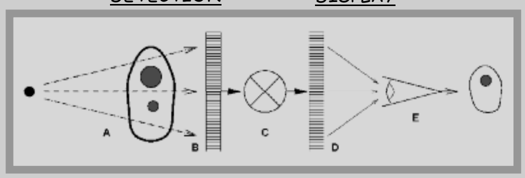
Henry Ford Health System
RADIOLOGY RESEARCH

Digital Image Processing in Radiography

Michael Flynn
Dept. of Radiology
mikef@rad.hfh.edu

Subject contrast (A) recorded by the detector (B) is transformed (C) to display values and sent to a display device (D) for presentation to the human visual system (E) and cognitive interpretation.

DETECTION DISPLAY



Display processing is used to transform digital radiography data to display values for presentation using a workstation or film printer.

---

1. Understand how recorded signals are conditioned to produce image data for processing.
2. Understand the approaches used to improve the visibility of structures in radiological images.
3. Survey current commercial implementations and distinguish essential similarities / differences.

Intro - Disclosure

The presenter is a designated principal investigator on research agreements between Henry Ford Health System and the following companies (alphabetical);

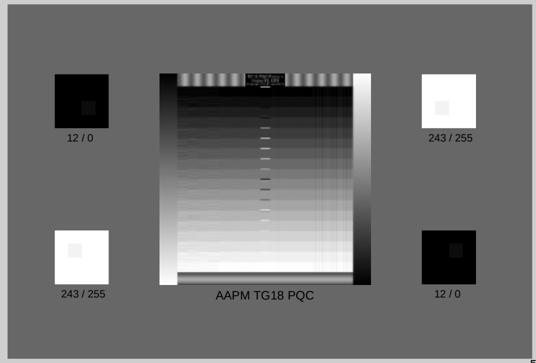
- * Agfa Medical Systems
- Brown & Herbranson imaging
- * Eastman Kodak Company
- Shimadzu Medical Systems
- Roche Pharmaceuticals

The presenter has provided consulting services over the last 12 months with the following companies (alphabetical);

- Gammex-RMI
- * Vidar Systems Corp.

* Involves DR image processing

Projection Test Pattern

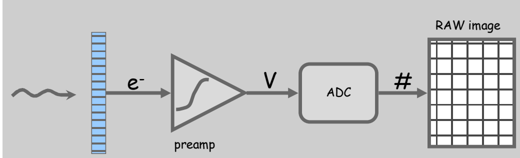


1- Course Outline

1. Preprocessing
2. Generic Image Processing
3. Commercial Implementations

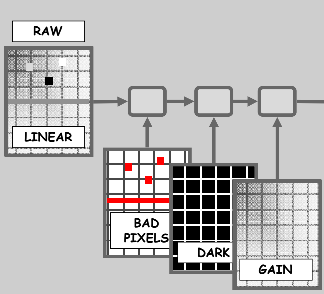
1 - Raw Image Data

- For CR and DR systems, radiation energy deposited in the detector is converted to electrical charge.
- Preamplifier circuits then convert this to a voltage which is digitized using analog to voltage converter (ADC) to produce RAW image values.



1 - DR 'For Processing' Data

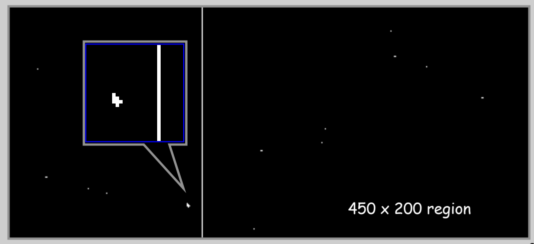
RAW data from the detector is pre-processed to produce an image suitable for processing.



DICOM SOP Class
For Processing Digital X-ray Image Storage

1 – Bad pixels

- Pixels with high or low values or with excessive noise
- Values corrected by interpolation from neighbors
- There are presently no requirements to report bad pixel statistics as a part of DR system purchase.



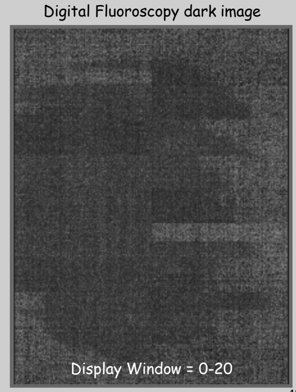
1 – New Bad pixels

- New pixel defects can develop in DR panels that are in service.
- Frequent gain calibration can help detect newly developed problems.
- The defects shown to the right were reported by the radiologist interpreting the study.

1 – Dark image

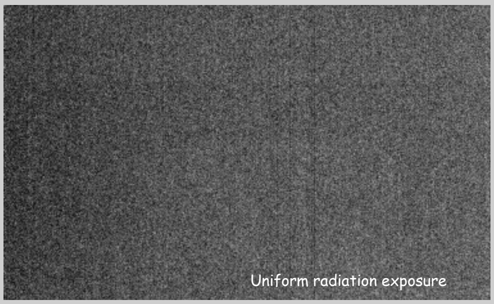
- The signal recorded when no x-rays are incident on the detector is referred to as the 'dark image' or 'offset image'.
- Most detectors produce a signal that linearly increase from the offset value of each pixel as x-ray incident exposure is increased.
- Dark image values are susceptible to drift and often have high thermal dependence.

Digital Fluoroscopy dark image



1 – Gain image

- The linear gain may slightly differ from pixel to pixel.
- These variations produce fixed pattern noise.



