Diagnostic Medical Image Processing
Reconstruction – Fan Beam Reconstruction: Truncation

WS 2015/2016

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Topics

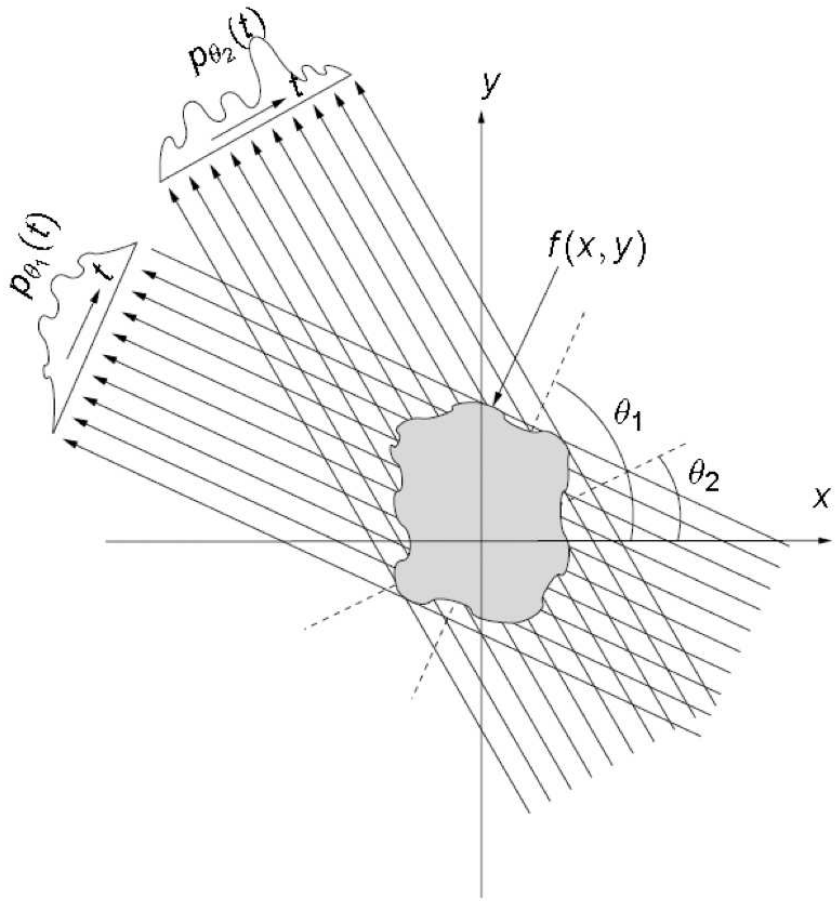
Reprise: Fan Beam Reconstruction

What is Truncation?

Truncation Correction Algorithms

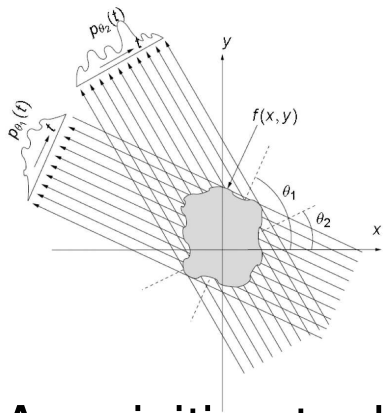
Phantoms

Parallel Beam Geometry



- Earliest Acquisition Geometry
- Principle: Rotate & Translate

Parallel Beam Geometry



- Acquisition took 5 Minutes
- Reconstruction took 30 Minutes
- Slice resolution was 80 x 80 pixels

First CT Scanner: EMI (1971)

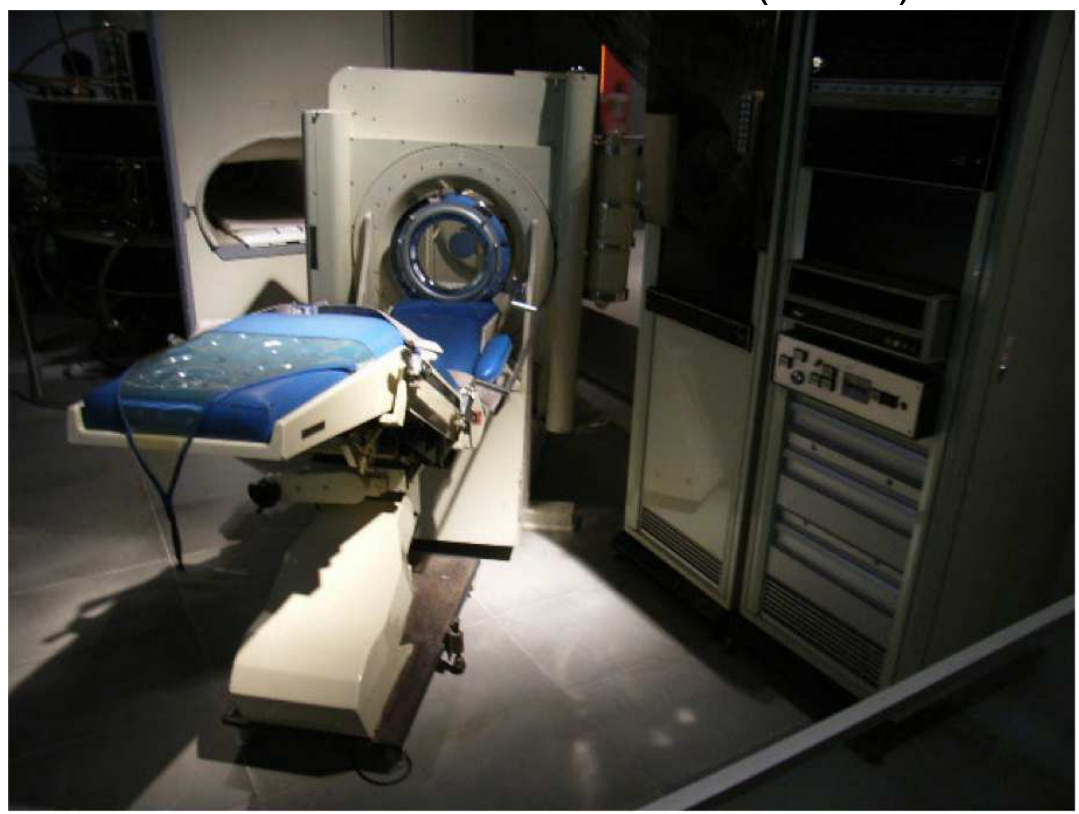
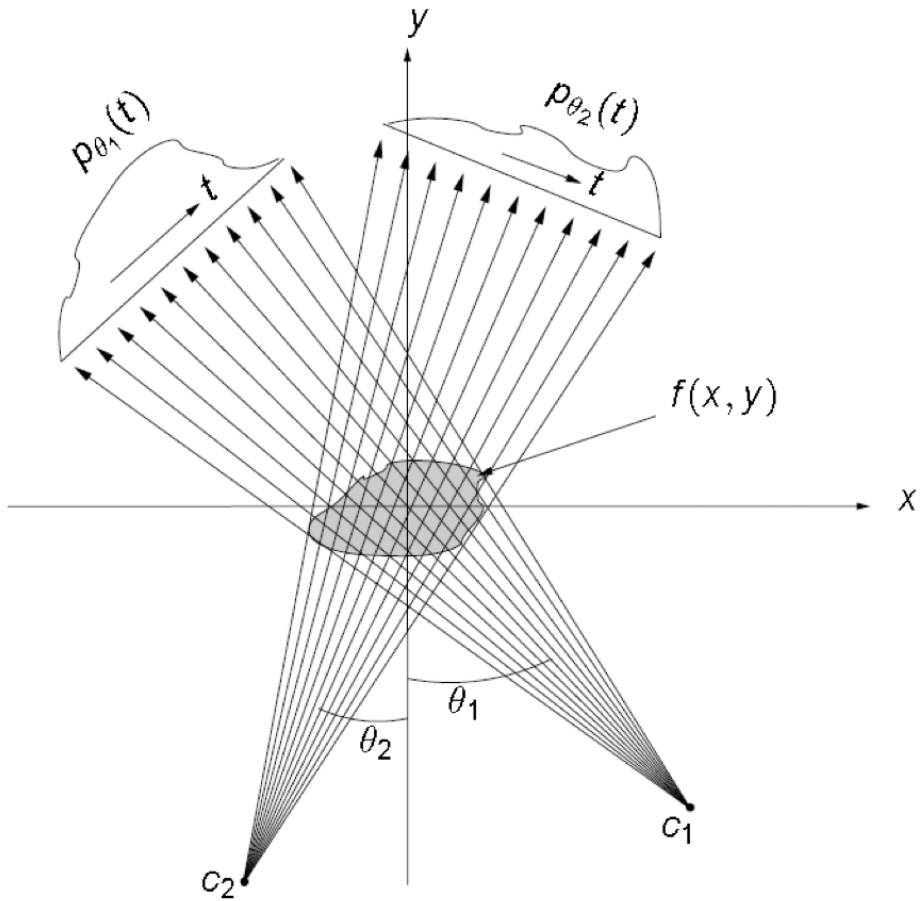
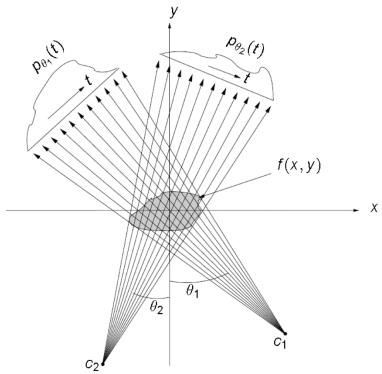


Image: Wikipedia

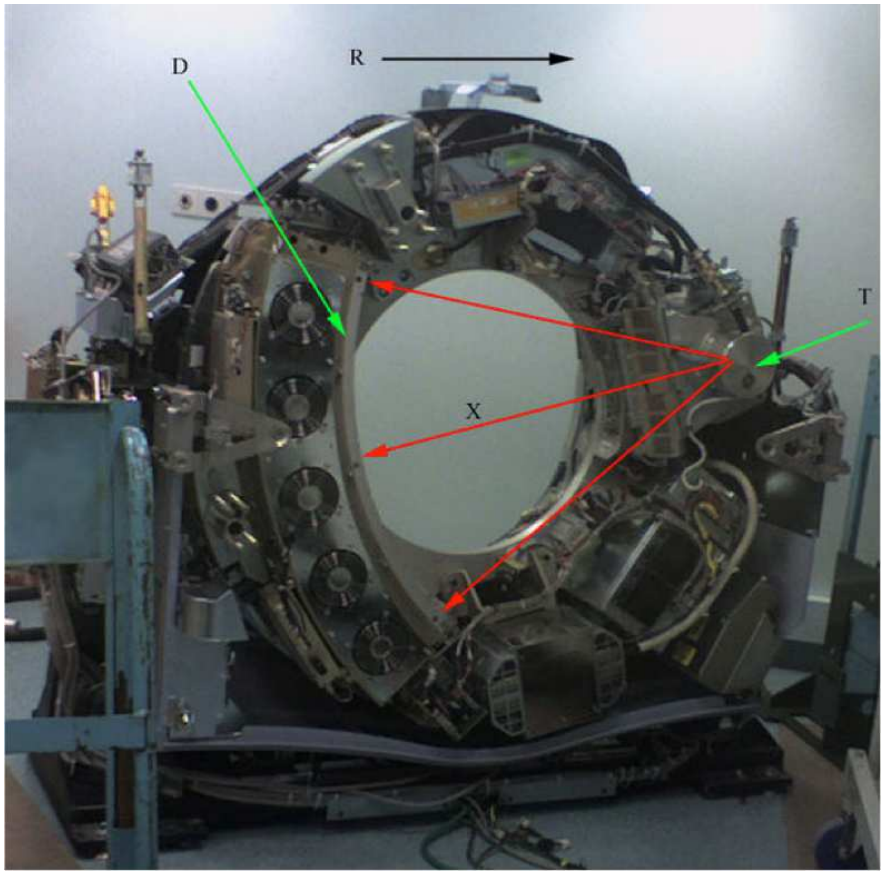
Fan Beam Geometry



Fan Beam Geometry



- Fan beam Scanners became available in 1975 (20s / slice)
- Fast rotations became possible 1987 with slip rings (300ms / slice)



