APS-U FORUM

HOW COMPUTING CAN MAKE FAST INSTRUMENTS FASTER?

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PURPOSE

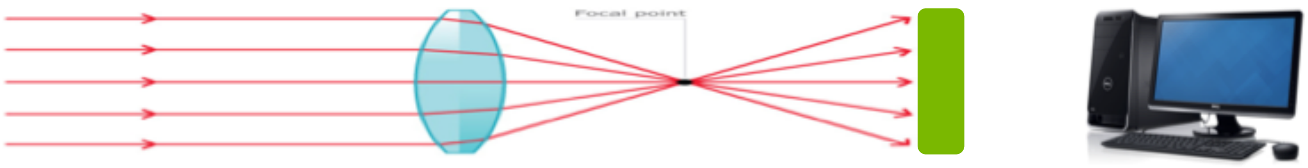
How computing can make fast instruments faster?

- *Target:* Faster 3D volumetric imaging.
- *Focus:* Scanning-probe hard X-ray microscopy.
- *Approach:* Computing-driven instrument design.

Argonne NATIONAL LABORATORY

UPGRADED SOURCE

How do we best make use of the improved coherence (resolution) & flux (speed) for the microscopy beamlines?



Source

Optics

Scanners (encoder)

Detector (encoder)

Computer (decoder)

UPGRADED SOURCE

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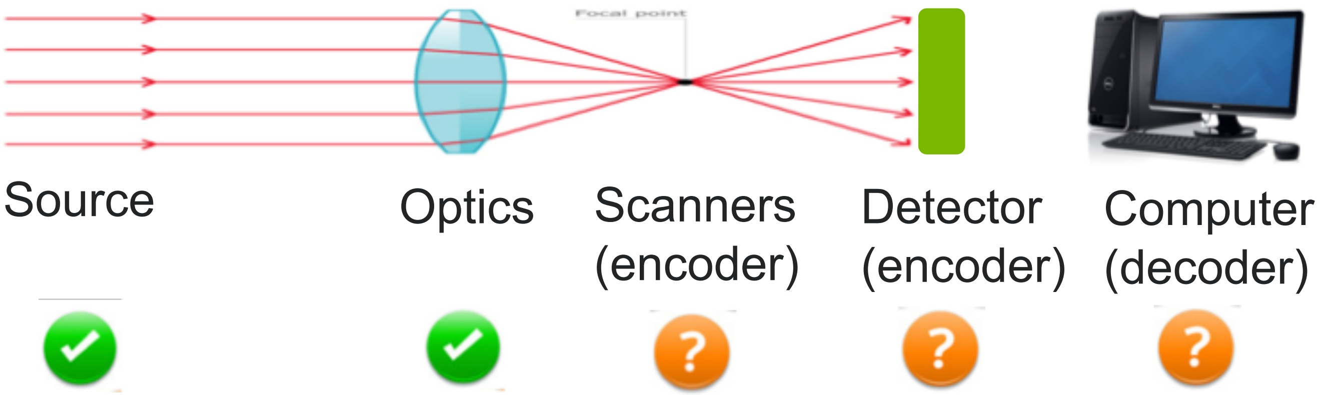
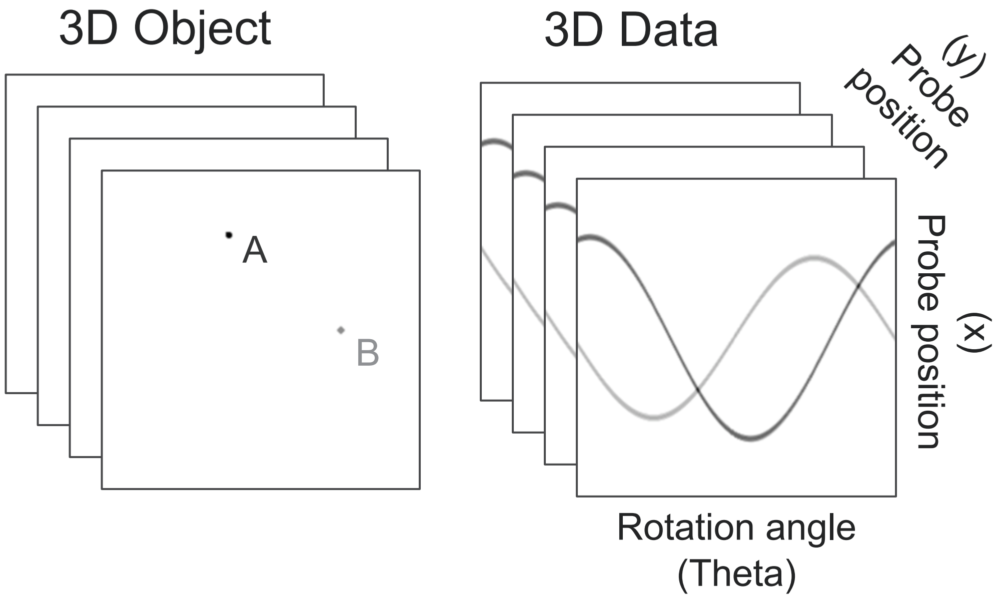


Which component is of "primary importance" for faster volumetric imaging?

3D VOLUMETRIC IMAGING

Fundamentals

- Radon transform forms the basis of 3D imaging.
- Scanning of a sample is a spatial information encoding.
- Reconstructing an object is information decoding.

