GPU & CMSSW Integration

The Service: Portability & Ease of Use

Konstantinos Samaras-Tsakiris
School of Electrical and Computer Engineering
Aristotle University of Thessaloniki

Dr. Vincenzo Innocente
CERN

Felice Pantaleo
CERN - University of Hamburg

Introduction

Studies

- Electrical & Computer Engineering
- 3rd year Undergraduate student

Interests

- Artificial Intelligence
- GPU computing
- Robotics

Project Goal

Incorporate GPUs into
CMS software framework

Tenets

1) Portability
2) Ease of Use
3) Efficiency

Solution

✔ GPU managing Service

Contents

- Problem Definition
- Service usefulness
- Service architecture
  - System overview
  - Elements
- Tests & Examples
- Challenges & Future Work

Problem Definition

Problem Definition

- GPU accelerators
  - ✔ Massive parallelism
- But how to program them?
  - ✔ CUDA!

Well...

(not so fast)

```
1 float *a, *d_a;
2 a= (float*)malloc(sizeof(float));
3 cudaMalloc((void**)&d_a, sizeof(float))
4 *a= 1.0;
5 cudaMemcpy(d_a, a, sizeof(float),
              cudaMemcpyHostToDevice);
6 someKernel<<<grid,block>>>(d_a);
7 cudaMemcpy(a, d_a, sizeof(float),
              cudaMemcpyDeviceToHost);
8 cout << *a;
9 cudaFree(d_a); free(a);
```

Problem Definition

- ✗ *Cumbersome programming model*
- ✗ *Too intricate*
- ✗ *Not portable*
  - ✗ *Not even compiles with GCC*

➔ *On the other hand…*

Example

Using CudaService

```
1 int size, param;
2 cudaPointer<float> data(size);
3 auto GPUResult= cudaService->
4    cudaLaunch(size, someKernel_wrapper,
5                     param, data);
  ...<other work>...
6 GPUResult.get();
```

➔ *Prettier, isn't it?*

Service Usefulness

Service Usefulness

- New capability
  - Write CUDA in CMSSW
  - Call from normal C++

Service Usefulness

- Portable
  - Handle common GPU failures
    - e.g. temporarily insufficient memory
  - Plug-in fallback CPU versions
    - Manual fallback, or...
    - *Luca's work* fits here

Service Usefulness

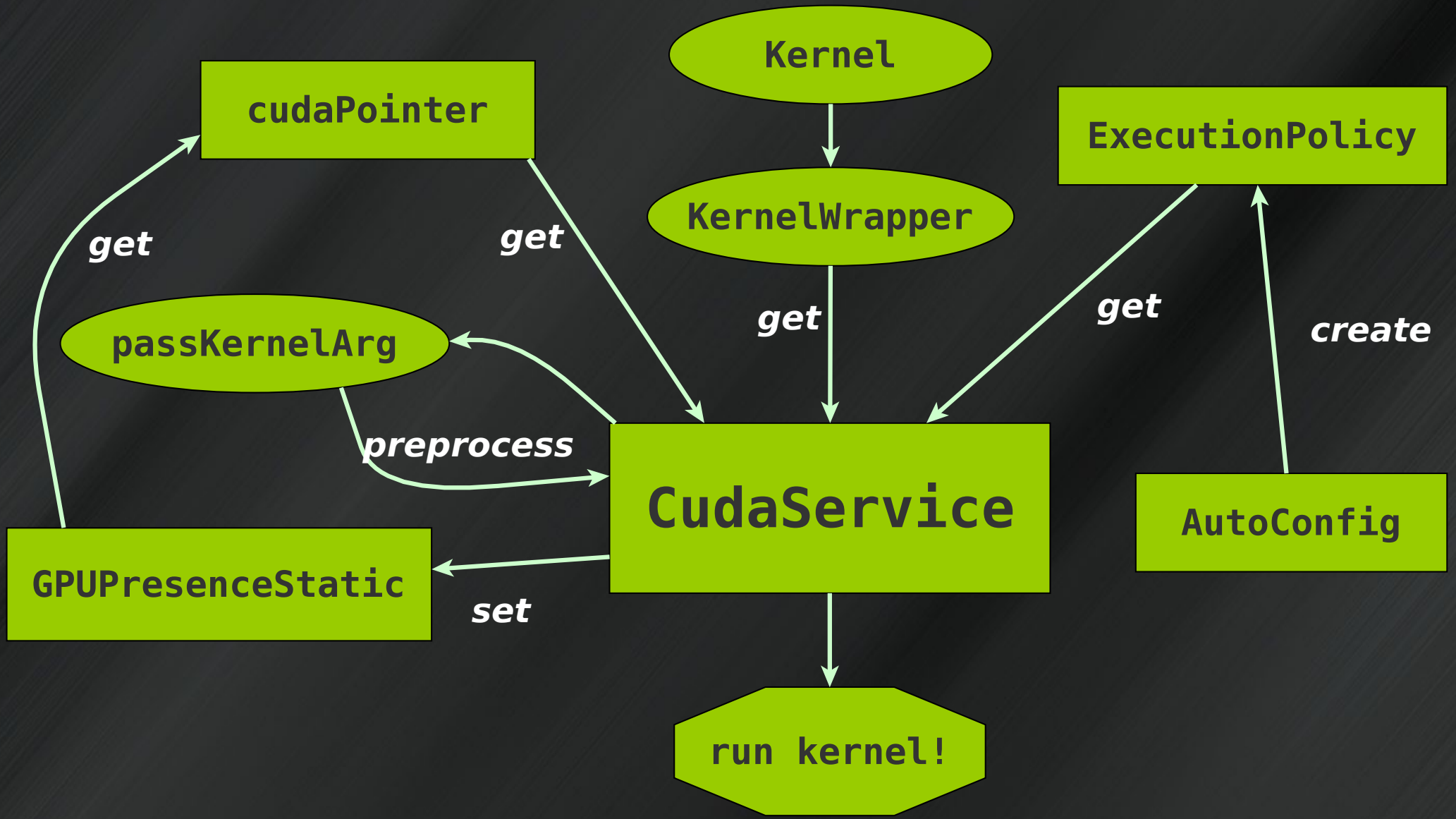
- Simplified model
  - Launch task → Get future
  - CudaPointer
    - ✔ Manages CUDA memory
  - Auto launch configuration
    - ✗ Only for 1D configurations

