Maximizing GPU Throughput Across Multiple Streams – Tips and Tricks

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Discussion Today

- Why use GPU streams?
- Stream Basics
- Example use cases
- cudaMemcpyAsync
- Custom Thrust allocator

Examples used in this presentation is available at:
https://github.com/chuckseberino/CCT.git

Why Use GPU Streams?

- Use streams when you have more than one kernel that can be executed simultaneously
  - Could be several compute tasks for an aggregated result
  - Could be completely independent work products

- Better utilization of resources – shared memory, compute, thread blocks
- Provides more opportunities for kernel scheduler to insert more work when other kernels stall

Basics of Stream Usage

Create additional streams:

- cudaStreamCreateWithFlags(&stream, *cudaStreamNonBlocking*)

Issue kernel/CUDA calls on proper stream:

- kernel<<<grid, block, shmem, *stream*>>>(args)
- cudaMemcpyAsync(dst, src, size, kind, *stream*)

Create and use events for synchronization:

- cudaEventCreate(), cudaEventRecord(), cudaStreamWaitEvent()

When using more than one stream, never use default stream:

- Remove implicit synchronization with default stream
- Makes it easier to debug default stream problems
- Helps to identify and fix synchronization bugs
- Able to verify in NVVP correct behavior

First Priority – Schedule “Enough” Work

- Make sure there are always 16-32x the number of threads queued
  - 4,000 cores = 64k to 128k threads of work
  - Provides enough work to allow the kernel scheduler to maximize functional units and hide memory latency.
- What if my kernel doesn’t use that much parallelism?
- What if my kernel uses (much) more than 32x?
  - Limited return or even degradation in performance
  - Reduce parallelism by making “fatter” threads

Example 1 – Combine Components

Problem: One ore more kernels don’t individually create enough work, but they are independent calculations

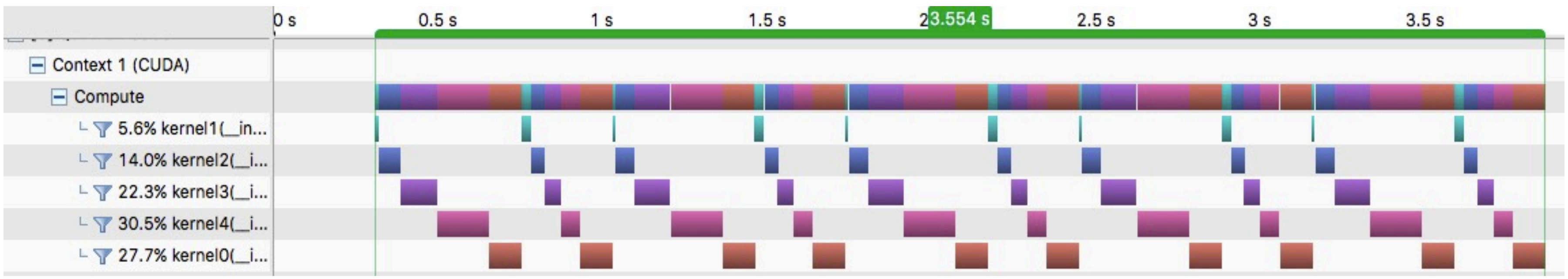
Solution: Run them concurrently and synchronize their completion

- Create a separate stream for each component
- Place an event record in each stream after kernel call
- Have the aggregation stream wait on all event records of component streams

