Informatics in Radiology
Ronilda Lacson MD PhD
Brigham & Women’s Hospital
Center for Evidence-Based Imaging
Harvard Medical School
Boston, MA

Definitions
Radiology – the scientific discipline of medical imaging using ionizing radiation, radionuclides, magnetic resonance and ultrasound
Interventional radiology is the performance of medical procedures with the guidance of imaging.

What’s Special About Medical Images?
- Data Variability
  - What is abnormal?
  - Within Normal Range
  - From day-to-day
  - Positional
  - Technique-dependent
  - Noise → Motion

Radiology Consult Process
- Choose Imaging Procedure (consider efficacy, cost, risk)
- Analyze Images
- Integrate Imaging Findings with Clinical Context
- Determine Diagnosis or Set of Diagnostic Possibilities
- Communicate Results to Referring Physician
- Offer Recommendations

Imaging Tasks
- Image Generation
- Image Manipulation
- Image Management
- Image Integration

Shortliffe, Biomedical Informatics
Limitations
- Imaging techniques require use of energy
- Heat generation → Cell damage.

Cost/Benefit
- Imaging should not endanger a human being and cause undue pain, trauma or discomfort.

Image Generation
- Process of generating images and converting them to digital format
- A digital image is represented in a computer as a 2D array (a bit map)
- Each array element represents the intensity of a square area of the picture (pixel)

Image Parameters
- Spatial Resolution (# of pixels/image area)
- Contrast Resolution (# of bits/pixel)
- Temporal Resolution

Issues
- Dose Creep
- Pediatric Imaging (ALARA)

Comparative Imaging Parameters

<table>
<thead>
<tr>
<th></th>
<th>CR</th>
<th>MRI</th>
<th>CT</th>
<th>US</th>
<th>NM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixels per image</td>
<td>2548x2566</td>
<td>256x256</td>
<td>512x512</td>
<td>512x512</td>
<td>128x128</td>
</tr>
<tr>
<td>Bits per pixel</td>
<td>12</td>
<td>10</td>
<td>12</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td># images per study</td>
<td>2</td>
<td>100</td>
<td>60</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Bytes per study</td>
<td>20M</td>
<td>12M</td>
<td>30M</td>
<td>7.5M</td>
<td>0.5M</td>
</tr>
<tr>
<td>Contrast resolution</td>
<td>low</td>
<td>high</td>
<td>high</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>high</td>
<td>low</td>
<td>mod</td>
<td>mod</td>
<td>low</td>
</tr>
<tr>
<td>Temporal resolution</td>
<td>low</td>
<td>low</td>
<td>mod</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Radiation</td>
<td>mod</td>
<td>none</td>
<td>mod</td>
<td>none</td>
<td>mod</td>
</tr>
<tr>
<td>Cost</td>
<td>mod</td>
<td>high</td>
<td>high</td>
<td>low</td>
<td>mod</td>
</tr>
</tbody>
</table>
Terms

- DLP (Dose Length Product)
- CTDI (CT Dose Index)

Image Manipulation

- Uses pre and post processing methods to enhance, visualize and analyze images

Basic Image Processing

- Global processing – enhances visualization
- Segmentation – extract regions of interest
- Feature detection
- Classification

Global Processing

- Image enhancement (e.g. windowing)
- Contrast enhancement (e.g. histogram equalization)
- Edge enhancement
- Noise filtering

