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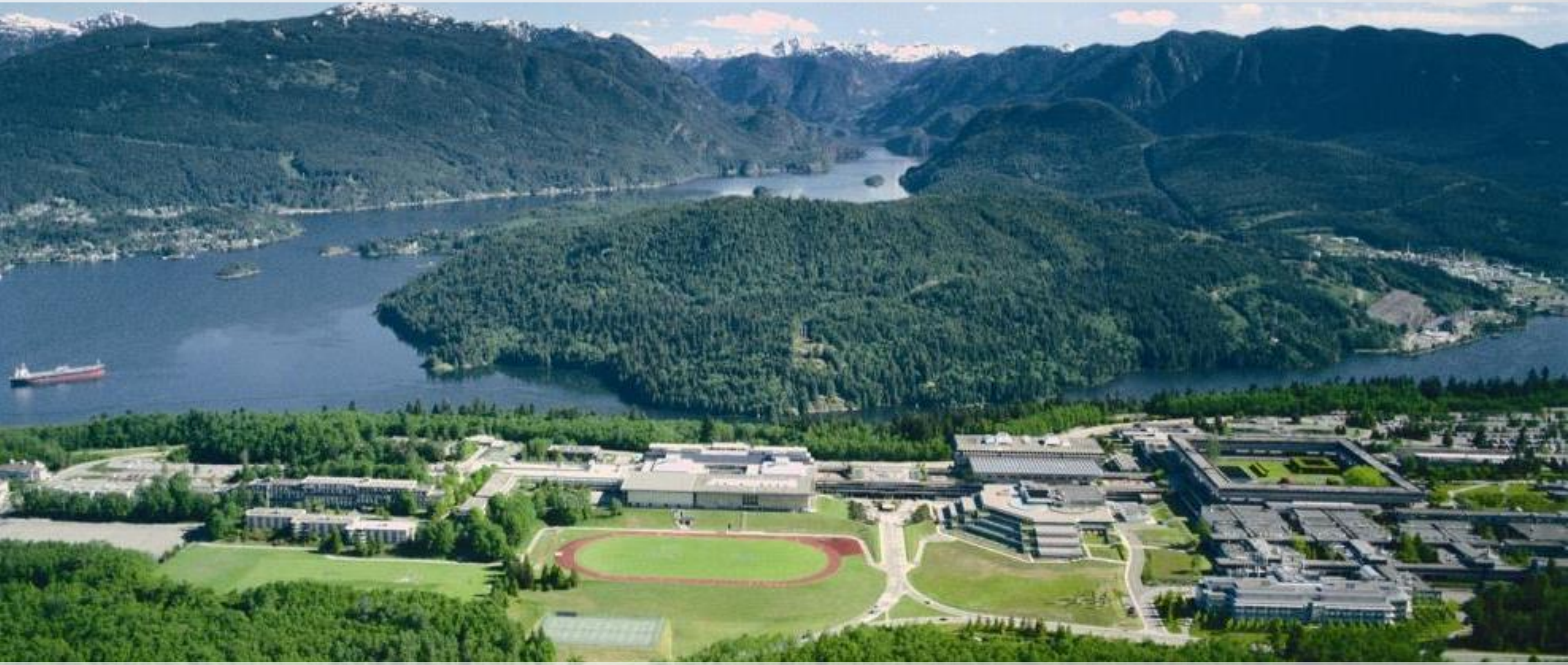
GPU Acceleration of Processing and Visualization for Various Optical Coherence Tomography Methodologies



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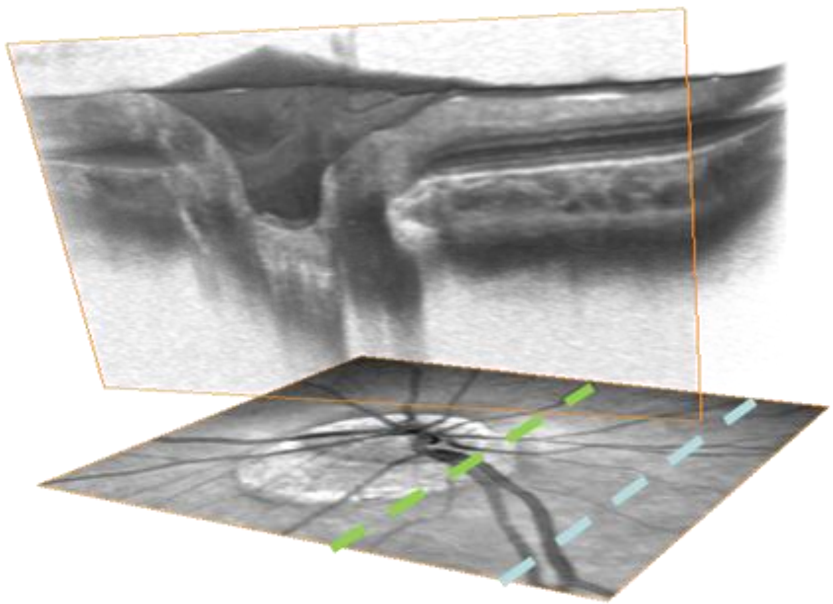
Biomedical Optics Research Group (BORG), Simon Fraser University
S4513, GPU Technology Conference — March 26, 2014

OCT for Ophthalmology

- Optical Coherence Tomography (OCT) is a rapidly growing imaging modality in ophthalmology
- OCT is an optical analogue of ultrasound imaging
  - OCT uses light, while ultrasound imaging uses sound
  - Both use similar terminology: A-scans and B-scans



