# Model observers for 3D image modalities

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Lausanne, Switzerland

AAPM 2013, Indianapolis

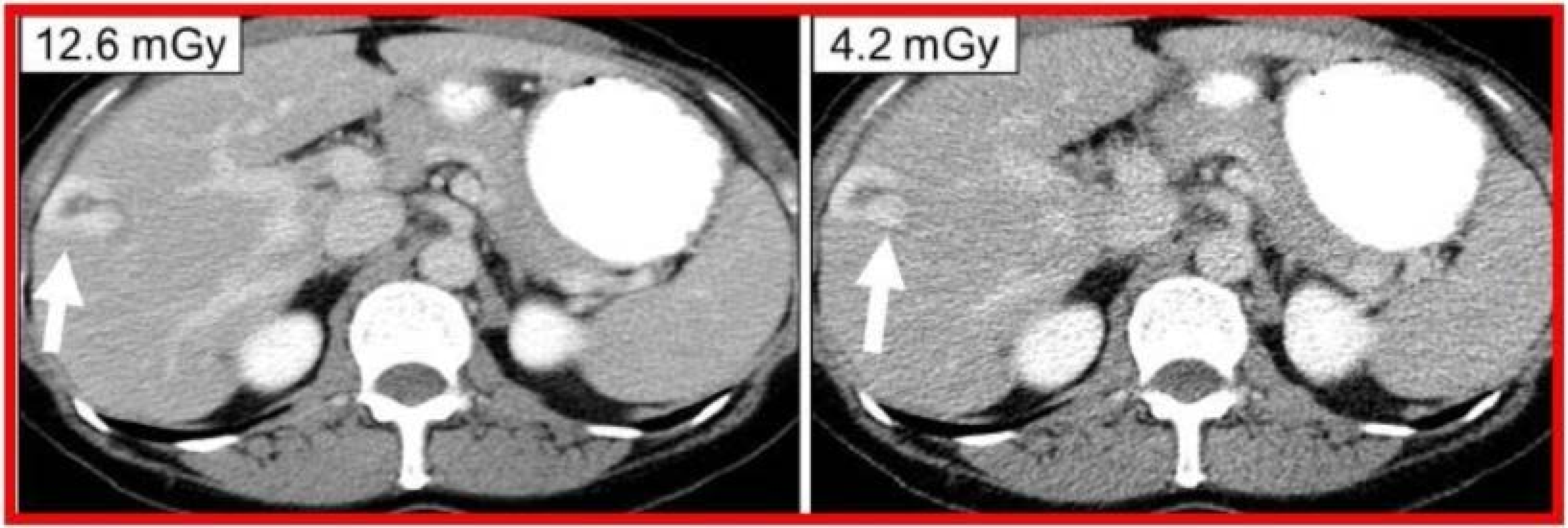


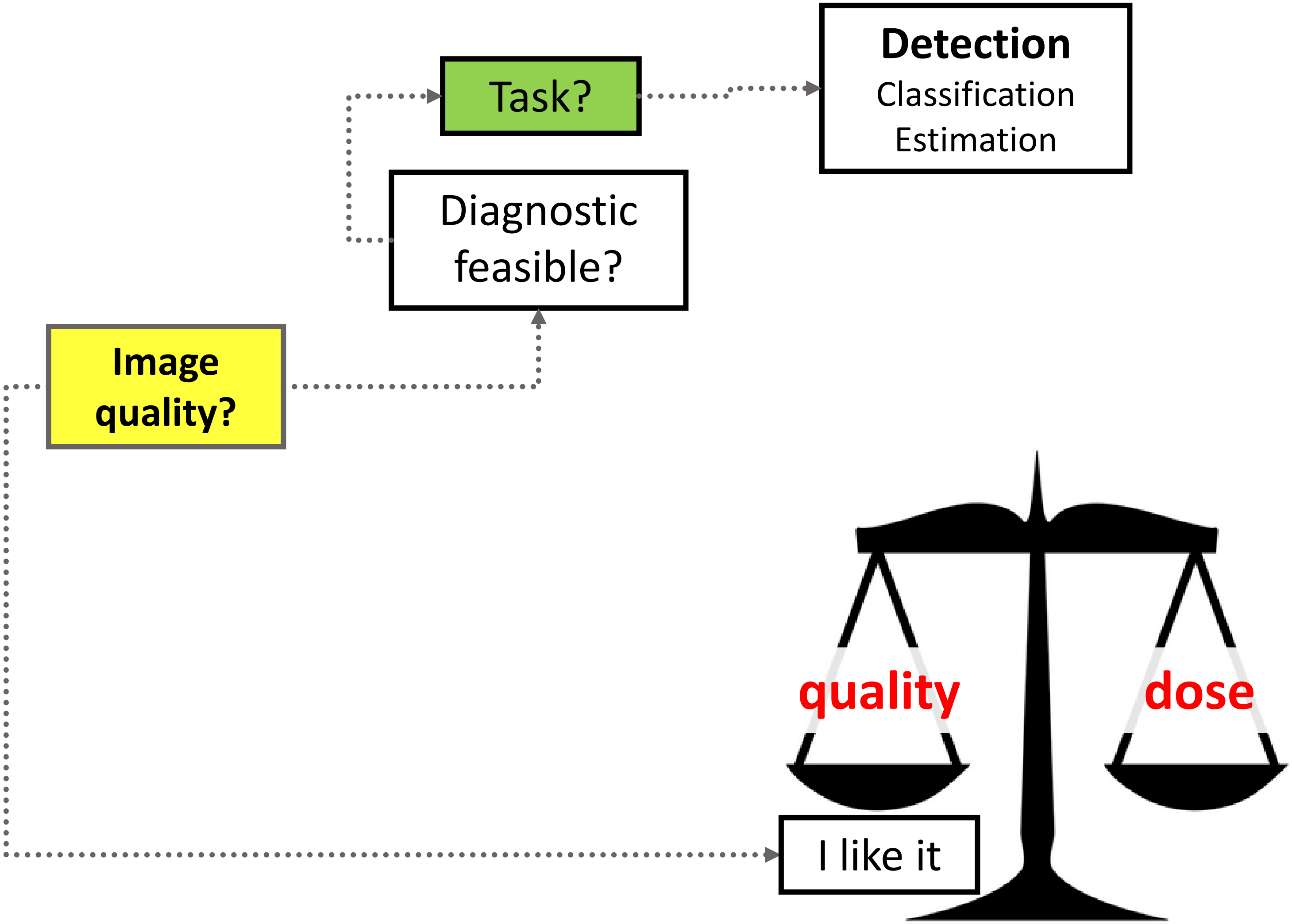

Image Quality: Unnecessarily high

Image Quality: Adequate for diagnosis

**High quality /Crisp images may look nice but they impart higher radiation dose to patients**

**Start using images with some noise without loss of diagnostic information**

*Images courtesy of: MK Kalra, S. Singh, MGH Webster Center for Advanced Research and Education in Radiation*


Task?
Detection
Classification
Estimation
Diagnostic feasible?
Image quality?
quality
dose
I like it

# Detection

- Interaction of signal and background

Cyril Castella, PhD thesis, 2009


Things are easier when we know
where to look...

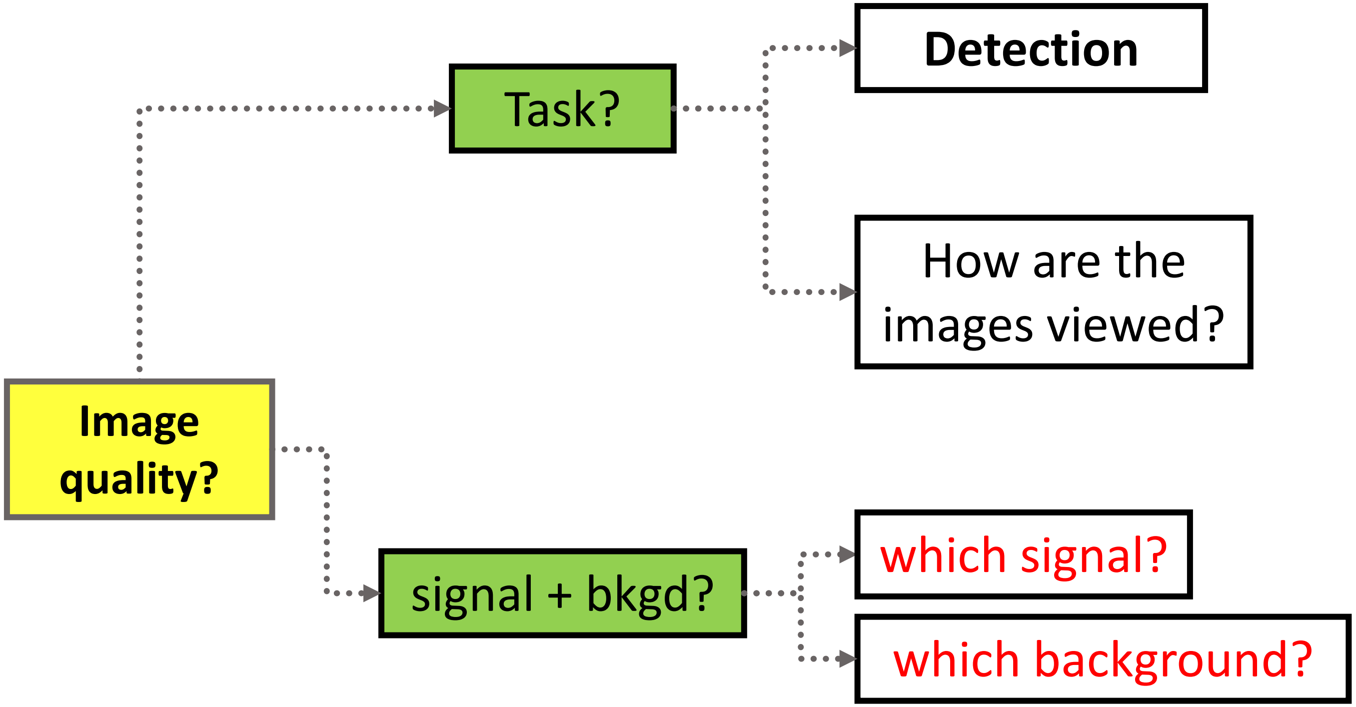


Image quality?
Task?
Detection
How are the images viewed?
signal + bkgd?
which signal?
which background?

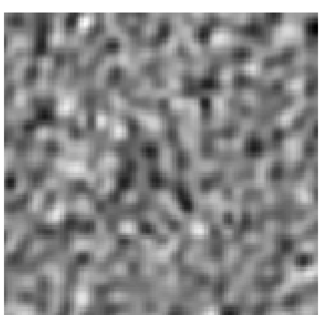
# What is the "true" signal in 3D?

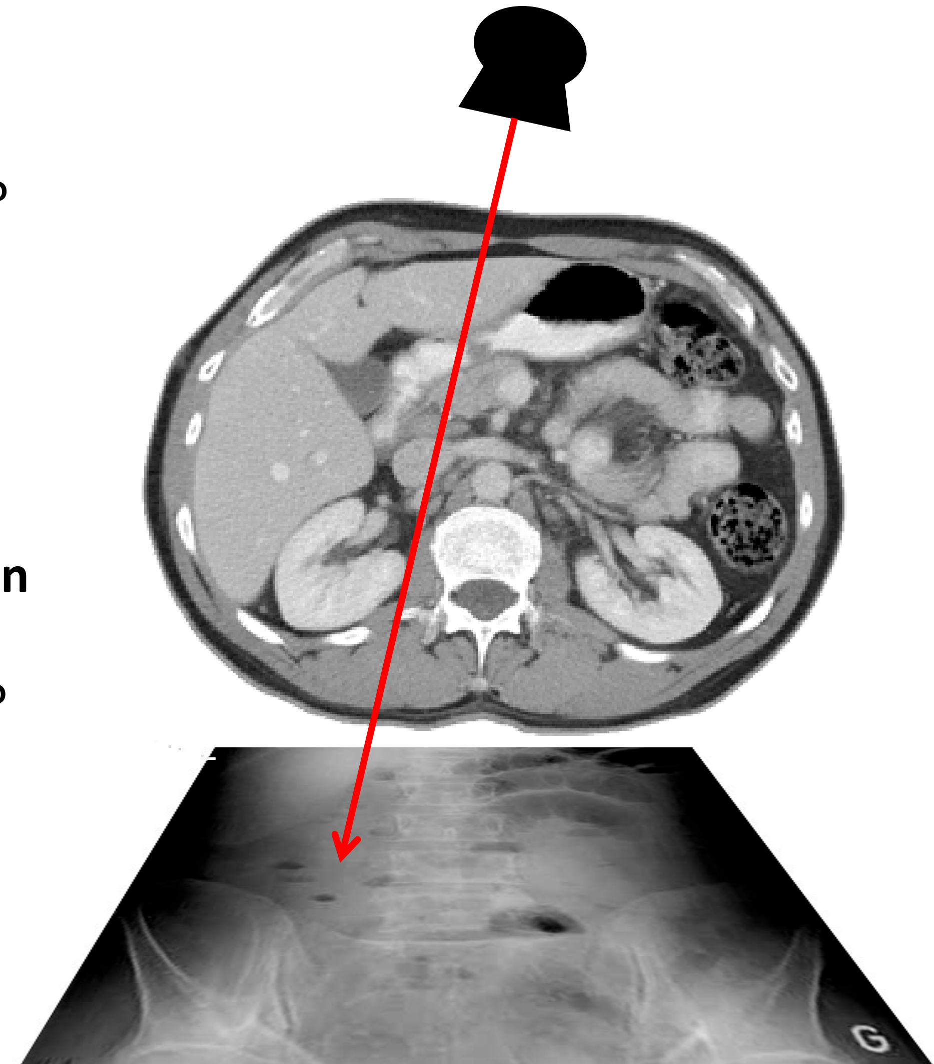
**Synthetic addition**

- Addition before each projection?
- Addition after each projection?
- Addition on the 3D volume?
- Replacement in the 3D volume?