1 - Offset/Gain correction

- Dark Image (I_D)

  Obtained by averaging many images obtained with no xray input to the detector.
- Gain Image (I_G)

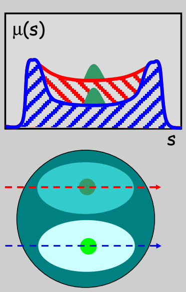
  Obtained by averaging many images obtained with a uniform x-ray fluence.
- Uniformity correction is performed subtracting the dark offset and adjusting for gain differences.

$$I_{COR} = (I_{RAW} - I_D)\{k/(I_G - I_D)\}$$

- Log transformation using a Log look-up table allows this to be performed with a subtraction.

$$I_{FP} = \log(I_{RAW} - I_D) - \log(I_G - I_D) - K$$

1 – log image values



The recorded signal recorded is approximately proportional to the exponent of the attenuation coefficient line integral;

$$P(x,y) = \int_s \mu(s)$$

$$I(x,y) \;\alpha\; Io \; \exp[-P(x,y)]$$

The log of the recorded signal is proportional to the line integral.

$$Ln(I(x,y)) \;\alpha\; -P(x,y) + Ln(Io)$$

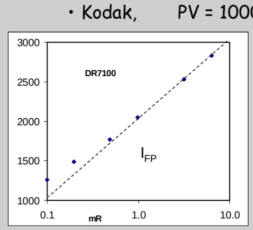
Small perturbations cause the same image value change whether in high or low transmission regions

$$I^1_{FP} \;\alpha\; P^1(x,y) + \Delta P$$

$$I^2_{FP} \;\alpha\; P^2(x,y) + \Delta P$$

1 - 'for processing' Log format

- Most 'for processing' image values are proportional to the log of the exposure incident on the detector.
- Samei et.al., Med Phys 2001
  - Agfa, PV = 1250 * log(cBE) -121
  - Fuji, PV = (1024/L)*(log(E) + log(S/200)
  - Kodak, PV = 1000*log(E) +Co



For I_{FP} values stored as a 12 bit number (0 – 4095), a convenient format has a change of 1000 for every factor of 10 change in exposure.

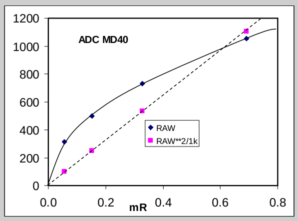
$$I_{FP} = 1000 \log_{10}(\text{mR}) + 2000$$

1 - I_{FP} proportional to $mR^{1/2}$

- One major manufacturer uses internal I_{FP} values that are proportional to the square root of exposure.
- The relative noise of the I_{FP} values is constant for all incident exposures, however the tissue contrast is not.

$I_{FP} = 1250\ mR^{1/2}$

For this system, this structure is used only for data stored in a multi-scale Agfa format used by Agfa products. Data exported using DICOM exchange (for processing) can be sent in a log exposure format.



1 - Normalized I_{FP} values, TG116

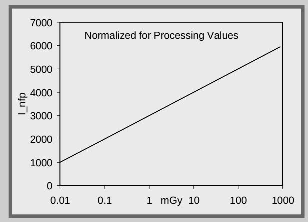
AAPM Task group 116 draft report

"Recommended Exposure Indicators for Digital Radiography"

Normalized For Processing Pixel Values (I_{NFP})

"For-processing pixel values, I_{FP}, that have been converted to have a specific relation to a standardized radiation exposure (E_{STD}). ..,"

I_{NFP} = 1,000*log10(E_{STD}/Eo) ,
E_{STD} in micro-Gray units,
Eo = 0.001 micro-Gray,

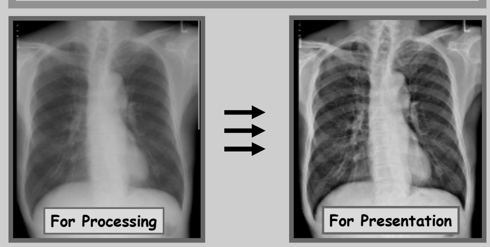


2- Course Outline

1. Preprocessing
2. Generic Image Processing
3. Commercial Implementations

2 - Five generic processes

- ⇒ **Grayscale Rendition:** Convert signal values to display values
- ⇒ **Exposure Recognition:** Adjust for high/low average exposure.
- ⇒ **Edge Restoration:** Sharpen edges while limiting noise.
- ⇒ **Noise Reduction:** Reduce noise and maintain sharpness
- ⇒ **Contrast Enhancement:** Increase contrast for local detail



2A - processing sequence

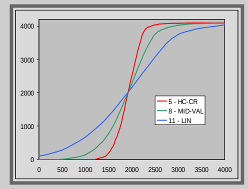
⇒ **Grayscale Rendition:**	Convert signal values to display values
⇒ Exposure Recognition:	Adjust for high/low average exposure.
⇒ Edge Restoration:	Sharpen edges while limiting noise.
⇒ Noise Reduction:	Reduce noise and maintain sharpness
⇒ Contrast Enhancement:	Increase contrast for local detail

Exposure Recognition → Spatial Processes (•Edge Restoration •Noise Reduction •Contrast Enhance) → Grayscale (VOI-LUT)

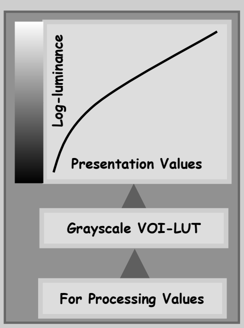
2A - Grayscale Rendition

Grayscale LUTs

'For Processing' data values are transformed to presentation values using a grayscale Look Up Table



2A - Presentation Values



- ⇒ The Grayscale Value of Interest (VOI) Look up Table (LUT) transforms 'For Processing' values to 'For Presentation Values.
- ⇒ Monitors and printers are DICOM calibrated to display presentation values with equivalent contrast.
- ⇒ The VOI-LUT optimizes the display for radiographs of specific body parts.

2A - DICOM VOI LUT

The VOI-LUT may be applied by the modality, or sent to an archive and applied by a viewing station

Exposure Recognition → Spatial Processes (•Edge Restoration •Noise Reduction •Contrast Enhance) → (VOI-LUT)

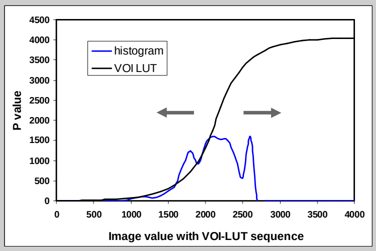
DICOM PS 3.3 2004, Pg 80

- When the transformation is linear, the VOI LUT is described by the Window Center (0028,1050) and Window Width (0028,1051).
- When the transformation is non-linear, the VOI LUT is described by VOI LUT Sequence (0028,3010).

2A - VOI LUT sent with image values

When communicating images to a PACS systems, it can be beneficial to send the VOI-LUT sequence for application at display.

