Digital Image Processing in Radiography

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Outline

- Display Processing
  - Data preprocessing
  - ROI segmentation and analysis
  - Tonal rendering
  - Signal equalization
  - Edge restoration
  - Noise suppression
  - Collimation masking
  - Display compensation
- Image Processing Features
  - Stationary grid detection and suppression
  - Long-length imaging
  - Dual energy imaging
  - Mammography
  - Oncology processing
  - Quality control testing

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Display Processing

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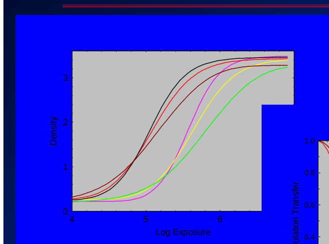
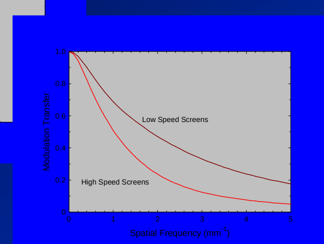
“Analog” Image Processing…



Screen/Film Radiography (S/F)



Film ⇒ Speed & Contrast
Screen ⇒ Speed & MTF

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Digital Image Processing

Digital Image Acquisition

Digital Image Processing

Digital Image Display

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Why Image Processing?

- Maintain the familiar characteristics of S/F
  - Provide a similar tonal rendering
  - Restore desired sharpness
- Beyond the familiar
  - Automatically adjust for errors in exposure
  - Automatically accommodate changes in latitude
  - Increase the range of exposures visualized
  - Enhance selected spatial frequencies
  - Highlight regions of interest (ROI)
  - Assist the radiologist to find features of interest

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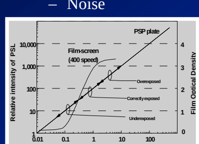
Display Processing

- Transform digital radiography raw data to display values for presentation using a workstation or film printer, *automatically*, *robustly*, and *consistently*.
- Components of Image Quality
  - Latitude
  - Contrast
  - Brightness
  - Sharpness
  - Noise



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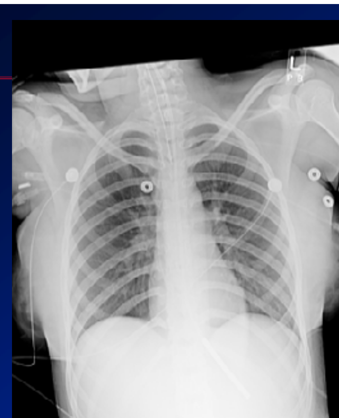

Original Image

Tone Scale

Edge Restoration

Signal Equalization

Collimation Masking

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Original Image

Tone Scale

Edge Restoration

Signal Equalization

Collimation Masking

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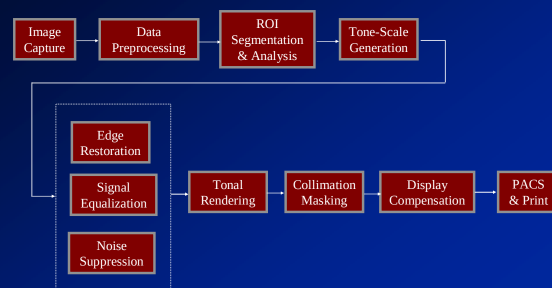
Schematic Flow Chart of Display Processing



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Data Preprocessing

- Image reformation
  - Composition (dual-side CR reading)
  - Decomposition (dual energy)
  - Resize
- Signal filtering
  - Gain, offset, and bad pixel correction (DR)
  - Noise reduction
  - Stationary grid artifact suppression
- Data space conversion
  - Linear to logarithmic (const. object contrast vs. pixel value)
  - Linear to square root (const. quantum noise vs. pixel value)

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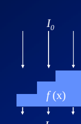
Data Preprocessing (cont.)

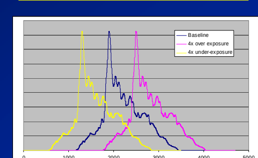
Linear-to-log conversion

Shape of image histogram invariant to exposure



$I = I_0 e^{-f(x)}$

$f(x) = \log(I_0 / I) \sim -\log(I) + const.$



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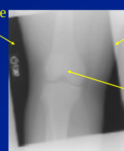
ROI Segmentation & Analysis

- Extract diagnostically relevant ROIs
- Analyze ROI characteristics
- Derive the optimal display-rendering parameters
- Include four basic steps
  - Detect collimation mask
  - Detect direct exposure
  - Extract anatomy regions
  - Calculate key image descriptors



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Segmentation – Collimation Mask

- Confine exposure regions
- Mask applied to collimated regions to reduce viewing flare

“Method for recognizing multiple radiation fields in computed radiography,” X. Wang, J. Luo, R. Senn, and D. Foos, Proc SPIE 3661, 1625-36, 1999.

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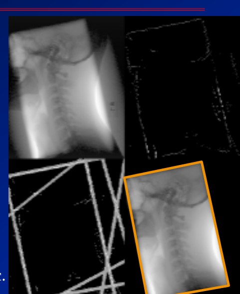
Segmentation – Collimation Mask (cont.)