CUDA Research

- Unified Memory
  - Auto memory management
  - Future hardware support
- Task parallelism – Streams
  - 1 per host thread (compiler option)
  - Overlap data movement & execution
- Auto kernel launch configuration

Service Architecture

Overview

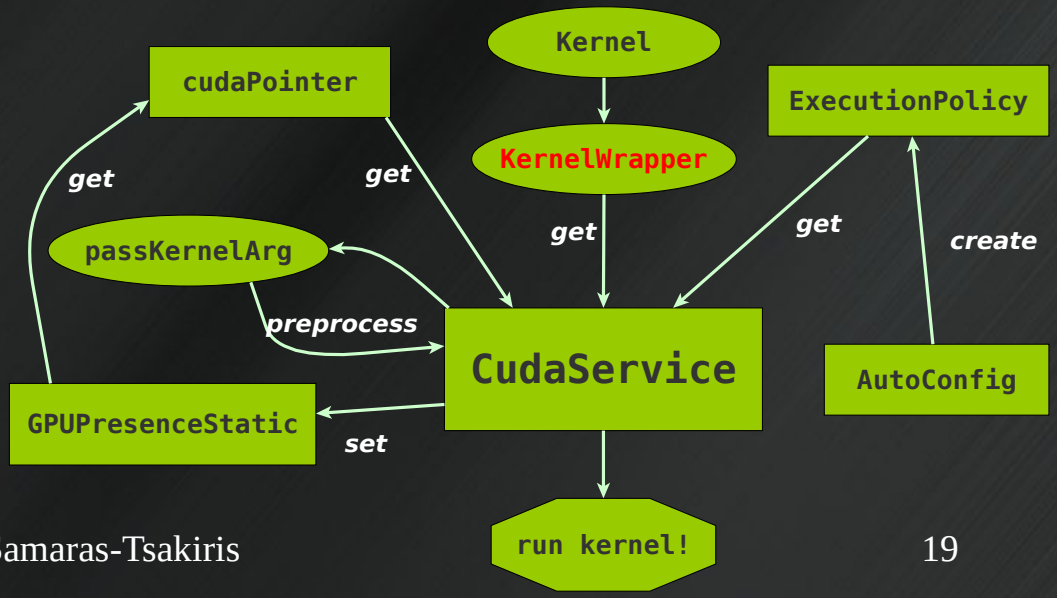

Kernel
cudaPointer
ExecutionPolicy
KernelWrapper
get
get
get
get
create
passKernelArg
preprocess
CudaService
AutoConfig
GPUPresenceStatic
set
run kernel!

Let's check each element...

Kernel Wrappers

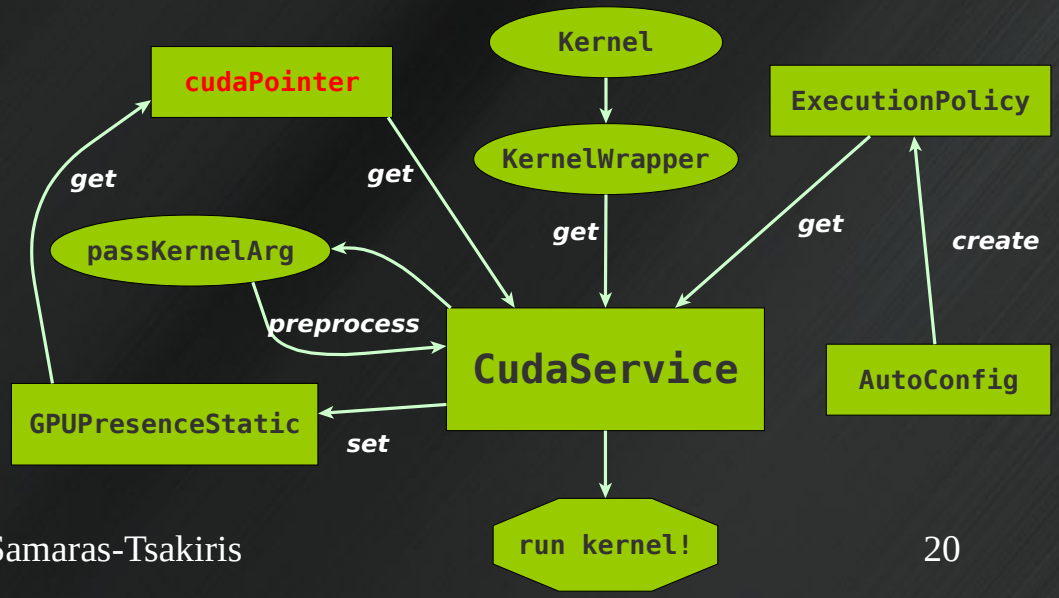
```
1 __global__ void kernel(int param);

2 void Wrapper(bool gpu, int& launchSize,
                int param){
3    auto execPol= cuda::AutoConfig()
4                   (launchSize, task_kern);
5    if (gpu) kernel<<<execPol.getGridSize(),
6              execPol.getBlockSize()>>>(param);
7 }
```

