Graphics Processor Units (GPUs)

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# Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>BOK</td>
<td>Body of Knowledge (document)</td>
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<tr>
<td>CUDA</td>
<td>Compute Unified Device Architecture</td>
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<tr>
<td>DUT</td>
<td>Device Under Test</td>
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<tr>
<td>GPGPU</td>
<td>General Purpose Graphics Processing Unit</td>
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<tr>
<td>GPU</td>
<td>Graphics Processing Unit</td>
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<tr>
<td>MBU</td>
<td>Multi-Bit Upset</td>
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<tr>
<td>MGH</td>
<td>Massachusetts General Hospital</td>
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<tr>
<td>NEPP</td>
<td>NASA Electronic Parts and Packaging</td>
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<tr>
<td>PTX</td>
<td>Parallel Thread Execution</td>
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<tr>
<td>RTOS</td>
<td>Real Time Operating System</td>
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<tr>
<td>SBU</td>
<td>Single-Bit Upset</td>
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<tr>
<td>SEE</td>
<td>Single Event Effect</td>
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<tr>
<td>SEFI</td>
<td>Single Event Functional Interrupt</td>
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<tr>
<td>SEU</td>
<td>Single Event Upset</td>
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<tr>
<td>SIMD</td>
<td>Single Instruction Multiple Data</td>
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<tr>
<td>SoC</td>
<td>System on Chip</td>
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<tr>
<td>TID</td>
<td>Total Ionizing Dose</td>
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To be presented by Edward Wyrwas at the NASA Electronics Parts and Packaging (NEPP) Electronics Technology Workshop (ETW), Greenbelt, MD, June 26-29, 2017
Outline

• What the technology is (and isn’t)

• Our tasks and their purpose
  – The setup around the test setup
  – Parametric considerations
  – Lessons learned

• Collaborations
  – Roadmap
  – Partners
  – Results to date
  – Plans

• Comments
Technology

- Graphics Processing Units (GPU) & General Purpose Graphics Processing Units (GPGPU) are considered compute devices that behave like coprocessors
  - Take assignments from another device
  - Inability to load and execute code on boot by itself

- Using high-level languages, GPU-accelerated applications run the sequential part of their workload on the CPU – which is optimized for single-threaded performance – while accelerating parallel processing on the GPU.
Purpose

• GPUs are best used for single instruction-multiple data (SIMD) parallelism
  – Perfect for breaking apart a large data set into smaller pieces and processing those pieces in parallel

• Key computation pieces of mission applications can be computed using this technique
  – Sensor and science instrument input
  – Object tracking and obstacle identification
  – Algorithm convergence (neural network)
  – Image processing
  – Data compression algorithms
Device Selection

- Unfortunately, GPUs come in multiple types, acting as primary processor (SoC) and coprocessor (GPU)

Nvidia TX1 SoC

Intel Skylake Processor

Nvidia GTX 1050 GPU

AMD RX460 GPU

Smart Phones
Device Software

• Does it need its own operating system?
  – E.g. Linux, Android, RTOS

• Can we just push code at it?
  – E.g. Assembly, PTX, C

• Payload normalization
  – Can we run the same code on the previous generation and next generation of the device?
  – Cannot with CUDA code; can with OpenCL

Real-time Operating System (RTOS)
Parallel Thread Execution (PTX)
CUDA is a parallel computing platform and application programming interface (API) model created by Nvidia
Payloads

- **Visual Simulations**
  - Sample code
  - Fuzzy Donut (i.e. Furmark)
- **Sensor streams**
  - Camera feed
  - Offline video feed
- **Computational loading**
  - Scientific computing models
- **Easy Math**
  - $0 + 0 \ldots$ wait $\ldots$ should $= 0$

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Test Setup

• Things to consider in the test environment
  – Operating system daemons
  – Location of payload and results
  – Data paths upstream/downstream
  – Control of electrical sources
  – Temperature control (i.e. heaters) in a vacuum

• Things to consider in the DUT
  – Is the die accessible?
  – What functional blocks are accessible?
  – Which functions are independent of each other?
  – Does it have proprietary or open software?
Test Environment

- **Beam line**
  - DUT testing zone where collateral damage can happen
  - Shielding for everything non-DUT

- **Operator Area**
  - Cables, interconnects and extenders
  - Signal integrity at a distance
  - “Everything that was done in a lab, in front of you on a bench, now must be done from a distance…”
Test Environment (Cont’d)

- Hardware Info Gathering
  - Thermocouples

Does not include any in-situ monitoring capabilities of the payload software

- Power Supply Control Computer
  - Power Supply A
  - Power Supply B
  - Power Feed Switch Control

- GPU
  - Interposer
  - Riser Cable

- Headless Display
  - Real Display
  - IP Camera

- Motherboard
  - Network Access
  - Power Switch

- Software Info Gathering
  - GPU (I, V, P)
  - Motherboard (I, V, P)
  - Memory dump
  - System logs

- Operator Area
  - KVM
  - Laptop 1
  - Laptop 2

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Test Environment (Cont’d)

Tripod and mounting

External power

Power injection

**Arrows and circle** mark locations of the lead and acrylic block fortresses

Pictures are from Massachusetts General Hospital Francis Burr Proton Facility
Test Environment (Cont’d)

X-ray Test

Windows Machine - HWInfo

GPU

Linux NUC – Python Script, Logging from Power Supply Stack
DUT Health Status

- Accessible nodes
  - Network
    - Heart beat by inbound ping
    - Heart beat by timestamp upload
  - Peripherals response
    - “Num lock”
  - Visual check
    - Remote
    - Local
    - Local with remote viewing
- Electrical states
  - At the system
  - At the DUT
Monitoring Data

Voltage Rails

12V

... lines...