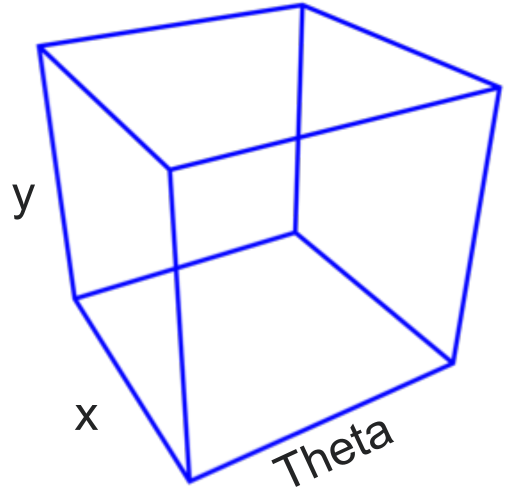


How can we optimally "encode" information for an easier "decoding"?

SCANNING

How to sample a 3D volume?

- 3 degrees of freedom
- Current practice: raster-scan for each rotation angle.
- Other ways to speed up?



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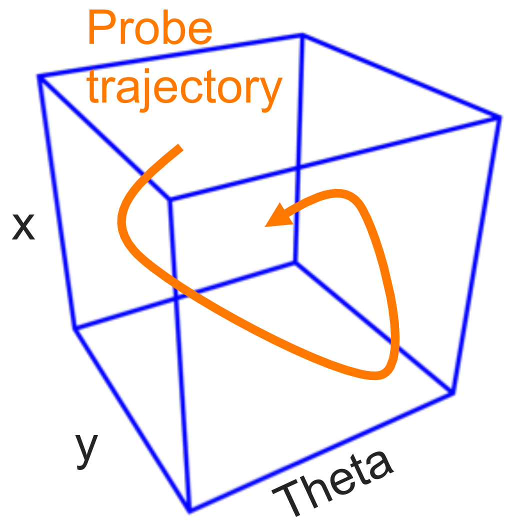


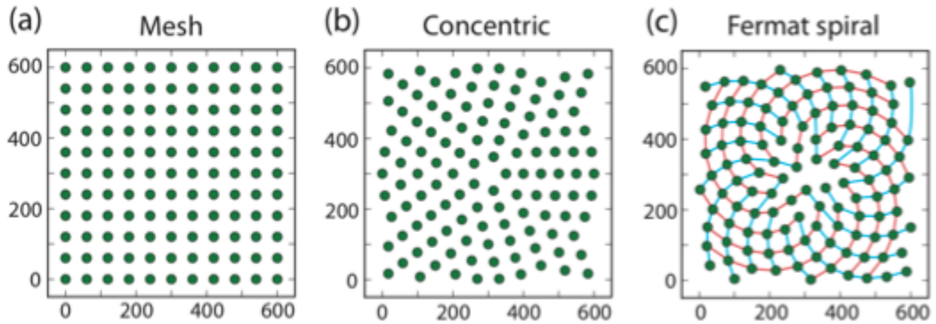
If you want to go fast, don't stop!

- **Discrete-scan:** Stop when you are measuring.
- **Continuous-scan:** Always move, don't stop!

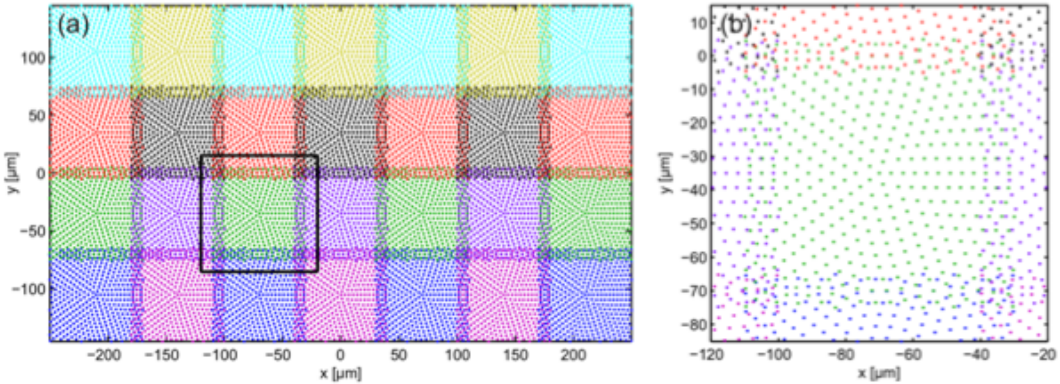
SCANNING

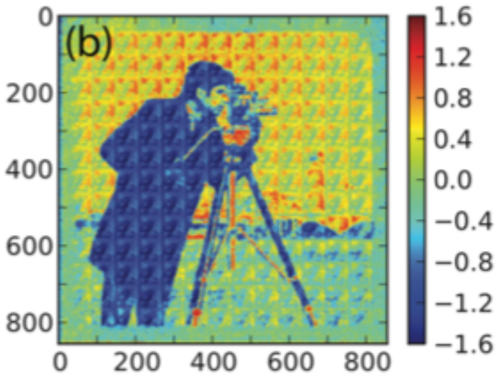
A little bit of history

Experimental efforts towards optimizing “sampling points” in 2D scans.



Huang *et al.* “Optimization of overlap uniformness for ptychography”, **Opt. Exp.,** 2014





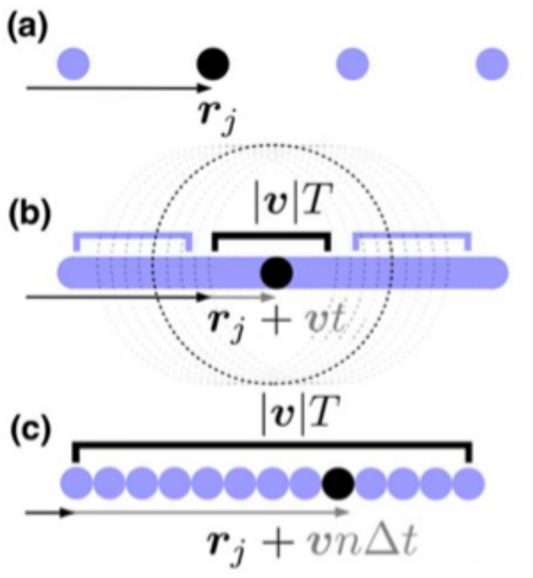
M. Guizar-Sicairos *et al.* “High-throughput ptychography using Eiger: scanning X-ray nano-imaging of extended regions ”, **Opt. Exp.,** 2014

SCANNING

A little bit of history

Experimental efforts towards continuous-scanning.