**Already present during acquisition**

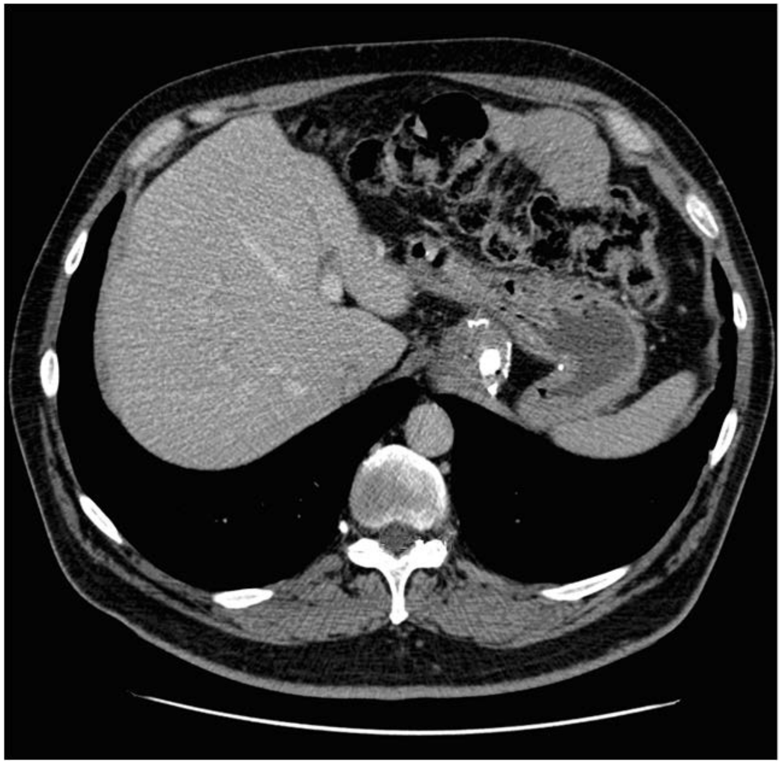
- Where exactly?
- How do you know its real shape?





# Background variation more complex in 3D than in 2D

*Almost no system noise in the **lung***



*Quantum noise very present in the **liver***

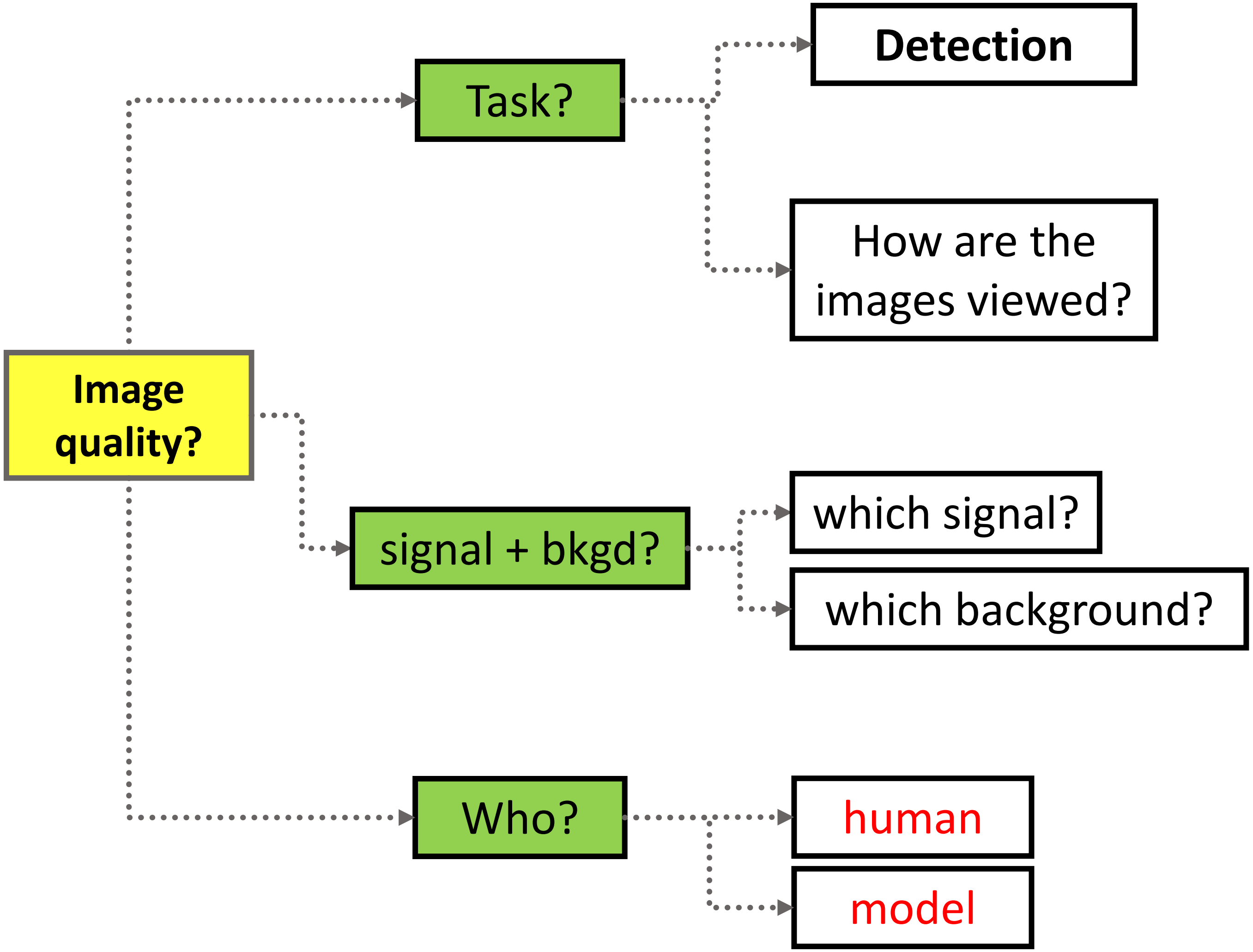
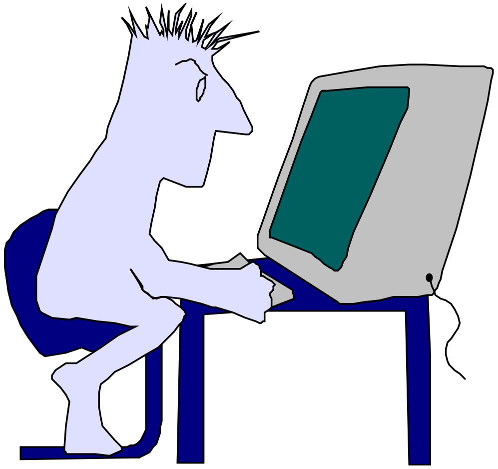
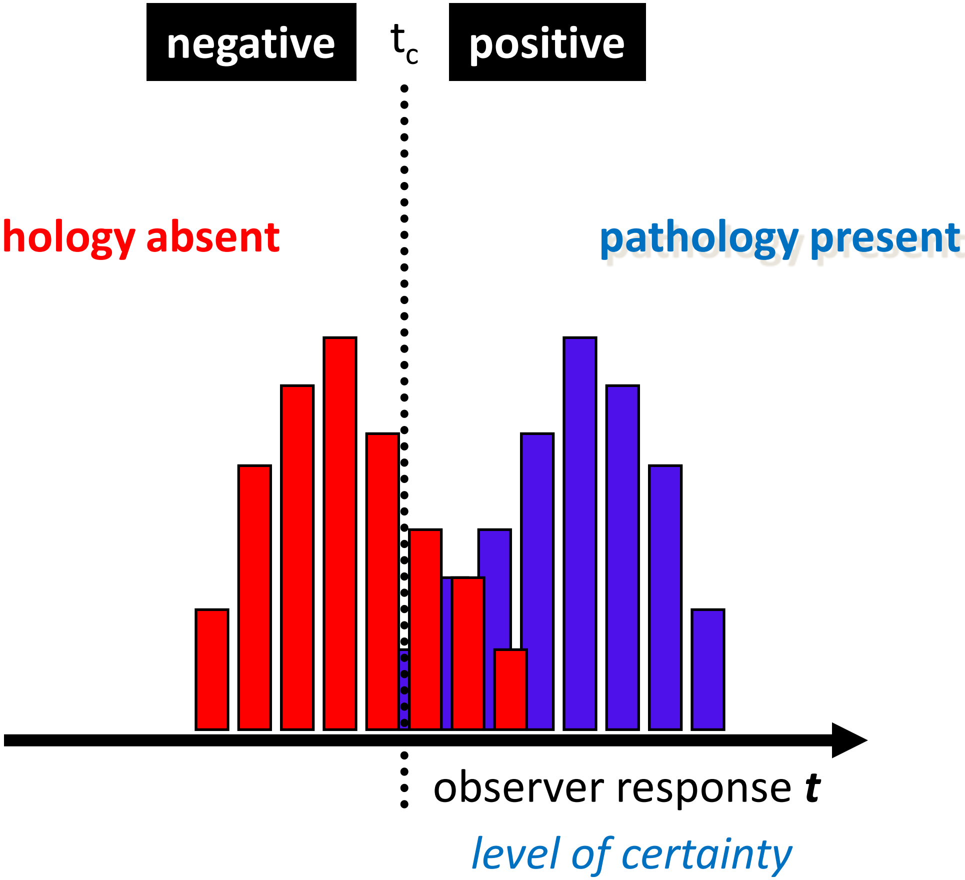


Image quality?
Task?
Detection
How are the images viewed?
signal + bkgd?
which signal?
which background?
Who?
human
model

