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Virtual tools and simulation methods from an industry perspective

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Answers for life.

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Early attempts to bridge technical parameters and visual perception

In the 1990's:

Sarnoff Visual Discrimination Model
Jeff Lubin, David Sarnoff Research Center
in Visual Models for Target Detection and Recognition, ed E Peli
World Sci Publ 1995

Visible Difference Predictor
Scott Daly, Eastman Kodak
in Digital Images and Human Vision, ed AB Watson,
MIT Press, 1993

Modeling of the human visual system to predict perceived differences in images in terms of JNDs (Just Noticable Differences)

Early version of a model observer

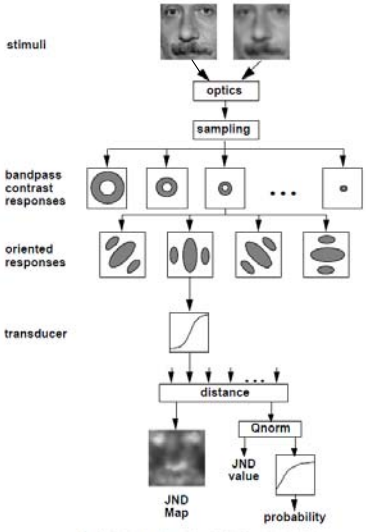

Figure 8. Flow diagram for the Sarnoff Visual Discrimination Model.

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Virtual Tools – what is it ?

Types of virtual tools	Purpose (examples)
Component simulation	Product development
Virtual reality / computer simulated environment	Service & sales
System simulation	Complex interaction of components
Workflow simulation	Decision support, surgery planning
Virtual phantoms	Image quality evaluation
Mathematical model observer	Image quality evaluation
Virtual clinical trial	Image quality evaluation

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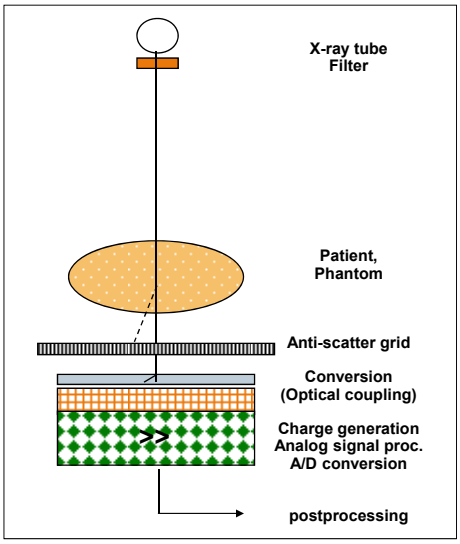
Simulation of X-ray chain for system design



Deterministic and Monte-Carlo Simulation
Siemens:
Drasim, Mocassim, XChain
external: e.g. GEANT4, Penelope

Ingredients:
- X-ray generation, spectrum
- Phantom model
- X-ray interaction with matter
- Detection model

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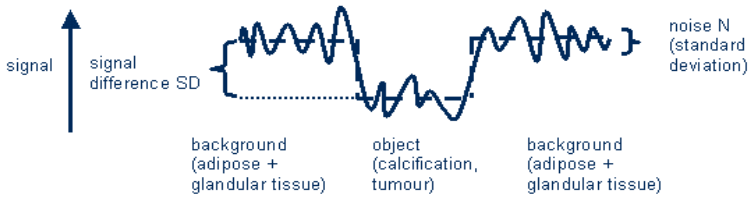
X-ray chain Example 1: Spectrum optimization

Task: maximize SDNR²/dose

as function of
kVp, anode/filter combination (Mo/Mo, Mo/Rh, W/Rh), (filter thickness)

SDNR = signal difference to noise ratio
Dose = estimate for average glandular dose AGD



Advantage: SDNR is independent of the W/L setting

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Simulation: SDNR²/Dose as function of tube voltage