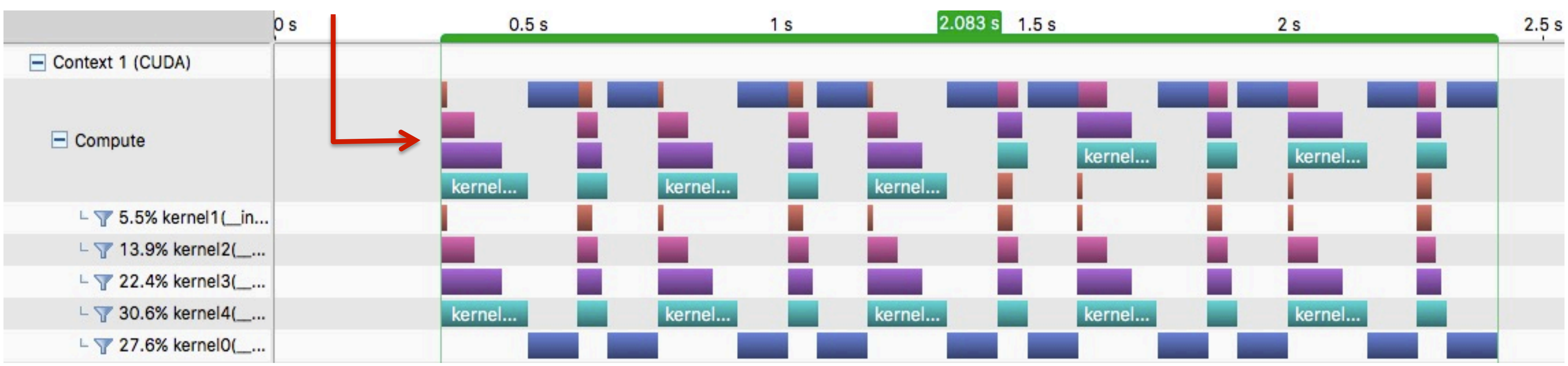
- Events work across GPU devices and CPU threads
  - Make sure that a cudaStreamWaitEvent() is issued **after** the cudaEventRecord() has been placed in the stream.
  - Particularly important when working across CPU threads.
    - Use CPU synchronization primitives to guarantee order.

Example 1 - Parallelize Along Work Components

- Kernel{1-4} create independent sub-results that are aggregated in Kernel0.