# Detection task: observer modeling



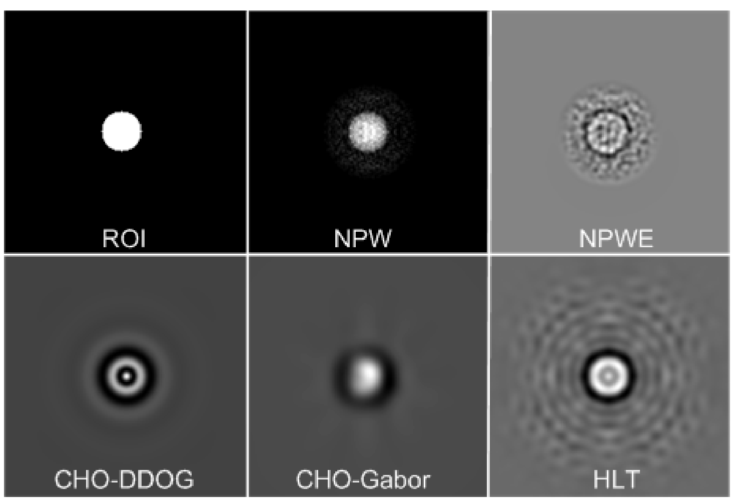


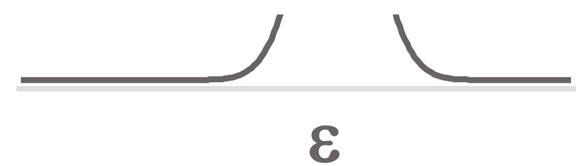
# Linear model observer

$$t = \mathbf{w}^T \mathbf{g} + \varepsilon$$

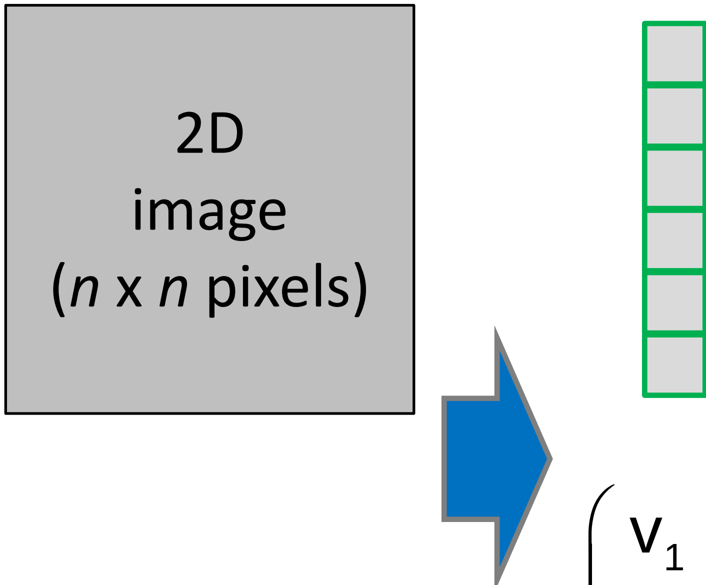
Observer's template

Image



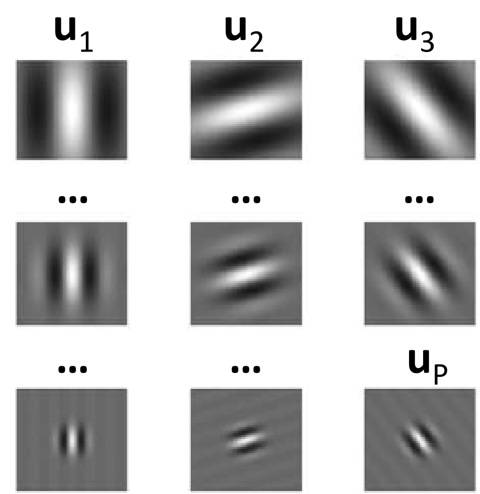
# Channelizing mechanism




**g**

$$\begin{pmatrix} v_1 = \mathbf{u}_1^t \mathbf{g} \\ \cdots \\ v_p = \mathbf{u}_P^t \mathbf{g} \end{pmatrix} = \mathbf{v}$$

*reduces dimensionality*
*mimic our visual system*




*examples of channels (each has the same dimension as the image **g**)*

# Channelized Hotelling observer **(CHO)**

2D
image
(*n* x *n* pixels)

**g**

P channel
responses

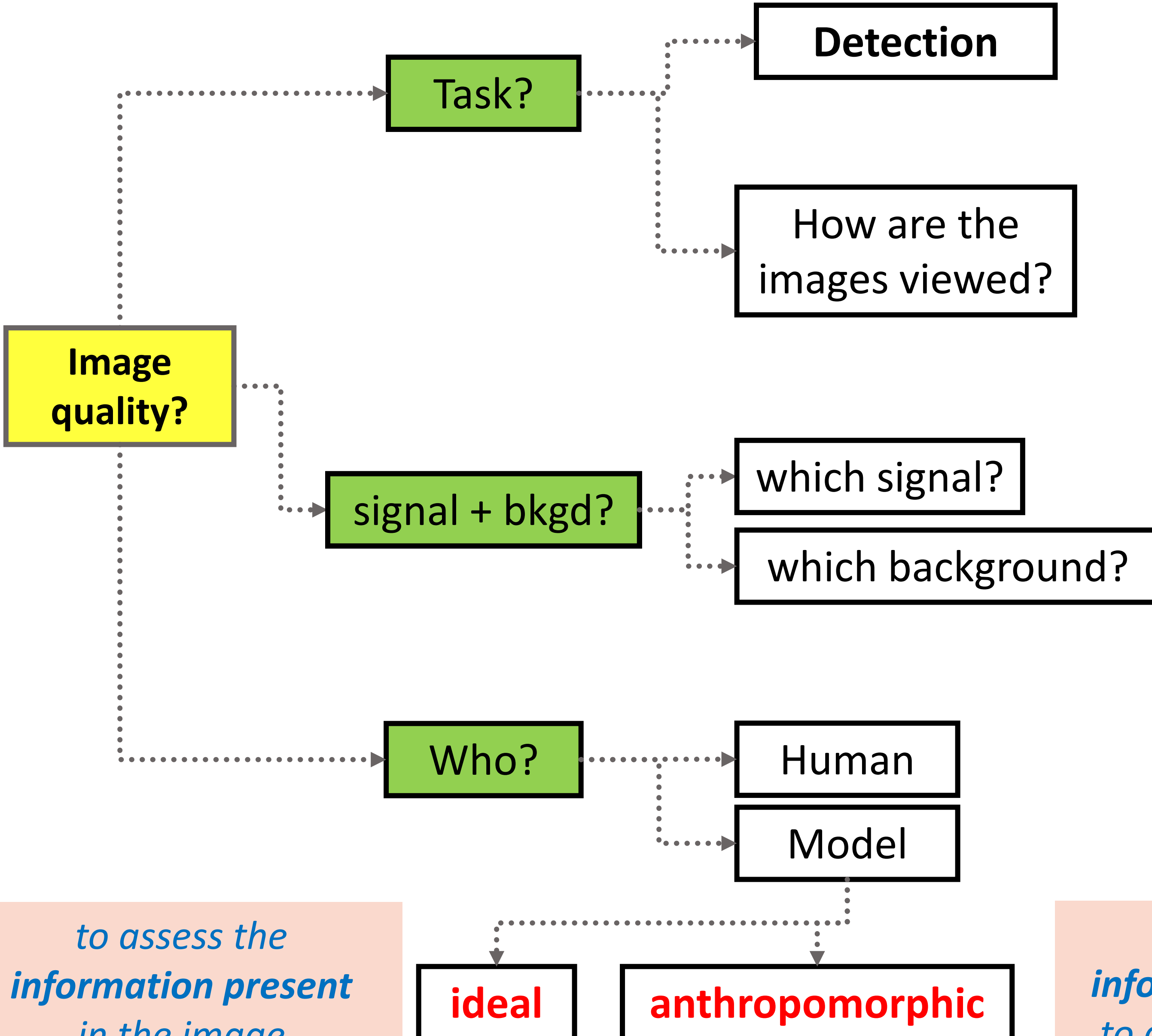
$$\begin{pmatrix} v_1 = \mathbf{u}_1^t \mathbf{g} \\ \cdots \\ v_p = \mathbf{u}_P^t \mathbf{g} \end{pmatrix} = \mathbf{v}$$

*reduces dimensionality*
*mimic our visual system*

$$t = \mathbf{w}^t \mathbf{v} + \varepsilon$$

$$\mathbf{w}_{HO} = \mathbf{K}_v^{-1} \Delta \mathbf{v}$$

*best linear template*



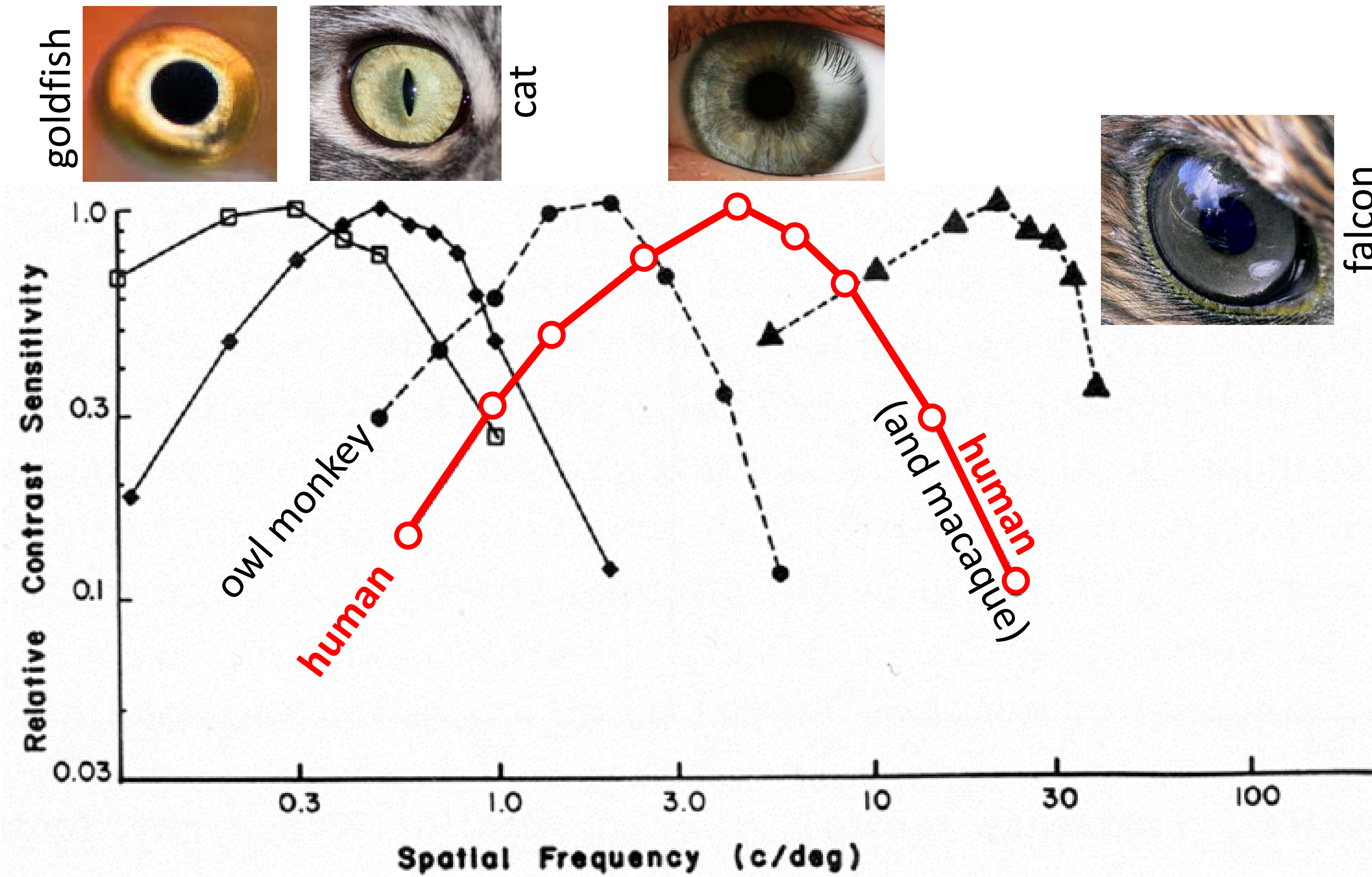

*to assess the* ***information present*** *in the image*

*(potential to tune detectors)*

*to assess the* ***information available*** *to a* ***human observer***

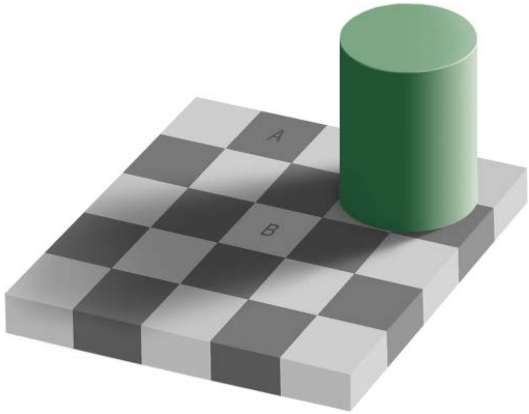
*(potential to tune processing & display)*

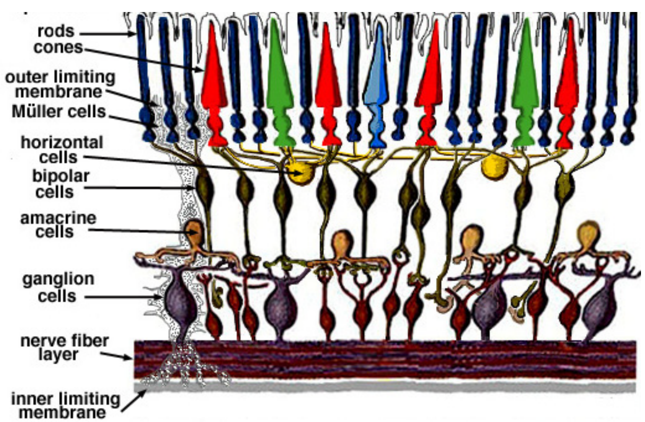
# Our contrast sensitivity peaks around **4 cycles per degree**