- J. Clark *et al.* “Continuous scanning mode for ptychography”, **Optics Letters**, 2014.
- M. Guizar-Sicairos *et al.* “On-the-fly scans for X-ray ptychography”, **Applied Physics Letters**, 2014
- J. Deng *et al.* “Continuous motion scan ptychography: characterization for increased speed in coherent x-ray imaging”, **Optics Express**, 2015.
- X. Huang *et al.* “Fly-scan ptychography”, **Scientific Reports**, 2015.



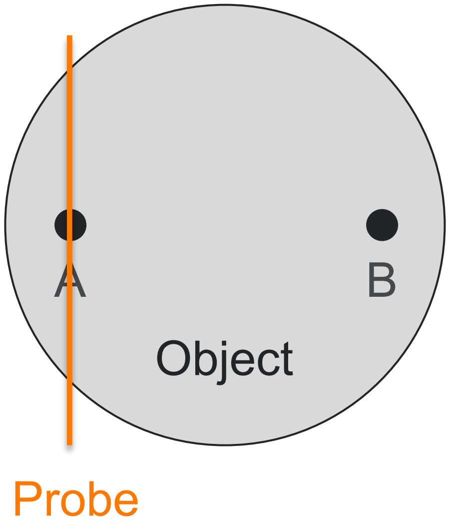
$$I_j(q) = |\mathcal{P}_z[P(r)O(r + r_j)]|^2$$

$$I_j(q) = \sum_{n=0}^{N-1} \Delta t|\mathcal{P}_z[P(r - r_n)O(r + r_j)]|^2$$

SCANNING

How do you understand if a person is a ptychographer or a tomographer?

What is the fastest way to go from point A to point B?



SCANNING

How do you understand if a person is a ptychographer or a tomographer?

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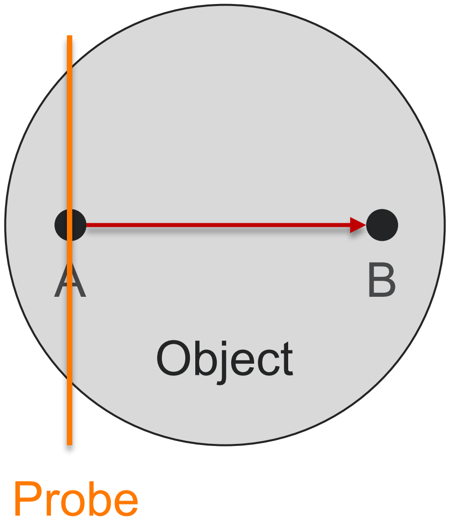
Move sample from A to B using a translation motor



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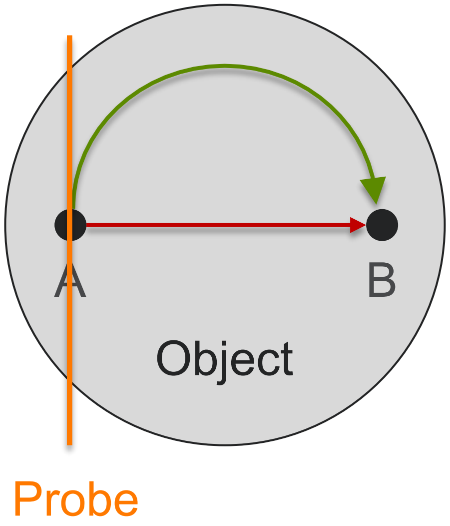
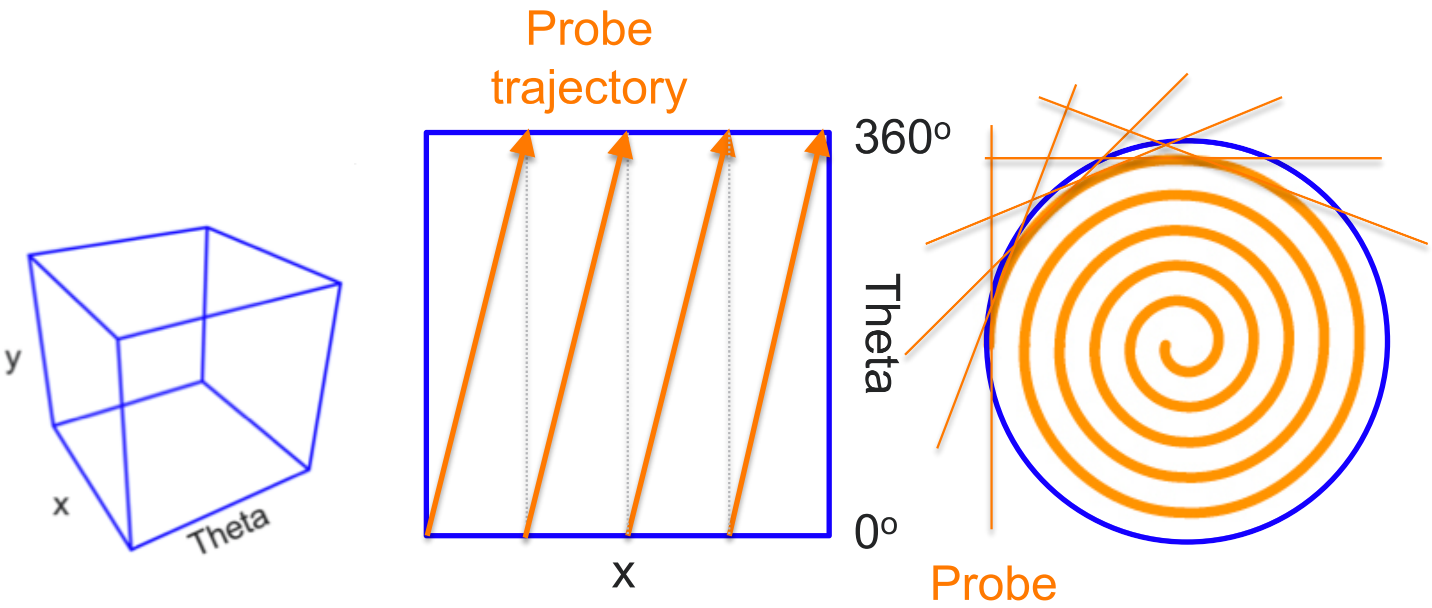


