DATA/THREAD LEVEL PARALLELISM

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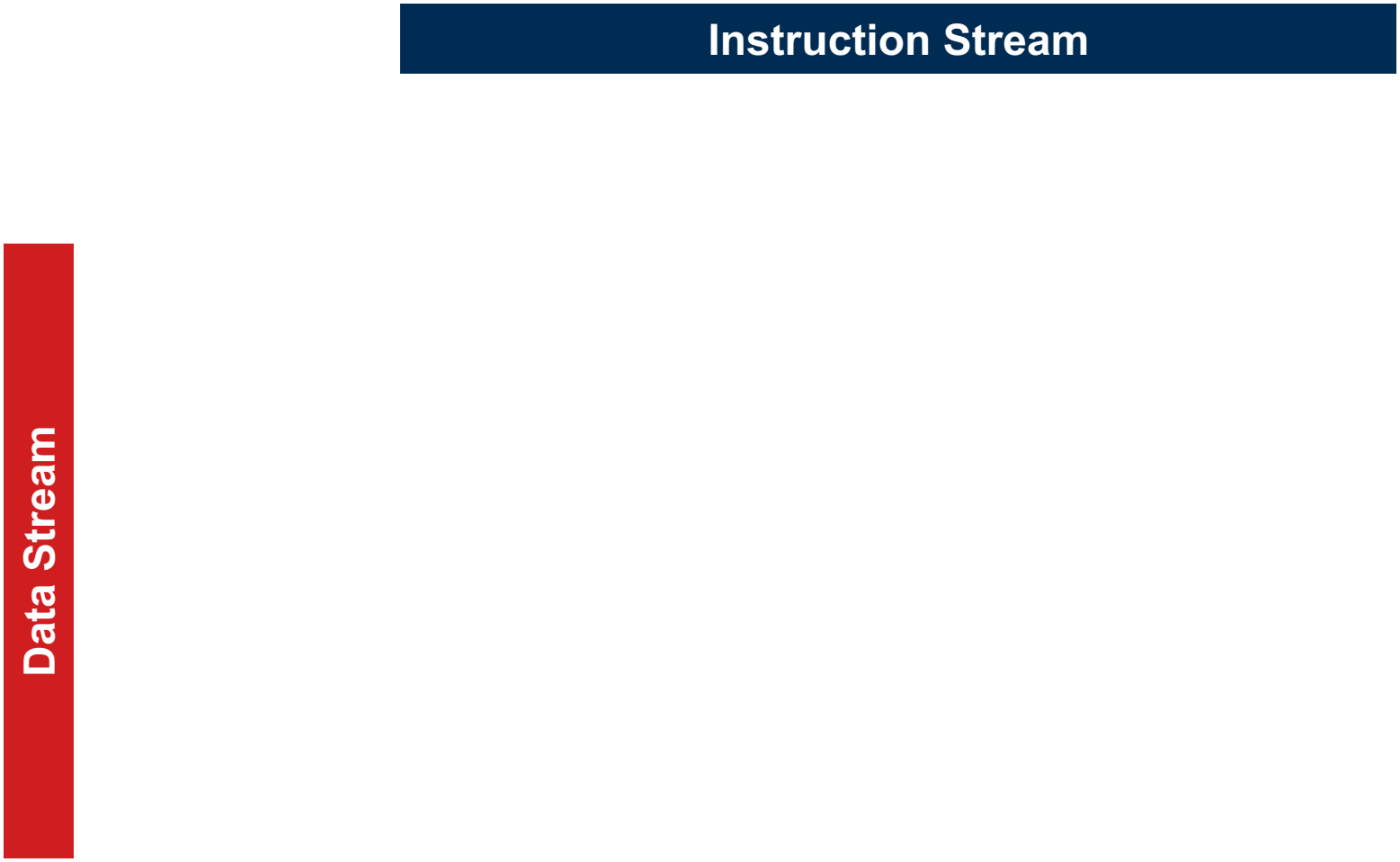
Overview

- Announcement
  - Tonight: Homework 5 is due
  - Reminder: we will drop one of your HW with the least grade

- This lecture
  - Data level parallelism
    - Graphics processing unit
  - Thread level parallelism

