GPU Architecture
(not covered on exam)

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Announcements

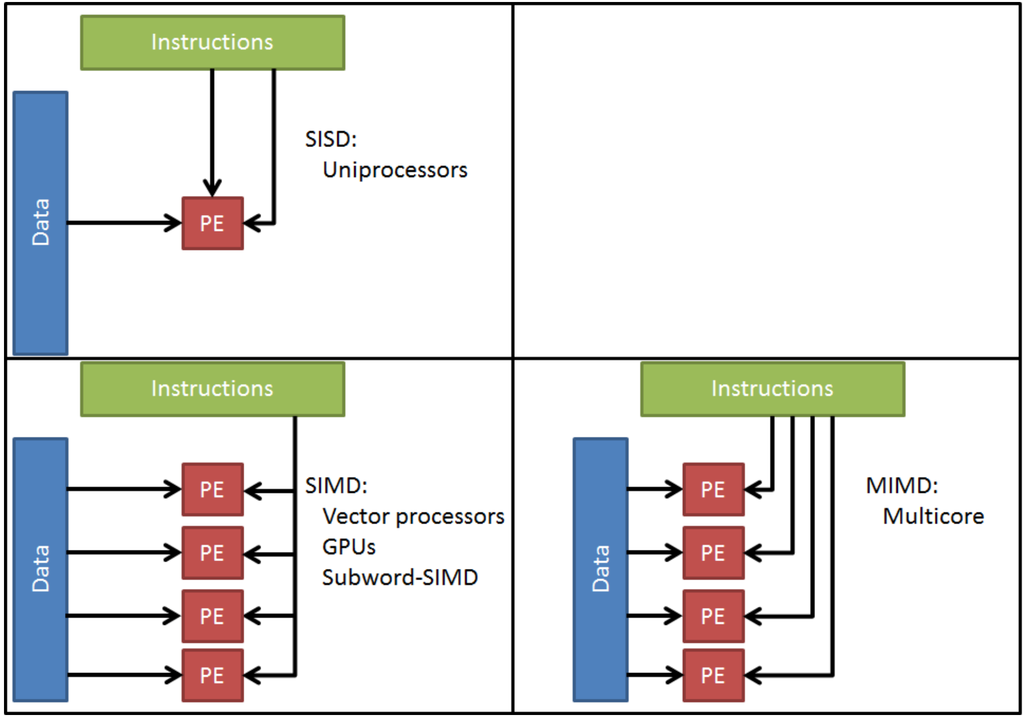
- Lab
  - Assignment due Wednesday
  - Canvas quiz by Thursday
  - Meet Fr/M
- Project 3
  - Checkpoint due Thursday – 5%
  - Full project due next Thursday
- HW 3
  - Out later today
  - ~2 weeks to finish

Data-Level Parallelism (DLP)

- Multiple instances of instructions that operate on different data
- Usually found across iterations of a “for” loop

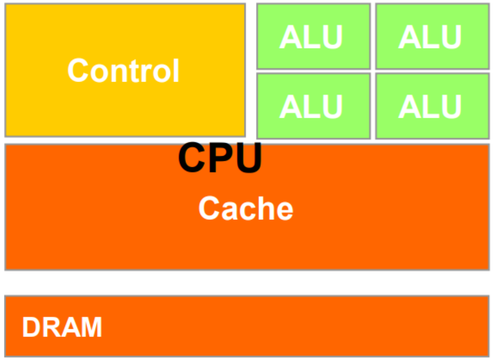
```
for (I = 0; I < 100; I++)
   Z[I] = A*X[I] + Y[I];
```

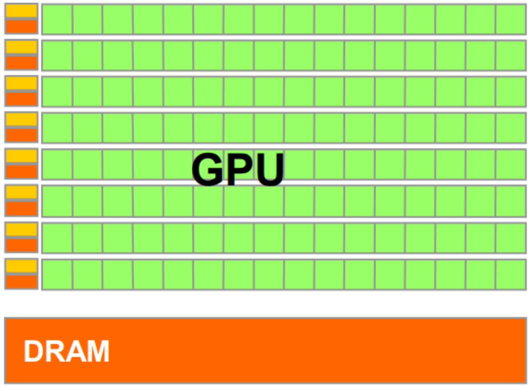
SIMD Methodology



SIMD Methodology

- Fetch / decode / schedule an instruction once
- Execute it several times
- Allows for much more of the die space to be dedicated to ALUs