- Collimation boundary pixels
  - Edge profile analysis
  - Transition segments classification
- Candidate collimation blades
  - Edge delineation
  - FOM analysis
    - straightness
    - connectedness…
- Candidate configurations
- Select “best” configuration
  - Parallelism, convexity, orthogonality, etc.



J. Luo and R. Senn, “Collimation detection for digital radiography," Proc. SPIE **3034**, 74-85 (1997).

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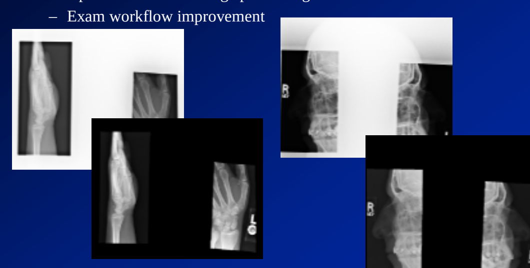
Segmentation – Collimation Mask (cont.)

- Multiple radiation field masking
  - Optimal individual image processing
  - Exam workflow improvement



“Method for recognizing multiple radiation fields in computed radiography,” X. Wang, J. Luo, R. Senn, and D. Foos, Proc SPIE 3661, 1625-36, 1999.

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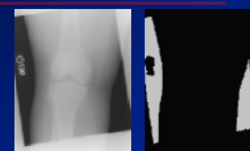
Segmentation – Collimation Mask (cont.)

Aggressive Failure

Conservative Failure

Segmentation - Direct Exposure Detection

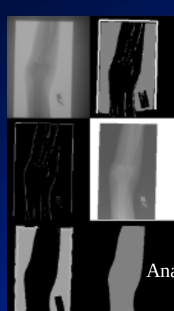
Exclude non-anatomical regions within the collimation.

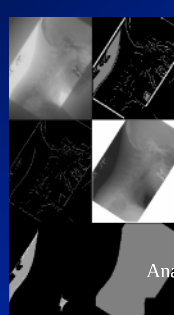


- Compensate
  - Radiation field non-uniformity
  - X-ray scatter
  - Multiple exposures
- Transition segment analysis
  - Line profile analysis
  - Background transitions characterized by slope and extent
  - Background pixel histogram analysis
  - Spatial correlation of exposure variations

L. Barski and R. Senn "Determination of direct x-ray exposure regions in digital medical imaging," U.S. Patent 5,606,587 (1997).

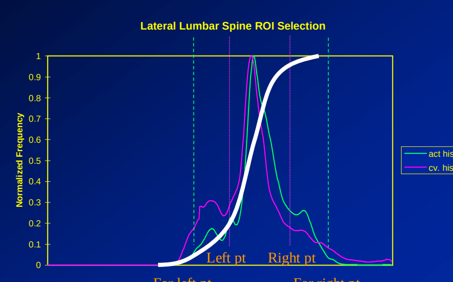
Segmentation – Anatomy Extraction





"Automatic and exam-type independent algorithm for the segmentation and extraction of foreground, background, and anatomy regions in digital radiographic images," X. Wang, H. Luo, Proc. SPIE 5370, 1427-1434, 2004.

ROI Analysis - Key Image Descriptors



Tone-Scale Generation

- Render image with proper brightness and contrast
  - Calculate average exposure within ROI
  - Automatically adjust for errors in exposure
- Sigmoid curve shape in general
  - Curve shift (brightness adjustment)
  - Curve rotation (contrast adjustment)
  - Toe & shoulder adjustment
- Bear different names
  - Kodak: PTS (Perceptual Tone Scale)
  - Fuji: Gradation Processing
  - …

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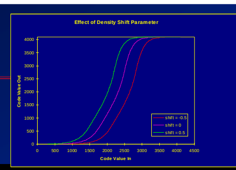
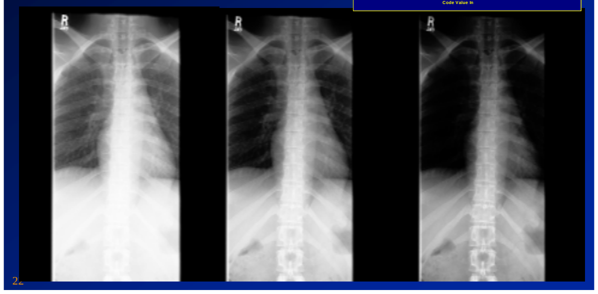
Brightness Adjustment





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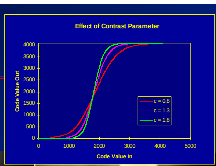
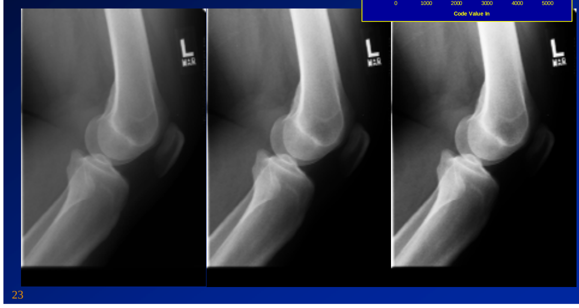
Contrast Adjustment