Flynn's Taxonomy

- Data vs. instruction streams



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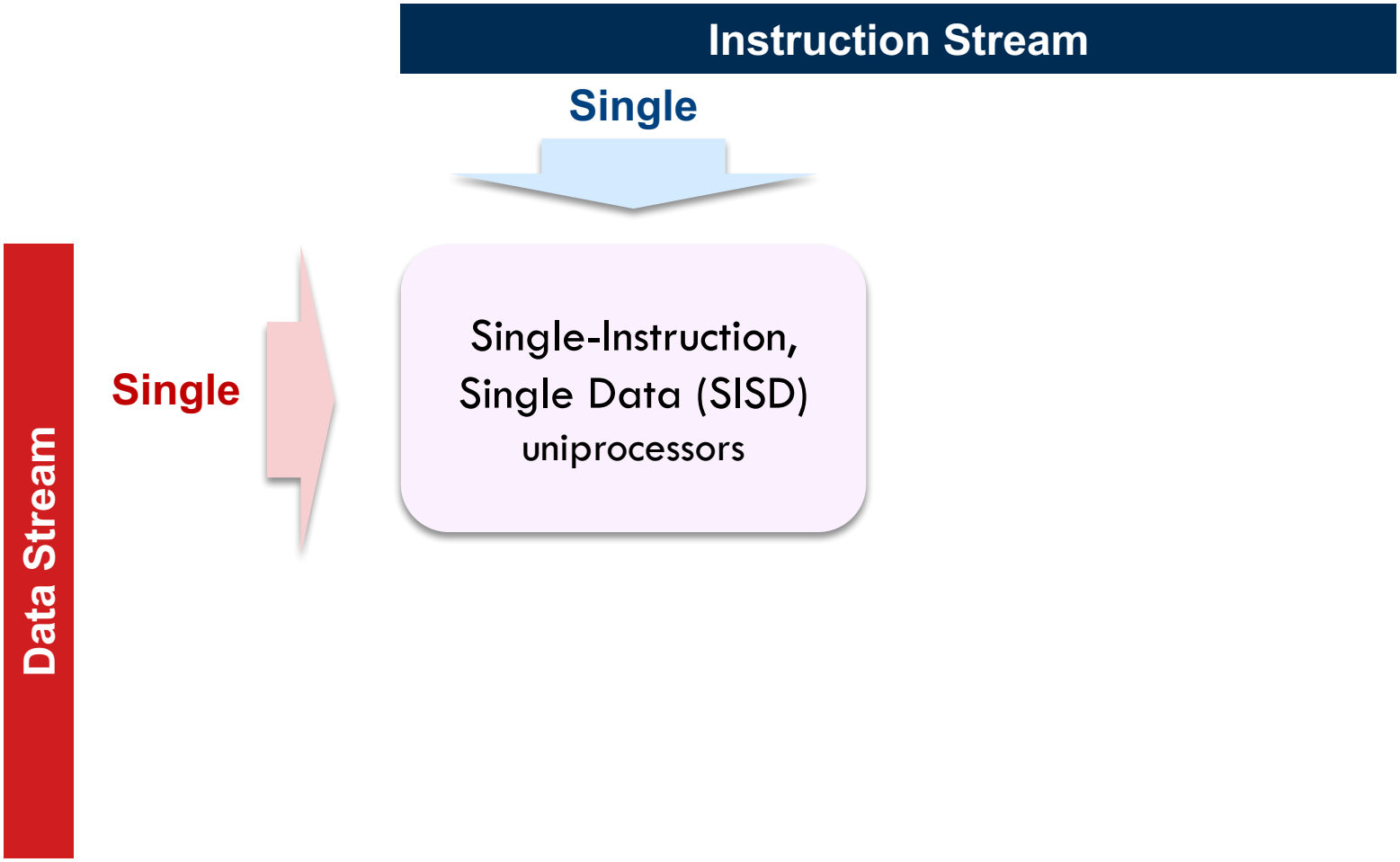

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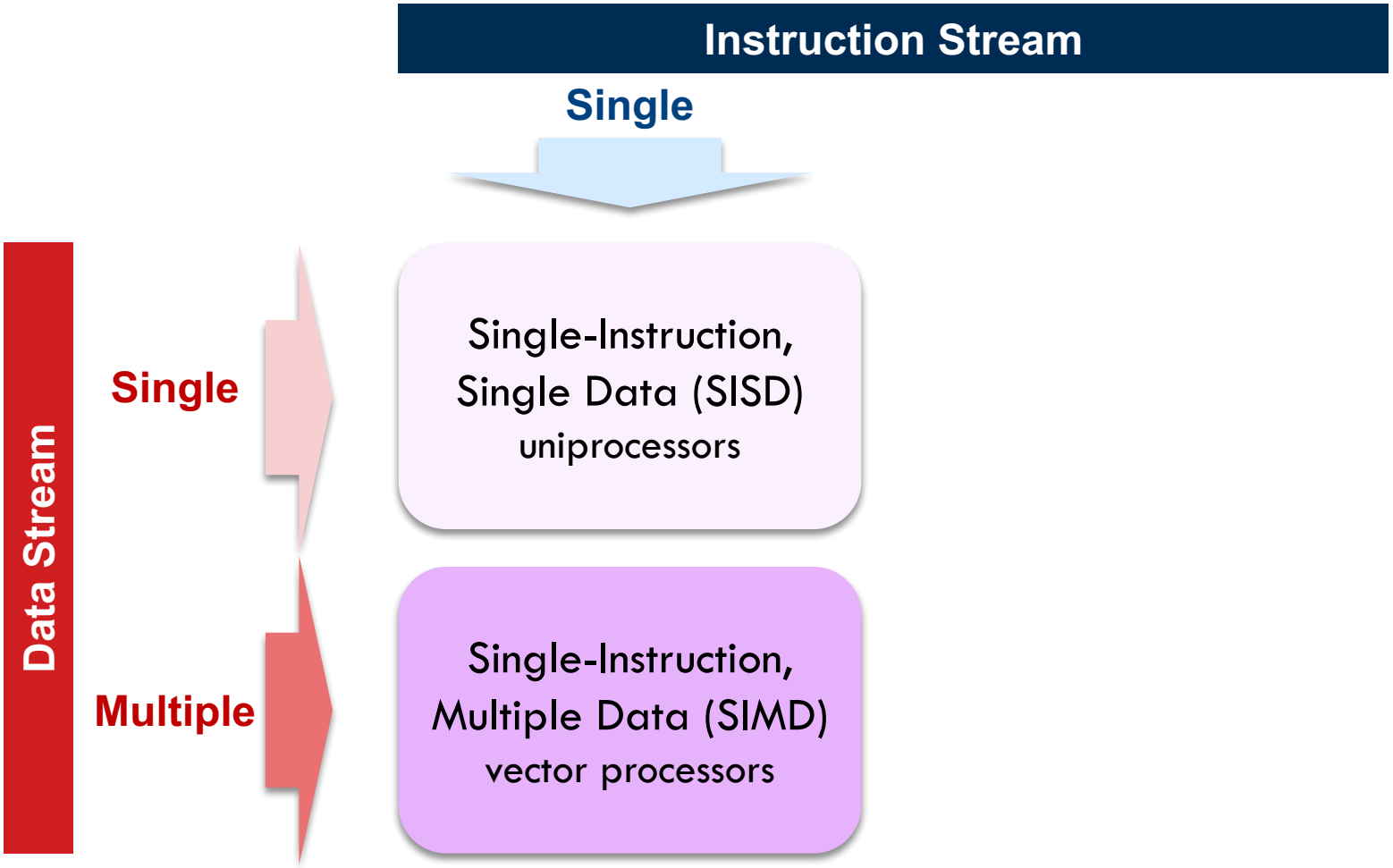

