

X-ray focal spot estimation from a single image of a tungsten sphere

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Summary

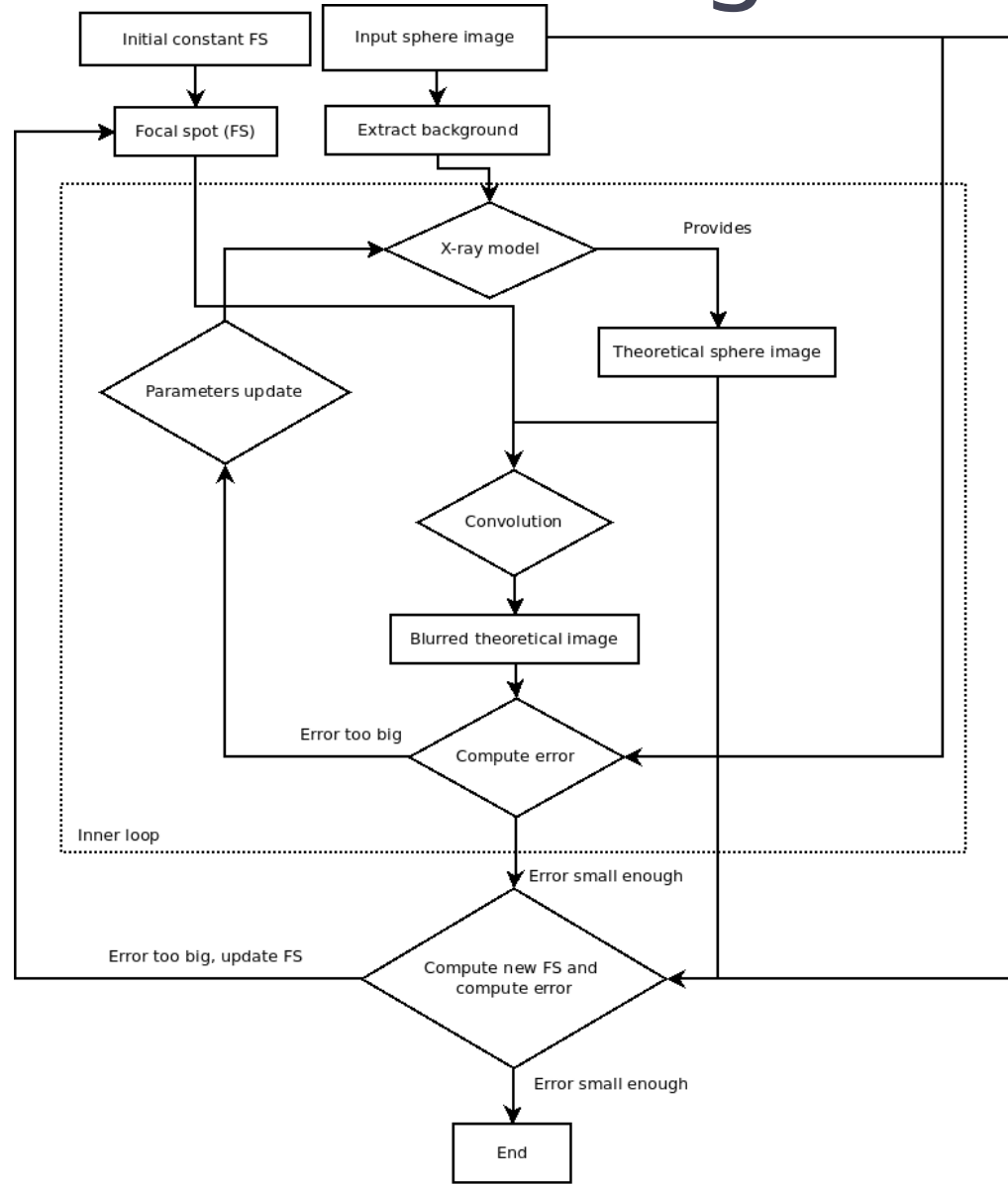
- Motivation
- Focal spot estimation algorithm
 - Background extraction of image
 - Simple X-ray model of a sphere
 - Focal spot estimation from two images
- Focal spot estimation results
- Deconvolution results

Motivation

- X-ray imaging: important tool in non-destructive testing.
- Issues: small details (cracks, porosities...) hard to identify because anisotropic blur induced by the focal spot.
- Size and shape may vary following instrumentation and applied voltage.
- Aim: retrieve focal spot shape and use deconvolution techniques to get sharpened images.

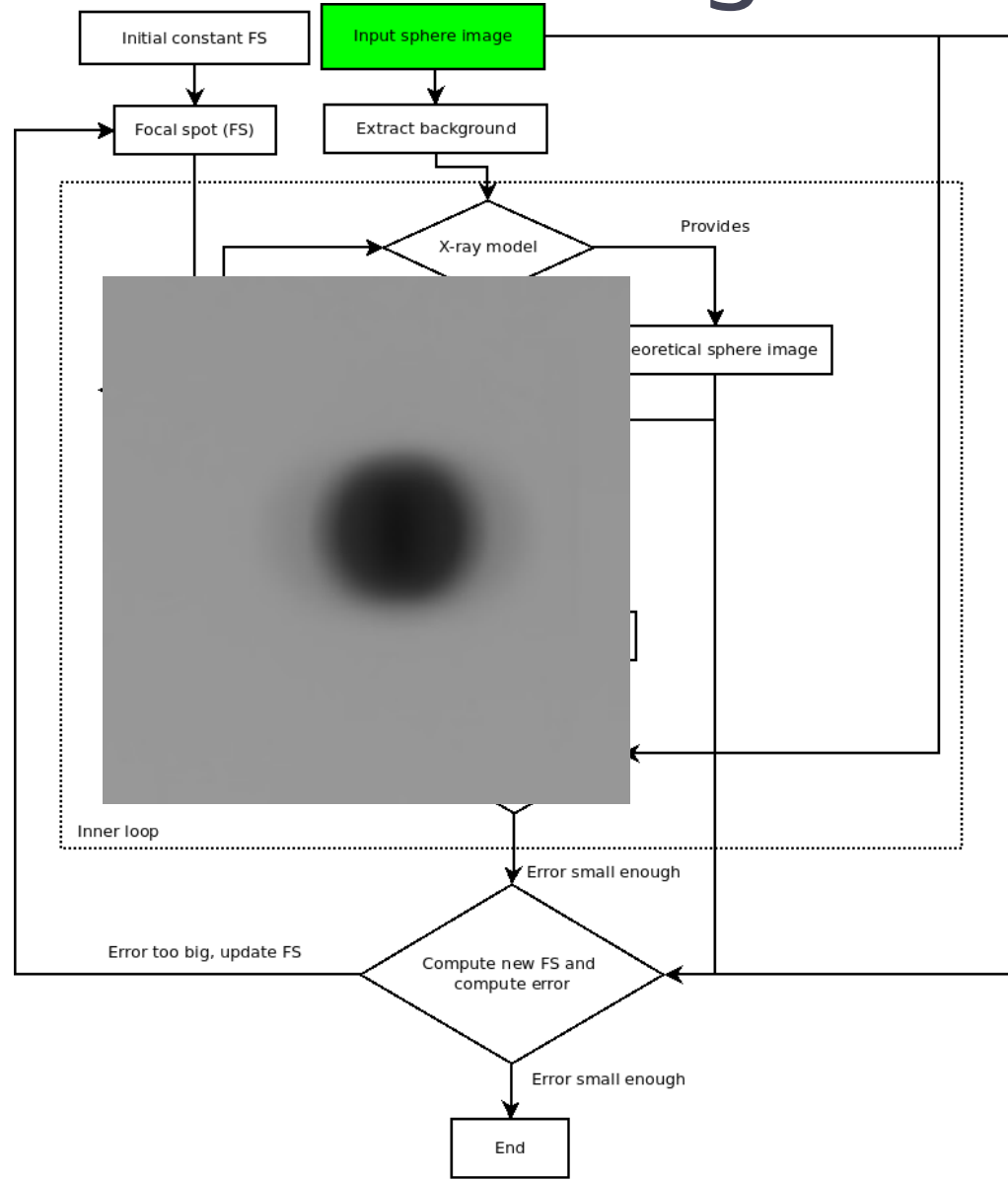
Focal spot estimation algorithm

- Algorithm:



Focal spot estimation algorithm

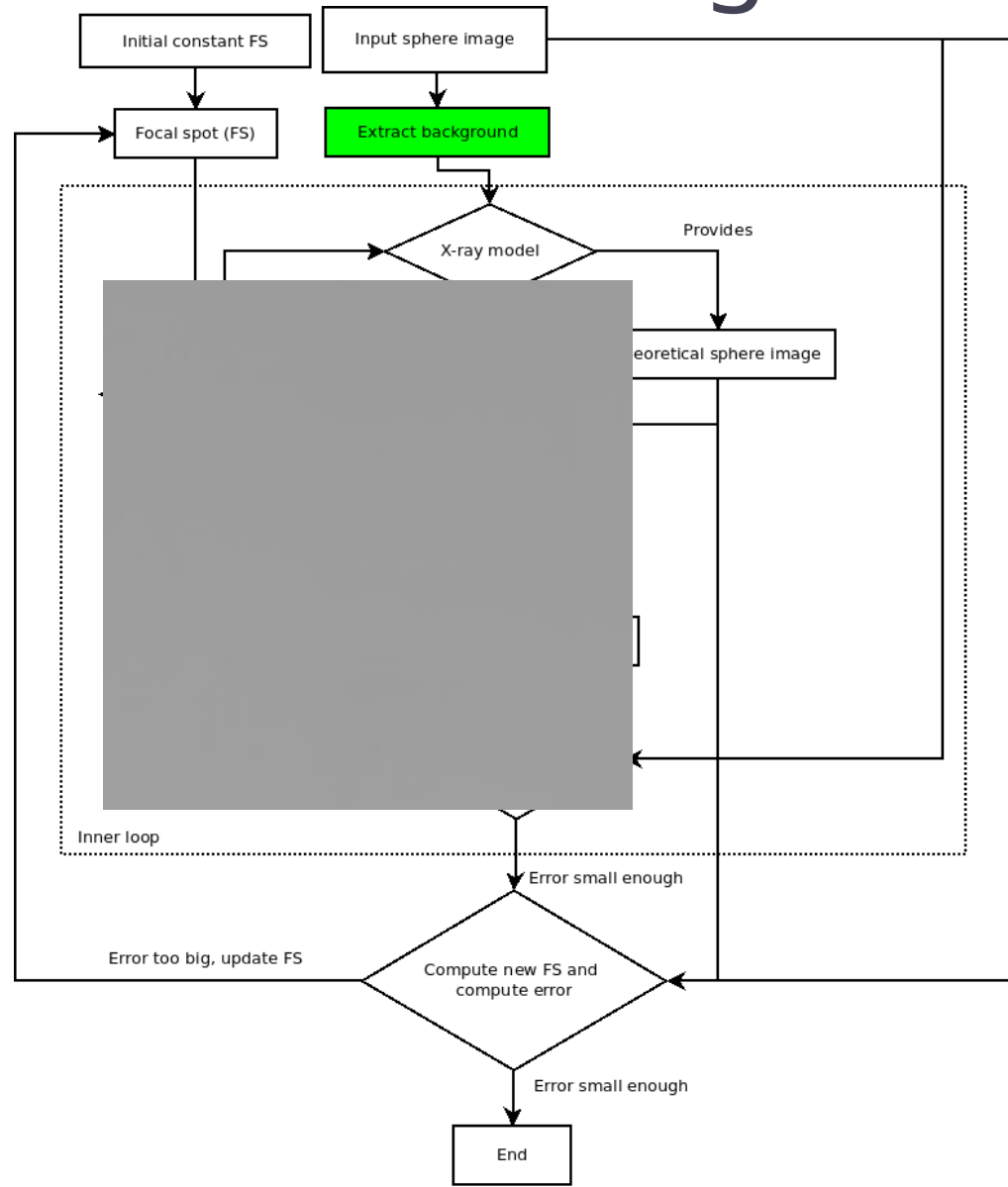
- Algorithm:



