A compressed sensing method for cardiac C-arm computed tomography

What is a C-arm ?

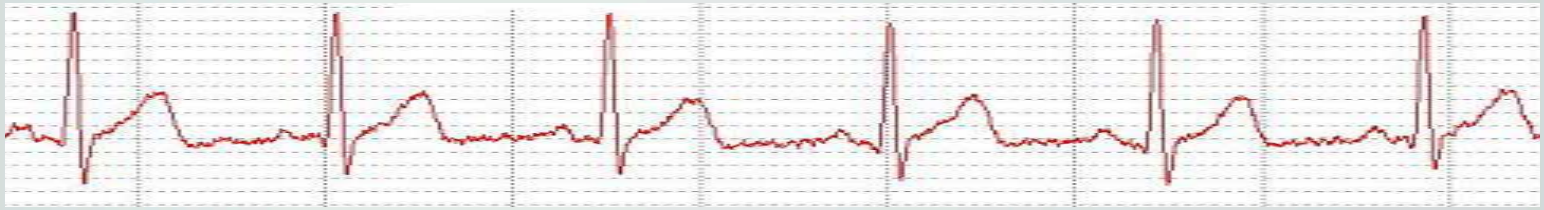
- C-shaped gantry mounted on a robotic arm
- Used for real-time 2D imaging during
  - Diagnostic angiography
  - Stenting
  - Vascular surgery
  - Aortic valve implantation
  - …
- Can mimic a CT scanner acquisition

Clinical and technical constraints

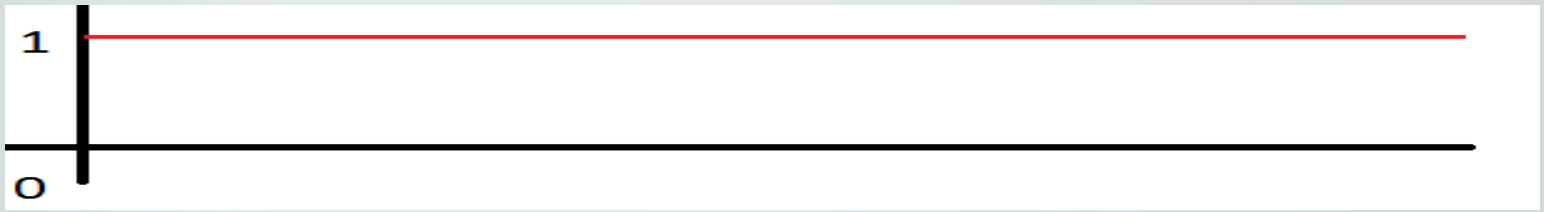
- Single breath hold
- Patients with cardiac / vascular diseases
- Short acquisition (10 to 15 seconds)
- Single sweep acquisition
- Simultaneous acquisition of electrocardiogram

