CUDA编程基础 – 利用CUDA加速图像处理

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CUDA并行计算基础

AGENDA

- GPU硬件平台
- CUDA 安装
- CUDA线程层次
- CUDA线程索引
- CUDA线程分配
- 图像处理
- 编程实例：Sobel边缘检测

What is CUDA?

- CUDA
  - Compute Unified Device Architecture

- CUDA C/C++
  - 基于C/C++的编程方法
  - 支持异构编程的扩展方法
  - 简单明了的APIs，能够轻松的管理存储系统

- CUDA支持的编程语言：
  - C/C++/Python/Fortran/Java/.......

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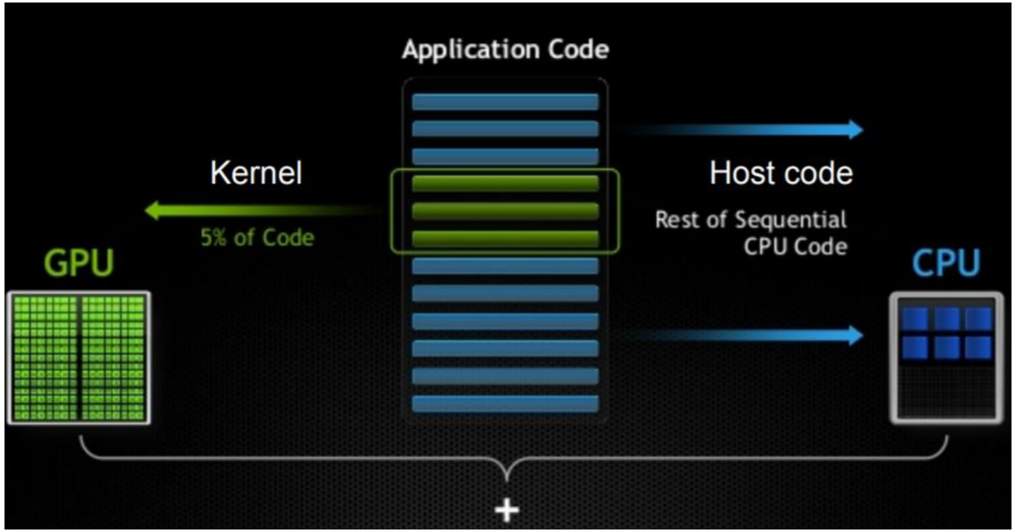
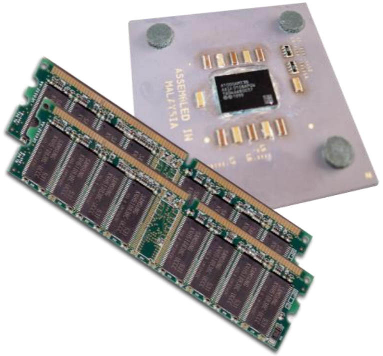
500k

异构计算

- 术语:
  - *Host*　CPU和内存(host memory)
  - *Device*　GPU和显存(device memory)