User writes
Kernel & Wrapper



cudaPointer

- Smart pointer → std::*unique_ptr*
- Construct and move semantics – no copy
- Handles stream attachment
- Portable allocation/deallocation
- 2 flavours:
  - Single objects
  - Arrays

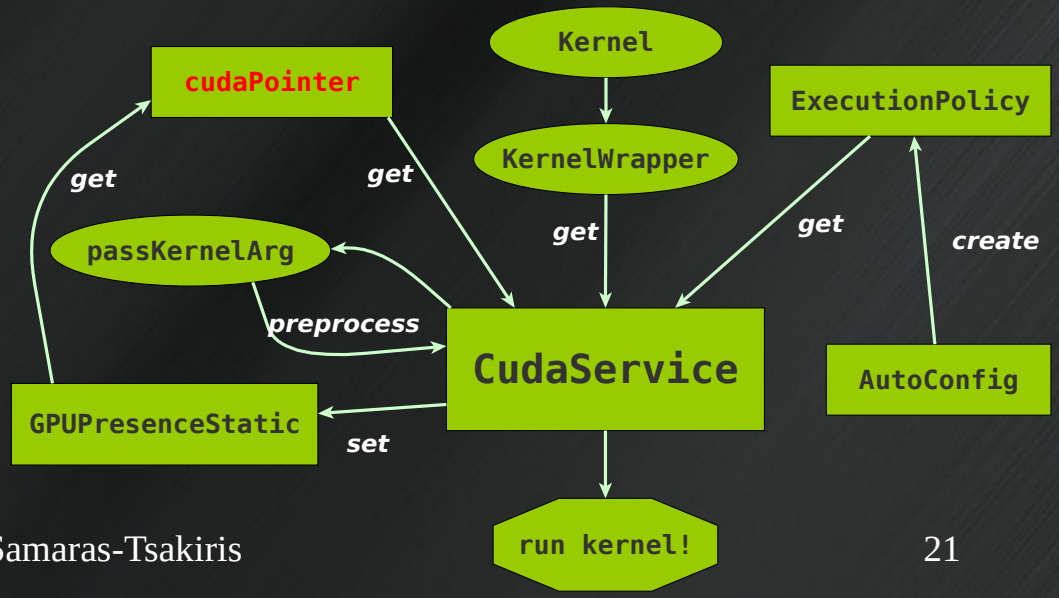


cudaPointer

```
1 __global__ void kernel(int a, int* b,
                         float* c)
```

should be called as…

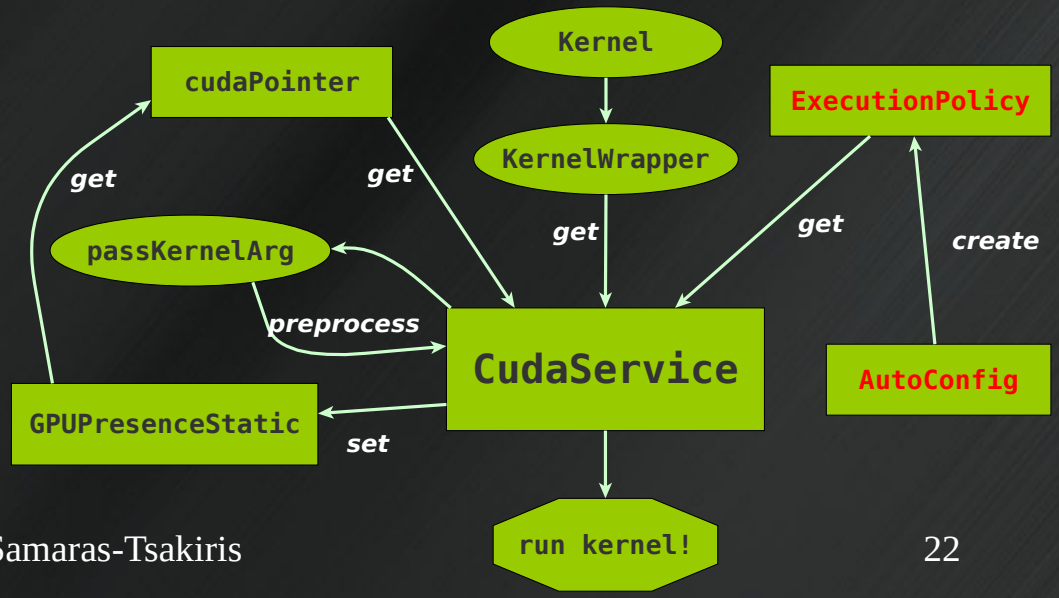
```
2 kernel_wrapper(int, cudaPointer<int[]>,
3                cudaPointer<float[]>)
```