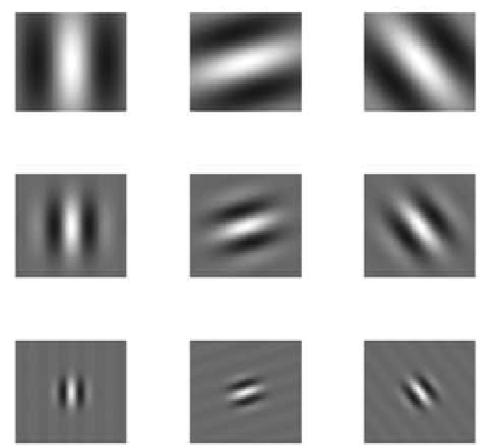

http://homepage.psy.utexas.edu/homepage/class/Psy380E/VS_8_retina.pdf

# The visual cortex does not analyze the image pixel by pixel

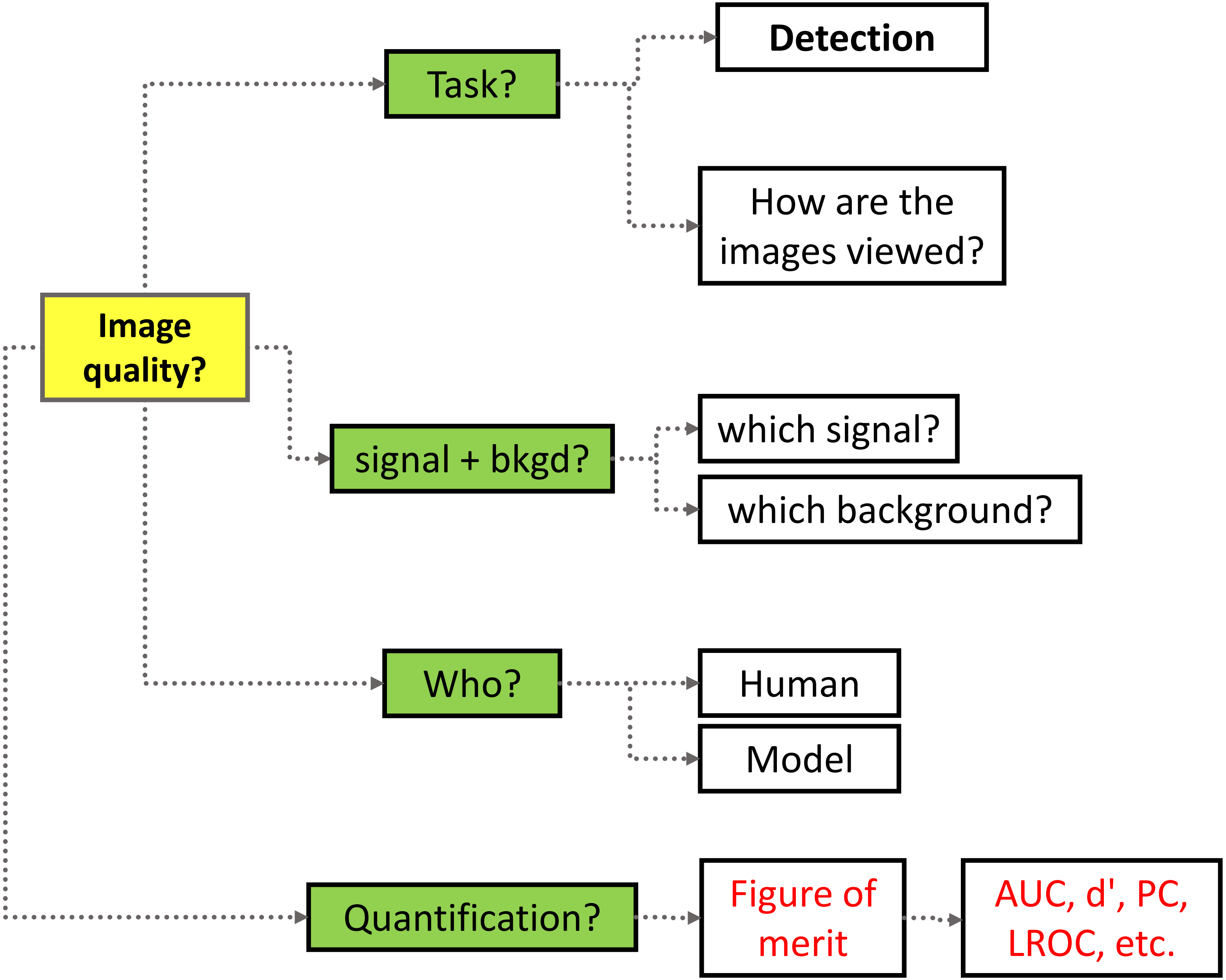



*Pre-processing is performed*
***at the retina level***



*Images appear to be processed*
***as "seen" through channels***

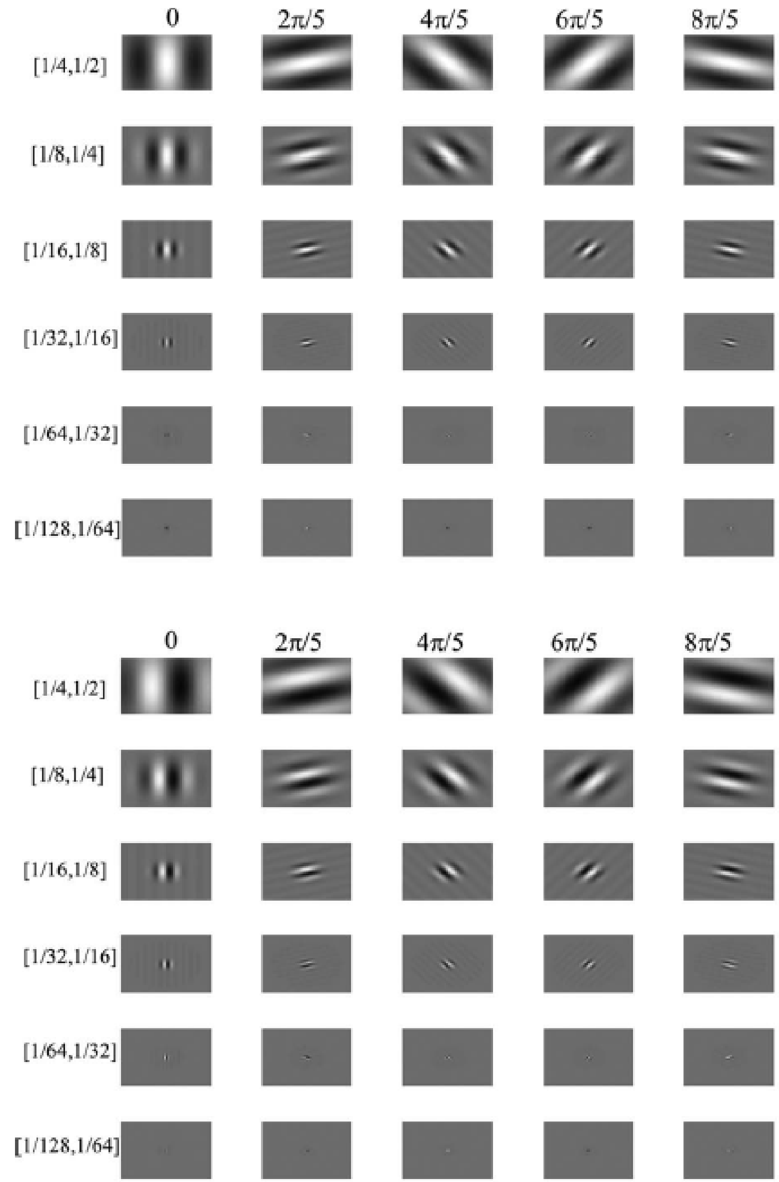



*have to be cautiously chosen in order to be able to do* ***comparisons***

# Examples of model observers recently used in Medical Physics

# Detection in chest CT

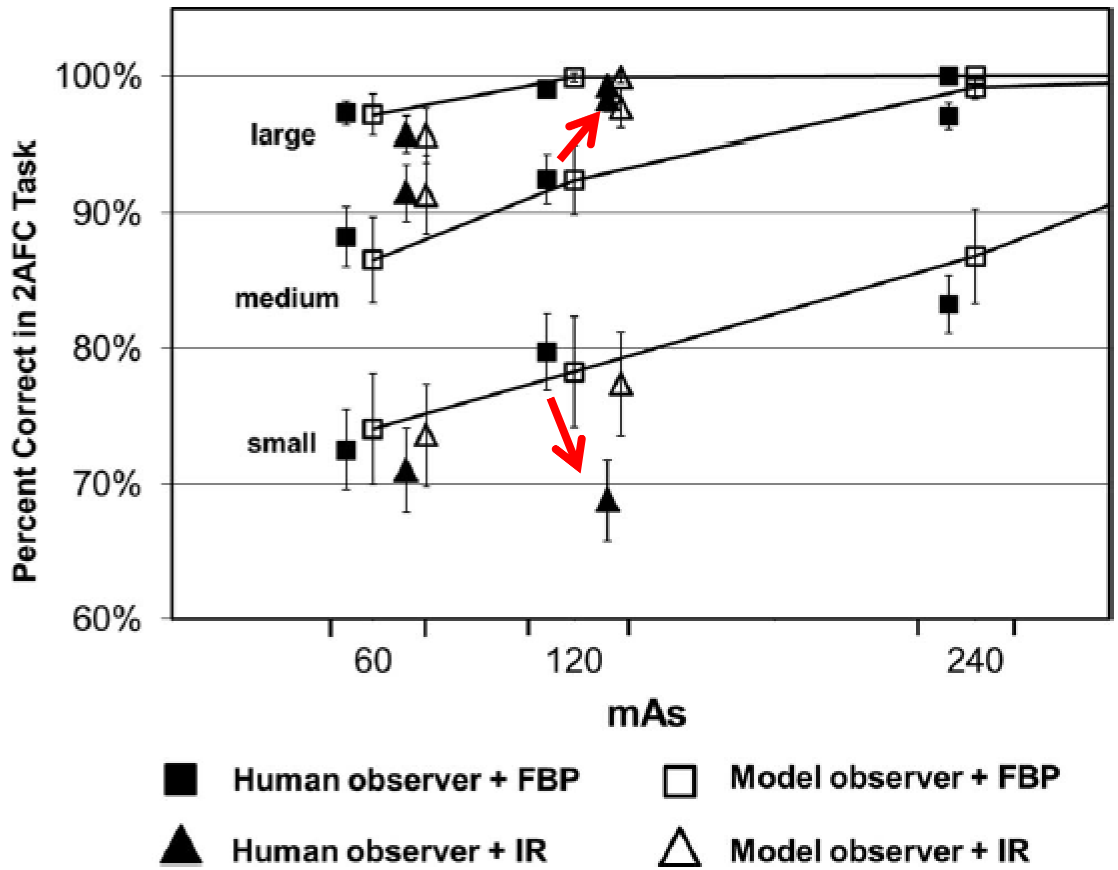
- Comparison between FBP & IR
- 100 repetitions of each condition
  - several mAs
  - with & without rod
- 2-AFC experiment
  - 4 human observers
  - CHO
    - Gabor 60 channels
    - Adjusted internal noise




Yu *et al*, Med. Phys. 40:041908, April 2013

# Detection in chest CT

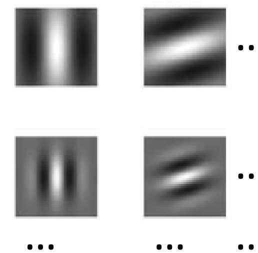
- Excellent adequacy between human and CHO
- IR slightly better at 120 kV for medium size rod
  - but not for small size

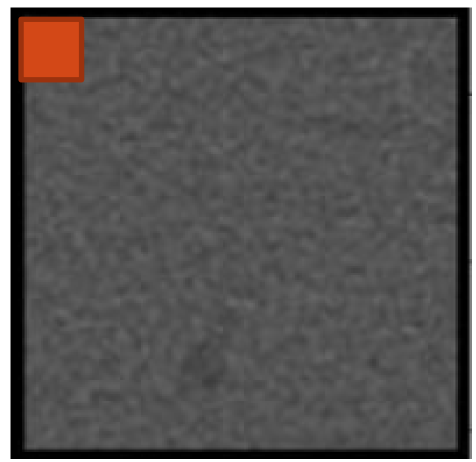



Yu *et al*, Med. Phys. 40:041908, April 2013

# Detection in chest CT (uncertain location)

- Same experiment
  - but uncertain location
  - but defined in term of $CTDI_{vol}$
- Same signal
  - but no large size
- Same observers
  - 3 humans
  - CHO
    - performed by scanning