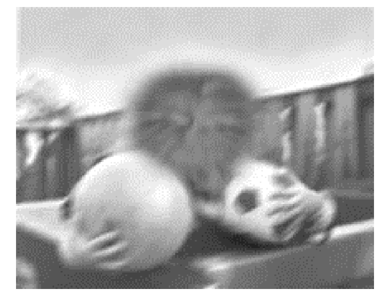
Vision Robbing Diseases

- OCT can be used for detecting many types of vision robbing diseases

Healthy

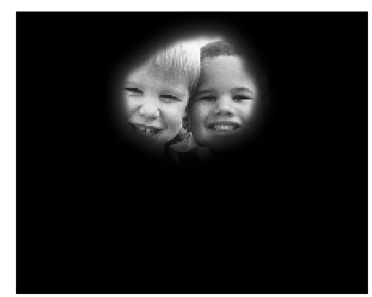
Glaucoma

Macular Degeneration



Diabetic Retinopathy

Retinitis Pigmentosa



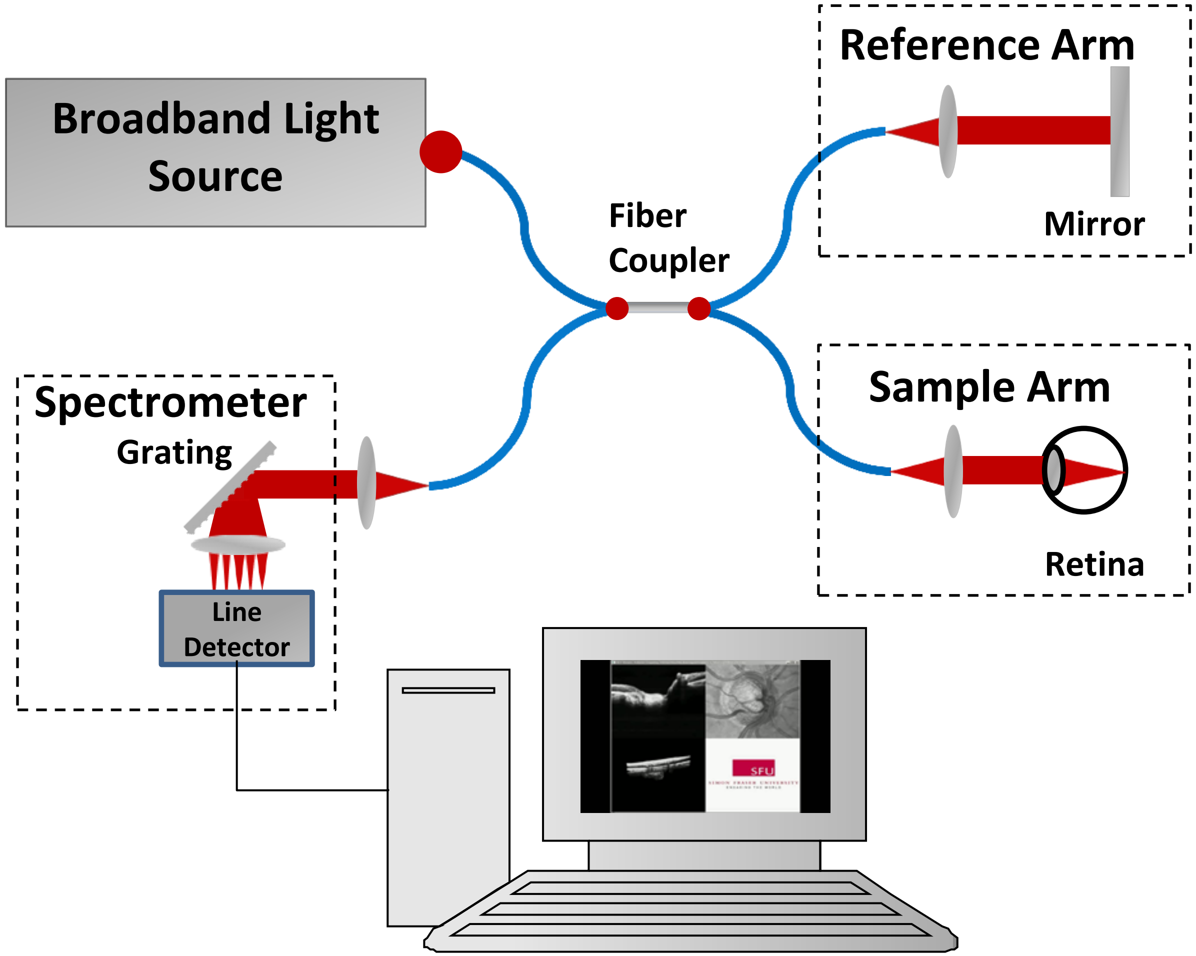
National Eye Institute, National Institutes of Health, REF#: EDS01, EDS02, EDS04, EDS05, EDS07

Motivation

- OCT processing pipeline is computationally intensive
- Consumer-grade CPUs provide inadequate throughput for sustaining real-time high speed OCT
- We demonstrate a custom GPU/CUDA implementation for volumetric OCT and imaging applications:
  - Label-free angiography with OCT
  - Adaptive Optics OCT
  - OCT-guided microsurgery

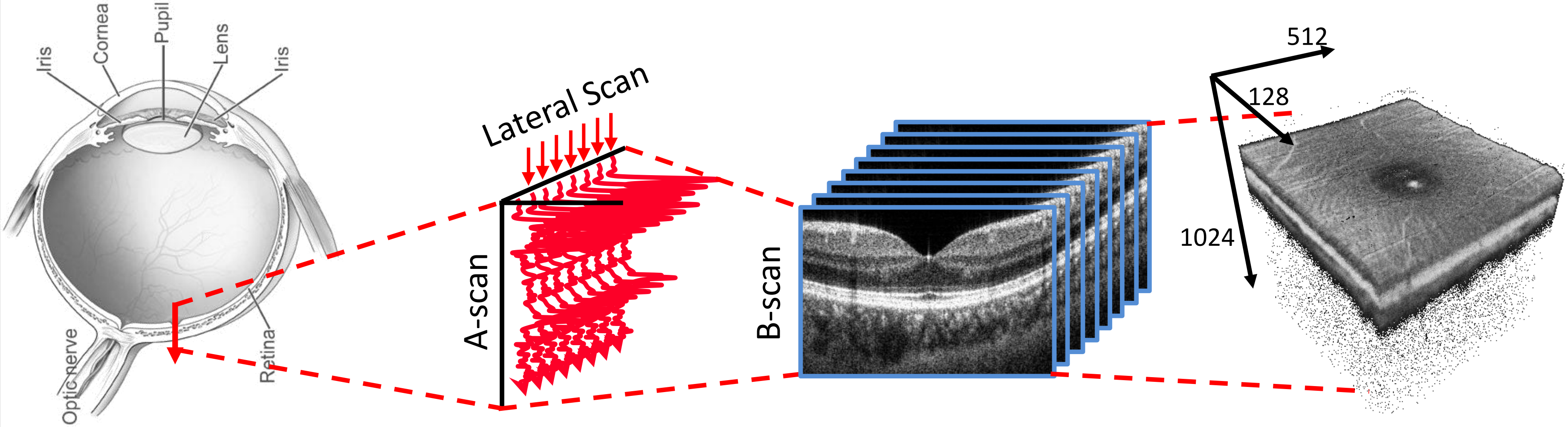
OCT Topology

- Optical path in Spectral-Domain OCT setup



OCT Volumetric Imaging

- An A-scan corresponds to a single depth profile (1024 pixels)
- A sequence of A-scans produces a B-scan (512 A-scans)
- Multiple B-scans create a volume (128 B-scans)
- OCT acquisition and processing throughputs are in terms of A-scans per second (e.g. 100 kHz = 100 000 A-scans/second)
- Overall 0.6 s acquisition time for this volume size



