AAPM 2005-Continuing Education Course in
Radiographic and Fluoroscopy Physics and Technology

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

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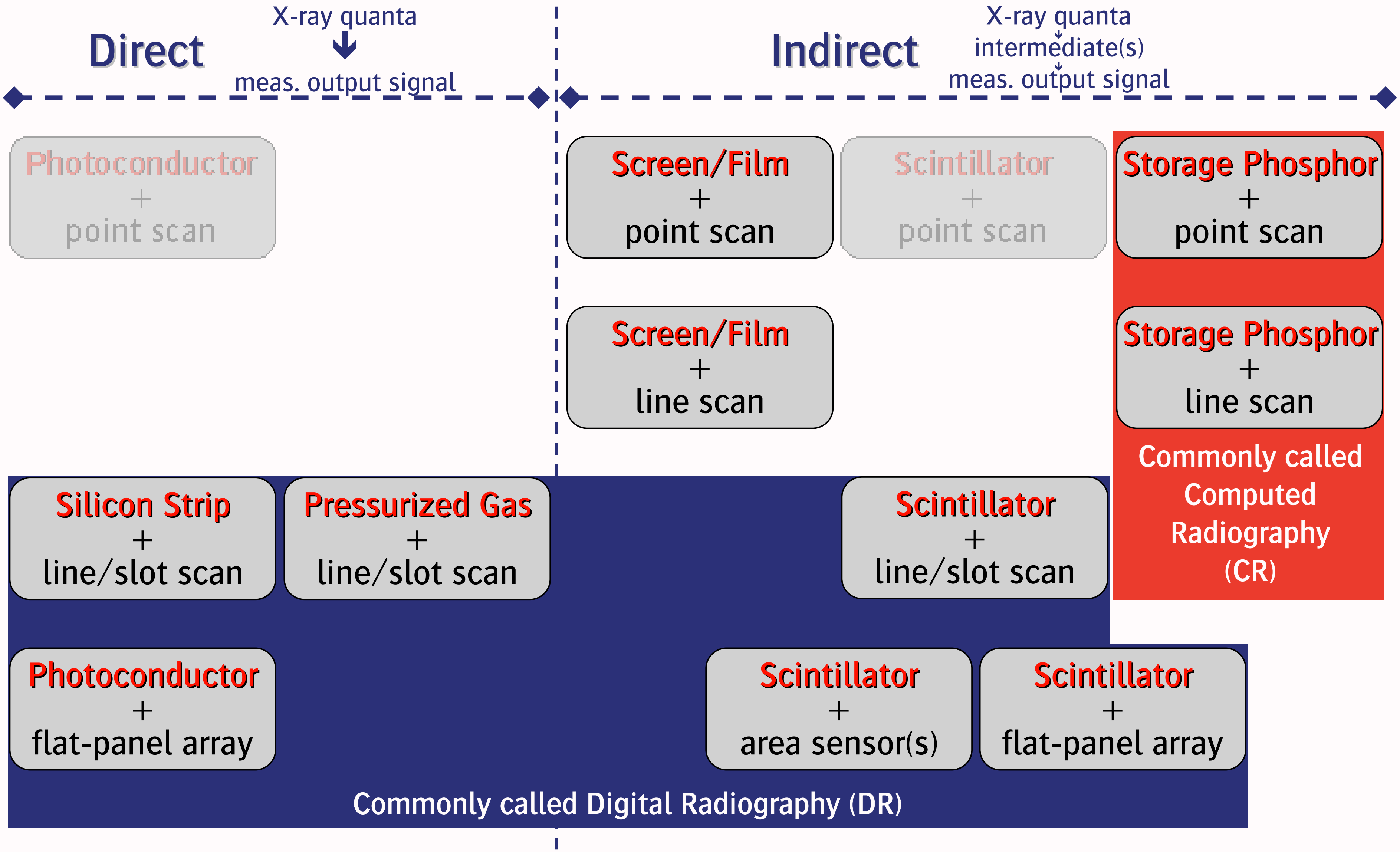
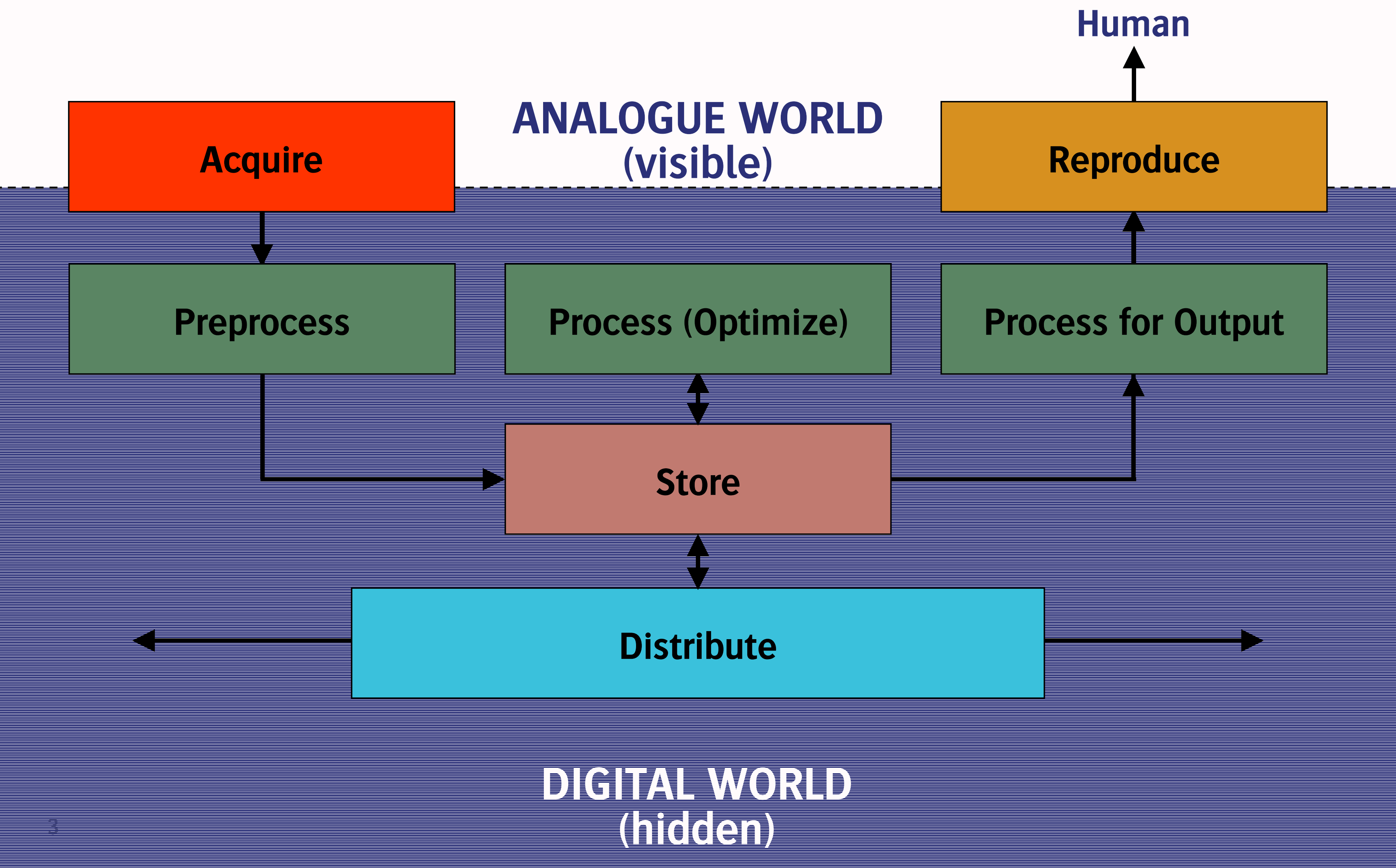
This presentation...