Windowing
Image Histogram

Image Pixels

<table>
<thead>
<tr>
<th>Value</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>52</td>
<td>1</td>
</tr>
<tr>
<td>55</td>
<td>3</td>
</tr>
<tr>
<td>58</td>
<td>2</td>
</tr>
<tr>
<td>59</td>
<td>3</td>
</tr>
<tr>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>61</td>
<td>4</td>
</tr>
<tr>
<td>62</td>
<td>1</td>
</tr>
<tr>
<td>63</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Value</th>
<th>Count</th>
<th>Value</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>64</td>
<td>2</td>
<td>72</td>
<td>1</td>
</tr>
<tr>
<td>65</td>
<td>3</td>
<td>73</td>
<td>2</td>
</tr>
<tr>
<td>66</td>
<td>2</td>
<td>75</td>
<td>1</td>
</tr>
<tr>
<td>67</td>
<td>1</td>
<td>76</td>
<td>1</td>
</tr>
<tr>
<td>68</td>
<td>5</td>
<td>77</td>
<td>1</td>
</tr>
<tr>
<td>69</td>
<td>3</td>
<td>78</td>
<td>1</td>
</tr>
<tr>
<td>70</td>
<td>4</td>
<td>79</td>
<td>2</td>
</tr>
<tr>
<td>71</td>
<td>2</td>
<td>83</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Value</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1113</td>
<td>1</td>
<td>122</td>
<td>1</td>
<td>144</td>
<td>1</td>
<td>154</td>
<td>1</td>
<td>166</td>
<td>1</td>
</tr>
<tr>
<td>153</td>
<td>2</td>
<td>104</td>
<td>2</td>
<td>106</td>
<td>1</td>
<td>109</td>
<td>1</td>
<td>110</td>
<td>1</td>
</tr>
<tr>
<td>1109</td>
<td>1</td>
<td>1108</td>
<td>1</td>
<td>1109</td>
<td>1</td>
<td>1109</td>
<td>1</td>
<td>1109</td>
<td>1</td>
</tr>
<tr>
<td>1106</td>
<td>1</td>
<td>1105</td>
<td>1</td>
<td>1106</td>
<td>1</td>
<td>1106</td>
<td>1</td>
<td>1106</td>
<td>1</td>
</tr>
<tr>
<td>1104</td>
<td>1</td>
<td>1103</td>
<td>1</td>
<td>1104</td>
<td>1</td>
<td>1104</td>
<td>1</td>
<td>1104</td>
<td>1</td>
</tr>
<tr>
<td>1102</td>
<td>1</td>
<td>1101</td>
<td>1</td>
<td>1102</td>
<td>1</td>
<td>1102</td>
<td>1</td>
<td>1102</td>
<td>1</td>
</tr>
<tr>
<td>1100</td>
<td>1</td>
<td>1100</td>
<td>1</td>
<td>1100</td>
<td>1</td>
<td>1100</td>
<td>1</td>
<td>1100</td>
<td>1</td>
</tr>
<tr>
<td>1108</td>
<td>1</td>
<td>1107</td>
<td>1</td>
<td>1108</td>
<td>1</td>
<td>1108</td>
<td>1</td>
<td>1108</td>
<td>1</td>
</tr>
<tr>
<td>1106</td>
<td>1</td>
<td>1105</td>
<td>1</td>
<td>1106</td>
<td>1</td>
<td>1106</td>
<td>1</td>
<td>1106</td>
<td>1</td>
</tr>
<tr>
<td>1104</td>
<td>1</td>
<td>1103</td>
<td>1</td>
<td>1104</td>
<td>1</td>
<td>1104</td>
<td>1</td>
<td>1104</td>
<td>1</td>
</tr>
</tbody>
</table>

Histogram Equalization formula

\[ b(v) = \text{round} \left( \frac{\text{cdf}(v) - \text{cdf}_{\text{min}}}{(M \times N) - \text{cdf}_{\text{min}}} \times (L - 1) \right) \]

\[ \text{cdf}_{\text{min}} = \min. \text{cdf value} \]

\[ M \times N = \text{image pixels} \]

\[ L = \text{number of grey levels} \]
Contrast Enhancement

Image Management
- Methods for storing, transmitting, displaying, retrieving and organizing images

Old workflow
- CT or MRI in digital format
- Technologist transfers optimized version to film
- Technologist labels film folder
- Radiologist views films on illuminated light boxes
- Clinician can check out film for viewing

New workflow
1. Clinician evaluates problem and decides on need for imaging
2. Procedure is requested and scheduled (indication and history made available)
3. Imaging is carried out
4. Radiologist reviews (and manipulates) the images
5. Report is created (results are communicated)
6. Quality control and monitoring are carried out
7. Continuing education and training/feedback to radiologist

Picture Archiving and Communication Systems (PACS)
- High resolution acquisition
- High capacity storage
- High speed networking
- Storage management
- Standard image transmission and storage formats
- Design workstations for radiologists

Data Compression
- Lossless compression
- Lossy compression (e.g. JPEG)
PACS

DICOM

- Digital Imaging and Communications in Medicine
- Standard for transferal of radiologic images and medical information between computers
- Enables digital communication between diagnostic and therapeutic equipment and systems from various manufacturers
- Copyright, National Electrical Manufacturers Association (joint work with ACR)

- Includes a file format and a communication protocol (using TCP/IP)

Entity-relationship diagram illustrates the DICOM real-world model, in which a Patient has one or more Studies and each Study contains one or more Series.

The CT Image IOD.

<table>
<thead>
<tr>
<th>ID</th>
<th>Module</th>
<th>Reference</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient</td>
<td>0.7.1.1</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>0.7.1.3</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>Image Phase</td>
<td>0.7.2.0</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>Image Pixel</td>
<td>0.7.2.1</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>Image Frame</td>
<td>0.7.2.2</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>Image Field</td>
<td>0.7.2.3</td>
<td>M</td>
<td></td>
</tr>
</tbody>
</table>

Entity-relationship diagram illustrates the DICOM real-world model, in which a Patient has one or more Studies and each Study contains one or more Series.