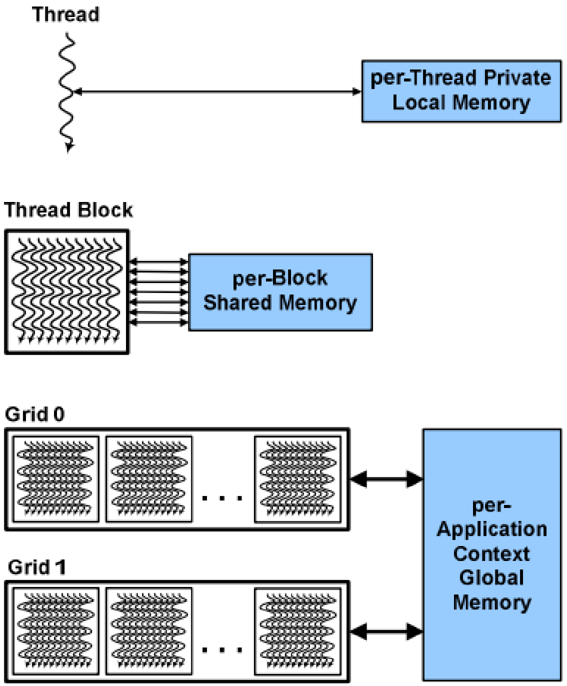




CUDA Programming Model

```
// CPU algorithm: sums two vectors sequentially

for(int a=0; a<size; a++)

        array1[a]+=array2[a];

// GPU algorithm: sums two vectors in parallel
__global__ void AddInts(int *a, int *b, int size) {
        int id = blockIdx.x * blockDim.x + threadIdx.x;
        if(id < size) {
                a[id] += b[id];
        }
}                    # thread blocks    threads / block
AddInts <<< ceil(size / 256),       256        >>>(a, b, size);
```