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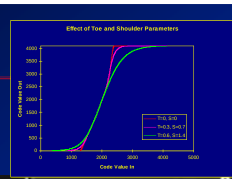
Toe & Shoulder Adjustment



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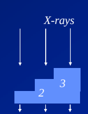
Visually Optimized Tone Scale

Perceptual Linearity -

Render ROI such that… equal physical contrast being perceived as equal brightness by the observer across the full brightness range



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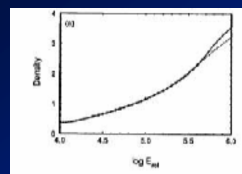
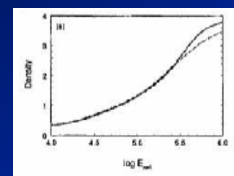
Visually Optimized Tone Scale (cont.)

Radiologists prefer S/F systems with perceptually linear sensitometric response.



Kodak Insight Thoracic Imaging System



Kodak Insight HC Thoracic Imaging System

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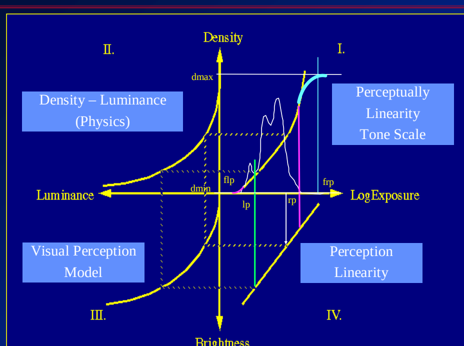
Perceptual Tone Scale



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Perceptual Tone Scale (cont.)

Equal Log (E) Equal Brightness

Daly's Global Cone Model

$$B = \frac{B_m L^n}{L^n + L_0^n}$$

B = perceived brightness
L = luminance of the image area
B_m = scale factor
n = 0.7

$$L_0 = 12.6*(0.2*L_w)^{0.63} + 1.083*10^{-5}$$

L_w = luminance of the reference white

H. Lee, S. Daly, and R. Van Metter, "Visual optimization of radiographic tone scale," Proc. SPIE 3036, 118-129, 1996.

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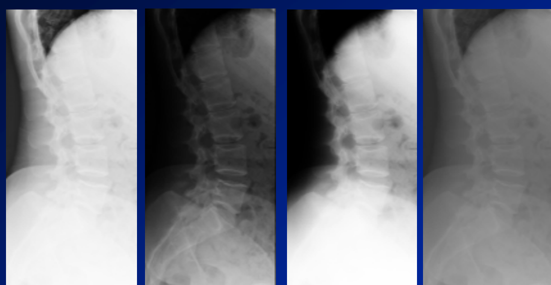
Tone Scale Failures



Too Bright | Too Dark | Too Much Contrast | Too Less Contrast

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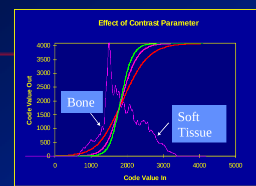
Signal Equalization

Balance between contrast vs. latitude



Good Soft Tissue Contrast | Signal Equalization | Good Bone Contrast

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Signal Equalization (cont.)

- Automatically accommodate changes in latitude
  - Compress the image-signal dynamic range such that all information within ROI can be rendered with optimal contrast
- Increase the range of exposures visualized
- Reduce exposure re-take and improve workflow
- Signal equalization processing is
  - 2D spatial processing
  - Digital wedge filter
  - Bearing different names:
    - EVP - Enhanced Visualization Processing (Kodak)
    - DRC - Dynamic Range Compression (Fuji)
    - Latitude Reduction (AGFA)
    - Tissue Equalization Processing (GE)
    - …

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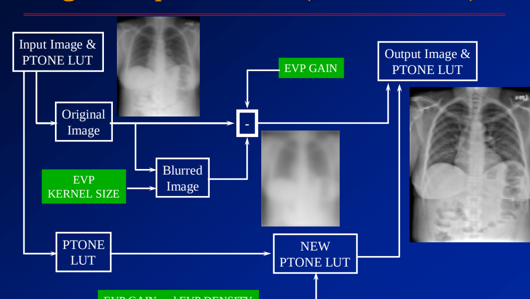
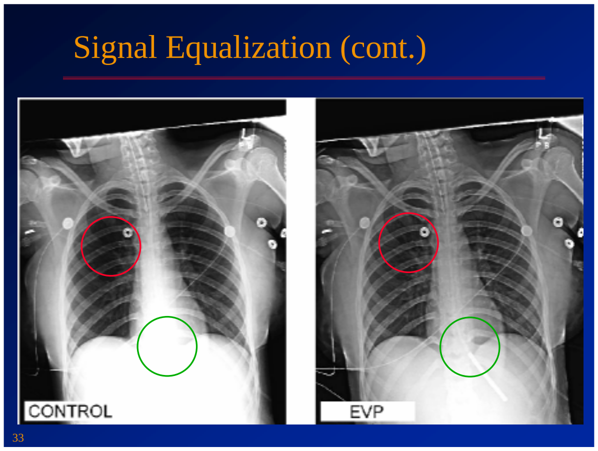
Signal Equalization (Kodak EVP)