ExecutionPolicy

- Grid & Block size (multidimensional)
- AutoConfig:
  - Creates ExecutionPolicy
  - Automatically calculates block size (occupancy)

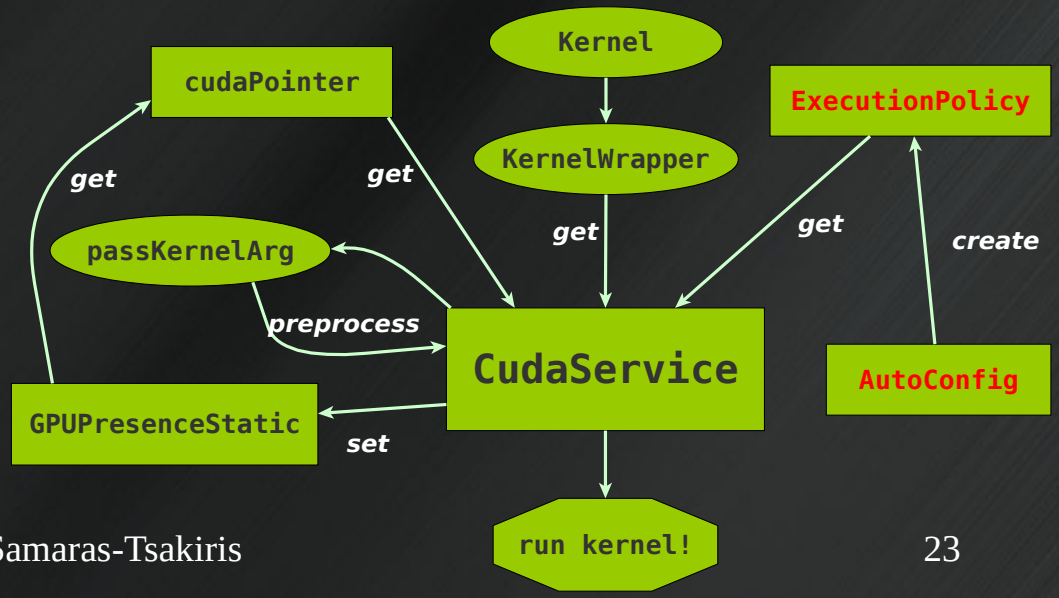
Based on
Mark Harris' HEMI



Example

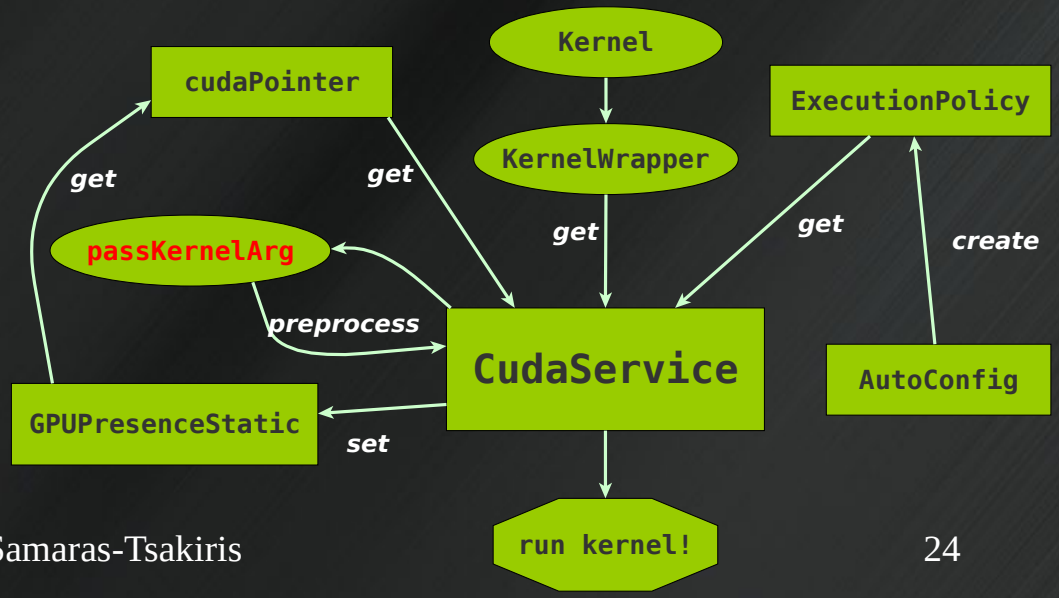
Creating an ExecutionPolicy

```
1 auto execPol= cuda::AutoConfig()(n,
2                                  (void*)kernel);
```



