Graphics Processing Unit Accelerated Ultrahigh-Speed Real-Time Fourier-Domain Optical Coherence Tomography

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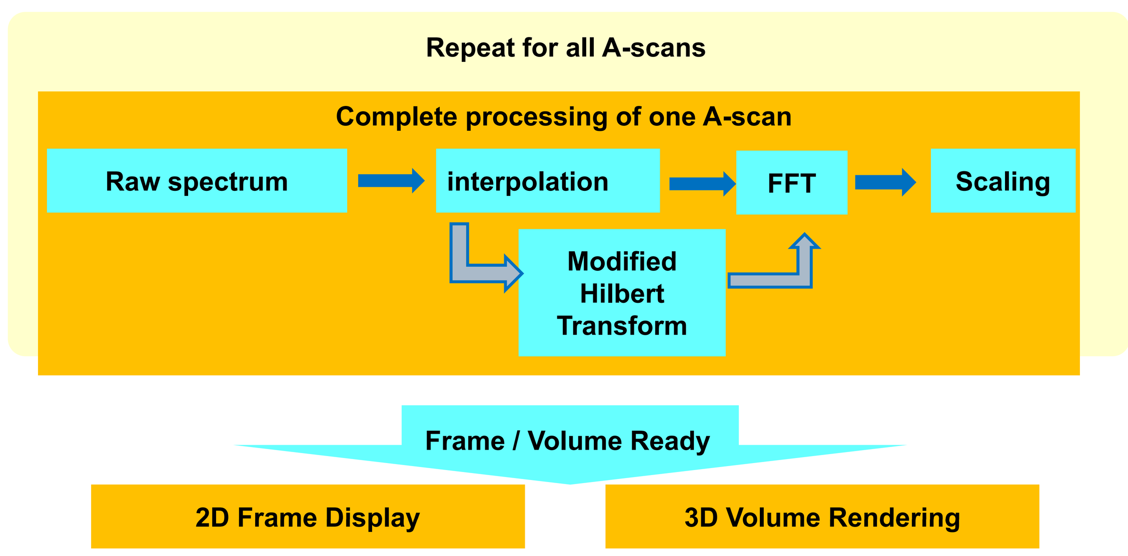
Introduction

Fourier-domain optical coherence tomography (FD-OCT) is a novel imaging modality capable of multi-dimensional imaging with micro-meter resolution, and has great potential for intervention in microsurgery, such as vitreo-retinal surgery, neurological surgery and otolaryngologic surgery. The acquisition line speed of FD-OCT has been advancing rapidly to >100k A-scan/second level in the last few years.

However, the image reconstruction and visualization speed are generally far behind the data acquisition. Current ultra-high speed OCT systems are usually non-real-time and working in a “post-processing mode”, which limits the interventional application of OCT.

In this work, we developed a series of GPU-based technologies to accelerate the imaging reconstruction and visualization for ultra-high speed real-time FD-OCT.

➢FD-OCT reconstruction is ideal for Massively Parallel Processing

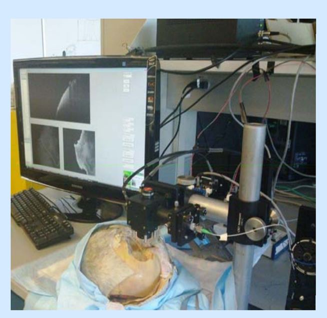


➢Comparison of High-Performance Computing solutions

Solution Example	Performance	Cost	Cost / Performance
Intel CPU Core i7 980X	~100 G FLOPS	$1000	$10/ GFLOPS
Xilinx FPGA Virtex-6 LX240T	~200 G FLOPS	$2000	$10/ GFLOPS
NVIDIA GPU GTX 580	~1600 G FLOPS	$500	$0.32/ GFLOPS

➢The GPU acceleration is highly cost-effective compared to the overall cost of an OCT system and no optical modification is needed for integration.