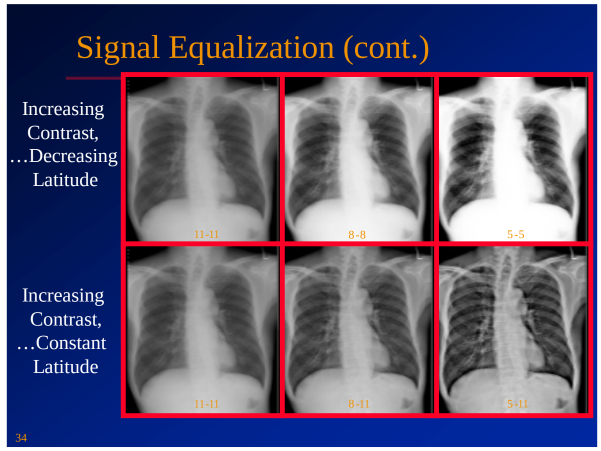


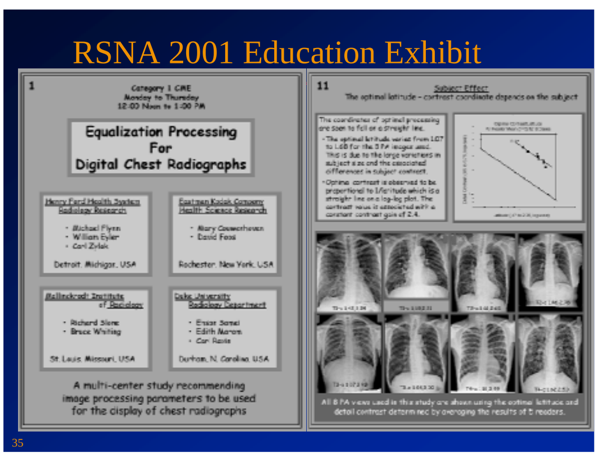
E'(i,j) = { E(i,j) K } + (1 -) E_{mid} + { E(i,j) - (E(i,j) K) }

D(i,j) = [E'(i,j)].

32 "Enhanced latitude for digital projection radiography," R. Van Metter and D. Foos, Proc. SPIE 3658, 468-483, 1999.







Observer "rendering preferences" established through collaborative studies with university hospitals (…to set default parameters for automatic processing)

High ↑ Contrast ↓ Low

Detail Contrast D/ LogE	Latitude LogE =>	0.35	0.47	0.56	0.78	0.92	1.09	1.46	1.75	2.06
6.75		1.4	1.8	2.2	3.0	3.6	4.2	5.6	6.8	7.9
5.75			1.5	1.9	2.6	3.0	3.6	4.8	5.8	6.8
5		1.0	1.3	1.6	2.2	2.6	3.1	4.2	5.0	5.9
3.75			1.0	1.2	1.7	2.0	2.3	3.1	3.8	4.4
3.1				1.0	1.4	1.6	1.9	2.6	3.1	3.6
2.25					1.0	1.2	1.4	1.9	2.3	2.6
1.9						1.0	1.2	1.6	1.9	2.2
1.6							1.0	1.3	1.6	1.9
1.2								1.0	1.2	1.4
1									1.0	1.2
0.85										1.0
	Latitude rel. to Ref.	0.38	0.51	0.61	0.84	1.00	1.19	1.58	1.90	2.24

Narrow ← Latitude → Wide

"Optimal display processing for digital radiography," M. Flynn, M. Couwenhoven, W. Eyler, B. Whiting, E. Samei, D. Foos, R. Slone, and E. Marom, Proc. SPIE 4319-36, 2001.

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Optimal PA View

Kodak T-Mat G Film detail contrast with 2X extended latitude

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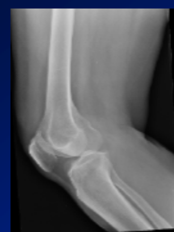
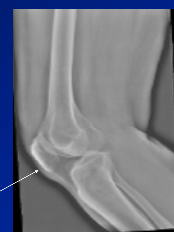
Signal Equalization (cont.)

Equalization Processing Artifact



Properly Processed

Halo Artifact



Overprocessed

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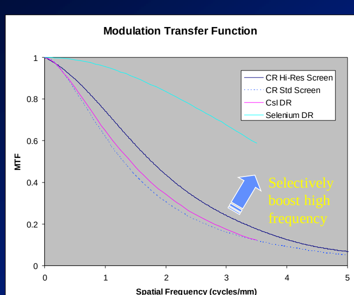
Edge Restoration



High-frequency signal is suppressed by system MTF.