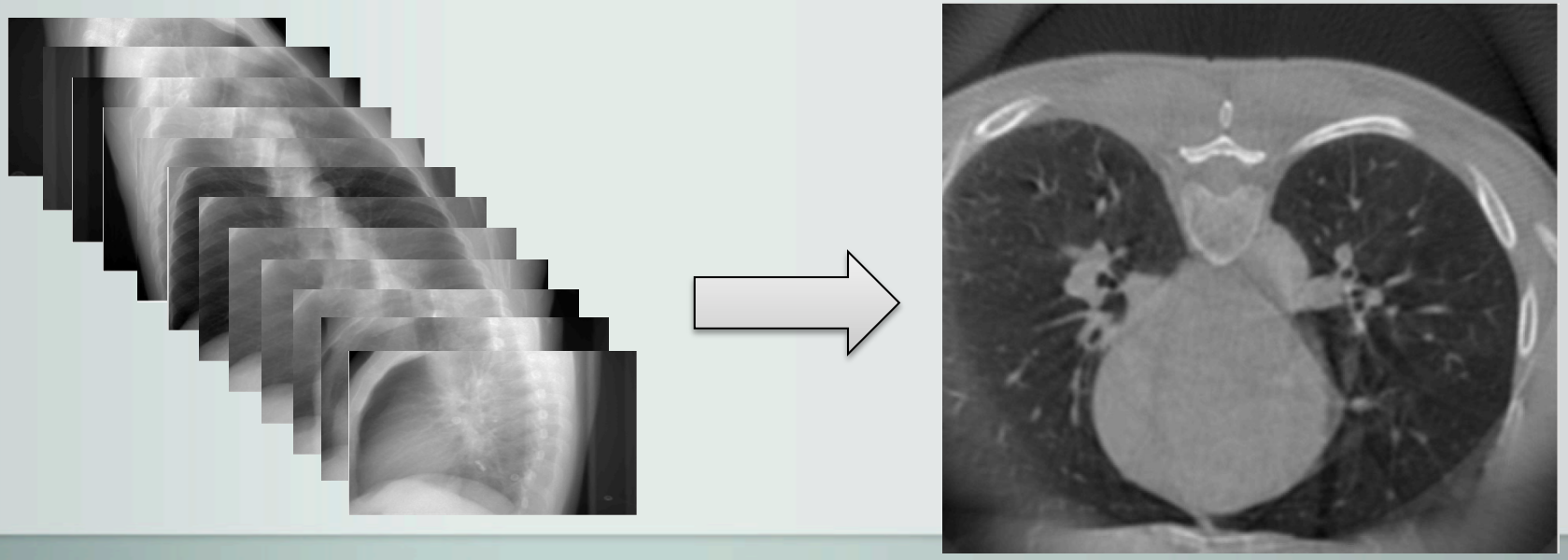
Ungated FDK reconstruction

ECG



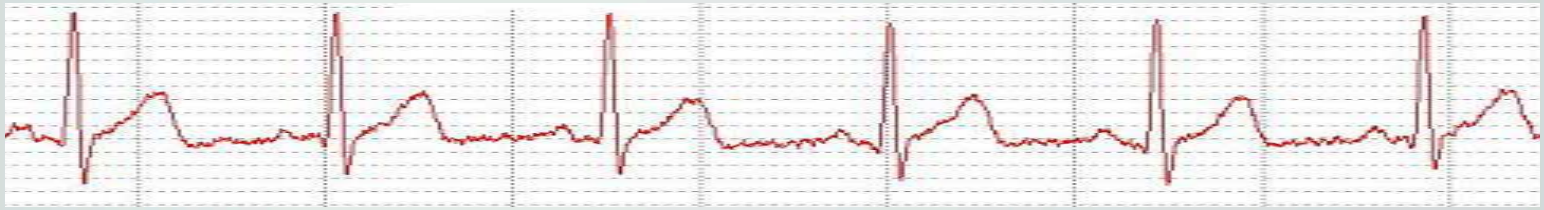
Projections utilisées



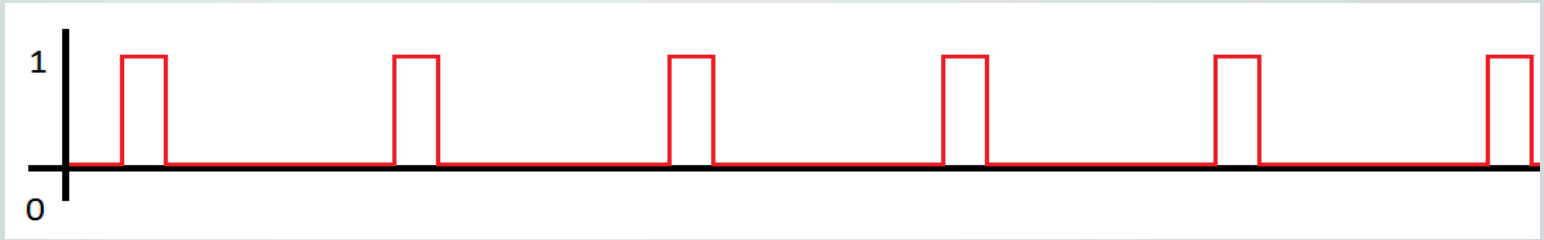