Rotate your sample 180 degrees around the mid point of A and B

NEED FOR SPEED!

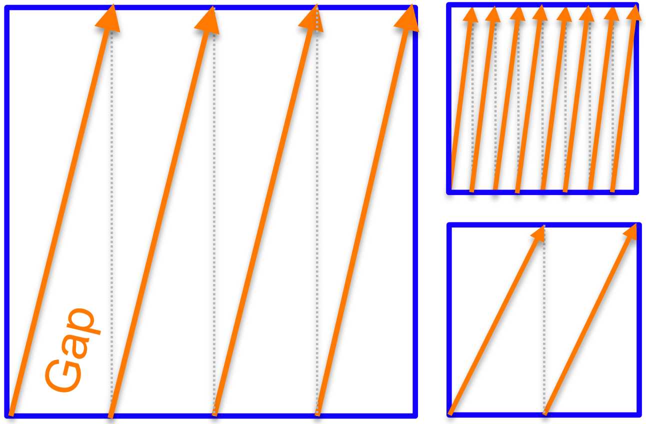
Advantages of rotational scans

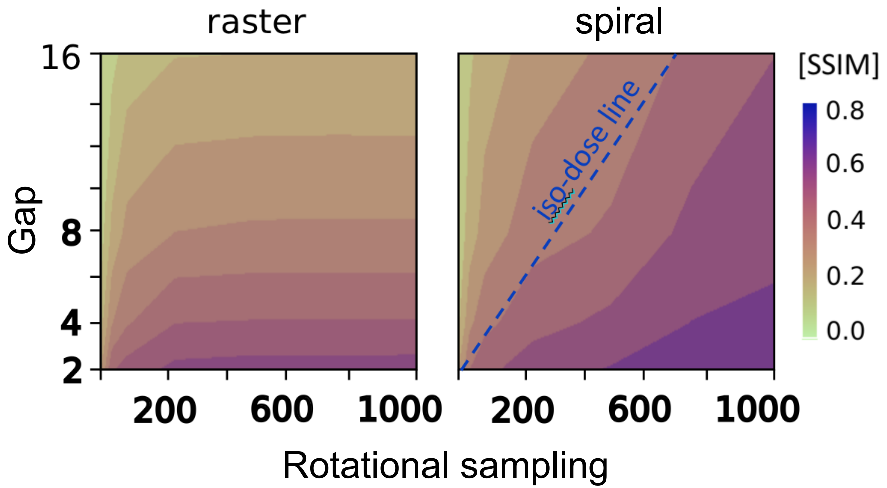
- Faster
- Periodic
- Simple



NEED FOR SPEED!

Reconstruction quality of rotational scans



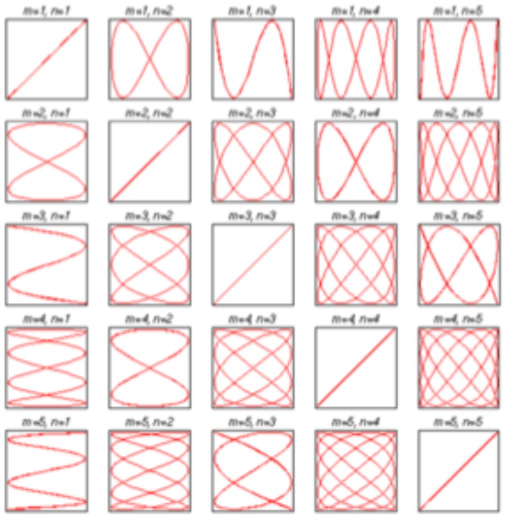


M. Ching and D. Gursoy "The effect of procedure coverage on tomographic reconstruction quality of scanning-probe x-ray microscopy", **J. Sync. Radiation,** 2018.

NEED FOR SPEED!

2D Lissajous scanning + Sample Rotation = Our speed limit!

- Lissajous curve: Dance of a sinusoid couple!
- Combine with continuous rotation



Design Challenges:

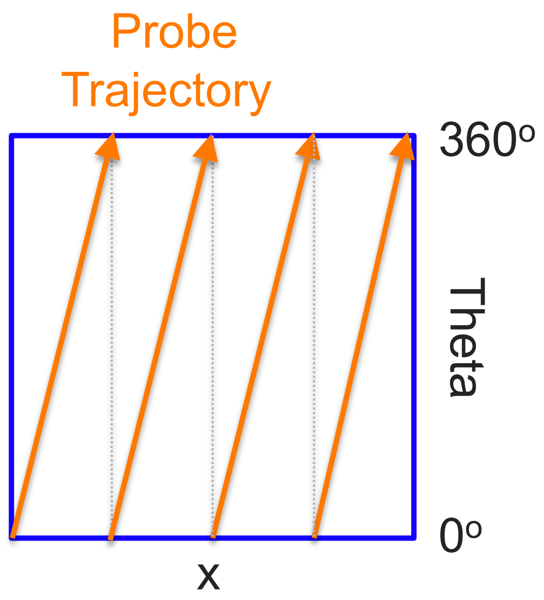
- Design system with specific resonance
- Don’t control, measure position!

