Electron Tomography and Its Limitations

Xin Chen

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Fig. 1. Tomographic reconstruction of HSV-1 virions in vitreous ice. **(A)** Zero-tilt projection from a tilt series. Black dots are 10-nm gold particles used as fiducial markers. **(B)** Gallery of parallel slices, 15.5 nm apart and 5.2 nm thick, through the virion framed in (A). Each slice represents the average over seven planes. Red arrowheads mark filaments in the tegument. Scale bars, 100 nm.

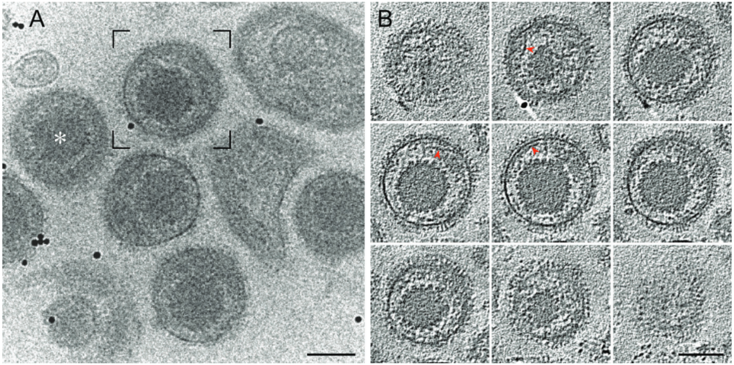


Figure: Grnewald, Kay, et al, 2003, resolution: 7nm

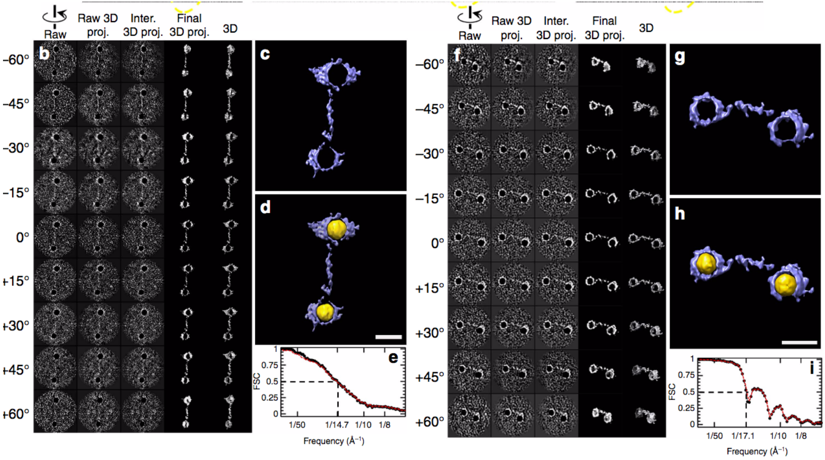
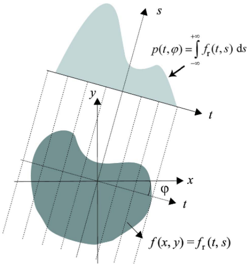


Figure: Lei Zhang, et al, 2016, resolution: 17.1Å, dsDNA: 30nm, gold particle: 6nm



$$p(t,\varphi) = \int\int f(x,y)\delta(x\cos\varphi + y\sin\varphi - t)\,dx\,dy$$

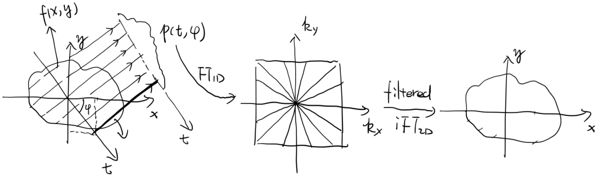
$$P(k,\varphi) = \mathrm{FT1}[p] = \int\int f(x,y)e^{-ikx\cos\varphi - iky\sin\varphi}\,dx\,dy$$