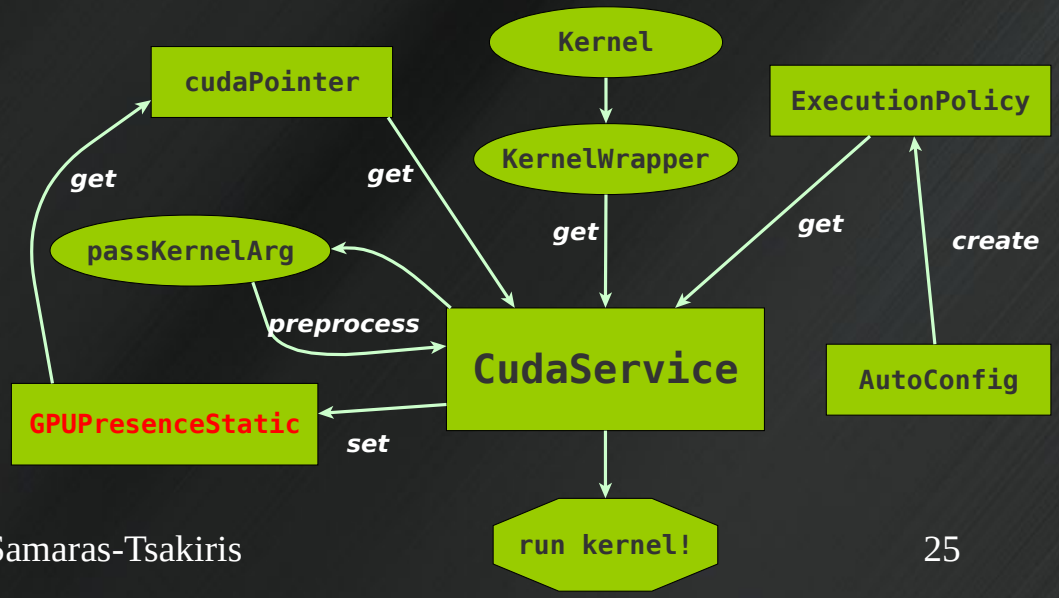
passKernelArg

- Pair of template functions
  - Template type identification – SFINAE
  - One for cudaPointer, one for everything else
- Signal cudaPointers → Passed to kernel
  - Change Stream attachment
- Siblings:
  - releaseKernelArg



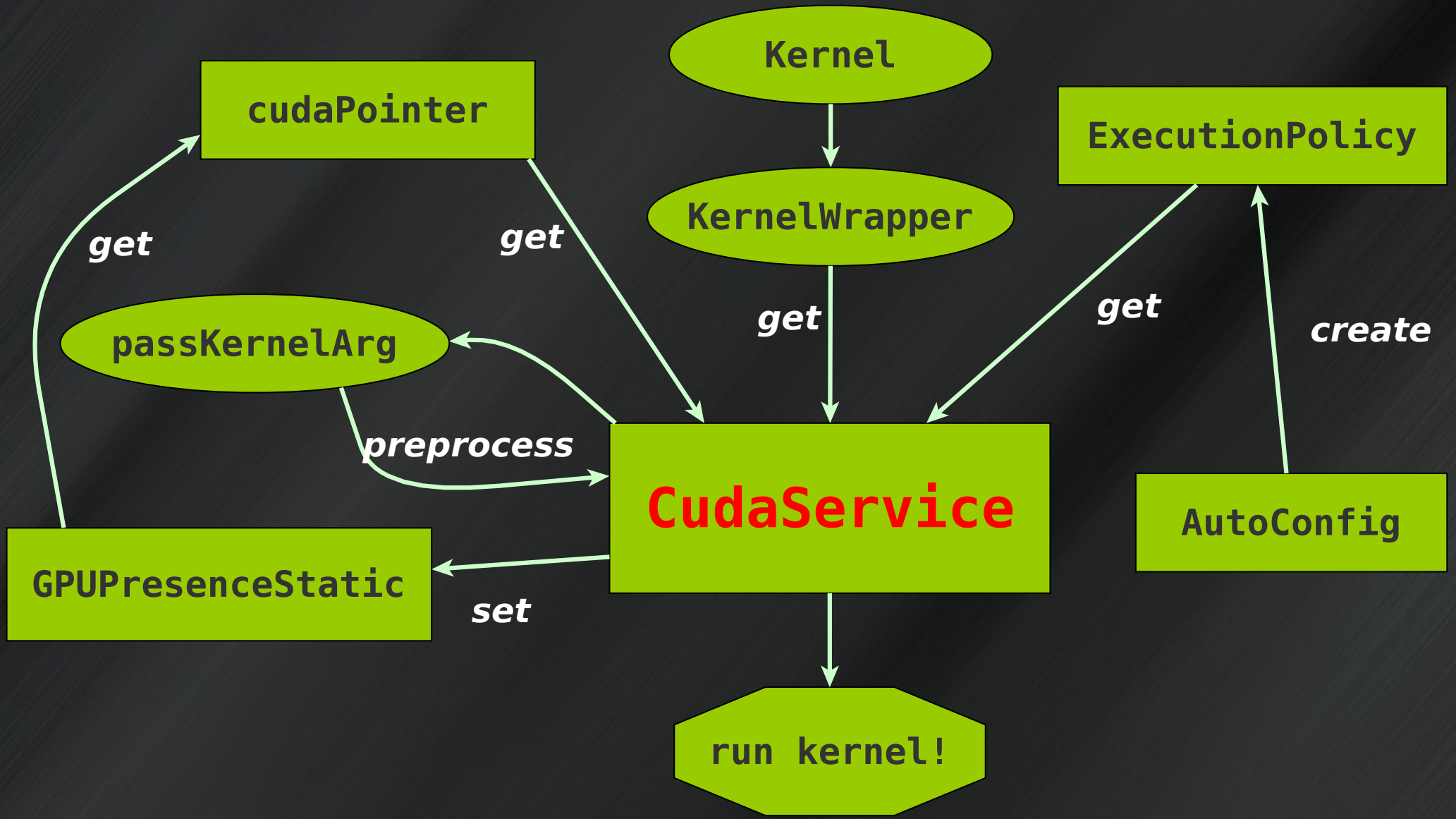
GPUPresenceStatic

- Broadcasts GPU presence
- Conditionally accessible
  - Static member: status_
  - SET: only CudaService
  - SFINAE