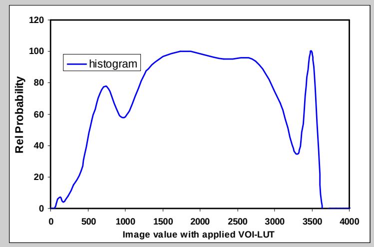
PACS workstations should be capable of translating or stretching the VOI LUT to make contrast and brightness changes



2A - LUT applied and P values sent

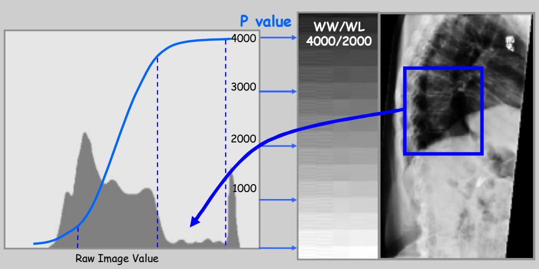
Presently, many systems send images to a PACS system as scaled P values with the VOI LUT already applied to the processed data.

PACS workstations can not adjust the VOI-LUT to demonstrate contrast in over or under penetrated regions.



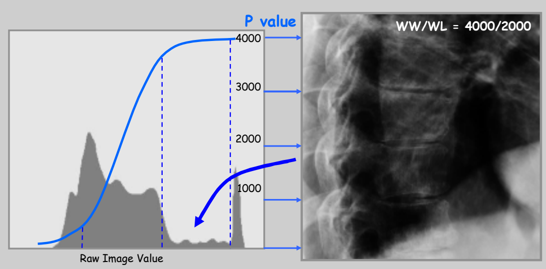
2A - A better WW/WL for CR/DR

The applied VOI-LUT produces good contrast for the primary tissues of interest. For the full range of P values, contrast is limited in the toe and shoulder regions.



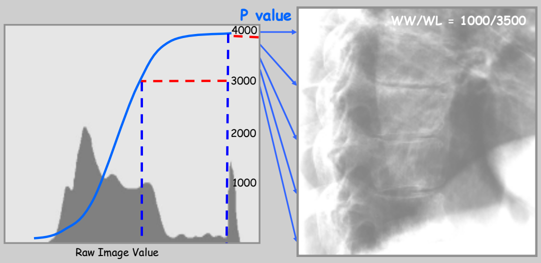
2A - A better WW/WL for CR/DR

The applied VOI-LUT produces good contrast for the primary tissues of interest. For the full range of P values, contrast is limited in the toe and shoulder regions.



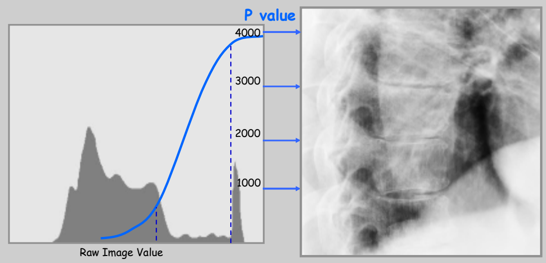
2A - A better WW/WL for CR/DR

Shifting the Window Level (WL) to inspect highly penetrated regions renders gray levels with a poorly shaped portion of the VOI LUT.



2A - A better WW/WL for CR/DR

The ability to shifting the VOI-LUT at the display workstation permits regions of secondary interest to be viewed with good radiographic contrast.



2B – Exposure Recognition

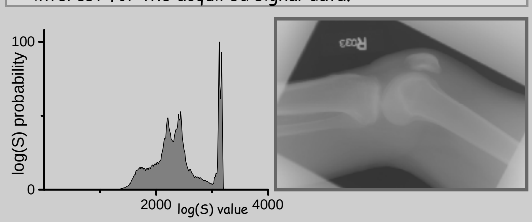
- ⇒ **Grayscale Rendition:** Convert signal values to display values
- ⇒ **Exposure Recognition:** Adjust for high/low average exposure.
- ⇒ **Edge Restoration:** Sharpen edges while limiting noise.
- ⇒ **Noise Reduction:** Reduce noise and maintain sharpness
- ⇒ **Contrast Enhancement:** Increase contrast for local detail

Exposure Recognition → Spatial Processes (•Edge Restoration •Noise Reduction •Contrast Enhance) → Grayscale (VOI-LUT)

2B – Exposure recognition - signal

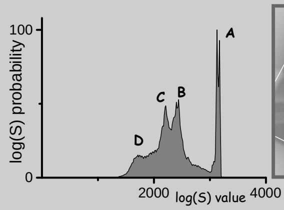
Signal Range:

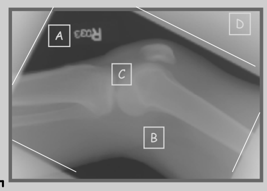
A signal range of up to 10^4 can be recorded by digital radiography systems. Unusually high or low exposures can thus be recorded. However, display of the full range of data presents the information with very poor contrast. It is necessary to determine the values of interest for the acquired signal data.



Exposure Recognition:

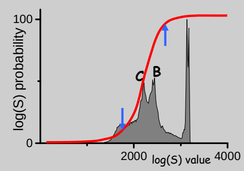
All digital radiographic systems have an exposure recognition process to determine the range and the average exposure to the detector in anatomic regions. A combination of edge detection, noise pattern analysis, and histogram analysis may be used to identify Values of Interest (VOI).





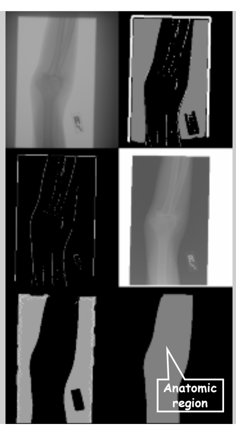
VOI LUT Level and Width:

- The values of interest obtained from exposure recognition processes are used to set the level and width of the VOI LUT.
- Areas outside of the collimated field may be masked to prevent bright light from adversely effecting visual adaptation.



Tissue region

Advanced image segmentation algorithms are used is some systems to identify the region where tissue attenuation has occurred. This provides information on the values of interest for presentation.