5V

3.3V

... noise...

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Monitoring Data (Cont’d)

- Significant digits are important
- Resolution is needed for correlation
  - Faster sampling speed
  - Smaller units (µV or mV, not Volts)
Monitoring Data (Cont’d)

• Even better (albeit being a mock up):
What does a failure look like?

- Request Timed Out
- Destination Host Unreachable
Failures (Cont’d)

Latchup situations

12 V Current

Dose (krad (CaF2))

Current (A)
Every test is another learning experience

- “Is the laser alignment jig in the beam path…”
- Nuances with controllable nodes
  - DUT power switch
  - Remote power sources
  - DUT electrical isolation from test platform
  - Thermal paths
- Improvements are always possible, but preparation time may not be as abundant
- Prioritization during development is important
  - Software payload
  - Hardware monitoring
  - Remote troubleshooting capabilities
GPU Roadmap
- collaborative with NSWC Crane, others

GPUs
- 14nm Nvidia GTX 1050
- 14nm AMD Radeon

GPGPUs
- 14nm Nvidia Tesla P100

Mobile System on Chip
- 20nm Nvidia Tegra X1
- 16nm Nvidia Tegra X2
- 14nm Intel HD Graphics

Neural Chips
- KnuEdge Hermosa
- KnuEdge Hydra

Radiation Testing
- Radiation Testing
- Radiation Testing
- Radiation Testing
- TBD
- TBD
- TBD
Partners

• Navy Crane
  – Conducting testing on Nvidia 14nm GPUs

• Collaboration with partners is yielding a comprehensive test suite
  – L1 and L2 cache
  – Registers
  – Shared, Internal, Texture and Global memory
  – Control logic
Qualification Guidance

- Creation of GPU Body of Knowledge (BoK) document
  - Technology
    - Silicon
    - Packaging
    - Heterogeneous constituents
  - Reliability
    - Semiconductor mechanisms
    - Package issues
    - Scaling issues
  - Failure categories and trends
  - Software & Hardware sources

- Future guidelines will be developed for this technology to include qualification and test methods
Results to Date

- Developing software for cross platform use
  - Nvidia Tegra X – SoC ARM with embedded Linux
  - Nvidia GPUs – GPU for x86 Windows and Linux
  - Intel Skylake Processor – IP Block for x86 Linux
  - Qualcomm Adreno & Mali GPU – IP Block for ARM Linux

- Proton test result ranges are dependent on physical target within DUT
  - Cross section ($\sigma$, cm$^2$): $1\times10^{-7}$ to $9\times10^{-9}$
  - Flux (p/cm$^2$/sec): $1\times10^6$ to $7\times10^6$
Plans (w Schedule)

– More proton testing on 14nm GPUs
  • Test OpenCL payloads
  • Test L1, L2, registers, shared memory & control logic
  • Record die temperature, 12V and 3.3V rail voltages and currents, system events (and observations)

– Two proton test sessions and significant in-lab work has permitted improvements to:
  • Thermal-electrical monitoring of the DUTs – though some more improvements are necessary to achieve the desired resolution
  • Proving out which code libraries won’t work for the type of testing we’re conducting
FY17-18: GPU Testing

Description:
- This is a task over all device topologies and process
- The intent is to determine inherent radiation tolerance and sensitivities
- Identify challenges for future radiation hardening efforts
- Investigate new failure modes and effects
- Testing includes total dose, single event (proton) and reliability. Test vehicles will include a GPU devices from nVidia and other vendors as available
  - Compare to previous generations
  - Investigate failure modes/compensation for increased power consumption

FY17-18 Plans:
- Continue development of universal test suite
- Probable test structures for SEE:
  - Nvidia (16, 14, 10nm)
  - AMD (14nm)
  - Intel (14nm)
- Tests:
  - characterization pre, during and post-rad

Schedule:

<table>
<thead>
<tr>
<th>Microelectronics T&amp;E</th>
<th>FY17</th>
<th>FY18</th>
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<tr>
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<td>M</td>
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<tr>
<td>On-going discussions for test samples</td>
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<td>GPU Test Development</td>
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<td>SEE Testing</td>
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<tr>
<td>Analysis and Comparison</td>
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Deliverables:
- Test reports and quarterly reports
- Expected submissions for publications

NASA and Non-NASA Organizations/Procurements:
- Source procurements: Proton (MGH), TID (GSFC)

Pls: GSFC/Lentech/Wyrwas
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Conclusion

- NEPP and its partners have conducted proton, neutron and heavy ion testing on several devices
  - Have captured SEUs (SBU & MBU),
  - Have seen traceable current spikes,
  - But predominately have encountered system-based SEFIs

- GPU testing requires a complex platform to arbitrate the test vectors, monitor the DUT (in multiple ways) and record data
  - None of these should require the DUT itself to reliably perform a task outside of being exercised

- Progress has been made in proving out multiple ways to simulate and enumerate activity on the DUT
  - Narrowing down on a universal test bench
  - End goal is to make test code platform independent
Acknowledgement

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