Service Architecture

Inside CudaService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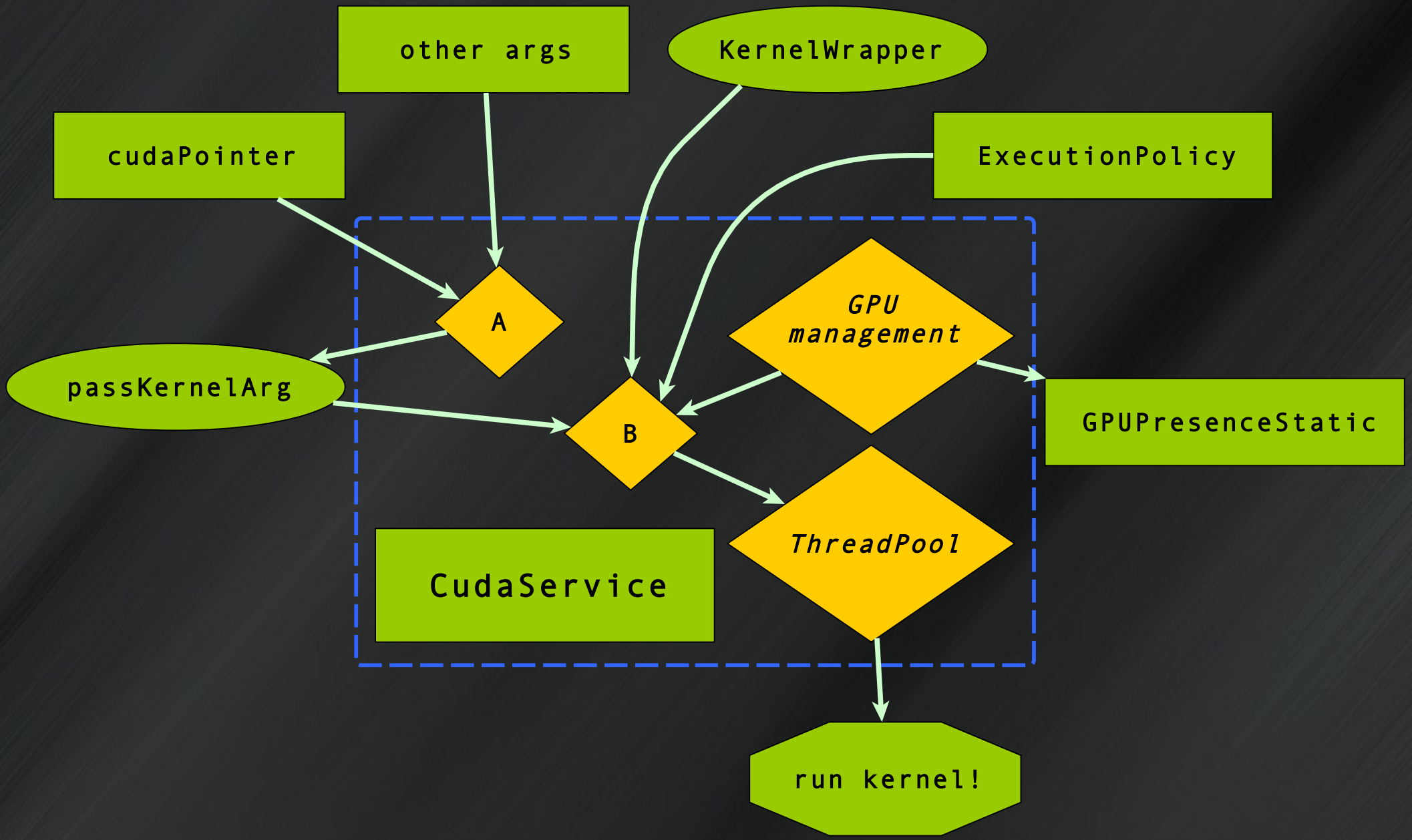
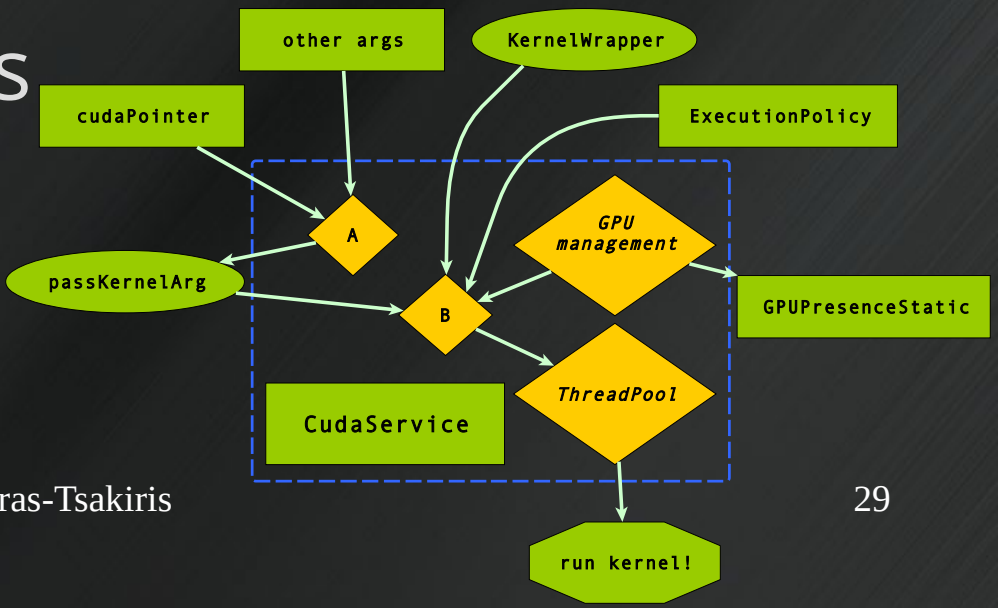