- 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

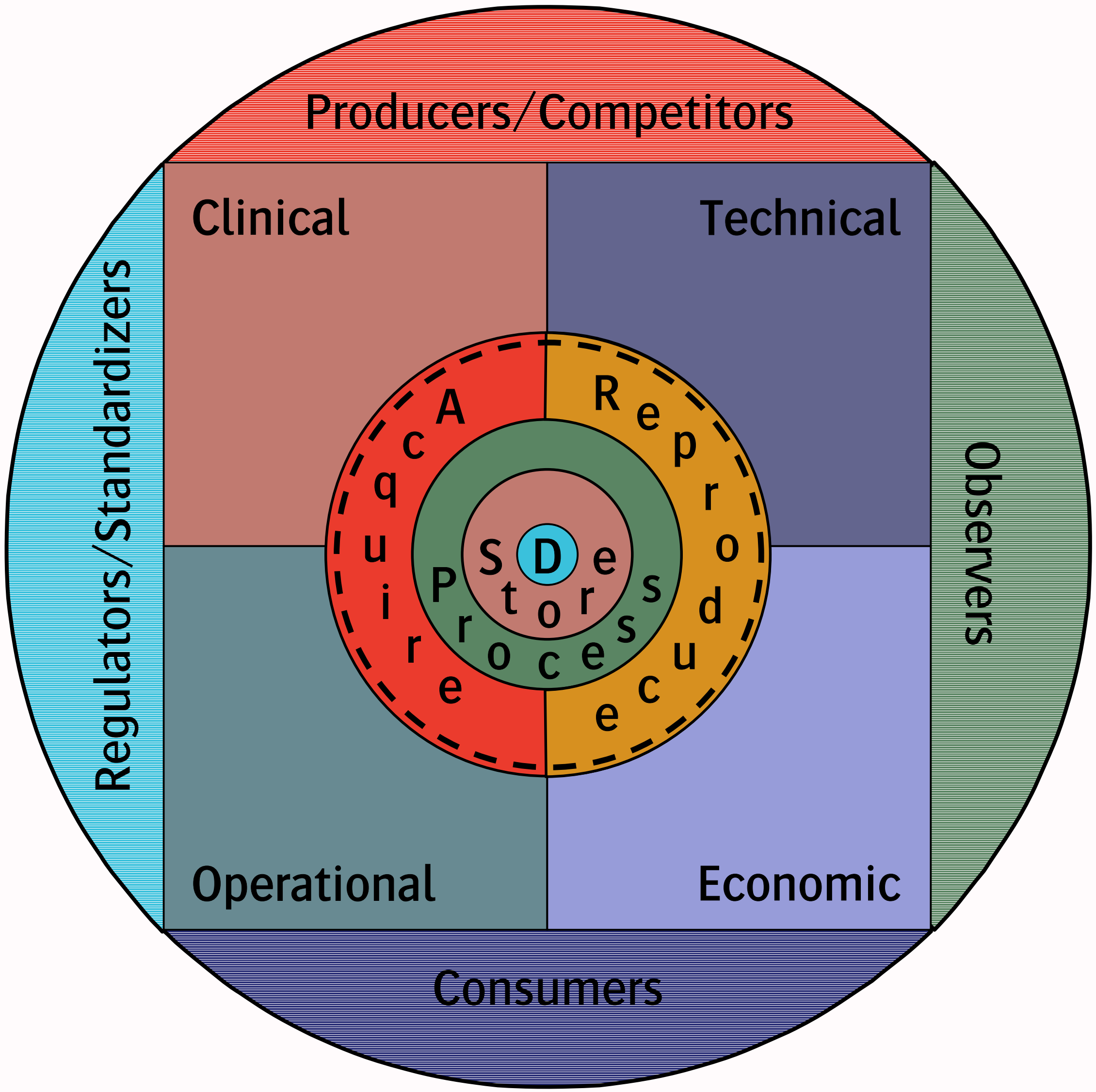
Digital Image Acquisition Technologies



The Medical Imaging Chain (Analog, Digital)



The Bigger Picture



Imaging and Information System Environment

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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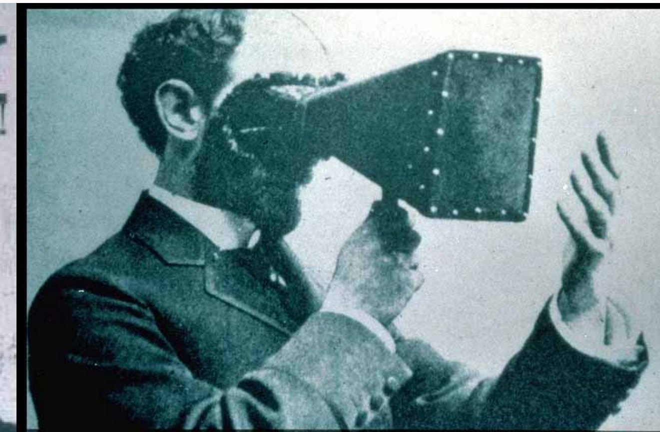
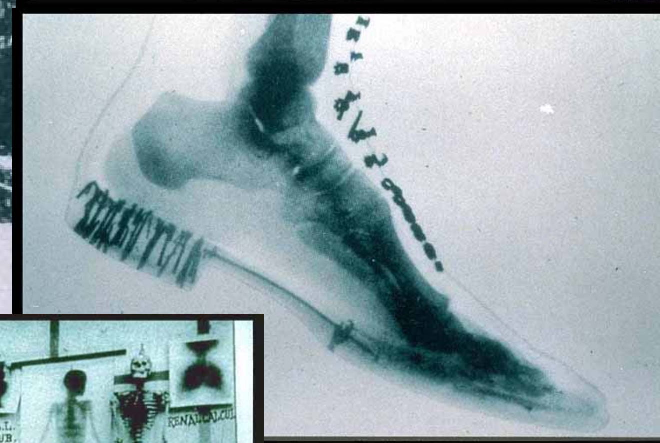
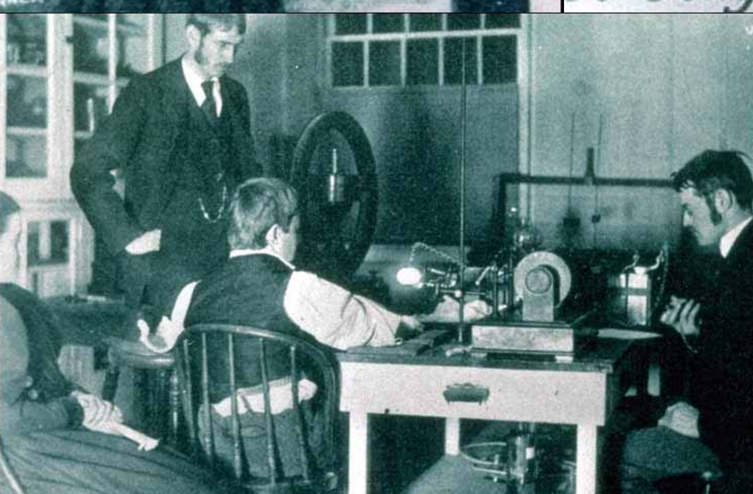
When x-ray dose wasn't so important...