$$= \int\int f(x,y)e^{-iux-ivk}\,dx\,dy$$

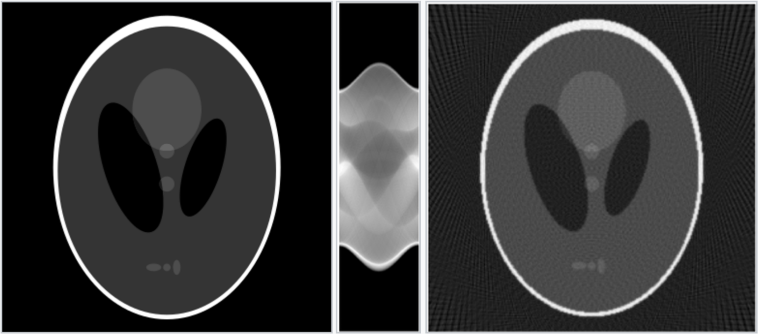
$$u = k\cos\varphi$$

$$v = k\sin\varphi$$

Fourier Slice Theorem: 1D FT of $p(t,\varphi)$ is equal to the slice of 2D FT of $f(x,y)$ at the angle ϕ — the math for iRadon.

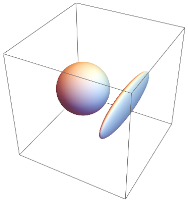


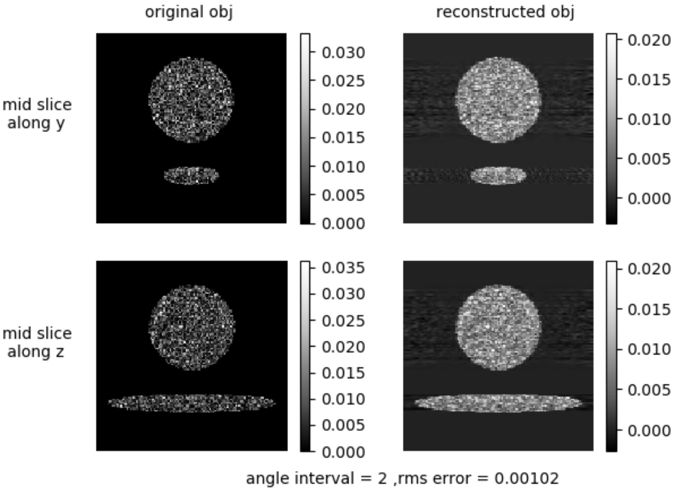
2D Reconstruction

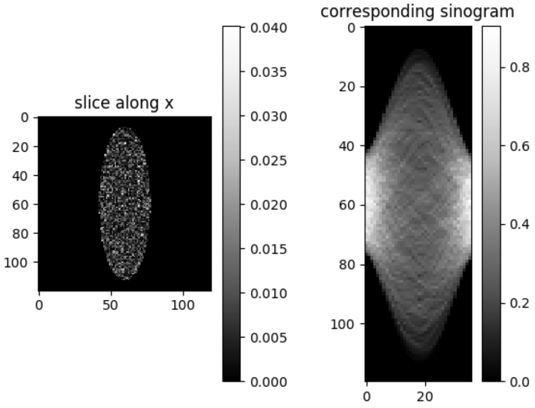


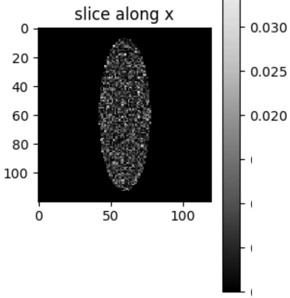
Shepp Logan phantom | Radon transform | Inverse Radon transform

