of objects to represent their 3D nature (volume rendered projections, stereoscopic, holographic displays; includes manipulation/analysis
Definitions (contd)

- **Segmentation**: Complex task of recognition and labeling of all individual objects in images.

- **Registration**: Determining transformations that brings different images of the same object into spatio-temporal congruence.

- **Visualization**: Display, manipulation and quantification of image data.