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
  - ISO 9236-1 (2004) *Photography -- Sensitometry of screen/film systems for medical radiography -- Part 1: Determination of sensitometric curve shape, speed and average gradient*

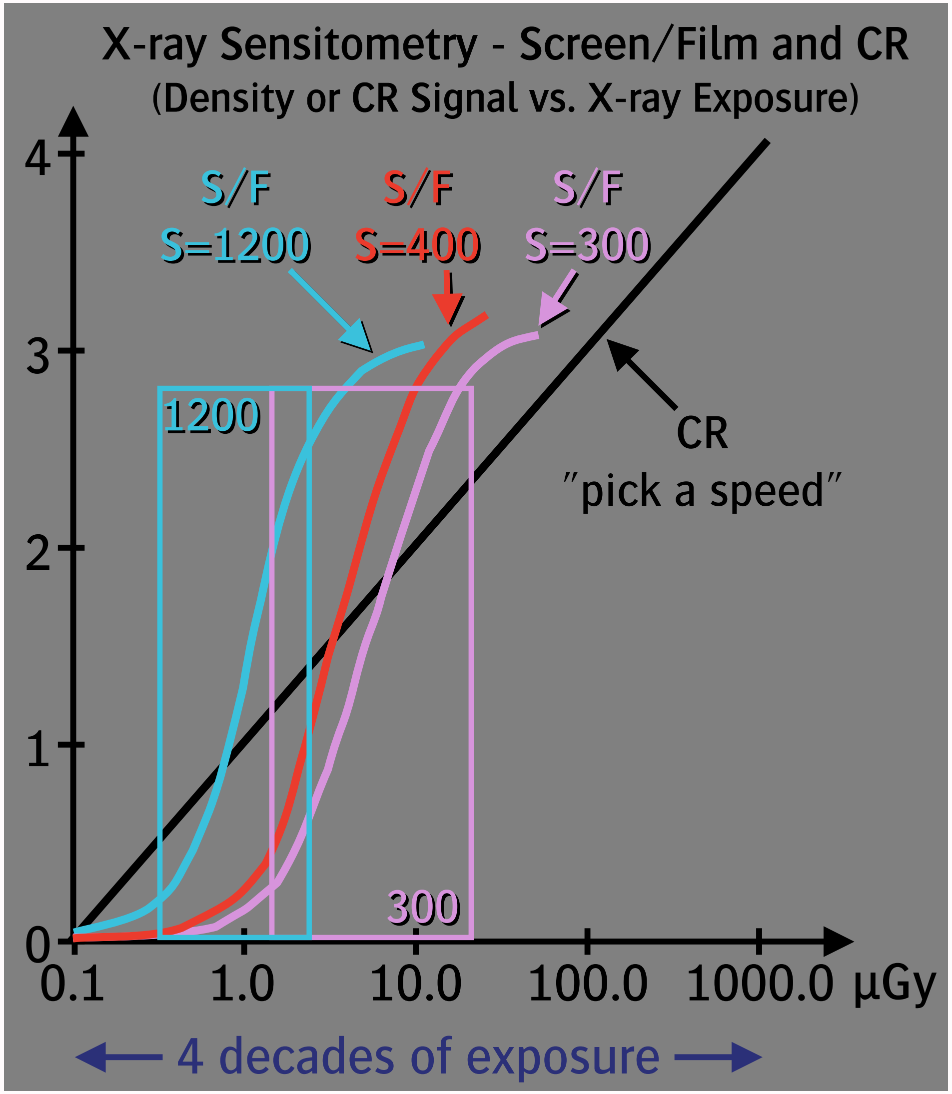
$$S = \frac{1000}{K_s(\mu Gy)}$$

  - Speed defined by incident air kerma (K_s) giving net density of 1.0 under specific conditions (exposure, processing, etc.)

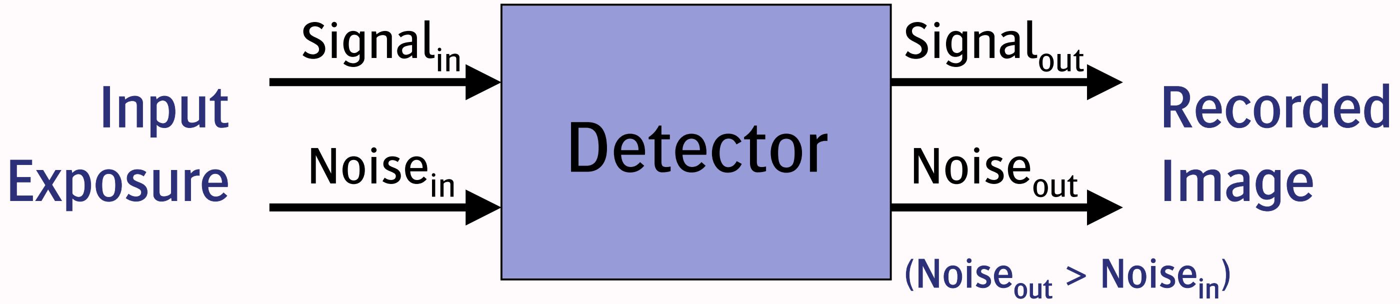
- Digital
  - Linear, wide-latitude response, and variable detector kV-dependence makes definition non-trivial, manufacturer-dependent
  - Confusion and frustration
  - Efforts underway to create standardized definition of speed (AAPM, DIN, IEC, manufacturers)

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)