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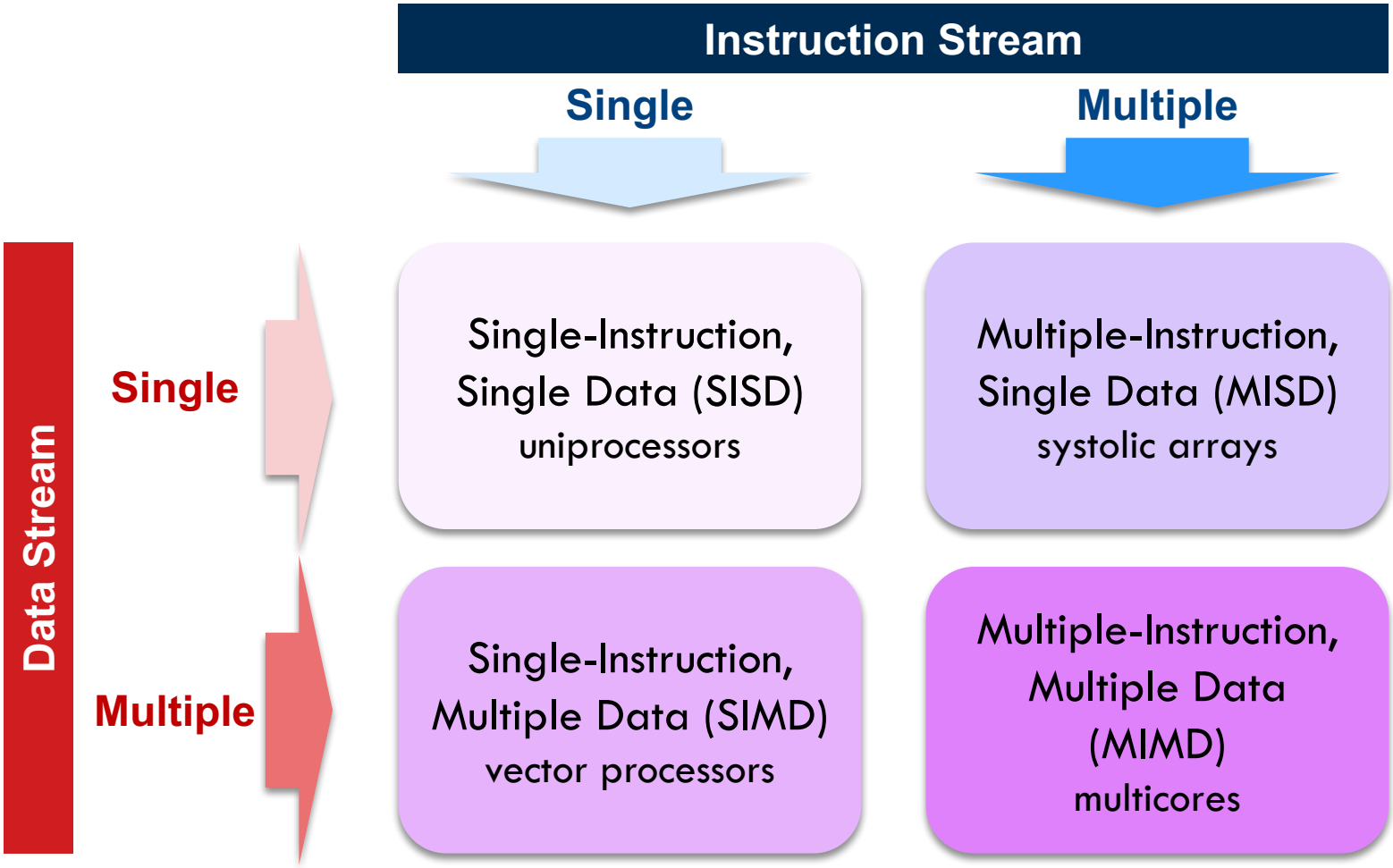
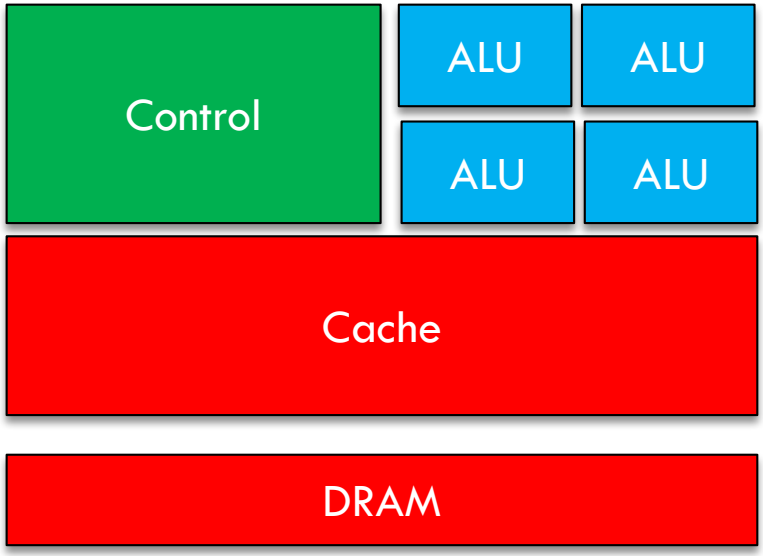