National Eye Institute, National Institutes of Health, REF#: NEA05

Clinical Human Imaging System

- Custom-built Swept Source OCT installed at the Vancouver General Hospital Eye Care Center
  - Light source A-scan speed is 100 kHz
  - ADC card converts analog signal into uint16
  - Overall acquisition throughput is 200 MB/s

Workstation Specifications

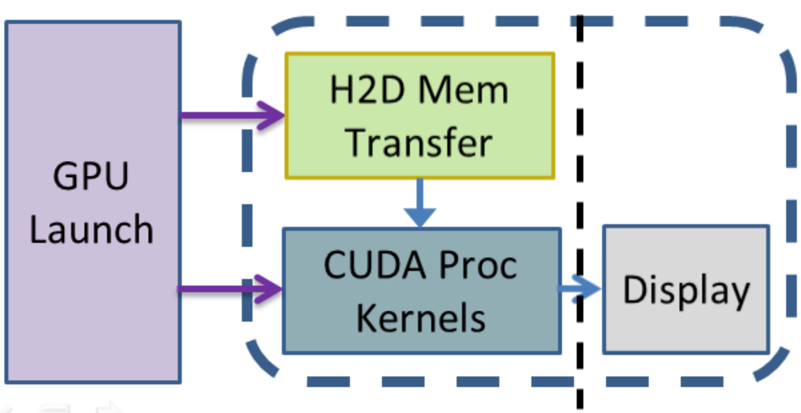
- Representative workstation specs:

CPU	Intel Core i7-3820 16 GB RAM
Motherboard	ASUS Rampage IV Formula
PCIe 2.0 Cards	ADC Digitizer OR Framegrabber Multi-function I/O card GPU (e.g. GTX 680 or GTX Titan)
CUDA Version	**5.5**

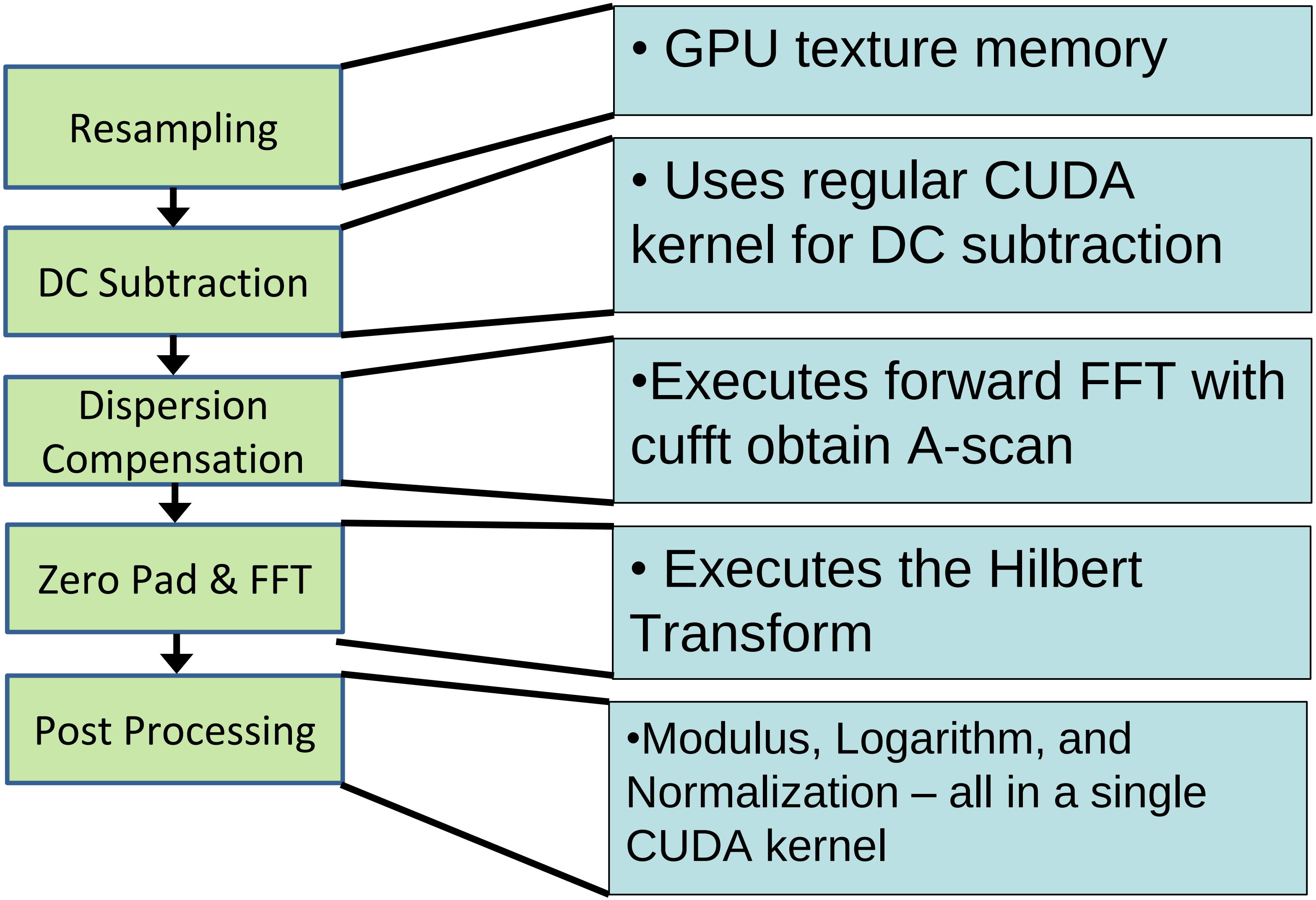
- Dealing with memory transfers between these components is non-trivial

Memory Transfer Management

- Initial CUDA implementation contains two overheads: H2D and D2H
- CUDA and OpenGL Interoperability eliminates D2H transfer
- CUDA Streams enabled parallelization of processing and memory transfer