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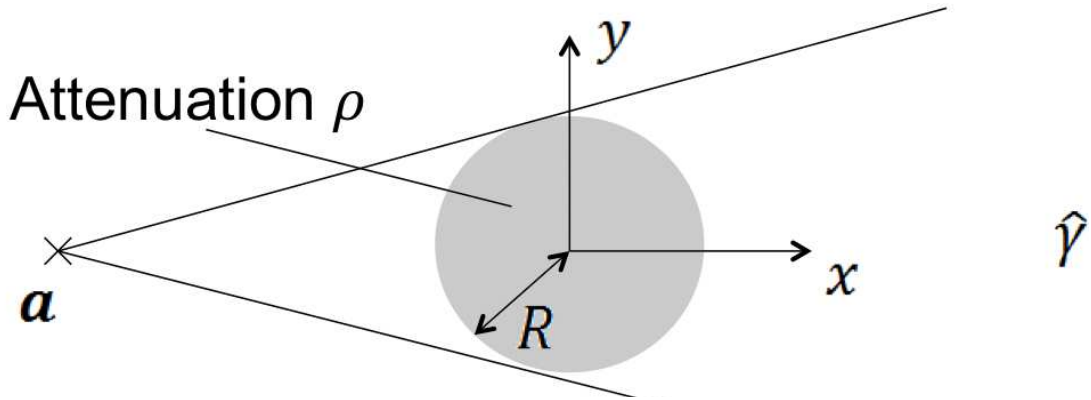
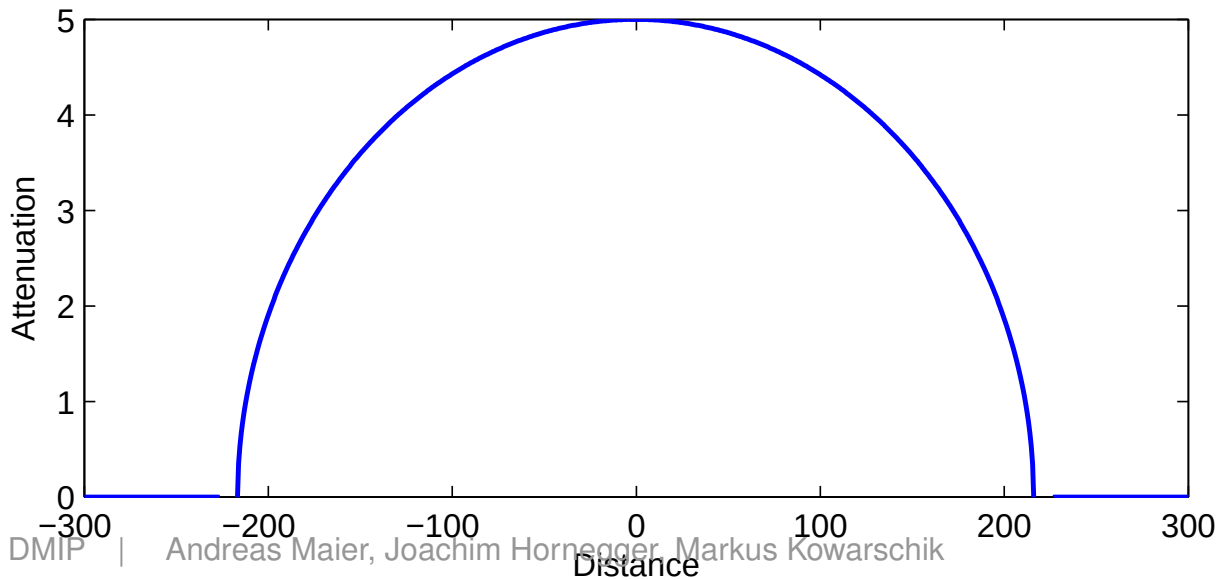
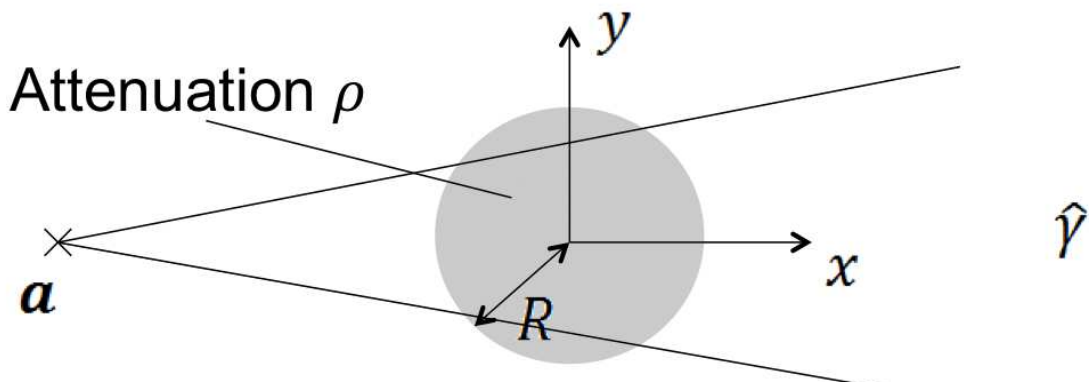
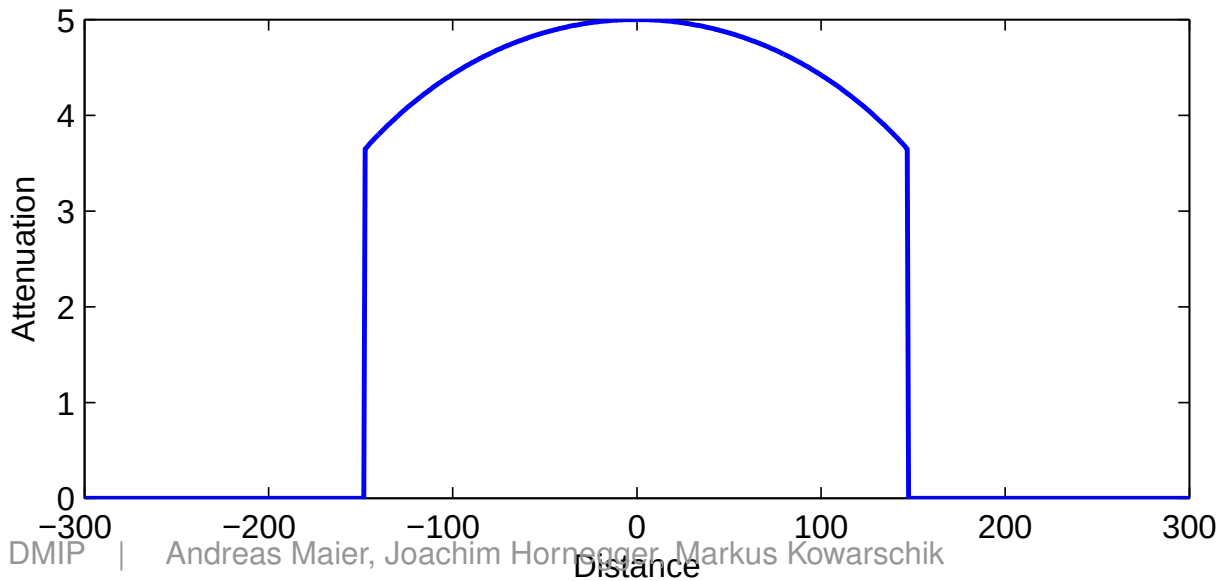
Example: Homogeneous Cylinder



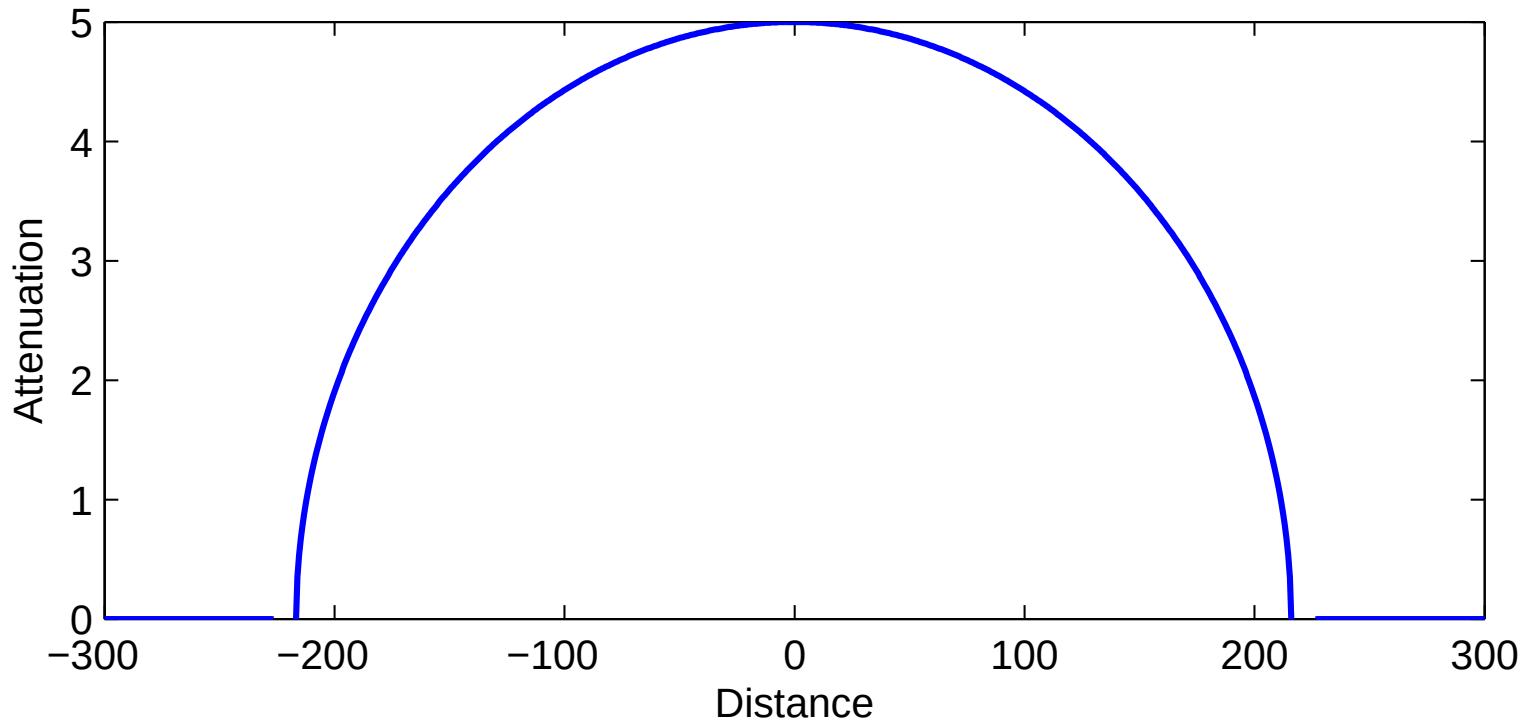


Example: Homogeneous Cylinder (2)