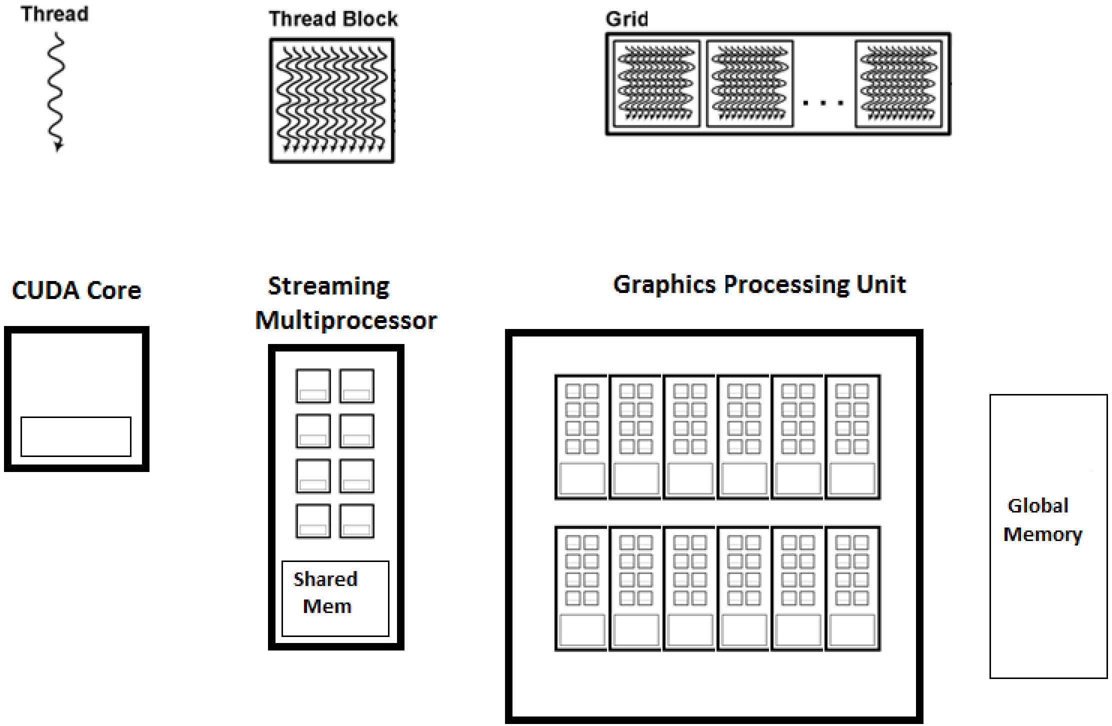
CUDA Programming Model



SIMT Model

- Assumption: there are millions of elements in a vector to apply an operation to
    - Treat each element as a "thread"
- Fetch an instruction to operate on a ~10-100 elements at a time
    - SIMD
- Start fetching next instruction right away
    - Pipelining
- On the next cycle, fetch from a different bundle of 32 threads
    - That way, cache misses won't stall the program
    - Multi-threading
- Include 100s of these SIMD cores to execute different thread blocks
    - Multi-processing
- Result is "Single-Instruction-Multiple-Thread (SIMT)" computing

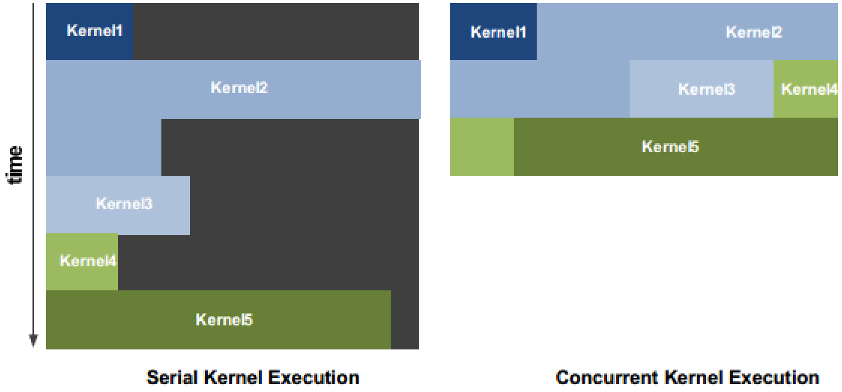
CUDA Hardware Hierarchy



CUDA Architecture

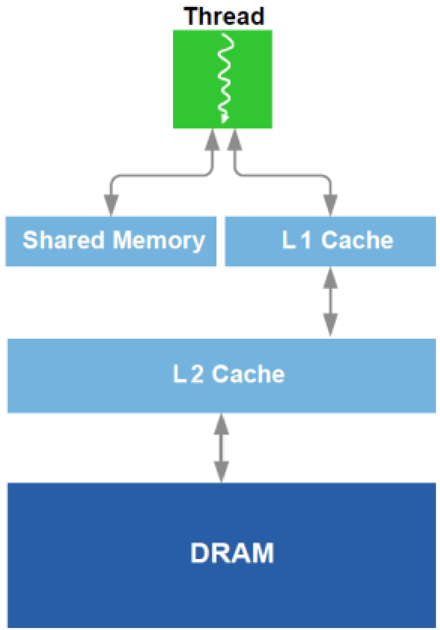
GigaThread Scheduler

- Concurrent Kernel Execution



- 10x Faster Context Switching between applications

True Cache Hierarchy



Shared Memory / L1 Cache

- Shared memory enables threads within same thread block to share data
  - Software controlled scratch pad
  - Typical in fairly deterministic GPU applications
- L1 beneficial for non-deterministic memory accesses

General-Purpose GPUs

- GPUs were originally designed to accelerate graphics workloads
- Millions of vertexes on a screen
  - Most are independent, can be calculated as separate thread
- But tons of workloads match this level of parallelism
- GPUs are designed to be more "general purpose"