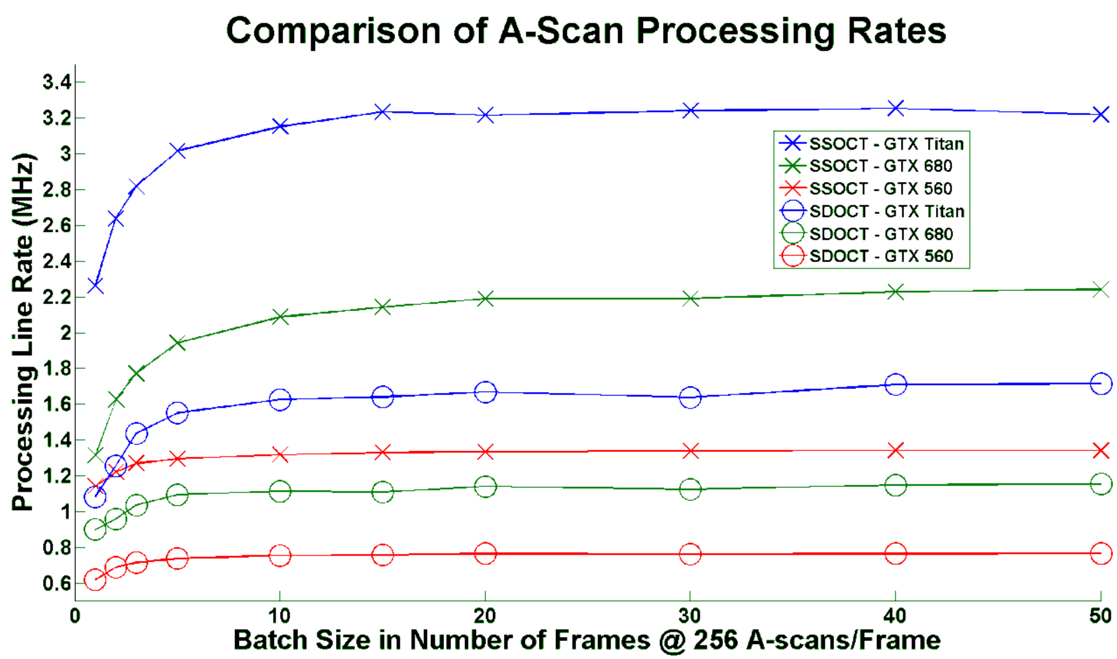
CUDA Processing Pipeline



[1]Wojtkowski et al., Opt. Express 12, 2404-2422 (2004)

GPU Performance Comparison

- Throughput rates for GTX 560, 680, Titan
- Swept Source OCT: 3.2 MHz achieved
- Spectral Domain OCT:1.7 MHz achieved
- Much faster than our acquisition rate of 100 kHz

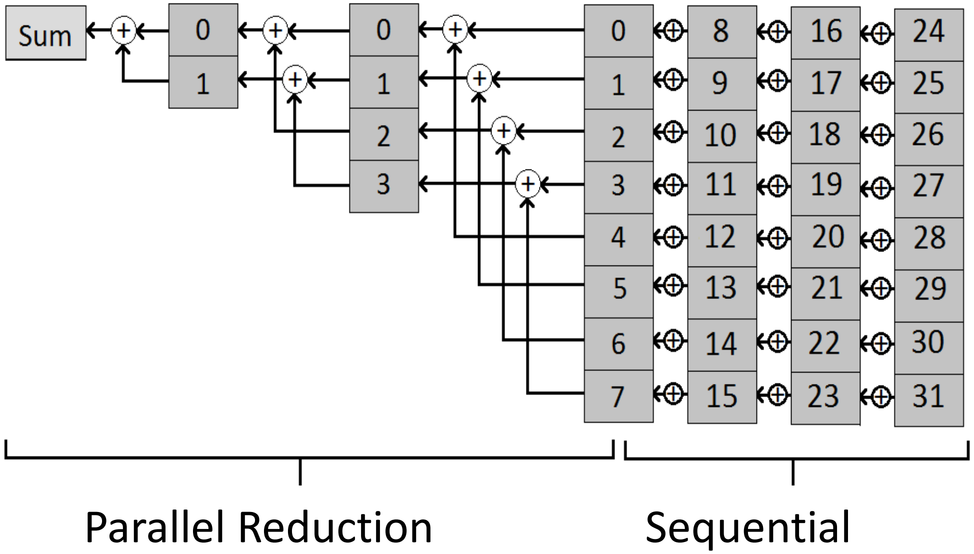


Y. Jian et al. , *Journal of Biomedical Optics* **15**(2), 2013

En Face Projection

- En face projection is produced by the summation of pixels within A-scans

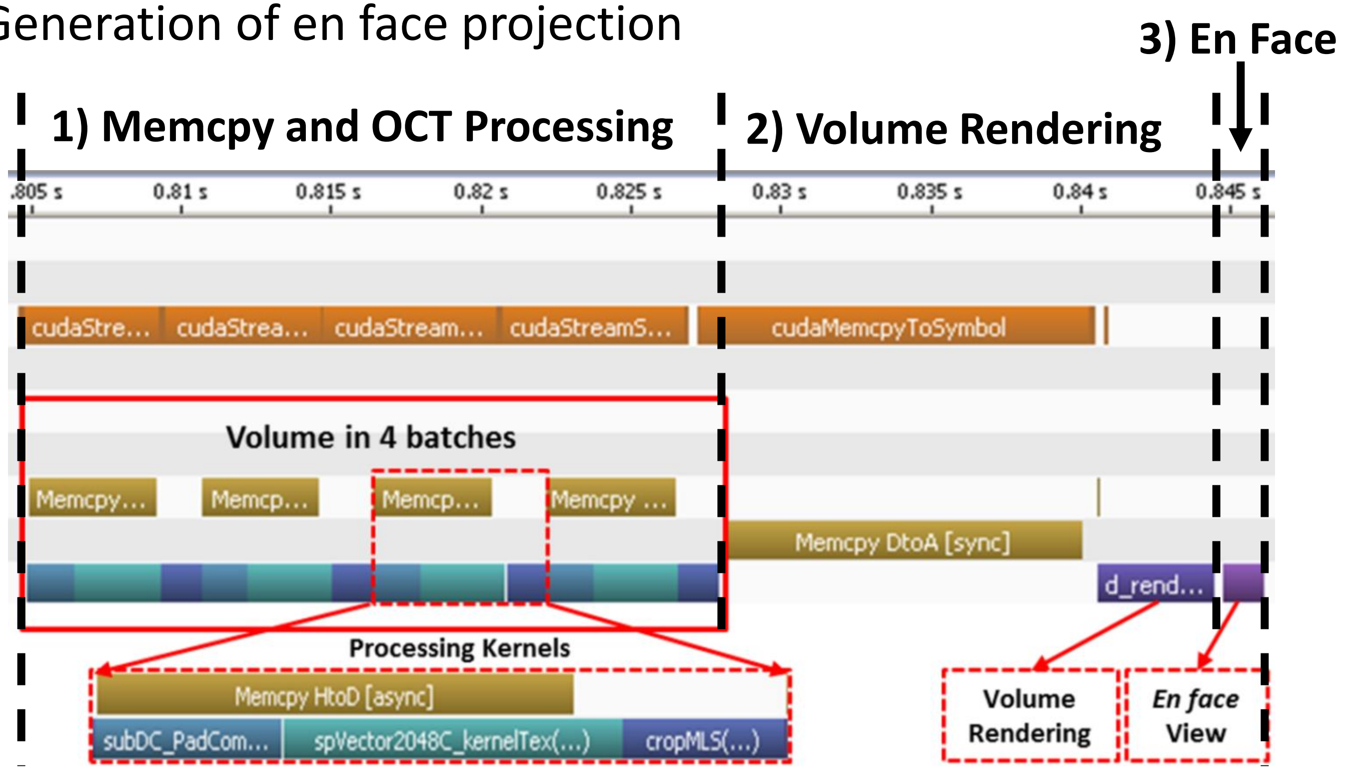
- Optimized parallel reduction consists of:
  - Sequential Summation
  - Parallel Reduction Summation[1]



