CUDA (Compute Unified Device Architecture) and OpenCL (Open Compute Language): Programming GPUs

Dr. Bharathwaj "Bharath" Muthuswamy

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February 20th 2018

CUDA (Compute Unified Device Architecture) and OpenCL (Open Compute Language): Programming GPUs

> Dr. Bharathwaj "Bharath" Muthuswamy

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Part II: OpenC

DTCNN and OpenCL



About me...

▶ BS (2002), MS (2005), PhD (2009) in EECS from the University of California, Berkeley (advisors: Dr. Leon O. Chua, Dr. Pravin P. Varaiya)

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About me...

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 - For my MS, I worked on biomimetic bipedal robotics using Central Pattern Generators (I did not work on this after 2006)
 - ► For my PhD, my primary contribution was designing, implementing and rigorously proving the existence of chaos in the Muthuswamy-Chua system (circuit): an inductor-capacitor-memristor circuit in series (parallel)

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 - For my PhD, my primary contribution was designing, implementing and rigorously proving the existence of chaos in the Muthuswamy-Chua system (circuit): an inductor-capacitor-memristor circuit in series (parallel)
- Areas of interest:
 - Computer vision and Quantum Computing
 - Nonlinear Dynamics (Circuits). Specifically: chaotic circuits and memristors

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► Embedded (FPGA) Systems and Education

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- ► Goal of this talk: Discuss GPU programming strategies (CUDA and OpenCL)

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 - ► Conclusion and Q/A



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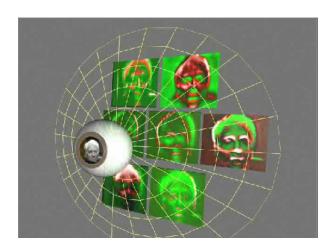
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Mammalian Retina



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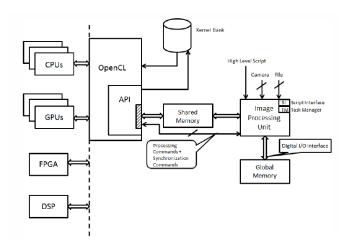
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Block Diagram of the Project



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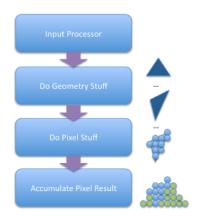
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Simple Raster Graphics Pipeline



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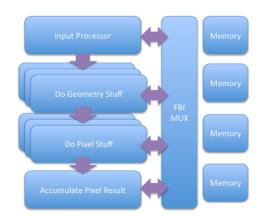
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Enhanced Graphics Pipeline



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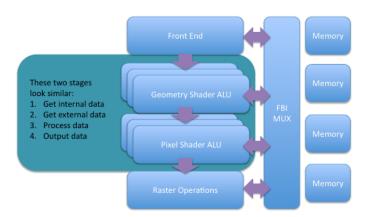
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General Purpose Pipeline



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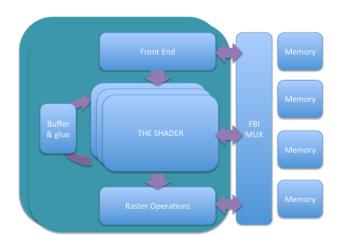
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Shader Pipeline



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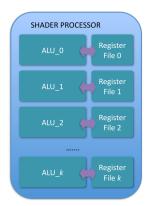
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SIMD Pipeline



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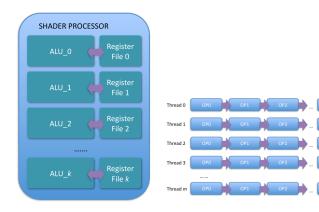
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SIMD Pipeline



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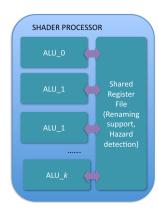
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SIMT Pipeline



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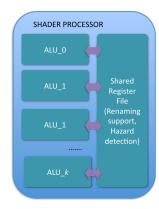
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CUDA: High-level overview

► Traditional serial version of the program...

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CUDA: High-level overview

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Traditional serial version of the program...