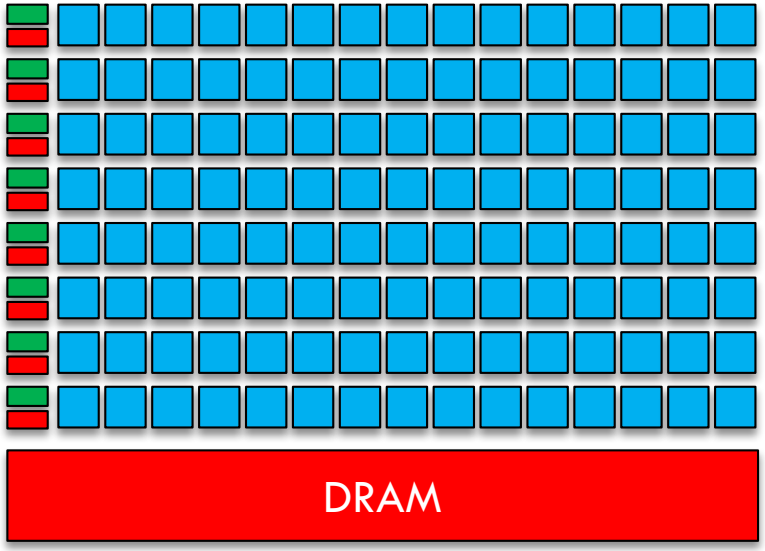
Graphics Processing Unit

- Initially developed as graphics accelerators
  - one of the densest compute engines available now
- Many efforts to run non-graphics workloads on GPUs
  - general-purpose GPUs (GPGPUs)
- C/C++ based programming platforms
  - CUDA from NVidia and OpenCL from an industry consortium
- A heterogeneous system
  - a regular host CPU
  - a GPU that handles CUDA (may be on the same CPU chip)

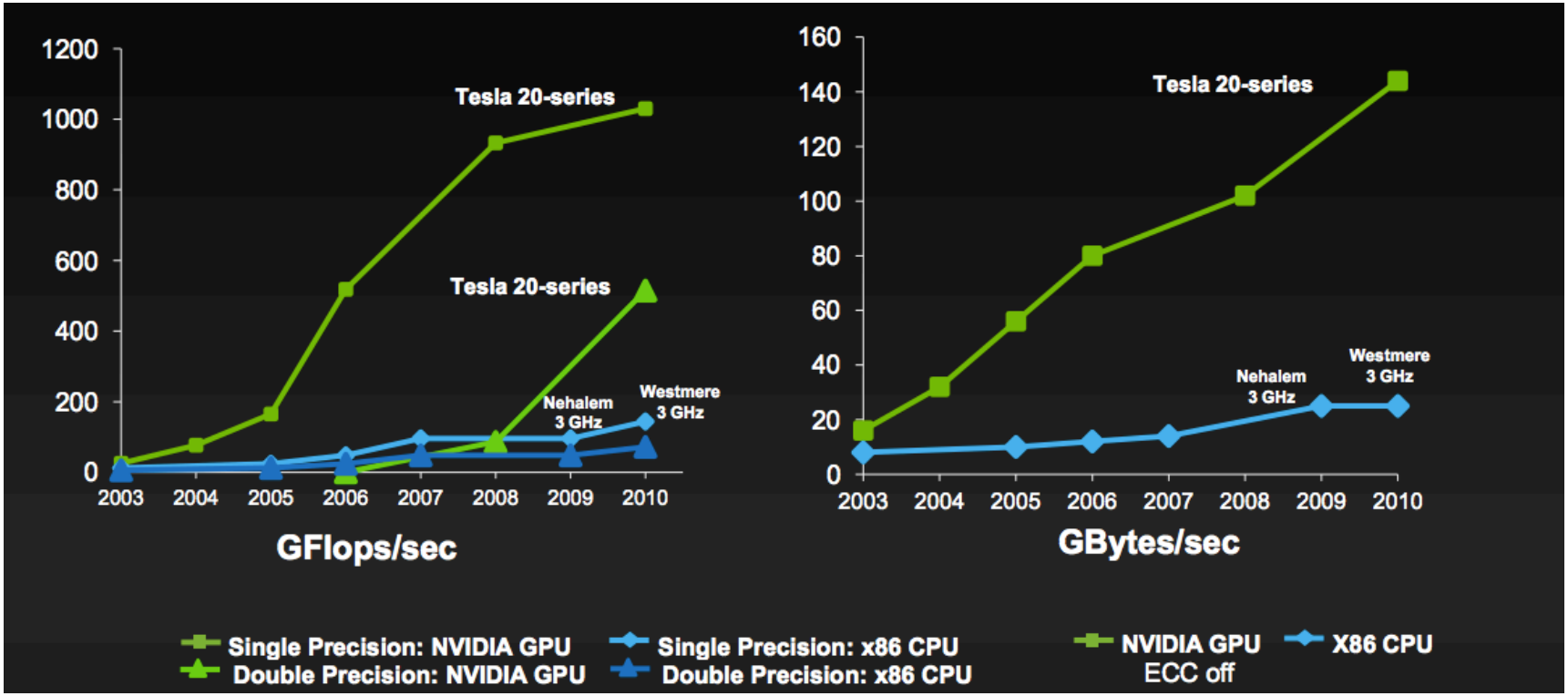
Graphics Processing Unit

- Simple in-order pipelines that rely on thread-level parallelism to hide long latencies
- Many registers (~1K) per in-order pipeline (lane) to support many active warps