Focal spot estimation algorithm

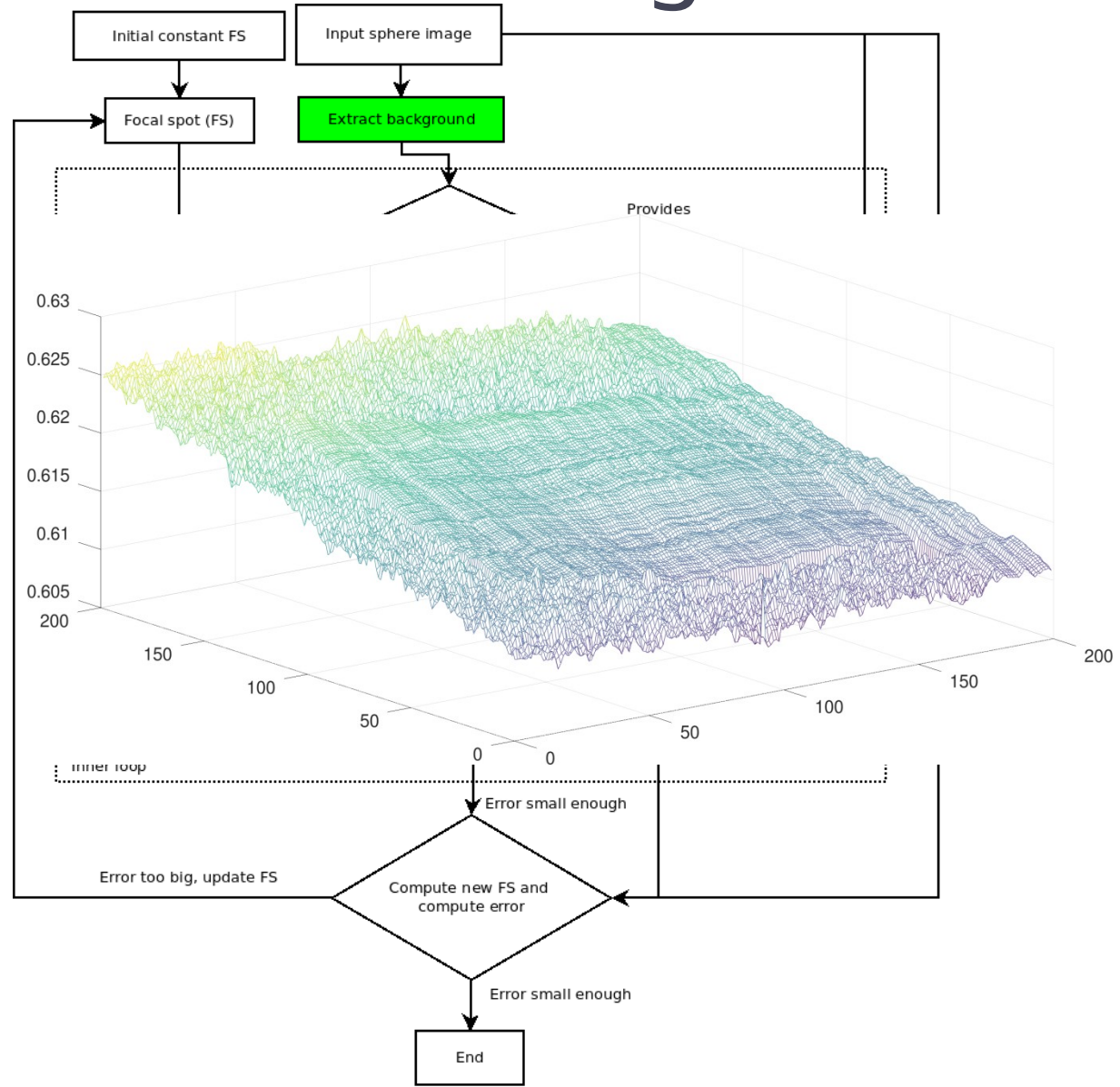
- Algorithm:

Background reconstruction obtained via *Empirical Orthogonal Functions* [6].



Focal spot estimation algorithm

- Algorithm:

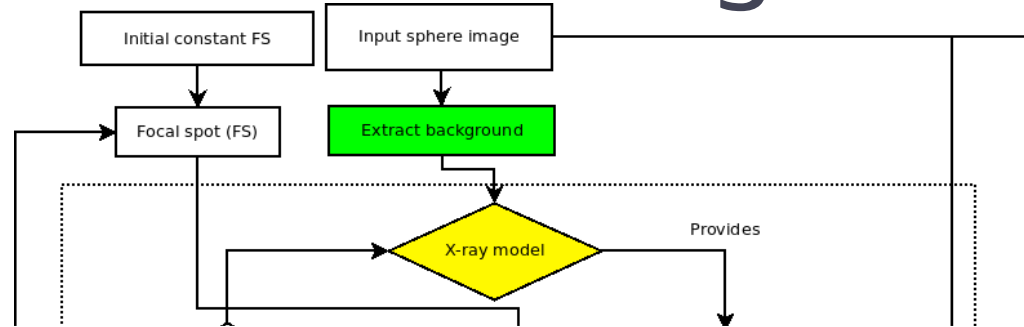


Background reconstruction obtained via *Empirical Orthogonal Functions* [6].

Allows smoothly varying backgrounds, which generally is not taken into account in other methods [7,8,9] or in norms such as the EN 12543-5.

Focal spot estimation algorithm

- Algorithm:



X-Ray model: simple ray-tracing using the simple and fast attenuation model:

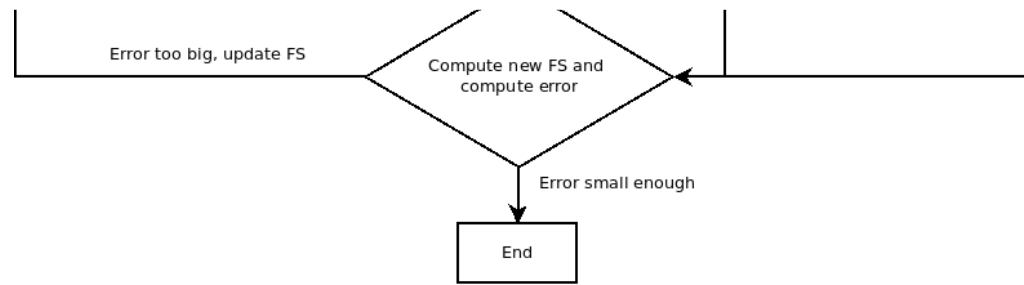
$$I(x, y) = I_0(x, y) \exp(-\mu l(x, y))$$

Output intensity at pixel (x, y)

Input intensity at pixel (x, y) (provided by the background)

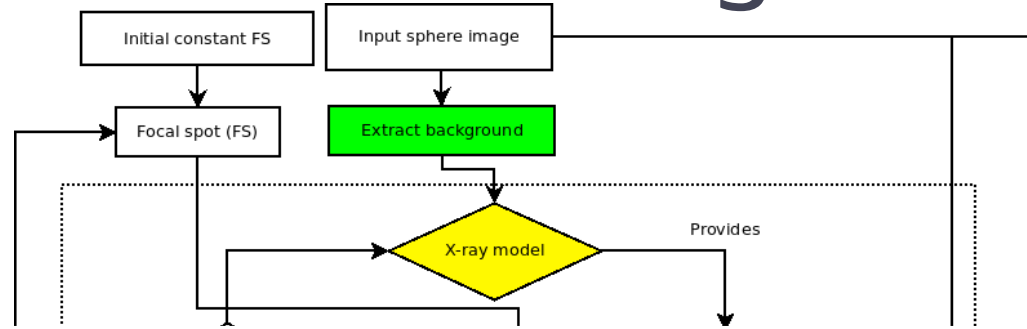
Attenuation coefficient

Sphere thickness crossed from source to pixel (x, y)



Focal spot estimation algorithm

- Algorithm:



X-Ray model: simple ray-tracing using the simple and fast attenuation model:

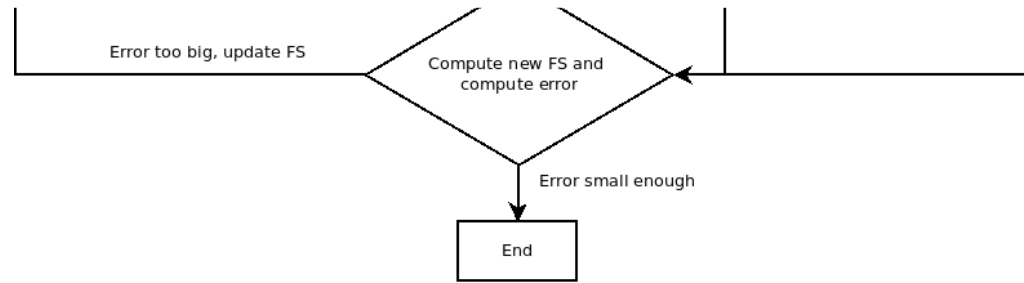
$$I(x, y) = I_0(x, y) \exp(-\mu l(x, y))$$

Parameters: X-Y screen size
 Source-screen distance
 Sphere radius

} Constant parameters provided by the user

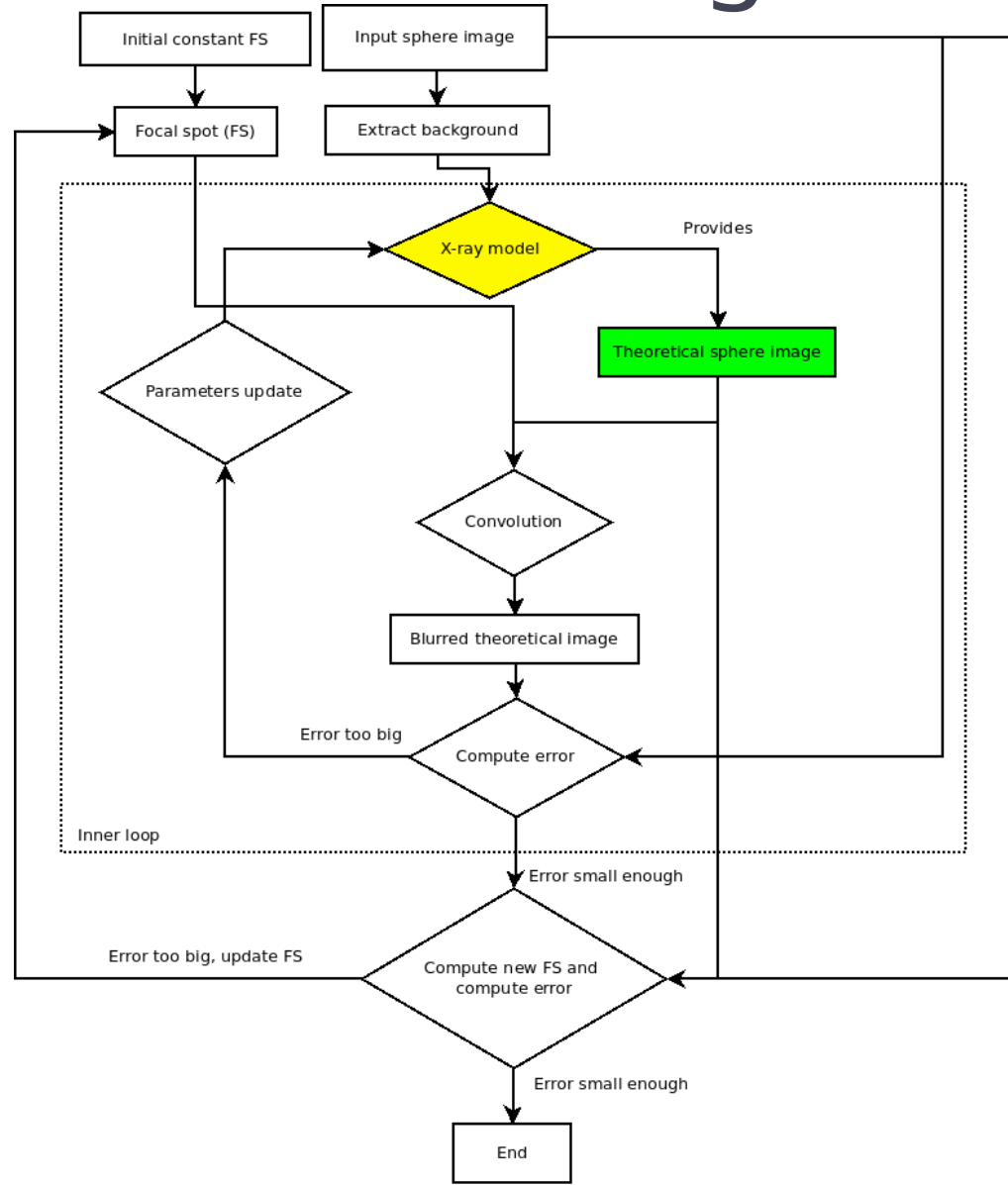
Attenuation factor μ
 Sphere position

} Parameters to be optimized.
 (Rough initial guesses needed).