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

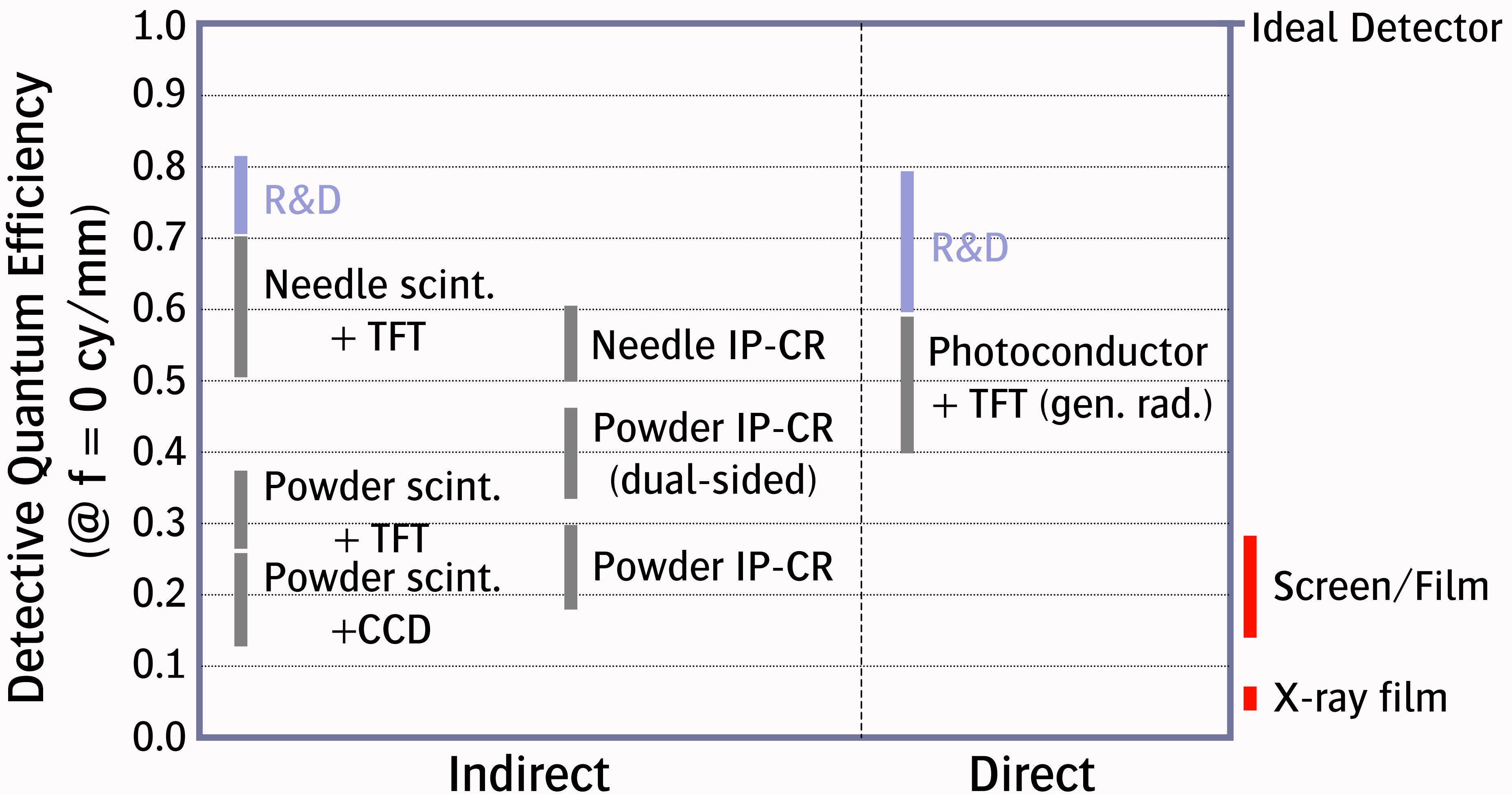
*Noise values must be expressed in same units

$$= \ 1.0 \text{ for ideal detector}$$

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

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

Comparing Dose Requirements:
Reported DQE(0) Values for S/F and Digital



Comparing Dose Requirements: DQE: Caveat Emptor…

- Standard exists…
  - IEC 62220-1 (2003)
    Medical electrical equipment - Characteristics of digital X-ray imaging devices - Part 1: Determination of the detective quantum efficiency
- But…
  - Make sure that standard was followed!

Which image has the highest quality?

A

C

B

D

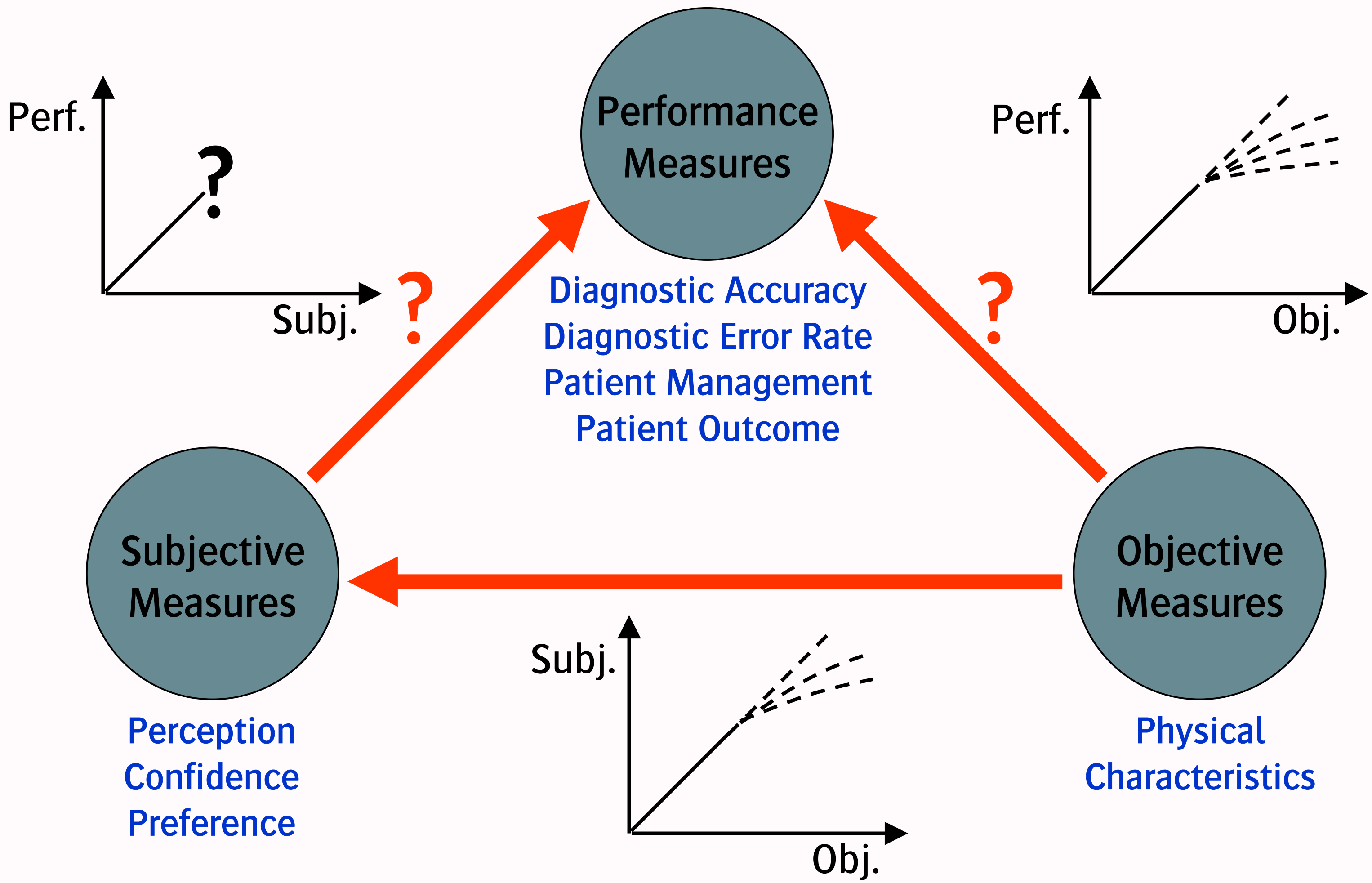
Image Quality: What is it?