A. Bazaei *et al.* “High-speed Lissajous-scan atomic force microscopy: Scan pattern planning and control design issues”, **Rev. Sci. Instr.,** 2012.

OUTLOOK

How do we want to collect data on probe trajectories?

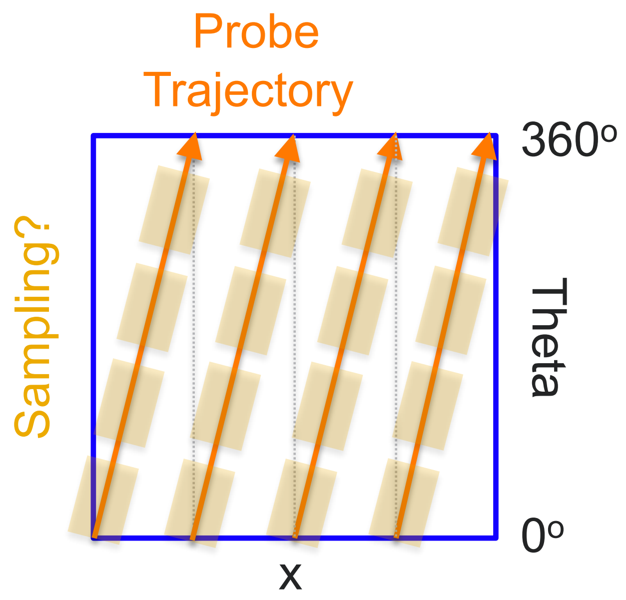
- Probe trajectory: spatial encoding (scanner)



OUTLOOK

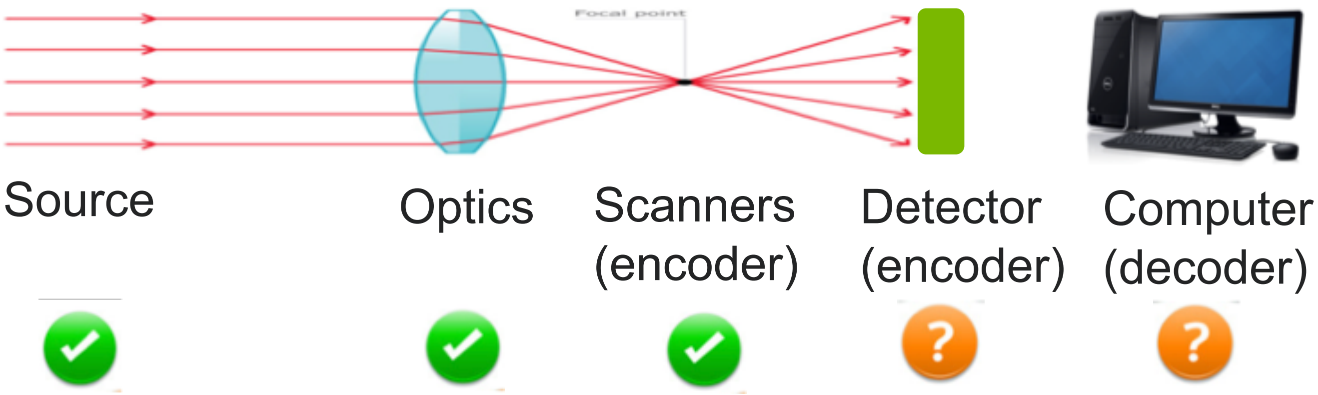
How do we want to collect data on probe trajectories?

- Probe trajectory: spatial encoding (scanner)
- Sampling: temporal encoding (detector)



DETECTORS

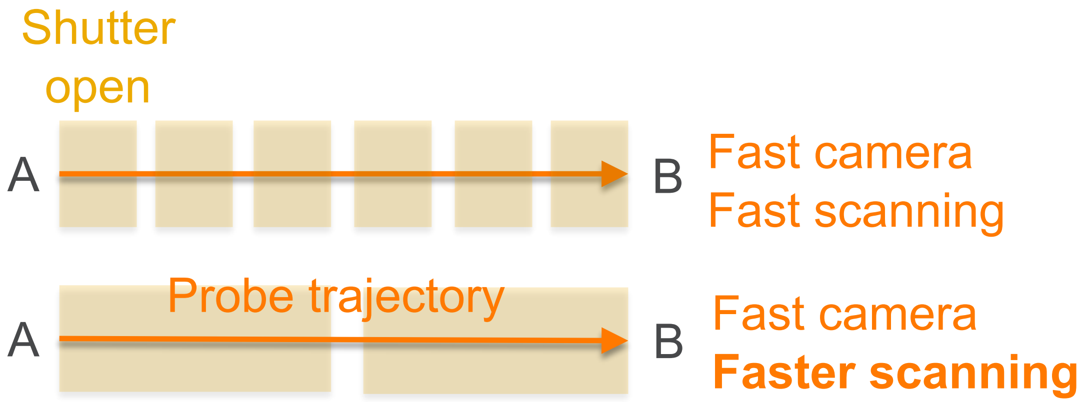
How do we want to collect data on probe trajectories?



