Visual Tracking of Surgical Tools in Retinal Surgery using Particle Filtering

Group 14
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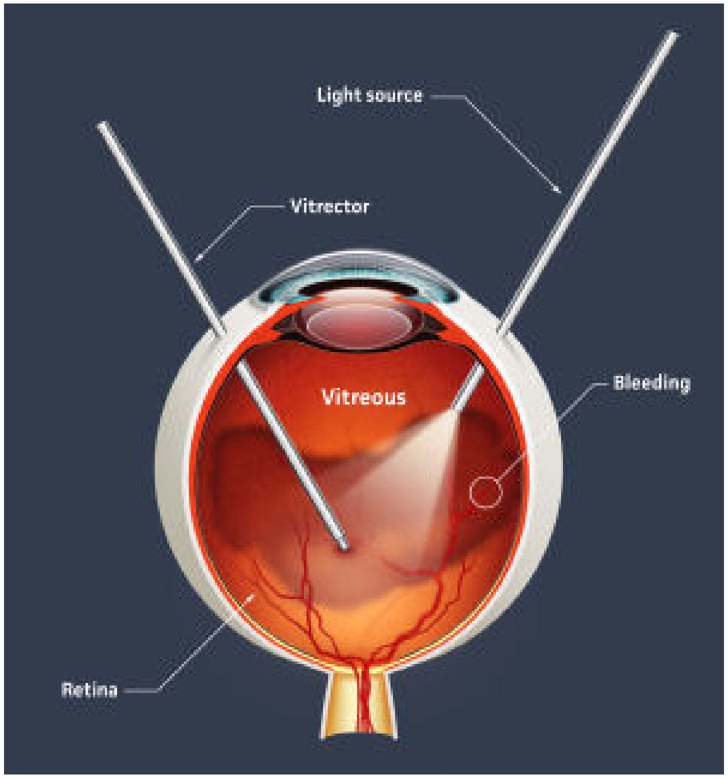
Project Background

- Vitreoretinal surgery treats problems with retina, macula, and vitreous fluid
- Many complications due to fragility of retina, indirect visualization, and physiological tremor
- Long operating times and risks of surgical error



http://www.eyedoctorguide.com/eye_problems/vitreoretinal_surgery_retina.html

Project Description

- Goal: Develop a direct visual tracking method for retinal surgical tools using particle filtering and mutual information
- Advantages:
  - Particle filter is computationally efficient and robust
  - Mutual information performs better than SSD and NCC in many cases
- Opportunity to parallelize computation in both particle filter and mutual information

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Research Paper

Mutual Information Computation and Maximization Using GPU

Yuping Lin and Gérard Medioni

Computer Vision and Pattern Recognition Workshops (CVPR)

Anchorage, AK, pp. 1-6, June 2008

Summary

- Problem:
  - Multi-modal registration of images is difficult to solve
  - Maximization of mutual information works but is slow
- Key result: Validated that calculation of mutual information can be parallelized on a graphics processing unit (GPU)
- Significance:
  - Use of mutual information to register multi-modal images can run in a reasonable amount of time

Mutual Information

$$h(v) = -\sum_{v} p(v) \ln(p(v))$$

$$h(u,v) = -\sum_{u,v} p(u,v) * \ln(p(u,v))$$

$$MI(u,v) = h(u)+h(v)-h(u,v)$$

Mutual Information Approximation

- "Viola's Approach" provides a closed form solution of derivatives
- Estimate probability density:

$$p(v) = (1/N_A) * \sum_{v_j \in A} G_\varphi(v-vj)$$

- Entropy:

$$h(v) \approx \frac{-1}{N_B} \sum_{v_i \in B} \ln \frac{1}{N_A} \sum_{v_j \in A} G_\psi(v_i - v_j)$$

Mutual Information Approximation

$$MI(u,v) \approx \frac{-1}{N_B}\left\{ \sum_{u_i \in B} \ln \frac{1}{N_A} \sum_{u_j \in A} G_{\psi_u}(u_i - u_j) + \sum_{v_i \in B} \ln \frac{1}{N_A} \sum_{v_j \in A} G_{\psi_v}(v_i - v_j) - \sum_{w_i \in B} \ln \frac{1}{N_A} \sum_{w_j \in A} G_{\psi_{uv}}(w_i - w_j) \right\}$$