[1]M. Harris et al., *Addison Wesley*, 2007

GPU Profiler Timeline

- Entire pipeline for OCT processing and display with GTX 680:
  1) OCT processing kernels and asynchronous memory transfer
  2) Volume rendering with raycasting
  3) Generation of en face projection



Y. Jian et al., *Journal of Biomedical Optics* **15**(2), 2013

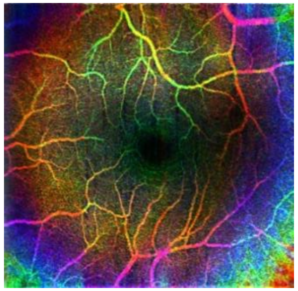
Real-Time Volumetric OCT Imaging

- Demonstration of real-time volumetric OCT for ophthalmology at the Eye Care Center

Videos available at http://borg.ensc.sfu.ca/research/fdoct-gpu-code.html

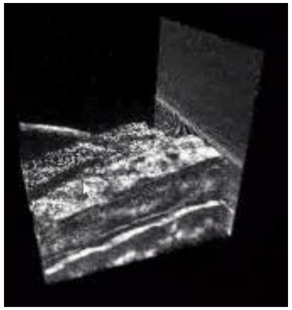
OCT Real-Time Imaging Applications

- Label-free angiography via Speckle Variance OCT



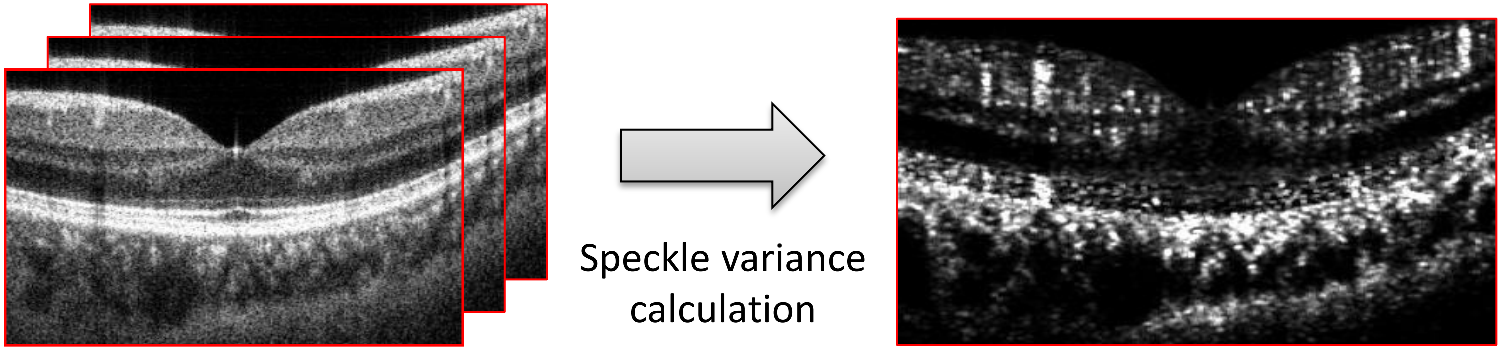
- High resolution imaging via wavefront sensorless adaptive optics OCT

- OCT-guided microsurgery via ultrahigh speed imaging with OCT



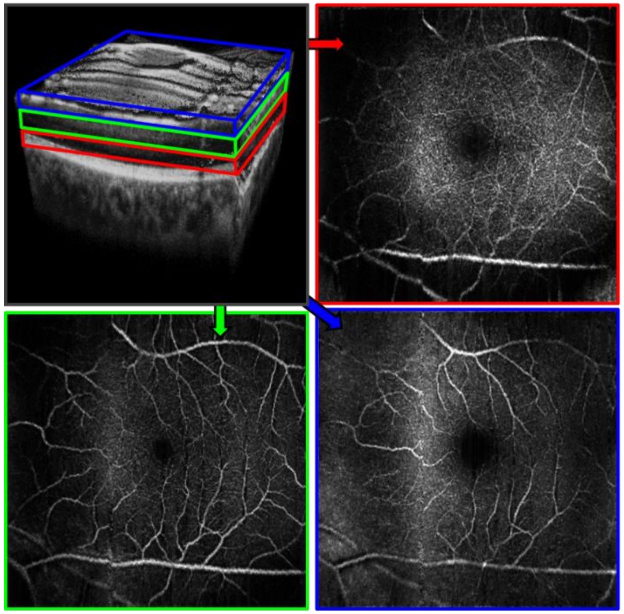
Speckle Variance OCT

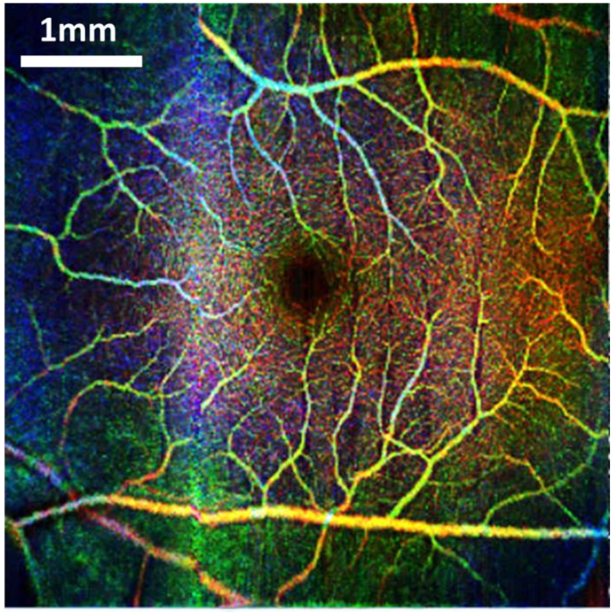
- OCT images contain only structural information
- Speckle Variance OCT provides blood flow information, which is highly desirable
- Speckle Variance steps include:
  1) Acquire 3 B-scans at a each location
  2) Compute variance for each set of 3 B-scans



Speckle Variance OCT: En Face Images

- Visualize vasculature with en face images
- Select depths dynamically in retinal volume
- Display blood vessels within each region
- Superimpose three layers into a single image