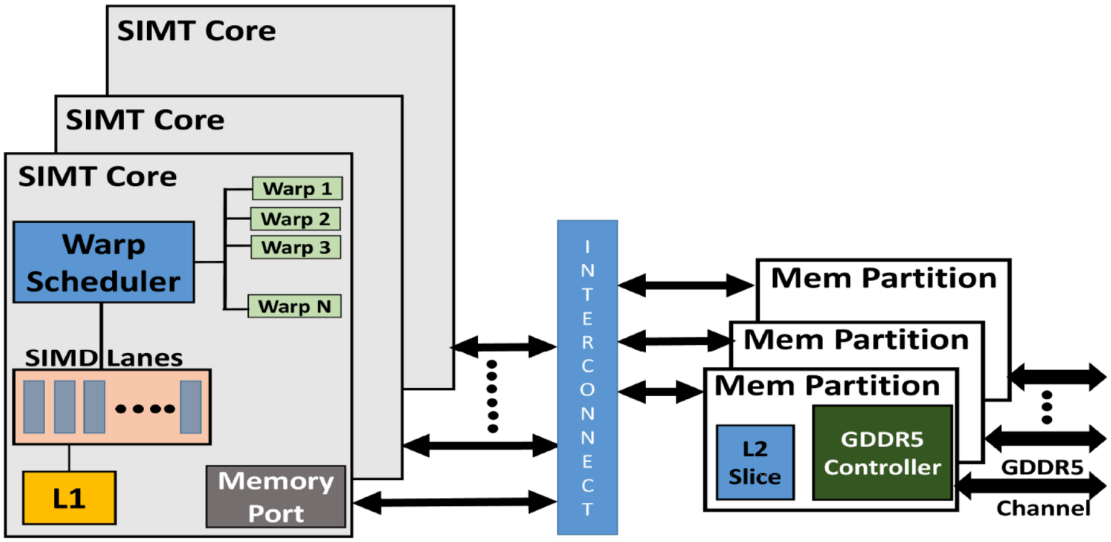
Why GPU Computing?



Source: NVIDIA

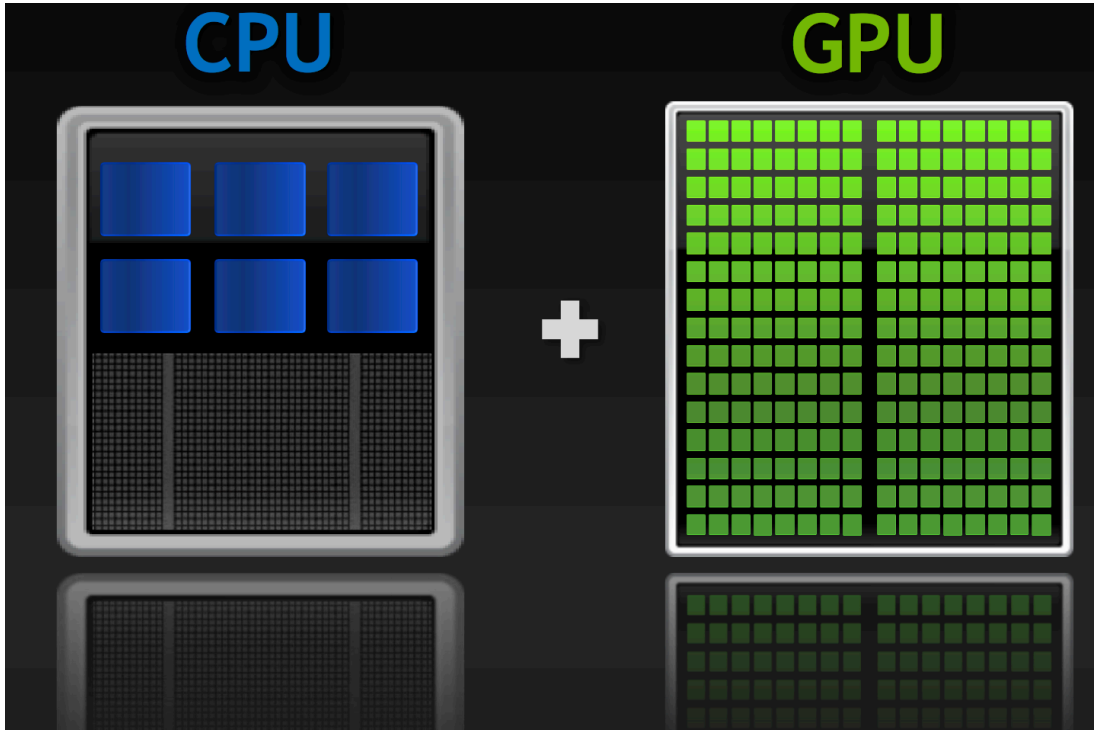
The GPU Architecture

- SIMT – single instruction, multiple threads
  - GPU has many SIMT cores
- Application → many thread blocks (1 per SIMT core)
- Thread block → many warps (1 warp per SIMT core)
- Warp → many in-order pipelines (SIMD lanes)