Irregular Parallelism

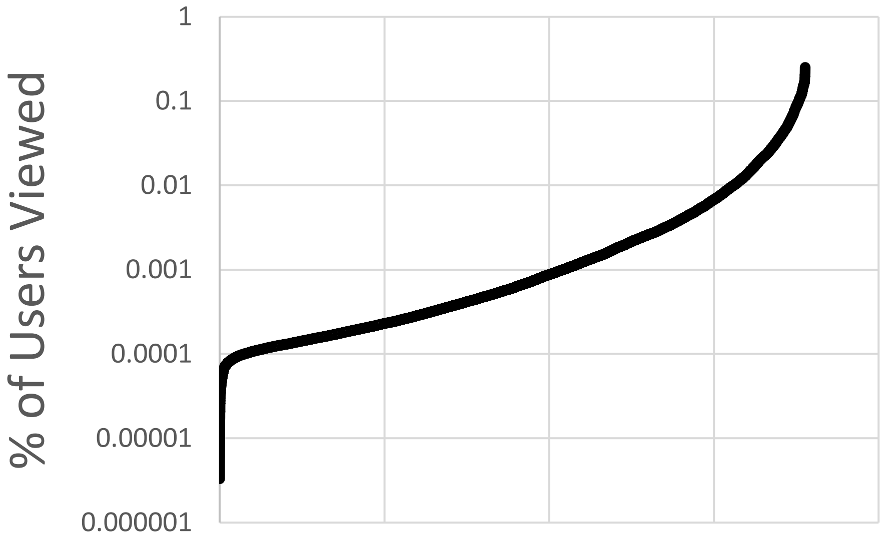
- Some “compute” operator performed over large elements of data
  - Data-level parallelism
- Which elements depends on specific structure
  - “Irregular” or “amorphous”
- Can often be represented as a graph
  - Breadth first search, n-body simulation, SGD

Irregular Data

- Real world data sets becoming increasingly "sparse"
  - Fewer relative connections between data
- E.g. number of Facebook users grew 19.8% from 2017 to 2018
  - Average number of "friends" per user grew 11.2%
  - Average density of "friend" graph decreases by 7.2%

Irregular Data

- E.g. number of Netflix users who've viewed content

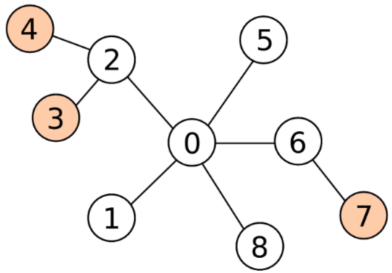


Irregular Algorithm Implementations

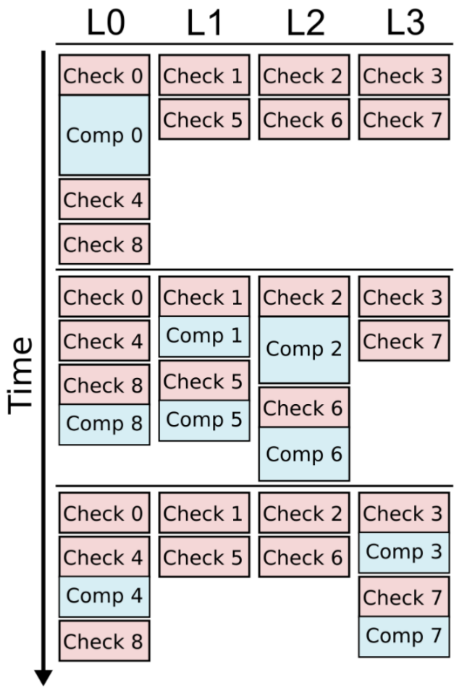
Two common approaches:

1. Topology-driven:
    - Every node is processed on each iteration until completion
2. Data-driven:
    - Active nodes are placed in a worklist, only visited when useful work to be done

