A Comparison of Screen/Film and Digital Imaging: Image Processing, Image Quality, and Dose

Ralph Schaetzing, Ph.D.
Agfa Corporation
Greenville, SC
This presentation...

- does...
  - focus on salient characteristics of two projection-radiography acquisition technology classes
    - Analog: screen/film (S/F)
    - Digital: generic

- does not...
  - focus on technology details (see other presentations)
    - Specific technologies used as examples only
  - address alternatives to projection imaging (i.e., x-sectional)
  - cheerlead
    - No technology-class recommendations - too many other issues
Digital Image Acquisition Technologies

Direct

X-ray quanta
↓
meas. output signal

- Photoconductor + point scan
- Silicon Strip + line/slot scan
- Photoconductor + flat-panel array

Indirect

X-ray quanta intermediate(s)
↓
meas. output signal

- Screen/Film + point scan
- Scintillator + point scan
- Screen/Film + line scan
- Scintillator + line scan
- Scintillator + area sensor(s)
- Scintillator + flat-panel array

- Storage Phosphor + point scan
- Storage Phosphor + line scan
  Commonly called Computed Radiography (CR)

Commonly called Digital Radiography (DR)
The Medical Imaging Chain (Analog, Digital)

ANALOGUE WORLD (visible)
- Acquire
  - Preprocess
  - Process (Optimize)
- Store
- Process for Output
- Reproduce

DIGITAL WORLD (hidden)
- Distribute

Human
The Bigger Picture

Imaging and Information System Environment

Producers/Competitors

Regulators/Standardizers

Clinical

Technical

Observers

Operational

Economic

Acquirers

Producers

Stores

Receives

Consumers
Outline of Presentation

- **Dose and Image Quality in S/F and Digital Systems**
  - Dose requirements: the speed limit
  - Image quality as a dose metric
  - Does image quality really matter?
- **Image Processing in S/F and Digital Systems**
  - Image processing for display optimization
  - Image processing for decision support
- **Wrap-up and Conclusions**
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When x-ray dose wasn’t so important...
When x-ray dose became important...

- Biological effects became clearer quickly

- Dose: a metric by which to compare systems (and facilities – e.g., FDA’s NEXT Survey)

- ALARA Principle: As Low As Reasonably Achievable
Comparing Dose Requirements:

Speed

- Analog S/F
    *Photography -- Sensitometry of screen/film systems for medical radiography -- Part 1: Determination of sensitometric curve shape, speed and average gradient*
    
    \[ S = \frac{1000}{K_s(\mu\text{Gy})} \]
  - Speed defined by incident air kerma \( K_s \) giving net density of 1.0 under specific conditions (exposure, processing, etc.)

- Digital
  - Linear, wide-latitude response, and variable detector kV-dependence makes definition non-trivial, manufacturer-dependent
  - Confusion and frustration
  - Efforts underway to create standardized definition of speed (AAPM, DIN, IEC, manufacturers)
Comparing Dose Requirements: Speed

- Linear, wide-latitude response of digital systems still confused with dose efficiency
  - Latitude ≠ Dose Reduction!
    (Can always find S/F system that operates at same dose level as digital system)
- Multiple, different S/F systems needed to cover same exposure range as one digital system
- Question: even if signal levels matched, is S/F image quality (e.g., sharpness, noise) level comparable to that of digital?
Comparing Dose Requirements:
Detective Quantum Efficiency (DQE)

\[ DQE = \frac{\text{(Measured) Noise from ideal detector}^*}{\text{Measured Noise from real detector}^*} \]

\( \propto \frac{(\text{Contrast or Gain})^2 \times (\text{Sharpness})^2}{\text{Measured Noise}} \)

spatial-frequency- and exposure-dependent, i.e., a SURFACE!

\( = 1.0 \) for ideal detector

*Noise values must be expressed in same units

\[ \text{Detector} \]

Input Exposure

\[ \text{Signal}_{\text{in}} \rightarrow \text{Signal}_{\text{out}} \rightarrow \text{Recorded Image} \]

\[ \text{Noise}_{\text{in}} \rightarrow \text{Noise}_{\text{out}} \]

\( \text{Noise}_{\text{out}} > \text{Noise}_{\text{in}} \)
Comparing Dose Requirements: Reported DQE(0) Values for S/F and Digital

Detective Quantum Efficiency (@ f = 0 cy/mm)
Comparing Dose Requirements:

DQE: Caveat Emptor...

- Standard exists...

- But...
  - Make sure that standard was followed!
Which image has the highest quality?
Image Quality: What is it?

- Image quality depends only on intrinsic, objective physical characteristics of an imaging system, and can be measured independently of an observer.

- Image quality is whatever the observer says it is (i.e., it is a subjective perception of the image, "in the eye of the beholder").

- Image quality is defined by an observer’s ability to achieve an acceptable level of performance for a specified task.
Image Quality: What is it?

Objective Measures

- Physical Characteristics

Subjective Measures

- Perception
- Confidence
- Preference
- Preference

Performance Measures

- Diagnostic Accuracy
- Diagnostic Error Rate
- Patient Management
- Patient Outcome

Objective Measures

- Physical Characteristics


Radiographic Image Quality: Does it matter?

### Evolution of Projection Radiography and Image Quality

<table>
<thead>
<tr>
<th>Photon Counting</th>
<th>DR (needle scint., TFT)</th>
<th>DR (photocond., TFT)</th>
<th>DR (scint., CCD)</th>
<th>CR (needle IP, line scan)</th>
<th>CR (powder IP, point scan)</th>
<th>DR (II, CCD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ANALOG</strong></td>
<td>S/F (UV)</td>
<td><strong>DIGITAL</strong></td>
<td>S/F (Green)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct Film Exposure (no screen)</td>
<td></td>
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</tr>
</tbody>
</table>

Significant image quality changes!
Significant dose changes: 50-100x

### Evolution of Radiologist Error Rate (unaided)

Very little change in performance...
Radiographic Image Quality: Does it matter?