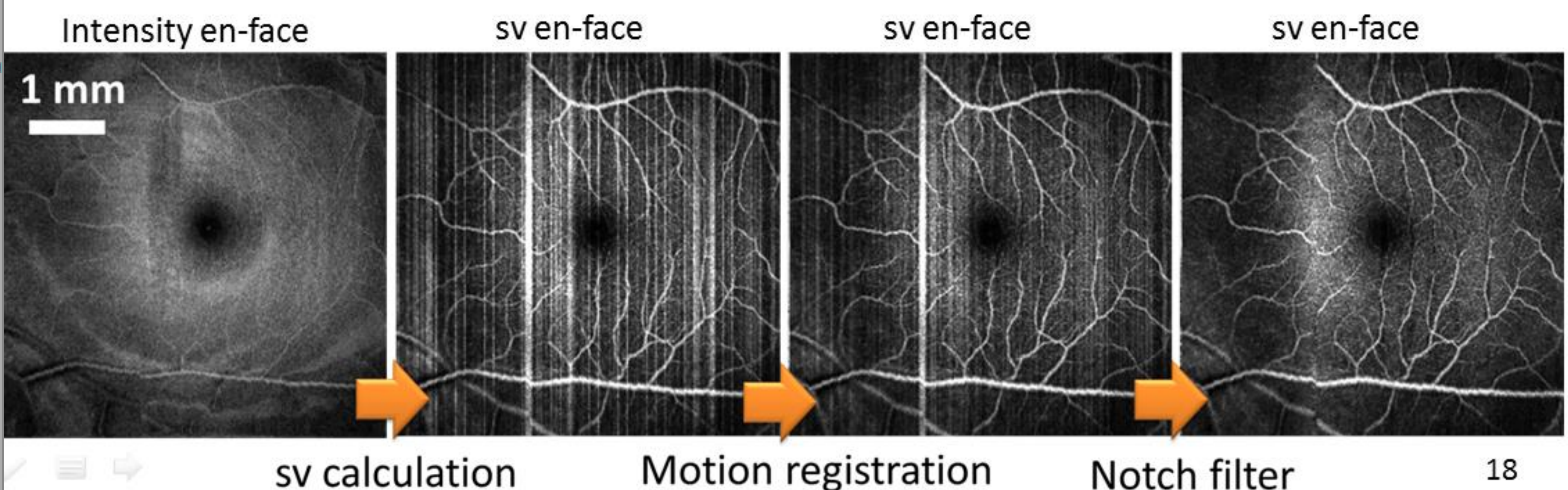




J. Xu et al. , *Journal of Biomedical Optics* **19**(2), 2014

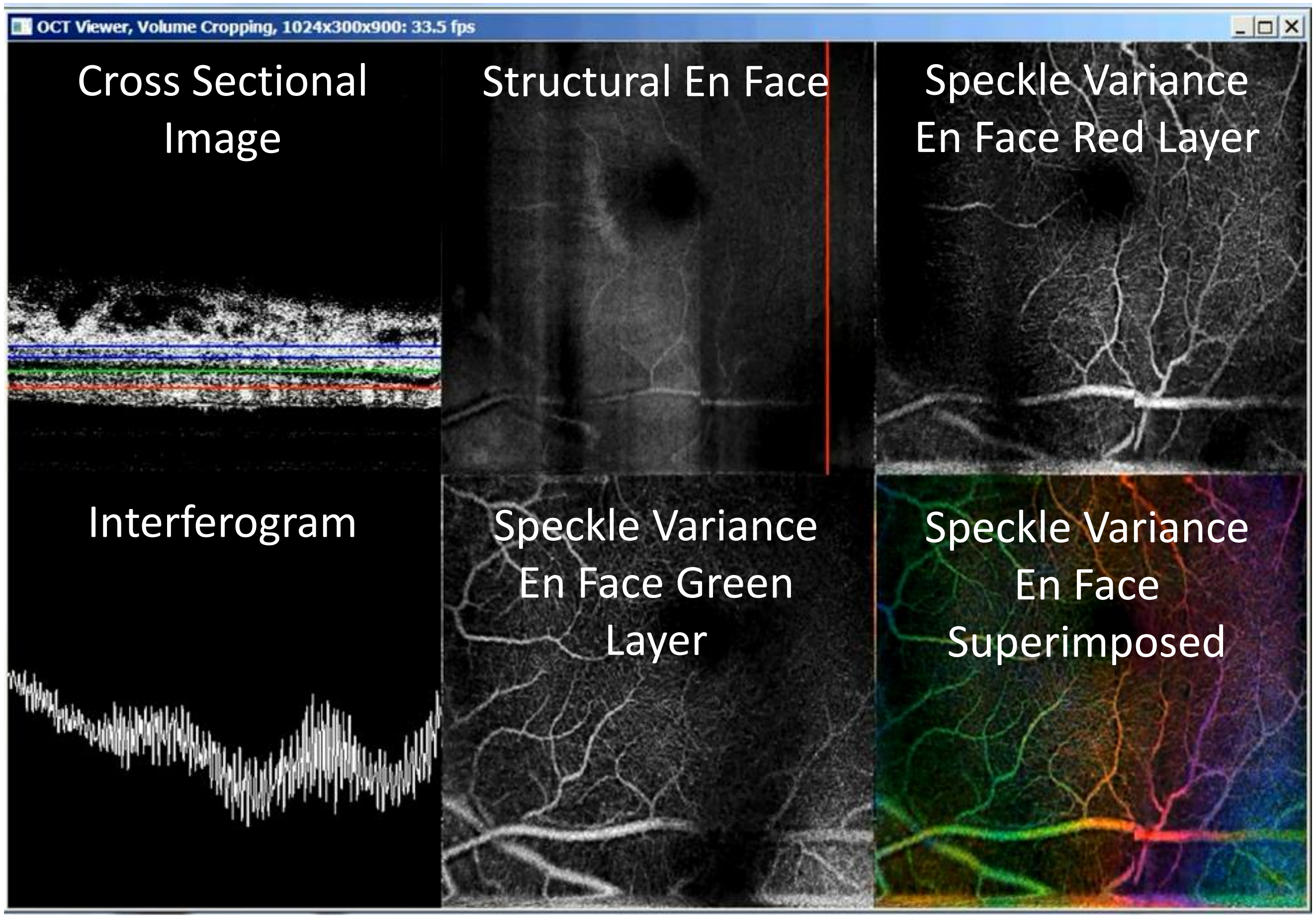
Speckle Variance OCT: Motion Correction

- Speckle variance volumes are 3x larger than normal
  - Susceptible to patient motion which leads to motion artifacts
- A GPU-based motion correction algorithm can correct small motion artifacts
- Remaining artifacts are removed using a notch filter