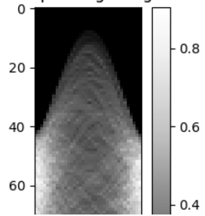
3D Reconstruction






slice along x
0
20
40
60
80
100
0
50
100
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
corresponding sinogram
0
20
40
60
80
100
0
20
0.8
0.6
0.4
0.2
0.0


slice along x
0
20
40
60
80
100
0
50
100
0.040
0.035
0.030
0.025
0.020


corresponding sinogram
0
20
40
60
0.8
0.6
0.4

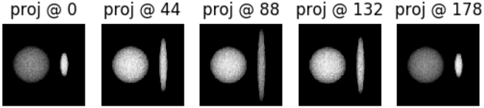
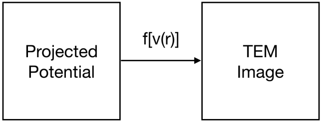

proj @ 0
proj @ 44
proj @ 88
proj @ 132
proj @ 178

Image delivered projection



The simplest model: Projection Approx + Weak Phase Object Approx

$$\Psi_i^{\mathrm{BF}}(\boldsymbol{k}) = [\delta(0) + \mathrm{i}\sigma_e \mathcal{V}_{\mathrm{proj}}(\boldsymbol{k})]\mathrm{e}^{-\mathrm{i}\chi(\boldsymbol{k})}$$

Tune χ to achieve $-\pi/2$ phase shift.

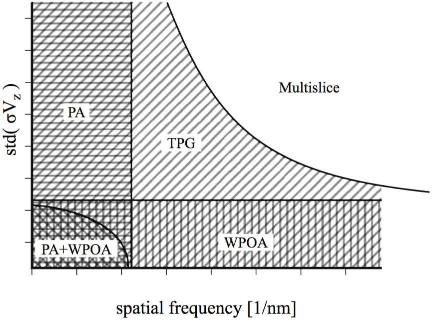
$$\psi_i^{\mathrm{BF}}(\boldsymbol{r}) = 1 - \sigma_e \nu(\boldsymbol{r}),\ \ g^{\mathrm{BF}}(\boldsymbol{r}) = 1 - 2\sigma_e \nu_{\mathrm{proj}}$$

ADF-TEM: transmitted wave is excluded.

$$\psi_i^{\mathrm{ADF}}(\boldsymbol{r}) = 1 - \psi_i^{\mathrm{BF}}(\boldsymbol{r}),\ \ g^{\mathrm{ADF}}(\boldsymbol{r}) = [\sigma_e \nu(\boldsymbol{r})]^2$$

Validity

- PA: single scattering, thin specimen, potential varies slowly over distance $\sqrt{\Delta z\lambda/2\pi}$ (Kazuo Ishizuka & Natsu Uyeda, 1977). And the spatial frequency q of interest is much smaller than $\sqrt{1/4\lambda\Delta z}$ (cited by Vulovi, Milo, et al, 2014).
- WPOA: thin specimen, low atomic number, $\sigma_e\nu < 0.36$ (Vulovi, Milo, et al, 2014).



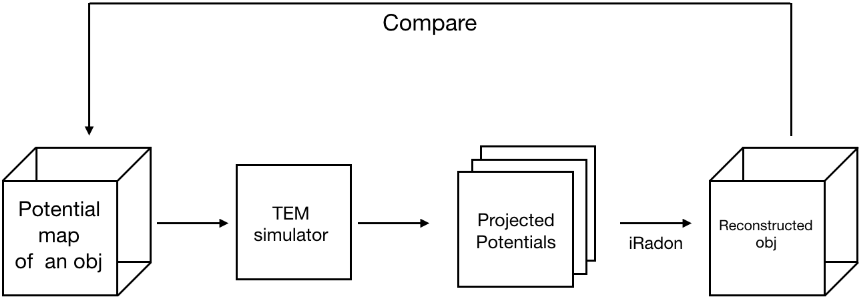
Another problem: electron does

Tow requirements that contradict each other (Wolfgang Baumeister, Rudo Grimmand Jochen Walz, 1999):

- minimum electron does.
- sampling as much as possible and high SNR

commonly used does: $10 - 20e^{-1}/\text{Å}^2$

A numerical approach to study the limitations



Thanks!