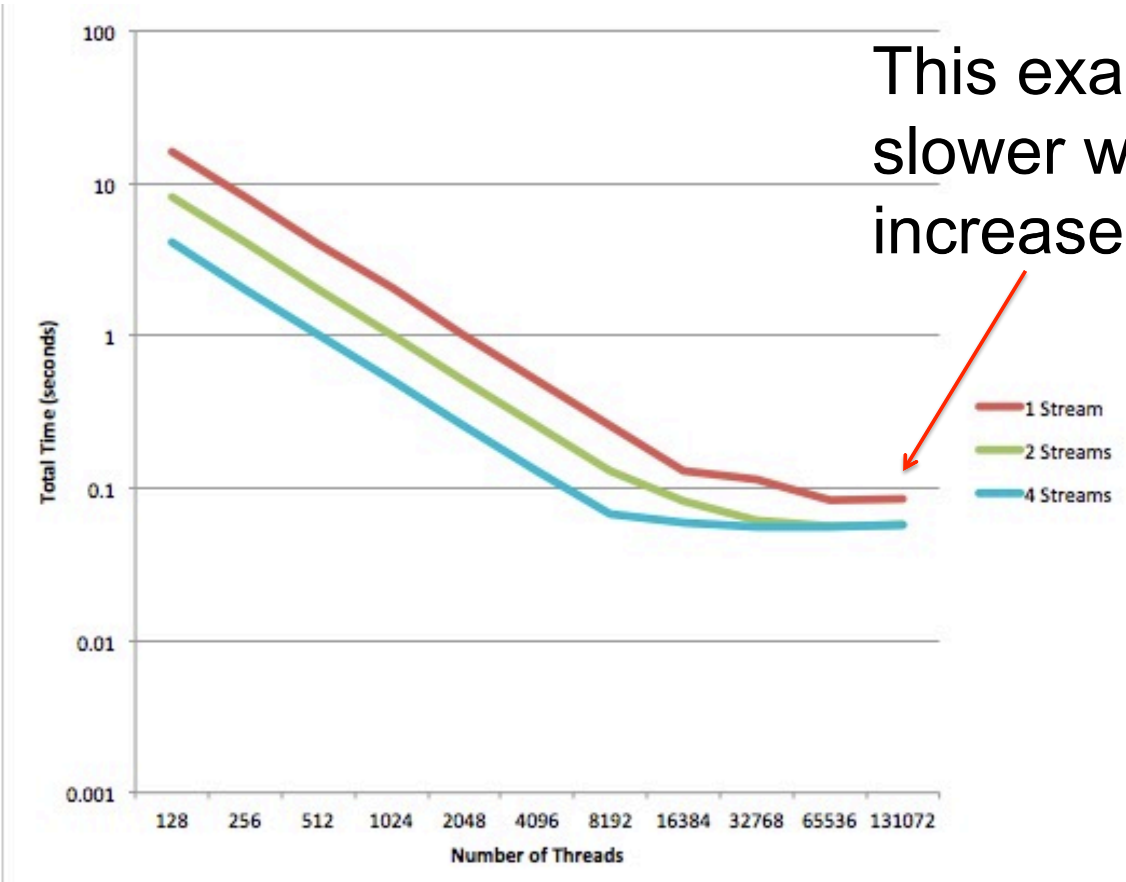


- Increased utilization of GPU!



Example 2 – "Too Much" Parallelism

- Column sum operation with 32M elements
  - Run on Quadro P6000 with 3840 cores



This example gets slower with increased threads!

Example 3 – Resource Utilization

Problem: One kernel requires large amount of shared memory, limiting occupancy

- Maxwell & Pascal have 48KB or 64KB of shared memory