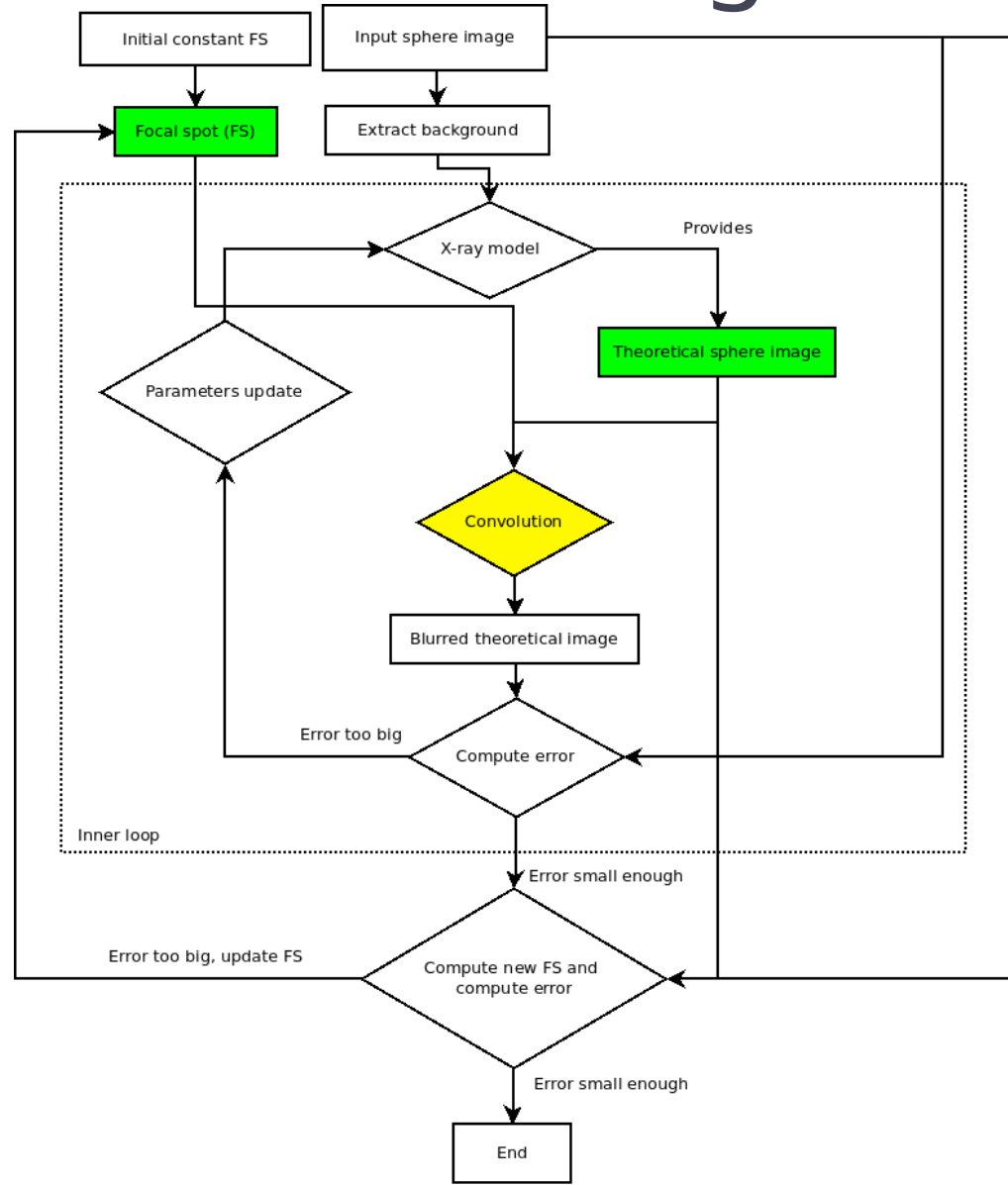
Focal spot estimation algorithm

- Algorithm:



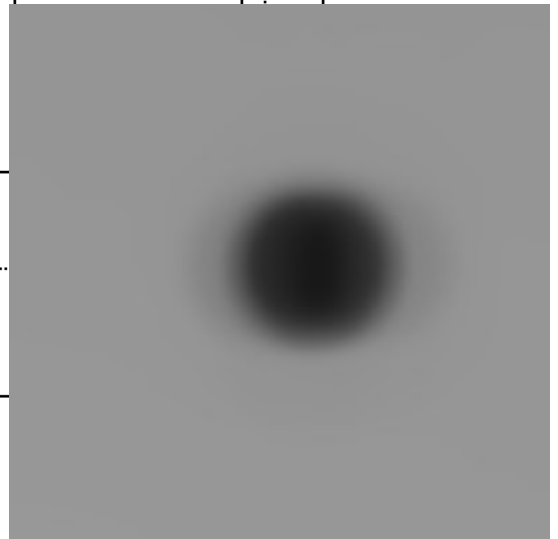
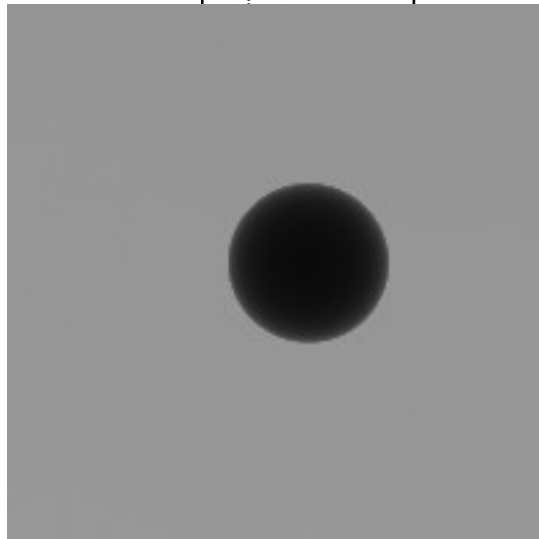
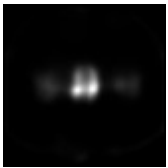
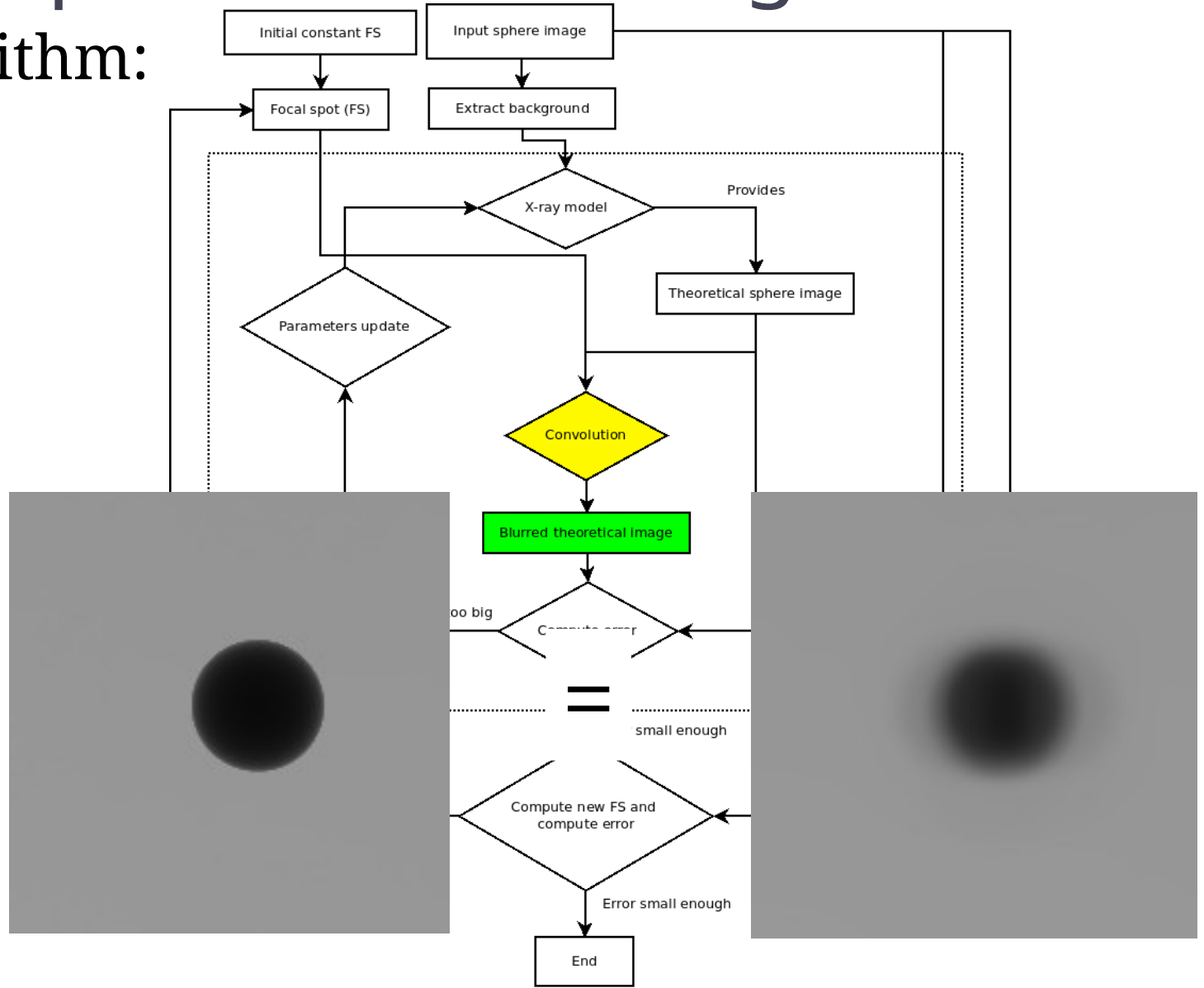
Focal spot estimation algorithm

- Algorithm:



Focal spot estimation algorithm

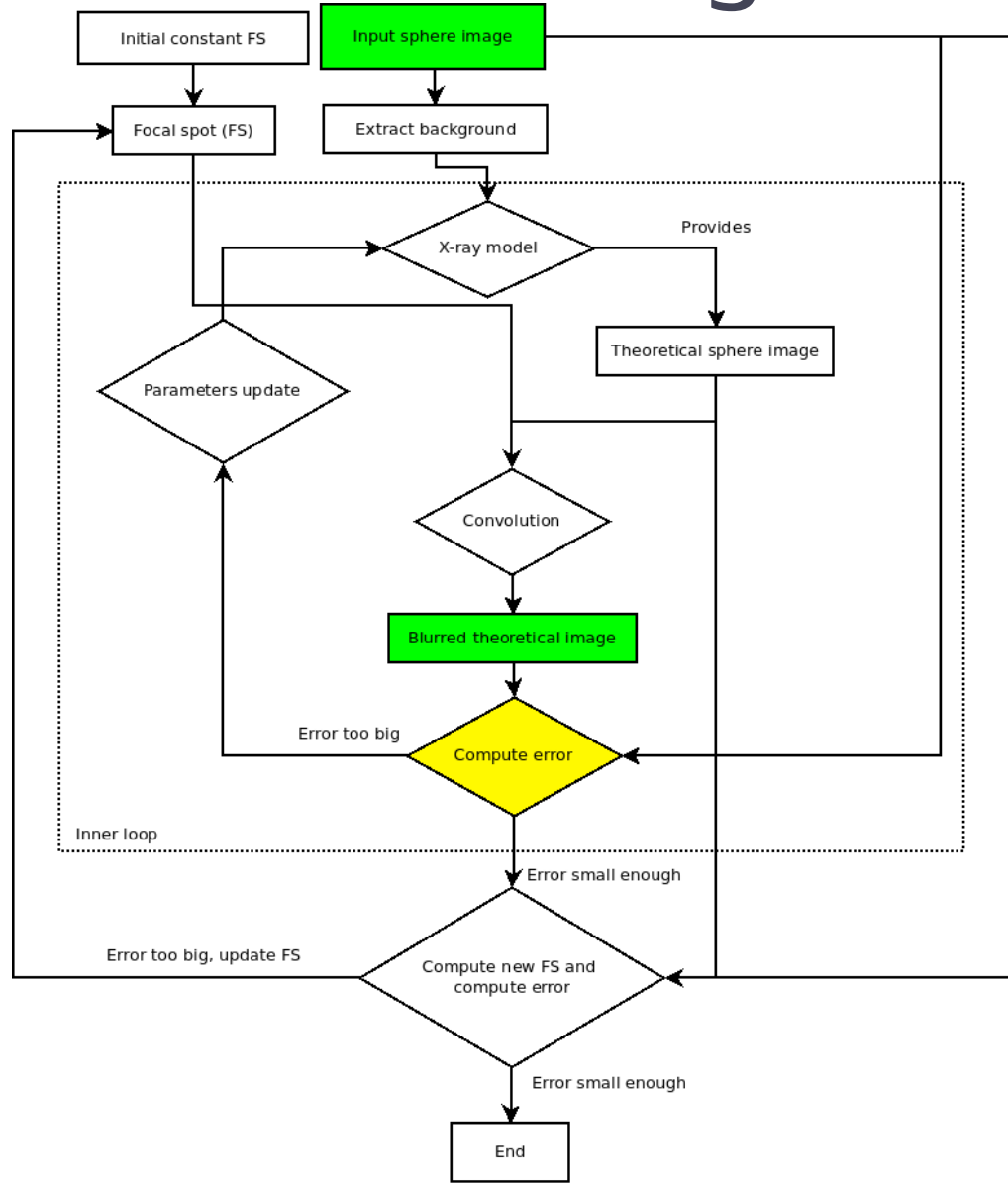
- Algorithm:



Focal spot estimation algorithm

- Algorithm:

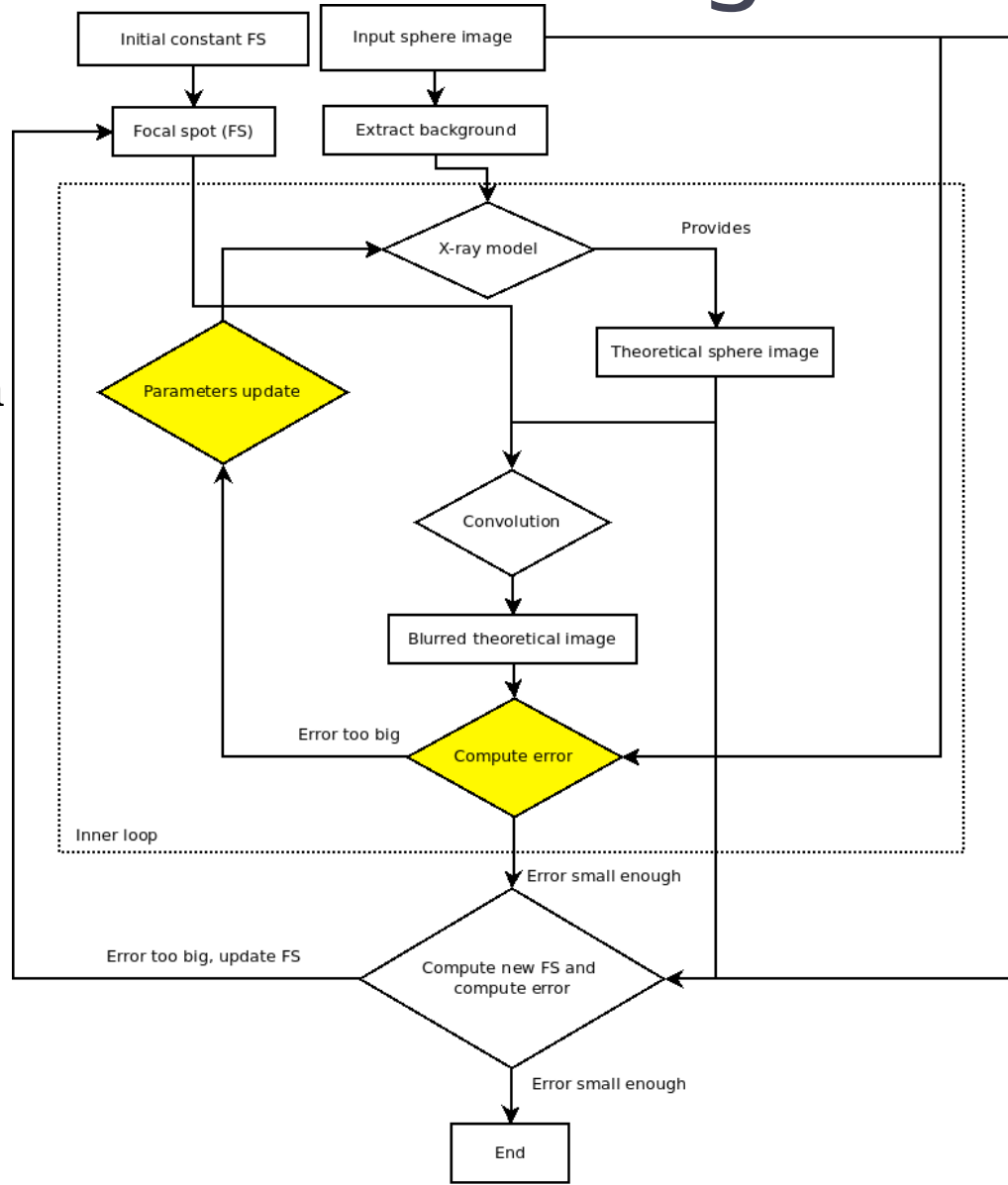
Error: simple sum of absolute distances
Between pixels.



Focal spot estimation algorithm

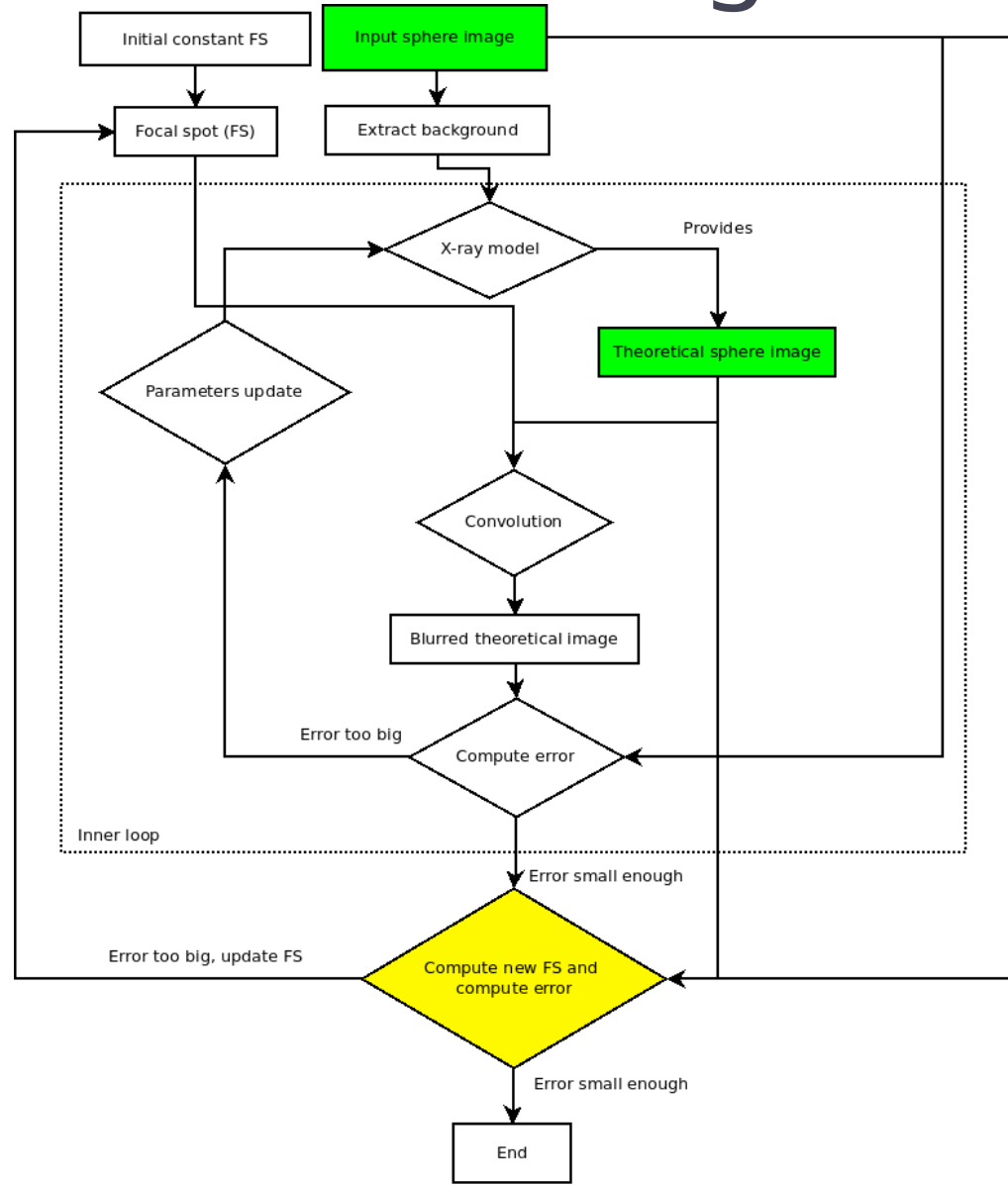
- Algorithm:

Parameter update:
decided via one step
of the simplex algorithm
(Nelder-Mead).



Focal spot estimation algorithm

- Algorithm:



Focal spot estimation algorithm

- Estimate focal spot shape from experimental image and theoretical image :

$$y = x * FS$$

vectorize

$$Y = X FS$$

Vectorized observed image

Vectorized PSF

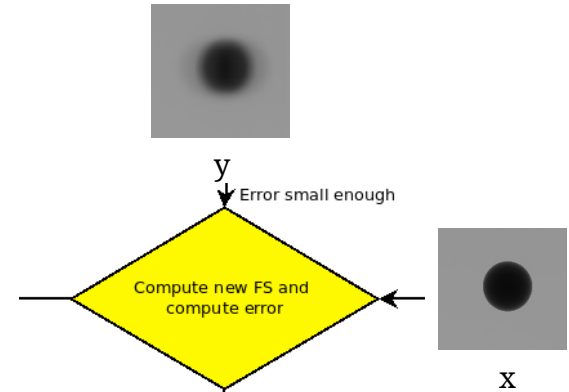
Reference image with vectorized neighbours for each pixel

Solve linear system

$$“FS = X^{-1}Y”$$

Problems:

- X can be huge
- The linear system is ill-conditioned.



Focal spot estimation algorithm

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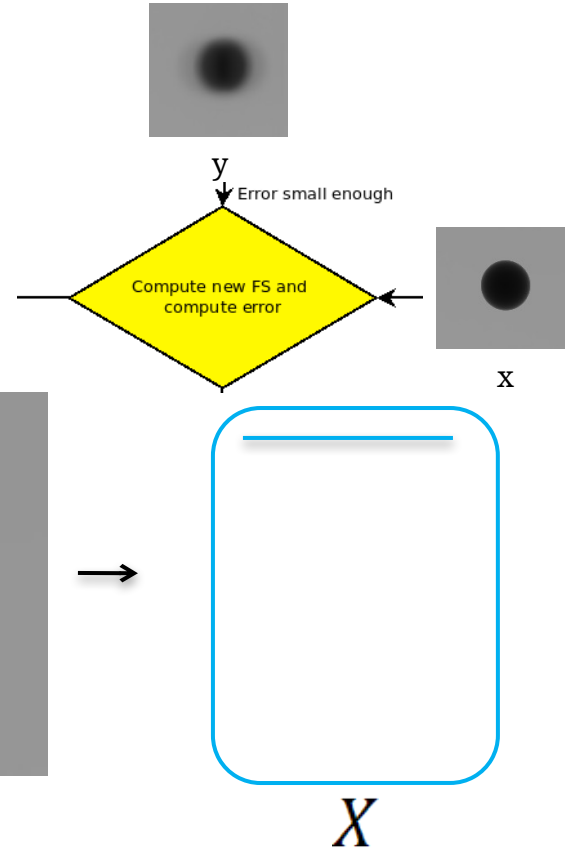
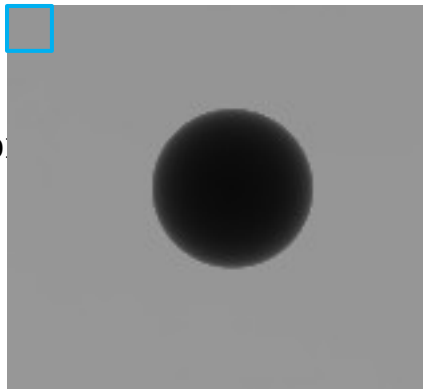
Vectorized observed image

Vectorized PSF

Reference image with vectorized neighbours for each pixel

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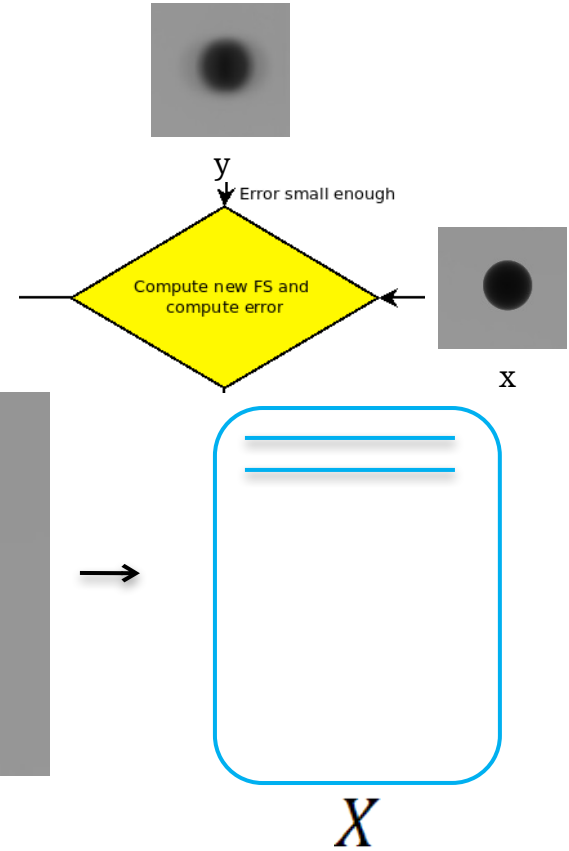
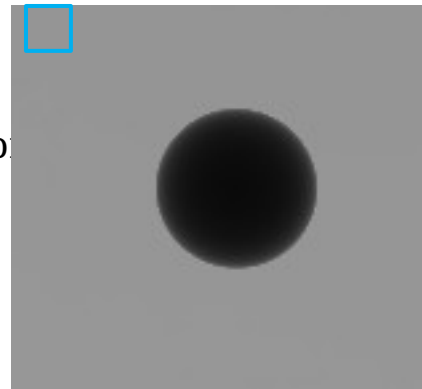
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Vectorized PSF

Reference image with vectorized neighbours for each pixel

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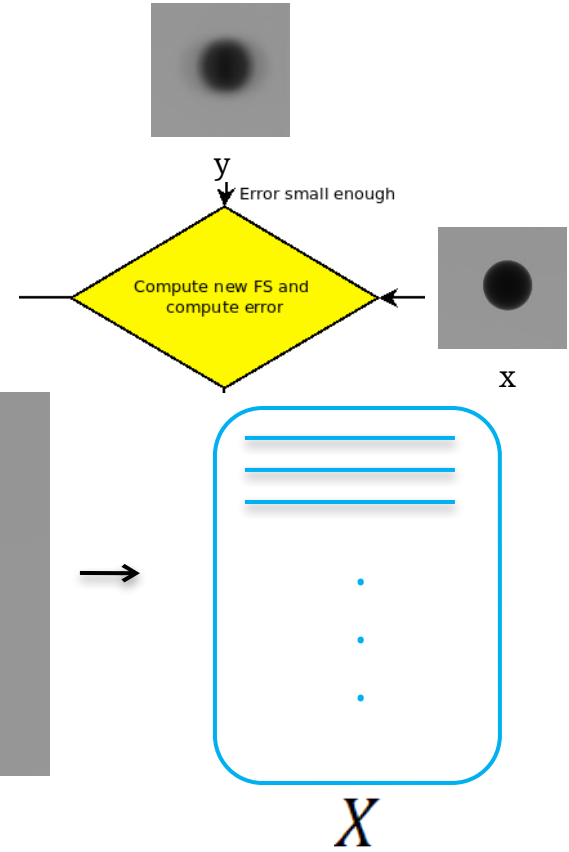
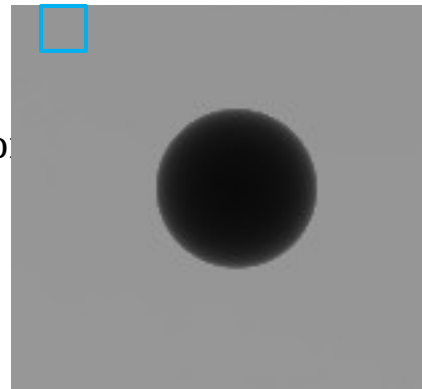
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Problems:

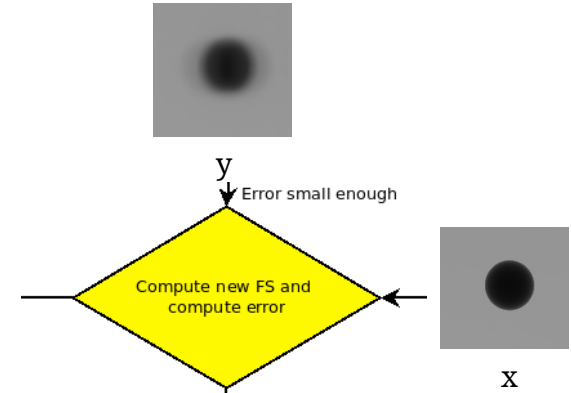
- X can be huge.
- The linear system is ill-conditioned.