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Edge Restoration (cont.)

- Selectively boost high-frequency signals based on
  - Exam type
  - Brightness
  - Exposure
  - Diagnostic features
  - Capture device characteristics
- Multi-frequency processing (2D spatial)
  - Kodak: EVP & USM (Enhanced Visualization Processing & UnSharp Mask)
  - AGFA: MUSICA (**MU**lti-**S**cale **I**mage **C**ontrast **A**mplification)
  - Konica: Hybrid (Mutil-Resolution Hybrid Processing)
  - Fuji: USM & MFP (Multi-Objective Frequency Processing)
  - Philips: UNIQUE (UNified Image QUality Enhancement)

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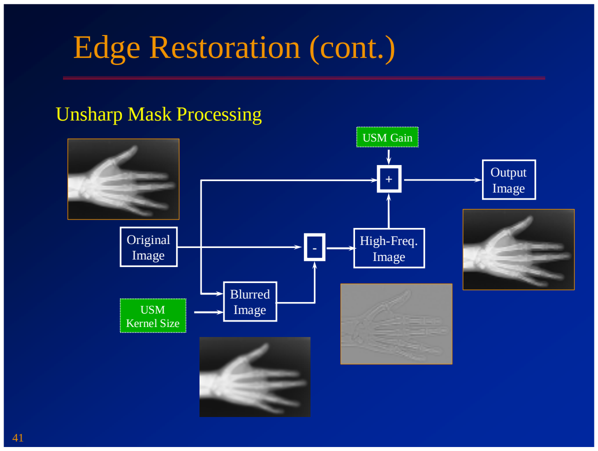
Edge Restoration (cont.)
Unsharp Mask Processing
USM Gain
Output Image
Original Image
High-Freq. Image
Blurred Image
USM Kernel Size
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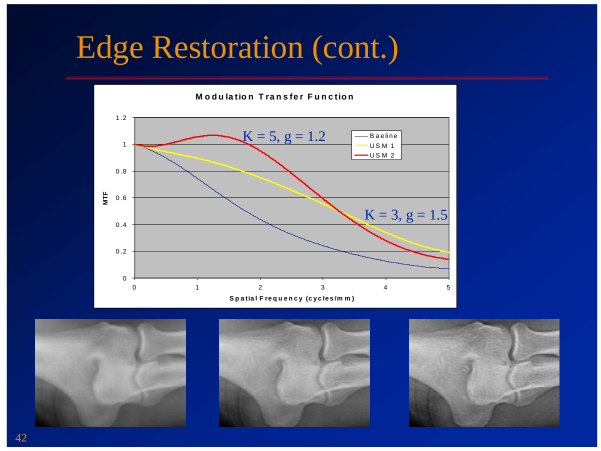
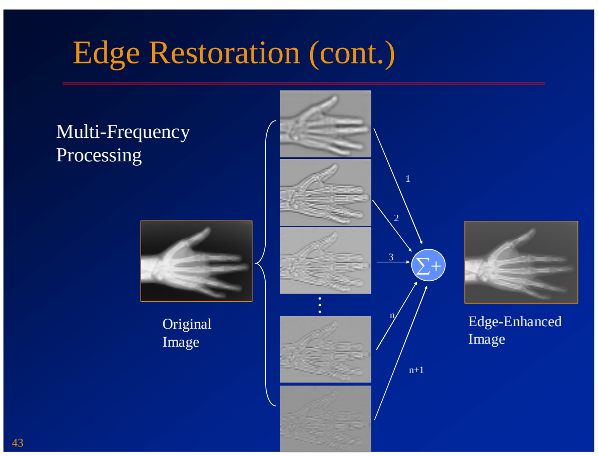
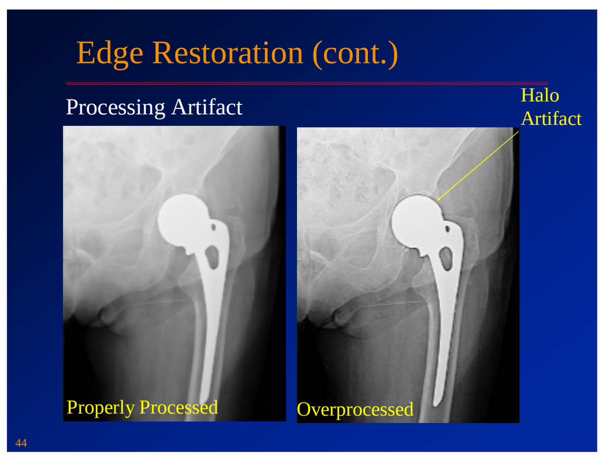

Edge Restoration (cont.)
Modulation Transfer Function
K = 5, g = 1.2
K = 3, g = 1.5
Baeline
USM 1
USM 2
MTF
Spatial Frequency (cycles/mm)
42


Edge Restoration (cont.)
Multi-Frequency Processing
Original Image
Edge-Enhanced Image
43


Edge Restoration (cont.)
Processing Artifact
Halo Artifact
Properly Processed
Overprocessed
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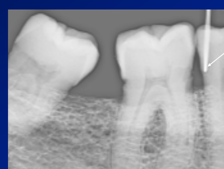
Edge Restoration (cont.)