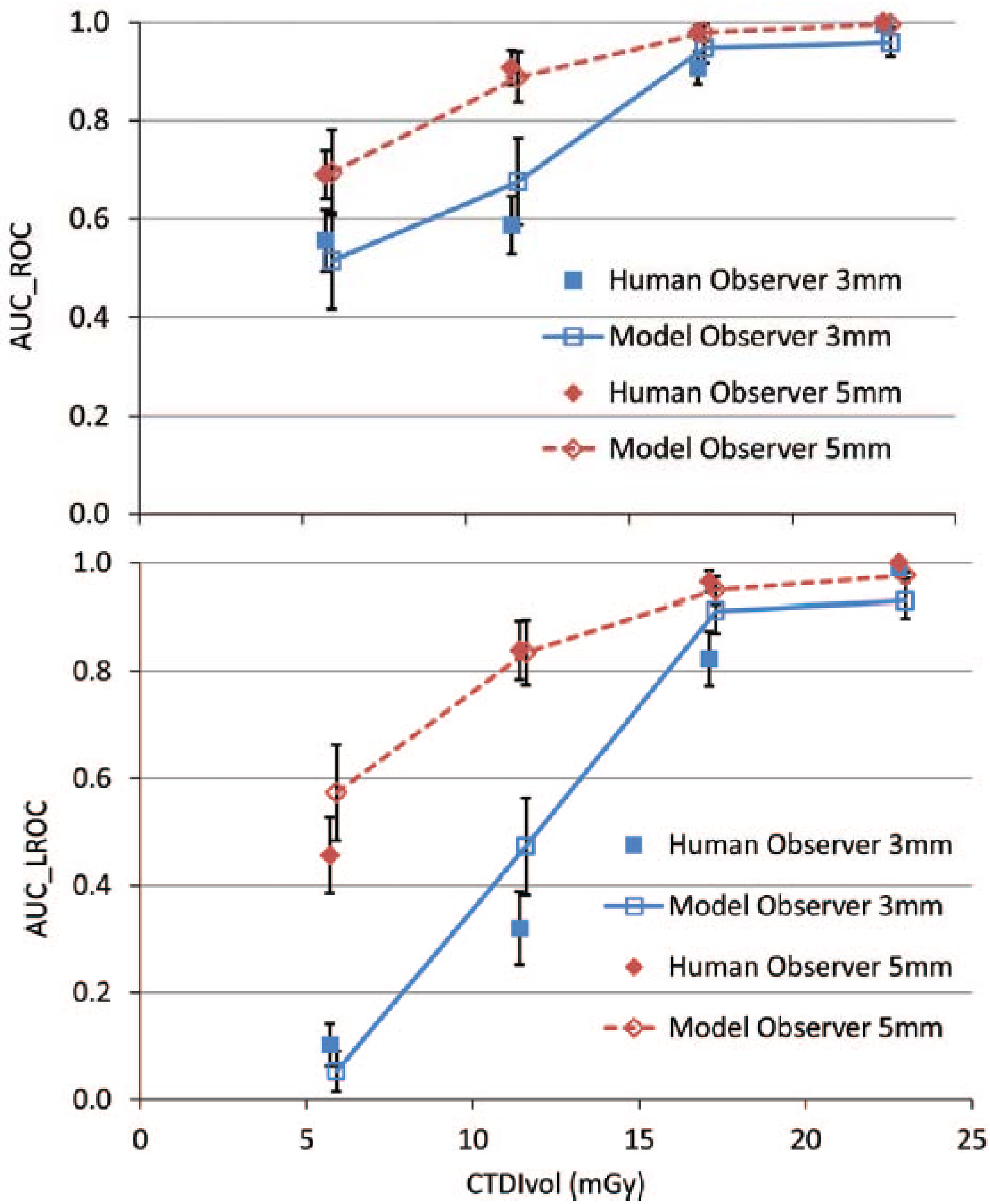


$$\lambda = \max_{i \in ROI} (\lambda_i)$$

Leng *et al*, Med. Phys. 40:081908, August 2013

# Detection in chest CT (uncertain location)

- Excellent adequacy between humans and CHO

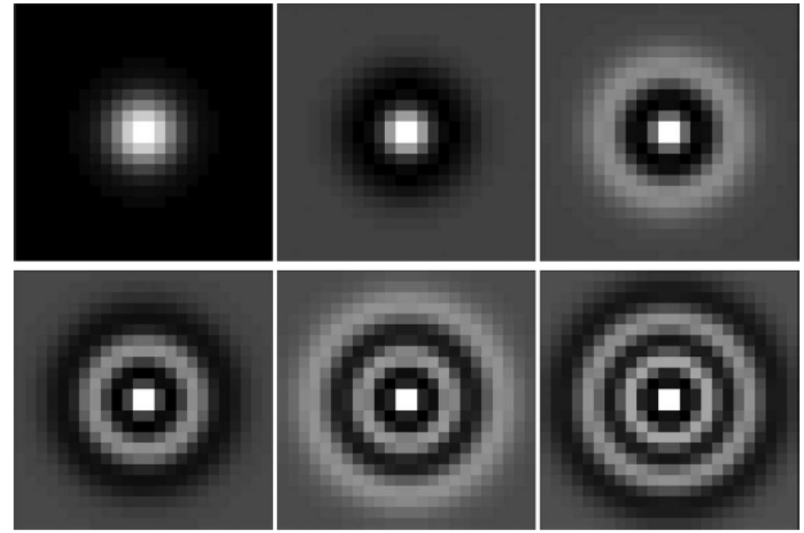



Leng *et al*, Med. Phys. 40:081908, August 2013

# Discussion of the study regarding **model observers**

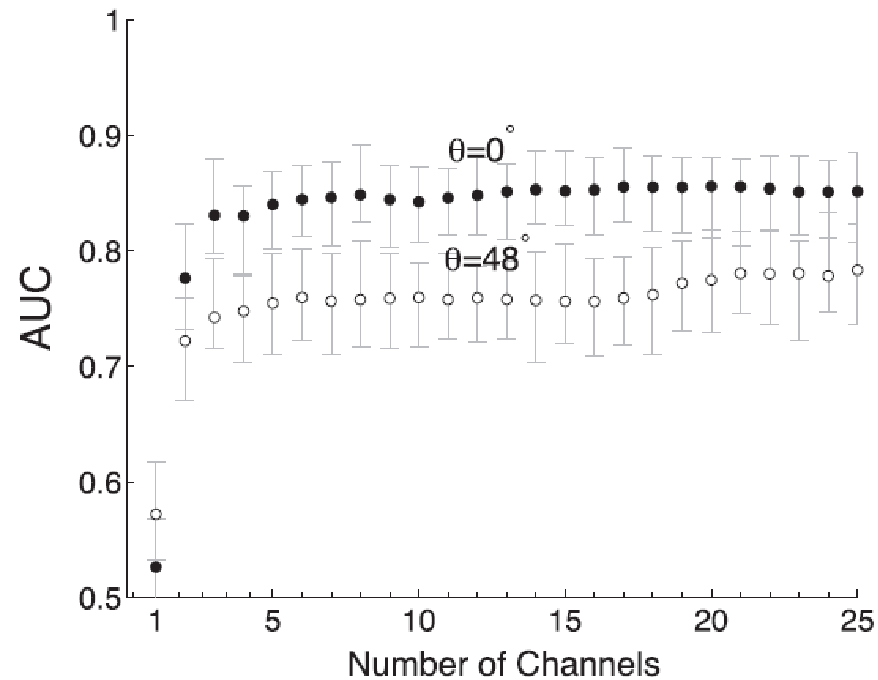
- **No anatomical noise** present
  – IR algorithms could have peculiar effects on anatomical backgrounds
- (Too) **many channels** in the CHO?
  – especially for a symmetric signal
- Images are 3D and reconstruction is 3D
  – Everything is performed in 2D
    - Humans look at 2D images
    - Models are **purely 2D**

# Detection



- Virtual trial framework specific for digital breast tomosynthesis
  - scan angles
  - number of projections
- Simulated image acquisition
  - Bakic's phantom
  - spherical microcalcification added before projection
- CHO
  - limited number of channels
  - AUC

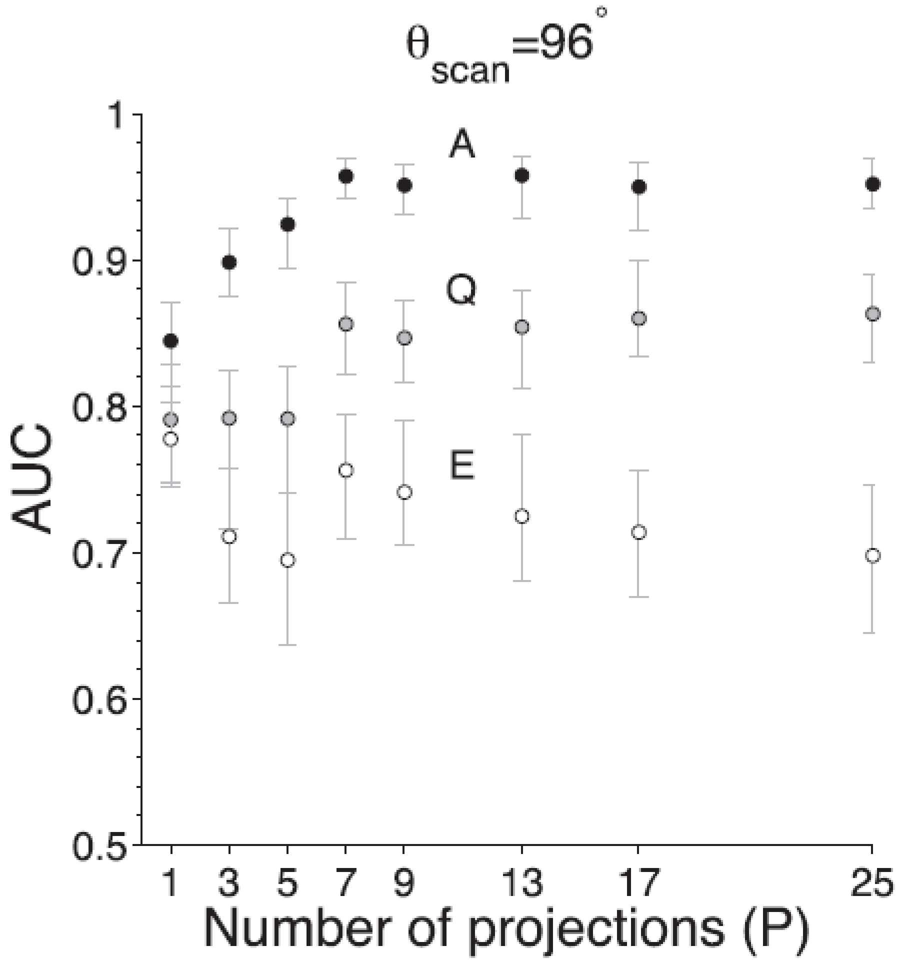
6 LG channels are adequate to mimic the **ideal observer** for a circular symmetric signal




Young *et al*, Med. Phys. 40:051914, May 2013

# Detection in DBT

- A **simulation framework** and a tool to estimate image quality in DBT is **established**
  - an application with scan angle and number of projection has been shown for different noise regimes




Young *et al*, Med. Phys. 40:051914, May 2013

# Discussion of the study regarding **model observers**

- Was it adequate to take the ***ideal*** observer?
  - **YES**: the goal was to choose hardware conditions

- It would have been different if the goal had been to choose ***processing*** or ***display*** conditions

- Image quality seems to be assessed **in 2D**

# Detection in Breast CT (real background)

- Selection of reconstruction of reconstruction parameters in IR
- Simulated image acquisition
  - breast model from mastectomy
  - spherical microcalcification added before projection
- Detectability for "ideal observer"

radial average Fourier transformed of the mean signal

$$d'^2 = \sum_k \frac{|S(\boldsymbol{k})|^2}{P(\boldsymbol{k})}$$

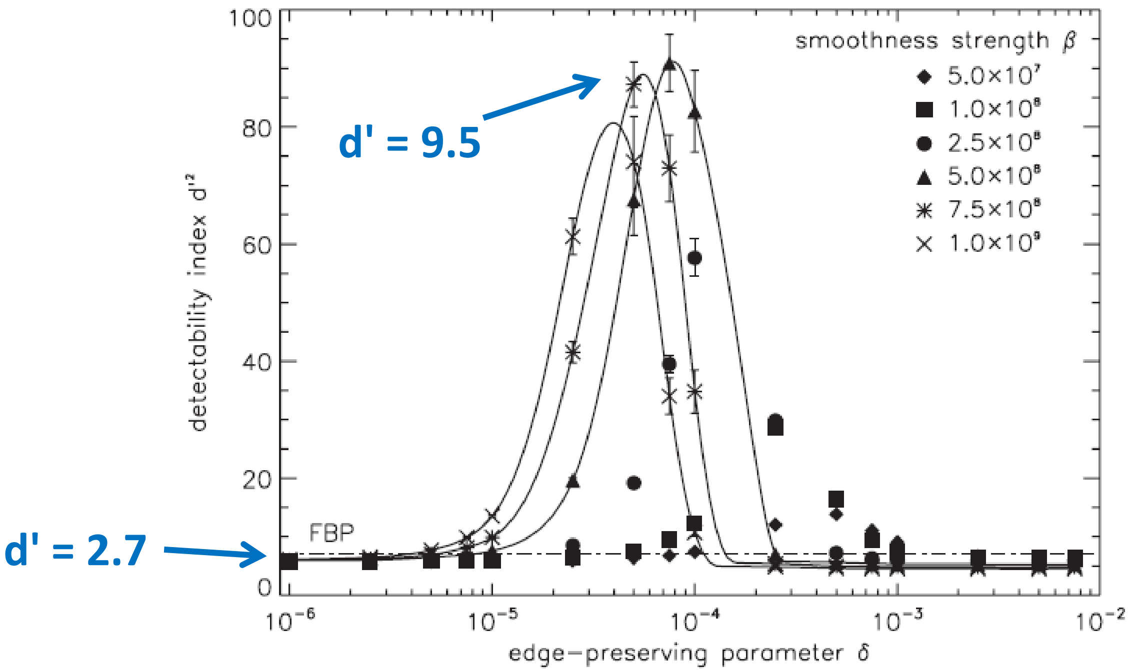
radial average NPP

*ideal observer for **stationary** and **isotropic** noise+background*

Makeev & Glick, Med. Phys. 40:081904, August 2013

# Detection in Breast CT (real background)

- Selection of reconstruction parameters
  - qualitatively by looking at the images
  - based on d'