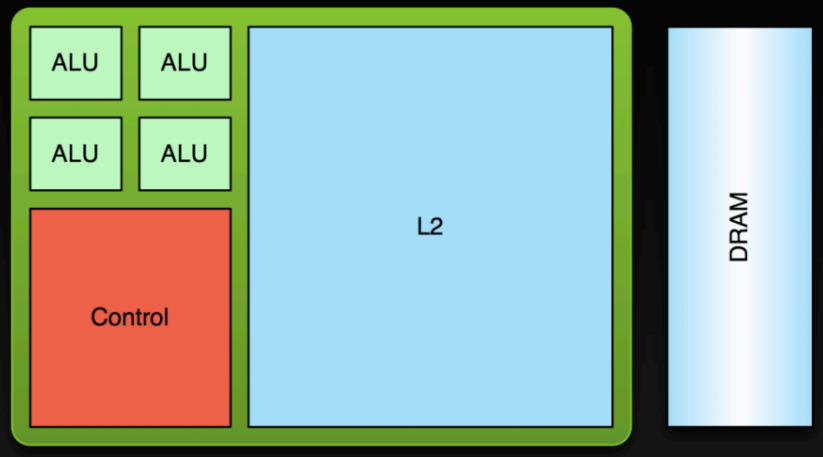
GPU Computing

- GPU as an accelerator in scientific applications



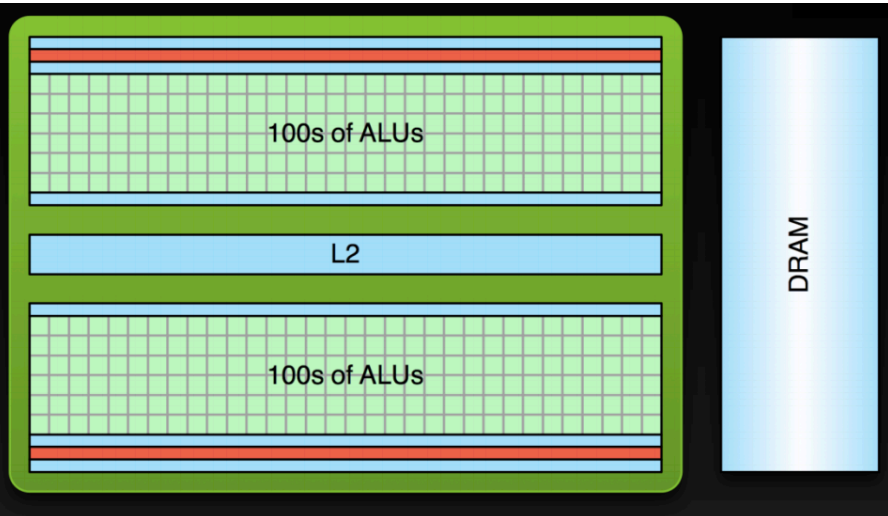
GPU Computing

- Low latency or high throughput?



CPU

- Optimized for low-latency access to cached data sets
- Control logic for out-of-order and speculative execution

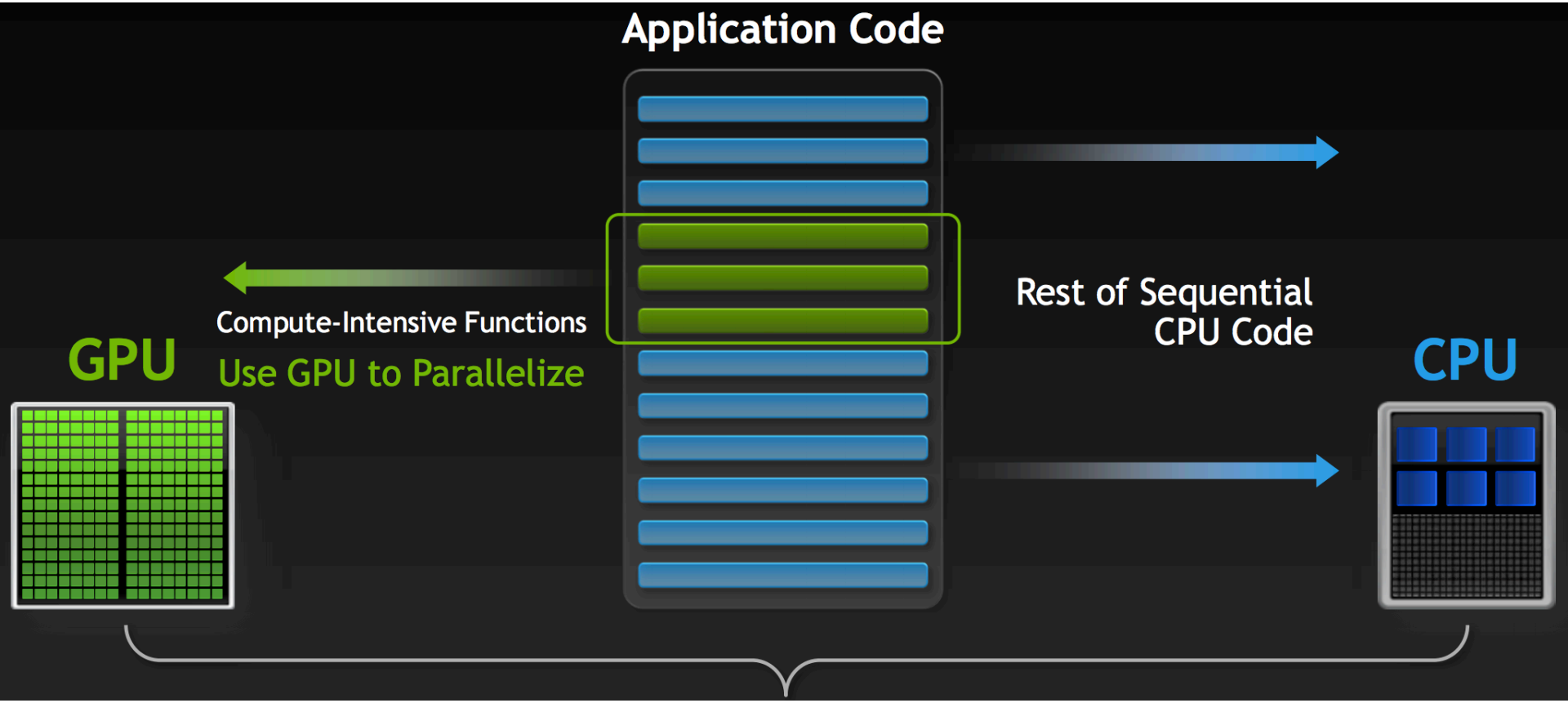


GPU

- Optimized for data-parallel, throughput computation
- Architecture tolerant of memory latency
- More transistors dedicated to computation

GPU Computing

- Low latency or high throughput



CUDA Programming Model

- Step 1: substitute library calls with equivalent CUDA library calls
  - saxpy (…) → cublasSaxpy (…)
    - single precision alpha x plus y ($z = \alpha x + y$)
- Step 2: manage data locality
  - cudaMalloc(), cudaMemcpy(), etc.
- Step 3: transfer data between CPU and GPU
  - get and set functions
- rebuild and link the CUDA-accelerated library
  - nvcc myobj.o –l cublas

Example: SAXPY Code

```
int N = 1 << 20;
```

```
// Perform SAXPY on 1M elements: y[]=a*x[]+y[]
saxpy(N, 2.0, x, 1, y, 1);
```

