Dynamic Pixel Binning Allows Spatial and Angular Resolution Tradeoffs to Improve Image Quality in X-ray C-Arm CT

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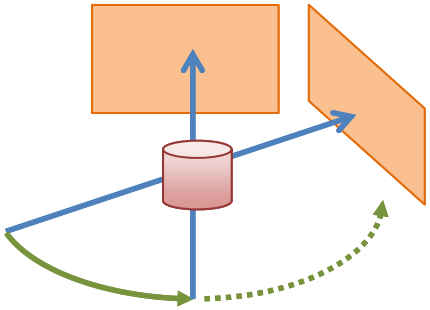
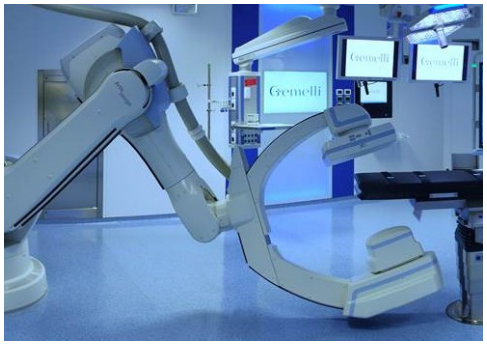
Amount of Data vs. Scan Time in X-ray C-Arm CT

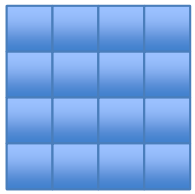




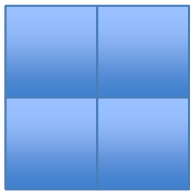
- More data (resolution, projections) allow better reconstructions
- For clinical reasons, scan time is limited.
  In C-arm CT, the bottleneck oftentimes is the data rate.
- Typical scan protocols: 1024x768 pixels with 493 projections, or 2048x1536 pixels with 123 projections (about 800MB of data)

- **Question: How can we optimize C-Arm CT reconstruction quality for a given data limit?**

Idea of this Work



1x1 binning



2x2 binning

- Detector binning greatly influences the amount of generated data by adjusting resolution
- State-of-the-art: globally uniform detector binning, most notably 1x1 pixel binning and 2x2 pixels binning.

- What if we could ***dynamically*** **bin the data**? Therefore,
  - keep high resolution in quickly changing regions (e.g., around edges)
  - Switch to low resolution in homogeneous regions

  The saved space can be reinvested, e.g., in acquiring more projections

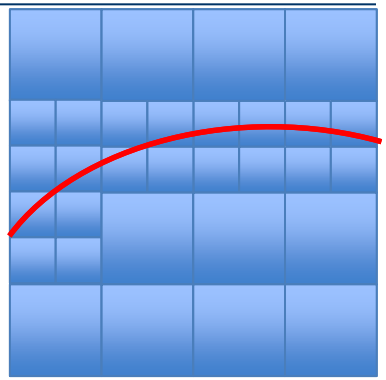
Dynamic Binning via "Smart Cameras"

- Recently, several works proposed to add (elementary) image processing operators onto camera hardware (see, e.g. [1], [2])
- General properties of smart camera data processing:
  - Fast, "almost-for-free" preprocessing of raw data
  - Strong preference of local operators in a small neighborhood (say, 5x5 pixels)
  - Strong preference for elementary calculations

- Thus,
  - Estimate smoothness of a local pixel neighborhood
  - Set binning size for that neighborhood based on the local smoothness

[1] de Sousa, "Smart Cameras as Embedded Systems", *Proc. 1st Intl. Conf. on Comp. Applications*, 2003.
[2] Belbachier, Goebel, "Smart Cameras: A Historical Evolution", *Smart Cameras*, 2010.

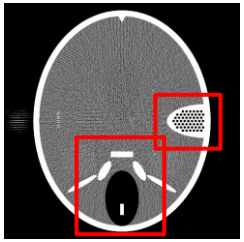
Proposed Algorithm



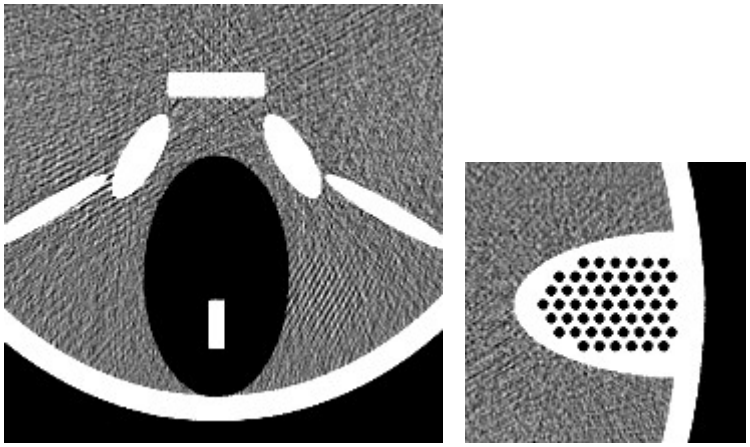
- For each pixel:
  - copy the raw data signal
  - Edge-preserving smoothing: bilateral filter on pixel neighborhood
  - Edge map: Sobel filter
  - Neighborhood smoothness: use large binning if standard deviation of local edge map is low. Otherwise, use small binning.
  - Add a bit to this pixel indicating large binning (1) or not (0)