High-end OCT system cost: ~$50,000 to $100,000



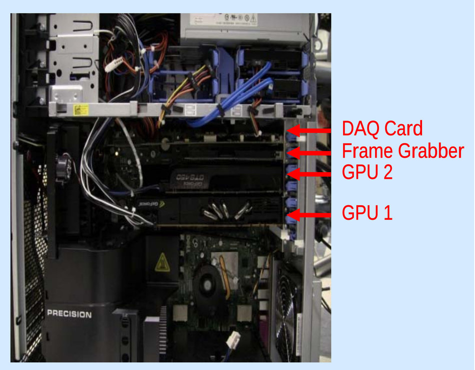
A OCT system developed for neurosurgery intervention in Johns Hopkins Hospital

High-end GPU cost: ~$500

NVIDIA GeForce GTX 580
512 GPU core
1.6 GHz each core

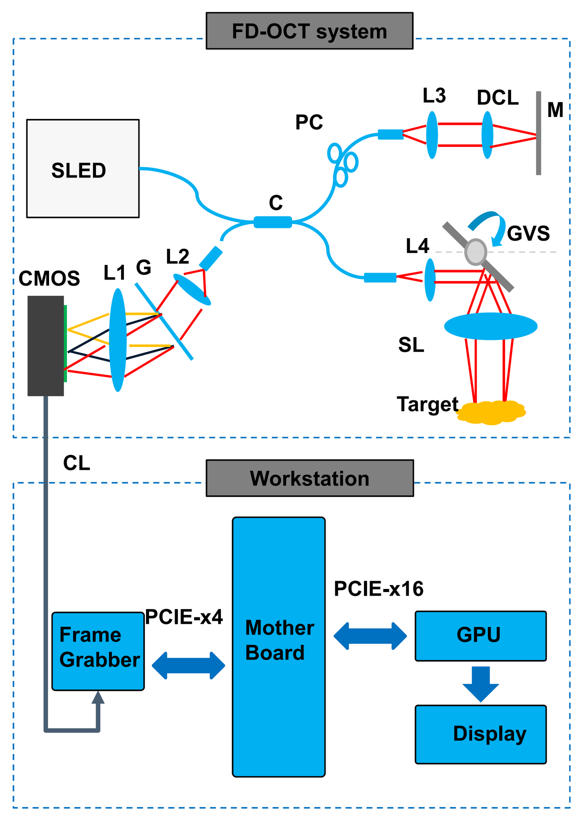
Card Manufactured by EVGA

GPU integration into a FD-OCT imaging workstation

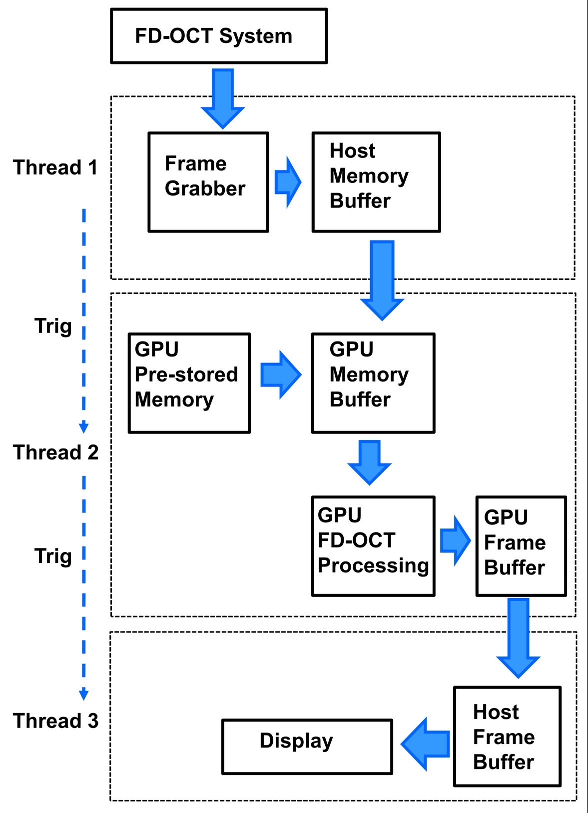


A FD-OCT imaging workstation with dual GPUs integrated. GPU1 (GTX 580) for image reconstruction and GPU2 (GTS 450) for volume rendering.