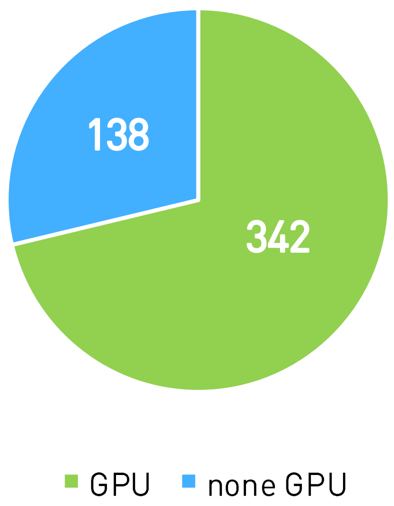


Host

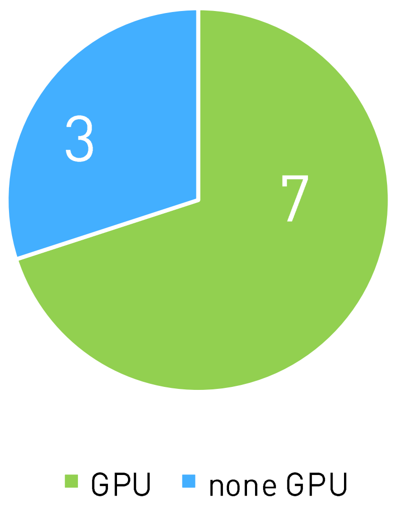
Device

异构计算

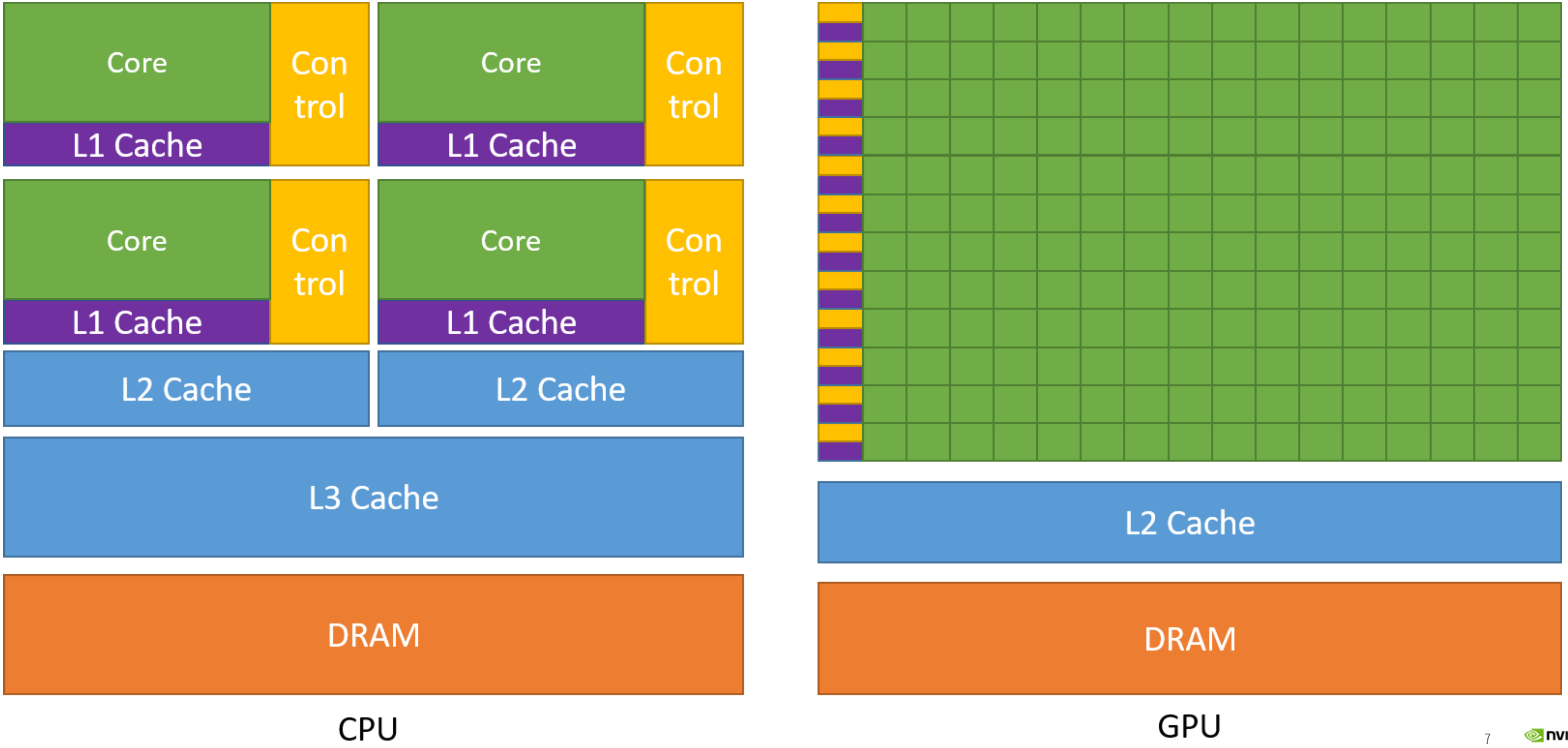
高性能计算大会ISCTOP 500



高性能计算大会ISC TOP10



芯片结构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