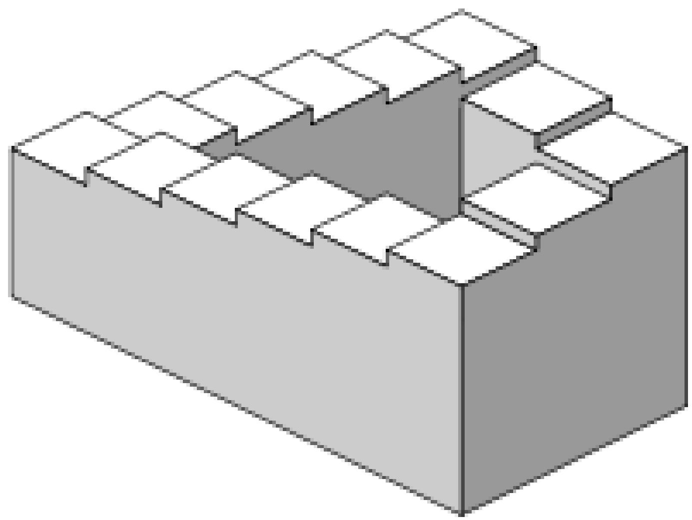



Makeev & Glick, Med. Phys. 40:081904, August 2013

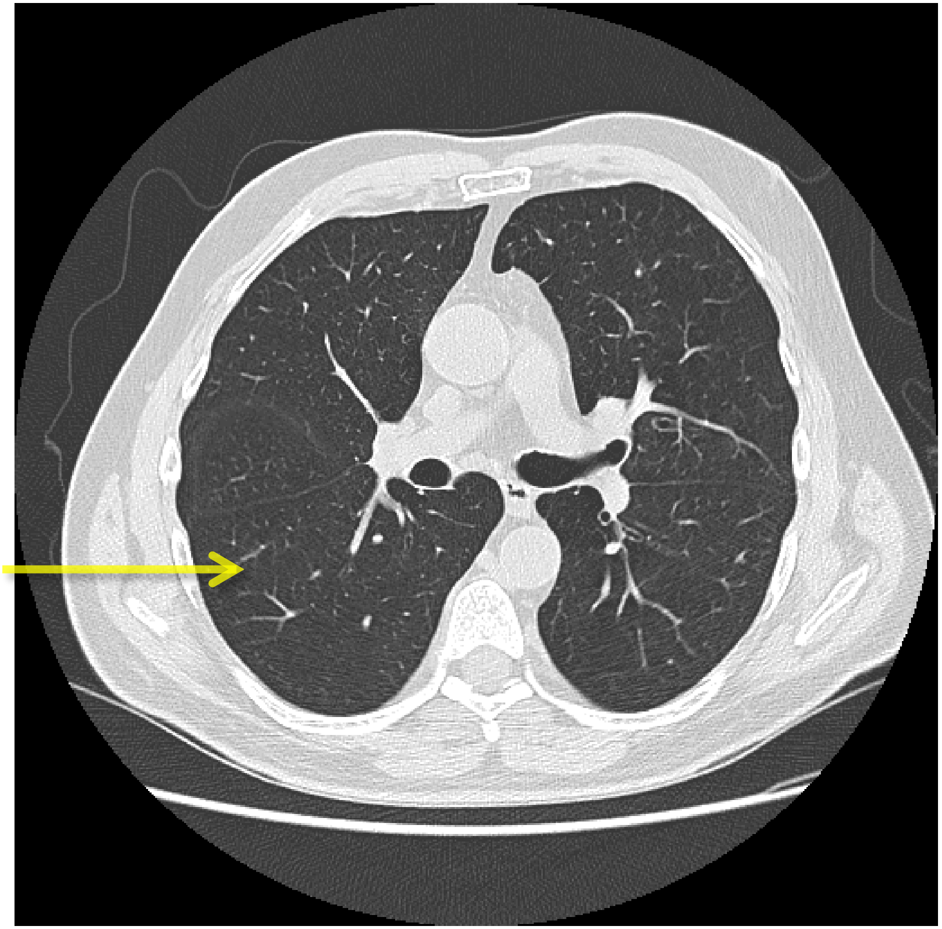
# Discussion of the study regarding **model observers**

- Partial use of the model
  - d' calculated after exclusion of **"unnatural"** and **"patchy background textures"**
- **Expression** of the ideal observer used in a **different context**
  - anatomical breast imaging not stationary and not isotropic
- Ideal observer useful to estimate the **information content**
  - ideal observer would even prefer the sinograms!
- Image quality assessed in 2D

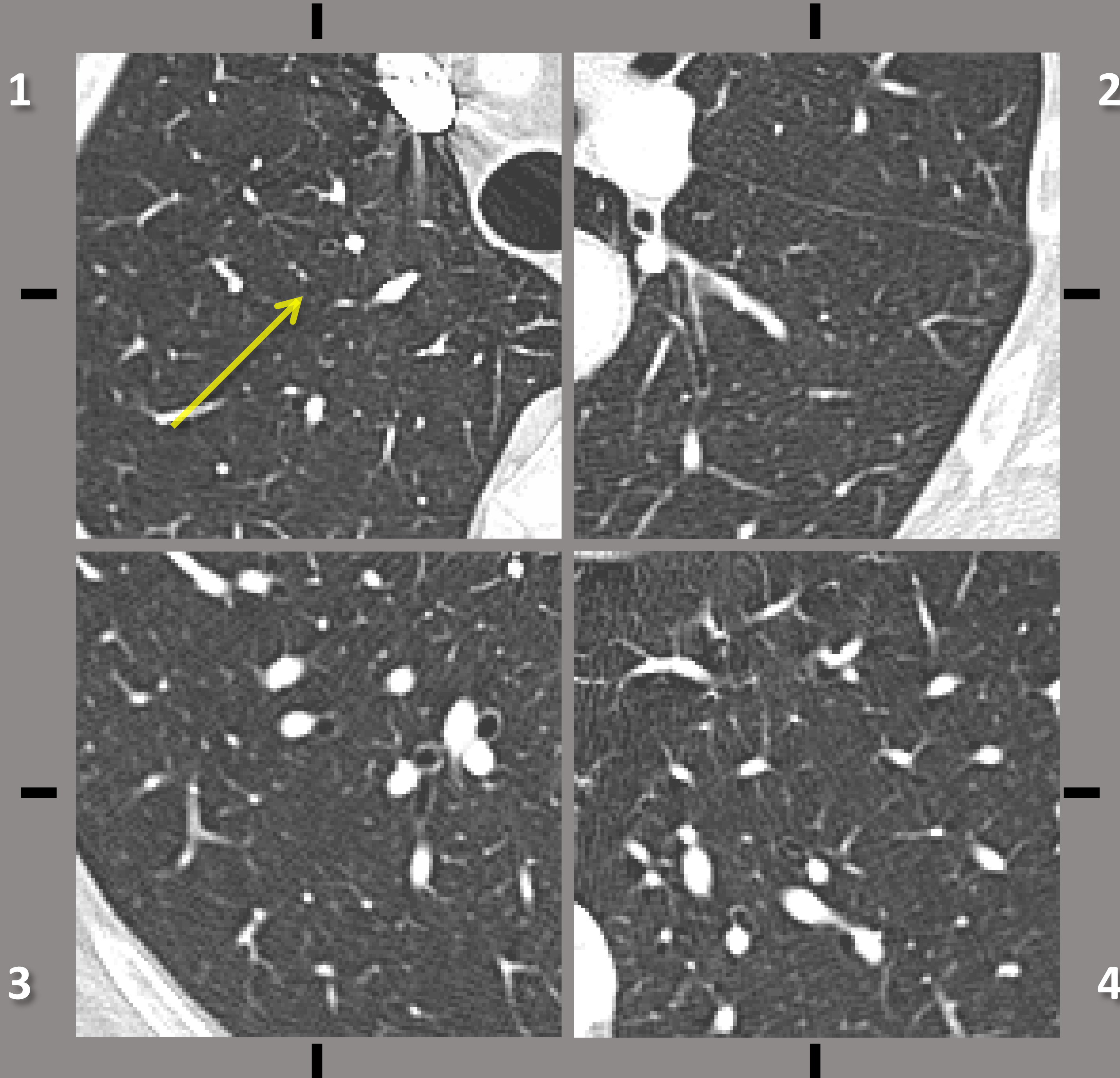
# Can we model the 3D process?



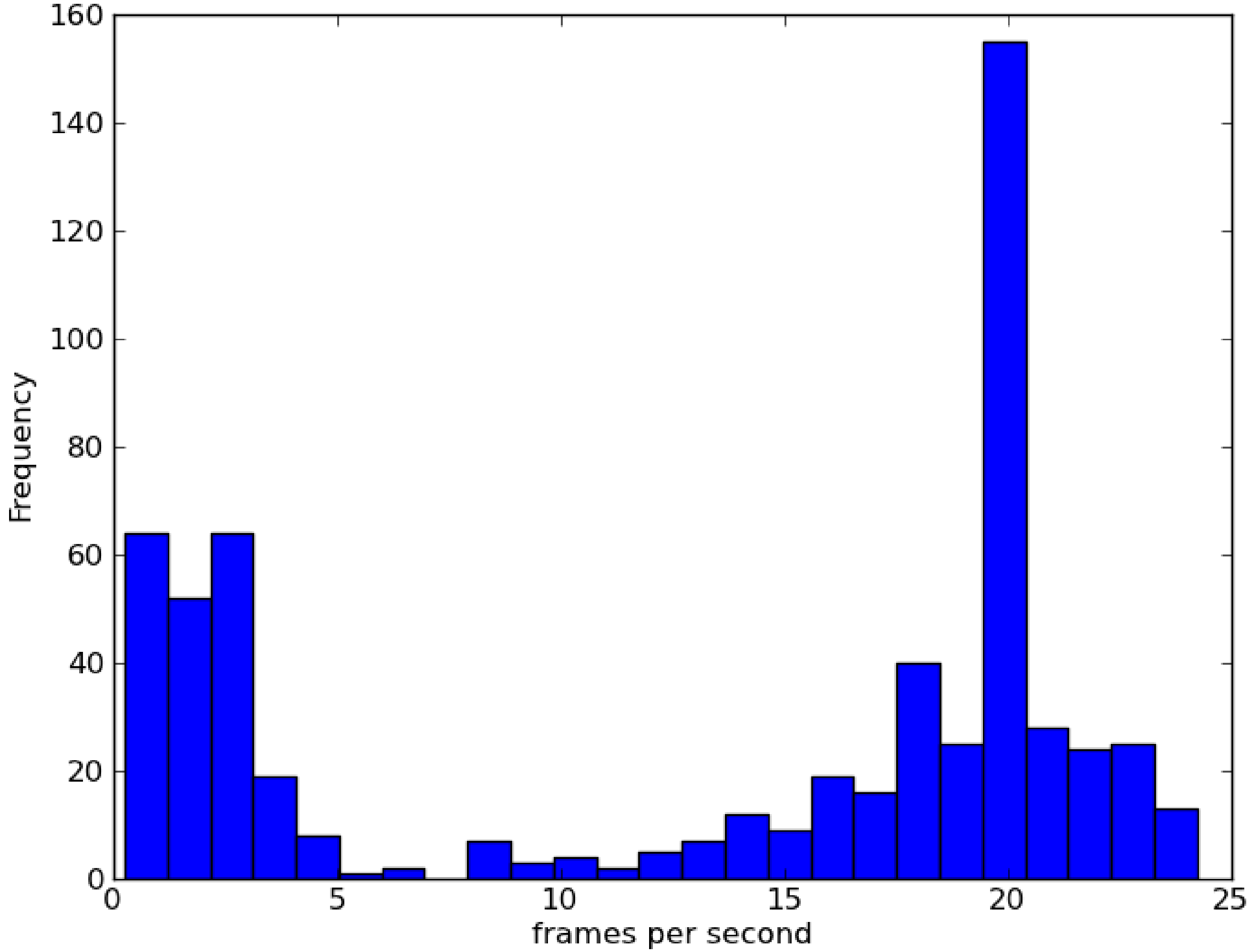
# Where is the nodule ?