Example: Homogeneous Cylinder (3)



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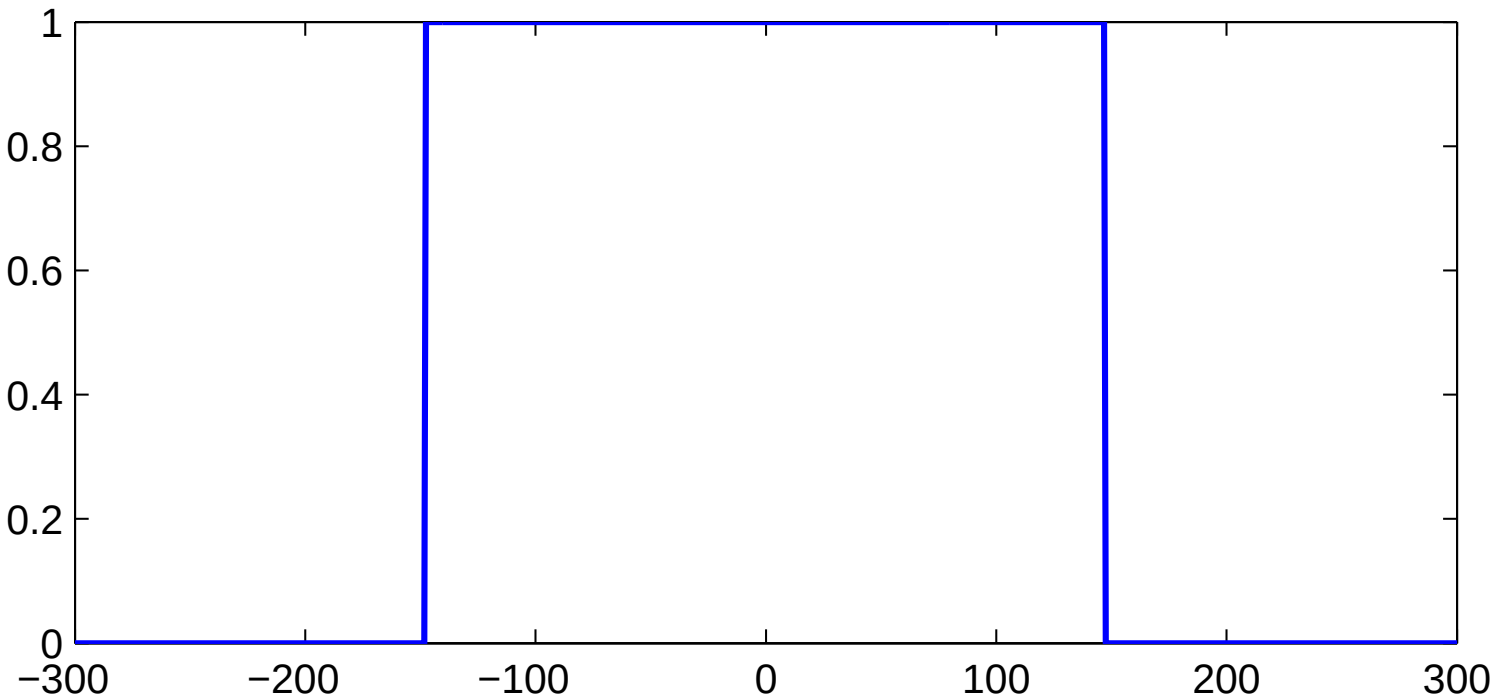

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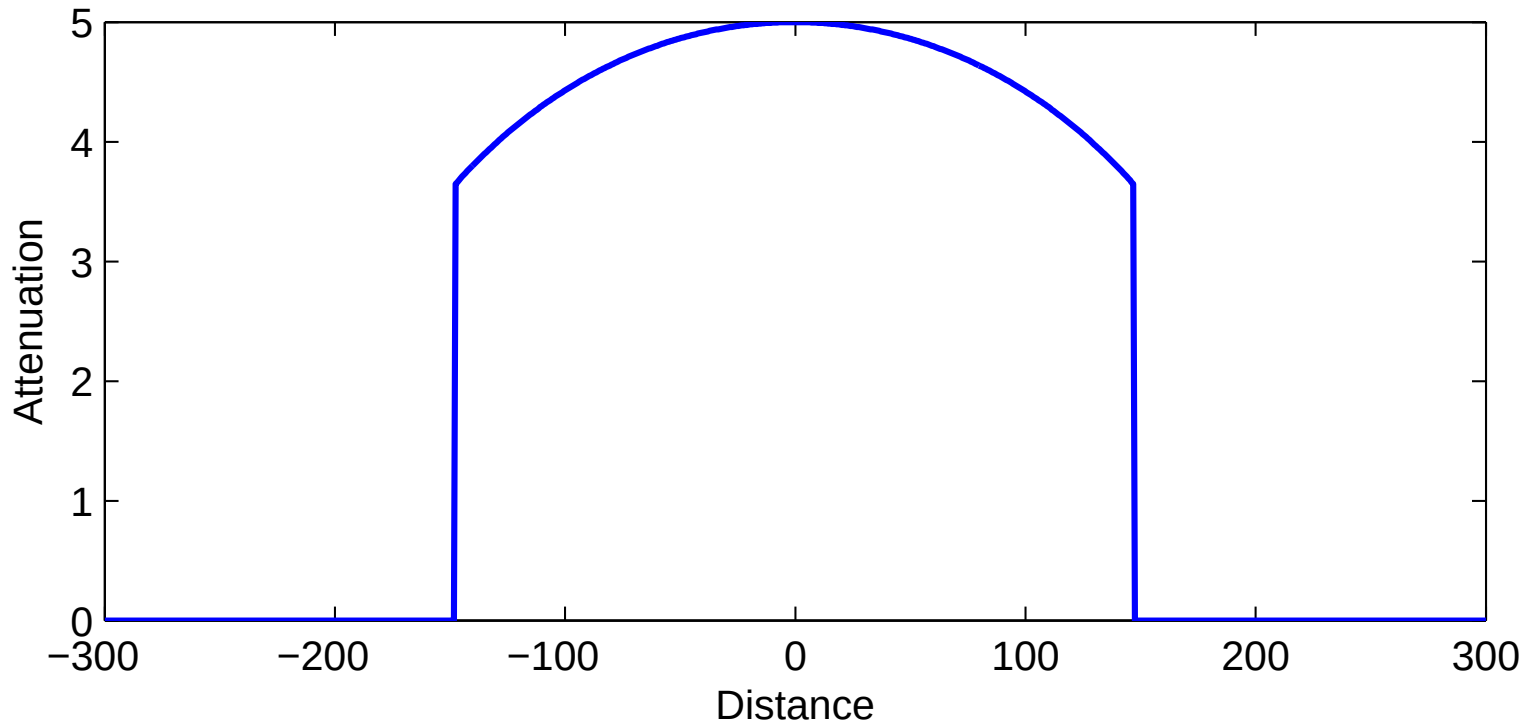
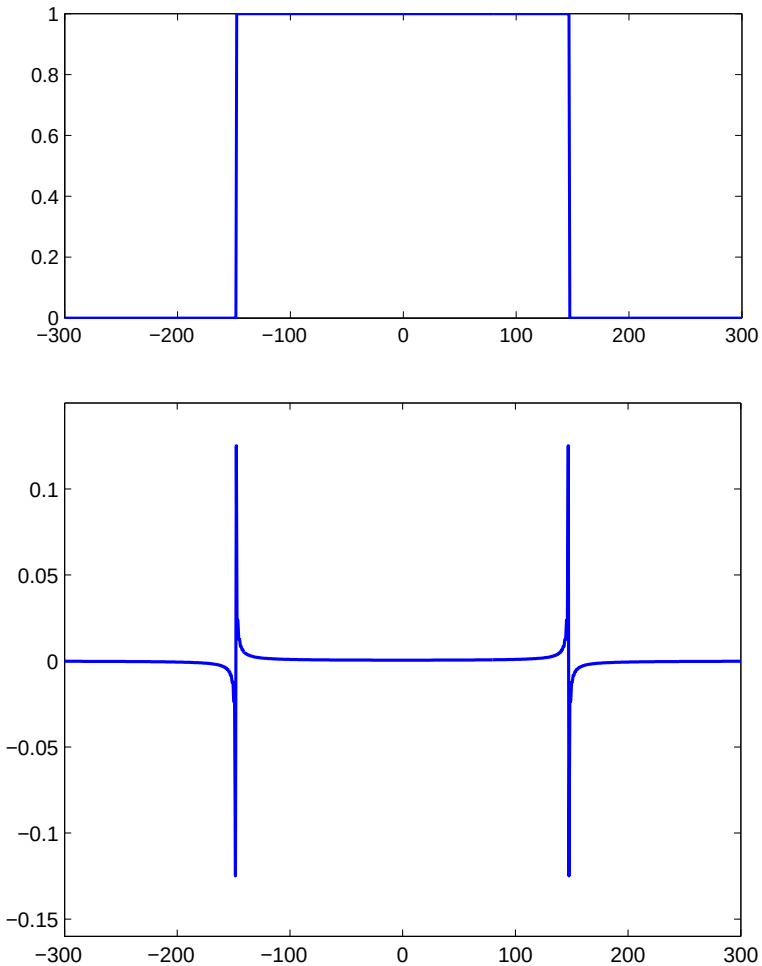
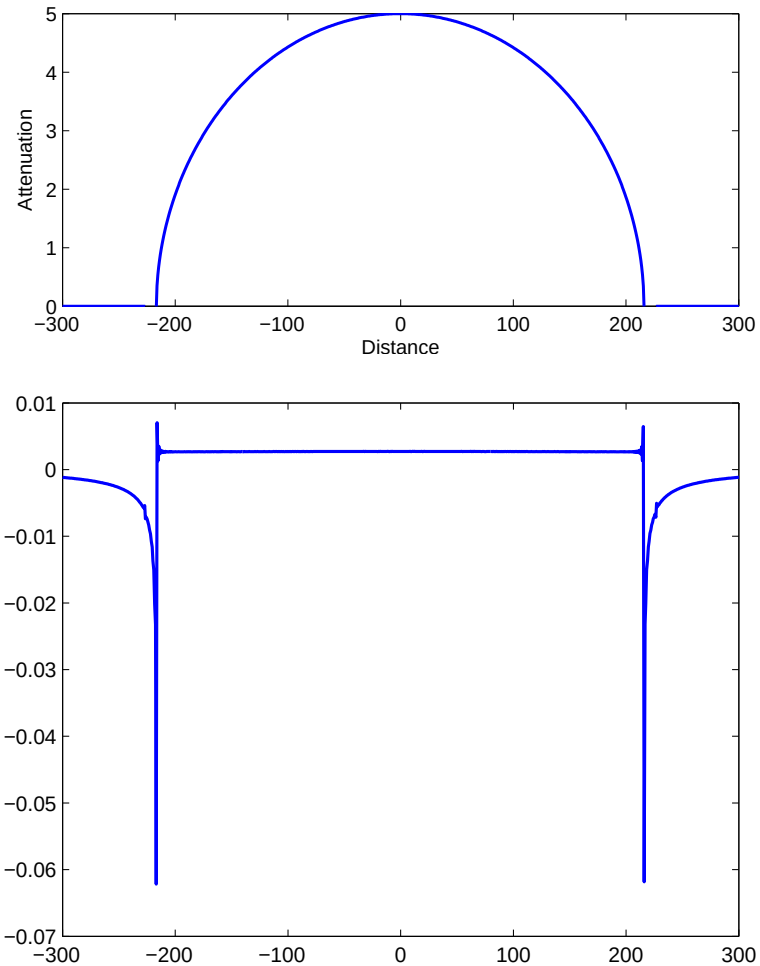