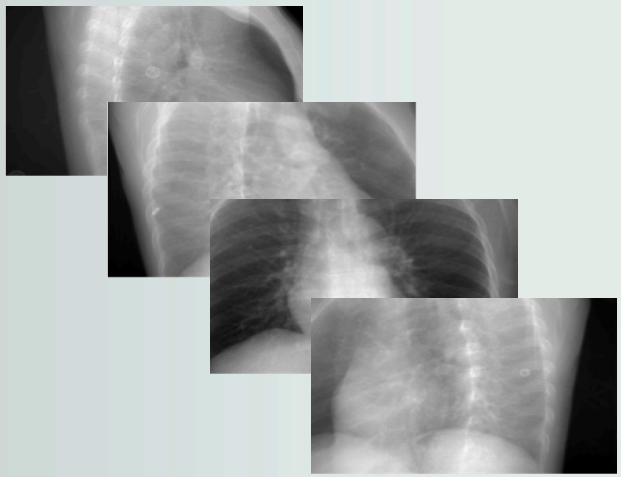
Gated FDK reconstruction

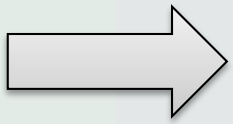
ECG

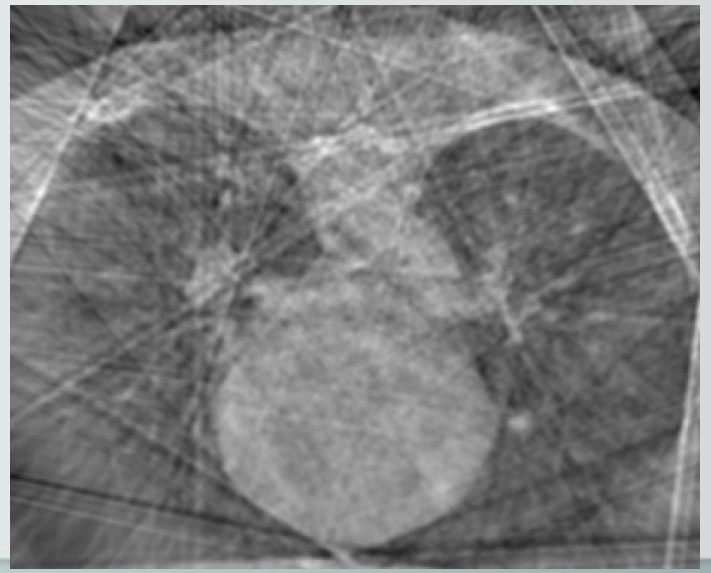


Projections utilisées