other args
KernelWrapper
cudaPointer
ExecutionPolicy
A
GPU management
passKernelArg
B
GPUPresenceStatic
ThreadPool
CudaService
run kernel!

CudaService

Lifecycle

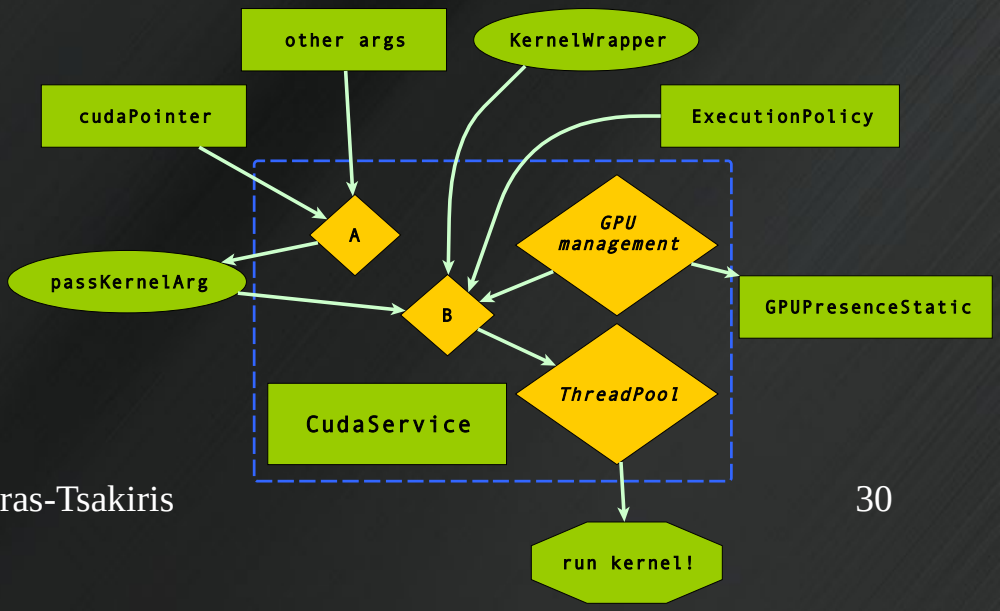
- "Default" constructor only
  - Checks number of GPUs present
  - Registers start/end work callbacks
- No copy/move semantics
- Shared between threads
  - Never > 1!
  - Thread-safe



CudaService

State

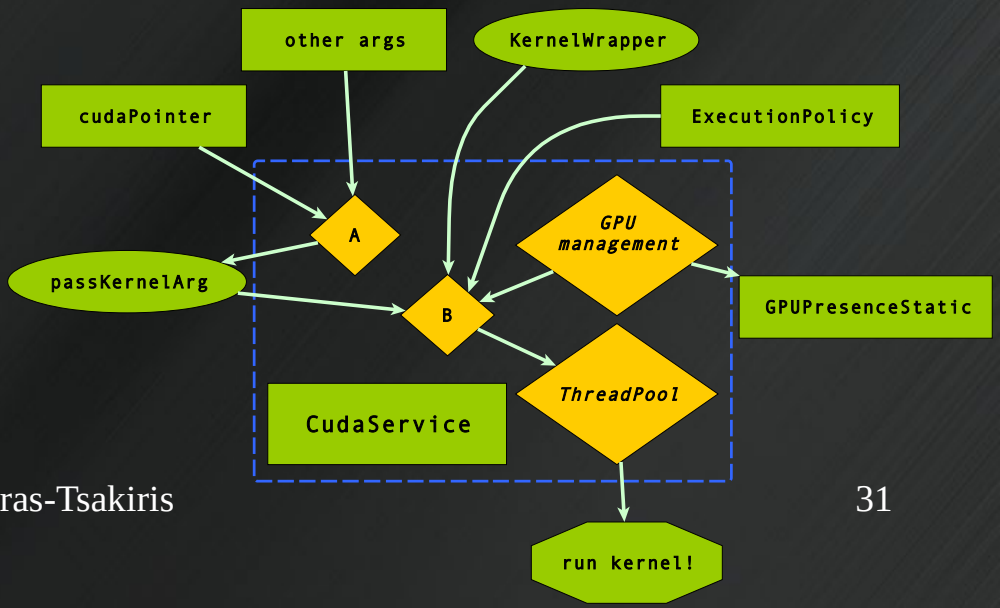
- Derives from ThreadPool
- Thread-safe
- Task store
  - tbb::concurrent_bounded_queue
- Waiting threads
  - std::vector



CudaService

API

- cudaLaunch(launch type, wrapper, args...)
  - Manual|Auto launch ← SFINAE
- schedule(callable, args...)
  - For any CPU task
- GPUpresent()



Test-driven development

a.k.a. "Why should I trust you?"