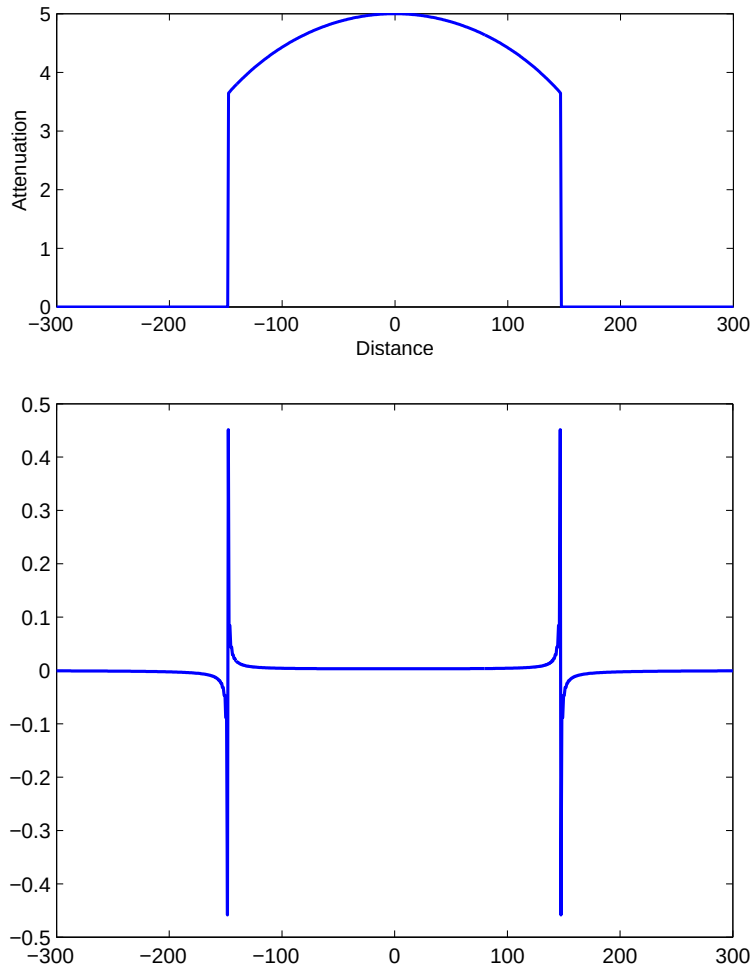
Example: Homogeneous Cylinder (4)



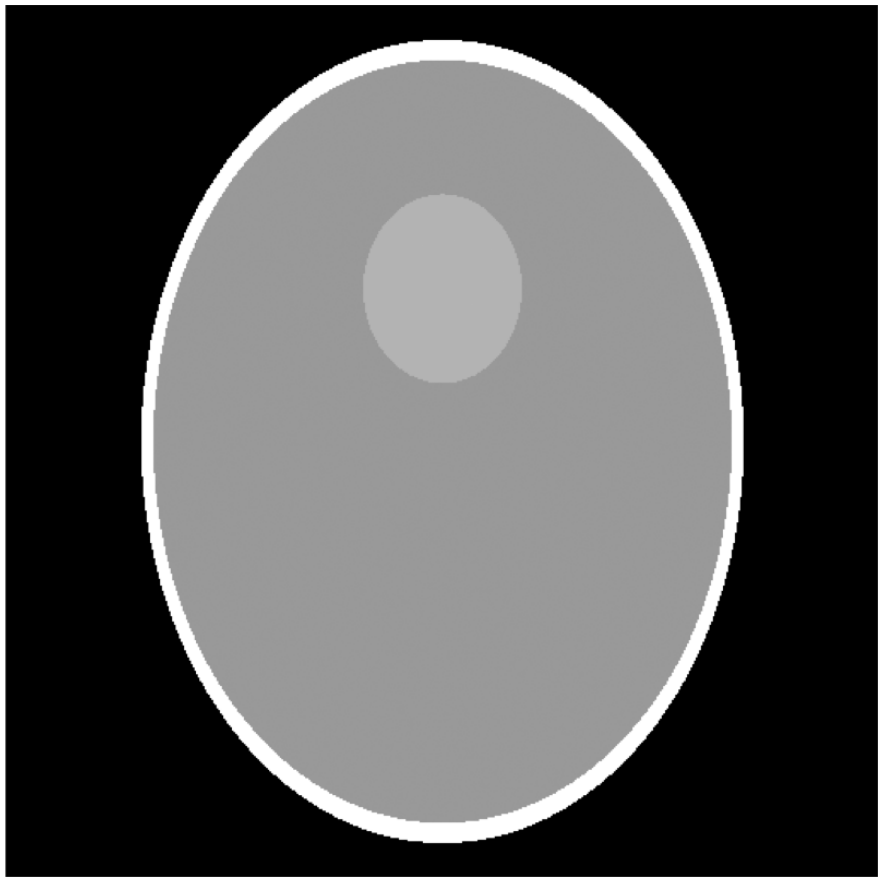
Example: Homogeneous Cylinder (5)



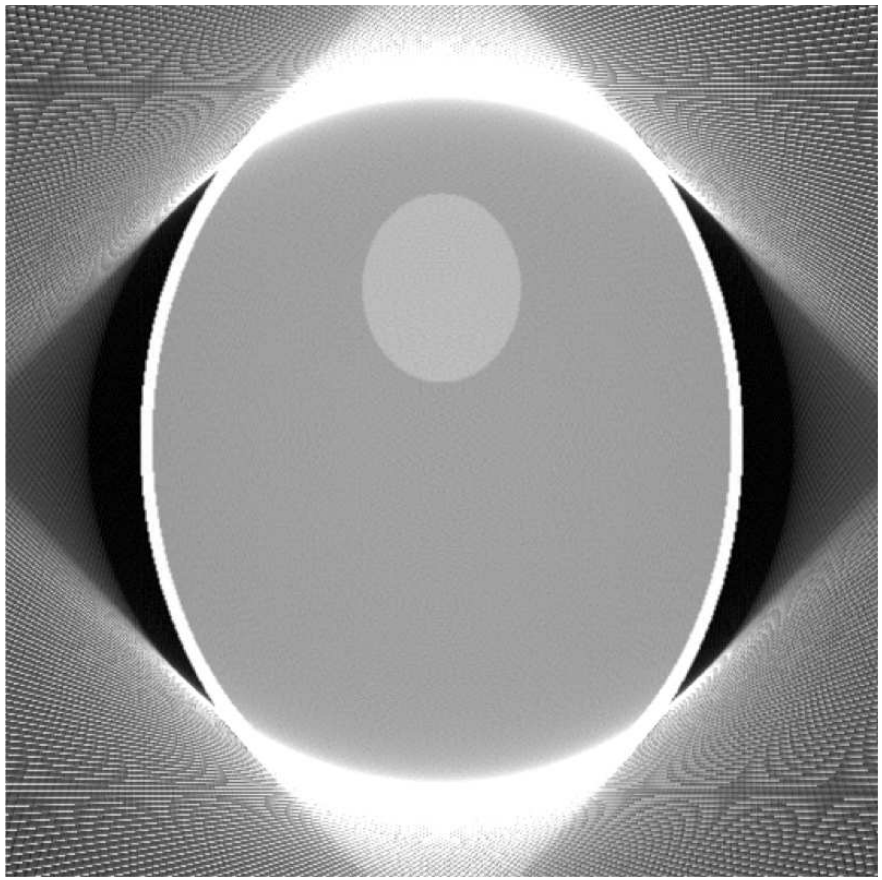
Example: Homogeneous Cylinder (6)



Example: Shepp-Logan Phantom



Example: Shepp-Logan Phantom (2)



Truncation

- Happens when the imaged objects extends the field-of-view
- Can be modeled as a multiplication with a rectangular window function in spatial domain
- Introduces artificial frequencies in the reconstruction
- Causes typical artifact at the end of the field-of-view

Topics

Reprise: Fan Beam Reconstruction

What is Truncation?