Focal spot estimation algorithm

- Estimate focal spot shape from experimental image and theoretical image :

Problems:

- X can be huge.
- The linear system is ill-conditioned.



$$“FS = X^{-1}Y”$$

Instead recursively compute [10]:

$$FS_0 = X^T Y$$

$$FS_{k+1} = FS_k \cdot \frac{X^T Y}{X^T X FS_k}$$

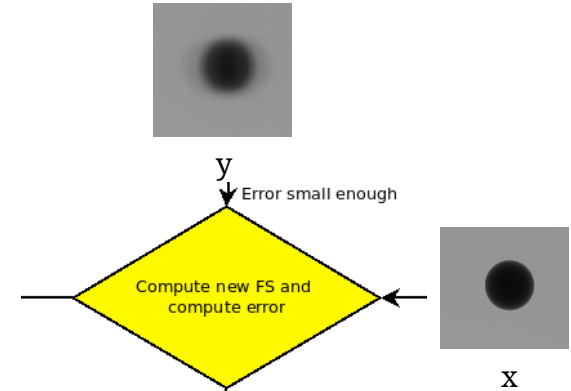
Multiplication “.” and division “/” done on each component.

Focal spot estimation algorithm

- Estimate focal spot shape from experimental image and theoretical image :

Problems:

- X can be huge.
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“ $FS = X^{-1}Y$ ”

Instead recursively compute [10]:

$$FS_0 = X^T Y$$

$$FS_{k+1} = FS_k \cdot \frac{X^T Y}{X^T X FS_k}$$

Is a vector.

Size depends only on the size of the FS (usually small).

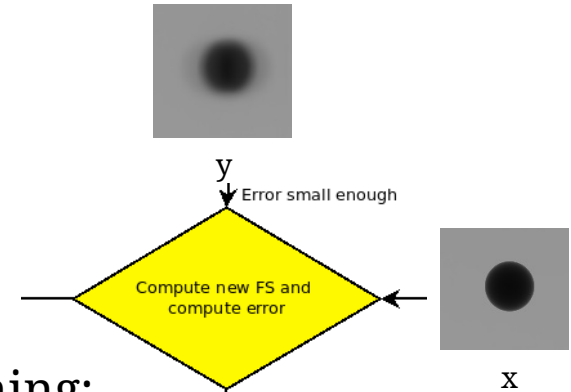
$X^T Y$ and $X^T X$ do not need to explicitly construct X in order to be computed.

Focal spot estimation algorithm

- Estimate focal spot shape from experimental image and theoretical image :

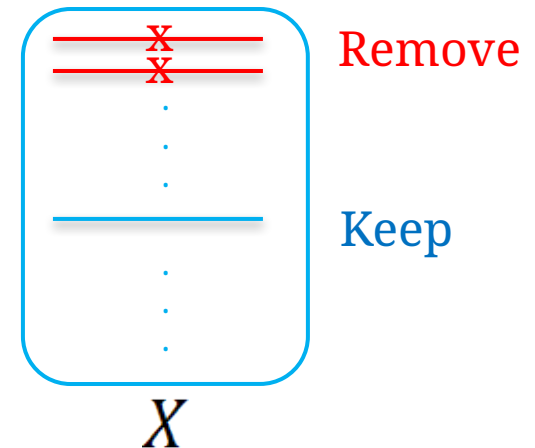
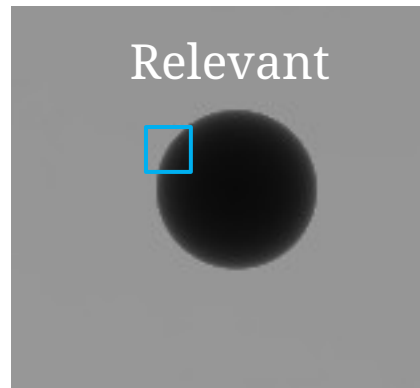
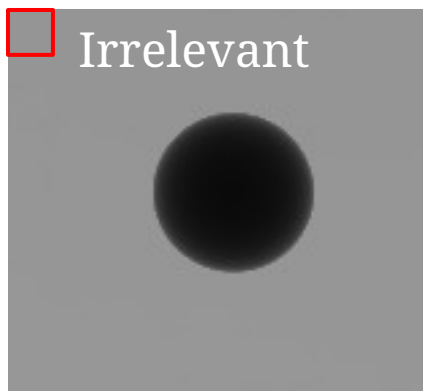
Problems:

- X can be huge.
- The linear system is ill-conditioned.



Further reduce the size of X and improve conditioning:

Only consider “relevant windows” in the image for estimating the focal spot shape

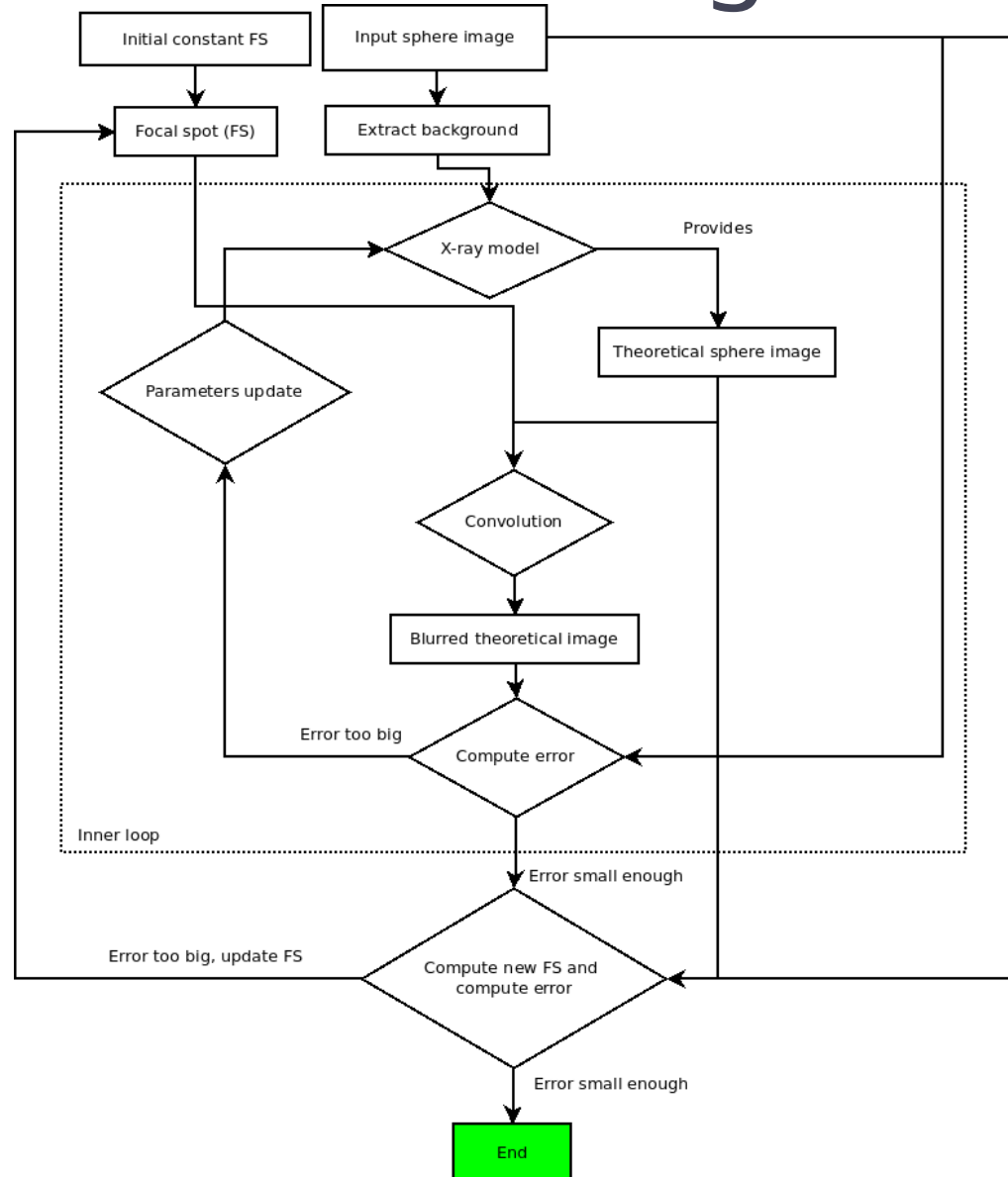


“Windows” are selected from parts of the image with big standard deviations among the pixels in that window [11].

Focal spot estimation algorithm

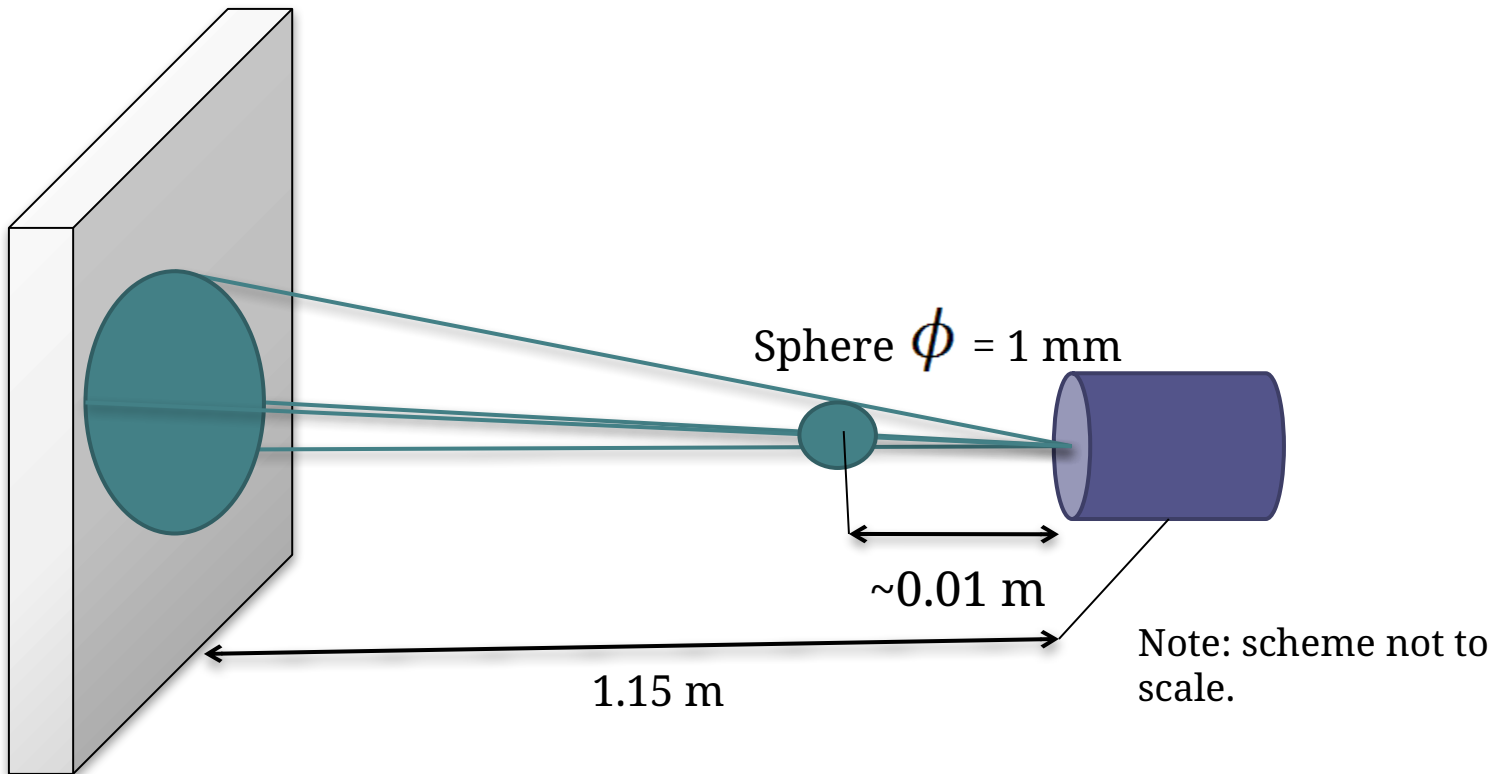
- Algorithm:

Get the full 2D focal spot shape and not only intensities profiles as obtained by methods using wire gauges or tungsten tips [7,8].