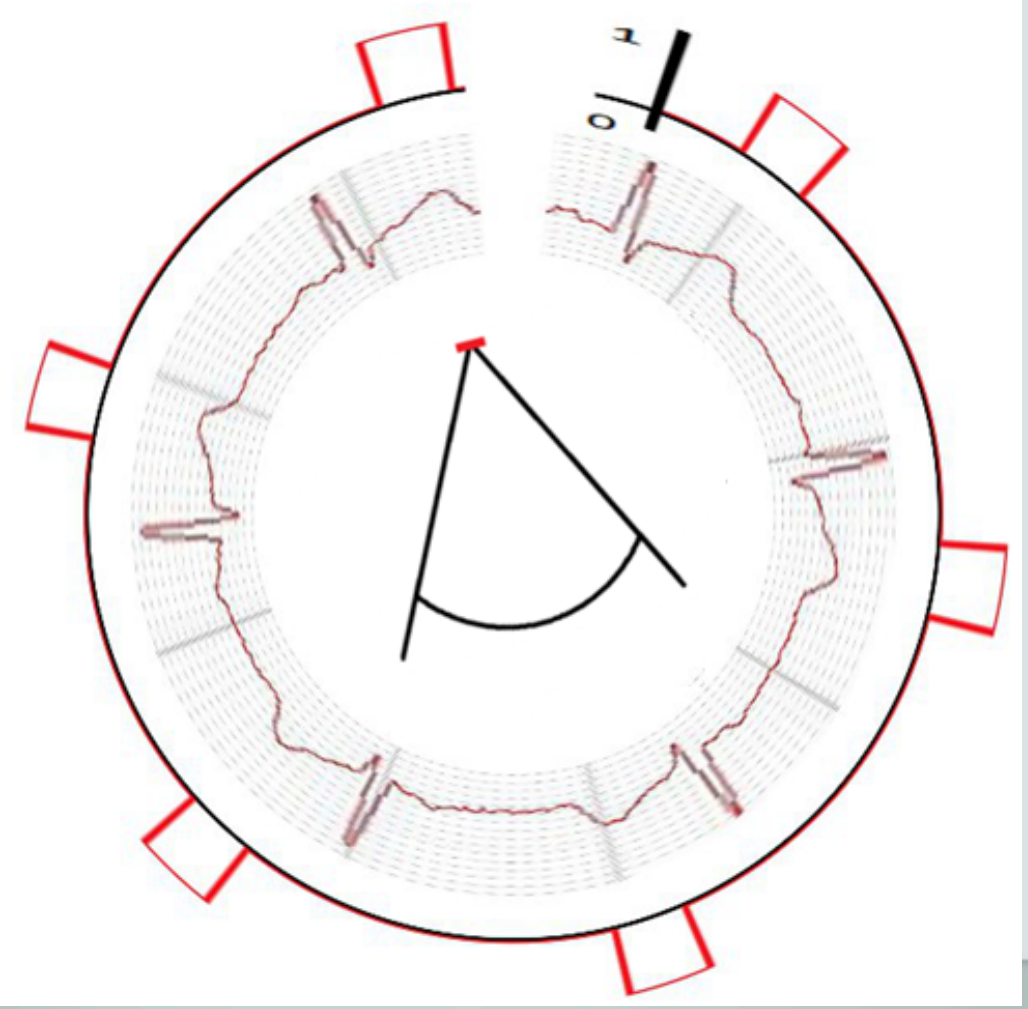
ECG gating and angular sampling

- 308 projections
- 20% gating

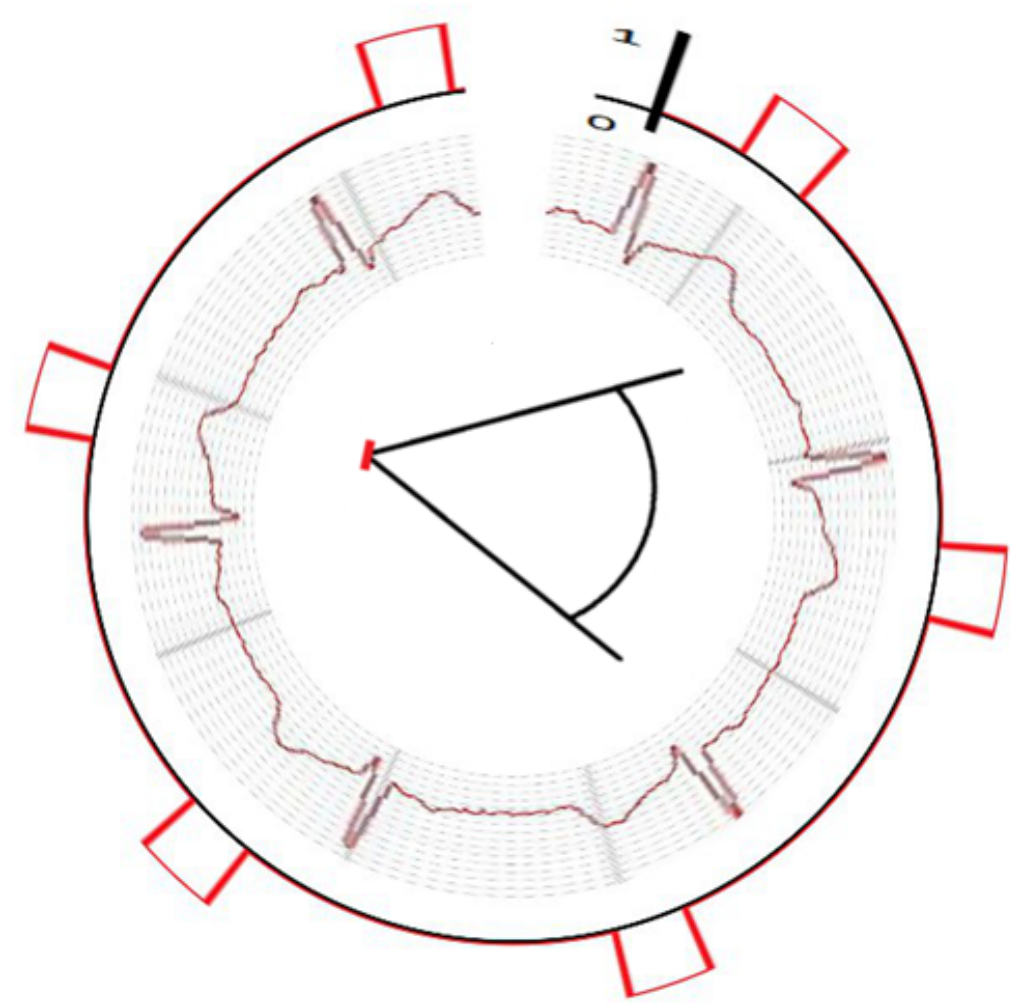
} 60 projections for each ECG-gated reconstruction