Unit Tests

- Auto|manual|multidim launch configuration
- cudaPointer
  - cudaPointer to arithmetic struct
  - Struct containing cudaPointers: Not working yet!
- CPU task latency benchmark
- GPU kernel latency benchmark
- Share service with task (CPU task)
  - Validates recursive task launch

Launch configurations

Auto

```
1 cudaService->cudaLaunch(n, task_auto,
2                         param).get();
```

Manual

```
3 auto execPol= cudaConfig::ExecutionPolicy
4       (blockSize, (n-1+blockSize)/blockSize);
5 cudaService->cudaLaunch(execPol, task_man,
6                         param).get();
```

Multidimensional (manual)

```
7 execPol.setBlockSize({blockSize, blockSize
8                       }).autoGrid({n,m});
```

CPU task latency

```
1 start= chrono::steady_clock::now();
2 for(register int task=0; task<threadN; task++)
3   futVec[task]= cudaService->schedule([] (){
4     for (register short k=0; k<2; k++)
5       cout<<"";
6   });
7 for(auto&& elt: futVec) elt.get();
8 end = chrono::steady_clock::now();
```

2.2 μs

GPU task latency

Nontrivial kernel

```
1 start= chrono::steady_clock::now();
2 for(register int task=0; task<threadN; task++)
3   futVec[task]= cudaService->cudaLaunch(
4     execPol,nontrivial,param,dataIn,dataOut);
5 for(auto&& elt: futVec) elt.get();
6 end = chrono::steady_clock::now();
```

20 μs

What do ***20µs*** mean?

- Kernel launch in traditional CUDA
  - ✔ **~10µs**
- Thread pool latency
  - ✔ **2µs**

➔ Kernel execution time?

➔ Data copy time?

➔ *Service overhead?*

20 µs

GPU task latency

Trivial kernel

```
1 start= chrono::steady_clock::now();
2 for(register int task=0; task<threadN; task++)
3   futVec[task]= cudaService->cudaLaunch(
4     execPol,trivial);
5 for(auto&& elt: futVec) elt.get();
6 end = chrono::steady_clock::now();
```

9.5 µs

As little as launching a kernel in traditional CUDA!

Latency Hiding

- Related to number of ThreadPool threads
  - Optimal: 3-5 per GPU
  - Much higher latency when only 1 thread in pool
    - ✔ More threads (3-5) hide some latency
- Related to kernel execution/data transfer overlap?
  - ✔ Needs profiling

Integration Test

- Change physics code to call CudaService
- Python cfg script for cmsRun
- Call cmsRun with 4 threads
- Compare GPU with CPU results

Integration Test

Original CPU loop

```
1 for (unsigned int subcl_idx = 0;
2       subcl_idx < meanExp; subcl_idx++){
3   if (cls[subcl_idx] != 0) {
4     clx[subcl_idx] /= cls[subcl_idx];
5     cly[subcl_idx] /= cls[subcl_idx];
6   }
7   cls[subcl_idx] = 0;
8 }
```

Integration Test

Kernel Replacement

```
1  __global__ void original_kernel(unsigned
2      meanExp, float* cls, float* clx, float* cly)
3  {
4    unsigned i= blockDim.x*blockIdx.x+threadIdx.x;
5    if(i<meanExp){
6      if (cls[i] != 0){
7        clx[i] /= cls[i];
8        cly[i] /= cls[i];
9      }
10     cls[i]= 0;
11   }
12 }
```

Integration Test

Kernel Wrapper

```
1  void original_wrapper(bool gpu, unsigned&
2       launchSize, unsigned meanExp, float* cls,
3       float* clx, float* cly)
4  {
5    if(!gpu) original_CPU(meanExp,cls,clx,cly);
6    else{
7      auto execPol= cuda::AutoConfig()
8          (launchSize, (void*)original_kernel);
9      original_kernel<<<execPol.getGridSize(),
10                     execPol.getBlockSize()>>>(
11                       meanExp, cls, clx, cly);
12   }
13 }
```

Integration Test

Service call code

```
1 edm::Service<edm::service::CudaService>
2                                 cudaService;
3 cudaPointer<float> cls(meanExp),
4                    clx(meanExp),
5                    cly(meanExp);
6 auto GPUresult= cudaService->
7       cudaLaunch(meanExp, original_wrapper,
8                  meanExp, cls, clx, cly);
9 GPUresult.get();
```

PASS!

- ✔ Without GPU, uses CPU fallback

Documentation

Github

https://github.com/Oblynx/cmssw/tree/kernelLaunch/FWCore/Services

CMS Twiki tutorial

https://twiki.cern.ch/twiki/bin/view/Main/CudaService

Knowledge gained

- C++11
- CUDA
- Thread Safety
  - *“or how I learned to worry and hate shared state”*
- Template idioms -- SFINAE, enable_if
- How CMSSW works

Future Work

- cudaPointer enhancements
  - Allow structs containing cudaPointers
  - Work with Thrust for GPU data structures
  - Use GPU texture/constant memory
- Automate kernel wrapper generation
- Profile CudaService
  - Investigate latency hiding

Future Work

- Explore GPU Libraries
  - ArrayFire & Thrust
  - ✗ CUDA not always best option!

Thank you

for your attention!