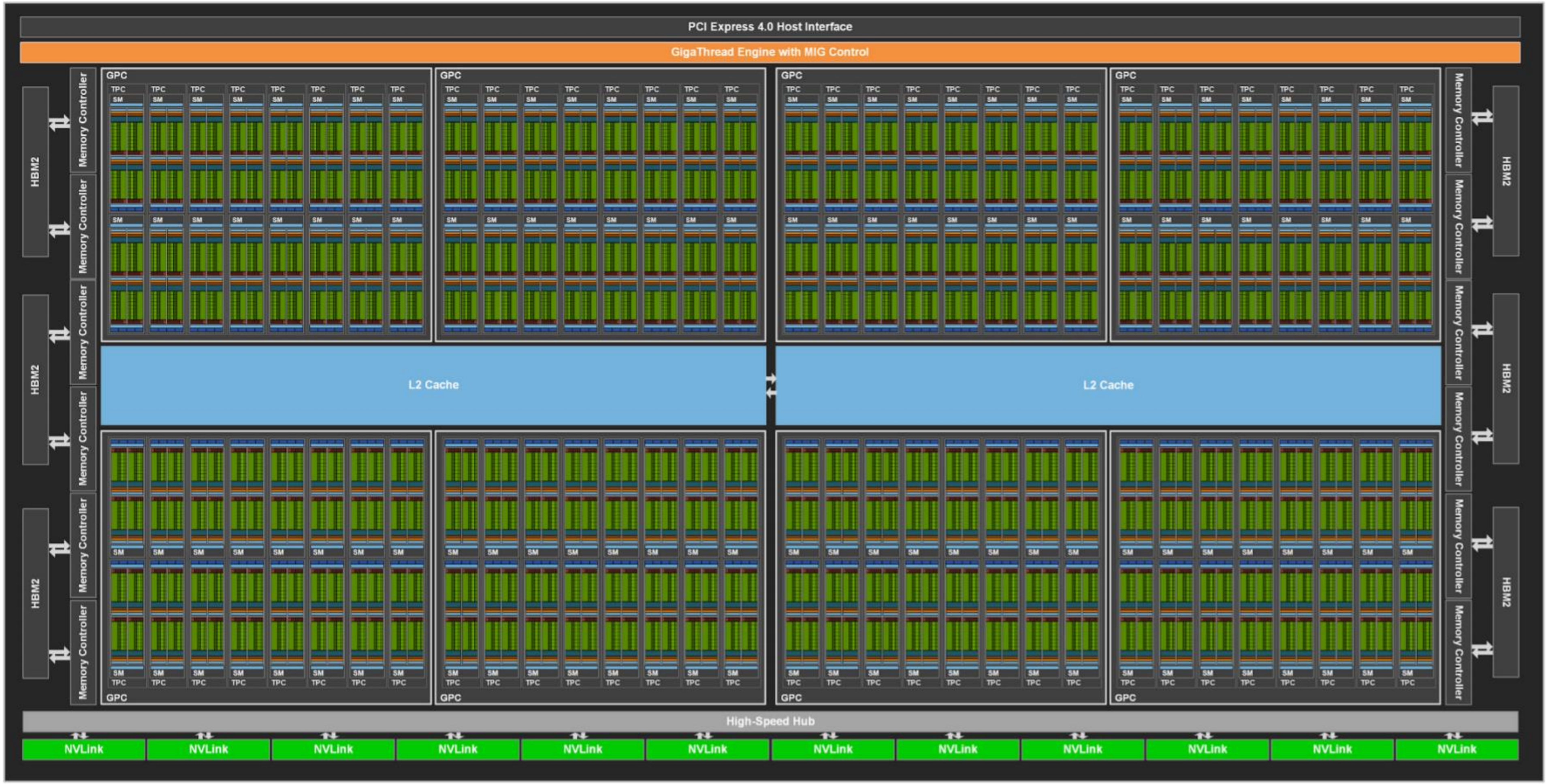
DRAM
GPU

GPU结构---GA100



PCI Express 4.0 Host Interface
GigaThread Engine with MIG Control
GPC
TPC
SM
Memory Controller
HBM2
L2 Cache
High-Speed Hub
NVLink