- More than enough if they are evenly distributed
- Unfortunately, they are not

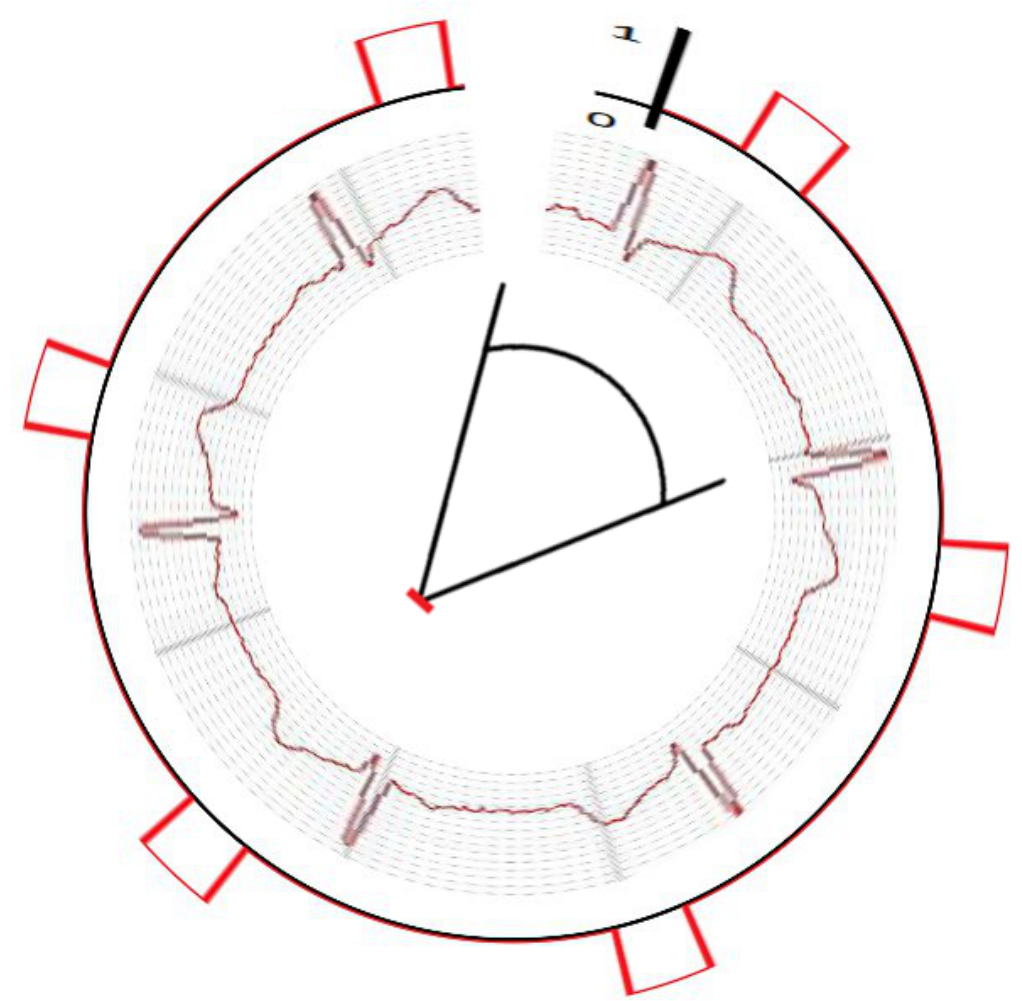
ECG-gated reconstruction: angular sampling



