AI 芯片 – GPU 详解

GPU工作原理

ZOMI

Talk Overview

1. AI 计算体系
   - 深度学习计算模式
   - 计算体系与矩阵运算
2. AI 芯片基础
   - 通用处理器 CPU
   - 从数据看 CPU 计算
   - 通用图形处理器 GPU
   - AI专用处理器 NPU/TPU
   - 计算体系架构的黄金10年

1. **硬件基础**
   - GPU 工作原理
   - GPU AI编程本质
2. **英伟达 GPU 架构**
   - 从 Fermi 到 Hopper 架构
   - Tensor Code 和 NVLink 详解
3. **GPU 图形处理流水线**
   - 图形流水线基础
   - GPU 逻辑模块划分
   - 图形处理算法到硬件

Talk Overview

1. **硬件基础**
   - GPU 工作原理
   - GPU AI编程本质
2. **英伟达 GPU 架构**
   - GPU基础概念
   - 从 Fermi 到 Volta 架构
   - Turing 到 Hopper 架构
   - Tensor Code 和 NVLink 详解
3. **GPU 图形处理**
   - GPU 逻辑模块划分
   - 算法到 GPU 硬件
   - GPU 的软件栈
   - 图形流水线基础
   - 流水线不可编译单元
   - 光线跟踪流水线

Talk Overview

I. GPU 工作原理

- AX+Y DEMO – AX+Y 例子
- What is inference system – 并发与并行
- Optimization objectives and constraints – GPU 缓存机制
- Difference bet inference system and engine – GPU线程原理

What is GPU & what make it diff

What is GPU：

- GPU (Graphics Processing Units, GPUs) 原是设计用于处理图像视频等数据。

What Make GPU Diff CPU：

- 真正让GPU与CPU不同的是，GPU设计目标是最大化吞吐量 (Throughout)，比单任务执行快慢，更关心并行度 (parallelism)，即同时可以执行多少任务；CPU则更关心延迟 (latency) 和并发 (concurrency)。

AX+Y DEMO

看GPU工作原理

AX+Y 计算 DEMO

- 2FLOPs：multiply & add
- 2 Memory Loads: x[i] & y[i] (per element)
- Single Operation: FMA(fused multiply-add)

```
void demo(double alpha, double *x, double *y)
{
    int n = 2000;
    for(int i = 0; i < n; ++i)
    {
        y[i] = alpha * x[i] + y[i];
    }
}
```

AX+Y 计算 DEMO

Memory Bandwidth: 131 GB/sec

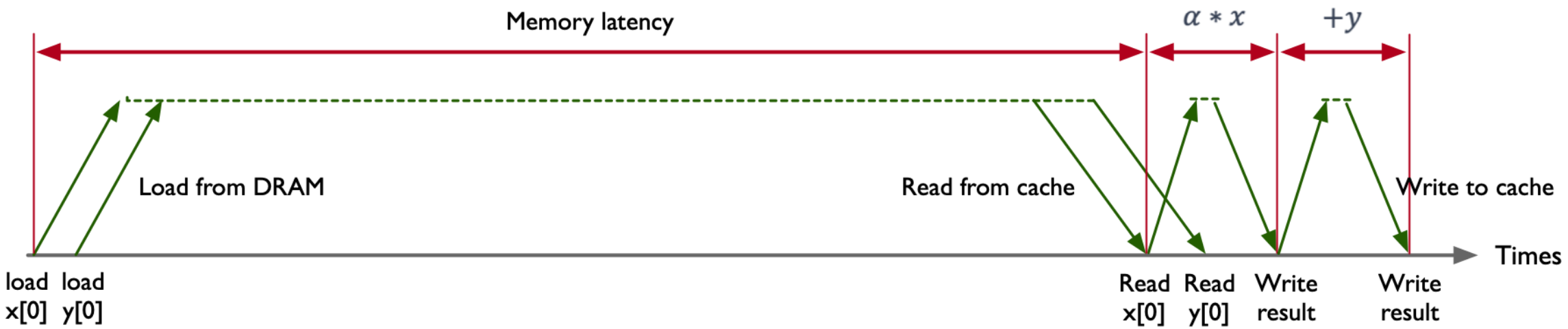
Memory latency: 89 ns

11,659 bytes can be moved in 89 ns

AXY demo move 16 byes per 89 ns latency

Memory efficiency = 0.14%

AX+Y 计算 DEMO



memory bus is idle 99.86% of the time

AX+Y 内存利用率

	AMD Rome 7742	Intel Xeon 8280	NVIDIA A100
Memory B/W(GB/sec)	204	131	1555
DRAM Latency(ns)	122	89	404
Peak bytes per latency	24,888	11,659	628,220
Memory Efficiency	0.064%	0.14%	0.0025%

Z=AX+Y 通过并发进行循环展开

```
2   void fun_axy(int n, double alpha, double *x, double *y)
3   {
4       for(int i = 0; i < n; i += 8)
5       {
6           y[i+0] = alpha * x[i+0] + y[i+0];
7           y[i+1] = alpha * x[i+1] + y[i+1];
8           y[i+2] = alpha * x[i+2] + y[i+2];
9           y[i+3] = alpha * x[i+3] + y[i+3];
10          y[i+4] = alpha * x[i+4] + y[i+4];
11          y[i+5] = alpha * x[i+5] + y[i+5];
12          y[i+6] = alpha * x[i+6] + y[i+6];
13          y[i+7] = alpha * x[i+7] + y[i+7];
14      }
15  }
```

Keep Memory bus busy, run 11,659/16=729 iterations at once.