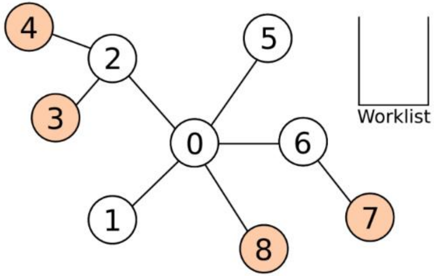
Topology-Driven



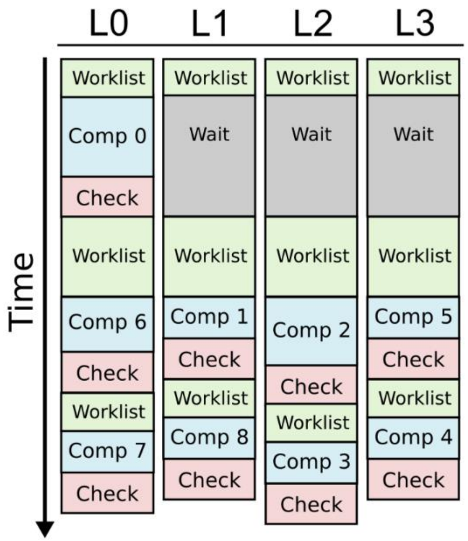

```
__global__ void topo(Node *nodes, bool *done) {
  Node node = nodes[threadIdx];
  if( node.active() ) {
    node.process();
    *done = false;
  }
}

int main() {
  //...
  while (!finished) {
    done = true;
    topo<<<N>>>(nodes, &done);
  }
}
```



Data-Driven



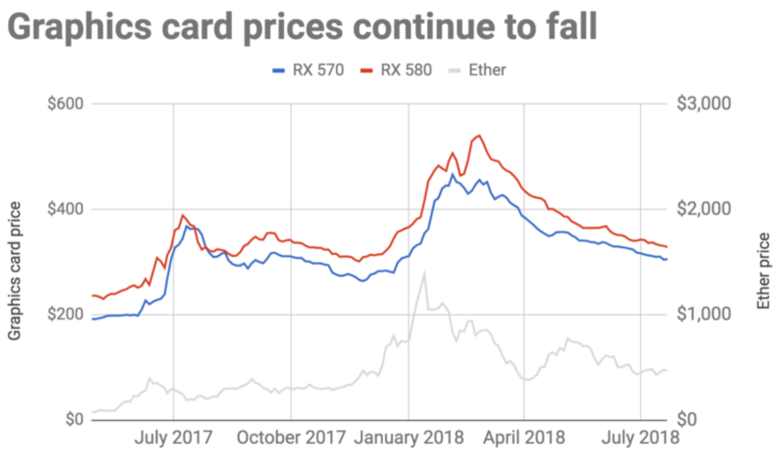

```
__global__ void data(Node *nodes, WL *wl)
  while(idx = wl->pop()) {
    Node node = nodes[idx];
    node.process();
    for(i=0; i<node.num_neighbors; i++) {
      wl->push(node.neighbor(i));
    }
  }
}

int main() {
  //...
  init<<<N>>>(nodes, wl);
  data<<<M>>>(nodes, wl);
}
```



Why Have GPUs Been in the News?

- GPUs surged in popularity during the crypto-boom
- Cryptomining
  - A transaction is verified by someone performing "proof-of-work"
  - Basically, reversing a hash function
  - Whoever reverse-hashes first gets rewarded with currency
- GPUs can attempt multiple reverse-hashes simultaneously
- Power efficiency is more important than raw throughput
  - Easy to spend more money on electricity than what you earn

GPU Costs



Credit: Sam Huitfeld, Viperlair

Why Have GPUs Been in the News?

- AI Boom
  - Spurred by bots like ChatGPT
- Large language models, deep learning, other AI/ML techniques rely on processing massive amounts of data
  - Language of linear algebra
  - Massive vectors and matrices
- GPUs can provide huge benefits over CPUs

Will We See Another GPU Shortage?

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NEWS

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By Stephen Nellis and Max A. Cherney

August 24, 2023 2:14 PM EDT · Updated 3 months ago

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Tech Industry > Artificial Intelligence

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News By Mark Tyson published August 01, 2023

Hopefully we can avoid a repeat of the cryptomining-GPU situation.

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TECH

ChatGPT and generative AI are booming, but the costs can be extraordinary

PUBLISHED MON, MAR 13 2023·8:58 AM EDT | UPDATED MON, APR 17 2023·2:09 AM EDT

Jonathan Vanian Kif Leswing

Wanna Learn More?

- EECS 570 – Parallel computer architecture
  - Learn more about how GPUs are designed (one topic in the class)
- EECS 471 – Applied Parallel Programming with GPUs
  - How to efficiently program these things