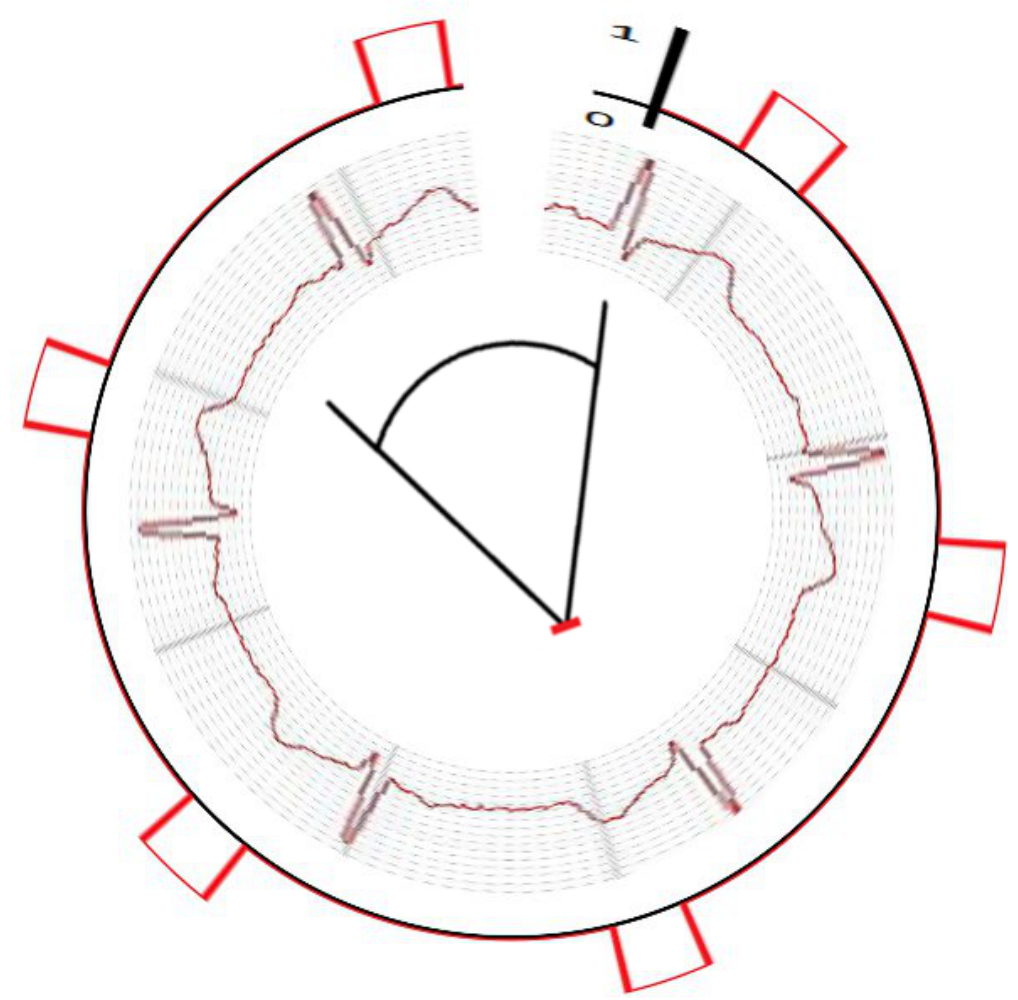
ECG-gated reconstruction: angular sampling



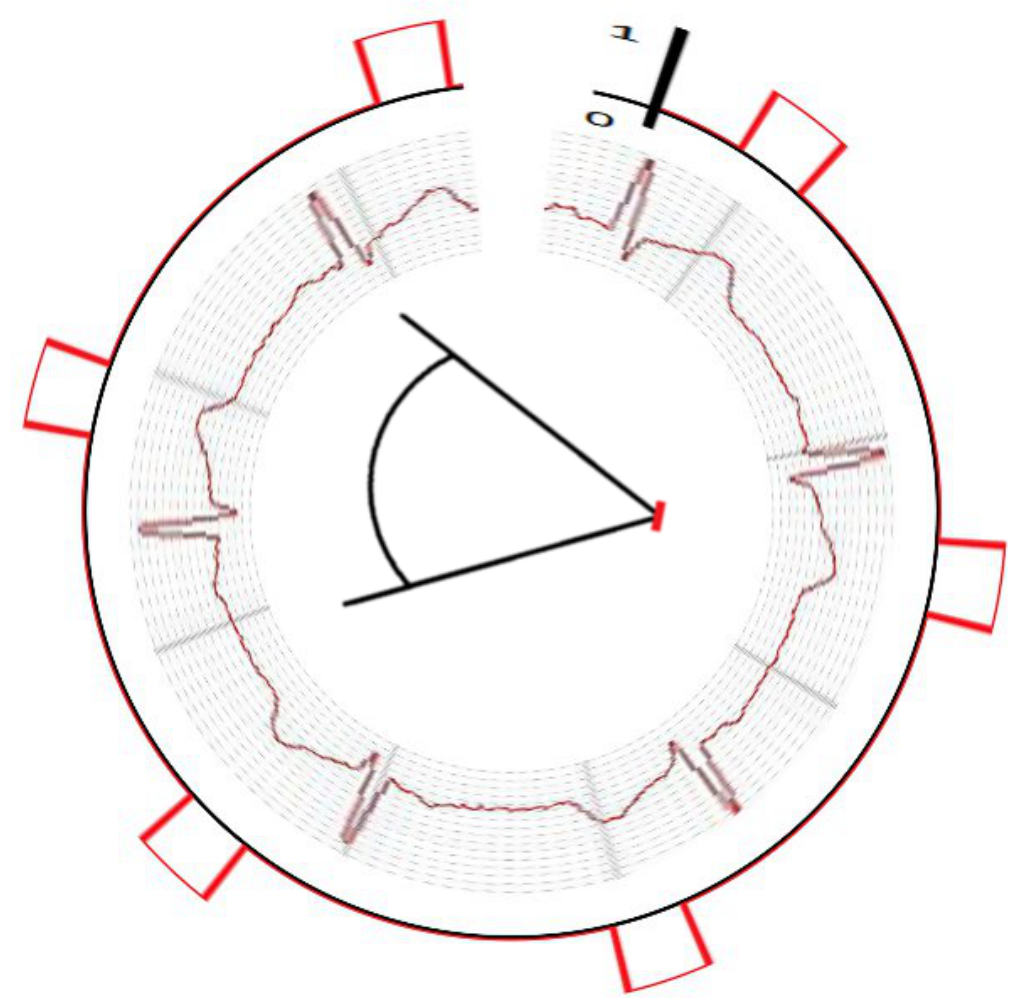
ECG-gated reconstruction: angular sampling