GPU accelerated FD-OCT Imaging System



System Configuration



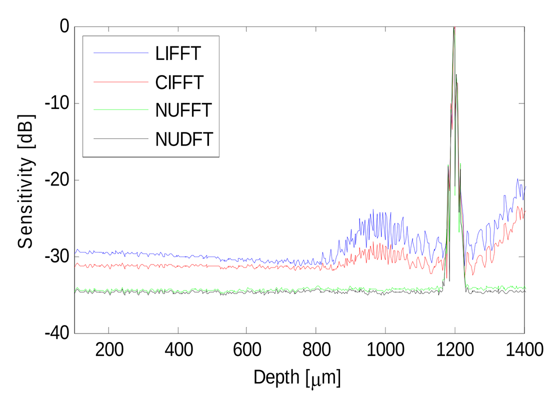
Data Processing Flowchart

GPU based Non-Uniform Fast Fourier Transform (NUFFT)

Non-Uniform Discrete Fourier Transform (NUDFT)

$$A[z_m]=\sum_{k=0}^{N-1} I[k]\exp\left[-j\frac{2\pi}{\Delta k}(k_i-k_0)*m\right],$$

$m=0,1,2,\ldots,N-1.$



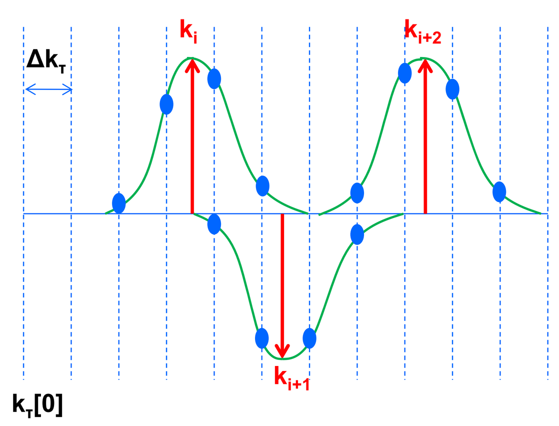
Fast Gaussian Gridding based NUFFT

$$I_\tau[u]=\sum_i I[i]\,g_\tau[k_\tau[u]-k[i]],\ u=0,1,2,\ldots,Mr-1.$$

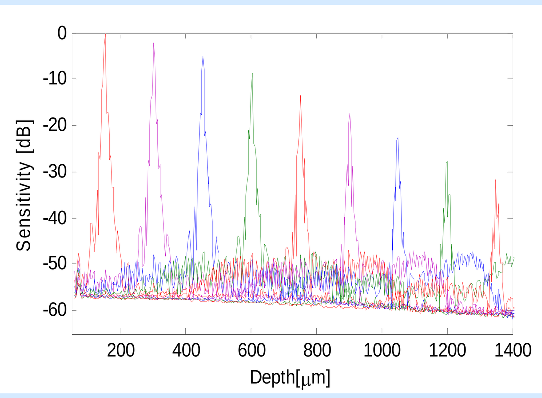
$$g_\tau[k]=\exp\left[\frac{-k^2}{4\tau}\right],\quad \tau=\frac{1}{N^2}\frac{\pi}{R(R-0.5)}M_{sp},$$

