Improving Performance Portability of the Procedurally Generated High Energy Physics Event Generator MadGraph Using SYCL.

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Introduction – Portable Solutions in High Energy Physics

• Introduction
  • What is MadGraph?
  • High level overview
  • A look inside the main kernel

• Performance and Scaling
  • Single Node
  • SYCL vector types
  • HPC machine runs
MadGraph – Advancing HEP with SYCL

- What is MadGraph?
- Role in High Energy Physics
  - Generating Feynman Diagrams
  - Calculating Cross-Sections
  - Event Generation
- Integral for Research
  - Facilitates High Energy Physics Studies
  - Using SYCL enables Cross-Platform Portability
$e^+ e^- \rightarrow \mu^+ \mu^-$

$gg \rightarrow t\bar{t}$

$gg \rightarrow t\bar{t}g$

<table>
<thead>
<tr>
<th>Process</th>
<th>Generated Function Calls</th>
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<tbody>
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$gg \rightarrow t\bar{t}gg$
Experimental Setup – Hardware + Software Environment

• Hardware Specifications
  • JLSE Testbed
    • Nvidia A100
    • Nvidia V100
    • AMD MI50
    • AMD MI100
    • AMD MI250
    • Skylake 8180M
  • ALCF Clusters
    • Aurora*
    • Sunspot*
    • Polaris

• Software Tools
  • oneAPI DPC++
  • GCC 11.3
  • CUDA 11.4 and 11.8
  • ROCm 4.5.0 and ROCm 4.5.3

*Intel provided access to early experimental versions of oneAPI DPC++ to target the Intel GPUs
Results – Performance Comparison

\[ e^+ e^- \rightarrow \mu^+ \mu^- \]

- CUDA
- OpenMP
- SYCL

Matrix Elements Per Second [s^{-1}]

- XE-HPC
- Xeon 8180
- MI50
- MI100
- MI250
- V100 SXM2
- A100

Logarithmic scale
Results – Performance Comparison

$gg \rightarrow t\bar{t}gg$

- XE-HPC
- Xeon 8180
- MI50
- MI100
- MI250
- V100 SXM2
- A100

Matrix Elements
Per Second [s⁻¹]

- CUDA
- OpenMP
- SYCL
Results – Parameter Scaling on Single-Node Devices

$e^+e^- \rightarrow \mu^+\mu^-$

check.exe EventsPerIteration/256 256 10

Throughput (Matrix Elements per Second)

EventsPerIteration

- A100
- XE-HPC
Results – Parameter Scaling on Single-Node Devices
Performance on the CPU?

typedef sycl::vec<fptype, MGONGPU_VEC_DIM> fptype_sv;
typedef sycl::vec<long, MGONGGPU_VEC_DIM> int_sv;
typedef sycl::vec<long, MGONGGPU_VEC_DIM> bool_sv;
#if defined MGONGGPU_COMPLEX_CXSMPL
    typedef mgOnGpu::cxsmpl<fptype_sv> cxttype_sv;
#elif defined MGONGGPU_COMPLEX_EXTRAS
    typedef extras::complex<fptype_sv> cxttype_sv;
#elif defined MGONGGPU_COMPLEX_STD
    typedef std::complex<fptype_sv> cxttype_sv;
#elif MGONGGPU_COMPLEX_ONEAPI
    typedef sycl::ext::oneapi::experimental::complex<fptype_sv> cxttype_sv;
#elif MGONGGPU_COMPLEX_CUTHRUST
    typedef thrust::complex<fptype_sv> cxttype_sv;
#elif MGONGGPU_COMPLEX_SYCLCPLX
    typedef sycl::ext::cplx::complex<fptype_sv> cxttype_sv;
#else
    #error Unconfigured vector complex type. Add details to `mgOnGpuVectors.h` or set MGONGGPU_VEC_DIM to 1 in `mgOnGpuConfig.h`.
#endif
Results – SYCL Vector Type vs. Vector Intrinsics

gg→ťεgg: Single-Threaded
check.exe EventsPerIteration/8 8 10

Throughput (norm)