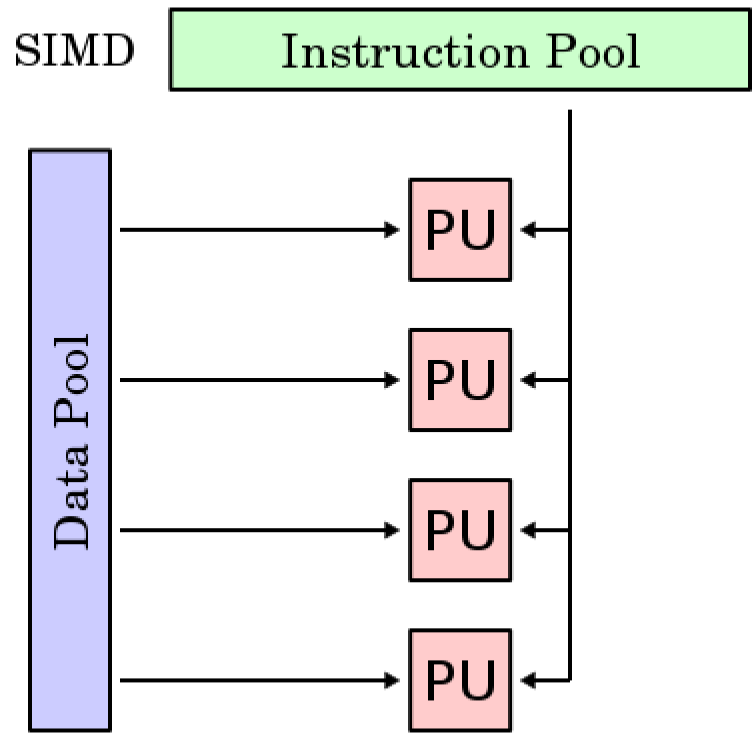
- Maximize this over a rigid transformation T using approximate derivative:

$$\frac{d}{dT} MI(I_u(x), I_v(T(x))) = \frac{1}{N_B} \sum_{x_i \in B} \sum_{x_j \in A} (v_i - v_j)^T W(x_i, x_j) \frac{d}{dT}(v_i - v_j)$$

Independent Calculations!

GPU/CUDA Architecture

- Single Instruction Multiple Data (SIMD) architecture



http://en.wikipedia.org/wiki/File:SIMD.svg

GPU/CUDA Architecture

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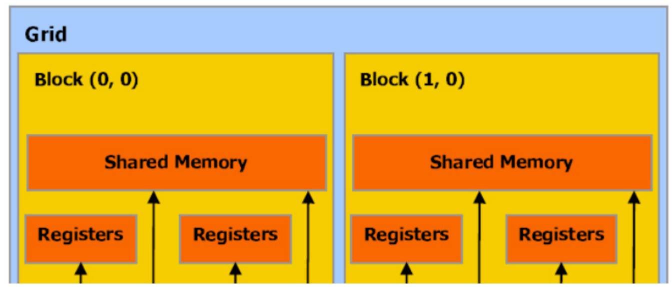
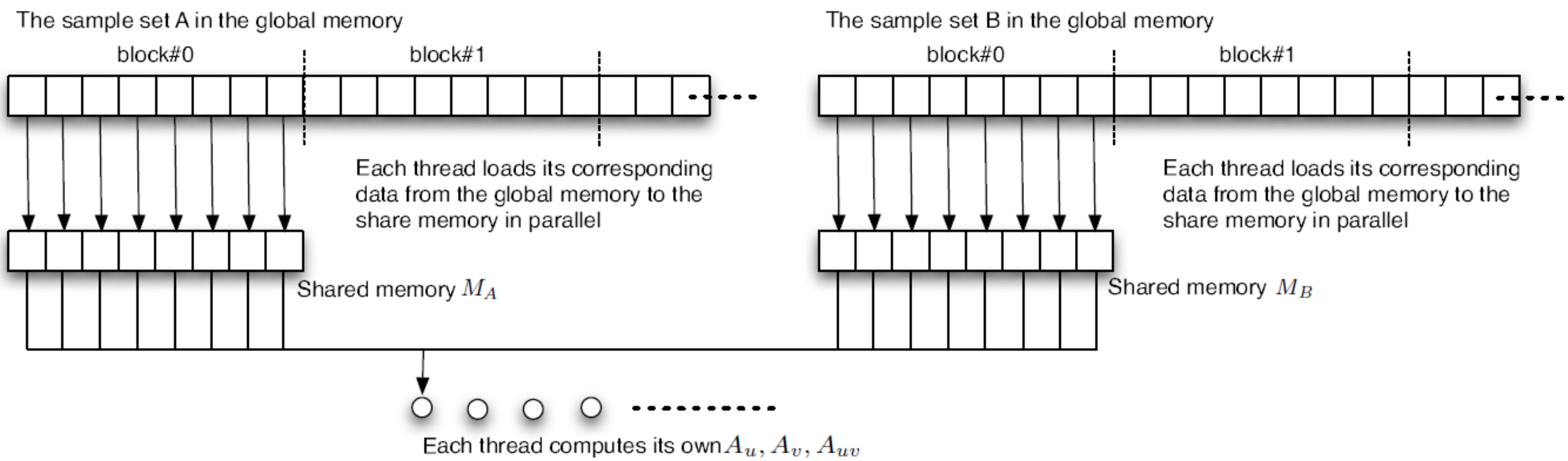
- Shared memory is key: on-chip and programmable