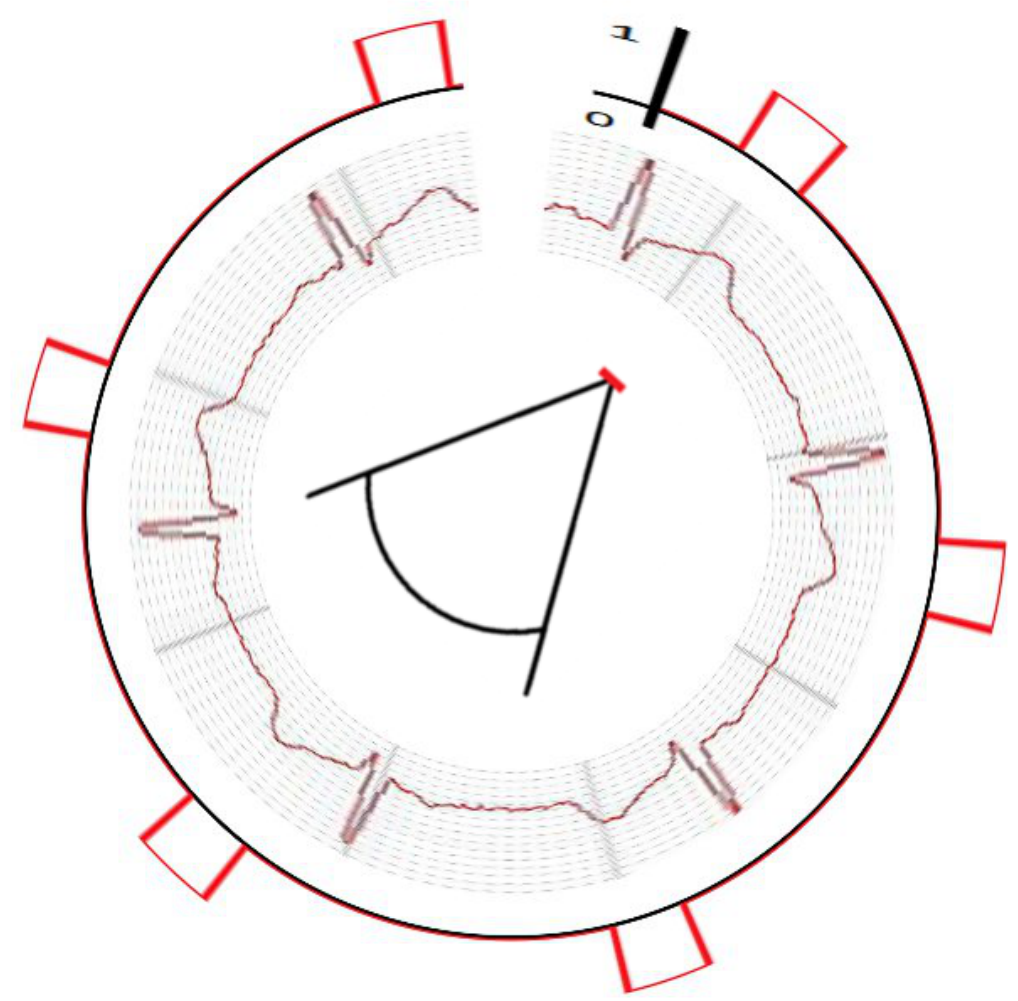
ECG-gated reconstruction: angular sampling