Truncation Correction Algorithms

Phantoms

Truncation Correction via Extrapolation

- Solution 1: Defect pixel extrapolation
- Solution 2: Heuristic extrapolation
- Solution 3: Water cylinder assumption
- Solution 4: Use of prior knowledge
- Solution 5: Use of a semi-transparent filter

Defect Pixel Extrapolation

- Model extrapolation as deconvolution
- Use defect pixel interpolation algorithm

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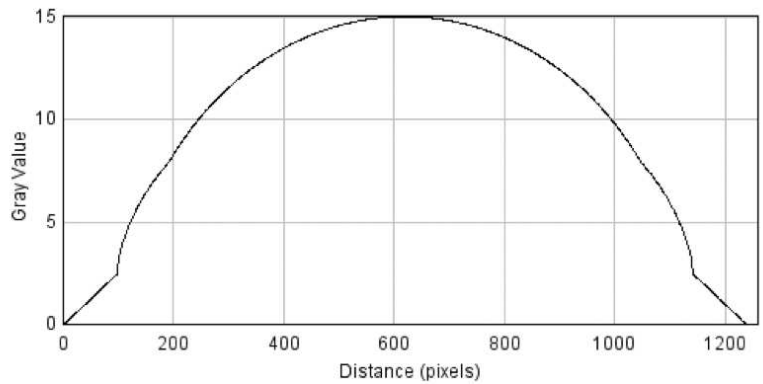
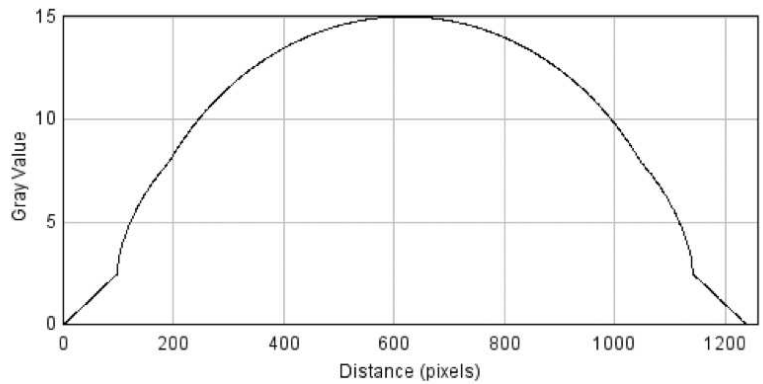


Defect Pixel Extrapolation

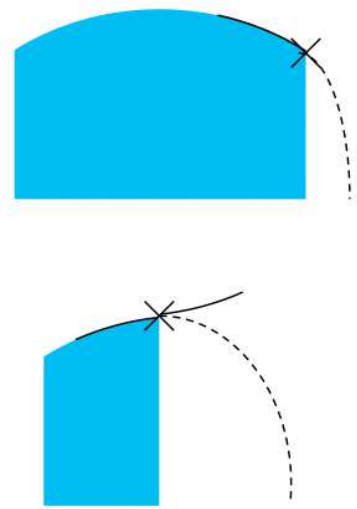
- Model extrapolation as deconvolution
- Use defect pixel interpolation algorithm



$\Rightarrow$ Unfortunately, the algorithm works not as well as expected

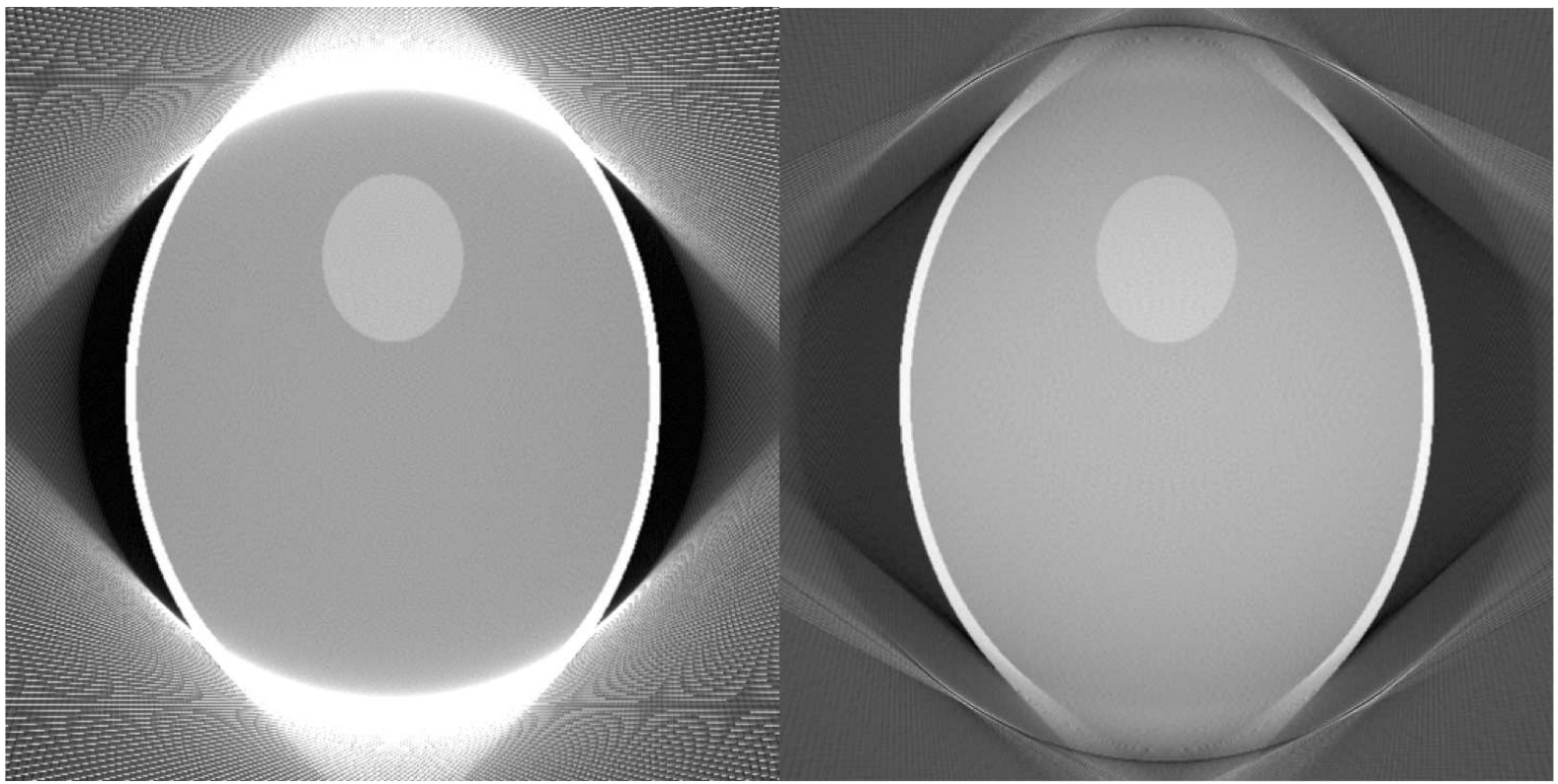
Heuristic Extrapolation

- Use mirroring for extrapolation
- In order to enforce a limited size of the object, a cosine-like weighting is added



Ohnesorge B, Flohr T, Schwarz K, Heiken JP, Bae KT. Efficient correction for CT image artifacts caused by objects extending outside the scan field of view. Med Phys. 2000 Jan; 27(1):39-46.

Heuristic Extrapolation (2)



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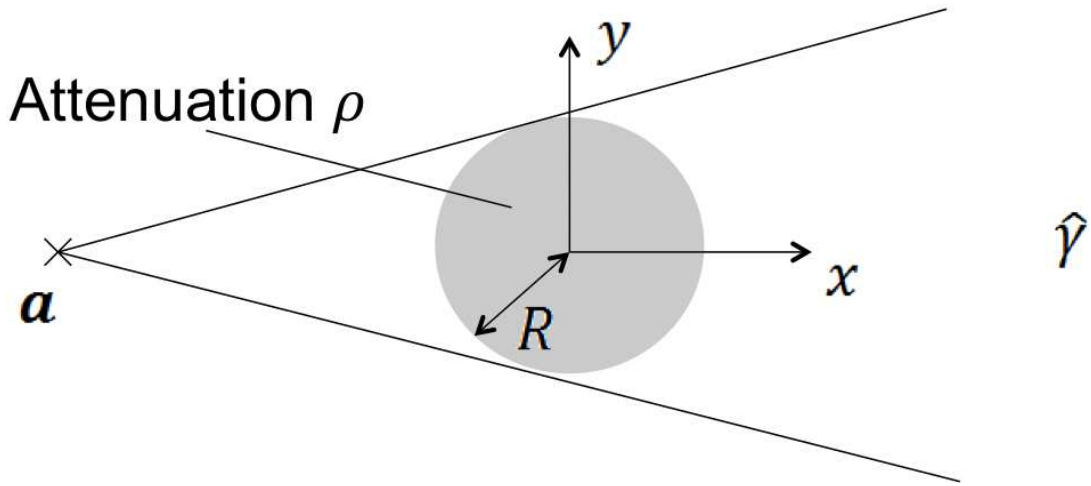
Water Cylinder Assumption



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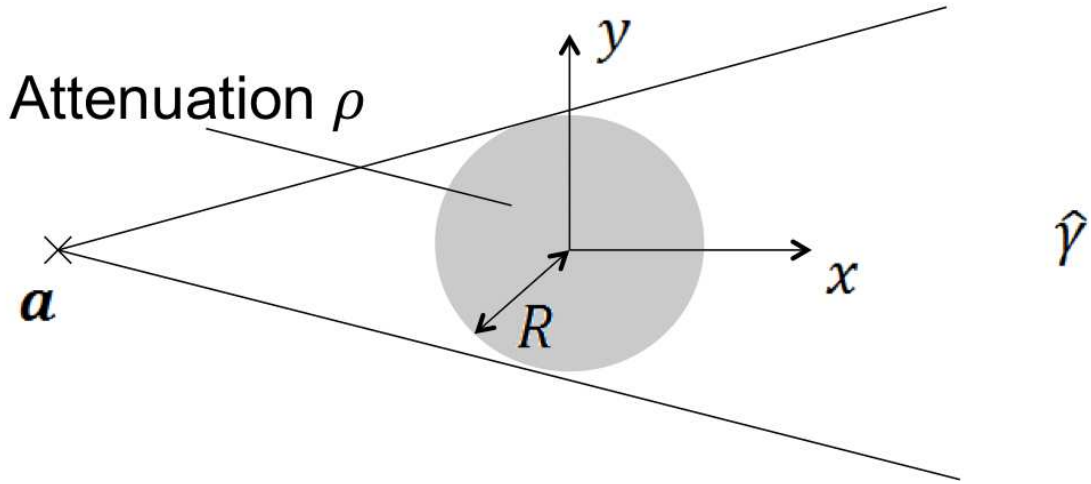
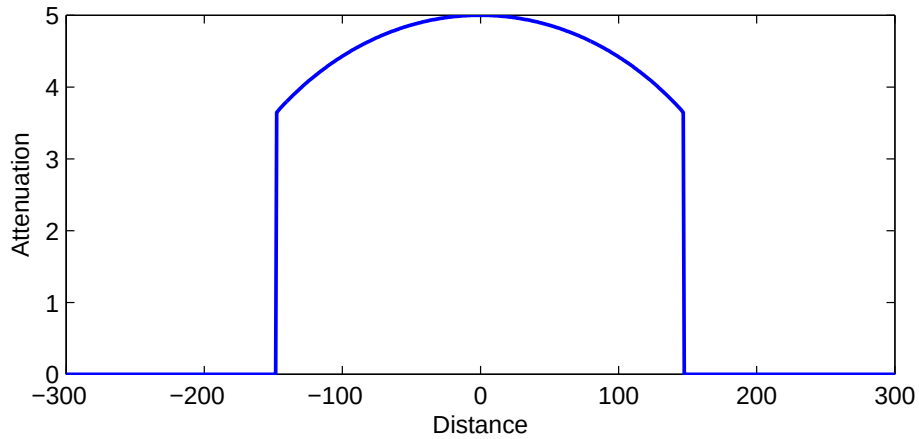