...that sets up subroutines or kernels that are to be executed in parallel



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CUDA Examples

http://www.harpgroup.org/muthuswamy/computerVision/CUDA/helloWorld

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CUDA Examples

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Part I: CUDA

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Think of OpenCL as a "personal robot army":

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- ▶ Think of OpenCL as a "personal robot army":
 - ► Each robot or **OpenCL work unit** works on specific data **independent** of other robots

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- ▶ Think of OpenCL as a "personal robot army":
 - Each robot or OpenCL work unit works on specific data independent of other robots
 - ► Each robot has a unique id, robots can be grouped

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- ▶ Think of OpenCL as a "personal robot army":
 - ► Each robot or **OpenCL work unit** works on specific data **independent** of other robots
 - ▶ Each robot has a unique id, robots can be grouped
- ► Limitation: data-parallelism (see example of DTCNN later)

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► Get list of available platforms

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- ► Get list of available platforms
- Use platforms to select appropriate device(s)

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- Get list of available platforms
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- ► Get list of available platforms
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- Get list of available platforms
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- Get list of available platforms
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- Get list of available platforms
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- Create kernel
 - ► Load kernel specified via OpenCL C-extension(s)

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- ► Create memory objects
- Create kernel
 - Load kernel specified via OpenCL C-extension(s)
 - Compile kernel to obtain kernel object

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 - Set any kernel parameters

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 - ► Set any kernel parameters
- Execute the kernel

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- Execute the kernel
- Read result from previously created memory object

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- Read result from previously created memory object
- ► Free memory

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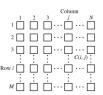
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(DT)CNN: Concept(s)

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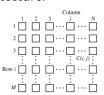
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(DT)CNN: Concept(s)

 $\blacktriangleright M \times N$ CNN architecture:



State equation and output equation (nonlinear):

$$\begin{split} \dot{x}_{ij} &= -x_{ij} + \sum_{C(k,l) \in S_r(i,j)} A(i,j;k,l) y_{kl} \\ &+ \sum_{C(k,l) \in S_r(i,j)} B(i,j;k,l) u_{kl} + z_{ij} \end{split}$$

$$y_{ij} &= \frac{1}{2} \left(|x_{ij} + 1| - |x_{ij} - 1| \right)$$

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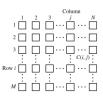
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ightharpoonup M imes N CNN architecture:



State equation and output equation (nonlinear):

$$\begin{split} \dot{x}_{ij} &= -x_{ij} + \sum_{\substack{C(k,l) \in S_r(i,j)}} A(i,j;k,l) y_{kl} \\ &+ \sum_{\substack{C(k,l) \in S_r(i,j)}} B(i,j;k,l) u_{kl} + z_{ij} \end{split}$$

$$y_{ij} = \frac{1}{2} (|x_{ij} + 1| - |x_{ij} - 1|)$$

► DTCNN:

$$\begin{split} X_{i,j}(t+1) &\approx \sum_{c(k,l) \in N} A\left(i,j;k,l\right) f\left(X_{k,l}(t)\right) \\ &+ \sum_{c(k,l) \in N} B\left(i,j;k,l\right) \ U_{k,l} + I \\ &= \mathbb{E} \quad \text{a.s.} \quad \mathbb{E} \quad \text{b.s.} \quad \mathbb{E} \end{split}$$

CUDA (Compute Unified Device Architecture) and OpenCL (Open Compute Language): Programming GPUs

Dr. Bharathwaj "Bharath" Muthuswamy

About me..

Goals and Organization

Conceptual Overv

Jnderstanding the Graphics Pipeline

Part I: CUDA

Part II: OpenCL

DTCNN and OpenCL



OpenCL flow

▶ DTCNN state equation can be written as:

$$x_{ij}(t+1) = T_A * y_{kl}(n) + T_B * u_{kl} + I$$

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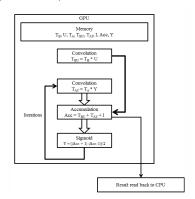


OpenCL flow

▶ DTCNN state equation can be written as:

$$x_{ij}(t+1) = T_A * y_{kl}(n) + T_B * u_{kl} + I$$

Proposed OpenCL implementation:



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Conclusion and Q/A

- Current work: Implementing various retinal "filters" via DTCNN using OpenCL
- ► Future work: post-processing of images obtained from hand-drawn electronic circuit diagrams:
 - Deep learning (?): Learn data representations, but use images obtained from retinal "filters". Note: it is known the visual cortex processes in parallel the images obtained from the retina
- *Potential* funding: https://www.grants.gov/web/grants/viewopportunity.html?oppId=300721
- Reference: Detailed howto and code is online: http://www.harpgroup.org/muthuswamy/computerVision

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