  - A block size of 1024 gives ***only 48(64) bytes of memory per thread - 12(16) floats***
  - Reduce block size to get more memory per thread
  - 4x increase in shared memory per thread requires 4x reduction in occupancy

Solution: Given that another independent kernel is available that requires no shared memory, run it in a separate stream

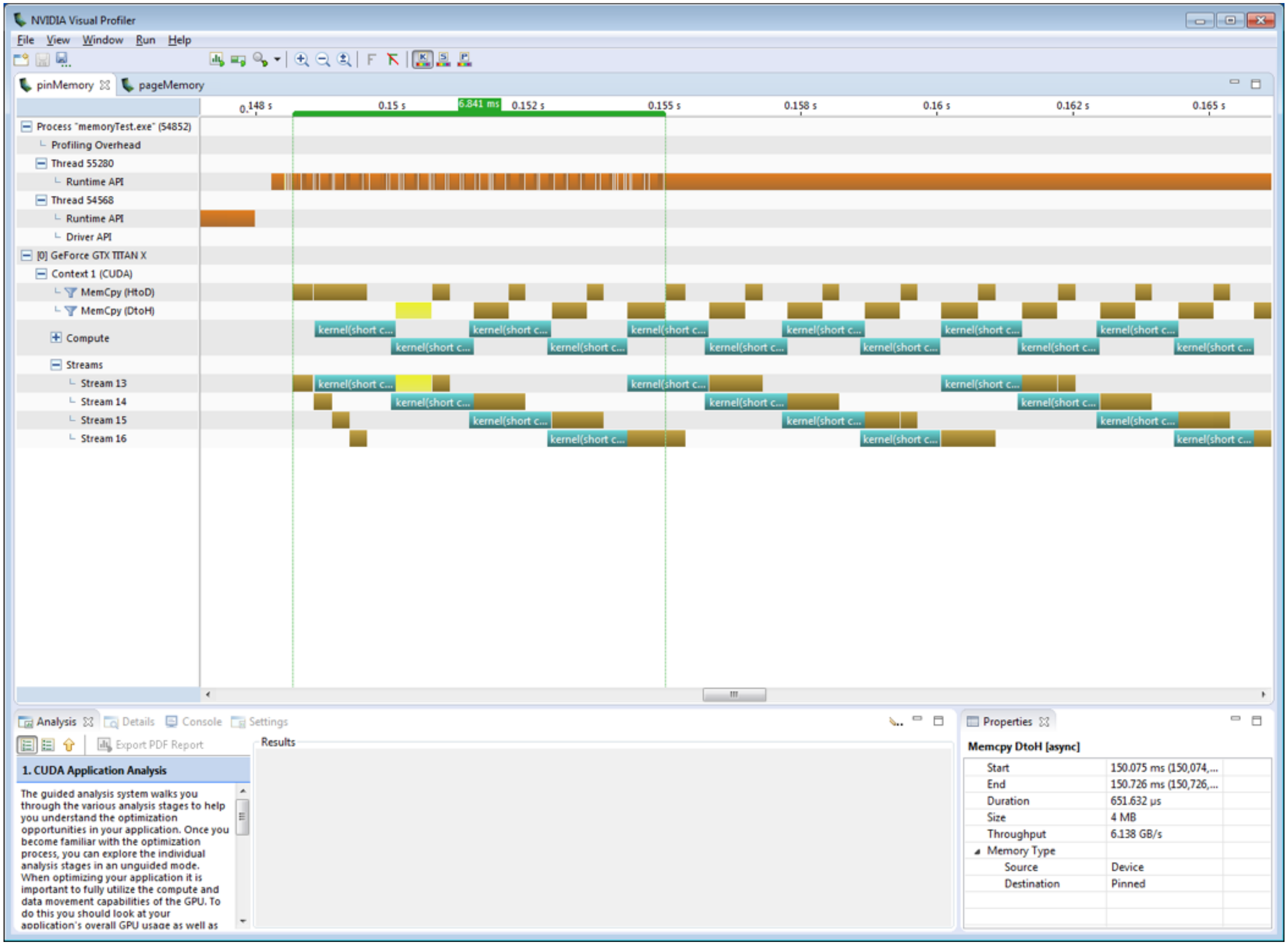
Examples – median, percentile, sort, histogram, transpose

