Accelerated tracking using GPUs at CMS High Level Trigger

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On behalf of the CMS Collaboration

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• Today the online farm consists of ~20k Intel Xeon cores
  – One event per logical core
• At the moment tracks are not reconstructed for all the events at the HLT
  – In 2016: 64% and 44% of events run pixel clustering and pixel tracking respectively
• This will be even more difficult at higher pile-up
  – Combinatorics time in seeding O(μ!)
  – More memory/event
• Profit from the end-of-year upgrade of the Pixel to redesign the seeding code
  – Exploiting the information coming from the 4th layer would improve efficiency, b-tag, IP resolution
• GPUs are becoming wider
  – Thousands of threads on the fly
• Future-proof solution: scaling parallel algorithms inside the event

average processing time 149 ± 1 ms

full track reconstruction and particle flow e.g. jets, tau
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From RAW to Tracks during run 3

- Trigger avg latency should stay within 220ms
- Reproducibility of the results (bit-by-bit equivalence CPU-GPU)
- Integration in the CMS software framework

Ingredients:
- Massive parallelism within the event
- Independence from thread ordering in algorithms
- Avoid useless data transfers and transformations
- Simple data formats optimized for parallel memory access

Result:
- A GPU based application that takes RAW data and gives Tracks as result
Algorithm Stack

- Raw to Digi
- Hits - Pixel Clusterizer
- Hit Pairs – FKDTTree*
- Ntuplets - Cellular Automaton

*See talk “Fast GPU Nearest Neighbors search algorithms for the CMS experiment at LHC”
Triplet propagation
Propagate 1-2-3 triplet to 4th layer and search for compatible hits

Natural continuation of the current approach from pairs to triplets

Cellular Automaton
Create hit pairs from pairs of adjacent layers
Join compatible pairs that share hits
Compatibility checked

Evolution step, analogous to Game of Life, creates quadruplets
Calculations are simple, and localized in memory, straightforward to parallelize efficiently
Physics performance ttbar 50 pileup

CMS Simulation, 2017
Preliminary

<PU> = 50

Triplet propagation
GPU Pixel Tracking

efficiency

ratio

track $\eta$

track $p_T$ [GeV]
Physics performance $t\bar{t}$bar 50 pileup
Events with PU50 are not getting even close to saturate the GPU

- Only 2-5% of the GPU busy
- ~100MB GPU DRAM used per event
- This allows us to offload many events on the same GPU by many threads

<table>
<thead>
<tr>
<th></th>
<th>time per event CPU (ms)</th>
<th>time per event GPU (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triplet propagation</td>
<td>66.3</td>
<td>N/A</td>
</tr>
<tr>
<td>CA</td>
<td>22</td>
<td>1.6 (15.2)</td>
</tr>
</tbody>
</table>

- Hardware used:
  - CPU Intel 4771K
  - GPU NVIDIA K40
Motivation for the CA before run3

• A gradual restructure of the code at algorithmic level
  – Make use of parallel friendly algorithms
  – At the beginning of run 3 we won’t need to compare apples to oranges
  – Sequential CA produces exactly the same results as the parallel CA
  – Expose parallelism

• Porting from CUDA to sequential C++
  – 2x speedup wrt 2016 pixel tracking
  – 5x less fake rate wrt 2016
Integration in the HLT Farm

- Different possible ideas depending on:
  - the fraction of the events running tracking
  - other parts of the HLT reconstruction requiring a GPU

Filter Units

Today

Builder Units

CMS FE, Read-out Units
Integration in the HLT Farm

- A part of the farm is dedicated to a high density GPU cluster
- Tracks (or other physics objects like jets) are reconstructed on demand
Integration in the HLT Farm

- Every FU is equipped with GPUs
  - tracking for every event

Option 2

GPU Filter Units

Builder Units
• Builder units are equipped with GPUs:
  – events with already reconstructed tracks are fed to FUs with GPUDirect
  – Use the GPU DRAM in place of ramdisks for building events.
Conclusion

• Redesign of algorithms for parallel architectures will allow us to deal with the astonishing and always increasing performance of the LHC
  – Improvements in performance may come even when running sequentially
• The GPU and CPU algorithms run in CMSSW and produce the same bit-by-bit result
• Running Pixel Tracking at the CMS HLT will become cheap even with PU ~ 50 – 70
• What’s next:
  – Merge all the standalone demonstrators in a single one from RAW data to Tracks
  – Measure performance for HL-LHC pileup conditions (i.e. PU ~ 140-200)
Questions?

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