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

- DR systems report a metric indicating the detector response to the incident radiation exposure.
- The methods used to deduce this metric are all different
  - The regions from which exposure is measured vary.
  - Reported exposures may increase proportional to the log of exposure or may vary inversely with exposure.
  - The scale of units varies widely with factor of 2 changes in exposure associated with changes varying from 0.15 to 300.

• Fuji:	$S = 200/E_{in}$	80 kVp, unfiltered
• Agfa:	$lgM = 2.22 + \log(E_{in}) + \log(S_n/200)$	75 kVp, 1.5 Cu (mm)
• Kodak:	$EI = 1000 \log(E_{in}) + 2000$	80 kVp, 0.5 Cu 1.0 Al

2B – Exposure Indicators, TG116

AAPM Task group 116 draft 5a

"Recommended Exposure Indicators for Digital Radiography"

Indicated Equivalent Air Kerma (K_{IND})

- An indicator of the quantity of radiation that was incident on regions of the detector for each exposure made. …
- The regions .. may be defined in different ways ..
- The value should be reported in units of microgray ..

Relative Exposure (E_{REL})

- An indicator as to whether the detector response for a specific image, K_{IND}, agrees with K_{TAR}(b.v).
- Relative exposures are to be reported as

  $E_{REL} = \log2(K_{IND}/K_{TAR}(b,v))$ ..
- E_{REL} is intended as an indicator for radiographers and radiologists as to whether the technique used to acquire a radiograph was correct.

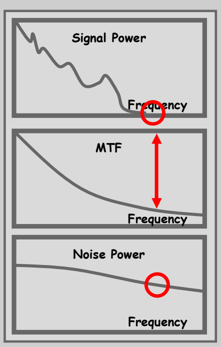
2C – Edge Restoration

⇒	Grayscale Rendition:	Convert signal values to display values
⇒	Exposure Recognition:	Adjust for high/low average exposure.
⇒	**Edge Restoration:**	Sharpen edges while limiting noise.
⇒	Noise Reduction:	Reduce noise and maintain sharpness
⇒	Contrast Enhancement:	Increase contrast for local detail

Exposure Recognition → Spatial Processes (•Edge Restoration •Noise Reduction •Contrast Enhance) → Grayscale (VOI-LUT)

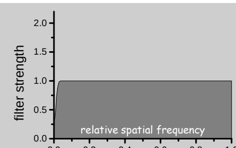
2C – Edge Restoration

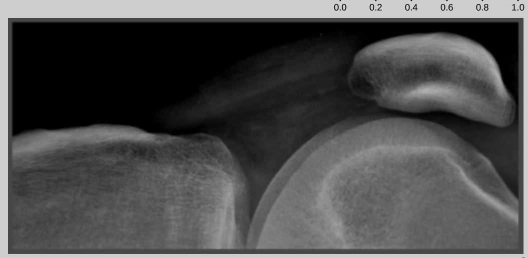
- Radiographs with high contrast details input high spatial frequencies to the detector.
- For many systems the detector will blur this detail as indicated by the MTF.
- Enhancing these frequencies can help restore image detail.
- However, at sufficiently high frequencies there is little signal left and the quantum mottle (noise) is amplified.
- The frequency where noise exceeds signal is different for different body parts/views



2C – Without Edge Restoration

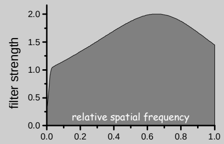
Lateral knee view with equalization but no edge restoration as indicated by the filter strength.

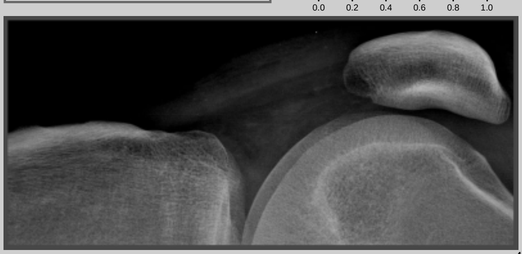




2C – With Edge Restoration

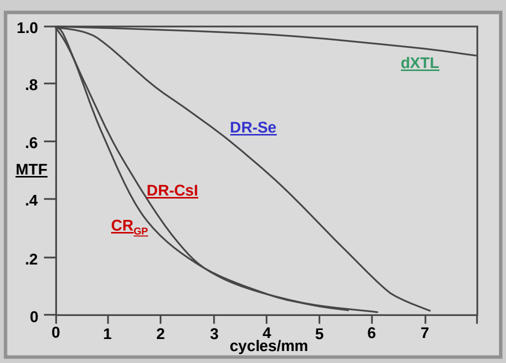
Edge restoration applied using a filter equal to 1/MTF with slight noise reduction at frequencies above .7 of the maximum.





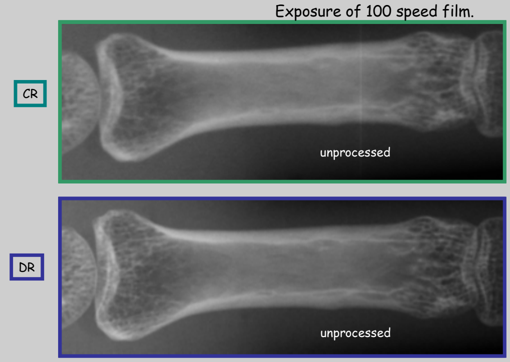
2C – With / Without

2C – MTF – CR, DR, and XTL



2C – Edge Restoration – DR and CR

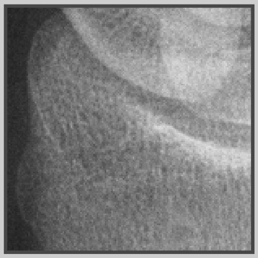
Phalanx of hand phantom
Exposure of 100 speed film.



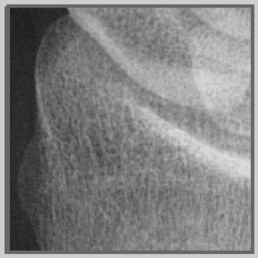
2C – Edge Restoration – dDR and iDR

Clinical Wrist
Identical Manual Exposure

dDR

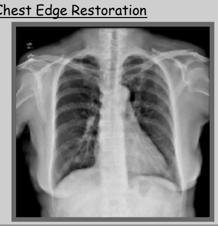


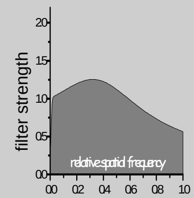
iDR



High DQE iDR systems can restore edges without producing excessive noise.