Z=AX+Y 通过并发进行循环展开

```
2  void fun_axy(int n, double alpha, double *x, double *y)
3  {
4      for(int i = 0; i < n; i += 8)
5      {
6          y[i+0] = alpha * x[i+0] + y[i+0];
7          y[i+1] = alpha * x[i+1] + y[i+1];
8          y[i+2] = alpha * x[i+2] + y[i+2];
9          y[i+3] = alpha * x[i+3] + y[i+3];
10         y[i+4] = alpha * x[i+4] + y[i+4];
11         y[i+5] = alpha * x[i+5] + y[i+5];
12         y[i+6] = alpha * x[i+6] + y[i+6];
13         y[i+7] = alpha * x[i+7] + y[i+7];
14     }
15 }
```

- 编译器很少对循环展开上100+
- 一个线程一次执行上千条指令
- 一个线程很难直接处理700个计算负载

Keep Memory bus busy, run 11,659/16=729 iterations at once.

Z=AX+Y 通过并行进行循环展开

```
1
2   void fun_axy(int n, double alpha, double *x, double *y)
3   {
4       Parallel for(int i = 0; i < n; i++)
5       {
6           y[i] = alpha * x[i] + y[i];
7       }
8   }
9
```

Keep Memory bus busy, run 11,659/16=729 iterations at once.

Z=AX+Y 通过并行进行循环展开

```
1
2   void fun_axy(int n, double alpha, double *x, double *y)
3   {
4       Parallel for(int i = 0; i < n; i++)
5       {
6           y[i] = alpha * x[i] + y[i];
7       }
8   }
9
```

- 每个线程独立负责相关计算
- 一共需要 729 个线程
- 程序会受到线程数和内存请求 Bound

Keep Memory bus busy, run 11,659/16=729 iterations at once.

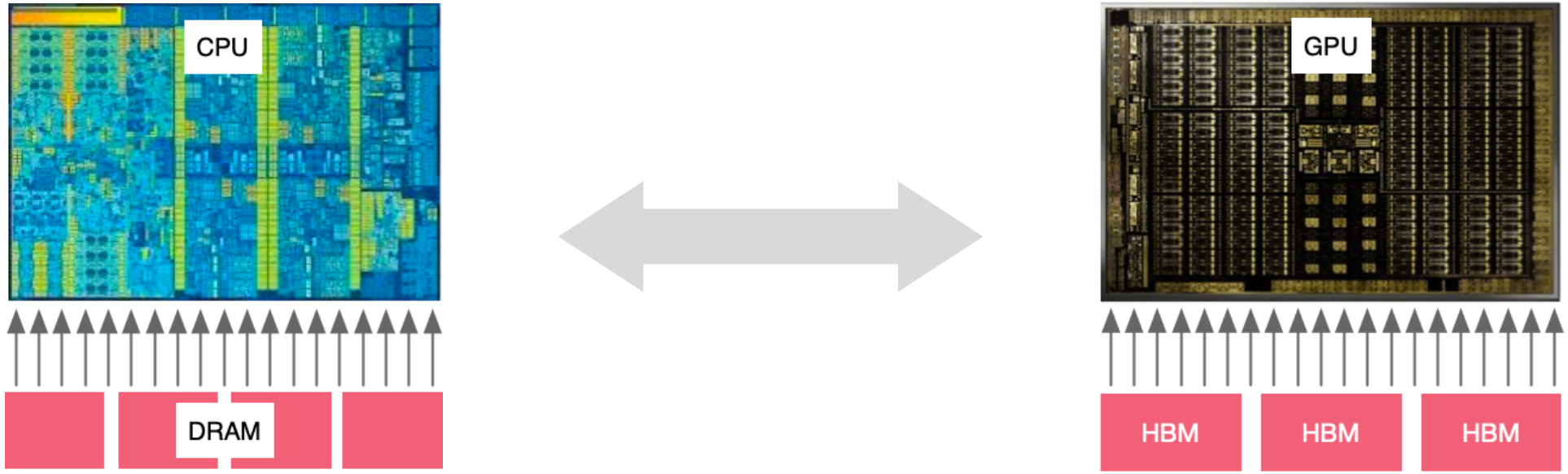
并行 Parallelism

并发 Concurrency

AX+Y 硬件架构线程区别

	AMD Rome 7742	Intel Xeon 8280	NVIDIA A100
Memory B/W(GB/sec)	204	143	1555
DRAM Latency(ns)	122	89	404
Peak bytes per latency	24,888	12,727	628,220
Memory Efficiency	0.064%	0.13%	0.0025%
Threads required	1,556	729	39,264
Threads available	2048	896	221,184
Thread Ration	1.3X	1.2X	5.6X