Focal spot estimation results

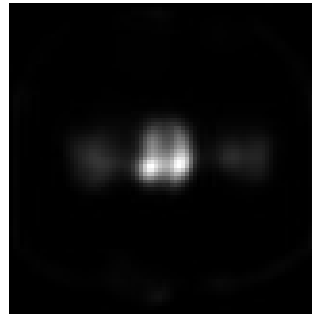
- X-ray generator: *Comet MXR 320 HP 1190* with a focal spot of 0.4mm, used at 650 μ A and 100kV.
- Experimental setup:



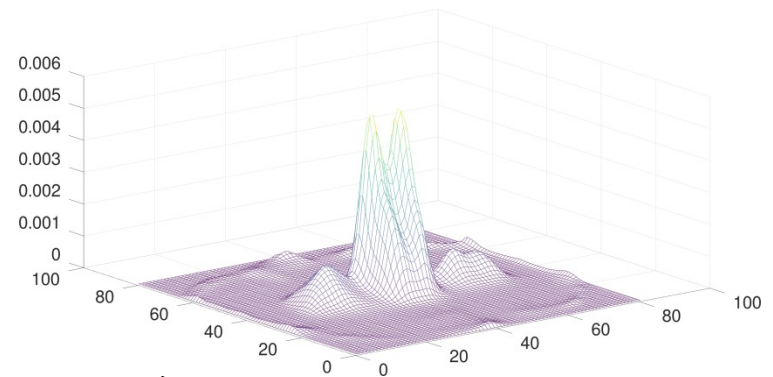
Screen: $0.4 \times 0.4 \text{ m}^2$ (2048 x 2048 pixels)

Focal spot estimation results

- X-ray generator: *Comet MXR 320 HP 1190* with a focal spot of 0.4mm, used at 650 μ A and 100kV.



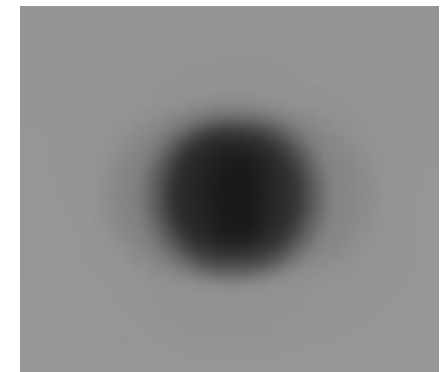
Estimated focal spot (81 x 81)



Experimental image



Estimated theoretical image



Theoretical image blurred with focal spot

Focal spot estimation results

- X-ray generator: *Comet MXR 320 HP 1190* with a focal spot of 0.4mm, used at 650 μ A and 100kV.

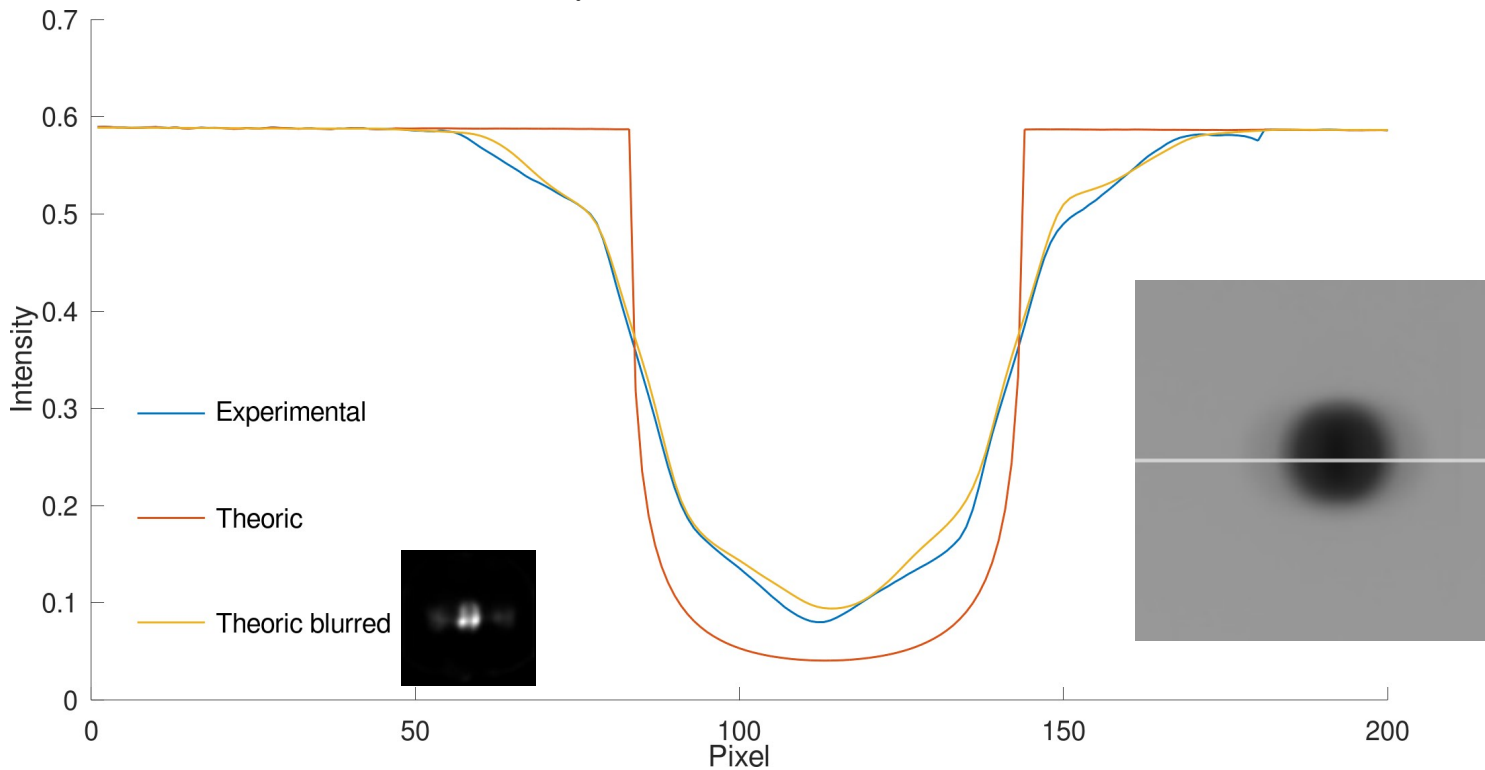
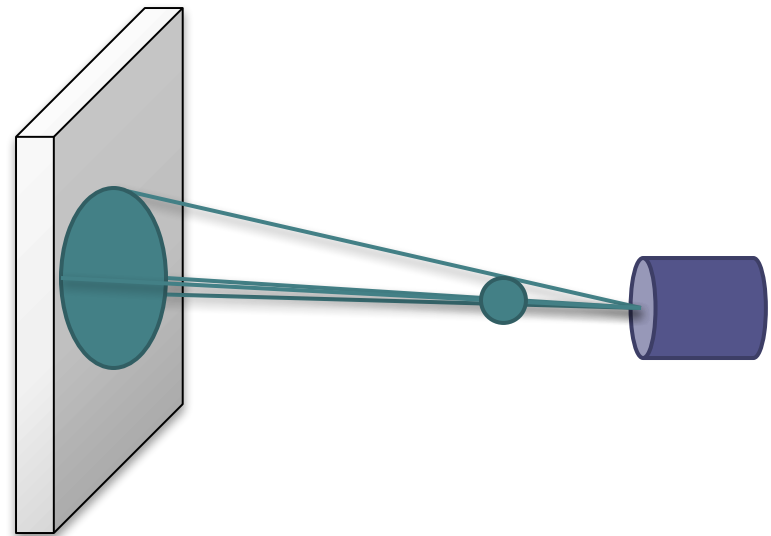
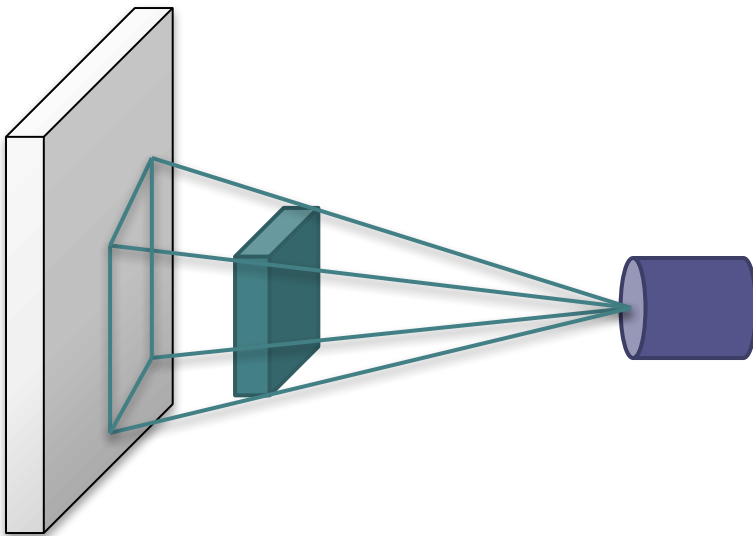


Image profiles

Deconvolution results

- Preliminary remark:
 - Scanned objects were not located at the same distance from the X-ray source than the sphere.
 - Consequently, there is a zoom factor to apply to the focal spot. → Zoom automatically determined by maximizing a sharpness criterion [5].



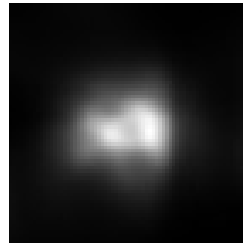
Deconvolution results

- Deconvolution algorithm used:
 - Non-blind deconvolution algorithm using estimated focal spots: *Fast Total Variation deblurring (FTVd)* [2,3].
 - Blind deconvolution used for comparison: *Provably Robust Image Deconvolution Algorithm (prida)* [4].

Deconvolution results

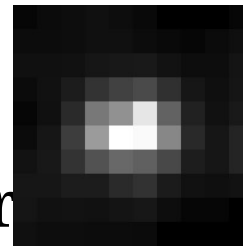
- X-ray generator Hamamatsu L121161-07, 66 μA , 150 kV, focal spot 50 μm .

- Estimated focal spot:

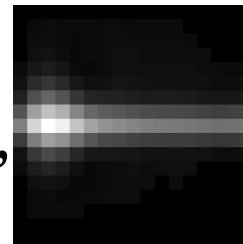


- Deconvolution of “IQI duplex”: zoom factor found: 0.141

- Focal spot with zoom factor

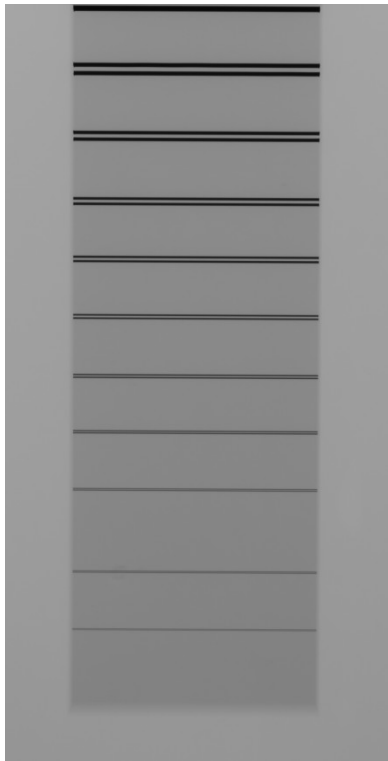


- Focal spot found by “prida”



Deconvolution results

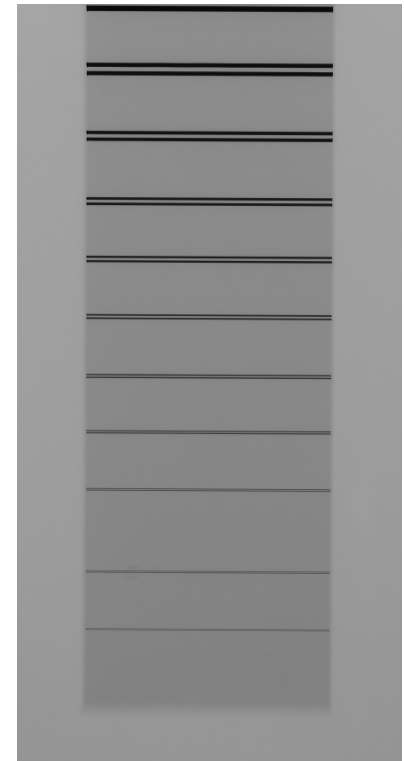
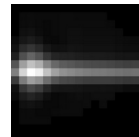
- Deconvolution of “IQI duplex”: zoom factor found: 0.141