*the nodule "pops out" in 3D*


1
2
3
4

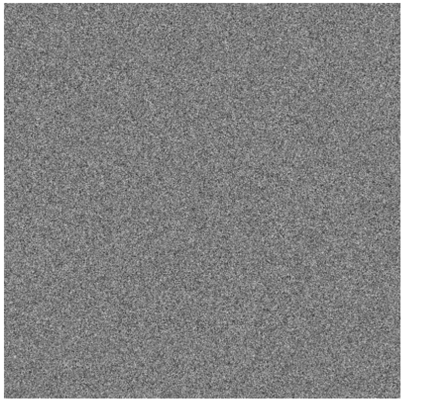
# The real scanning speeds of the radiologists are variable.
# (the most likely speed was higher than expected)




Diaz et al, Proc SPIE 8673 (2013); doi:10.1117/12.2007936

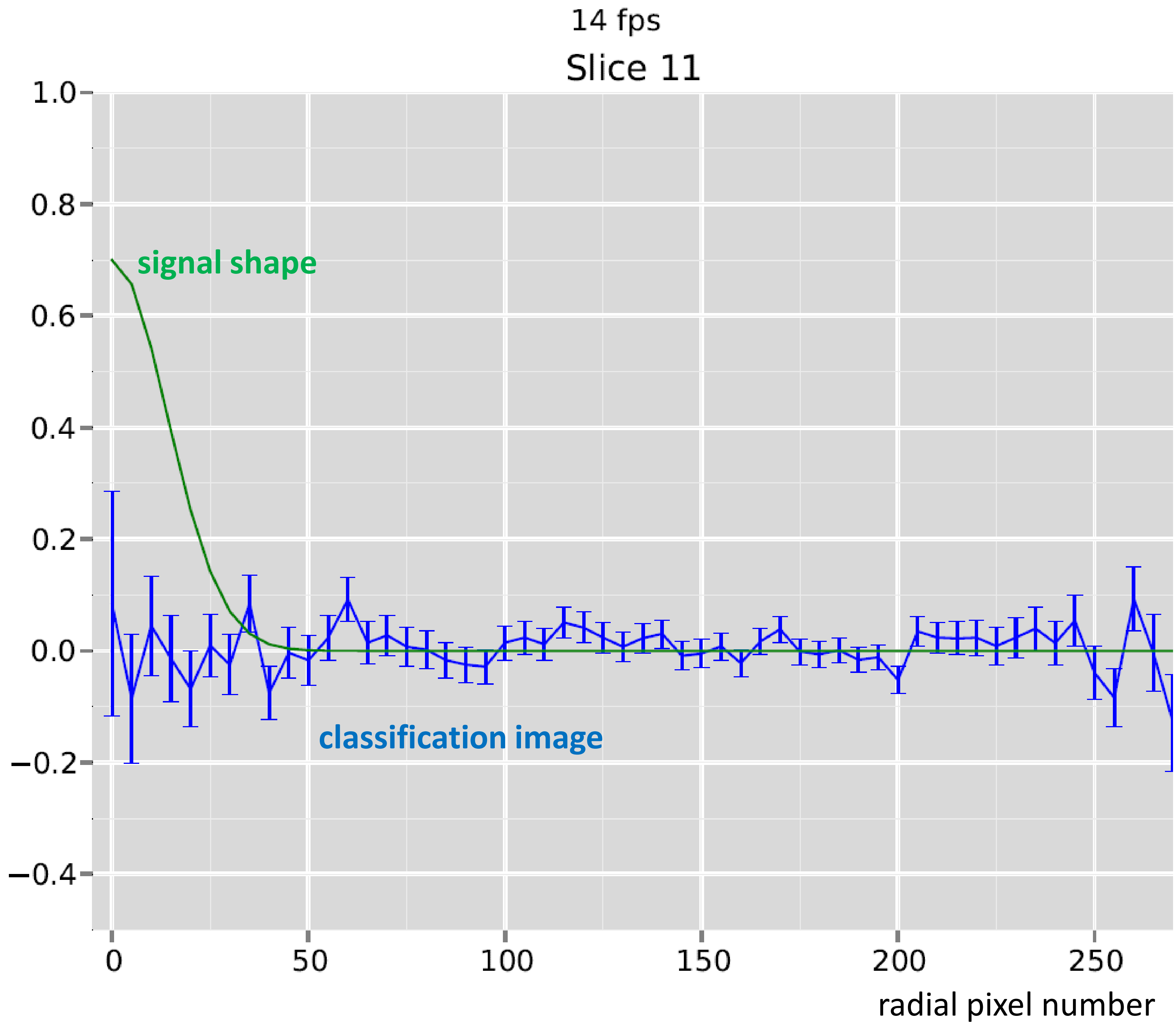
# The time response function needs to be estimated

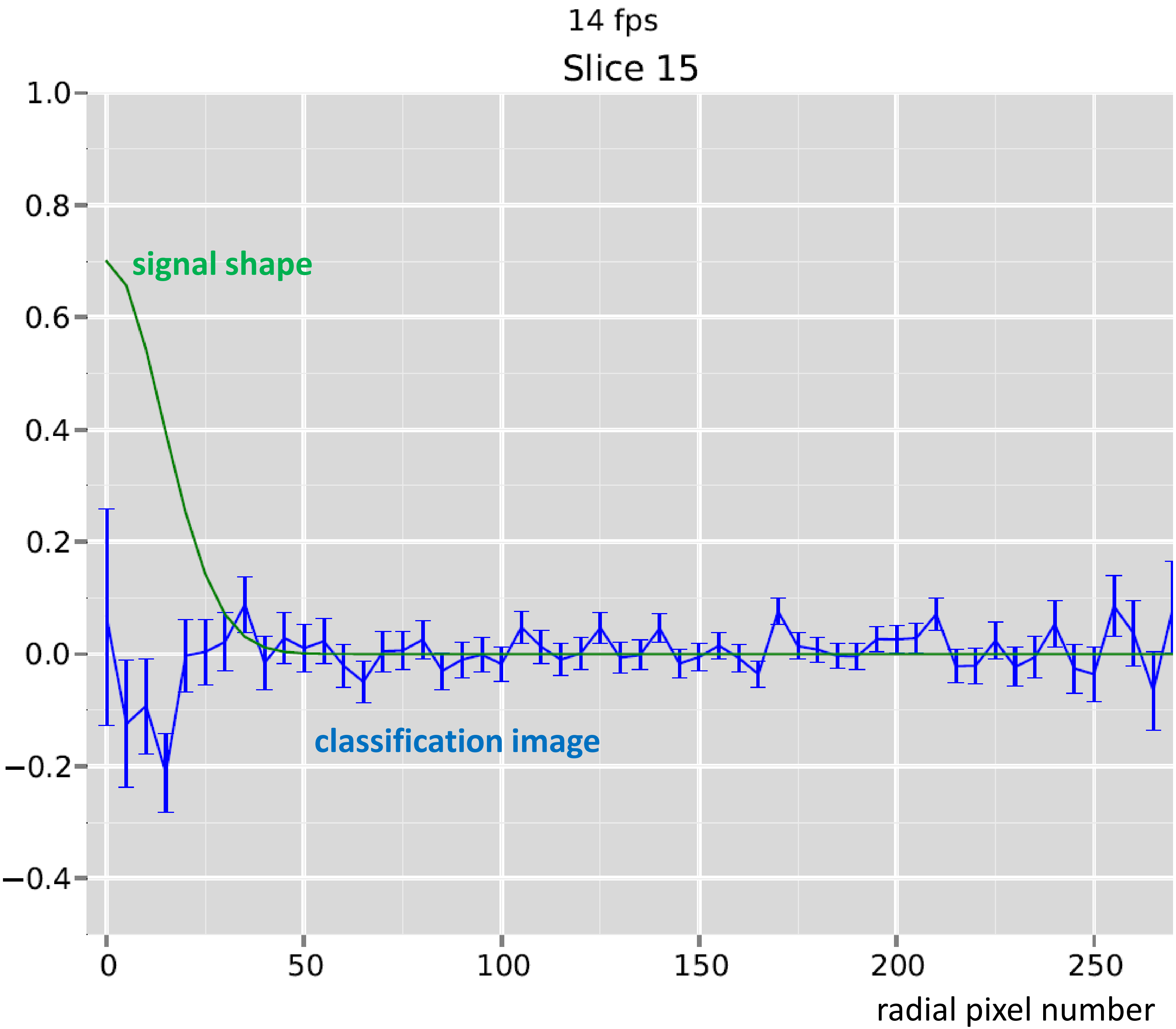
- It can be estimated by the **classification image** method
  - based on the work of Ahumada and Lovell (1971)
  - first applied to audition
- The idea:
  - “The stimuli used in an experiment, along with an observer’s decisions based on those stimuli, contain information about how the task is performed”
- Experiment
  - yes / no experiment
  - 29 slices of non-correlated Gaussian noise
  - middle slice Gaussian signal
  - 2000 trials
  - several speeds



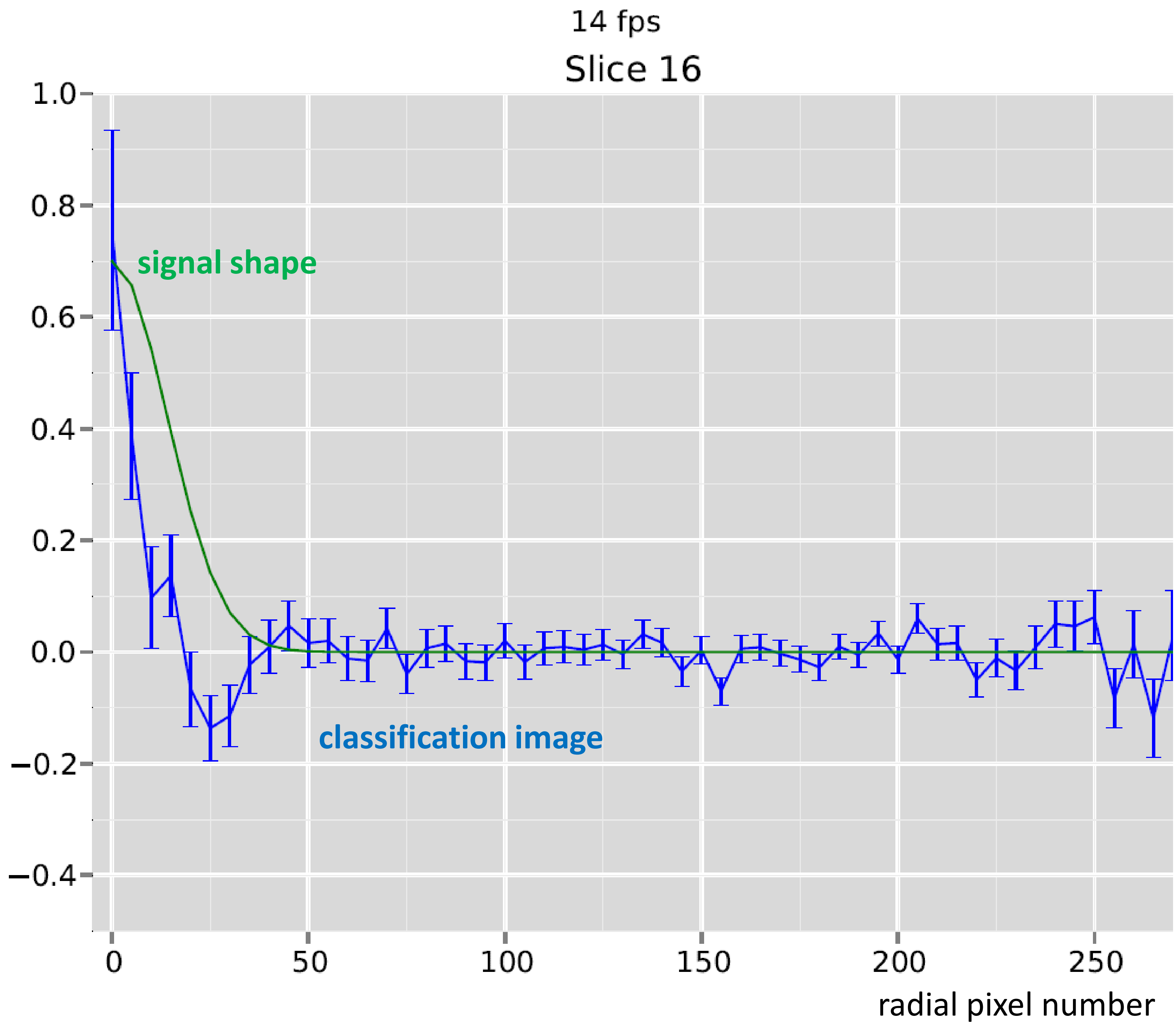
- Analysis
  - separate noise fields by TP, TN, FP, FN
  - calculate average of each set and subtract the negative fields (FN, TN) from the positive fields