架构线程工作原理

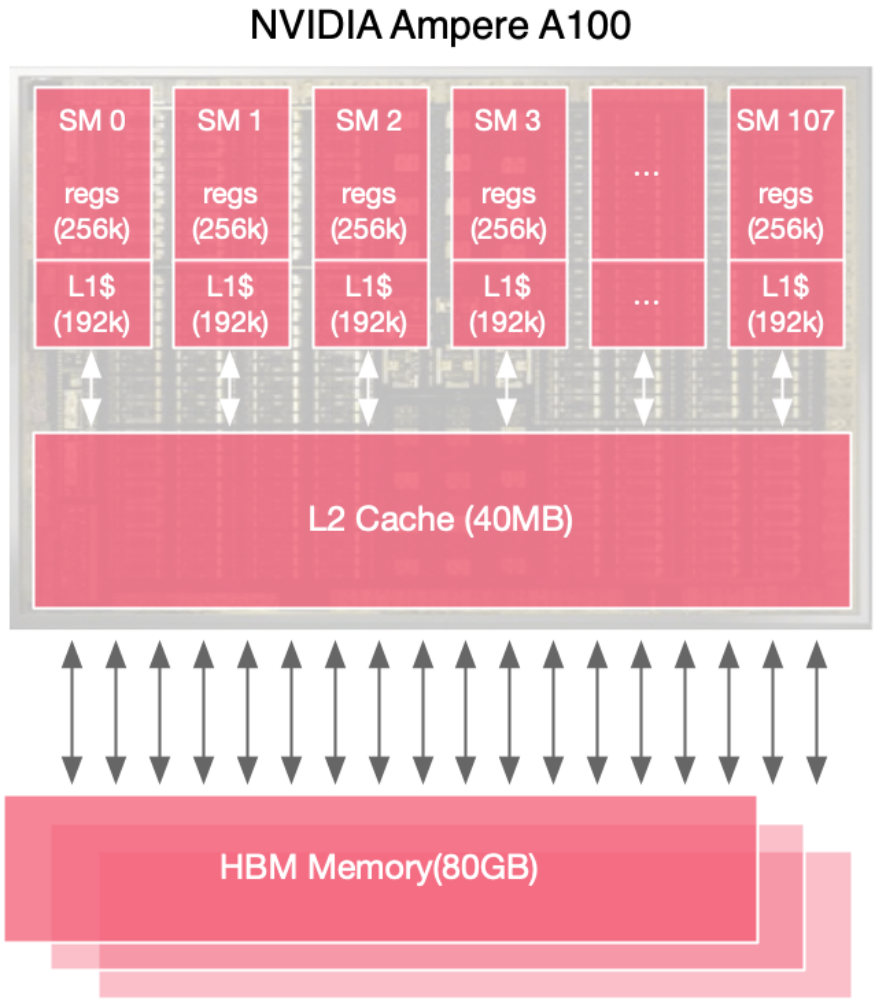


	AMD Rome 7742	Intel Xeon 8280	NVIDIA A100
Threads required	1,556	729	39,264
Threads available	2048	896	221,184
Thread Ration	1.3X	1.2X	5.6X