ECG-gated reconstruction: angular sampling

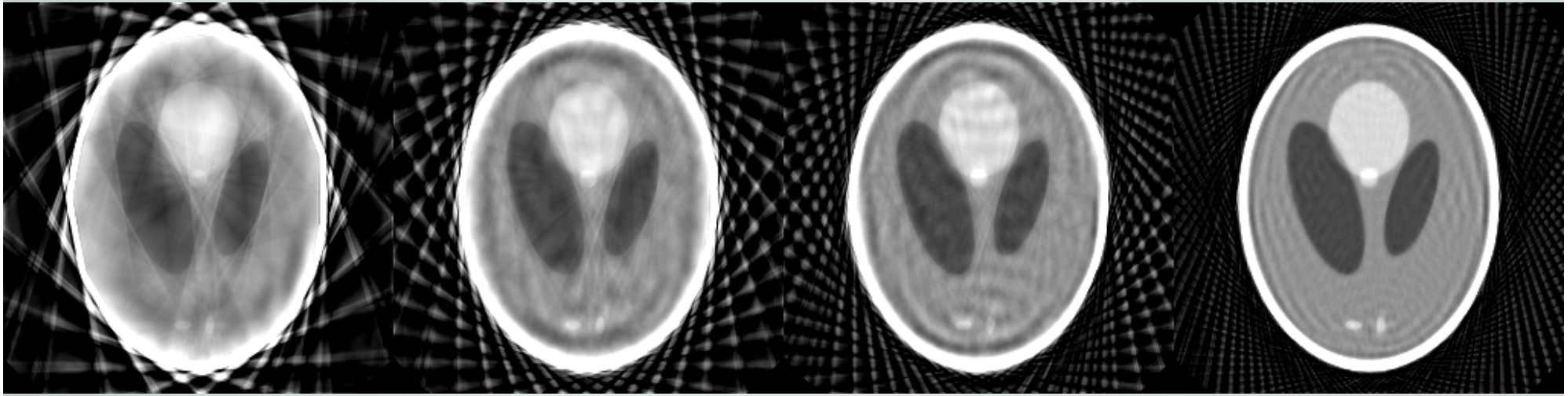


ECG-gated reconstruction: angular sampling



ECG-gated reconstruction: angular sampling

10 beats 20 beats 30 beats 60 beats



ECG-gated SART reconstructions of a Shepp & Logan phantom with several heart rates (initialized from zero)

Goals of cardiac C-arm CT

- Reconstruct a single volume, usually the heart in diastole
  - Locate and measure infarcted regions
  - Diagnose coronary artery diseases
- Reconstruct the whole cardiac cycle
  - Diagnose kinetic defects
  - Measure functional parameters (e.g. ejection fraction)

A compressed sensing method for 3D + time reconstruction

- 4D RecOnstructiOn using Spatial and TEmporal Regularization
  - Reconstruction of the whole cardiac cycle at once
  - Heart segmentation: movement allowed only inside
  - Spatial regularization: 3D total variation
  - Temporal regularization: 1D total variation
- Alternating algorithm:
  - Unregularized conjugate gradient (minimizing data attachment)
  - Regularization steps

4D RecOnstructiOn using Spatial and TEmporal Regularization

For k from 0 to N-1 :

$$\hat{f} = \arg\min_{f} \sum_{\theta} \left\| R_\theta S_\theta f - p_\theta \right\|_2^2 \quad \text{initialized with} \quad f^{(k)}$$

$$\forall i, H\hat{f}_i = \frac{1}{m} \sum_j H\hat{f}_j$$

$$\hat{f} = \max\left(\hat{f}, 0\right)$$

$$\hat{f} = \arg\min_{f} \lambda_{space} \left\| f - \hat{f} \right\|_2^2 + TV_{space}(f)$$

$$f^{(k+1)} = \arg\min_{f} \lambda_{time} \left\| f - \hat{f} \right\|_2^2 + TV_{time}(f)$$

f = current volume

R = Radon transform or X-ray transform

p = measured projections

S = interpolation operator

H = ROI selection

4D RecOnstructiOn using Spatial and TEmporal Regularization

Results

Thank you for your attention