P. Bernhardt et al., Med Phys 33 4337-4349 2006

calcifications

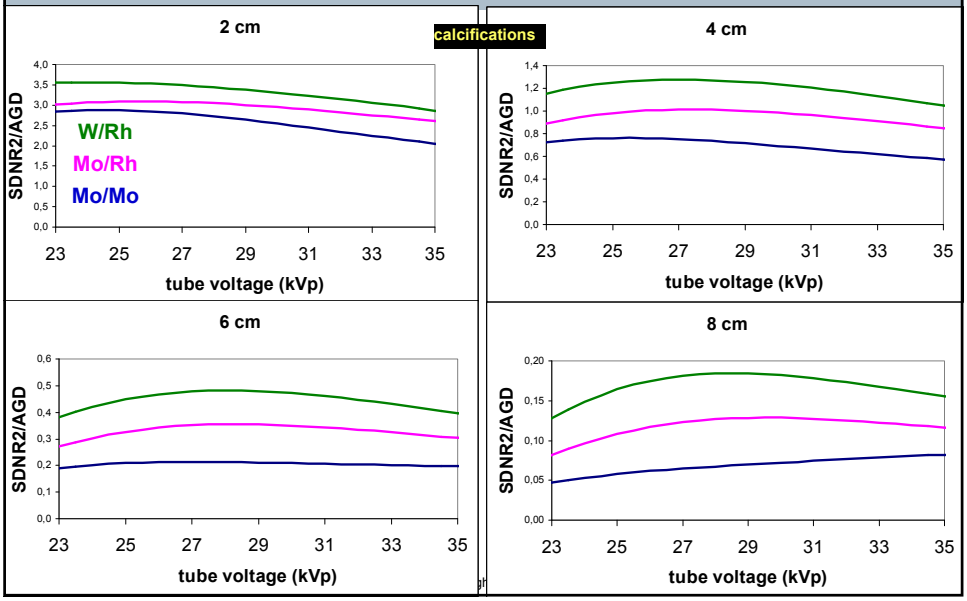

Image quality evaluation with virtual tools
Why now?

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Emerging of Tomosynthesis

- Tomosynthesis is more complex than CT:
  - MTF(0) ≠ 1 → non quantitative (no HU)
  - incomplete sampling → artifacts
  - superimposed tissue is reduced, but not completely
  - highly anisotropic resolution
- We need new QC procedures for tomosynthesis
  - for numerical, quantitative evaluation
  - CNR, i.e. a DC signal, is not enough,
    we have to take more frequencies into account
  - phantoms with structured background

Tomosynthesis Reconstruction

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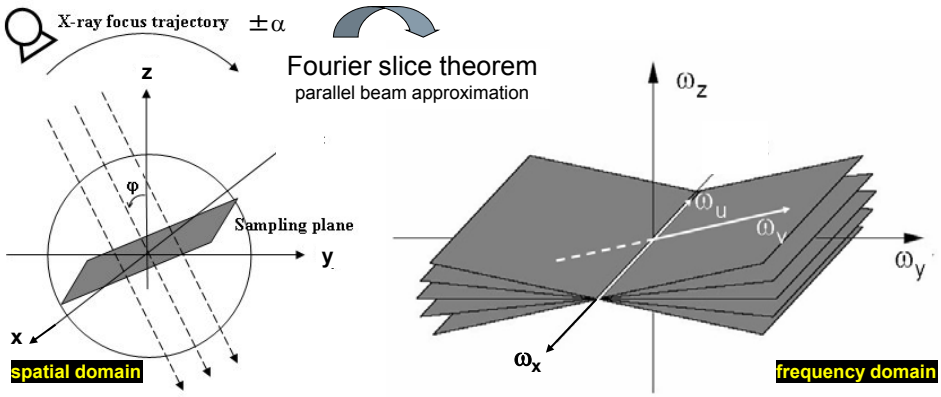
Incomplete Data due to sampling geometry



- sampling is incomplete
- sampling is often sparse

→ artifacts

→ anisotropic resolution

→ approximative inversion only

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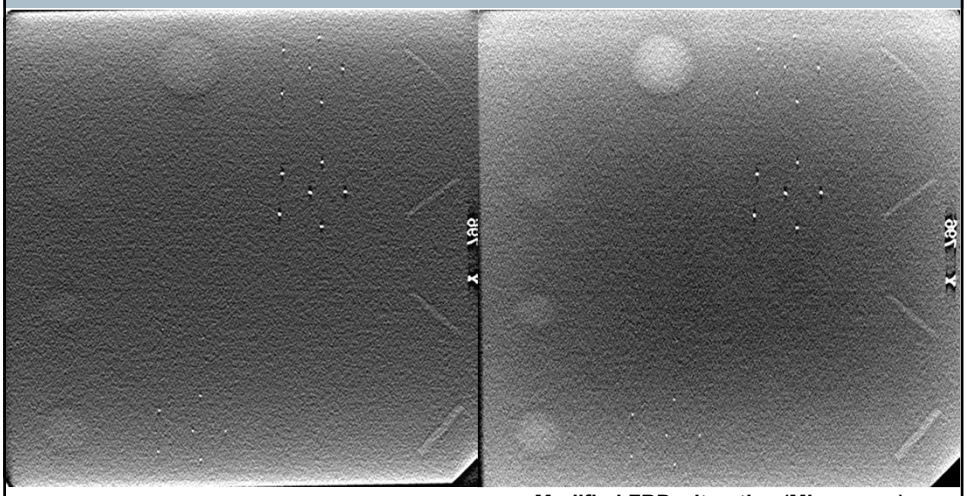
Image impression can be altered by recon