GPU Cache

缓存机制

GPU 缓存机制

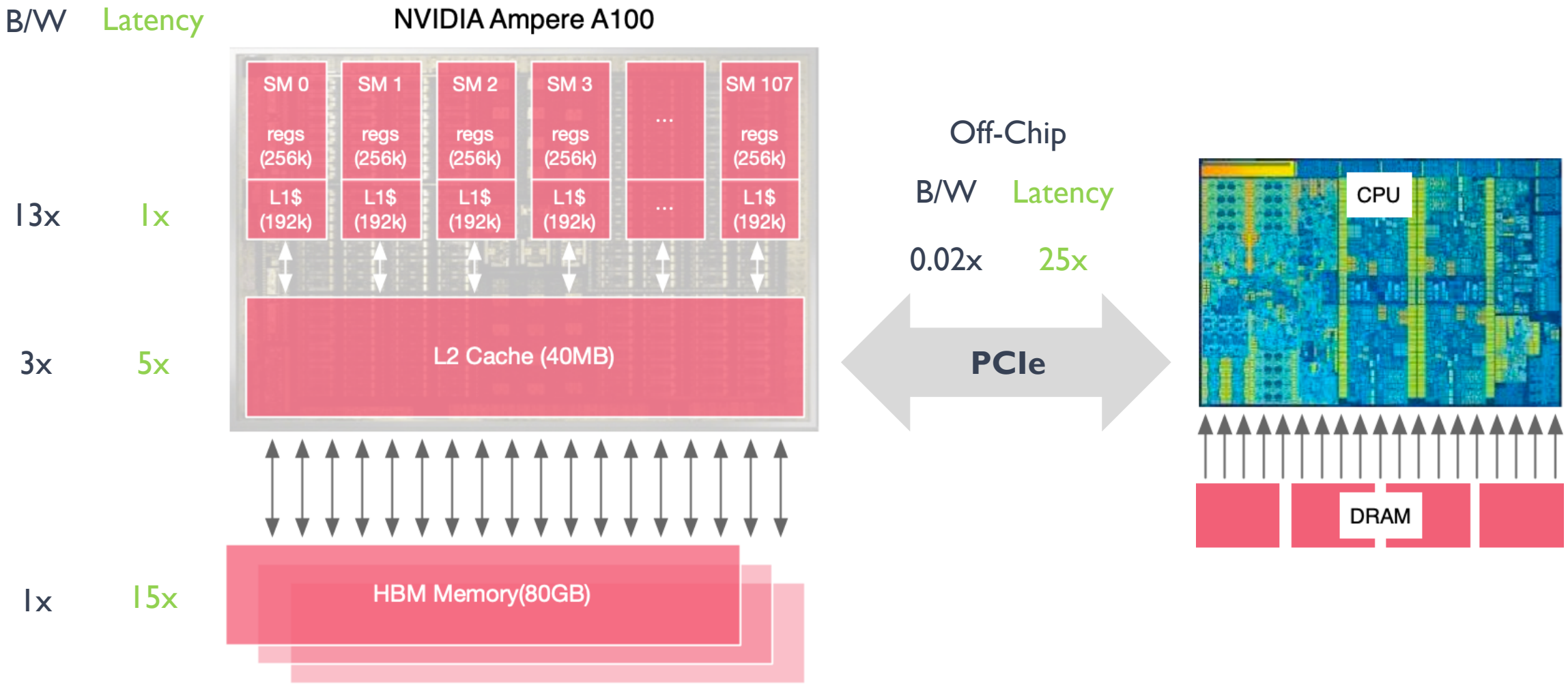


- 108 Streaming Multiprocessors(SMs)
- 256kB Register File per SM(27MB Total)
- 192kB L1 Cache & Shared Mem Per SM(20MB Total)
- 40MB L2 Cache Shared across all SMs