GPU结构---GA100

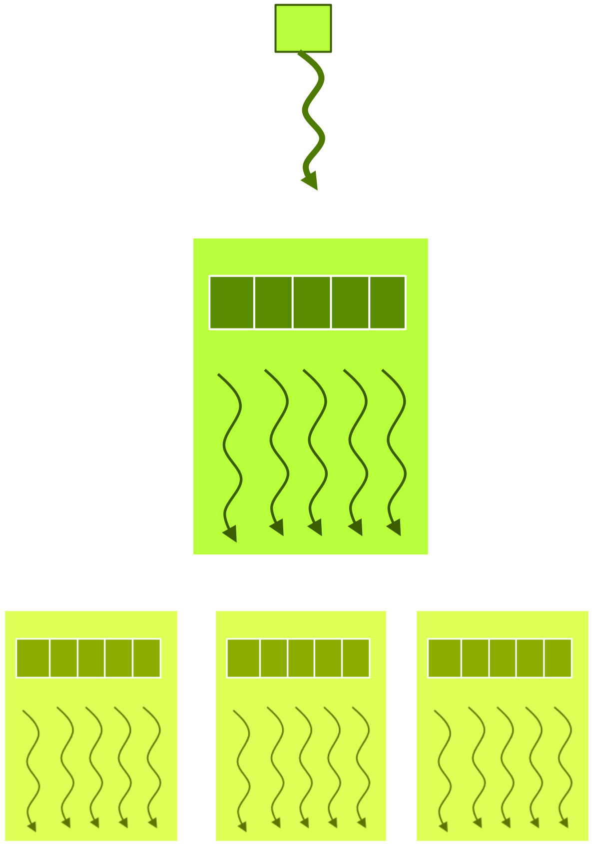
- 8 GPCs, 8 TPCs/GPC, 2 SMs/TPC, 16 SMs/GPC, 128 SMs per full GPU
- 64 FP32 CUDA Cores/SM, 8192 FP32 CUDA Cores per full GPU
- 4 third-generation Tensor Cores/SM, 512 third-generation Tensor Cores per full GPU
- 6 HBM2 stacks, 12 512-bit memory controllers

CUDA安装

- 适用设备:
  - *所有包含NVIDIA GPU的服务器，工作站，个人电脑，嵌入式设备等电子设备*
- 软件安装:
  - Windows：https://docs.nvidia.com/cuda/cuda-installation-guide-microsoft-windows/index.html
    只需安装一个.exe的可执行程序
  - Linux：https://docs.nvidia.com/cuda/cuda-installation-guide-linux/index.html
    按照上面的教程，需要6 / 7 个步骤即可
  - Jetson： https://developer.nvidia.com/embedded/jetpack
    直接利用NVIDIA SDK Manager 或者 SD image进行刷机即可

CUDA线程层次

```
HelloFromGPU <<<?, ?>>>();
```



- Thread: sequential execution unit
  - 所有线程执行相同的核函数
  - 并行执行
- Thread Block: a group of threads
  - 执行在一个Streaming Multiprocessor (SM)
  - 同一个Block中的线程可以协作
- Thread Grid: a collection of thread blocks
  - 一个Grid当中的Block可以在多个SM中执行

线程层次

- 执行设置:

dim3 grid(3,2,1), block(5,3,1)