DETECTORS

Current technology

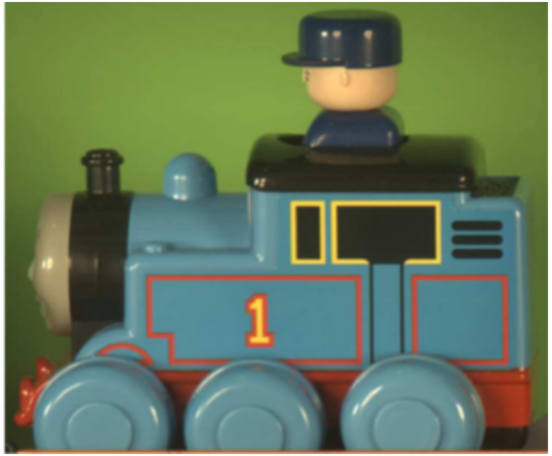
Pixelated detectors: Continuous read-out (kHz)
Single-pixel detectors: High-throughput (MHz)



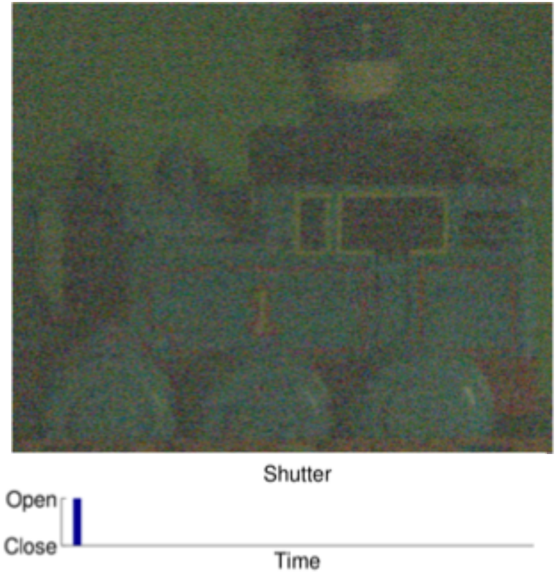
DETECTORS

2D motion blurring

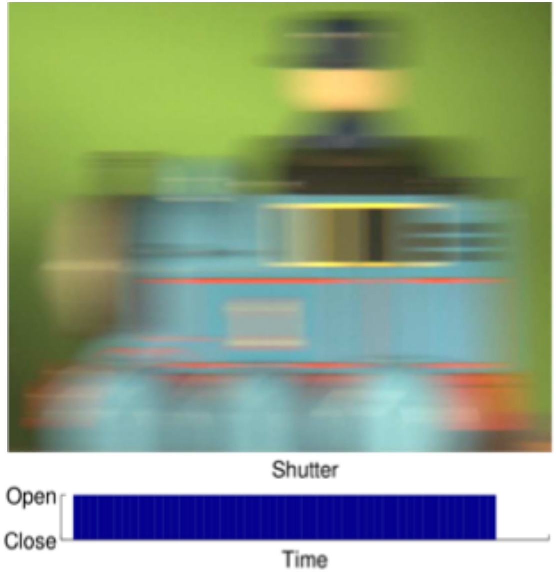
Original image



Short-exposure

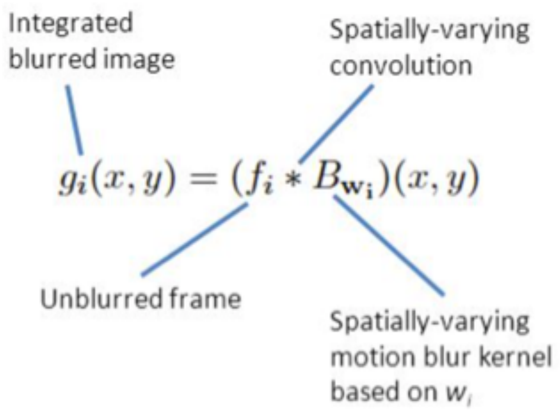


Long-exposure

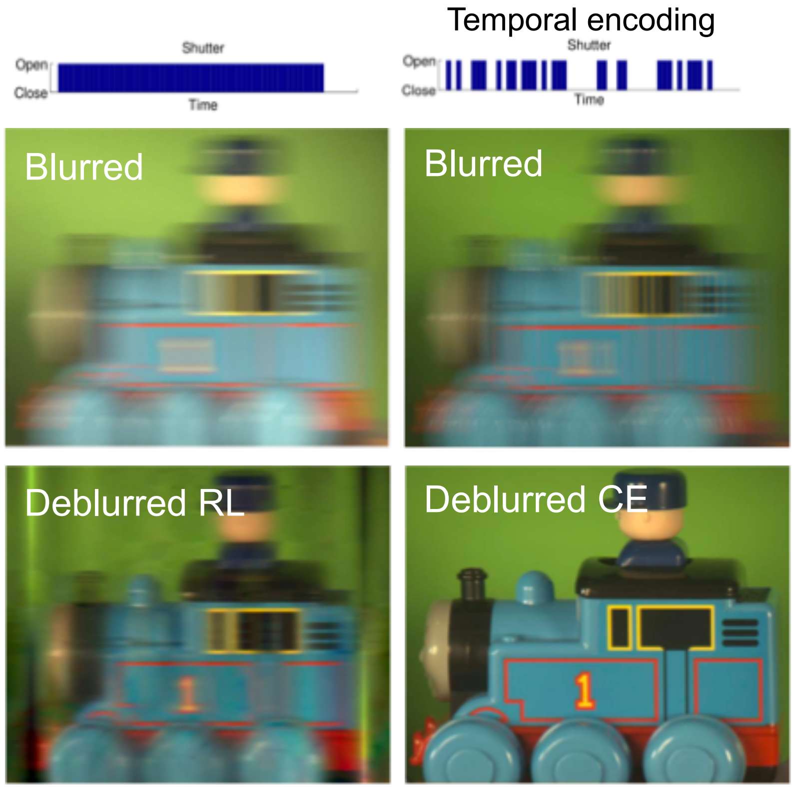


DETECTORS

2D motion deblurring problem



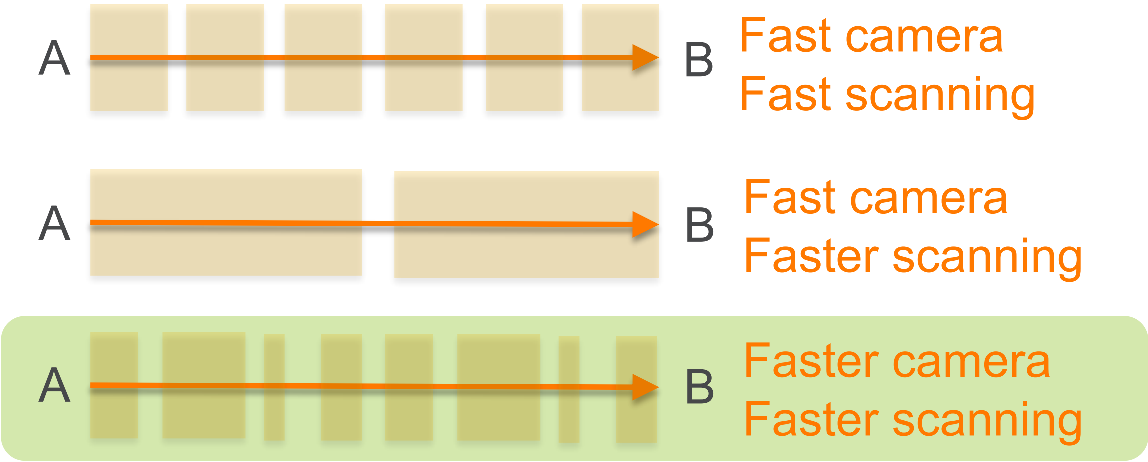
M. Raskar *et al.* “Coded exposure photography: Motion Deblurring using Fluttered Shutter”, **SIGGRAPH,** 2016.