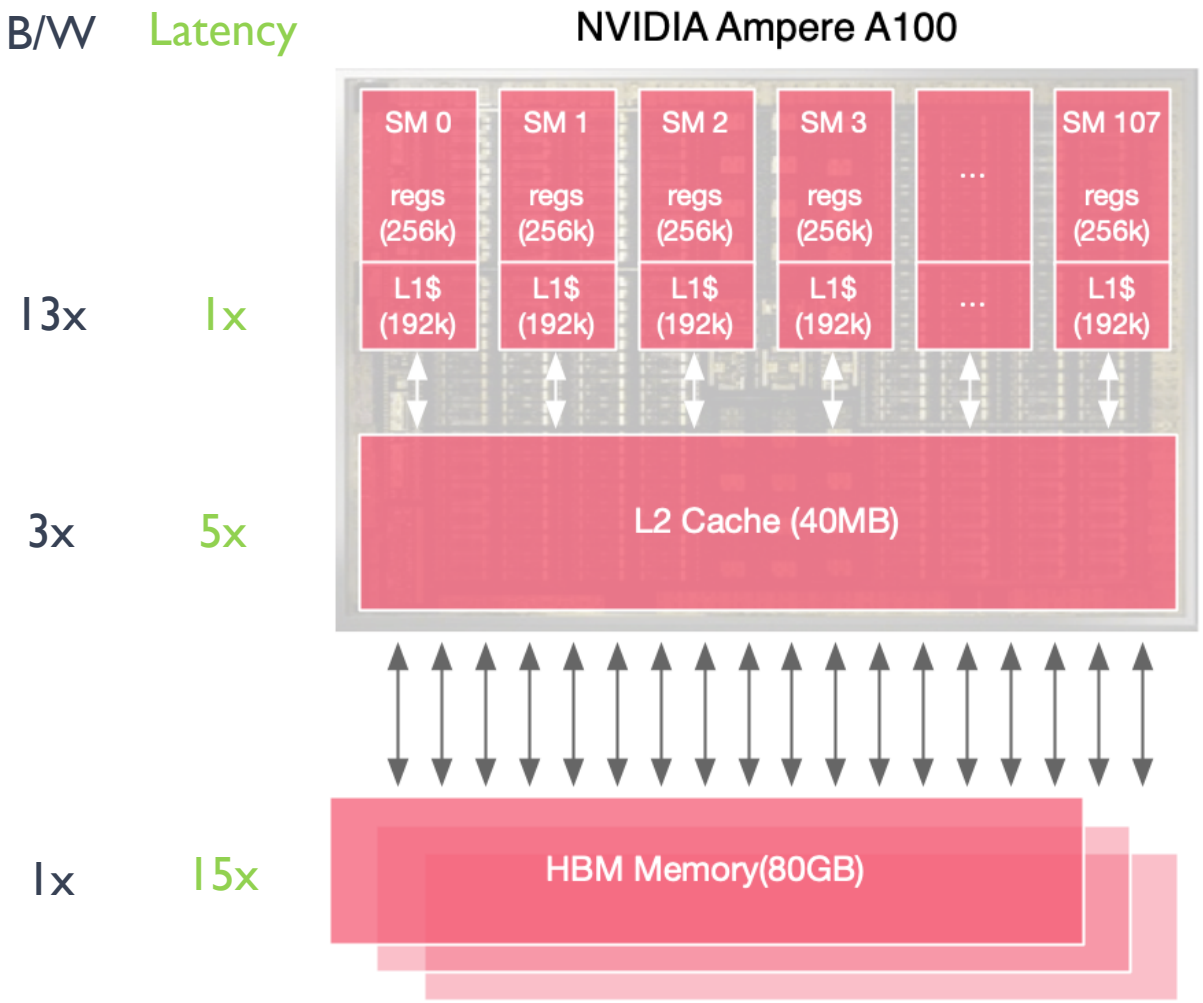
Caches 缓存

- 80GB High Bandwidth Memory

GPU 缓存机制

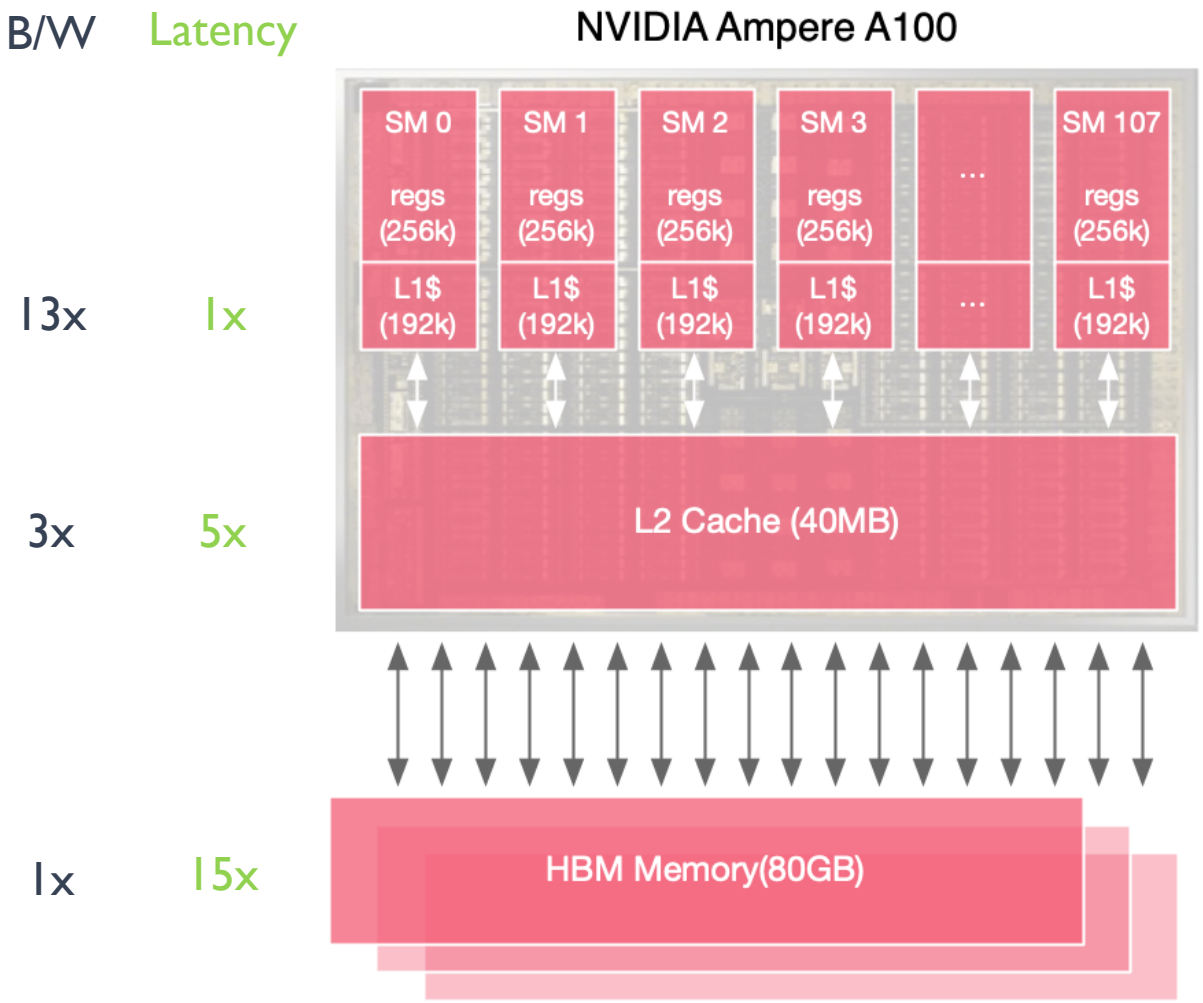


GPU 缓存机制



Data Location	Bandwidth (GB/sec)	Compute Intensity
L1 Cache	19,400	8
L2 Cache	4,000	39
HBM	1,555	100
NVLink	300	520
PCIe	25	6240