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

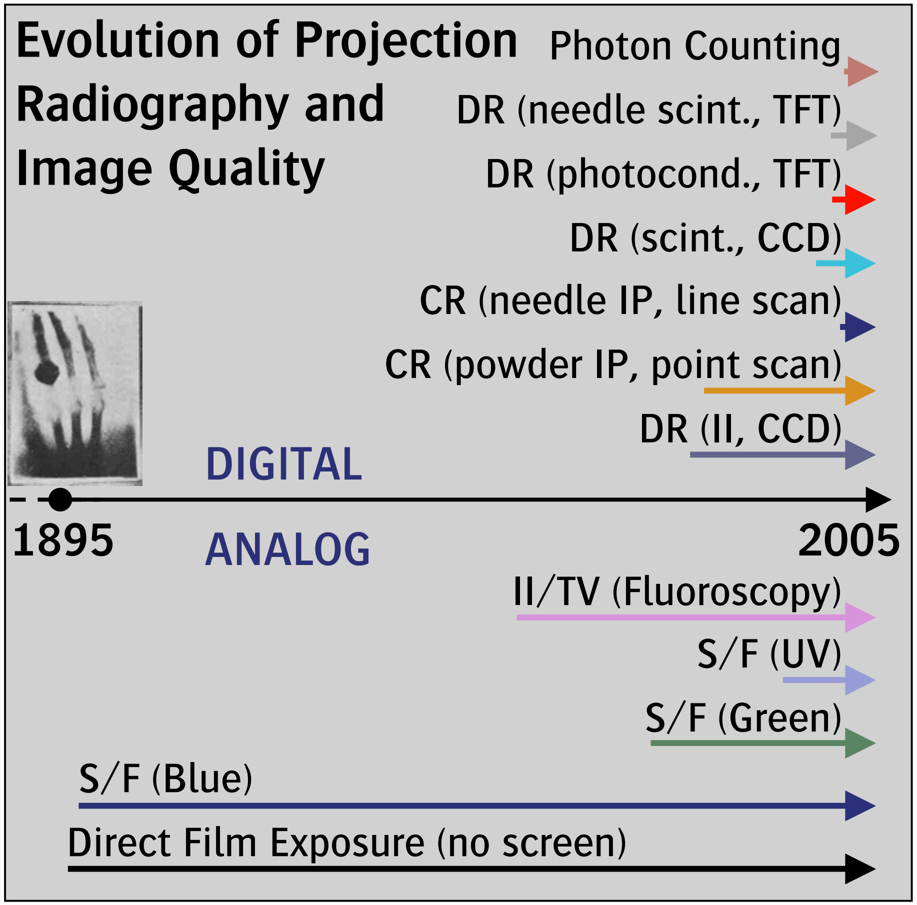
- Image quality is whatever the observer says it is (i.e., it is a subjective perception of the image, "in the eye of the beholder")

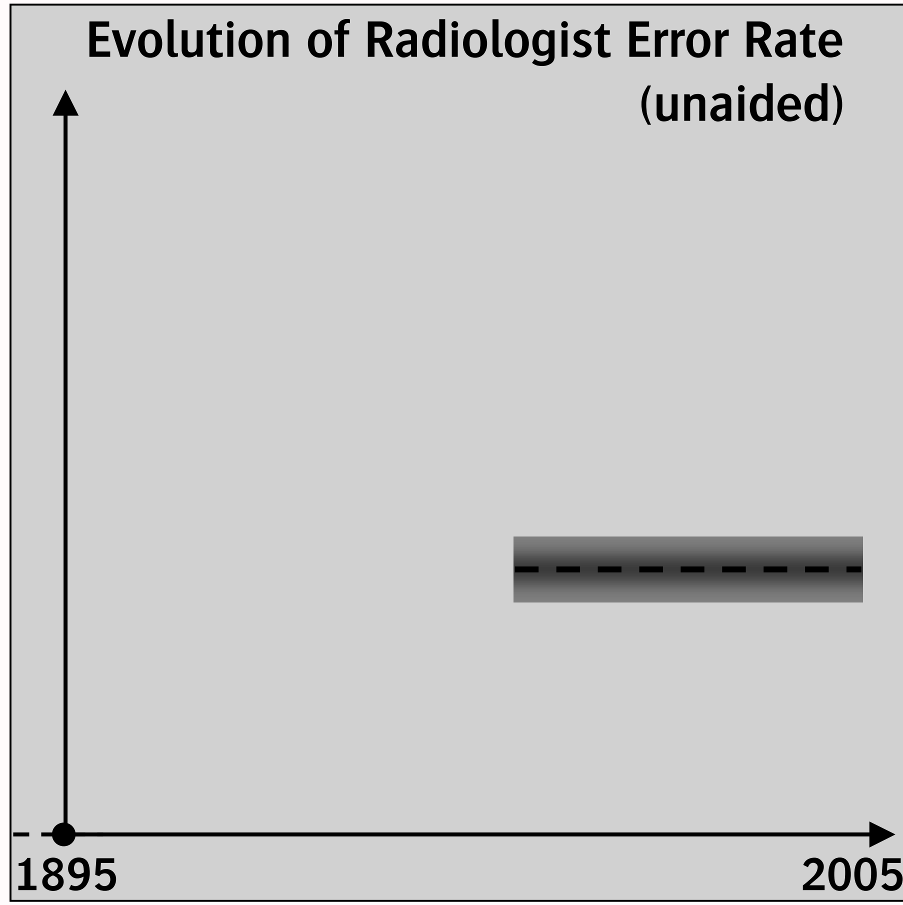
- Image quality is defined by an observer's ability to achieve an acceptable level of performance for a specified task

Image Quality: What is it?