Processing Artifact



Halo Artifact

Properly Processed

Overprocessed

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Noise Suppression

- It is desired to drive toward lower x-ray exposures to reduce patient dose
- The appearance of noise increases as exposure level is decreased
- A predominant source of noise in digital radiography is generally the quantum noise.
- Noise suppression should be signal dependent, it should be applied only to areas of the image that have a low SNR.
- A noise suppression algorithm needs to reduce the appearance of noise while preserving diagnostic detail.

"Observer study of a noise suppression algorithm for computed radiography images," M. Couwenhoven et al, Proc. SPIE 5749, 318-327, 2005.

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Noise Suppression (cont.)

Suppress the noise in low signal areas and phase out suppression in high signal areas

High Signal Areas / Less Dense Anatomy

Low Signal Areas / More Dense Anatomy

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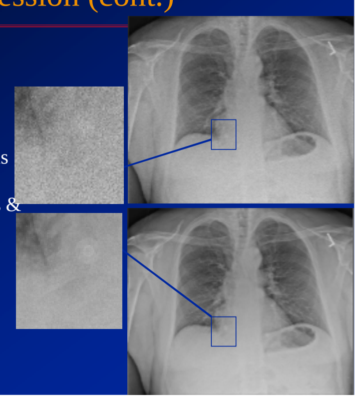
Noise Suppression (cont.)

Noise Suppression

- 2D spatial processing
- Applies to high freq. signals
- Signal dependent
- Balance between sharpness & noise



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Display Compensation

- Image pixel values can be mapped for different output devices
  - Film printer (monochrome 1)
  - Softcopy display (monochrome 2)
- Both capture and output devices need to be configured properly
- Output device calibration is critical to optimal image display
  - Different dynamic range and response
  - CRT vs. flat-panel
  - Images from multi-vendors viewed at same PACS workstation
  - Archived images
- DICOM Part 14 specifies grayscale display standard function (GSDF)
- AAPM TG-18 specifies display QA & QC testing

Display Compensation (cont.)

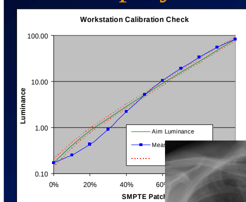
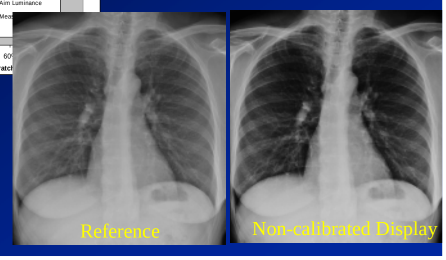


Image looks darker throughout the dark regions



Display Compensation (cont.)

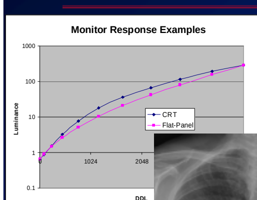


Image displayed at CRT looks brighter

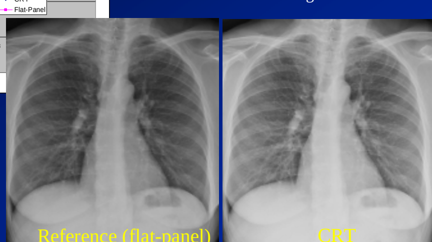
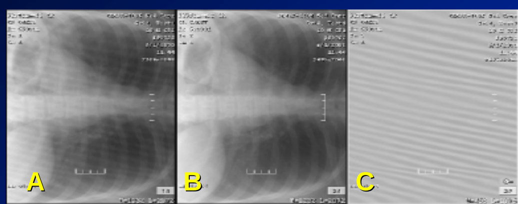


Image Processing Features

Stationary Grid Suppression

Moiré Pattern



(A) CR chest image minified by a factor of 0.2 showing a grid-caused Moiré pattern
(B) Filtered image fragment without Moiré pattern
(C) Difference image

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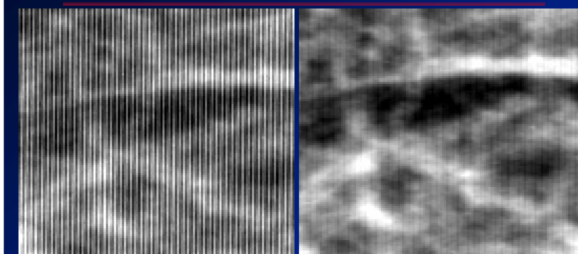
Automatic Grid Line Detection & Suppression



"Antiscatter stationary grid artifacts automated detection and removal in projection radiography imagery,"
I. Belykh and C. Cornelius, Proc. SPIE 2000.