OUTLOOK

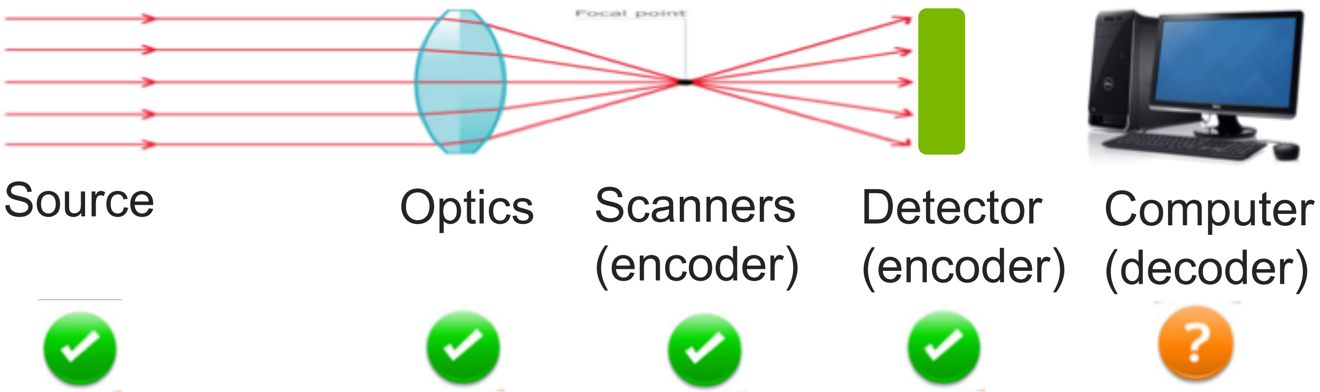
Optimized and flexible way of collecting data

- Probe trajectory: spatial encoding (scanner)
- Sampling: temporal encoding (detector)



COMPUTING

How computing glues it all together?

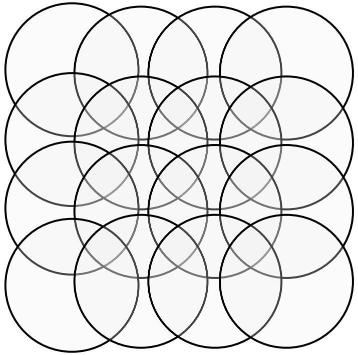


COMPUTING

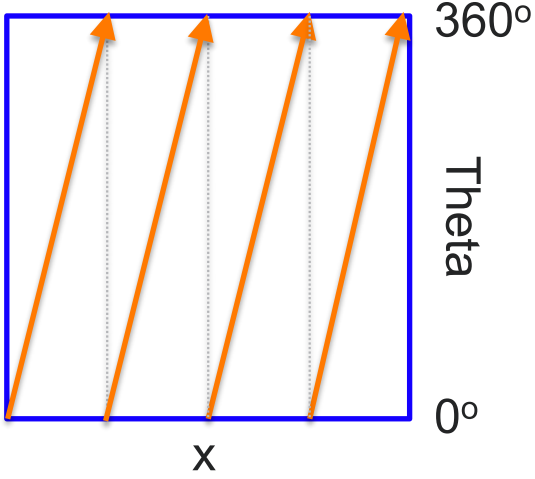
Thinking in 3D

- Ptychographic phase retrieval is traditionally a 2D problem.
- How can we use fast scanning approaches and still be able to reconstruct a 3D object?
- How can we apply motion deblurring in 3D?