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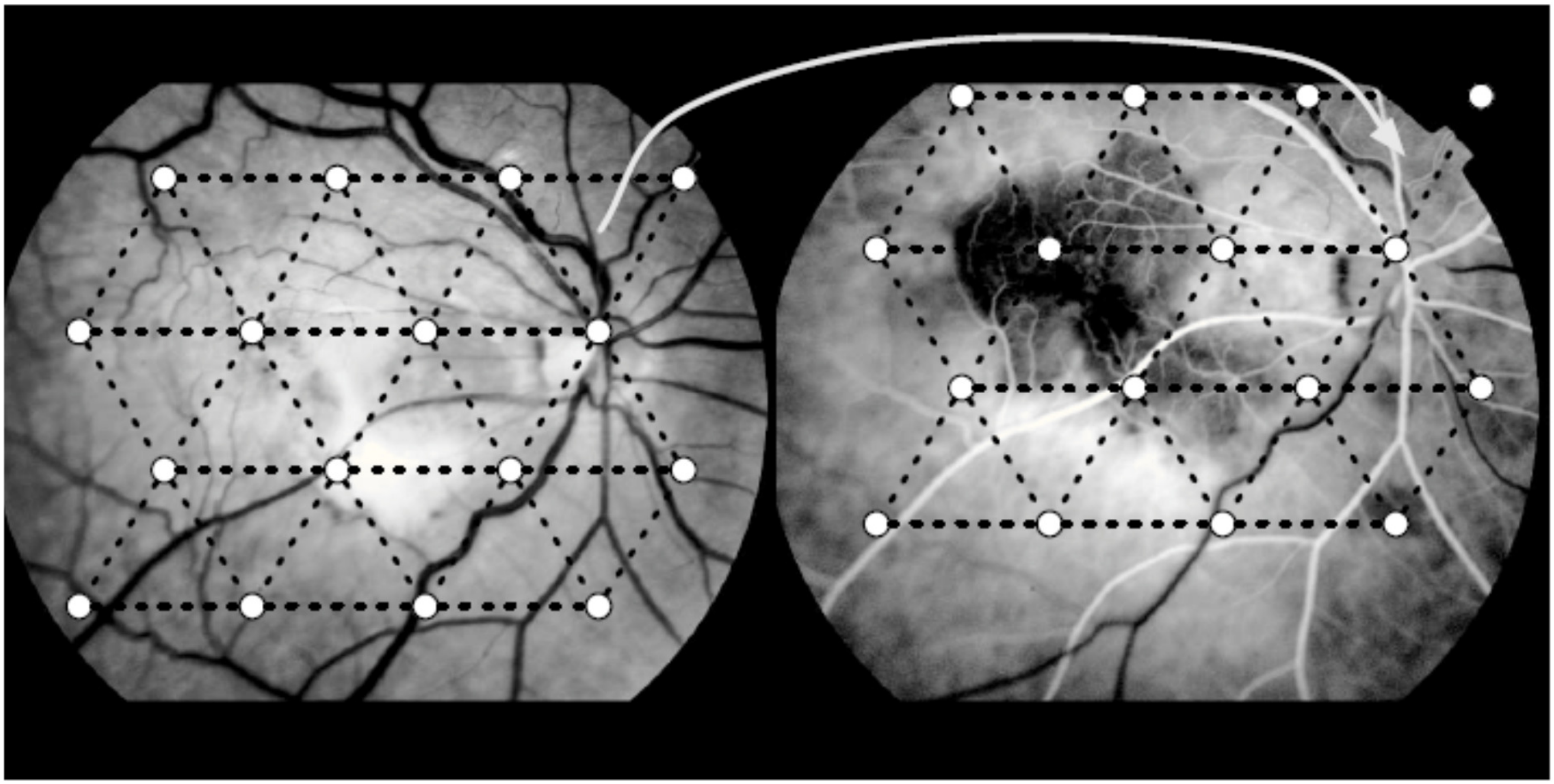
Validation and Results