2C – Chest Edge Restoration

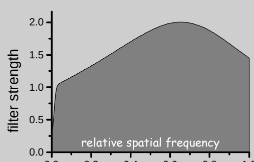


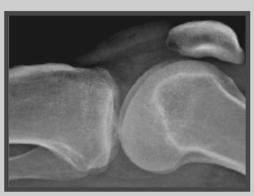


Chest Processing

- **Edge restoration:** lung tissue typically produces low frequency signals and the chest radiograph has high quantum noise. Thus, very modest edge restoration should be used.
- **Quantum mottle in the abdomen:** Low exposure and thick tissue result in significant quantum mottle below the diaphragm. Inverse MTF filters need to be damped at high frequency to prevent excessive noise (Metz filter).

2C – Skeletal Edge Restoration





Skeletal Processing

- **Edge restoration** may be extended to high frequencies particularly if high resolution screen are used. Noise is generally not problematic for extremity views.
- **Restoration versus enhancement:** 1/MTF edge processing as shown restores object detail to that which would be recorded with a perfect detector. The term restoration is recommended rather than enhancement.

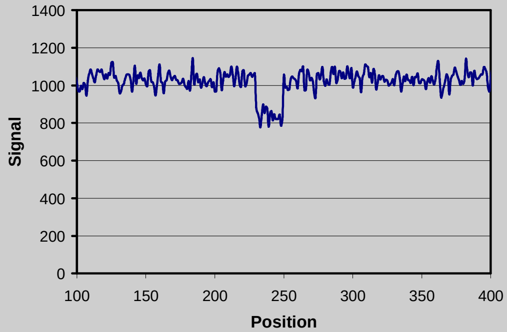
2D – Noise Reduction

⇨ **Grayscale Rendition:**	Convert signal values to display values
⇨ **Exposure Recognition:**	Adjust for high/low average exposure.
⇨ **Edge Restoration:**	Sharpen edges while limiting noise.
⇨ **Noise Reduction:**	Reduce noise and maintain sharpness
⇨ **Contrast Enhancement:**	Increase contrast for local detail

Exposure Recognition → Spatial Processes (•Edge Restoration •Noise Reduction •Contrast Enhance) → Grayscale (VOI-LUT)

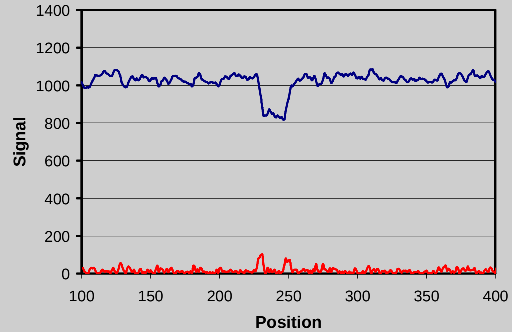
2D – noise and contrast

Quantum noise can mask low contrast structures



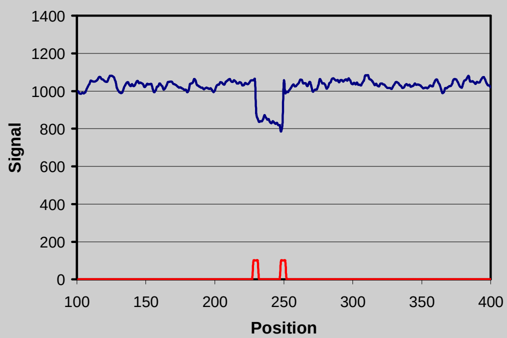
2D – noise smoothing

Smoothing reduces both noise and edge detail (5 pt avg).



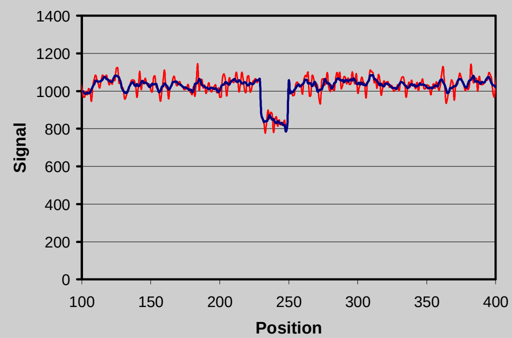
2D – adaptive smoothing

Adaptive noise reduction preserves edges for high gradients (lee filter)



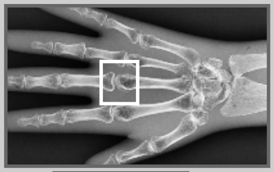
2D – noise reduction: with/wo

Comparison with and without adaptive noise reduction

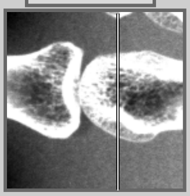


2D – mcp joint noise

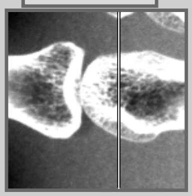
Radiograph of a hand phantom demonstates uniform noise in the lucite 'tissue' and detailed human bone features. Noise reduction is shown using a zoom view of the mcp joint.



Noise reduction ON



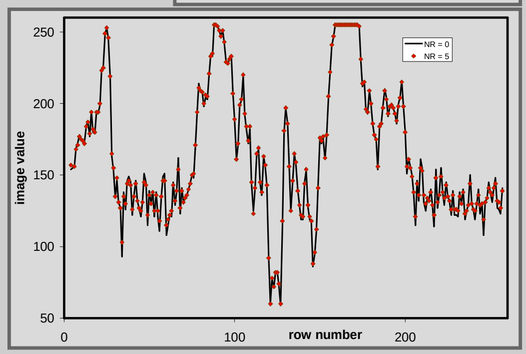
Noise reduction OFF



Agfa CR

2D – mcp joint noise

Vertical profiles of the mcp joint in an AP radiograph show the effects of noise reduction.



2D – 'coring'

Simoncelli EP, Adelson EH, "Noise removal via Bayesian wavelet coring," Proc. 3rd IEEE Int. Conf. Image Proc., vol. I, pp. 379–382, 1996

a) Original image (cropped).
b) Image contaminated with additive Gaussian white noise (SNR = 9.00dB).
c) Image restored using (semi-blind) Wiener filter (SNR = 11.88dB).
d) Image restored using (semi-blind) Bayesian estimator (SNR = 13.82dB).