GPU 缓存机制

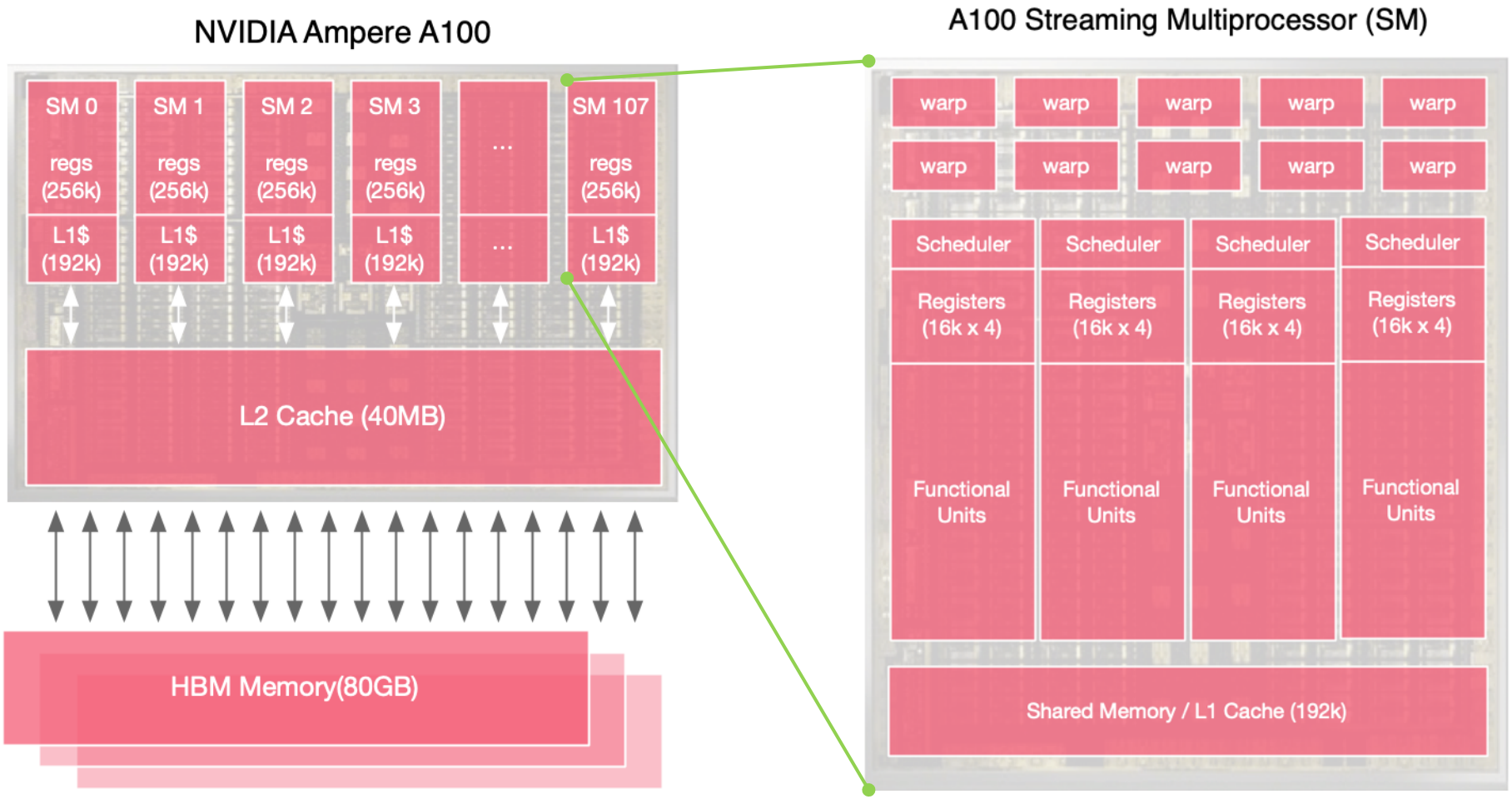


Data Location	Latency (ns)	Threads Required
L1 Cache	27	32,738
L2 Cache	150	37,500
HBM	404	39,264
NVLink	700	13,125
PCIe	1470	2297