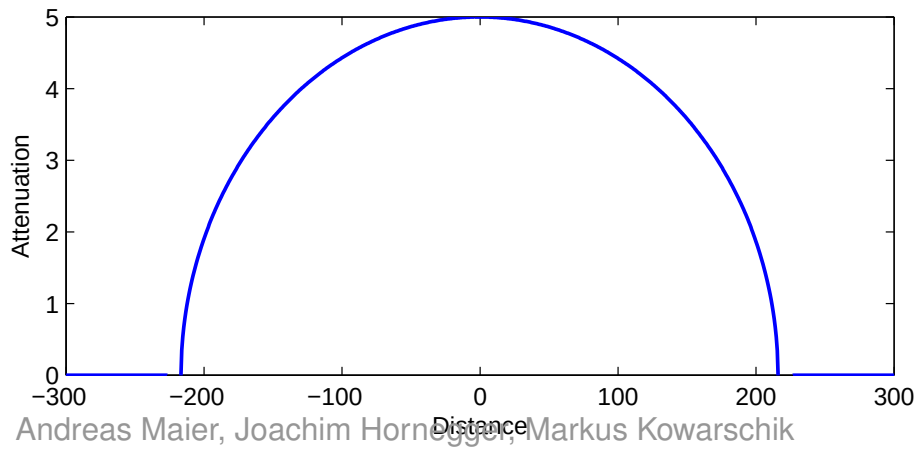
- Assume that the imaged object consists of water ($\rho = \rho_{H_2O}$)
- Fit water cylinder model to observed data

$$g(\gamma) = 2\rho_{H_2O}\sqrt{R^2 - D^2 \sin^2 \gamma}$$

- Use model to extrapolate

Water Cylinder Assumption (2)



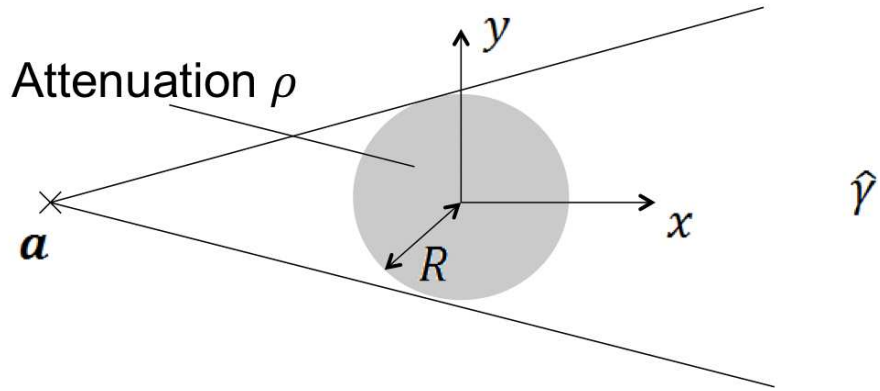


Water Cylinder Assumption (3)

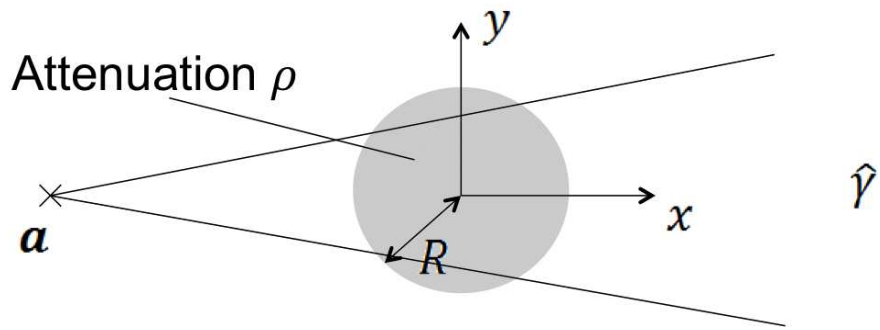
- Will work perfectly, if a water cylinder is imaged
- Yields good results for most objects
  (head, abdomen, etc...)
- Will yield suboptimal results if water cylinder assumption is viilated (e.g. two cylinders)
- Different versions exist:
  - Water ellipsoid assumption
  - Combination with cosine-like roll-off

Use of Prior Knowledge

Prior scan (low dose)



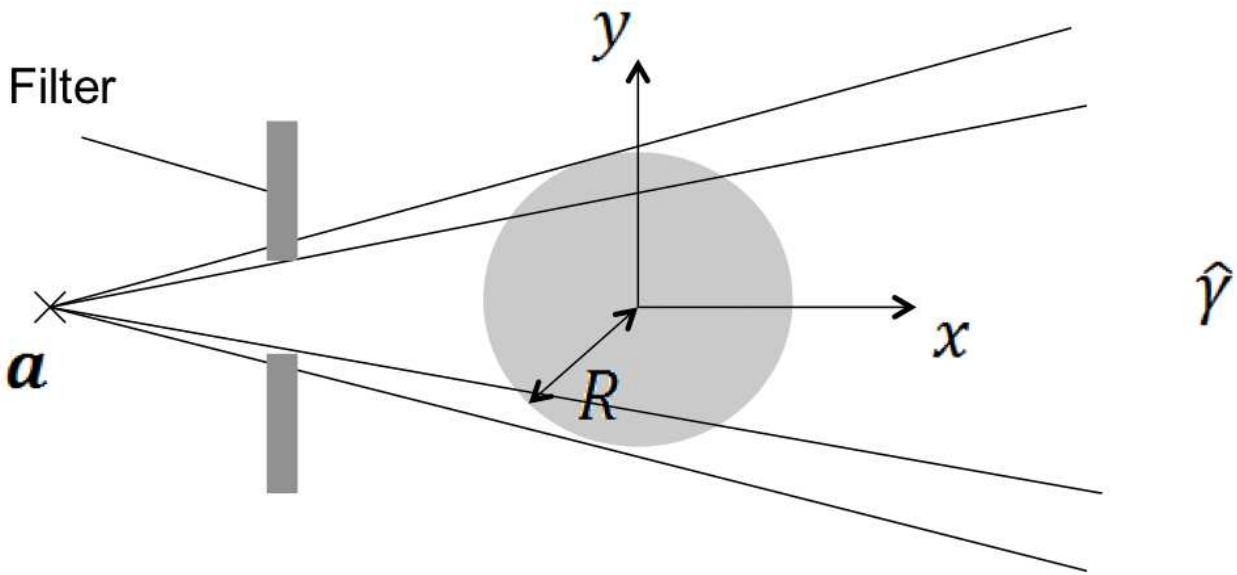
Volume-of-interest scan (higher dose)



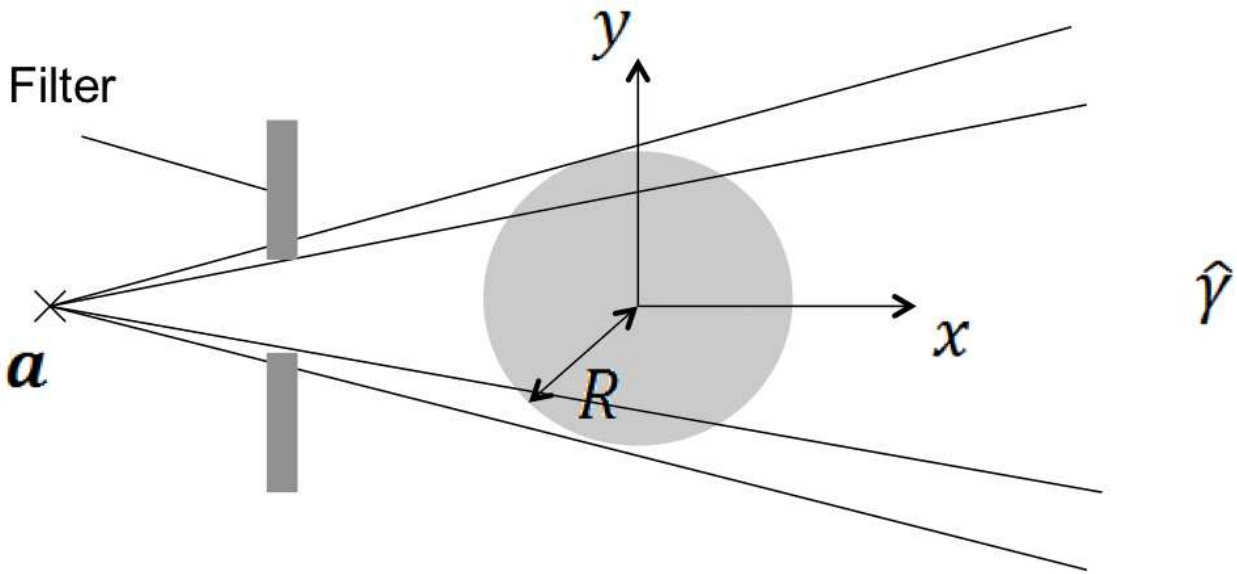
Use of Prior Knowledge (2)

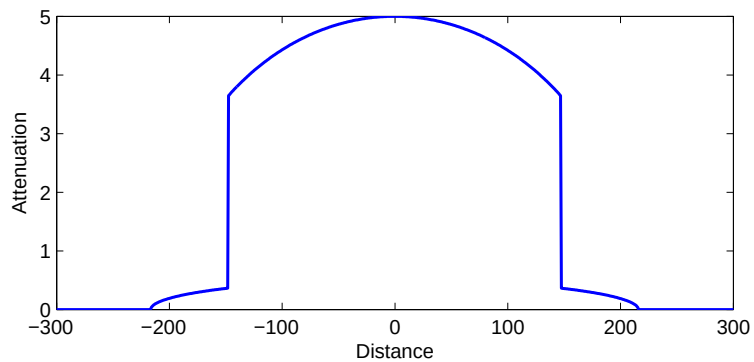
- Use data from a first scan to complete the data from a second scan
- Correction will be perfect, if the object did not change
- May also use a lower resolution prior scan
- Movement and deformation of the object have to be compensated
- Is only applicable, if a prior scan exists

Semi-transparent Filter



Semi-transparent Filter





Semi-transparent Filter (2)

- Locate Filter boundary
- Amplify filtered signal to original amplitude
- Reduce noise in the amplified signal
- Yields perfect truncation correction

Semi-transparent Filter (3)

- Filter boundary must be located correctly (which may be influenced by the object)
- Correct amplification factor has to be estimated
- Method has to be applied carefully in order not to introduce artificial high frequencies
- Requires additional hardware in the scanner