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Long-Length Imaging

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Long-Length Imaging with CR

- Multiple 35cm x 43cm CR screens arranged in alternating and partially overlapping fashion for patient imaging
- Storage phosphor screens scanned individually
- Image processing software used to automatically
  - Determine CR screen sequence and orientation
  - Correct for magnification, translation, and rotation among individual screens
  - Remove redundant image data in the overlap region
  - Construct (stitch) a large geometrically accurate composite
  - Eliminate the seam lines in the composite image
- Composite image stored to PACS for interpretation

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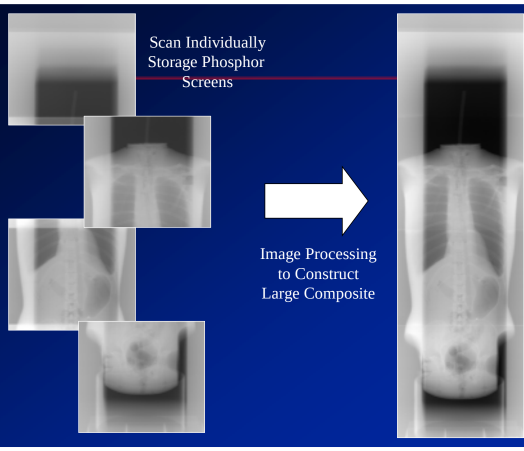

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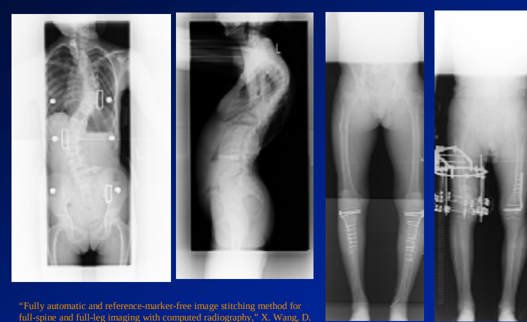
Long-Length Imaging (cont.)



"Fully automatic and reference-marker-free image stitching method for full-spine and full-leg imaging with computed radiography," X. Wang, D. H. Foos, J. Doran, and M. K. Rogers, Proc. SPIE 5368, p361-369, 2004.

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Long-Length Imaging (cont.)

- Measurements from CR equivalent to screen-film
  - Angular
  - Absolute distance
- Visual quality of CR superior to S/F
  - Wide exposure latitude of CR
  - Equalization processing
- 35% retake rate with S/F reduced to 0% retake rate with CR
  - 43 cm width
  - Equalization processing

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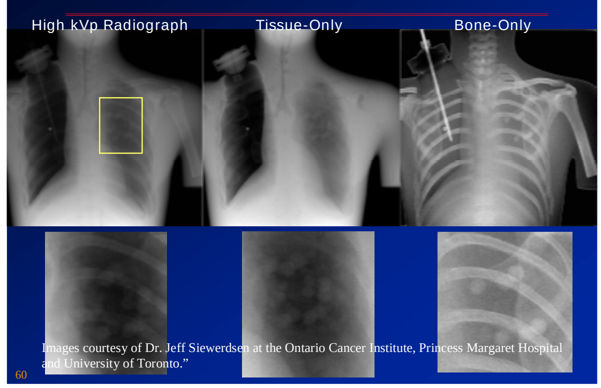
Dual-Energy Imaging



Images courtesy of Dr. Jeff Siewerdsen at the Ontario Cancer Institute, Princess Margaret Hospital and University of Toronto."

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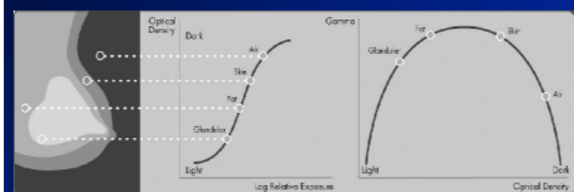
Mammography Processing

S/F: A large dynamic range is needed to detect and display all parts of the breast with good contrast



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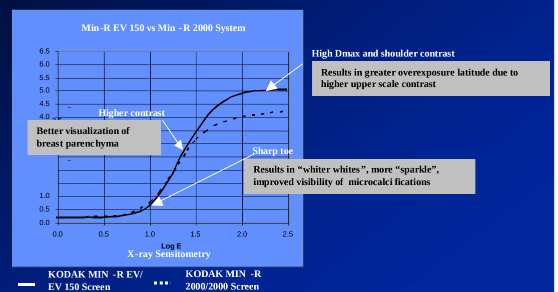
Mammography Processing (cont.)