GPU Thread

线程原理

GPU 线程机制



64 warps/SM

4x concurrent warp exec

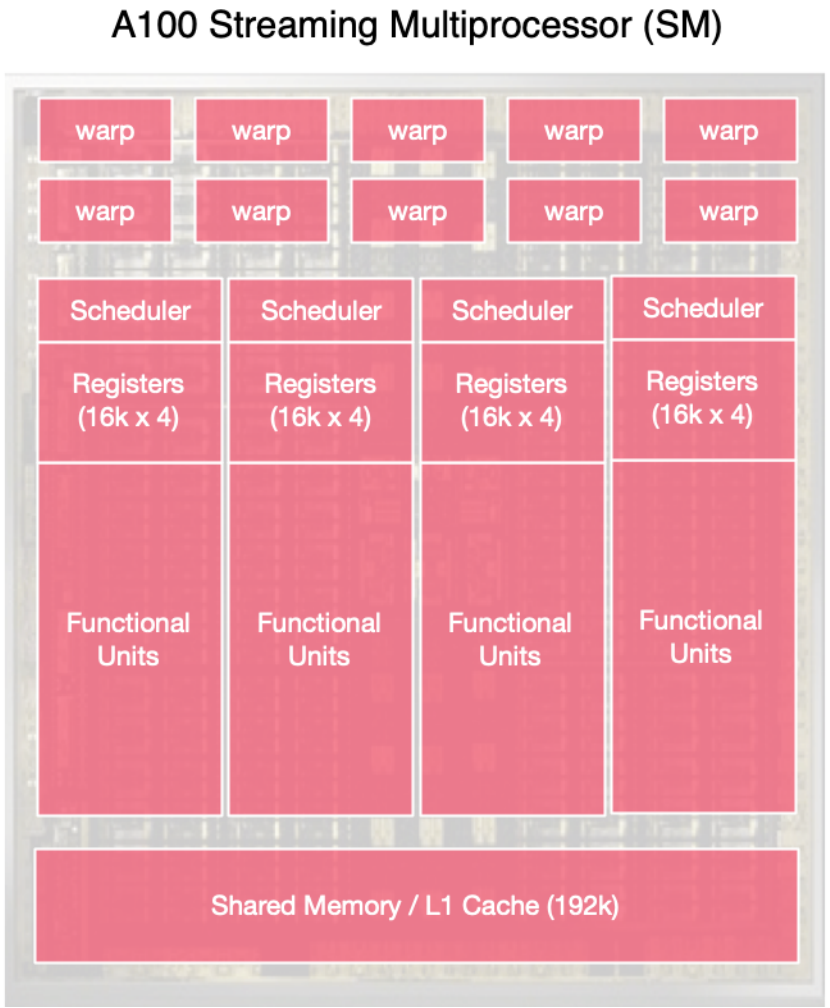
64k 4-byte registers

192KB L1/shared memory (configurable split)

GPU runs threads in groups of 32 – each group is known as a warp

GPU SMs 线程超配

	Pre SM	A100
Total Threads	2048	221,184
Total Warps	64	6,912
Active Warps	4	432
Waiting Warps	60	6,480
Active Threads	128	13,824
Waiting Threads	1,920	207,360