cudaMemcpyAsync Potential Pitfall

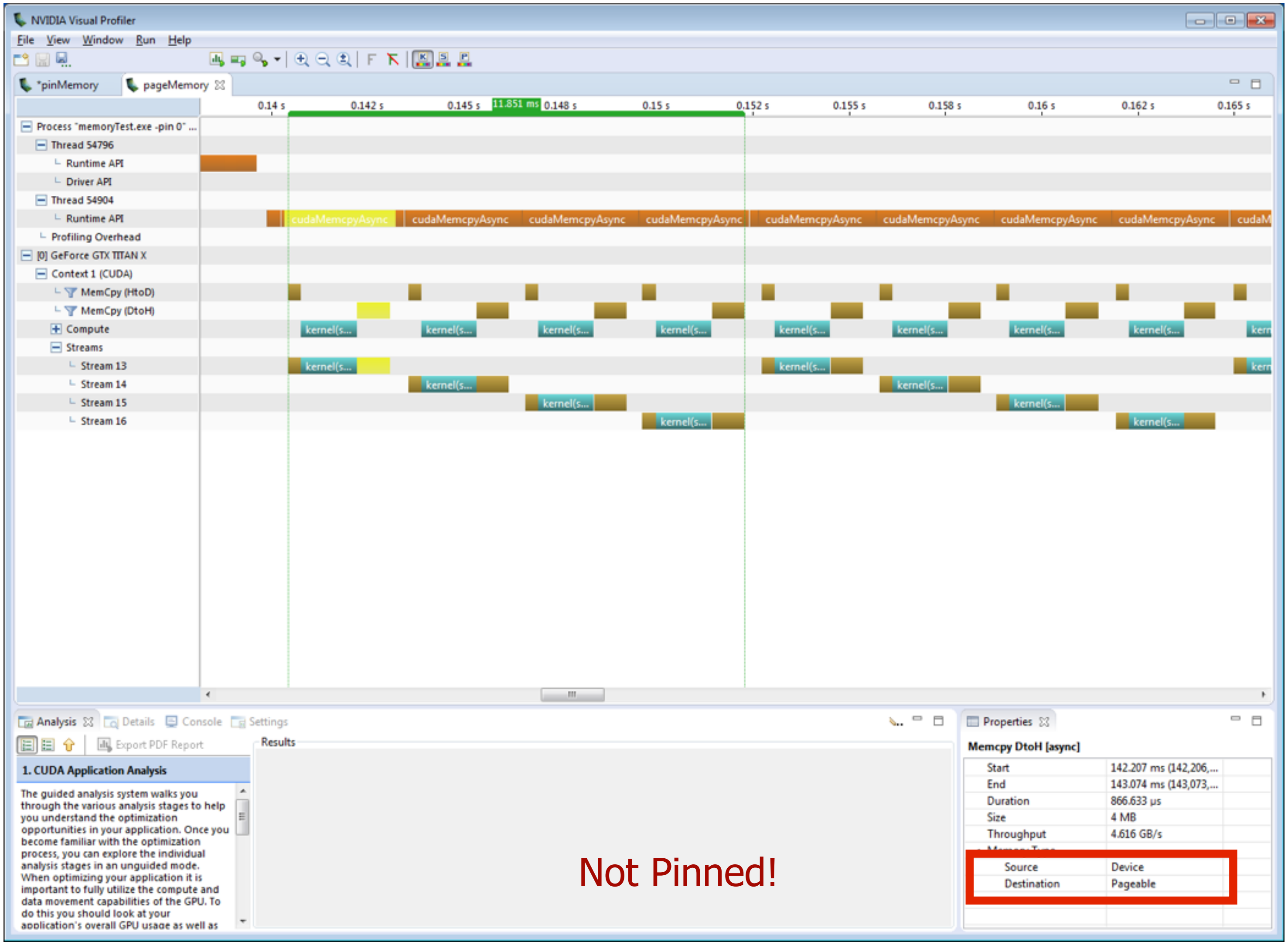
- From CUDA C Best Practices Guide Chapter 9.1:
  - "In contrast with `cudaMemcpy()`, the asynchronous transfer version requires pinned host memory …"
- What happens if I try to use `cudaMemcpyAsync()` with non-pinned memory?