Radiographic Image Quality: Does it matter?





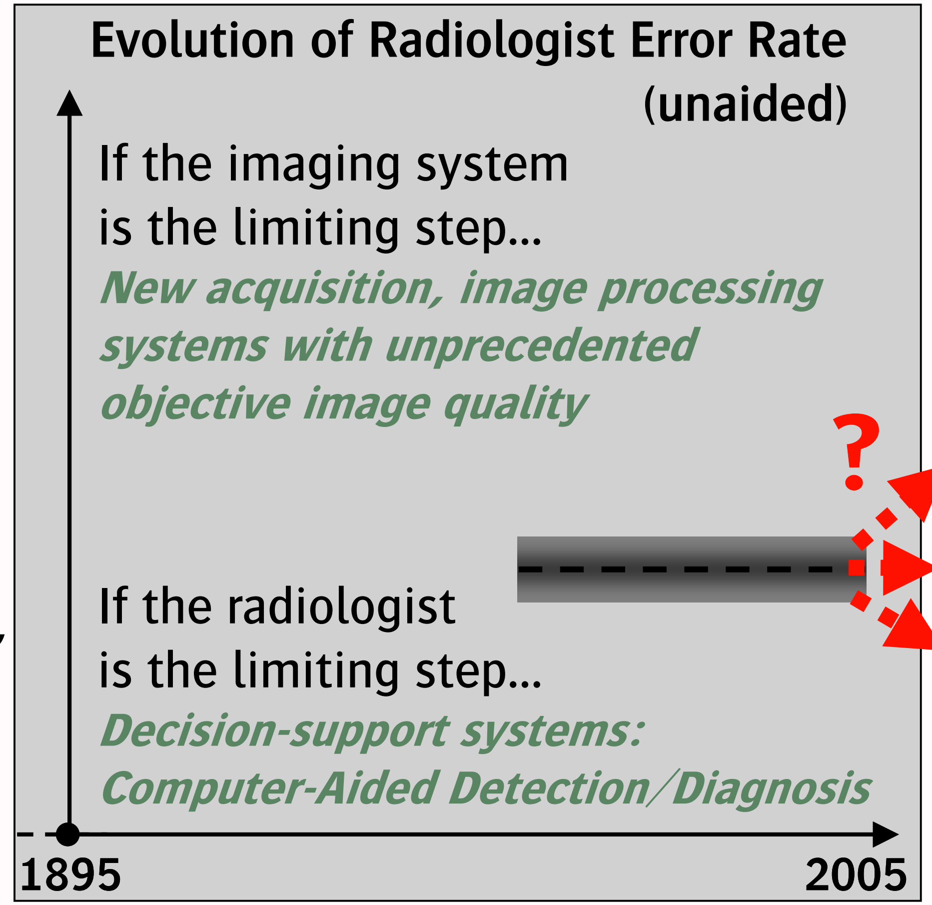
Significant image quality changes!
Significant dose changes: 50-100x

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



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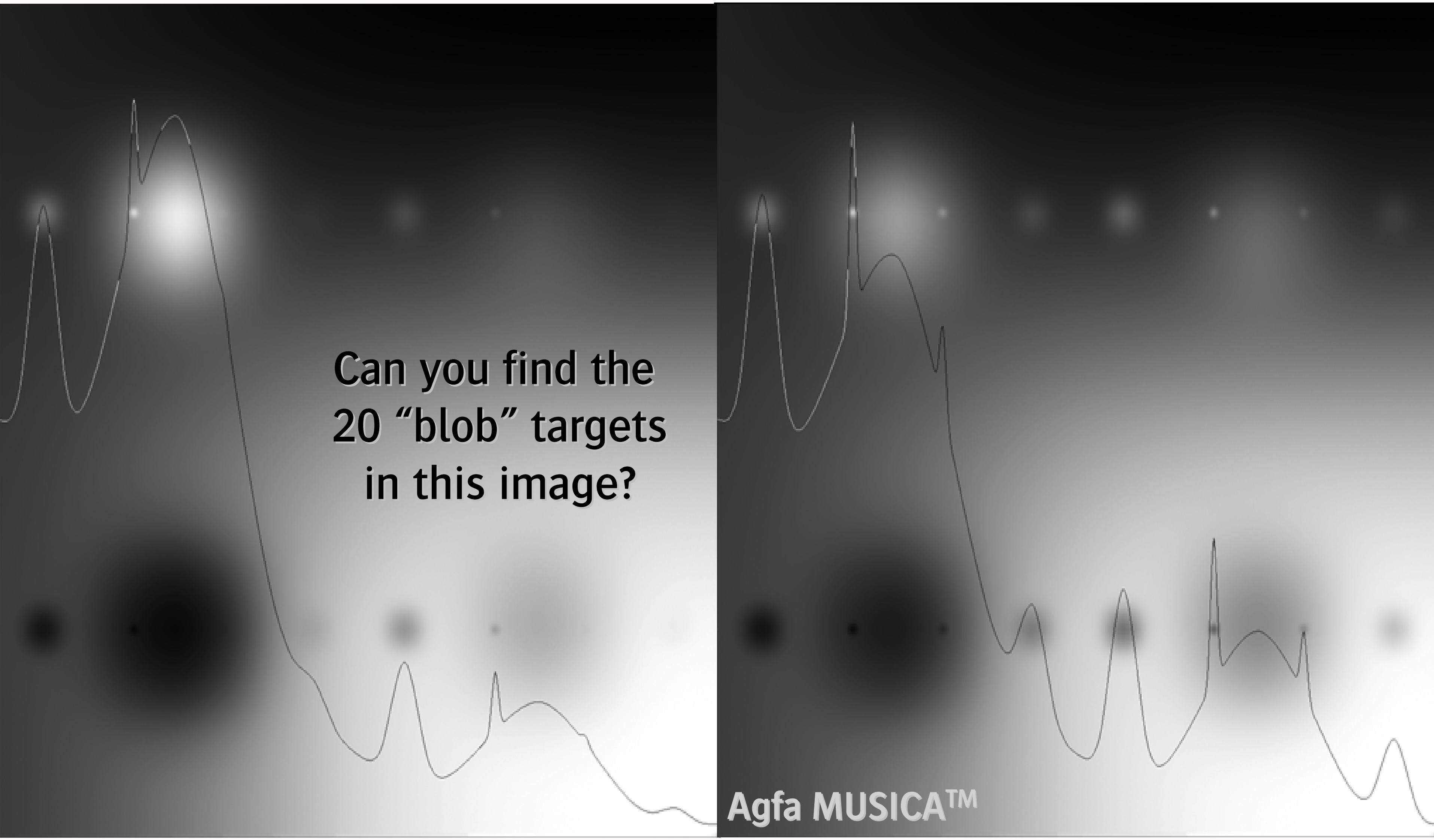
Medical Image Processing – Many Goals

- Optimize for human vision
  - Signal contrast
    - Latitude
    - Dynamic range (acquired vs. displayed)
  - Sharpness
  - Noise
- Optimize for machine vision
  - CAD
  - CAD_x

- 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



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_p, 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.