Speckle Variance OCT

- Demonstration of real-time speckle variance OCT



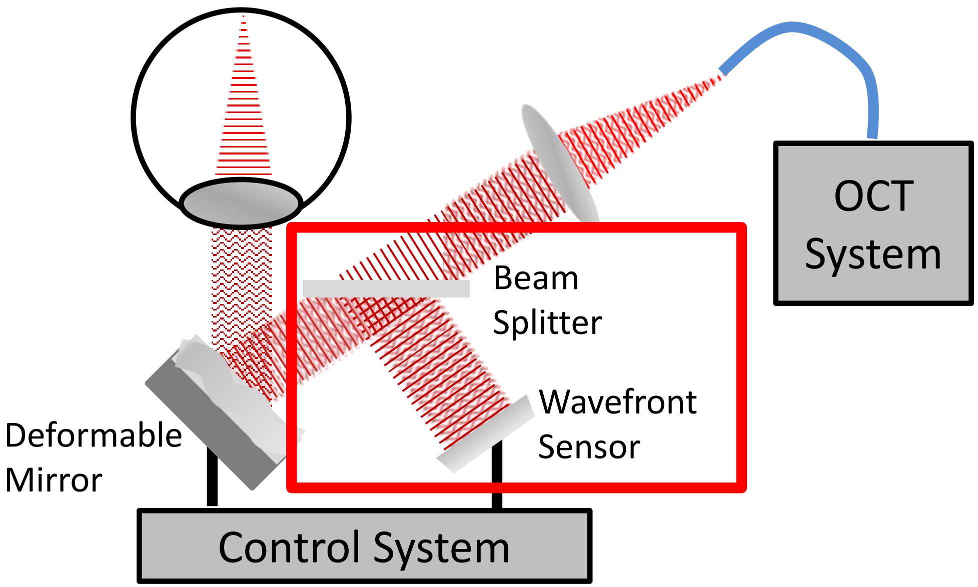
Video available at http://borg.ensc.sfu.ca/research/svoct-gpu-code.html

Adaptive Optics OCT

- Speckle Variance OCT can visualize vasculature, but optical resolution is limited
- Increasing optical resolution introduces more distortions due to imperfections in the lens and the sample
- We use adaptive optics, a technique borrowed from astronomy, to correct for these distortions

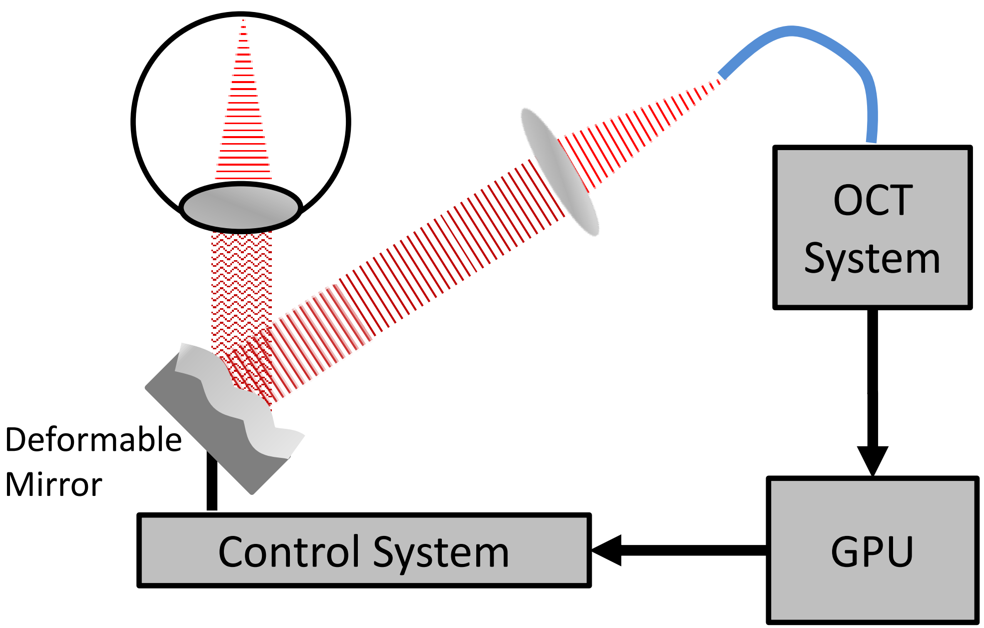
Adaptive Optics OCT: Topology

- AO-OCT uses deformable mirror to correct distortions
- A wavefront sensor is used to measure the distortions
- Accurate measurement of distortions is challenging with wavefront sensor



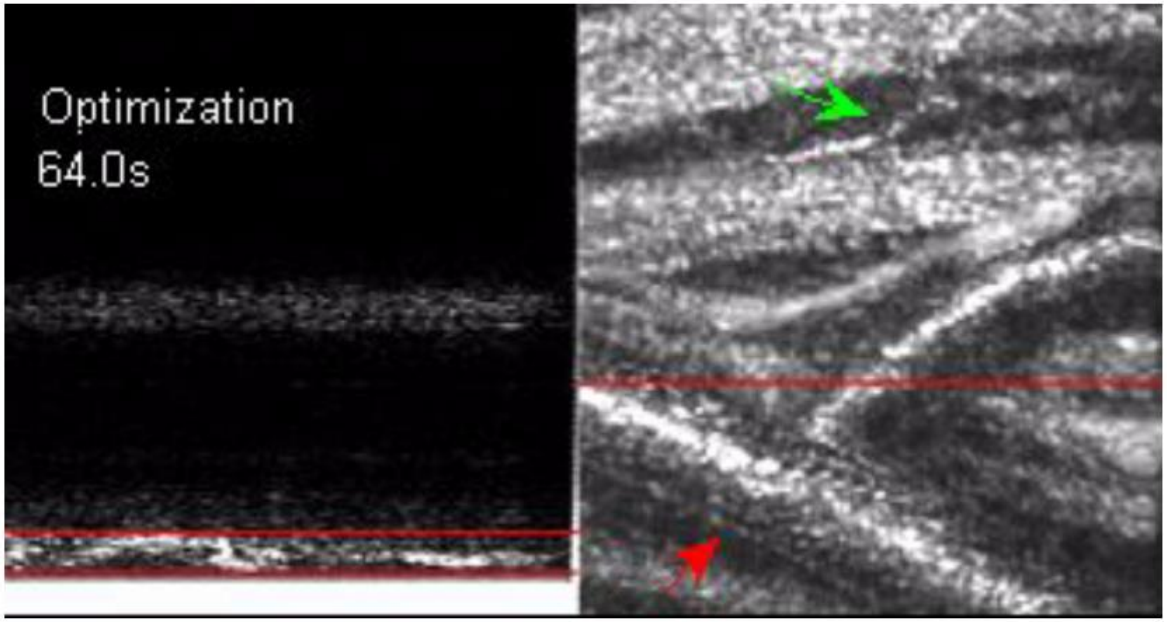
Wavefront Sensorless Adaptive Optics OCT