- Calling `cudaMemcpyAsync`() with pageable memory works, **but …**
  - Copy operation gets serialized on GPU along with kernel launches - no copy engine overlap with kernels
  - Host doesn't block on call though
  - Can examine in Visual Profiler

cudaMemcpyAsync Pinned

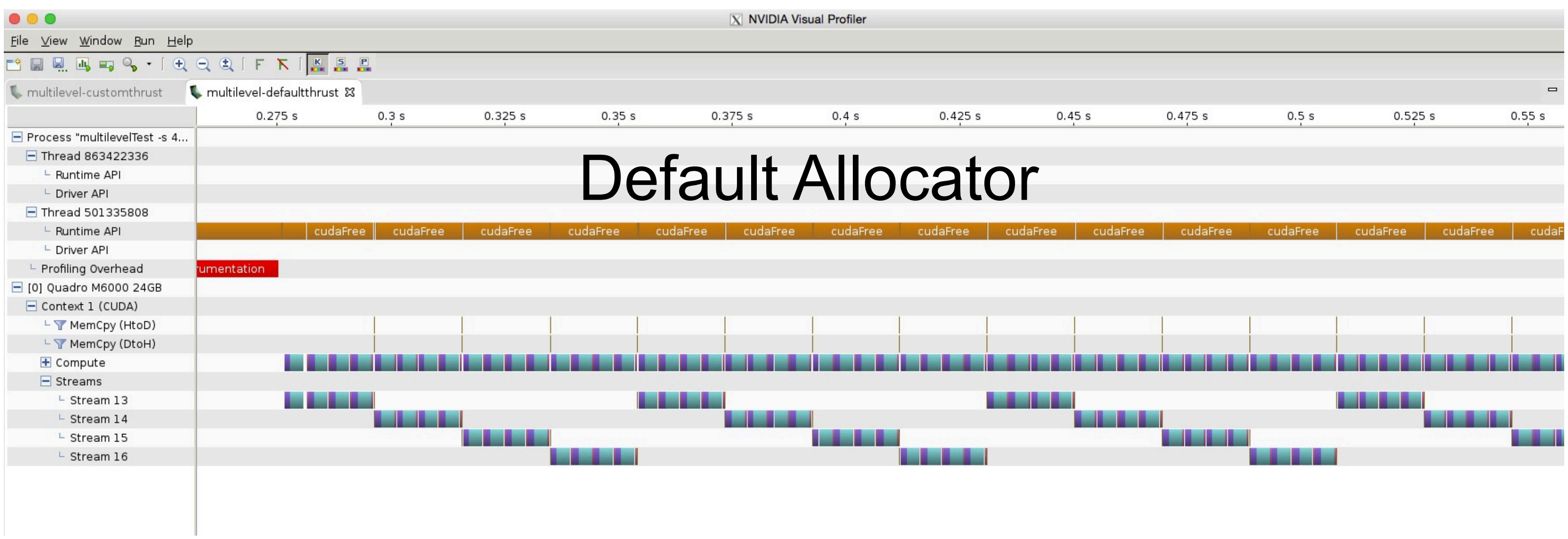


... vs. cudaMemcpyAsync Paged



Using Thrust

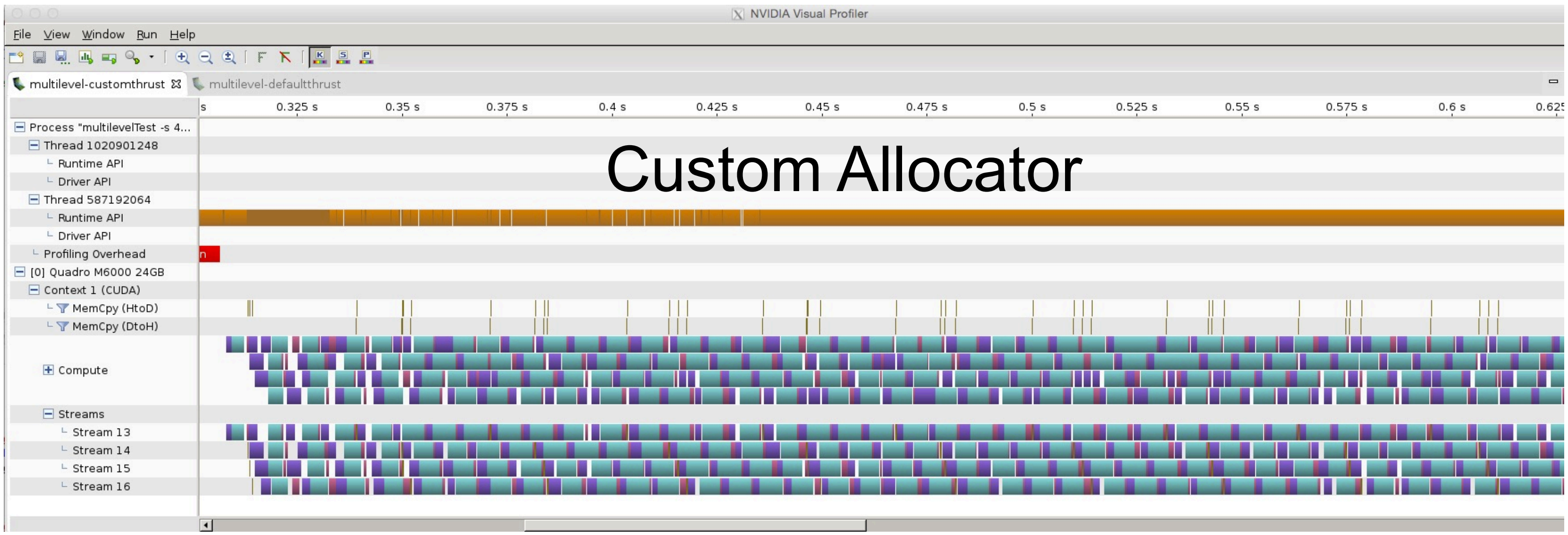
- Thrust is a great API that provides STL-like primitives
  - Because it behaves like standard algorithms, it is also limited in how it passes data back to the caller.
  - If a thrust function requires temporary memory, OR it passes back a result as the return value, then it will allocate and free CUDA memory



cudaMalloc/cudaFree every time! Serializes kernels!

Be Careful of Thrust Allocations!

- By using a custom allocator, you can control creation and deletion.



Calls cudaMalloc once the first time, then reuses on subsequent calls.

General Practice to Keep GPU Busy

1. Provide enough work for the GPU

- Create ~16x more threads than physical cores to provide enough opportunities for the scheduler to hide latency.

2. Use multiple streams to increase utilization of resources

- Balance ALU, Shared Memory, I/O

3. Minimize warp divergence

- Multiple streams do not help divergence. Conditional code gets disabled by thread mask

Thank You

- Source code is available:
- https://github.com/chuckseberino/CCT
    - GPU wrapper
    - Custom Thrust allocator (per stream)
    - Examples used in this presentation

- We are hiring GPU developers!