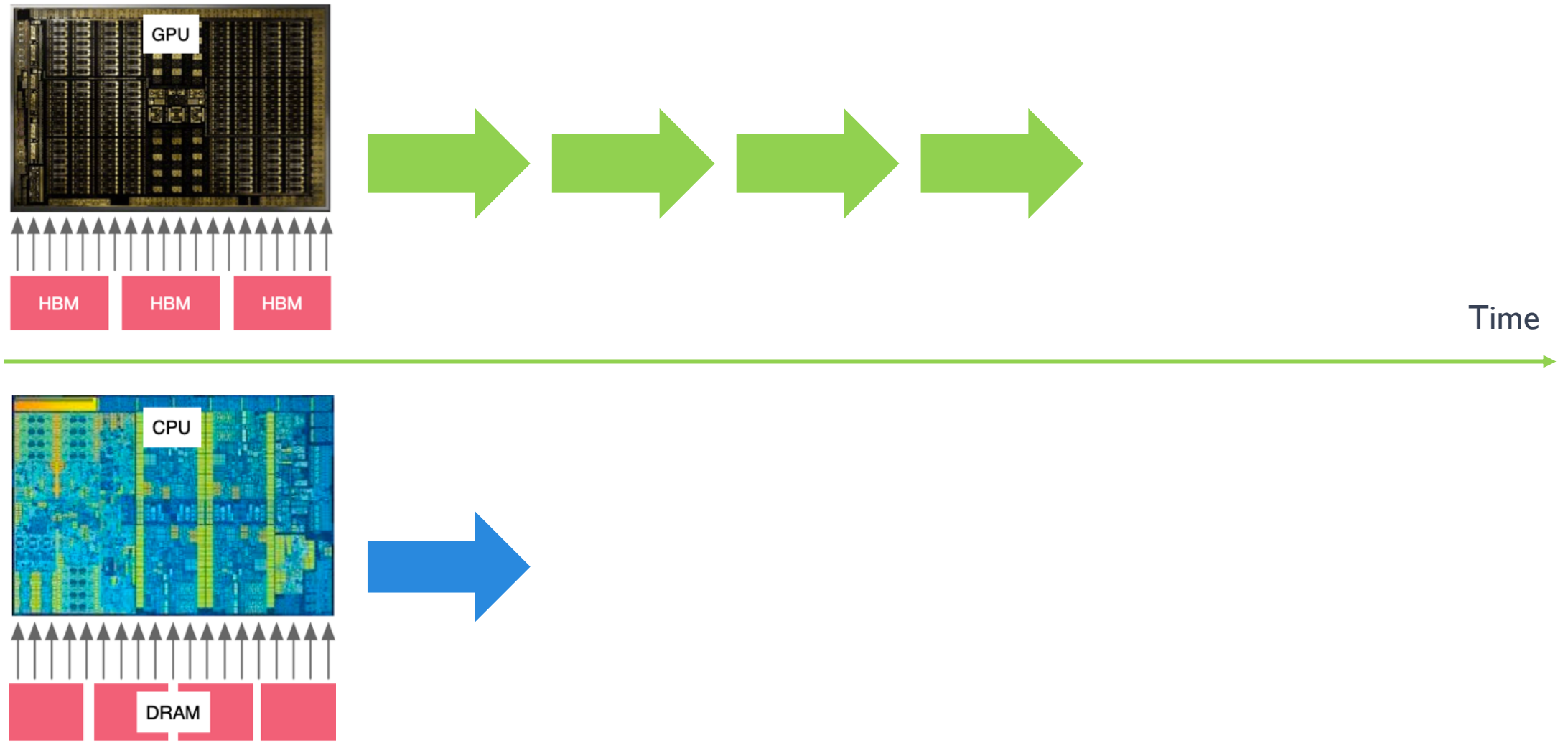
64 warps/SM

4x concurrent warp exec

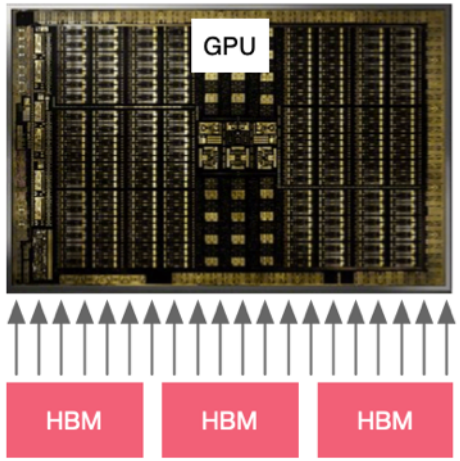
64k 4-byte registers

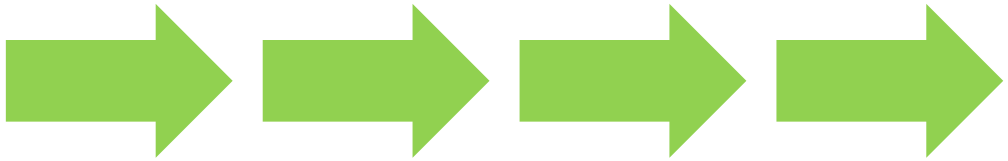
192KB L1/shared memory (configurable split)

CPU/GPU 并行才是本质

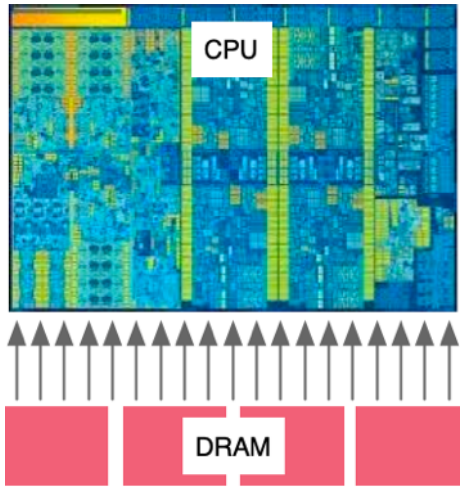


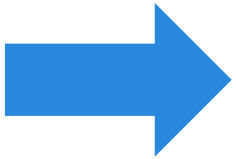
CPU/GPU 并行才是本质





Time





Reference

- https://www.techtarget.com/searchvirtualdesktop/definition/GPU-graphics-processing-unit
- https://www.techtarget.com/searchvirtualdesktop/definition/GPU-graphics-processing-unit#:~:text=GPUs%20work%20by%20using%20a,%2C%20high%2Dquality%20graphics%20rendering.
- https://computer.howstuffworks.com/graphics-card.htm
- https://www.cs.cmu.edu/afs/cs/academic/class/15462-f11/www/lec_slides/lec19.pdf
- https://www.intel.com/content/www/us/en/products/docs/processors/what-is-a-gpu.html
- https://www.investopedia.com/terms/g/graphics-processing-unit-gpu.asp
- https://www.youtube.com/watch?v=0_TN845dxUU
- https://www.youtube.com/watch?v=nEMzIwzmJT8
- https://www.heavy.ai/technical-glossary/cpu-vs-gpu
- https://www.youtube.com/watch?v=3110o0DYJXg
- https://www.youtube.com/watch?v=658n_Ym8dkk
- https://www.youtube.com/watch?v=5BiAlaFGCoE
- https://www.youtube.com/watch?v=bZdxcHEM-uc