Recent advances in s/f mammography



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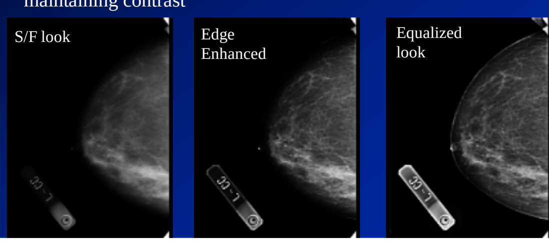
Mammography Processing

Digital Mammography

- Wide dynamic range (> 1000:1) captures all the image information
- Edge restoration enhances image details of different sizes
- Equalization processing compresses image latitude while maintaining contrast



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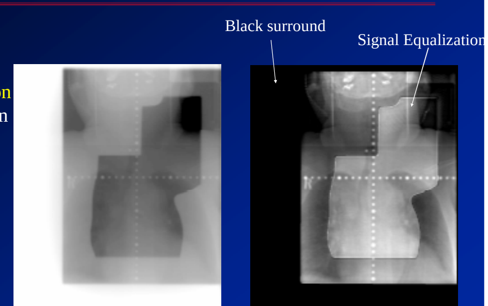
Oncology Processing

Simulation
Localization
Verification



"Method for contrast-enhancement of digital portal images," S. Young, W. E. Moore, D. H. Foos, US Patent US6836570 B2

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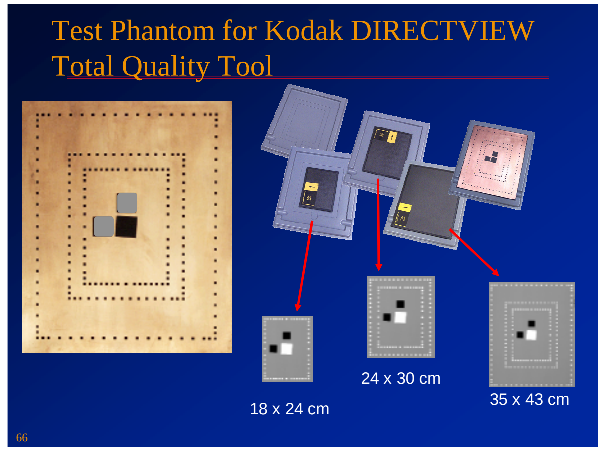
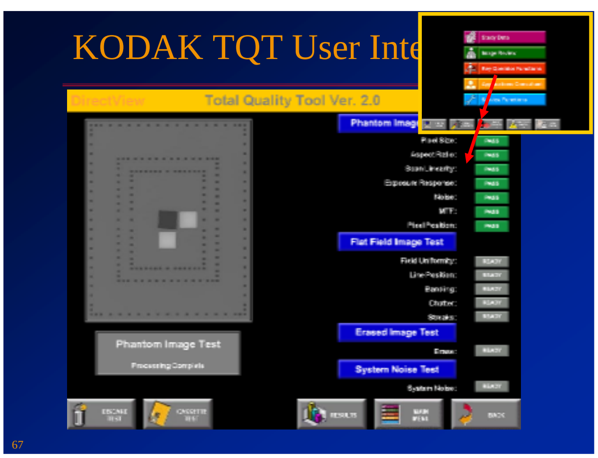
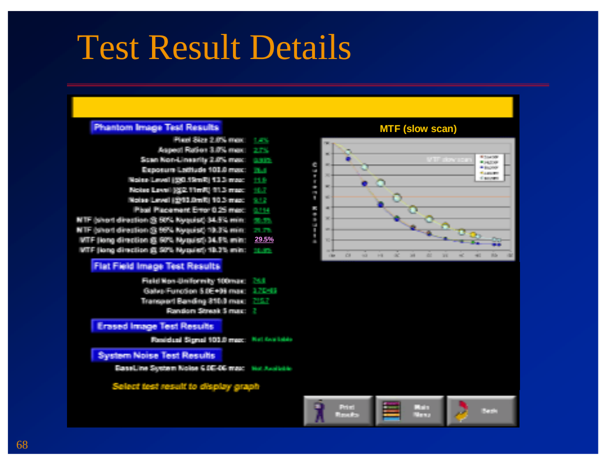
Quality Control Testing
0.5 mm Cu
1.0 mm Al
10.0   0.2 mR
@ 80 kVp
180 cm
65


Test Phantom for Kodak DIRECTVIEW
Total Quality Tool
18 x 24 cm
24 x 30 cm
35 x 43 cm
66


KODAK TQT User Inte
DirectView
Total Quality Tool Ver. 2.0
Phantom Image Test
Flat Field Image Test
Erased Image Test
System Noise Test
67


Test Result Details
Phantom Image Test Results
MTF (slow scan)
Flat Field Image Test Results
Erased Image Test Results
System Noise Test Results
Select test result to display graph
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Quality Control Testing (cont.)

Automated Image Quality Control Tool

- Precise and accurate quality control testing
- Highly reproducible quantitative results
- Detects sub-visible changes in CR image quality performance to initiate timely preventive maintenance
- Avoids hours of tedious and labor-intensive effort with a highly automated procedure
- Full data reporting in Excel format

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Summary

- Tone scale processing establishes the overall image brightness and global contrast
- Edge restoration enhances detail contrast
- Signal equalization extends the latitude that can be visualized while maintaining detail contrast
- Edge restoration, signal equalization, and noise suppression are 2D spatial processing
- Multi-frequency has been widely adopted, yet users should be aware of processing artifacts
- Display processing are becoming easier and more intuitive to use
- Image processing provides many new features unique to digital capture
- Image processing can provide many automations to improve work efficiency

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