Test dataset



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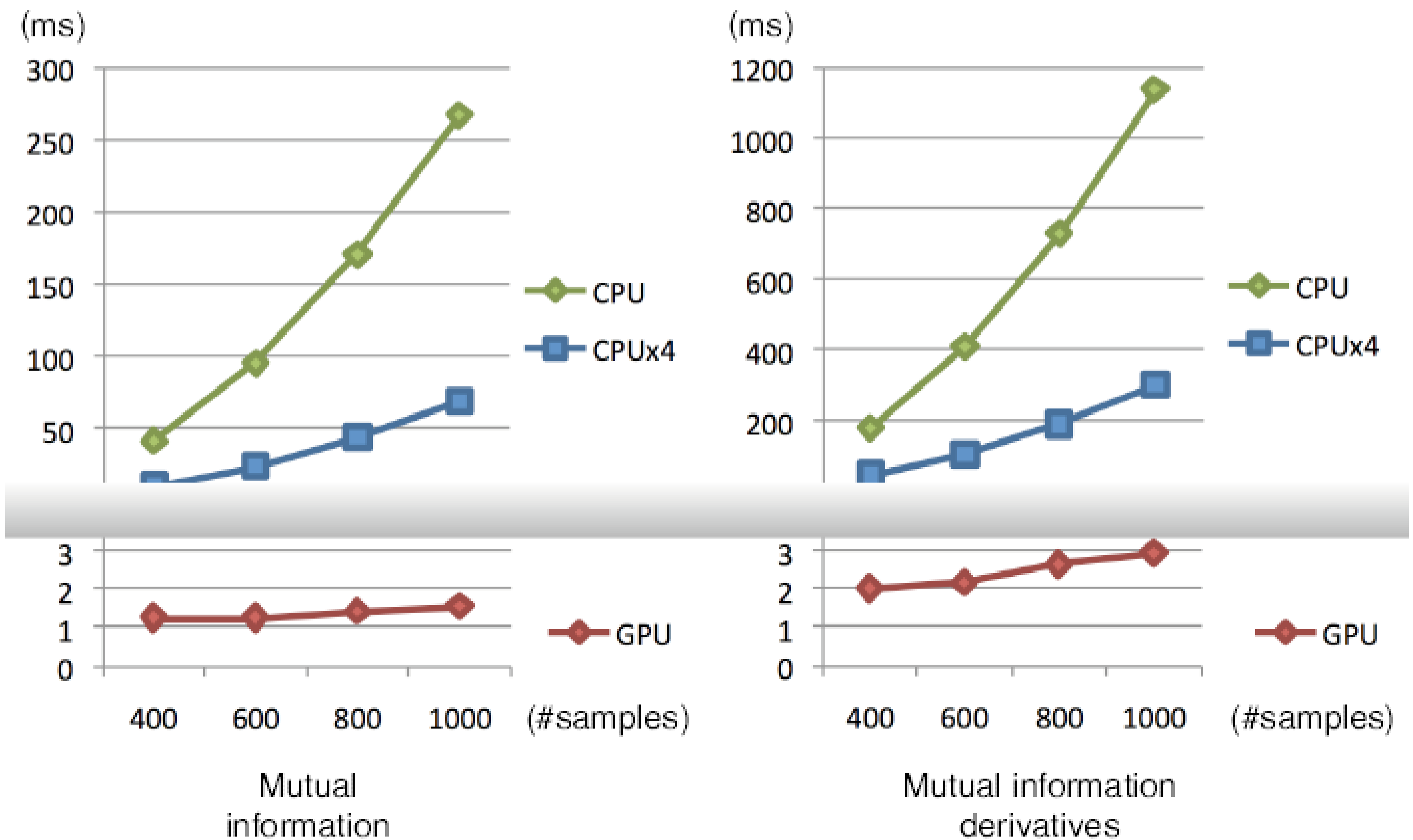
Validation and Results