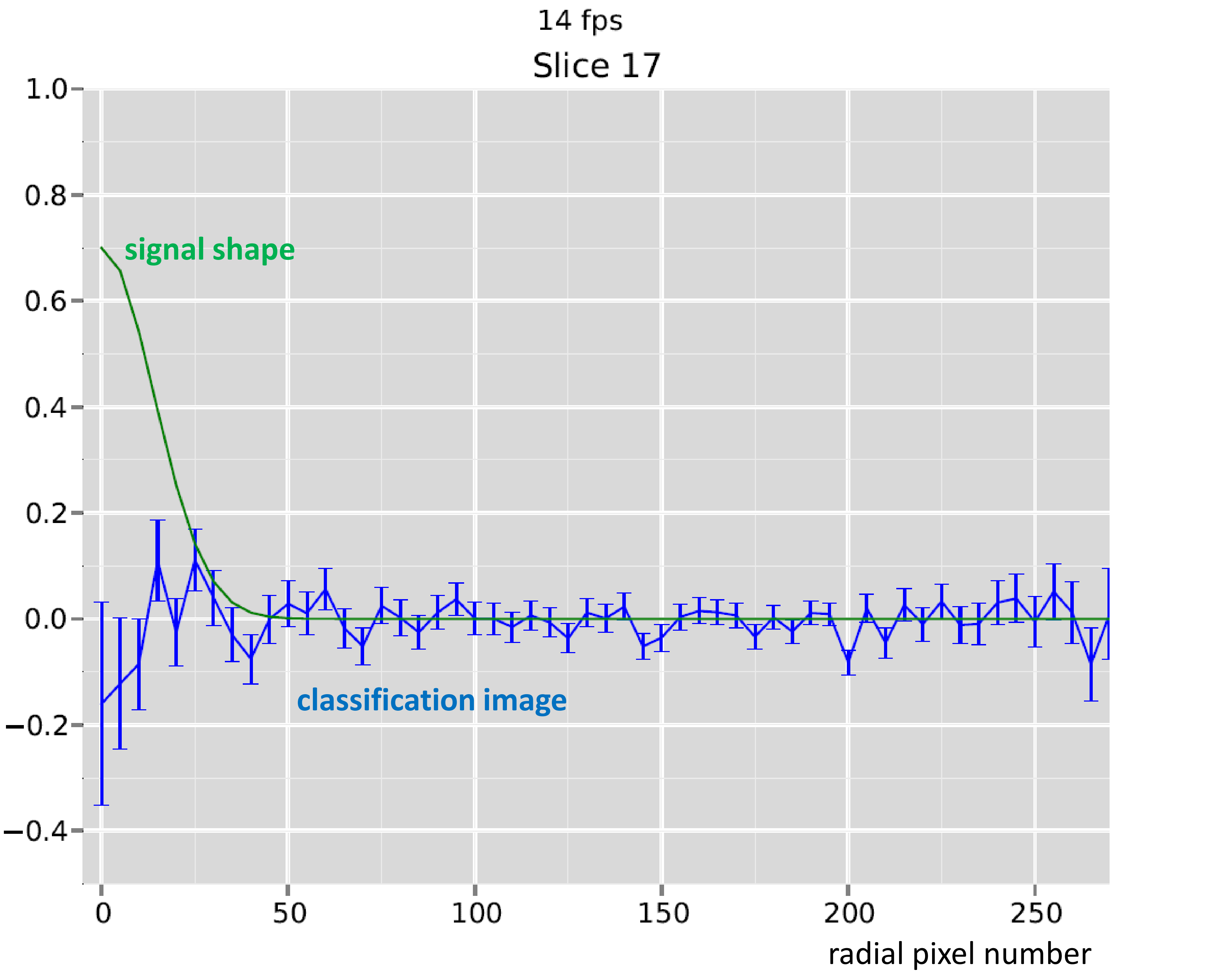
Diaz *et al.*, to be submitted to JOSAA


14 fps
Slice 11
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
signal shape
classification image
0
50
100
150
200
250
radial pixel number



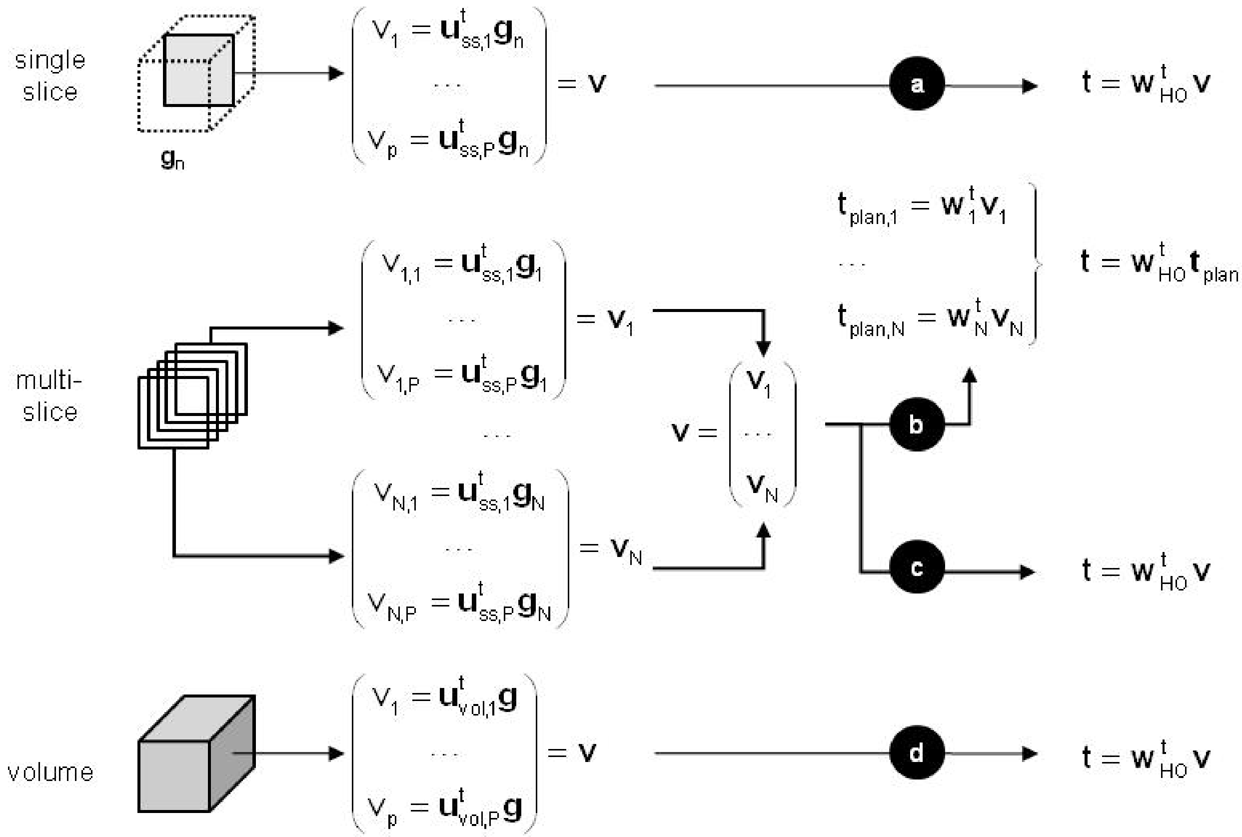
14 fps
Slice 15
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
signal shape
classification image
0
50
100
150
200
250
radial pixel number


14 fps
Slice 16
signal shape
classification image
radial pixel number
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
0
50
100
150
200
250

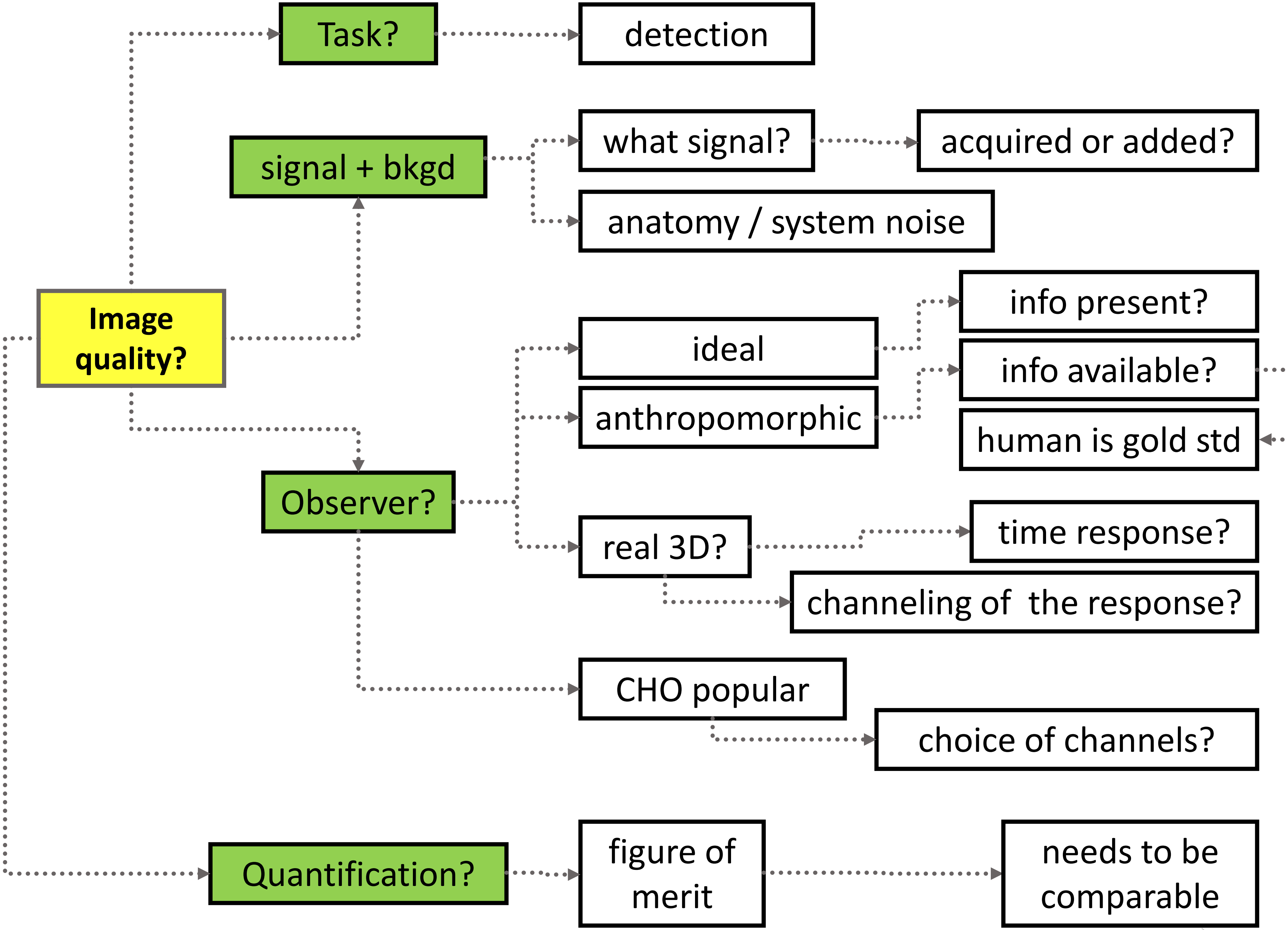


14 fps
Slice 17
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
signal shape
classification image
0
50
100
150
200
250
radial pixel number

# 3D model observers




Platiša *et al,* JOSA-A 28: 1145-1163 (2011)


Task?
detection
signal + bkgd
what signal?
acquired or added?
anatomy / system noise
Image quality?
info present?
ideal
info available?
anthropomorphic
human is gold std
Observer?
time response?
real 3D?
channeling of the response?
CHO popular
choice of channels?
Quantification?
figure of merit
needs to be comparable