- Imaging system manufacturers are wasting their time trying to maintain or improve image quality because end users can’t or don’t use it clinically
  Limiting factor: radiologist

- Radiologists are so skilled that they can locate the relevant clinical information consistently, independent of image quality (at least, to date)
  Limiting factor: imaging system

Evolution of Radiologist Error Rate (unaided)

If the imaging system is the limiting step...
New acquisition, image processing systems with unprecedented objective image quality

If the radiologist is the limiting step...
Decision-support systems: Computer-Aided Detection/Diagnosis
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Medical Image Processing – Many Goals

- Optimize for human vision
  - Signal contrast
  - Latitude
  - Dynamic range (acquired vs. displayed)
  - Sharpness
  - Noise
- Optimize for machine vision
  - CAD
  - CAD<sub>x</sub>

- Optimize for storage
  - Memory requirements
  - Storage media requirements
  - Cost

- Optimize for distribution
  - Network efficiency (bandwidth)
  - Transmission/delivery time (e.g., teleradiology)
  - Access time (read/write)
  - Cost
Image Processing for Display: Optimizing for Human Vision

Can you find the 20 “blob” targets in this image?

MUSICA = MUlti-Scale Image Contrast Amplification
Image Processing for Display:
Optimizing for Human Vision in S/F

- Detector choices
  - Screen
  - Film
- Exposure choices
  - Technique (kV<sub>p</sub>, mA, s)
  - Hypersensitization
    - Uniform pre-exposure to light nucleates sub-image that becomes developable with further exposure
    - Improves speed, SNR
- Chemical processing choices
  - Chemistry type, activity, seasoning, replenishment
  - Time
  - Temperature
  - Adjacency effect
    - Edge enhancement (unsharp masking!) through control of developer dynamics
- Viewing choices
  - Viewbox luminance, quality, spectrum, masking, magnif.
Image Processing for Display: Optimizing for Human Vision in Digital

- Wide latitude + post-processing flexibility of most digital systems enables HUGE variety of optimization techniques
  - Manual vs. ...
  - Semi-automatic (exam-dependent) processing vs. ...
  - Fully automatic (hands-free) processing
- Contrast (Gradation/Tone Scale)
  - Look-up Tables (LUTs)
  - Histogram-based
  - Contrast/Latitude dilemma
- Sharpness (Edge Enhancement)
  - Unsharp masking
  - Multi-scale techniques (custom contrast at each of a set of frequency bands)
- Noise (Reduction/Smoothing)
  - Used sparingly (effect on signals?)
Image Processing for Decision Support: Optimizing for Machine Vision (CAD)

Computers can be trained to do this well and consistently (for well-defined targets)

- Sources of radiologist error (chest*)
  - Search/Scanning: 15%
  - Recognition: 37%
  - Perceptual Decision:
  - Interpretive Decision: 48%

- Performance evaluation nontrivial
  - Pathology/target-dependent
  - Operating point? (TP, FP)
  - Best schemes can outperform radiologists (target-dependent)

Image Processing for Decision Support: CAD Implementation Issues

- Detection performance sensitive to acquisition system details
  - Contrast resolution
    - Wide/narrow latitude
    - Linear/nonlinear response
  - Spatial resolution (e.g., pixel size)
  - Noise
- Operational issues
  - S/F: extra digitization step
  - Consistency of results?

- Proc. protocol (image vs. study)
- Testing/Scoring/Training (“truth”)
- Productivity/Workflow/Recalls
- Case load (screening?, volume?)
- Satisfaction of Search (faith vs. blind faith)
- Observer experience/knowledge
- Clinical Efficacy
- Radiologist Acceptance
- Cost/reimbursement
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## Analog or Digital Technologies – Quo vadis?

<table>
<thead>
<tr>
<th></th>
<th>S/F</th>
<th>or</th>
<th>Digital</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dose</strong></td>
<td><img src="image1" alt="Weight" /></td>
<td><img src="image2" alt="Weight" /></td>
<td><img src="image3" alt="Weight" /></td>
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<tr>
<td><strong>Image Quality</strong></td>
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<tr>
<td>Physical</td>
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<td><img src="image8" alt="Weight" /></td>
<td><img src="image9" alt="Weight" /></td>
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<tr>
<td>Subjective</td>
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<td><img src="image11" alt="Weight" /></td>
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<td>Performance-based</td>
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<tr>
<td><strong>Image Processing</strong></td>
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<td><img src="image17" alt="Weight" /></td>
<td><img src="image18" alt="Weight" /></td>
</tr>
<tr>
<td>Display Optimization</td>
<td><img src="image19" alt="Weight" /></td>
<td><img src="image20" alt="Weight" /></td>
<td><img src="image21" alt="Weight" /></td>
</tr>
<tr>
<td>Decision Support (e.g., CAD)</td>
<td><img src="image22" alt="Weight" /></td>
<td><img src="image23" alt="Weight" /></td>
<td><img src="image24" alt="Weight" /></td>
</tr>
</tbody>
</table>
Back to the Bigger Picture:
The Path to System Equilibrium...

Convenience

Flexibility

Interaces (e.g., EPR)

Consumers

Technolust

Regulators/Standardizers

Clinical

Acquire

Operational

Producers/Competitors

Technical

Stores

Economic

Observers

Control

Interfaces

Technolust

Convenience Consistency

Control

Interfaces

Technolust
Thank You for Your Attention