Example: CUDA Lib Calls

```
int N = 1 << 20;
```

```
// Perform SAXPY on 1M elements: d_y[]=a*d_x[]+d_y[]
cublasSaxpy(N, 2.0, d_x, 1, d_y, 1);
```

Example: Initialize CUDA Lib

```
int N = 1 << 20;

cublasInit();

// Perform SAXPY on 1M elements: d_y[]=a*d_x[]+d_y[]
cublasSaxpy(N, 2.0, d_x, 1, d_y, 1);

cublasShutdown();
```

Example: Allocate Memory

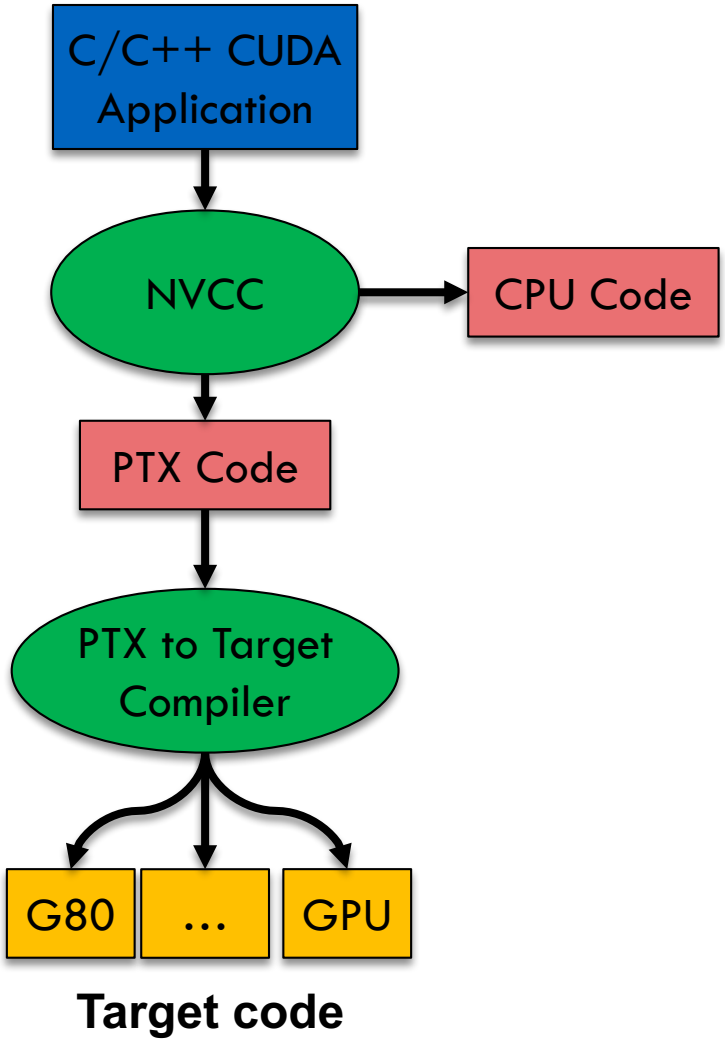
```
int N = 1 << 20;

cublasInit();
cublasAlloc(N, sizeof(float), (void**)&d_x);
cublasAlloc(N, sizeof(float), (void*)&d_y);

// Perform SAXPY on 1M elements: d_y[]=a*d_x[]+d_y[]
cublasSaxpy(N, 2.0, d_x, 1, d_y, 1);

cublasFree(d_x);
cublasFree(d_y);
cublasShutdown();
```

Example: Transfer Data

```
int N = 1 << 20;

cublasInit();
cublasAlloc(N, sizeof(float), (void**)&d_x);
cublasAlloc(N, sizeof(float), (void*)&d_y);

cublasSetVector(N, sizeof(x[0]), x, 1, d_x, 1);
cublasSetVector(N, sizeof(y[0]), y, 1, d_y, 1);

// Perform SAXPY on 1M elements: d_y[]=a*d_x[]+d_y[]
cublasSaxpy(N, 2.0, d_x, 1, d_y, 1);

cublasGetVector(N, sizeof(y[0]), d_y, 1, y, 1);

cublasFree(d_x);
cublasFree(d_y);
cublasShutdown();
```