FFT

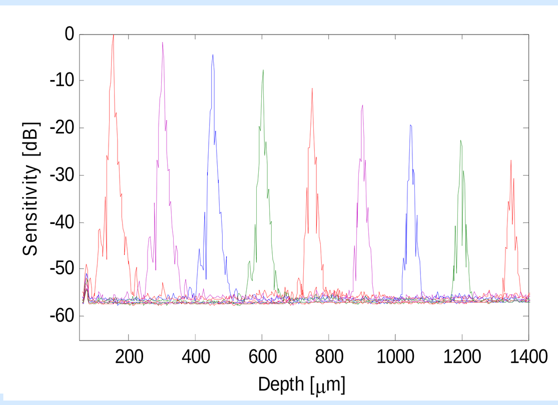
$$G_\tau[n]=\exp[n^2\tau],$$



➢Point Spread Function (PSF) Test

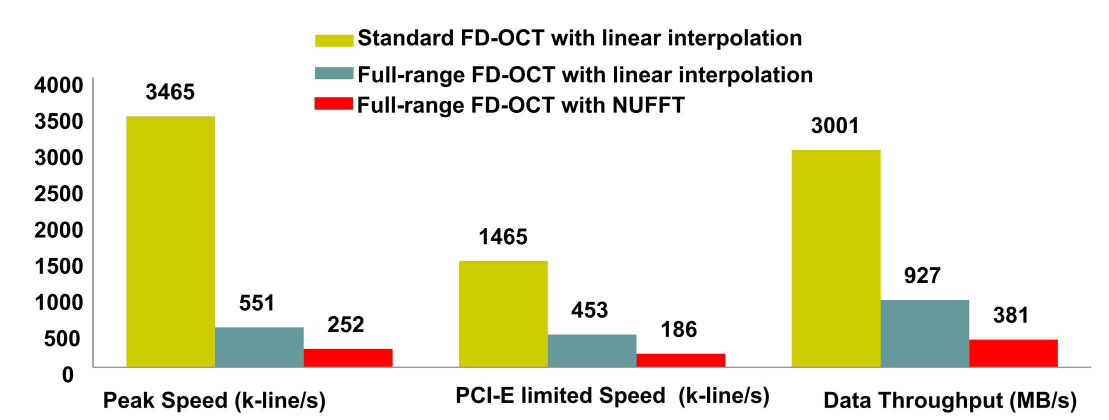


Linear Interpolation with FFT

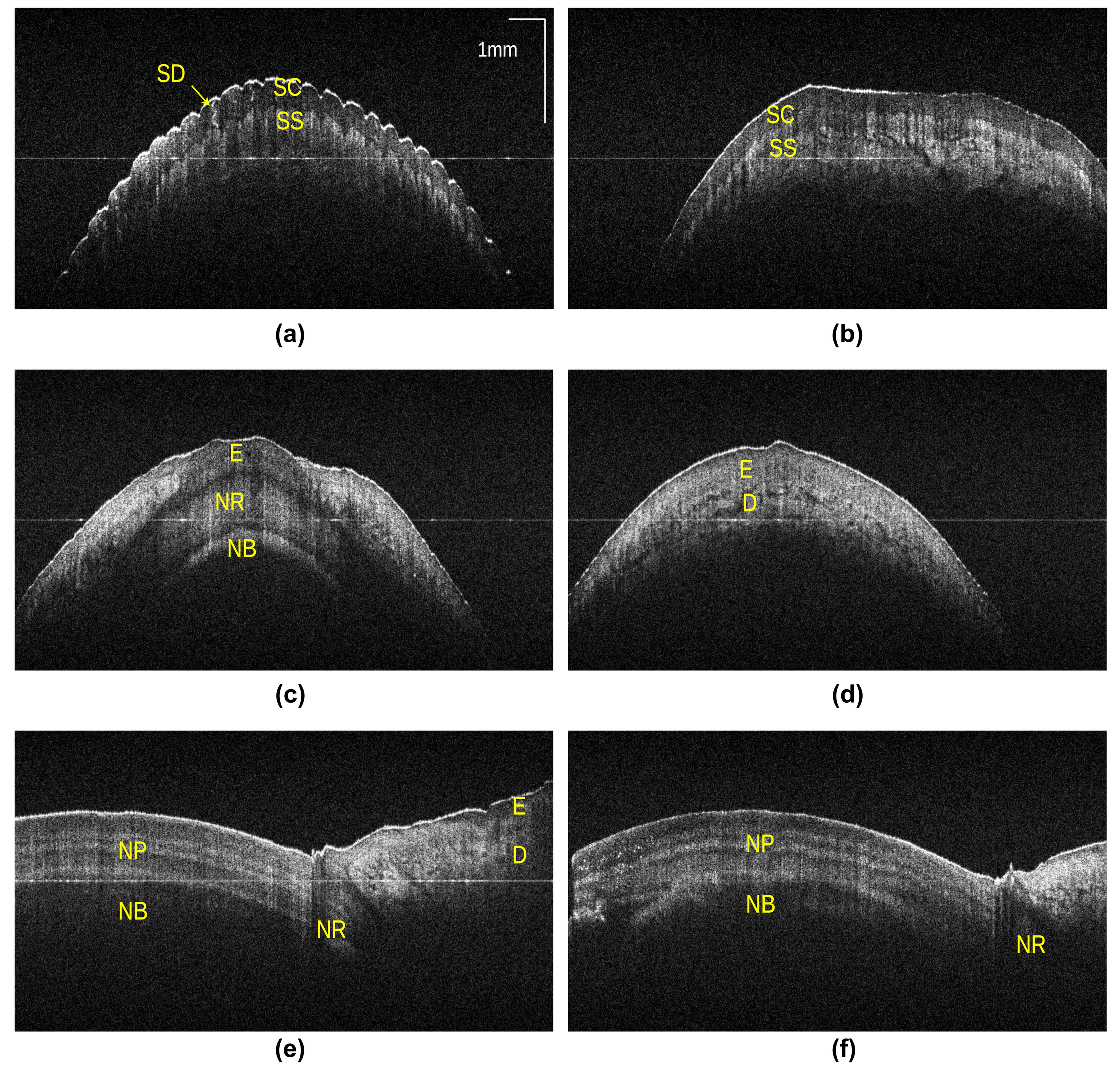


NUFFT

➢Benchmark Processing Speed Test on NVIDIA GTX 580 GPU



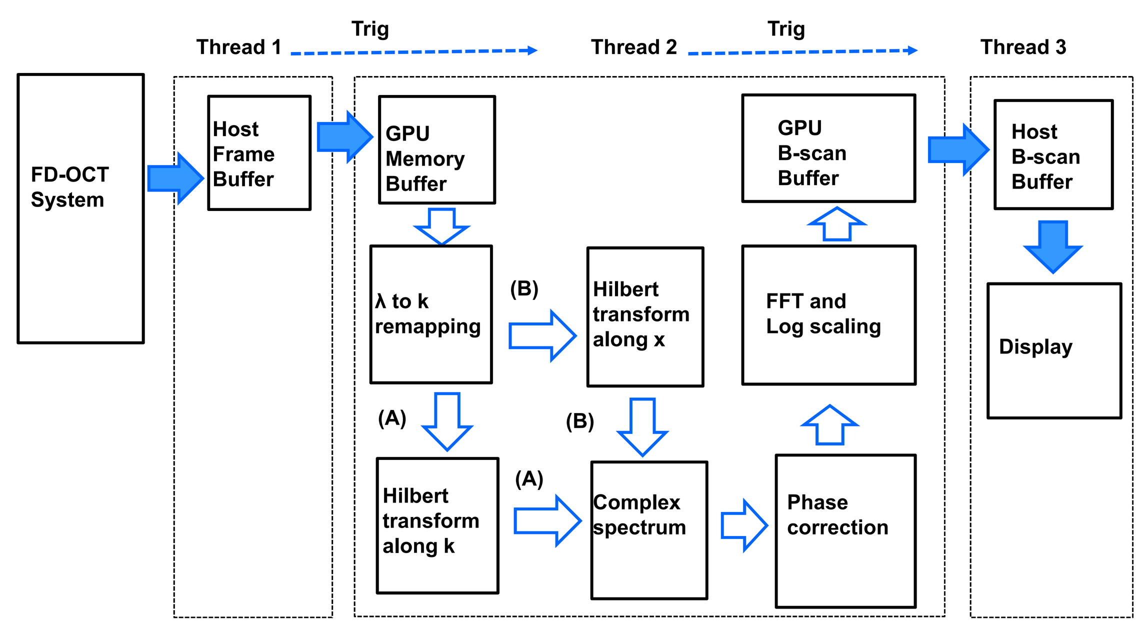
2D Imaging using GPU-NUFFT