Restrictions in 2D scanning



Probe Trajectory



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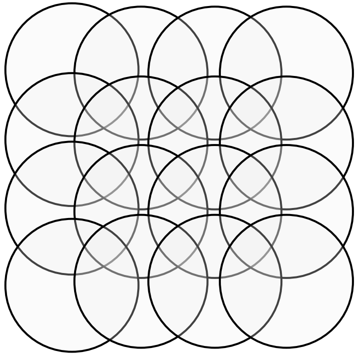
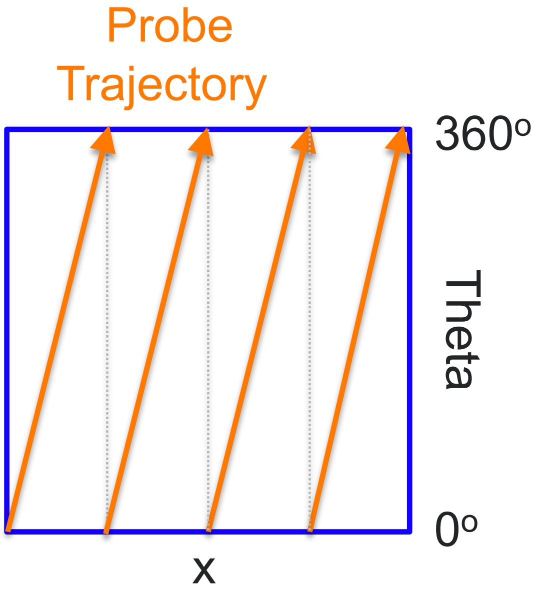
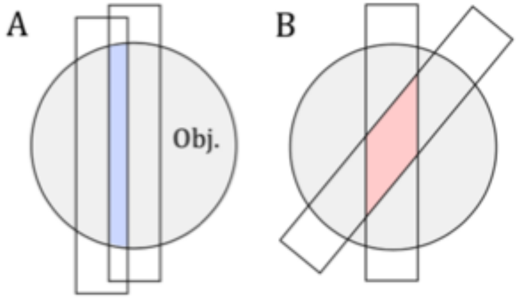




Extension of 2D problems into 3D: Re-modeling!

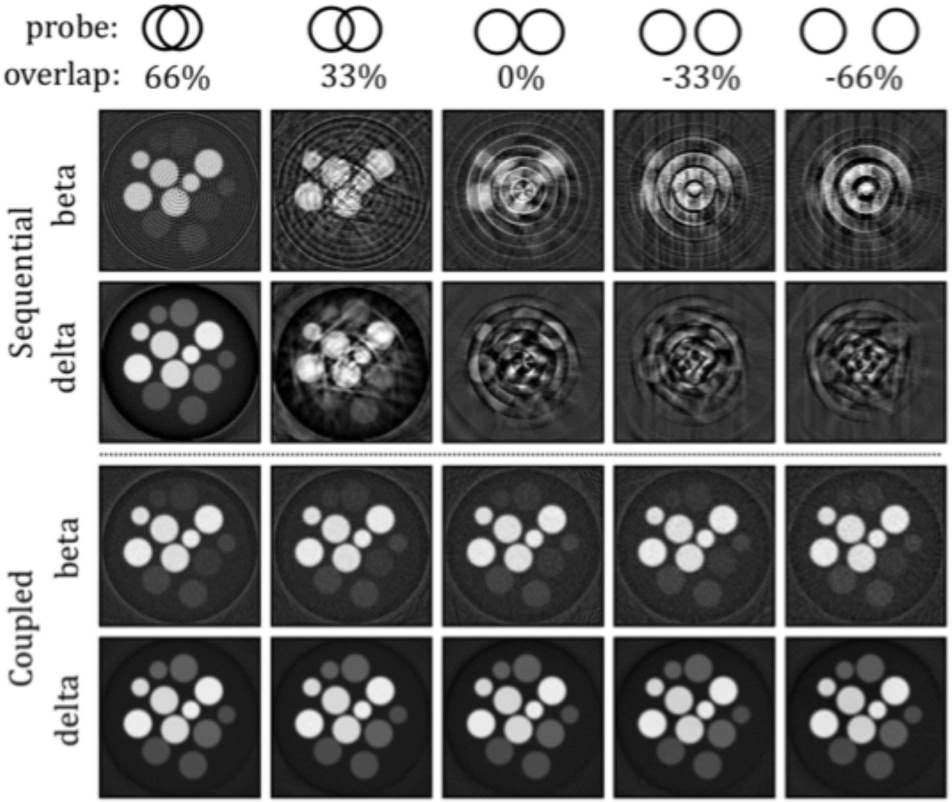
COMPUTING

Thinking in 3D



Lateral Overlap (costly)

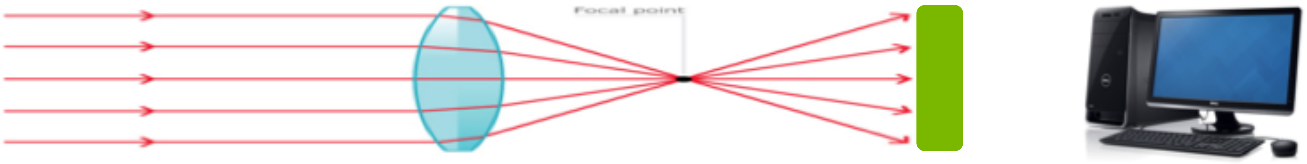
Angular overlap (comes for free)



D. Gursoy “Direct coupling of tomography and ptychography”, **Optics Letters,** 2017.

TAKE-HOME MESSAGE

"The whole is greater than the sum of its parts!" - Aristotle



Source

Optics

Scanners (encoder)

Detector (encoder)

Computer (decoder)

CHALLENGES

System design approach

How to get better spatial/temporal/spectral encoding that is easier to decode?

Scanning:

- High precision knowledge of system geometry & make use of resonance

Detectors:

- High-speed mechanical/electronic shutters

Computing

- Adaptation of 2D techniques and extension to 3D X-ray imaging.

THANKS?

BELIEVE IT OR NOT, HE'S ON A ROLL

Associated Press

Math professor Stan Wagon demonstrates his square-wheeled bicycle at Macalester College in St. Paul, Minn. In 1960, it was discovered that a square wheel would roll smoothly on a road made of catenaries (those bumpy things). Wagon said he became interested in the concept 7 years ago, did calculations and computer animations, then had the bike specially built.