Topics

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Phantoms

Phantoms

- Performance of reconstruction algorithms has to be evaluated
- X-rays are ionizing $\rightarrow$ We cannot use patients
- We don't know the exact geometry of patients
- We need an object that is precisely known

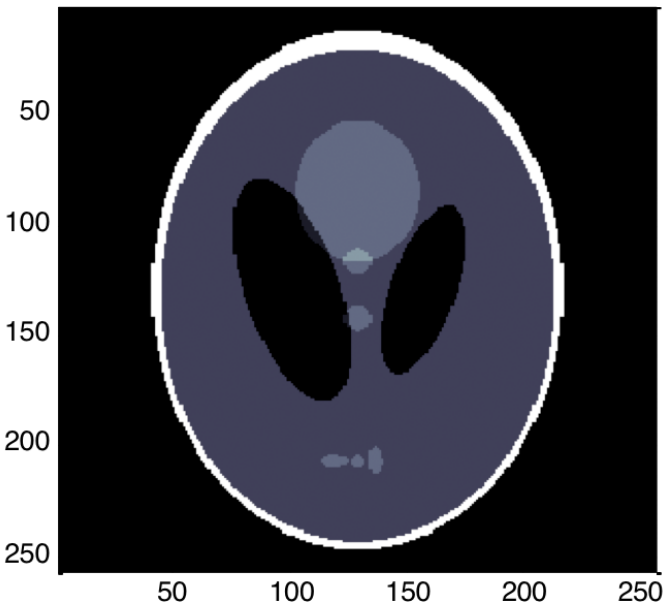
Phantoms (2)

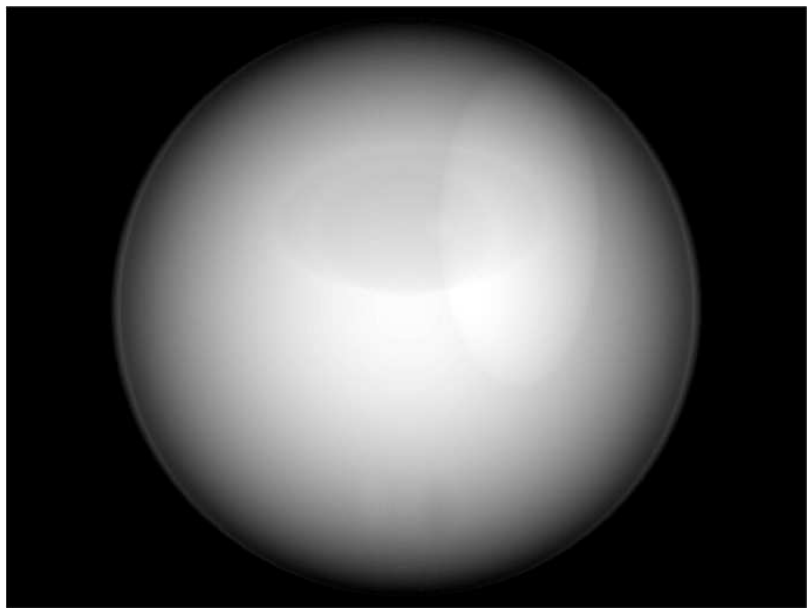
- We distinguish two kinds of phantoms:
  - Numerical / simulated phantoms
    - Originate from computer simulations
    - Are know exactly
    - Have only limited realism
  - Real phantoms
    - Are designed with desired properties
    - Are manufactured at a high accuracy
    - May be difficult to use
    - May still have a limited manufacturing accuracy

Phantoms (3)

- Commonly used numeric phantoms:
  - Shepp-Logan phantom
  - Forbild phantoms
  - X-Cat phantoms
  - Many more custom made phantoms

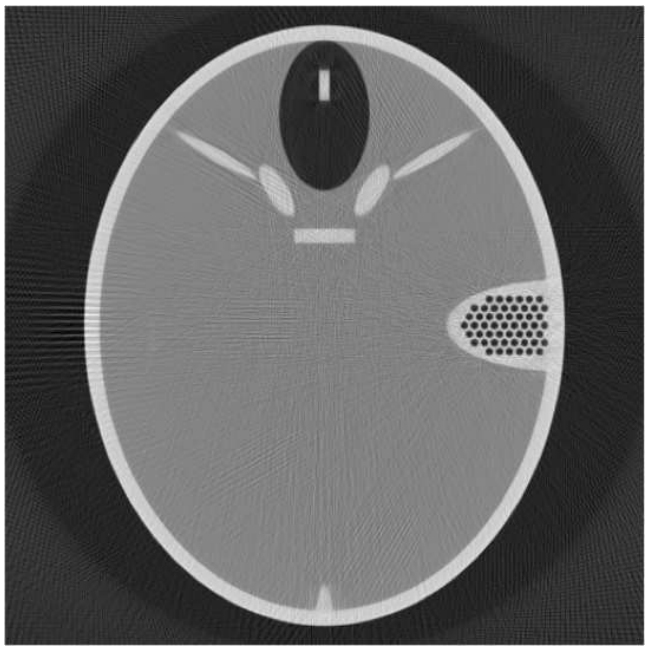
Shepp-Logan Phantom

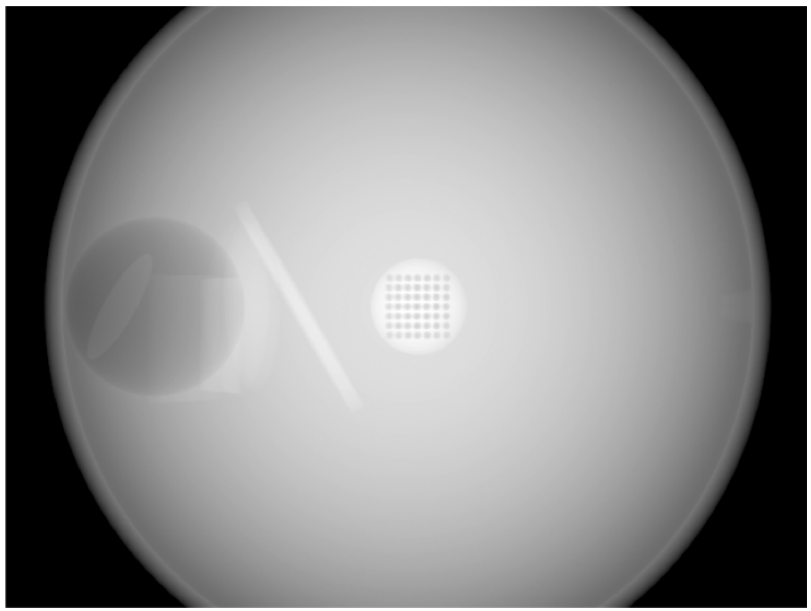




- Described by a series of additive ellipsoids
- Only available in 2D
- Extensions in 3D exists, but are not standardized

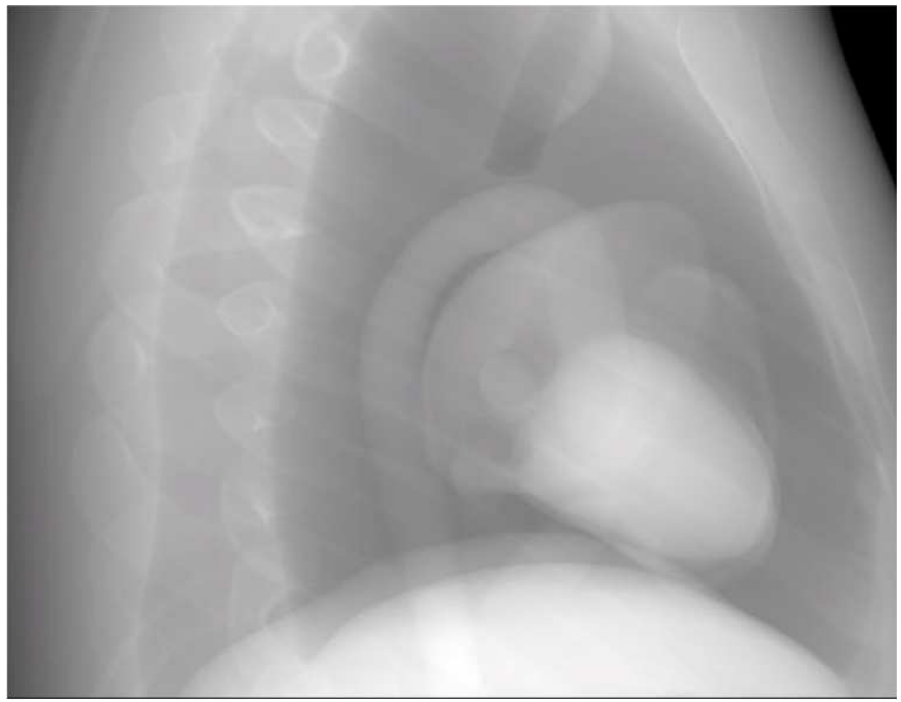
Forbild Phantoms





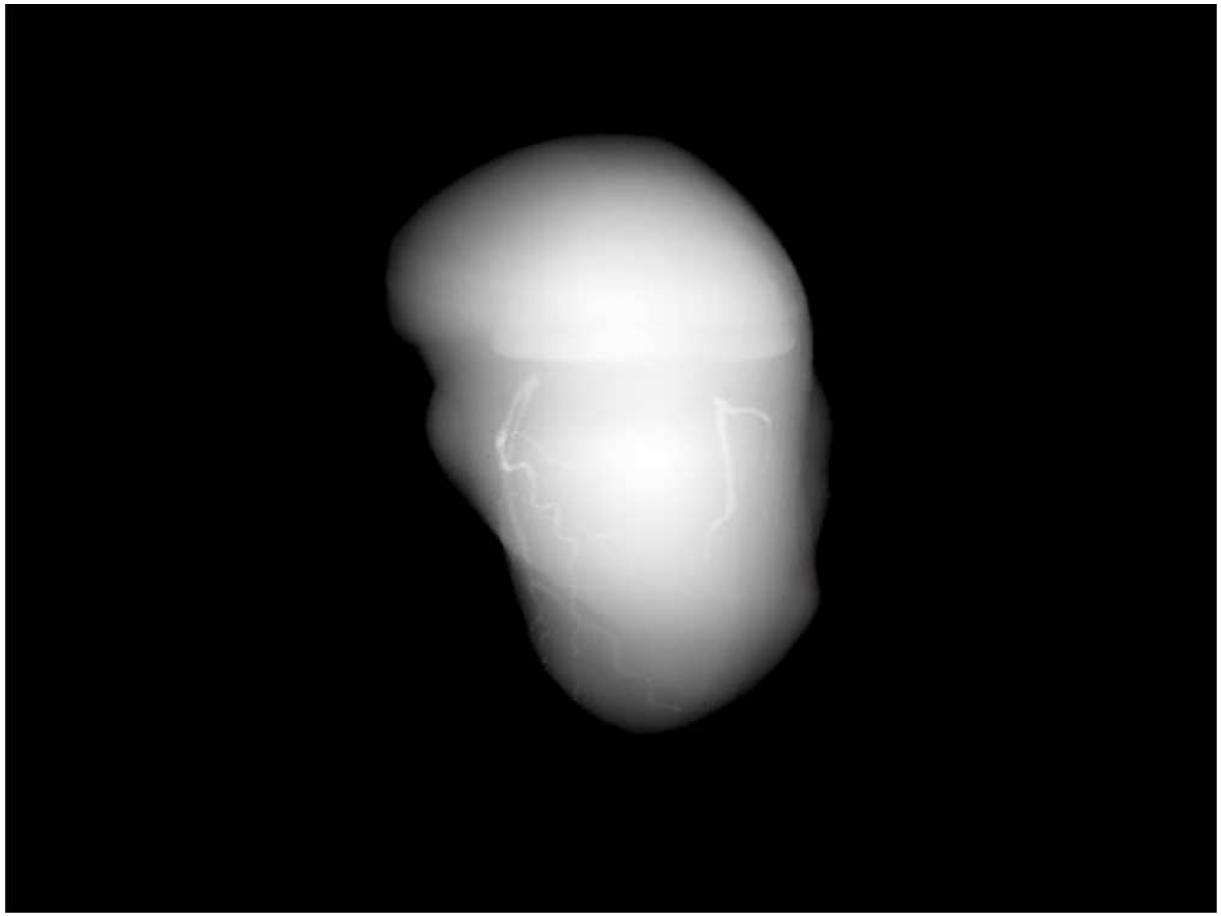
- A series of 3D phantoms that mimic anatomic details
- Descriptions are based on simple geometric descriptors (Cones, Cubes, Spheres, etc.) and their intersections