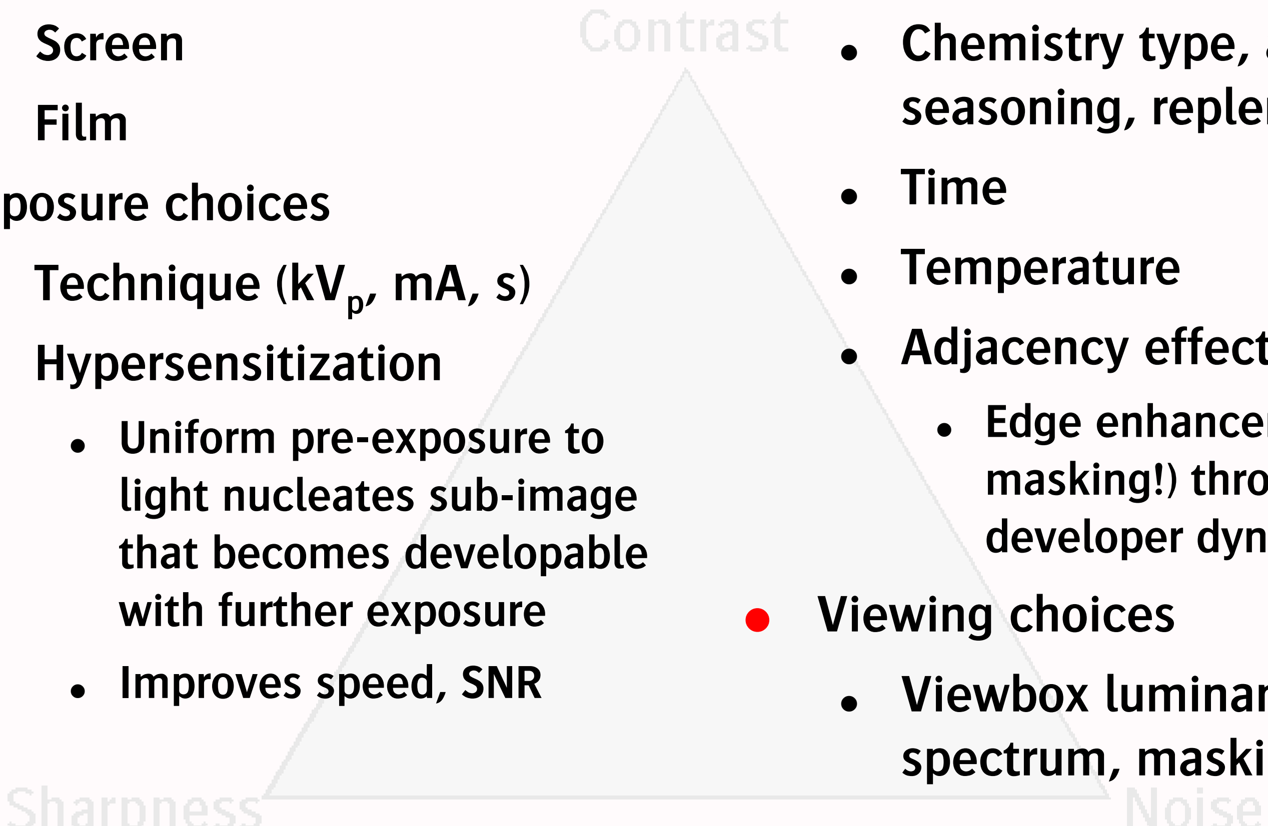


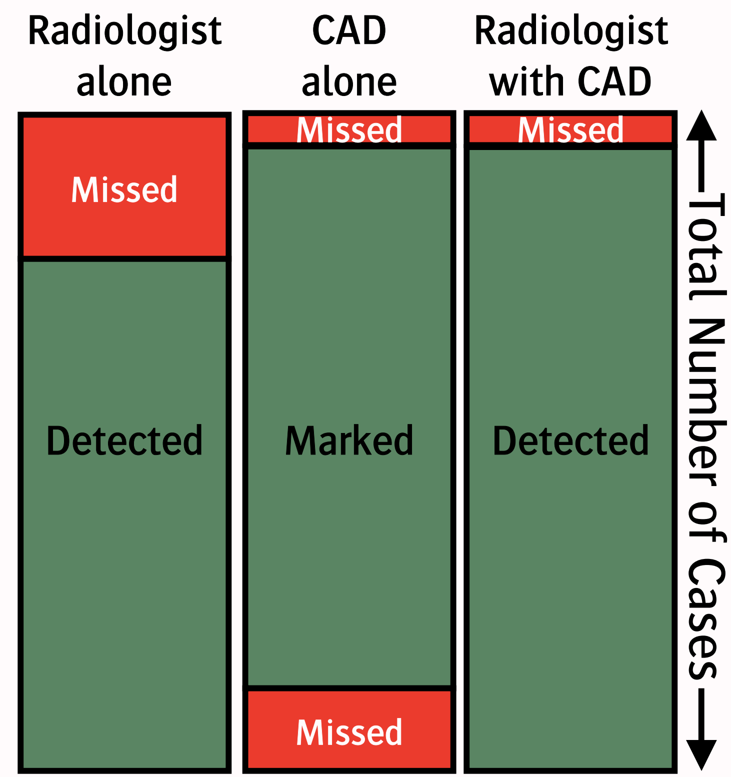
Image Processing for Display: Optimizing for Human Vision in Digital

- 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)



The Theory of CAD

*Kundel H, Visual search, object recognition and reader error in radiology, Proc. SPIE 5372 (2004), pp1-11 (SPIE Press, Bellingham WA)