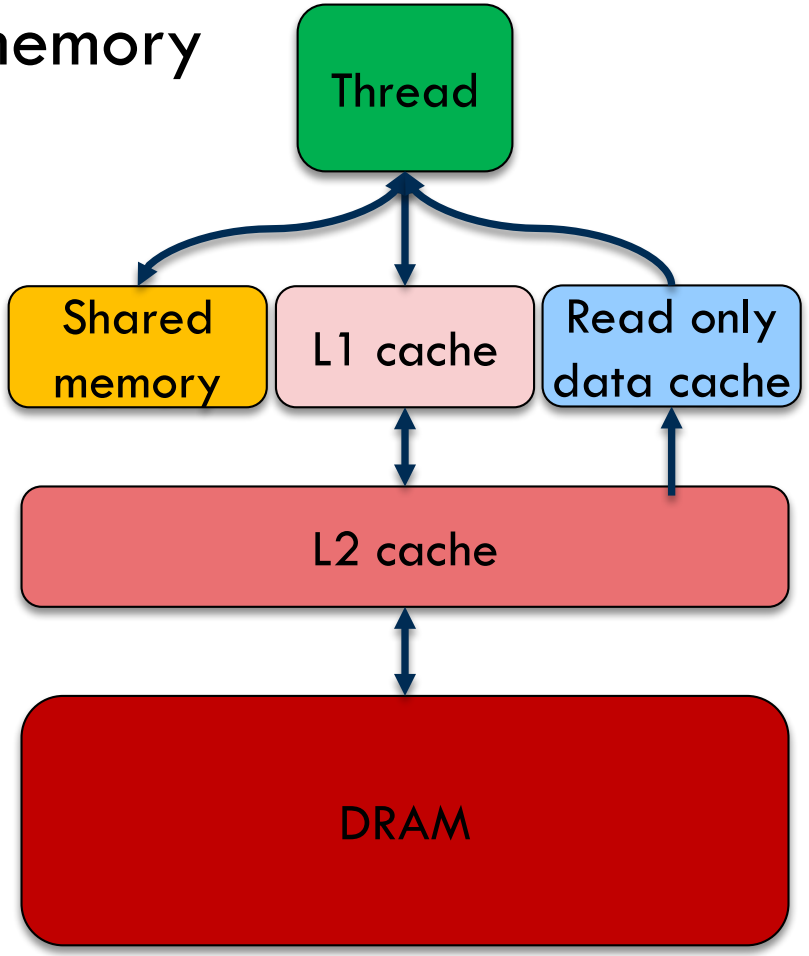
Compiling CUDA

- Call nvcc
- Parallel Threads eXecution (PTX)
  - Virtual machine and ISA
- Two stage
  - 1. PTX
  - 2. device-specific binary object



Memory Hierarchy

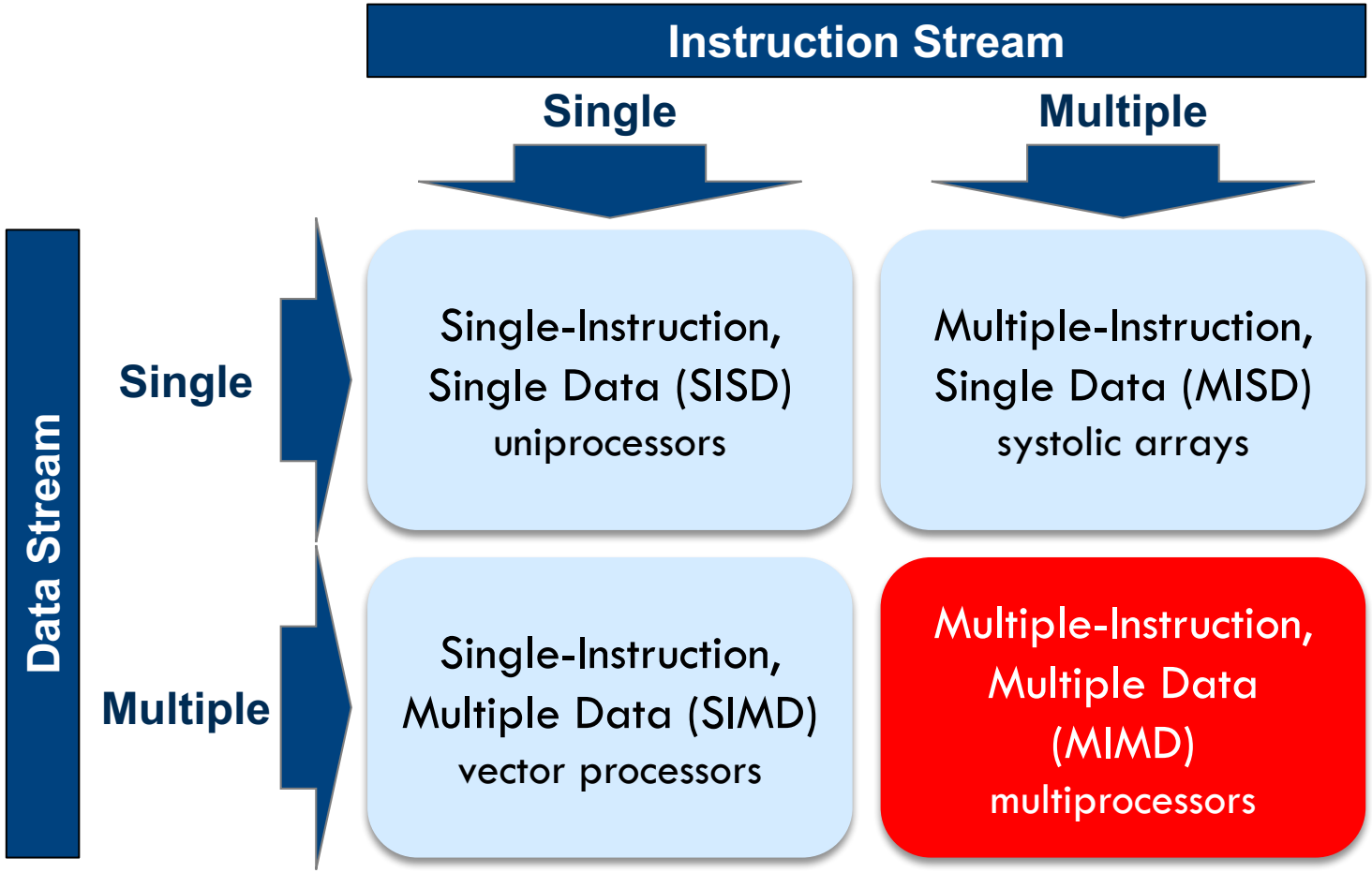
- Throughput-oriented main memory
  - Graphics DDR (GDDR)
    - Wide channels: 256 bit
    - Lower clock rate than DDR
  - 1.5MB shared L2
  - 48KB read-only data cache
    - Compiler controlled
  - Wide buses



Thread Level Parallelism

Flynn's Taxonomy

- Forms of computer architectures



Basics of Threads

- Thread is a single sequential flow of control within a program including instructions and state
  - Register state is called thread context
- A program may be single- or multi-threaded
  - Single-threaded program can handle one task at any time
- Multitasking is performed by modern operating systems to load the context of a new thread while the old thread's context is written back to memory

Thread Level Parallelism (TLP)

- Users prefer to execute multiple applications
  - Piping applications in Linux
    - `gunzip -c foo.gz | grep bar | perl some-script.pl`
  - Your favorite applications while working in office
    - Music player, web browser, terminal, etc.
- Many applications are amenable to parallelism
  - Explicitly multi-threaded programs
    - Pthreaded applications
  - Parallel languages and libraries
    - Java, C#, OpenMP