A portion of the table that defines the attributes of the CT Image module.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ImageType</td>
<td>0x0008.0008</td>
<td>Image type, in this case 0x3000.0010, indicating CT image.</td>
</tr>
<tr>
<td>SamplingMatrix</td>
<td>0x0018.1050</td>
<td>Sampling matrix, e.g., 1024x1024.</td>
</tr>
<tr>
<td>PhotometricInterpretation</td>
<td>0x0018.1051</td>
<td>Photometric interpretation, typically 0x2001.0010.</td>
</tr>
<tr>
<td>WinMin</td>
<td>0x0028.0010</td>
<td>Minimum window level, typically 0.0.</td>
</tr>
<tr>
<td>WinMax</td>
<td>0x0028.0011</td>
<td>Maximum window level, typically 4095.0.</td>
</tr>
<tr>
<td>HighBit</td>
<td>0x0028.0012</td>
<td>High bit for pixel sample (e.g., 8 bit, 16 bit).</td>
</tr>
<tr>
<td>RescaleIntercept</td>
<td>0x0028.1050</td>
<td>Intercept for linear rescale.</td>
</tr>
<tr>
<td>RescaleSlope</td>
<td>0x0028.1051</td>
<td>Slope for linear rescale.</td>
</tr>
<tr>
<td>SOPClassCode</td>
<td>0x0008.0008</td>
<td>SOP class code, typically 0x5200.1000.</td>
</tr>
</tbody>
</table>
A portion of the table that defines the attributes of the Patient module shows attribute names and their tags, which are defined in Part 6 of the DICOM Standard.

**Image Integration**

Combination of images with other information needed for interpretation, management and other tasks.

**Increasing Utilization of Imaging Examinations**

- Impact on patients’ outcome
- Radiation risk
- Imaging costs

- Will the imaging exam affect patient management?

**Decision Support**

- Incorporated into the CPOE
- Provides guidance when ordering exams

**Some Reasons for Inappropriate Imaging**

- Inappropriate clinically (e.g. low yield, better imaging available)
- Inappropriate frequency (e.g. duplicate orders, recently done elsewhere)
**Examples of Decision Support within the CPOE**

- American College of Radiology (ACR)
  - “Appropriateness criteria” for various imaging modalities

**Imaging Guidelines**
- Evidence-based versus opinion-based
- Increasing number
- Difficult to encode and update

**Critical Results**

<table>
<thead>
<tr>
<th>Alert Category</th>
<th>Examples of Critical Findings</th>
<th>Notification Timeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Alert</td>
<td>Transient ischemic stroke, subarachnoid hemorrhage</td>
<td>≤ 60 minutes</td>
</tr>
<tr>
<td>Orange Alert</td>
<td>Intra-abdominal abscess, impending pathologic hip fracture</td>
<td>≤ 3 hours</td>
</tr>
<tr>
<td>Yellow Alert</td>
<td>Lung nodule, Soft renal mass</td>
<td>≤ 3 days</td>
</tr>
</tbody>
</table>

**CCTR**

Impact of a Stakeholder Communication Strategy on Clinical Engagement Performance on 100% of Critical Test Results
QA

Advanced Image Processing
- CAD
- Surgical Planning

Potential Reasons for Errors
- Technical Limitations
- Insufficient Training
- Cognitive Overload

Training Materials
- Reference Materials (Books, Scientific journals, Image files)
- Clinical experience

On-Line Image Files
- ARRS GoldMiner (Am Roentgen Ray Soc)
- Yottalook™
- BWH Instance of RSNA MIRC
- MedPix
- StatDX

Advanced Processing & Computer-Aided Diagnosis (CAD)
- Role in improving diagnostic accuracy
- Potential for new clinical applications
**CAD Algorithms**

- Lung nodule detection in chest CT
- Lesions in Mammograms

**CAD**

- For some diseases, radiologists using CAD produce significantly better predictions than either the radiologist or the CAD algorithm alone.

**Advanced Image Processing**

Rubin et al, BMC Bioinformatics, 2009

**MR-guided Prostate Biopsy**

Pace et al, Slicer3 Training Compendium, NAMIC

**Diffusion Tensor Imaging**

Rosenberger et al, St Huesler Res, 2005

**Advanced Image Processing**

- CAD and advanced imaging are critical to radiology.
- Complete replacement of radiologist is unlikely.