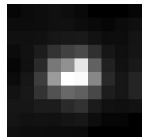
Experimental



prida

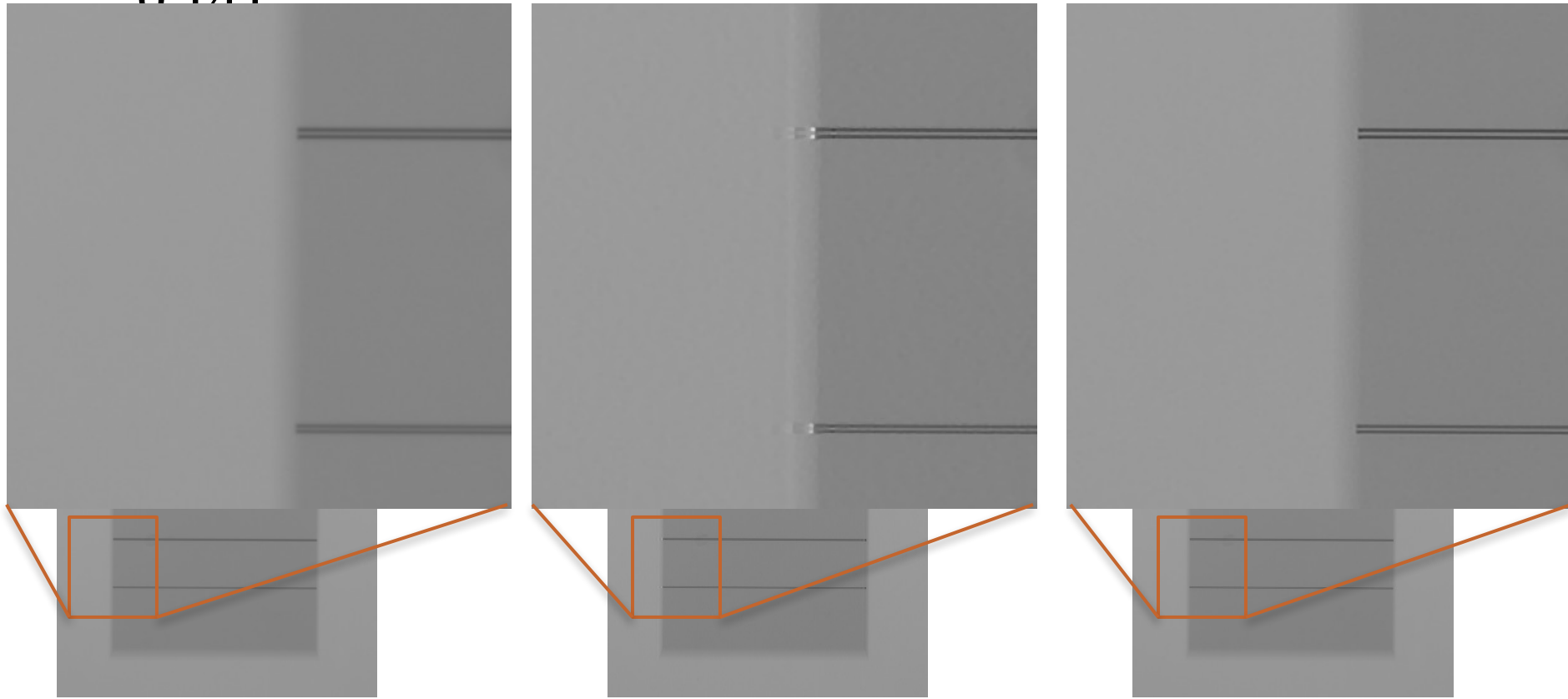


FTVd



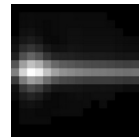
Deconvolution results

- Deconvolution of “IQI duplex”: zoom factor found: 0.141

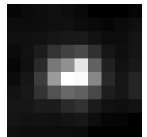


Experimental

prida

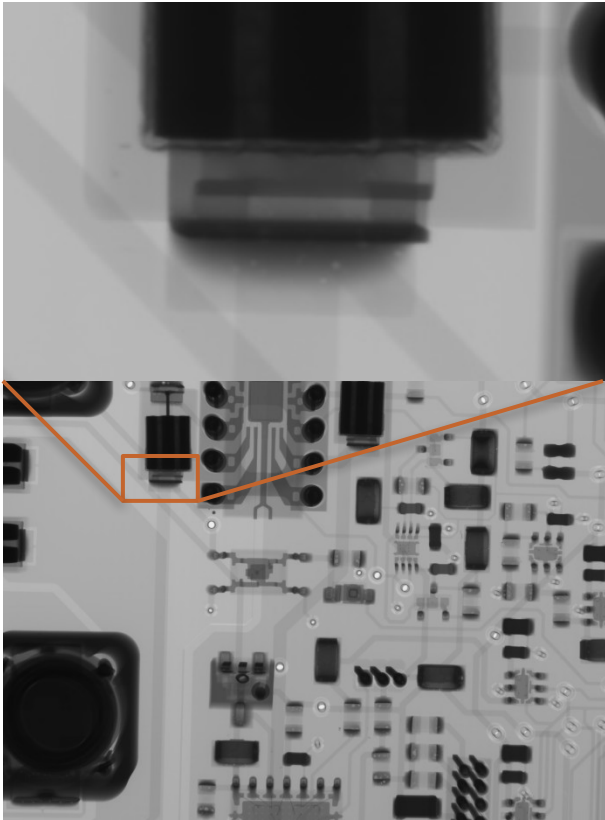


FTVd

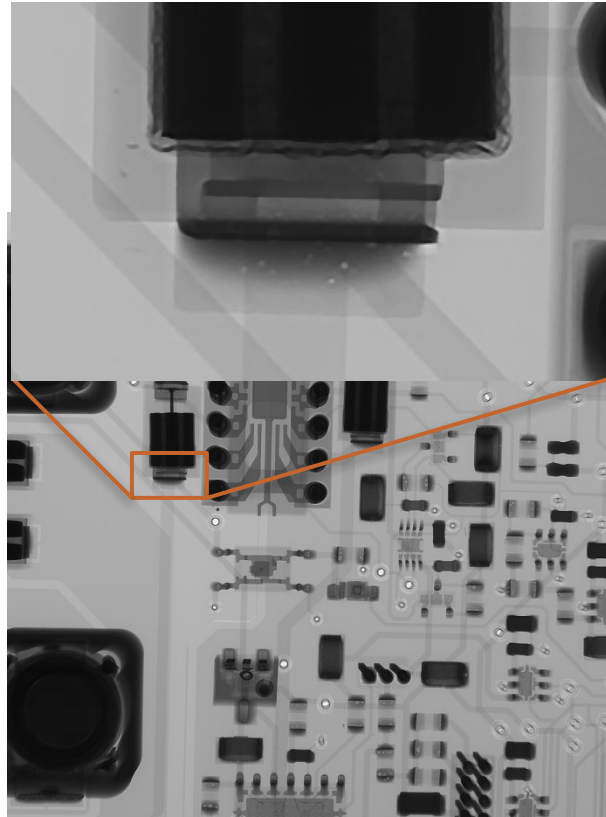


Deconvolution results

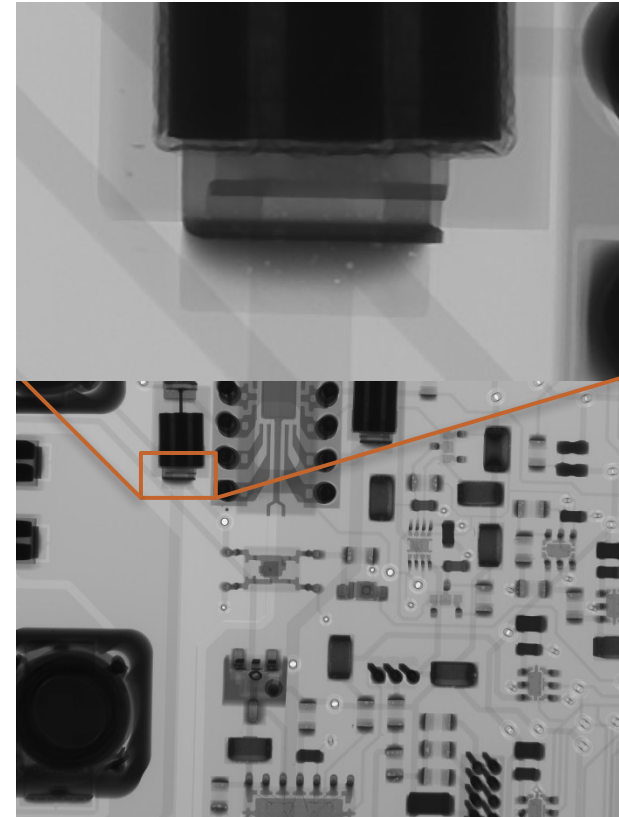
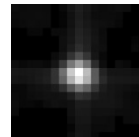
- Deconvolution of a printed circuit board: zoom factor found: 0.141



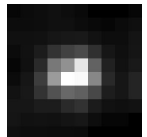
Experimental



prida



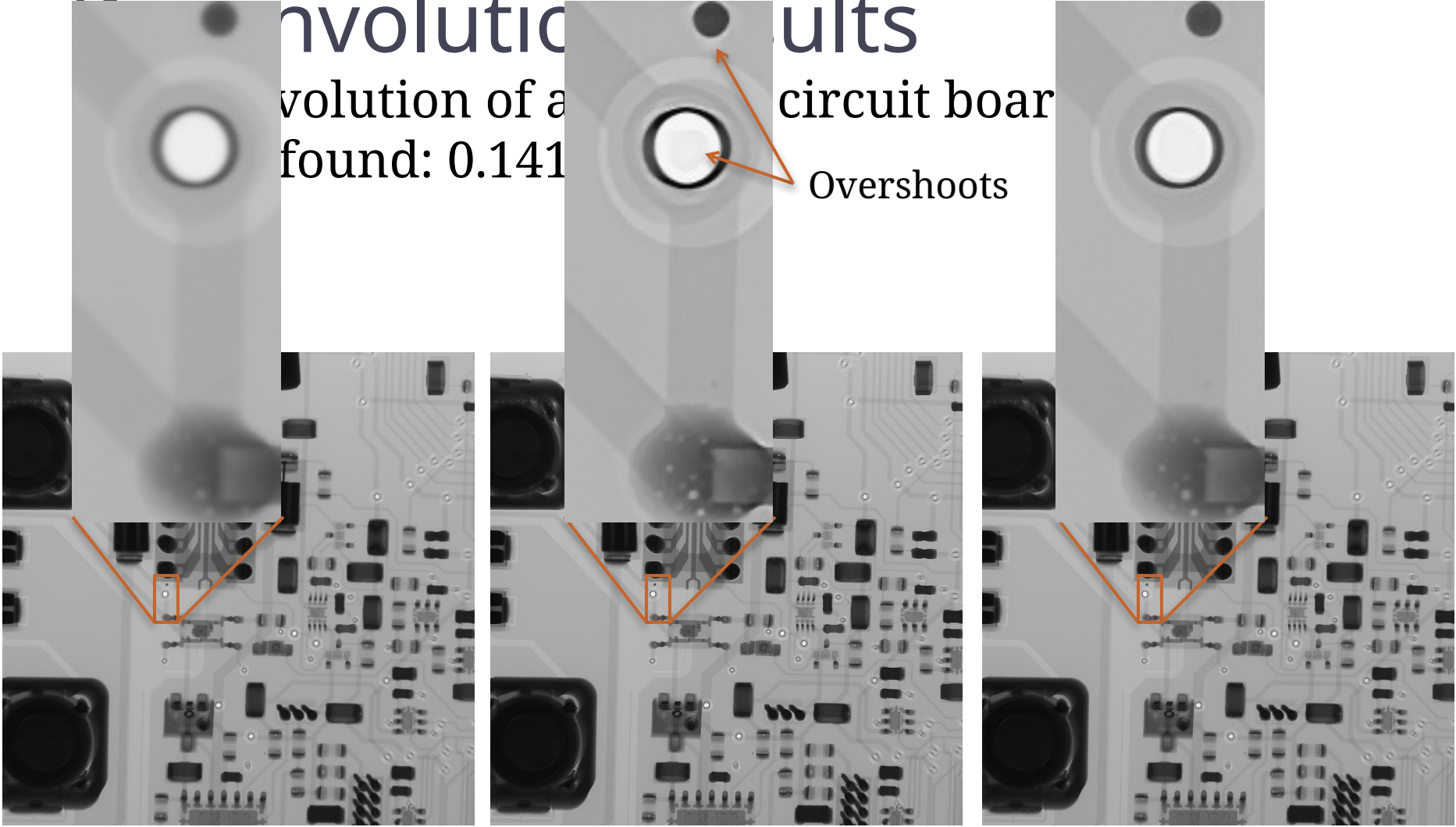
FTVd



Evolution of a circuit board

Evolution of a circuit board
found: 0.141

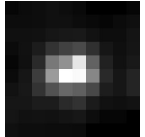
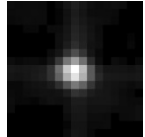
Overshoots



Experimental

prida

FTVd

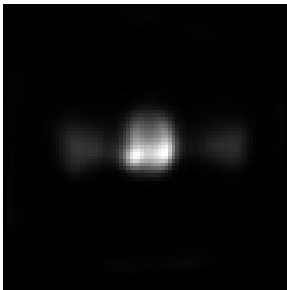


Conclusion

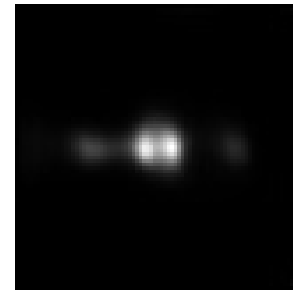
- Proposition of an algorithm for estimating 2D focal spot shapes from a single image of a tungsten sphere.
- Estimated focal spots can be used for image deblurring (provided a correction by a correct zoom factor).
- No assumptions made on the shape of the focal spot to estimate: can be Gaussian or have an arbitrary number of lobes.
- Include some basic physics through a simple X-ray model.
- Faster and more accurate than sheer blind deconvolution methods which ignore the physics.
- Background illumination can vary smoothly.
- Parameters of the experimental setup, from which the tungsten sphere image is obtained, do not need to be known accurately, only approximately.