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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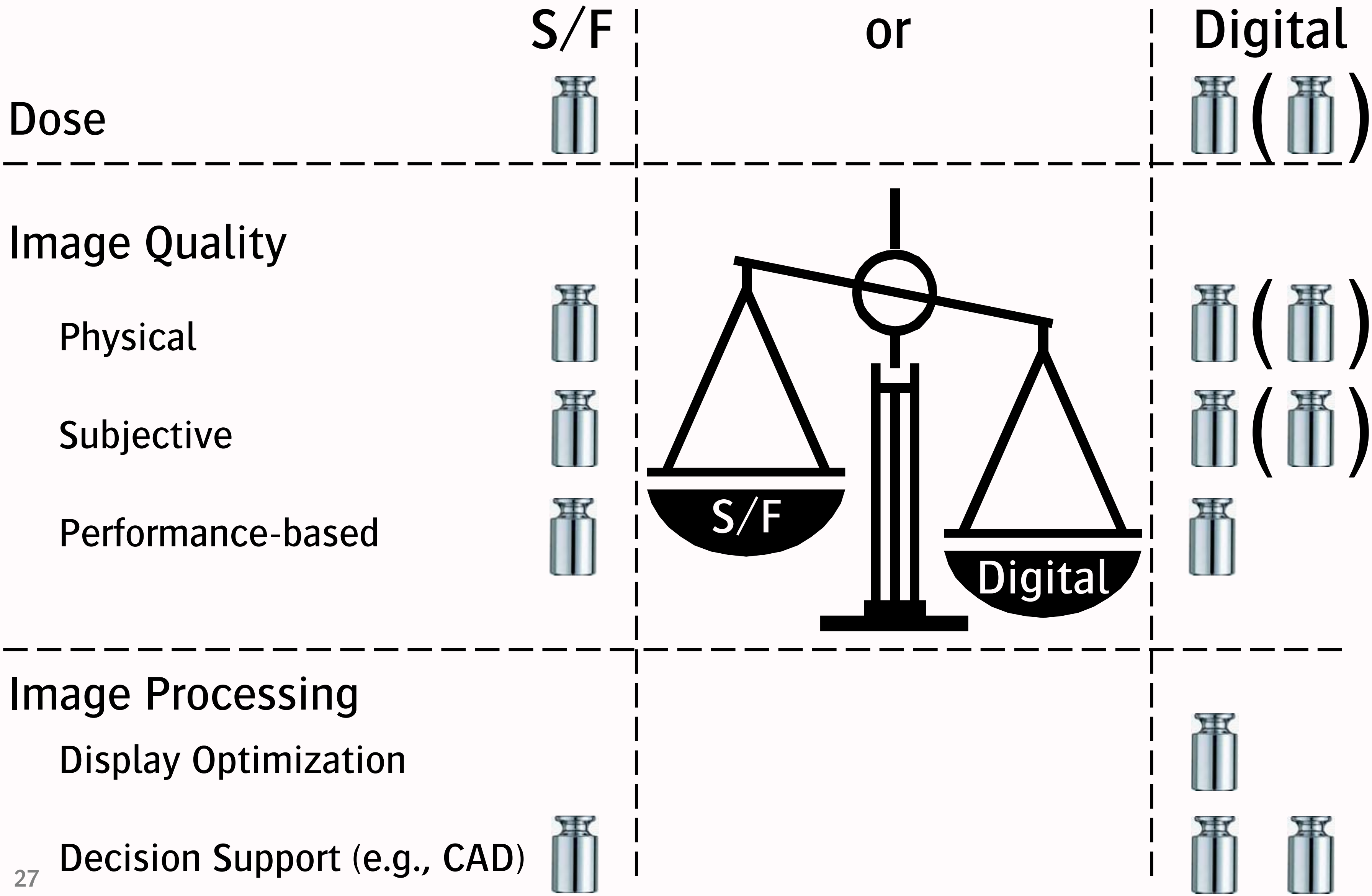
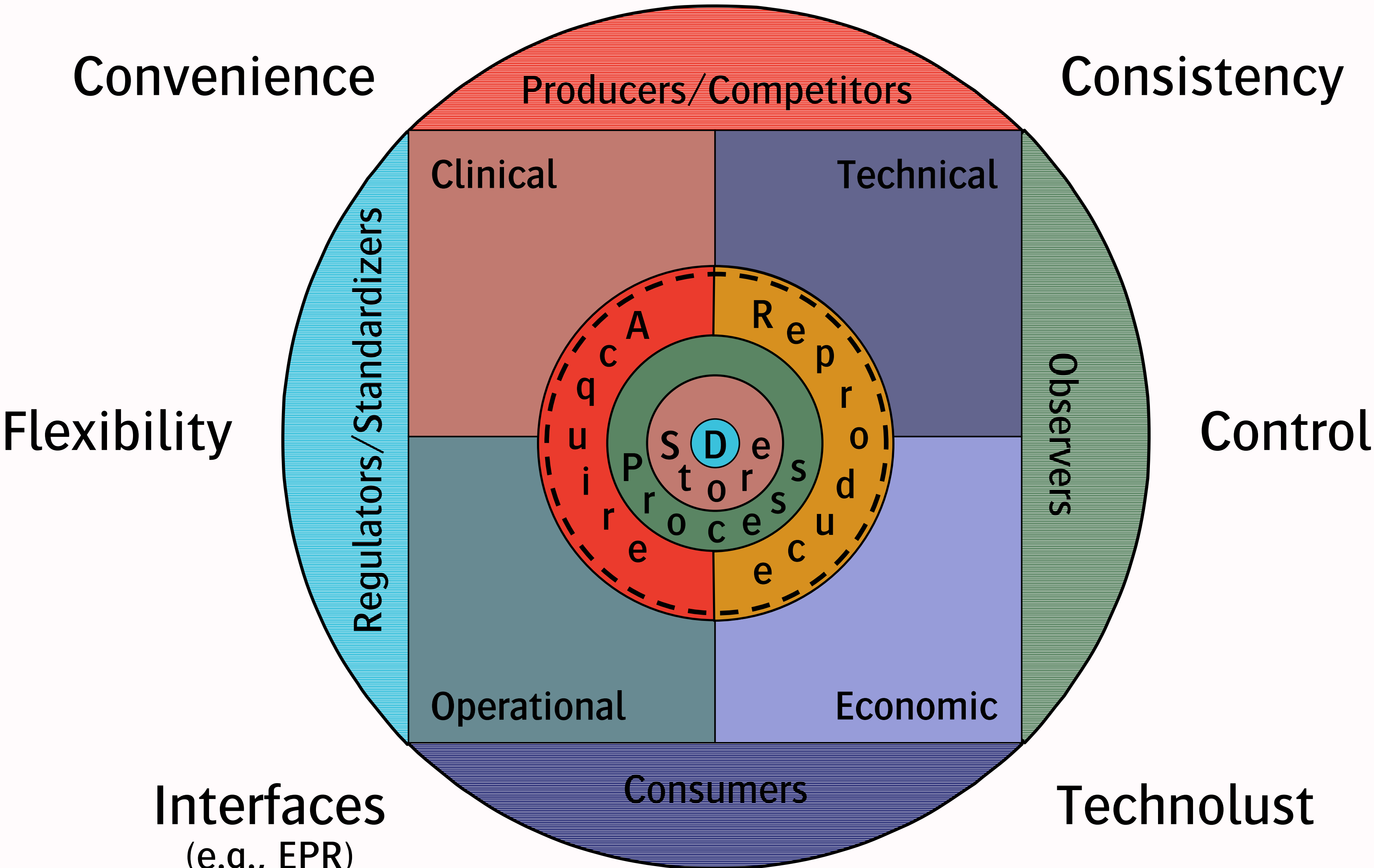
Analog or Digital Technologies – Quo vadis?



Back to the Bigger Picture:
The Path to System Equilibrium...



Thank You
for Your Attention

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