"Standard" FBP

Modified FBP ≈ iterative (ML convex)

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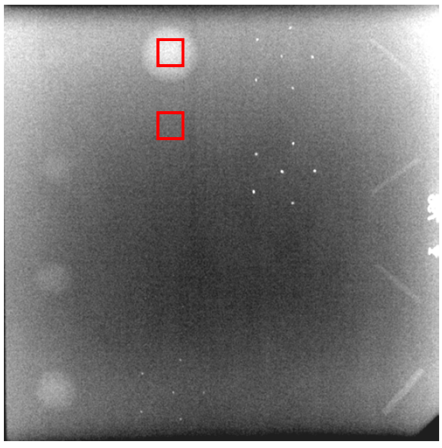
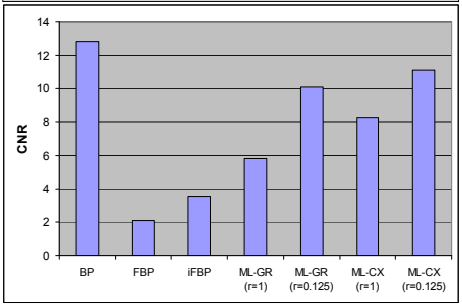
Contrast-to-noise ratio (CNR) may not be appropriate to measure image quality



Unfiltered BP

CNR from reconstructed slice:

$$CNR = \frac{Signal(mass) - Signal(bckgrnd)}{Stdev\ (bckgrnd)}$$



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Virtual phantoms, U Penn

Bakic et al. Med Phys 38 3165-3176, 2011, IWDM 2014

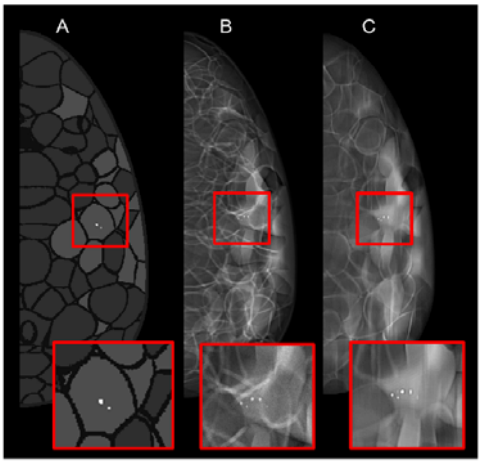
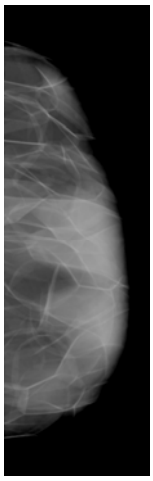


Fig. 2. Example of a breast model with calcifications in cross-section (A), together with the resulting mammogram (B), and DBT slice (C). A magnified image is inset

Projection image created with XChain



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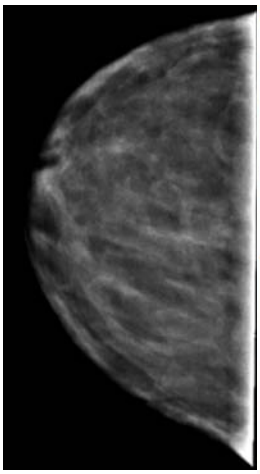
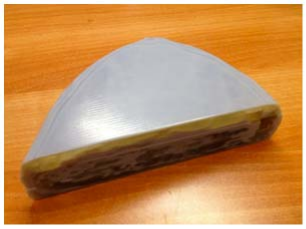
Virtual and physical phantoms: Duke University

Source: Joseph Lo, Duke University





Projection image

Fabricated (3D printed) physical breast phantoms, the Doublet (left) with two materials and the empty Singlet (right) with a single material, both in three slabs of 15 mm each.