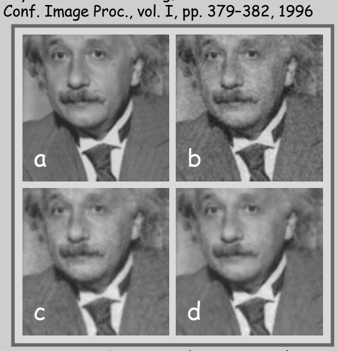


Figure 4. Noise reduction example.

2D – 'coring', non-linear subband transform

- Conceptual method (Simoncelli):

  "A common technique for noise reduction is known as 'coring'. An image signal is split into two or more bands; the highpass bands are subjected to a threshold non-linearity that suppresses low-amplitude values while retaining high-amplitude values."

- Statistical significance (Simoncelli):
  - "Removal of noise from images relies on differences in the statistical properties of noise and signal.
  - The classic Wiener solution utilizes differences in power spectral density, a second-order property.
  - The Bayesian estimator described .. provides a natural extension for incorporating the higher-order statistical regularity present in the point statistics of sub-band representations."

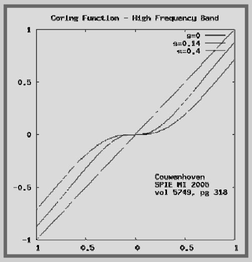
2D – adaptive non-linear coring

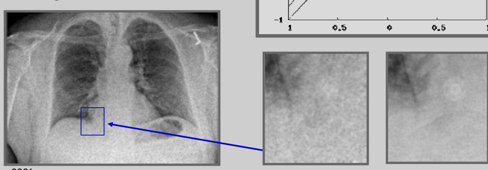
[Couwenhoven, 2005, SPIE MI vol 5749, pg318]

- High frequency sub-band
- Coring function

  $P = P/(1+s/P^2)$

- Adaptation
  - Signal amplitude
  - Signal to noise





2E – Constrast Enhancement

- ⇒ Grayscale Rendition: Convert signal values to display values
- ⇒ Exposure Recognition: Adjust for high/low average exposure.
- ⇒ Edge Restoration: Sharpen edges while limiting noise.
- ⇒ Noise Reduction: Reduce noise and maintain sharpness
- ⇒ **Contrast Enhancement:** Increase contrast for local detail

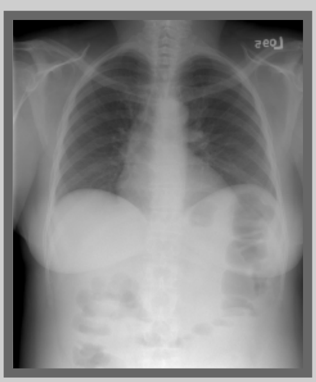
Exposure Recognition → Spatial Processes (•Edge Restoration •Noise Reduction •Contrast Enhance) → Grayscale (VOI-LUT)

2E – Contrast Enhancement

- A wide range of log(S) values is difficult to display in one view.
- Lung detail is shown here with low contrast.

Contrast Enhancement:

Enhancement of local detail with preservation of global latitude.



2E – Unsharp Mask

- A highly blurred image can be used to adjust image values.
- The Unsharp Mask can be obtained by large kernel convolution or low pass filter.
- Note that the grayscale has been reversed.

2E – Detail enhancement

The difference between the image and the unsharp mask contains detail.

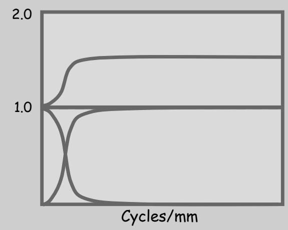
This is added to the image to enhance detail contrast

The contrast enhanced image has improved lung contrast and good presentation of structures in the mediastinum.

2E – Contrast Enhancement in frequency space

- the image is low pass filtered to get a smoothed mask image (illustrated as a gaussian low pass filter).
- Subtraction of the mask from the image yields a high pass filtered image having only the detail associated with local tissue structures.

Detail contrast enhancement is obtained by adding the scaled subtracted detail to the image.

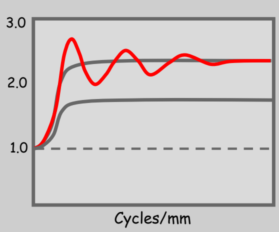


2E – Selecting contrast enhancement

In practice, the amount of contrast enhancement can be selected by first defining a grayscale rendition that achieves the desired latitude, and then applying a filter that enhances detail contrast.

The enhancement gain is adjusted to amplifying the contrast of local detailed tissue structures.

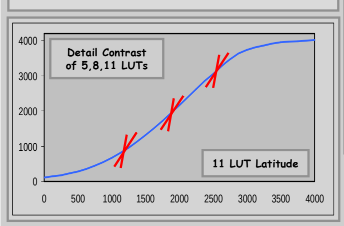
Methods using large kernel of equal weight have poor frequency response characteristics.



2E – Detail Contrast, Latitude, and Gain

For a specific grayscale rendition, detail contrast can be progressively enhanced.

- Latitude – the range of the unenhanced LUT.
- Detailed Contrast – the effective slope of the enhanced detail at each gray level.
- Gain – the increase in LUT local slope.



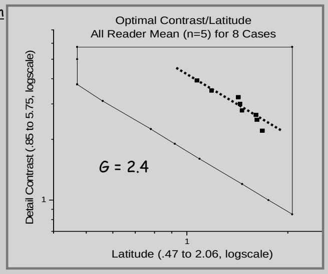
Extended Visualization Processing (EVP, Kodak).

Gain = 2.6

2E – Optimal PA chest gain

5 thoracic radiologists at 3 medical centers preferred a gain of 2.4 for the interpretation of PA chest radiographs of any latitude.