Time to compute MI derivatives



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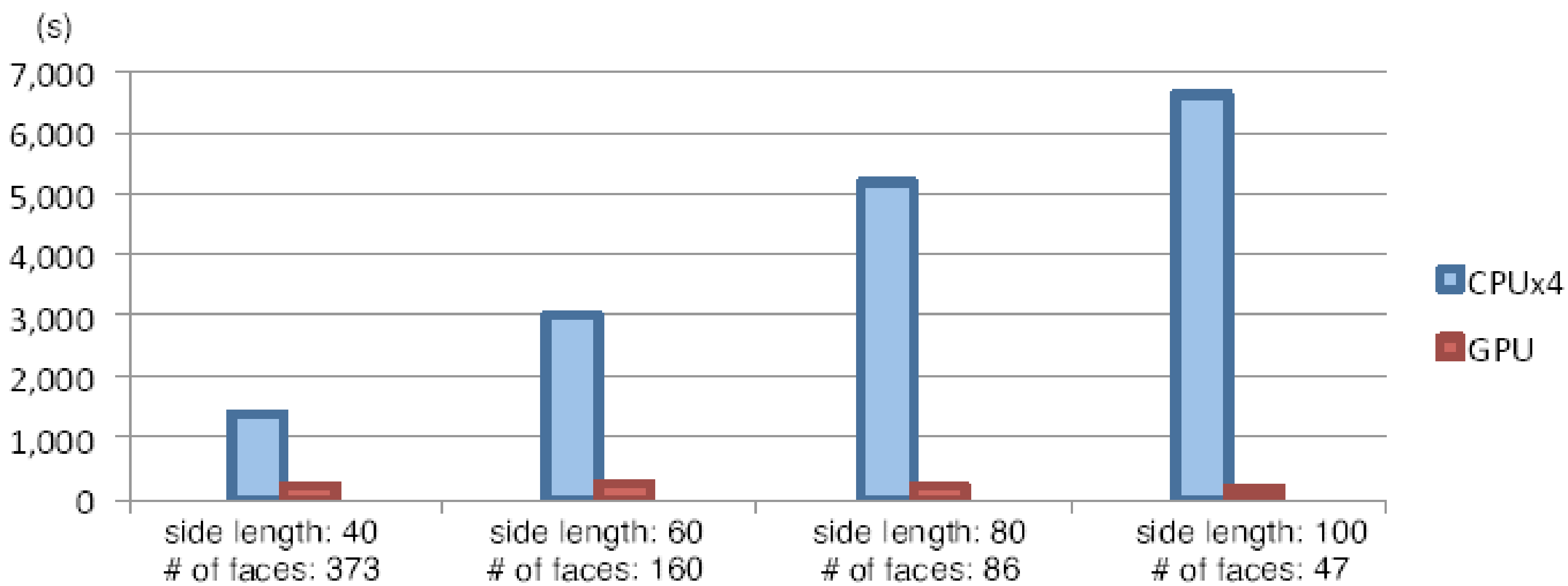
Validation and Results

Time to perform registration (50 iterations)



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Conclusions and Future Work

- Approximation methods and CUDA algorithm enables use of MI for image registration within a reasonable amount of time as compared to a CPU-based approach
- Integration into applications
- Performance of other MI approximations

Comments: Strengths

- Novel approach to solve problem
- Mathematical details presented adequately
- Pseudocode (serial execution) algorithm
- Description of computational hardware included

Comments: Weaknesses

- More information on test datasets
- No info on inter-trial variance in results
- Why was Viola's algorithm chosen?
- CPU memory bandwidth not discussed
- Future work: bilinear interpolation

Relevance to Project

- MI on GPU: high throughput!, but…
- MI calculation method differs
- Gradient descent: local minima problem
- Repeating many calculations of MI with low sample count
- Serial fast MI or parallel MI?

Reading List

- NVIDIA CUDA C Programming Guide 4.1. 2011
- R. Shams and N. Barnes. Speeding up mutual information computation using NVIDIA CUDA hardware. *Digital Image Computing Techniques and Applications*, pages 555–560, 2007.

Questions?