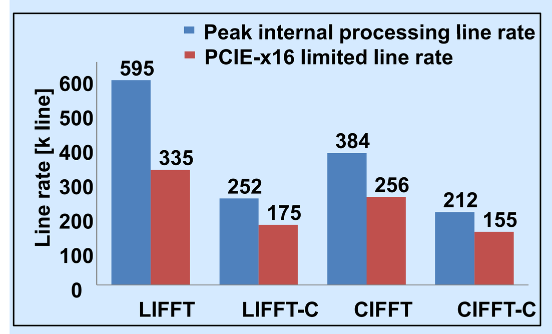
Real-time full-range FD-OCT images using GPU-NUFFT, where the bars represent 1mm in both dimensions for all images: (a) Finger tip, (coronal). (b) Finger palm (coronal). (c)~(d) Finger nail fold (coronal); (e)~(f) Finger nail (sagittal).
SD, sweat duct; SC, stratum corneum; SS, stratum spinosum; NP, nail plate; NB, nail bed; NR, nail root; E, epidermis; D, dermis.

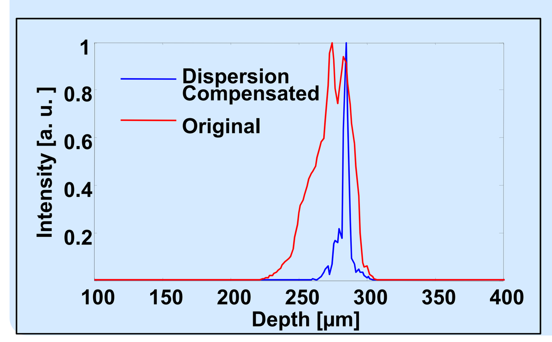
GPU accelerated Numerical Dispersion Compensation

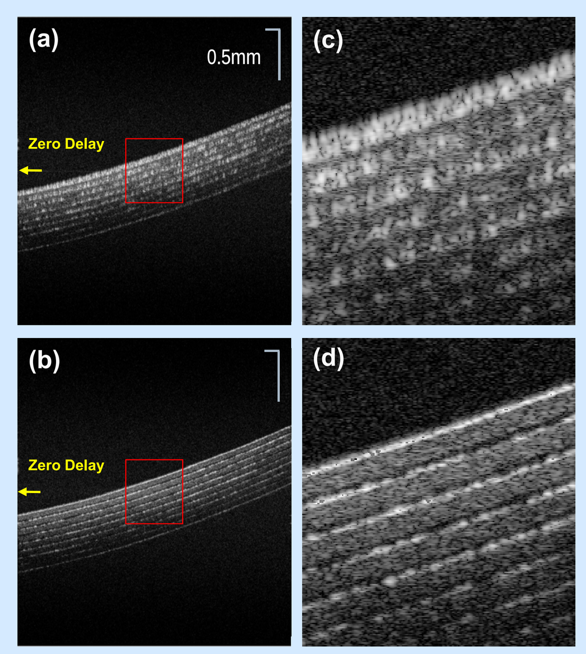
➢The numerical dispersion compensation was realized by adding a phase correction term $\Phi=-a_2(\omega-\omega_0)^2-a_3(\omega-\omega_0)^3$ to the complex spectrum after Hilbert transform, realized on GPU as below:



➢Benchmark and Imaging Results on NVIDIA GTX 580 GPU

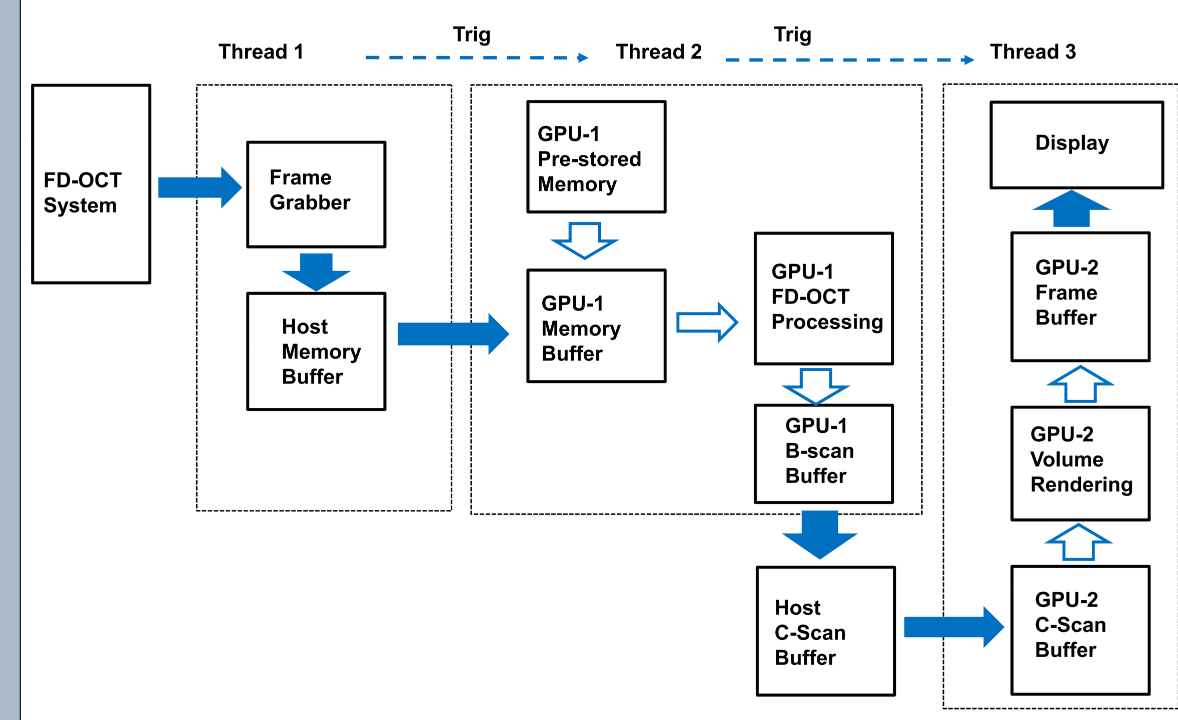




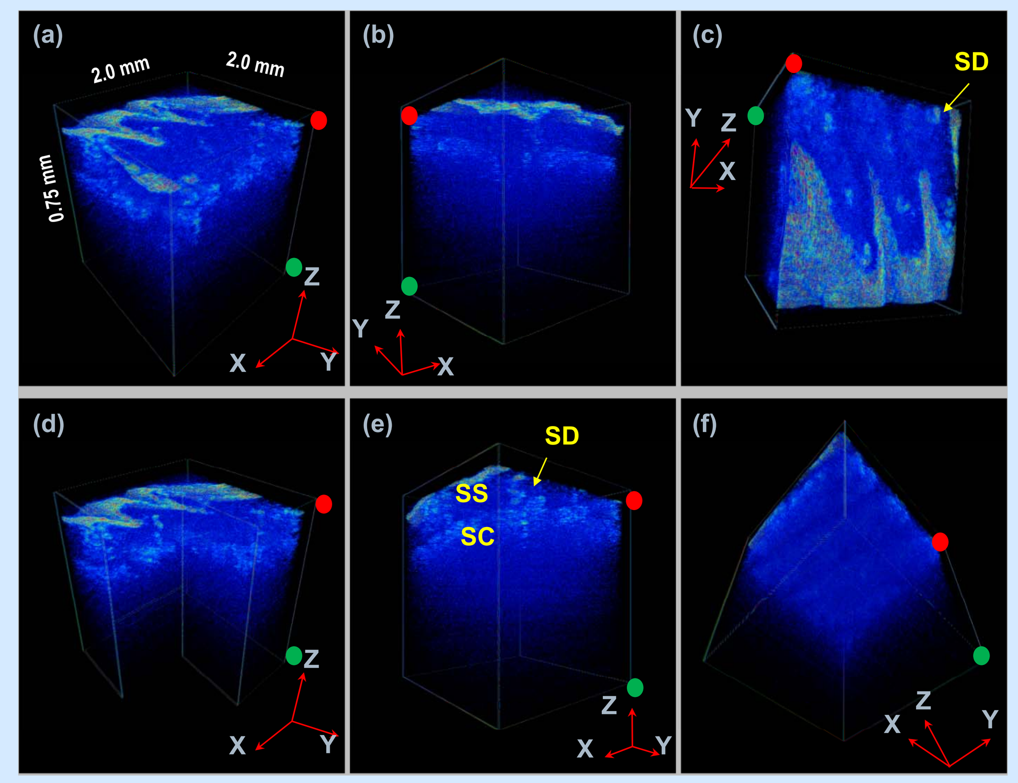


Dual-GPUs based 4D FD-OCT imaging

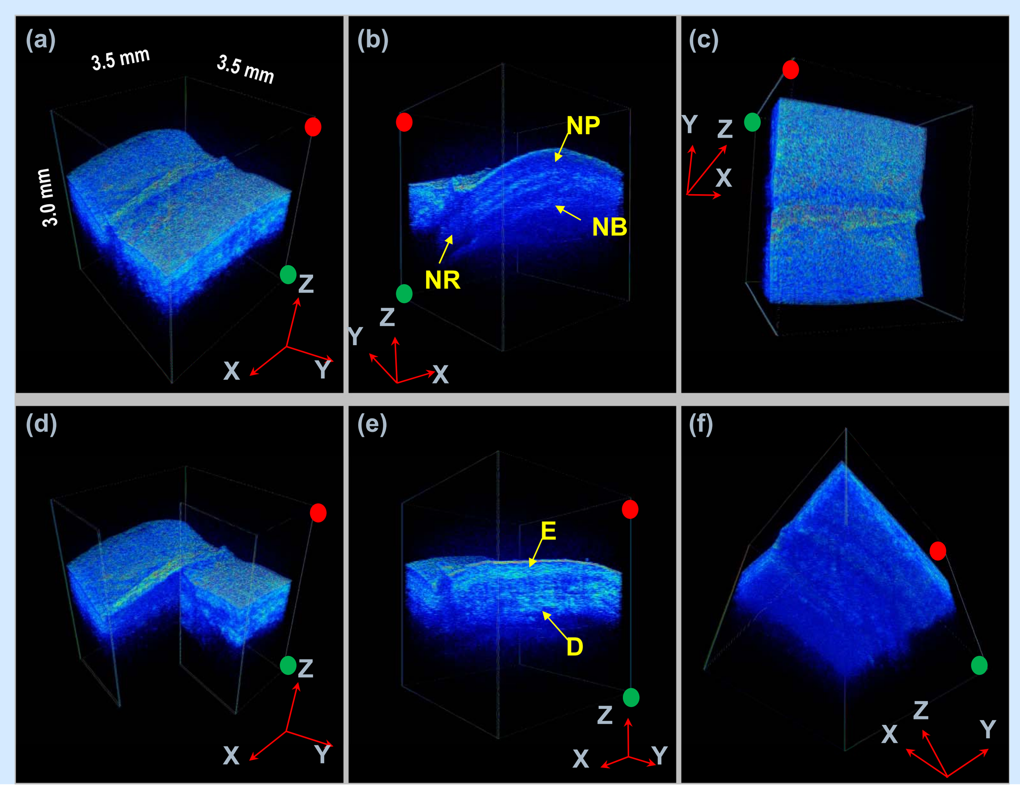
➢Dual-GPUs Processing Flowchart



➢Standard 4D FD-OCT Imaging (Finger Print)



➢Full-Range 4D FD-OCT Imaging (Nail Folding)



References

[1] K. Zhang, J. Kang, Electronics Letters, V47,309 (2011).
[2] K. Zhang, J. Kang, Biomedical Optics Express, V2, 764 (2011).
[3] K. Zhang, J. Kang, Optics Express, V18, 23472 (2010).
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Acknowledgement

NIH Grant R21 1R21NS063131-01A1