Perperspective

- Focal spot shape estimations work well for tungstene spheres.
- Estimations from spheres of less denser materials (e.g. iron) more “foggy”.



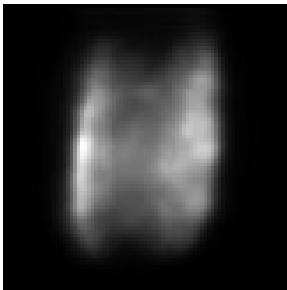
650 μ A, 100 kV, FS 0.4 mm
tungsten sphere.



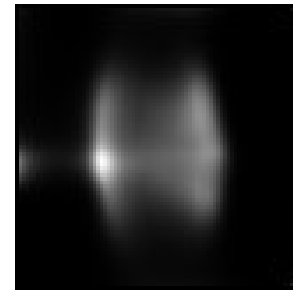
650 μ A, 100 kV, FS 0.4 mm
iron sphere.

Perperspective

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650 μ A, 100 kV, FS 1 mm
tungsten sphere.

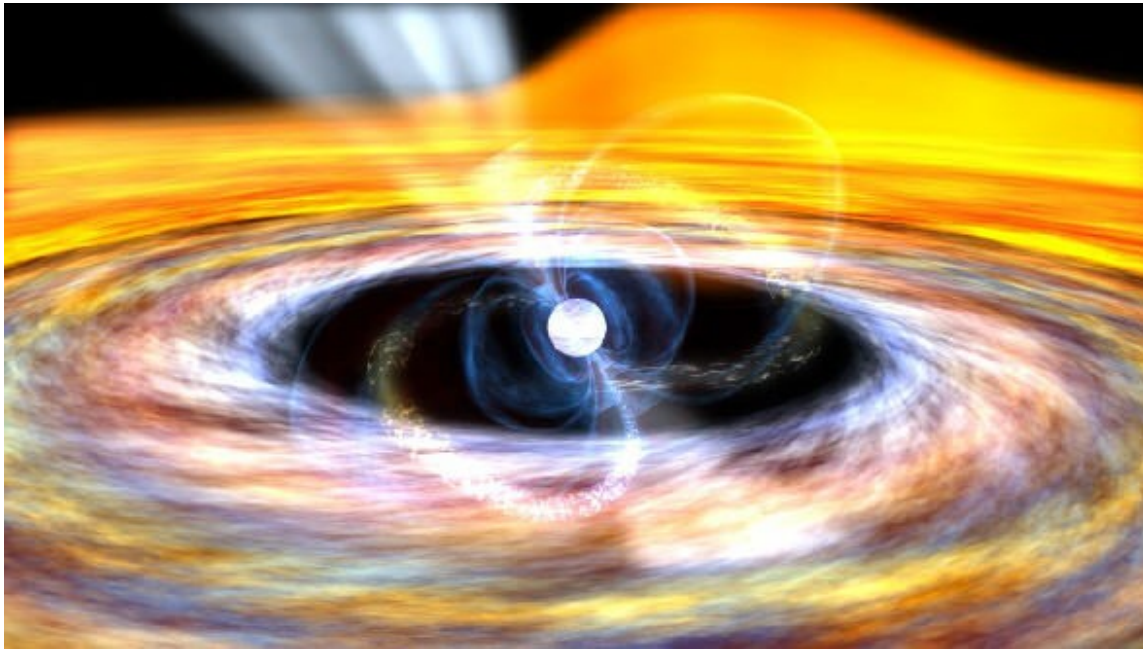


650 μ A, 100 kV, FS 1 mm
iron sphere.

Perperspective

- Focal spot shape estimations work well for tungstene spheres.
- Estimations from spheres of less denser materials (e.g. iron) more “foggy”.
 - Probably the X-ray model is too simple.
 - Should take into account:
 - X-ray spectrum.
 - Other phenomena such as backscattering and beam-hardening.
 - Such models already exist and may be incorporated into the algorithm in the future.
 - Possibility to consider other geometries than just a sphere.

Thank you for your attention



One of the most powerful collimated X-ray emitter in the universe.

Bibliography

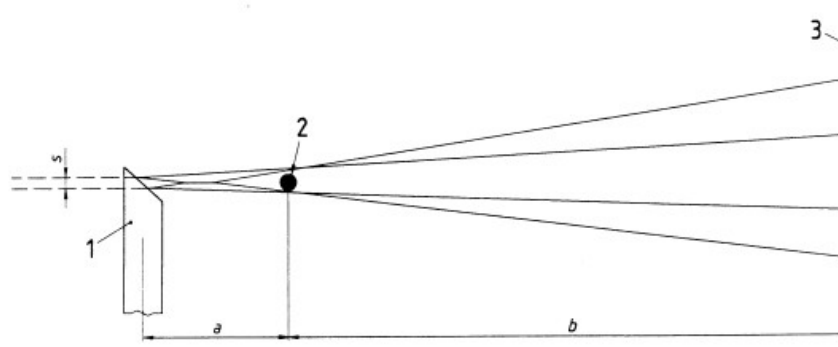
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Zoom factor

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Projection magnification
 $M = (a + b)/a$

Key

- 1 X-ray tube anode
- 2 test object
- 3 film plane

Figure 1 – Positioning of test object

Estimation of the focal spot from two images.

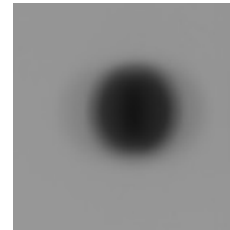
- Estimation via Fourier transform faster but poorly performs:

$$y = FS * x$$

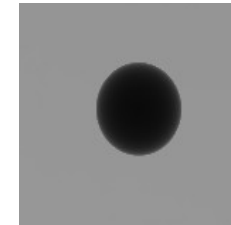
$$F(y) = F(FS).F(x)$$

$$F(FS) \approx \frac{F(y)}{F(x) + \lambda}$$

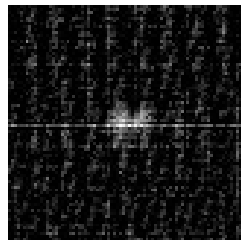
$$FS \approx F^{-1} \left(\frac{F(y)}{F(x) + \lambda} \right)$$



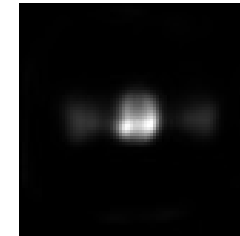
y



x



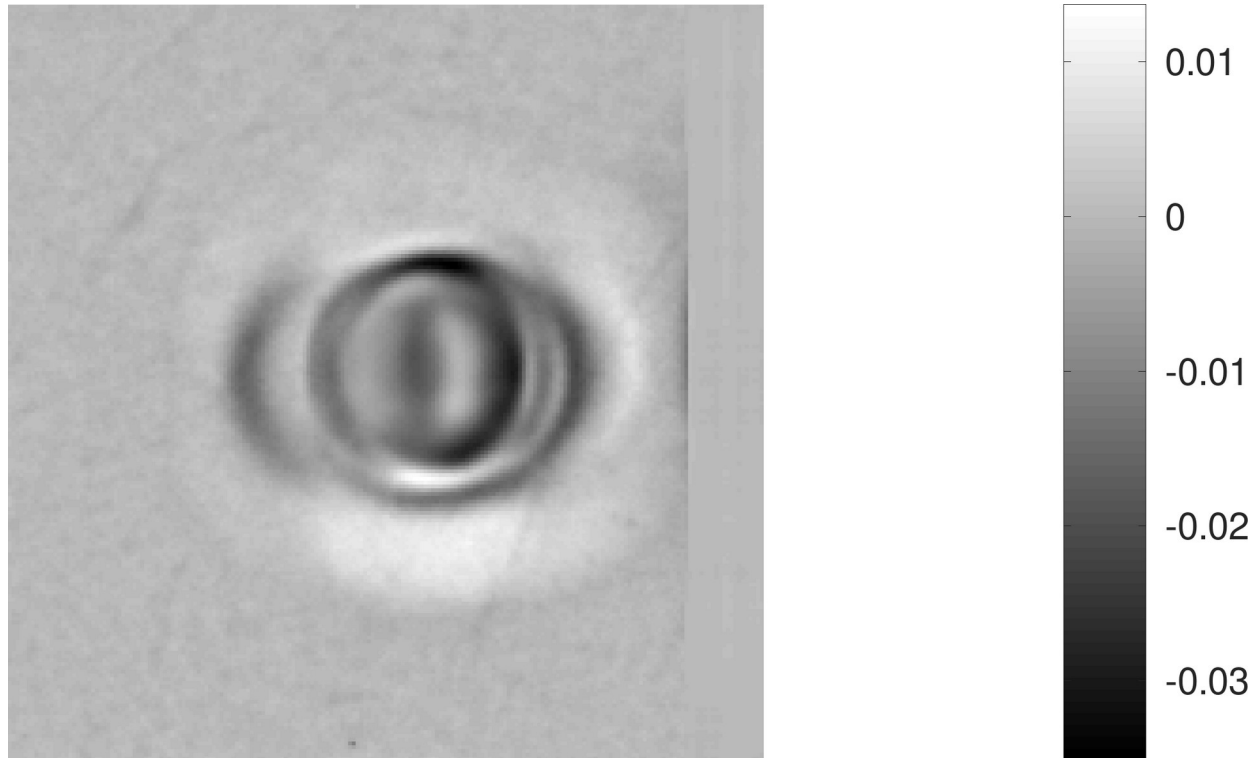
FS via Fourier



FS via proposed method

Focal spot estimation results

- X-ray generator: *Comet MXR 320 HP 1190* with a focal spot of 0.4mm, used at 650 μ A and 100kV.

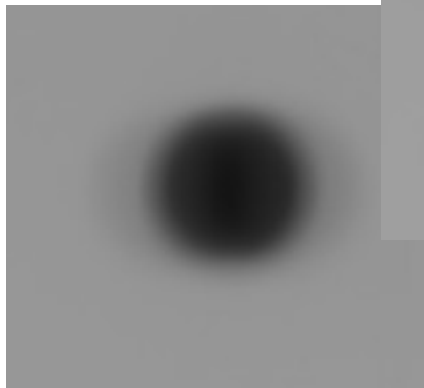
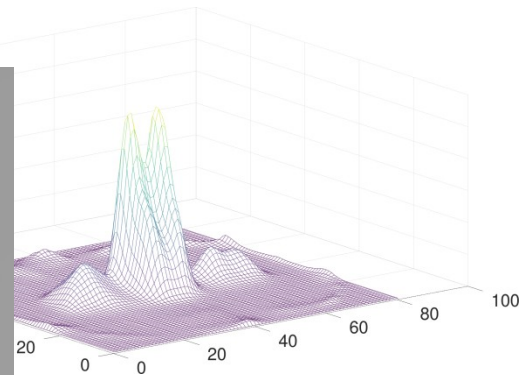
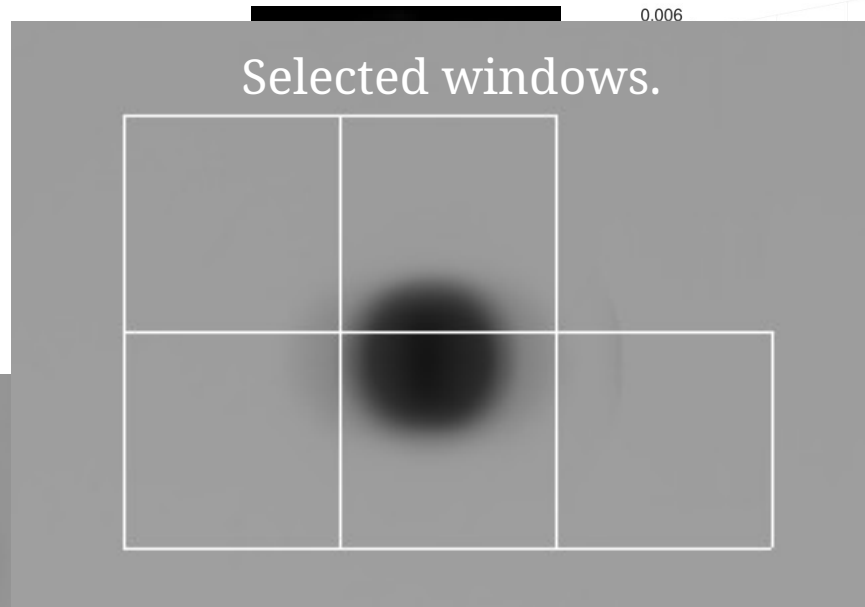


Difference between experimental and blurred theoretical images (max. rel. diff.:

6.5%)

Focal spot estimation results

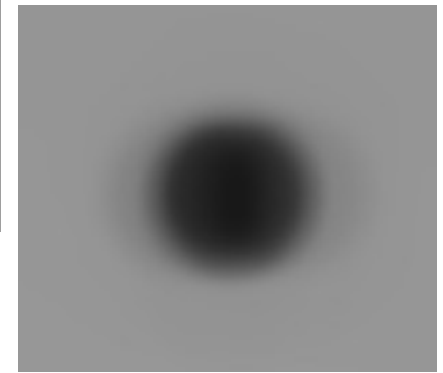
- X-ray generator: *Comet MXR 320 HP 1190* with a focal spot of 0.4mm, used at 650 μ A and 100kV.



Experimental image



Estimated theoretical image



Theoretical image blurred with focal spot