- Optimization on tomographic acquisitions:
  - Edge maps differ only slightly between neighbored projections (due to small angular increment)
  - This allows to parallelize binning and edge map computation: use edge map from current projection to decide for binning in next projection

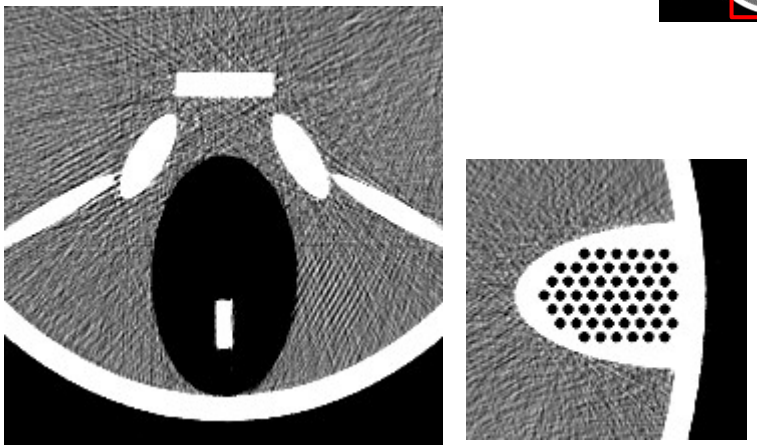
Qualitative Simulation Results



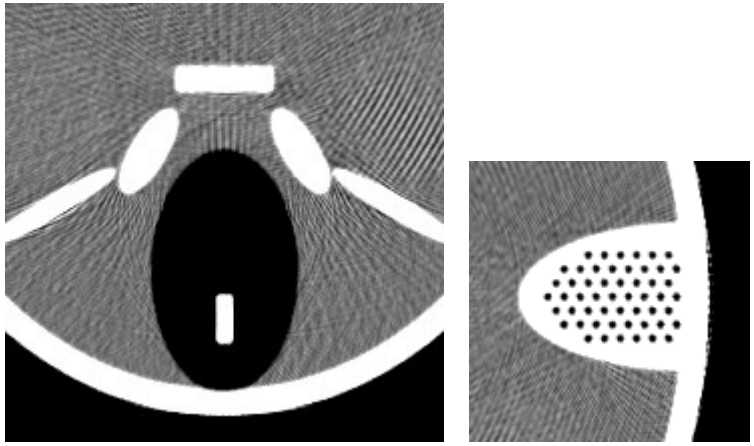
uniform 1x1 binning



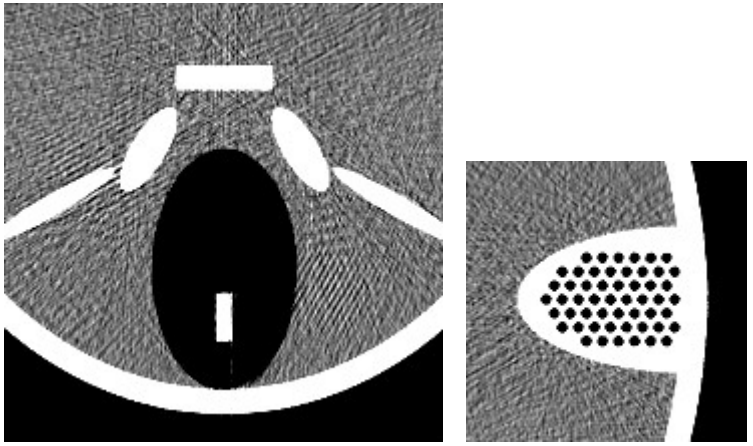
dynamic1x1 / 3x3 binning



uniform 2x2 binning



dynamic 1x1 / 5x5 binning



Quantitative Simulation Results

% saved data compared to uniform 1x1 binning

Spatial frequency at 10% MTF

Std.-dev. in homogeneous region

	Bins	t	r	SSIM(1)	SSIM(2)	MTF	σ_{sd}
uniform	1×1		0	1	0.773	1.112	0.242
	2×2		75	0.773	1	0.712	0.223
dynamic	3×3	0.07	75	0.893	0.783	1.108	0.239
	5×5	0.08	80	0.934	0.781	1.073	0.242

Summary and Outlook

- We study dynamic binning of C-arm CT projections with smart sensors
- Approach:
  - coarse binning on smooth areas,
  - fine binning on rough areas
- Prototypical implementation indicates large data reduction at comparable image quality

- Outlook:
  - Investigate noise behavior (larger bins – less photon noise, but coarser resolution)
  - Evaluate compression ratio on real (i.e., less sparse) data
  - Implementation of a (simulated) prototype in systemC
  - Stream real data into the simulator