- Removing the wavefront sensor eliminates these issues
  - Use image quality as a metric to determine distortions
  - Leverage the GPU processing power for image analysis
  - Step through different mirror shapes, and evaluate each image



Wavefront Sensorless Adaptive Optics OCT

- Demonstration of Wavefront Sensorless Adaptive Optics OCT by leveraging GPU processing power



Video available at http://borg.ensc.sfu.ca/research/wsao-oct.html

Y. Jian et al. , *Biomedical Optics Express* **5**(2), 2014

OCT-Guided Microsurgery

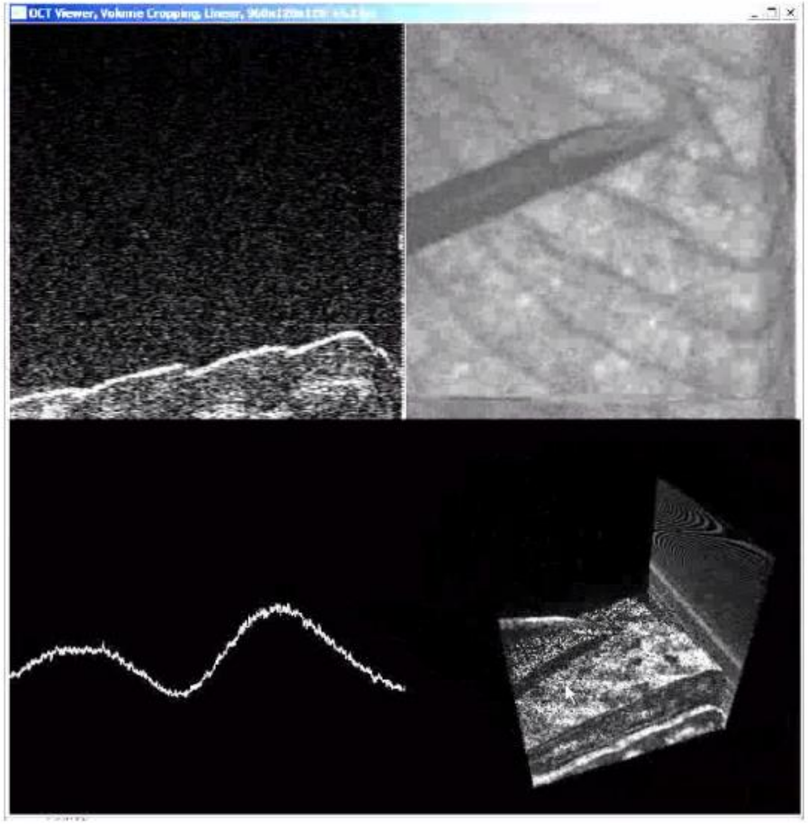
- Retinal surgeries are performed using a binocular microscope
- Provides stereo vision for tool placement, but no visualization of retinal layers

http://meditec.zeiss.com/meditec/en_de/products---solutions/ophthalmology/retina/therapy/surgical-microscopes/opmi-lumera-700.html , (Accessed March 26th, 2014)

OCT-Guided Microsurgery

- OCT-guided microsurgery can allow simpler real-time visualization

- Working towards this goal, we demonstrate real-time acquisition and processing at ~11 volumes/second



Video available at http://borg.ensc.sfu.ca/research/fdoct-gpu-code.html

Open Sourced GPU Code

- Open sourced projects and more information are available at:
  http://borg.ensc.sfu.ca/research/fdoct-gpu-code.html
  http://borg.ensc.sfu.ca/research/svoct-gpu-code.html
  http://borg.ensc.sfu.ca/research/wsao-oct.html

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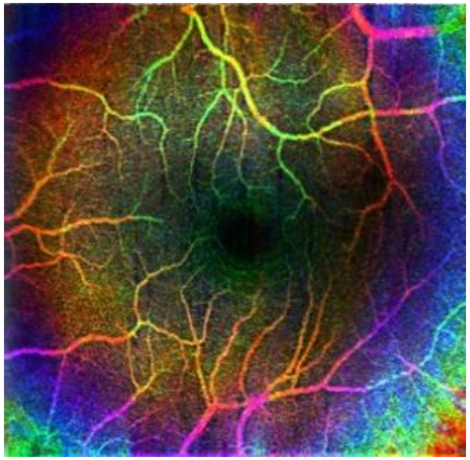
  - Marinko Sarunic – msarunic@sfu.ca



Acknowledgements

Biomedical Optics Research Group

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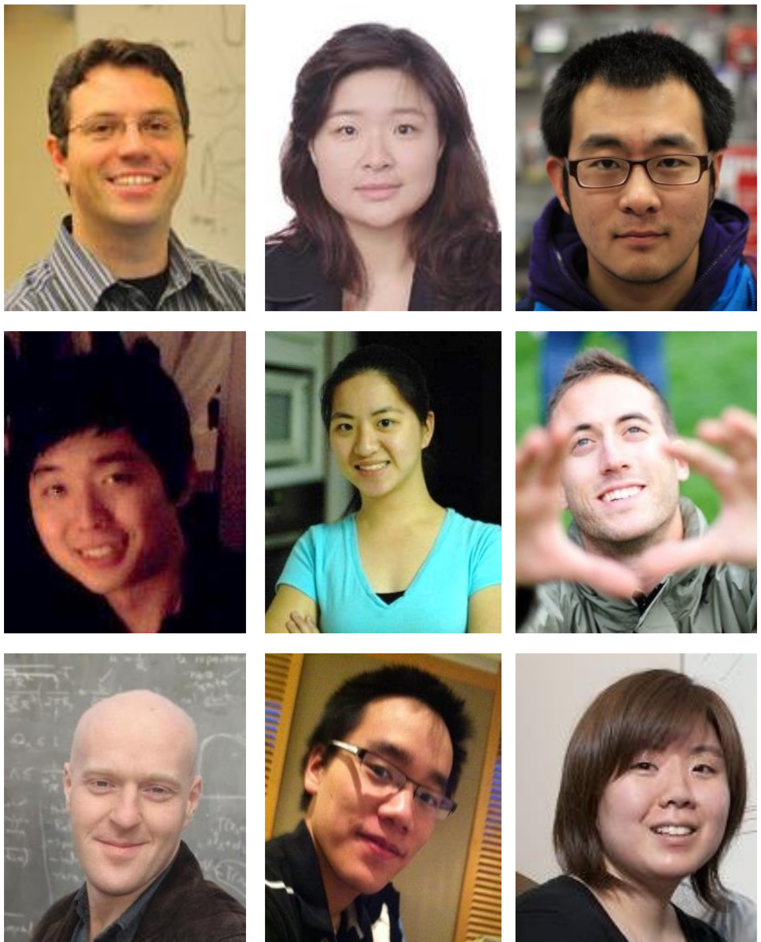

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Thank You