EventsPerIteration

- OpenMP: double (AVX-512F)
- SYCL: double
- SYCL: vec<double, 2>
- SYCL: vec<double, 4>
- SYCL: vec<double, 8>
Results – SYCL Vector Type vs. Vector Intrinsics

**gg→t̃gg**: Multi-Threaded

check.exe EventsPerIteration/8 8 10

- OpenMP: double (AVX-512F)
- SYCL: double
- SYCL: vec<double, 2>
- SYCL: vec<double, 4>
- SYCL: vec<double, 8>

Throughput (norm)

EventsPerIteration

2 Intel Skylake 8180M
MadGraph Workflow – A Simplified Diagram
Results – Kernel Performance at Small Scale
Results – Parameter Scaling on Single-Node Devices
Results – Kernel Performance at Small Scale
Results – Timing Components on Different HPC Systems
Time Spent in SYCL per rank on Aurora

(12 ranks per node)
Summary of Findings

• Portable Solution for Event Generation
• SYCL Performance
  • Similar or better than native implementations
• Parameter Scaling
  • Fine tune for better performance
• SYCL Vector Types
  • A vectorization route for complex codebases
• Scaling on Different Systems
  • Code scales efficiently
Acknowledgments

This research used resources of the Argonne Leadership Computing Facility, which is a DOE Office of Science User Facility supported under Contract DE-AC02-06CH11357.

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Questions?
Hardware Specifications – JLSE (Supplemental)

• Nvidia A100
  • Model: Gigabyte G242-Z11
  • CPU: AMD 7532 32c 2.4Ghz
  • RAM: DDR4-3200 256GB
  • GPU: 1x Nvidia A100 40GB PCIe 4.0
  • Networking: Mellanox ConnectX-6 EDR
  • Storage: Intel P4510 2TB NVMe

• Nvidia V100
  • Model: SuperMicro SuperServer 1029GQ-TVRT
  • CPU: 2x Intel Xeon Gold 6152 22c 2.10GHz
    • RAM: 192GB DDR4-2666
    • GPU: 4x Nvidia Tesla V100 SXM2 w/32GB HBM2
    • Networking: Mellanox ConnectX-5 EDR

• Skylake
  • Model: Intel S2600WF
  • CPU: 12 - 2x Intel Xeon Platinum 8180M CPU @ 2.50GHz
  • RAM: 768GB
  • Networking: EDR IB
  • Storage: Intel P4500 1TB NVMe SSD, Intel P4800X 375GB NVMe Optane SSD

• AMD MI50
  • Model: Gigabyte G482-Z51
  • CPU: 2x AMD EPYC 7742 64c Rome
  • GPU: 4x AMD MI50 32GB GPUs
  • RAM: 256GB DDR-3200 RAM
  • Networking: Infinity Fabric

• AMD MI100
  • CPU: 2x AMD EPYC 7543 32c (Milan)
  • GPU: 4x AMD MI100 32GB GPUs
  • RAM: 512GB DDR4-3200
  • Networking: Infinity Fabric

• AMD MI250
  • Model: Supermicro A5-4124GQ-TNMI
  • CPU: 2x AMD EPYC 7713 64c (Milan)
  • GPU: 4x AMD Instinct MI250 64GB HBM2e PCIe Gen4
  • RAM: 512GB DDR4-3200
  • Networking: EDR InfiniBand
ALCF System Details (Supplemental)

• Polaris
  • CPU: AMD EPYC Milan 7543P 32 core
  • RAM: 512 GB DDR4
  • GPUs: 4 Nvidia A100 with NVLink
  • Storage: 1.6TB SSD RAID0 per node
  • Network: Slingshot 10 (upgrading to Slingshot 11 in 2023)
  • Total Nodes: 560

• Aurora (Brief Overview)
  • CPUs: 2 Intel Xeon CPU Max Series processors
  • RAM: 64GB HBM on each, 512GB DDR5 each
  • GPUs: 6 Intel Data Center GPU Max Series
  • Network: 8 Slingshot 11 fabric endpoints
  • Total Nodes: 10624

• Sunspot (Testbed System Identical to Aurora)
  • Total Nodes: 128
Multiple Ranks to Fill GPUs

\[ gg \rightarrow t\bar{t}gg \]