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Virtual phantoms, Duke University

N. Kiarashi IEEE TMI 33 1401-1409 2014

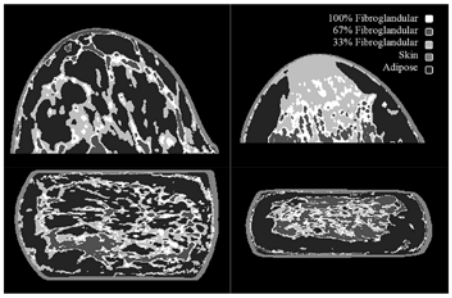

Fig. 1. Axial (top) and coronal (bottom) slices through a 28% dense breast phantom (left) and a 44% dense breast phantom (right). Both phantoms are compressed to 50% of the pendant breast diameter.

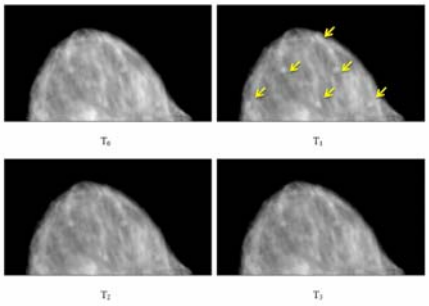

Fig. 7. Mammographic projection images of a 28% dense breast phantom with lesions following a washout kinetic pattern (Type III) acquired at low-energy (W/Rh 28 kVp) over four time points. Arrows point to the location of the lesions. Images are displayed at such window/level settings to match the backgrounds and help visualize the lesion behavior over time.

Incorporating the 4th dimension by modifying parts of the tissue by a time-varying fraction of iodine contrast agents
→ study of contrast enhanced mammography

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Hybrid technique: insert simulated lesion into clinical data

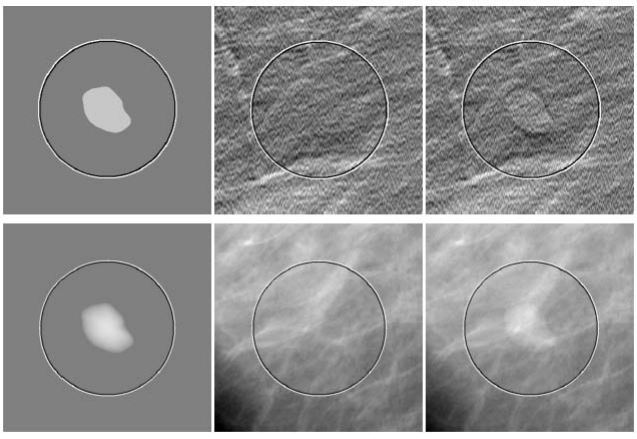

Figure 2: Sample images shown to observers prior to study. Top and bottom rows are BT and DM images, respectively. Column-wise, from left to right, are shown a signal-only image, a clinical background image, and the same background image with the signal added as described in the text.

M. Rushin: SPIE 6510, 65101J, (2007)

→ Tomosynthesis needs 4 x lower contrast than FFDM at the same detectability.

Virtual Clinical Trials comprise system simulation and visual perception

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Software modeling of the entire image chain including
- X-ray generation
- Human anatomy/Phantom
- X-ray detection
- Image processing/reconstruction
- Image display
- Human visual system

Goal is to predict task performance and decision of a human observer.
The result may be an ROC curve

Advantages of virtual methods

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- Investigation of single effects or parameters in complex systems without impact of other factors

  Understand influence and role of specific parameters
- Cost advantage: simulation is cheaper than building hardware
- Possibility to study more variants with simulation than with HW prototypes
- Model observers help to understand the relationship between physical image quality parameters and perceived image quality in clinical images
- Virtual Tools are portable – can be taken to the customer
- Virtual clinical trials are faster and cheaper than clinical trials with human subjects and readers,
  no ethical problems with dose to human subjects
  → helps regulatory approval of new methods and devices
- Virtual clinical trials may be more objective than human readers

Challenges

- Complex systems with many parameters – difficult to simulate

  Requires a thorough theoretical understanding of the important parameters and their impact

  Do not use a virtual tool as a black box!
- Realism – how to test the realism of a virtual model ?
- Validation ?
- There may be an acceptance problem
  “Human observer work differently!“
  “This is an oversimplification, you have forgotten effect x!“

Industry‘s perspective and interest

Virtual tools and virtual clinical trials will

- lower the cost of product development
- help licensing and approval of devices and methods
- enable to introduce new QC methods
- drive product and process innovation and support the development of new business
- improve healthcare and increase the productivity of health systems

Thank you for your attention!