SPIE 4319, 2001



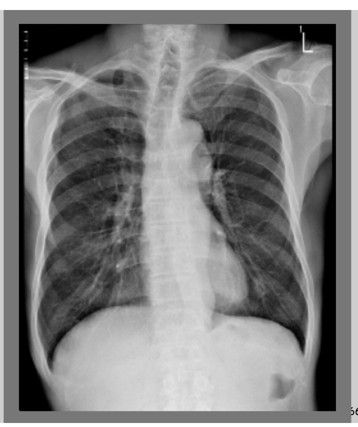
8 PA chest Radiographs
- 52 display processing conditions for each radiograph.
  - EVP gain varied from 1.0 to 6.8.
  - Detail contrast set to 8 values (rows).
  - Latitude set to 10 values (columns).

2E – chest, wide latitude

T1-c
- Lat = 1.68
- Con = 2.21
- *G* = 2.4

2E – chest, low latitude

T3-c
- Lat = 1.44
- Con = 3.00
- *G* = 2.4

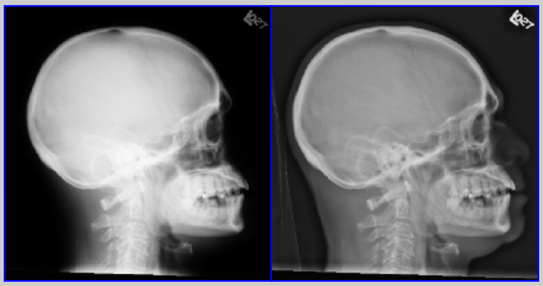


2E – foot – contrast enhancement

Contrast enhancement of wide latitude Musculoskeletal views improves visualization

Latitude 600 – 0X Gain contrast enhancement

2E – Display Processing: skull



Film-screen appearance

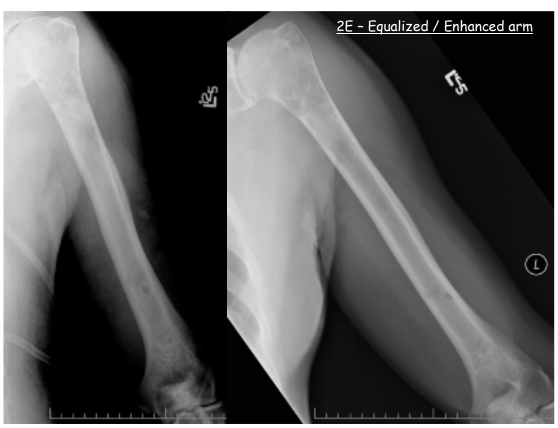
Equalized & Enhanced

2E – Display Processing: C-spine

Film-screen appearance

Equalized / Enhanced

2E – Equalized / Enhanced arm



3- Course Outline

1. Preprocessing
2. Generic Image Processing
3. Commercial Implementations

3 - Fujifilm Medical Systems USA

MFP (Multi-Frequency Processing)

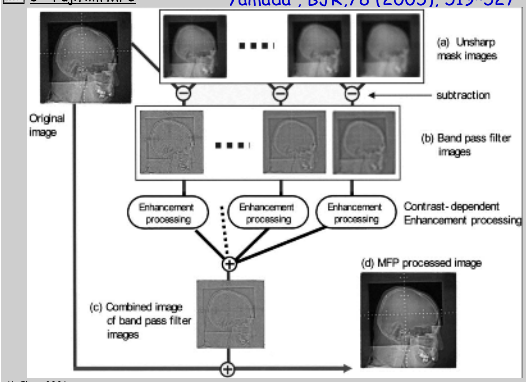
An optional software applicable for all types of FCR imaging. MFP is an enhanced version of Fujifilm's renowned Dynamic Range Control (DRC), and uses frequency enhancement to provide greater diagnostic information from a single exposure image.

FNC (Flexible Noise Control)

Through separation of the noise and signal of an image, it is possible to selectively decrease the noise level. Maximum selective exclusion of unnecessary information translates into easier diagnosis.

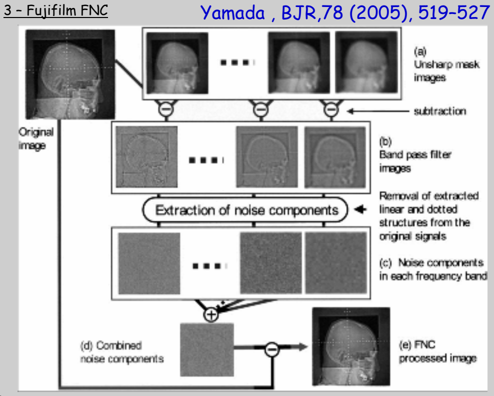
3 - Fujifilm MFC

Yamada , BJR,78 (2005), 519-527



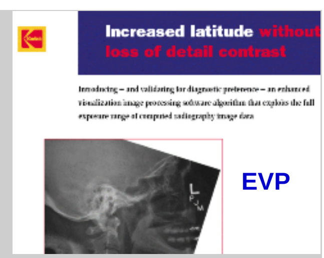
3 - Fujifilm FNC

Yamada , BJR,78 (2005), 519-527



3 - Eastman Kodak Company

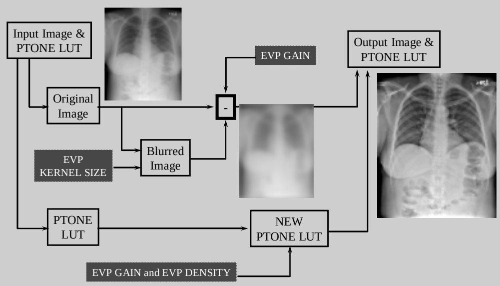
- 1997 SPIE3034
  Senn, skinline detection
- 1998 SPIE3335
  Barski, ptone grayscale
- 1999 SPIE3658
  Barski, grid suppression
- 1999 SPIE3658
  Van Metter, EVP
- 2001 SPIE4322
  Pakin, extremity segment.
- 2003 SPIE5367
  Couwenhoven, control
- 2004 SPIE5370
  Wang, auto segmentation
- 2005 SPIE5749
  Couwenhoven, noise



A series of proceedings articles describes the image processing approaches used by Eastman Kodak Company

3 - EKC Signal Equalization (Kodak EVP)