X-Cat

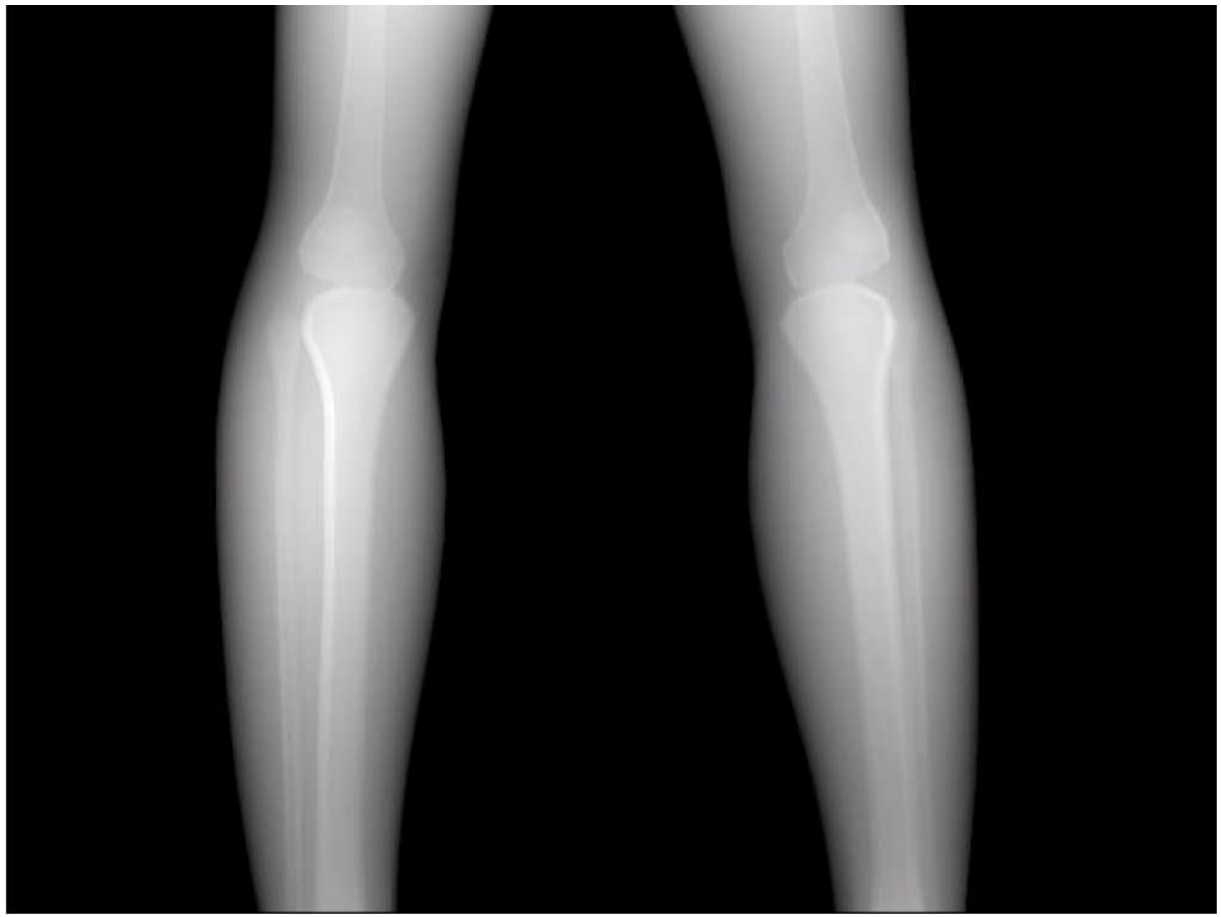


- Based on the visual human project
- Analytic description using splines
- Comes with motion models for the heart and the torso

X-Cat (2)



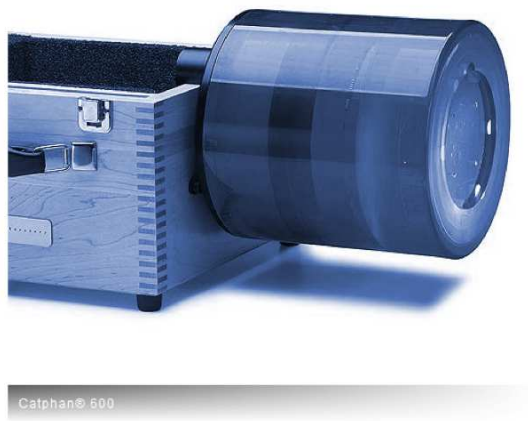
X-Cat (3)



Phantoms (4)

- Commonly used real phantoms:
  - Catphan
  - Rando Alderson
  - Calibration phantoms
  - Many more custom made phantoms

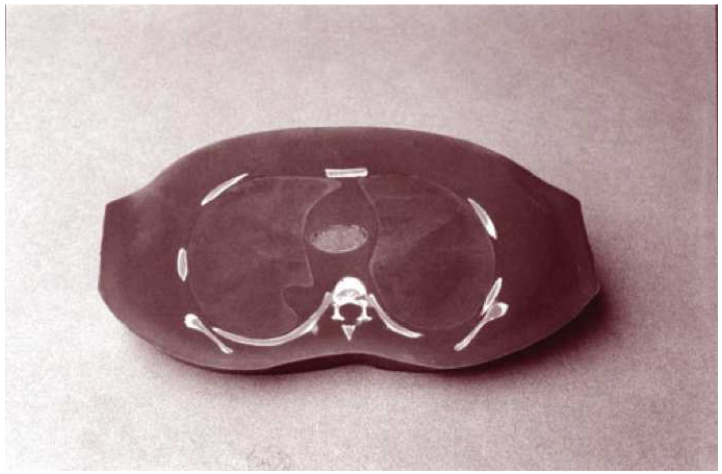
Catphan



Images: http://www.phantomlab.com

- Phantom that mimics a water cylinder
- Contains exchangeable modules
- Manufactured at high accuracy

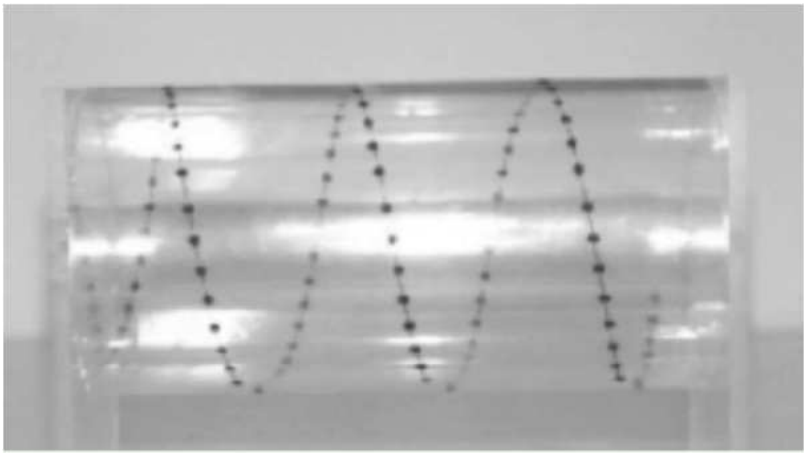
Rando Alderson Radiation Therapy Phantom

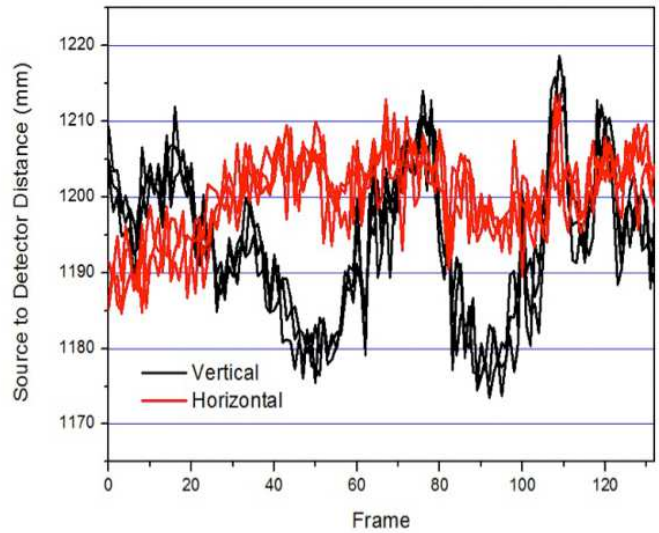


Images: http://www.rsdphantoms.com

- Phantom that mimics a human body
- Can be separated into slices
- Is also used to measure effective dose

Calibration Phantoms





- Phantom that encodes information that can be used for calibration
- Enables to perform detailed accuracy analyses

Further Readings

- Gengsheng Lawrence “Larry” Zeng.“Medical Image Reconstruction – A Conceptual Tutorial”. Springer 2009
- Ohnesorge B, Flohr T, Schwarz K, Heiken JP, Bae KT. Efficient correction for CT image artifacts caused by objects extending outside the scan field of view. Med Phys. 2000 Jan; 27(1):39-46.
- Shepp LA, Logan BF. The Fourier reconstruction of a head section. IEEE Transactions on nuclear science 21:21-43. 1974
- W. P. Segars, M. Mahesh, T. J. Beck, E. C. Frey, and B. M. W. Tsui. “Realistic CT simulation using the 4D XCAT phantom”. Med. Phys. 35, 3800 (2008)

Questions?