Wang, AAPM '06, CE



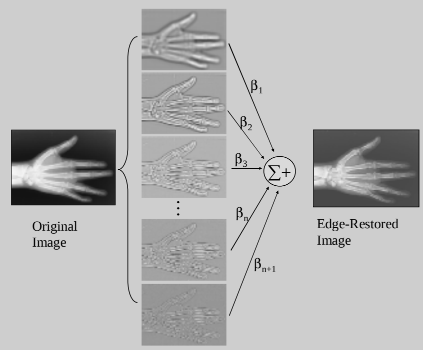
$E'(i,j) = \alpha \bullet \{ E(i,j) \otimes K \} + (1 - \alpha) \bullet E_{mid} + \beta \bullet \{ E(i,j) - (E(i,j) \otimes K) \}$

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

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

3 - EKC Multi-Frequency Processing

Wang, AAPM '06, CE

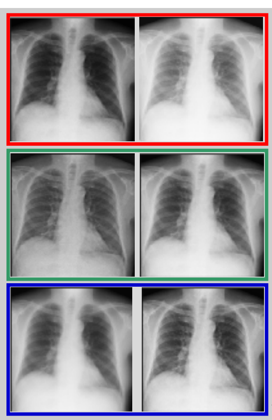


3 - EKC control variables.

Brightness

Latitude

Contrast



Couwenhoven,
RSNA Inforad
2005

1st World Congress
Thoracic Imaging
2005

3 - Philips

GXR, Th. Rohse, November 2005

PHILIPS

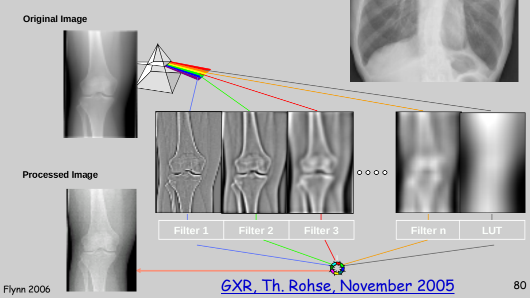
UNIQUE

UNified Image **QU**ality **E**nhancement

3 – Philips multi-resolution

UNIQUE Principle

Multi-Resolution Decomposition



GXR, Th. Rohse, November 2005

3 – Agfa MUSICA

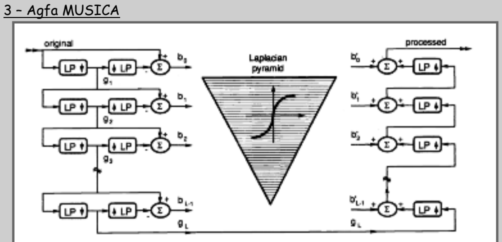
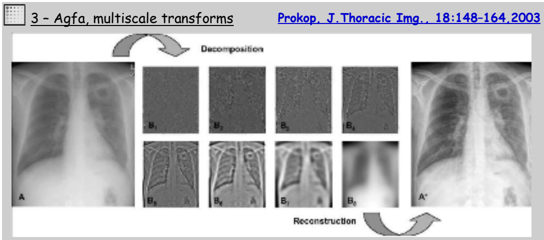


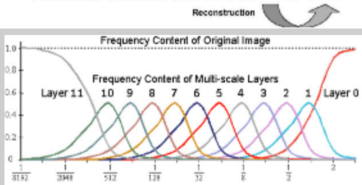
Fig. 3. Flow diagram of the MUSICA-algorithm.

- Vuylsteke P, Schoeters E, Multiscale Image Contrast Amplification (MUSICA), SPIE Vol 2167 Image Processing, pg 551, 1994
- Burt PJ, and Adelson EH, "The Laplacian pyramid as a compact image code", IEEE Trans. On Communications, Vol. 31, No. 4, pp. 532-540, 1983.

3 – Agfa, multiscale transforms

Prokop, J.Thoracic Img., 18:148-164,2003





3 – Agfa, non-linear transfer

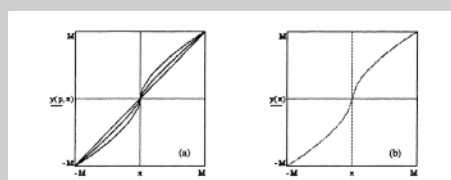


Fig. 5. (a) Power functions for modifying the transform coefficients, exponent values $p = 0.6, 0.8, 1.0$. (b) composite function for modifying transform coefficients $p = 0.6$, with linear part around origin for limiting the amount of amplification.

Non-linear transfer functions alter the contrast in each frequency band to amplify small signal contrast while controlling noise.

3 – Musica 2

Living Stone CD-ROM project wins Finalist Certificate in New York Festivals' Interactive & Alternative Media Awards competition

Only entry to win in Professional Education CD-ROM category

We're proud to announce that Living Stone has been awarded a Finalist Certificate in the prestigious New York Festivals' Interactive & Alternative Media Awards competition. We received the award for the MUSICA2 CD-ROM project, which was developed for Agfa HealthCare in 2005.

3 – "multi-frequency"

- Linear Filters

  Linear filters implemented with Fourier transforms or convolution with large area, variable amplitude kernels can achieve equalization and edge restoration with full control of the frequency transfer characteristics.
- Multi-scale Filters

  Multi-scale filters have coarse control of frequency transfer characteristics but can apply non-linear transformations to achieve noise reduction and prevent high contrast saturation.

3 - others

- Canon Medical Systems, Inc
- Del Medical Systems Group
- GE Healthcare Hologic, Inc
- Imaging Dynamics Co, Ltd
- Infimed Inc
- Konica Minolta Medical Imaging
- Lodox Systems
- Shimadzu Medical
- Siemens Medical Solutions
- Swissray International

3 – Commercial Implementation of DR Processing

- Image processing is provided by all CR/DR suppliers under a variety of trade names.
- While the computation approaches differ, the effect on the radiograph is similar.
- The processed digital image can appear very much different that a traditional screen film radiograph.
- It is possible to set up systems from similar suppliers to provide similar appearance (but difficult). Harmonized processing is needed.

- Processing parameters for equalization, grayscale rendition, and edge restoration are set specifically for each body part / view that may be done.
- This requires close cooperation between the user and the supplier to set up tables that conform to the body part-view used in a department.
- Dependence on body part size complicates processing
- New industry developments may provide processing software that automatically selects the proper parameters from the image data and makes adjustments for body part size.

?