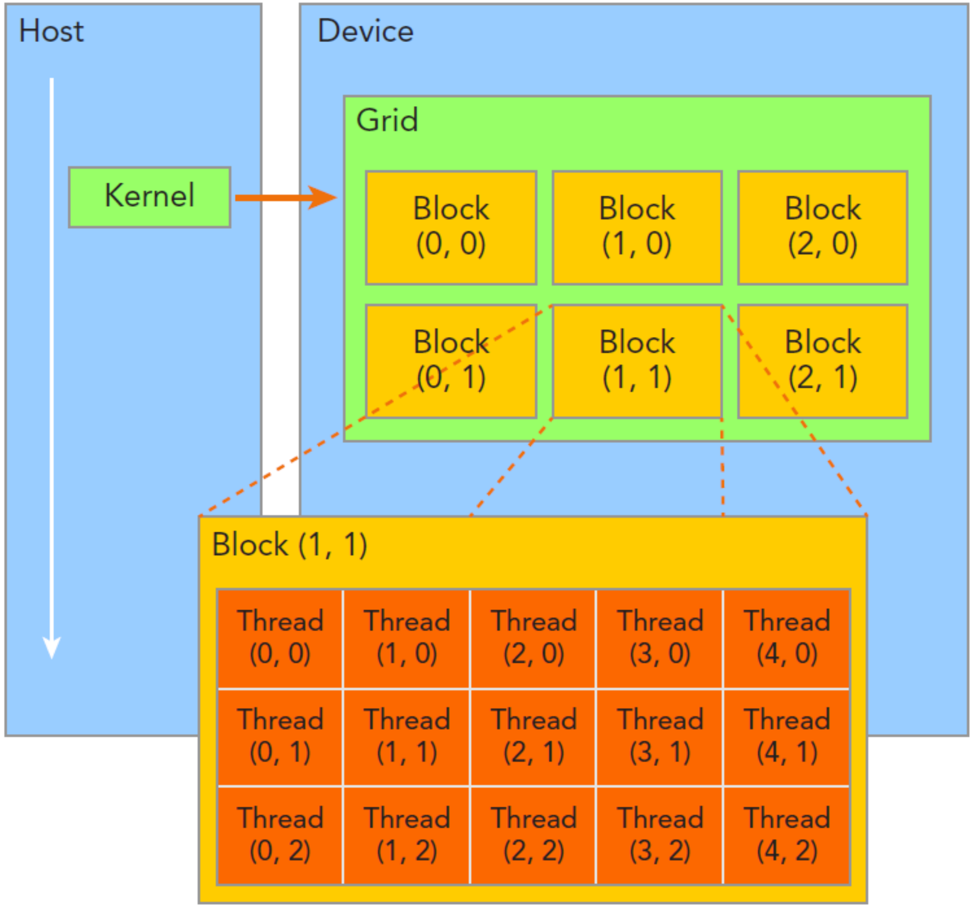
- Built-in variables:
  - threadIdx.[x y z]

    是执行当前kernel函数的线程在block中的索引值
  - blockIdx.[x y z]

    是指执行当前kernel函数的线程所在block，在grid中的索引值
  - blockDim.[x y z]

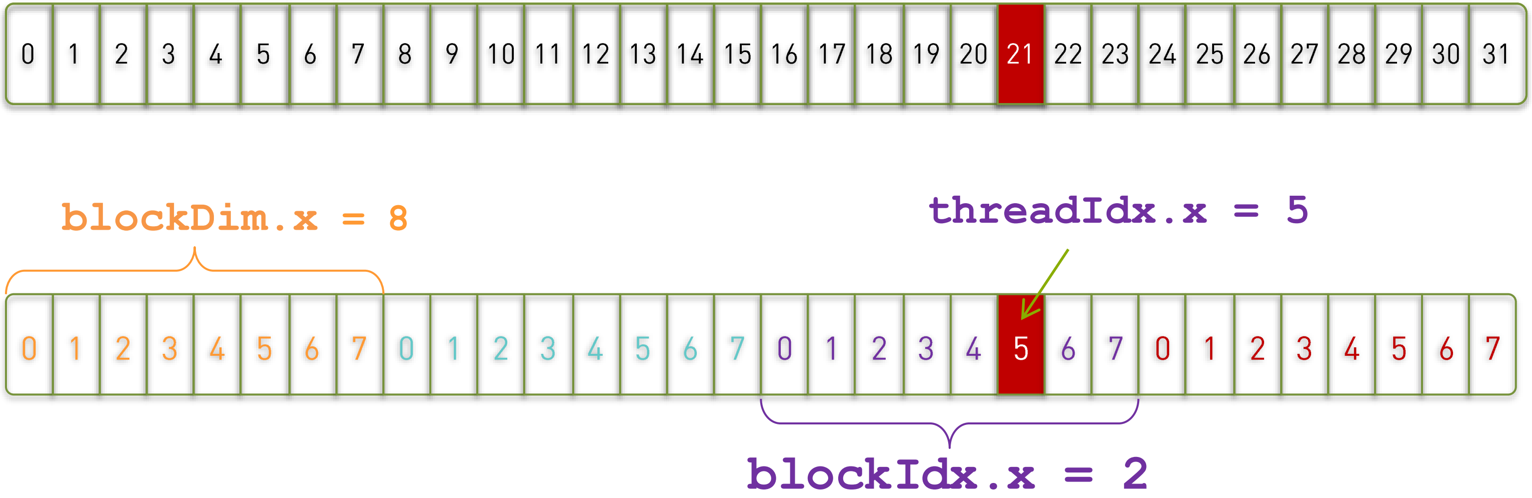
    表示一个grid中包含多少个block
  - gridDim.[x y z]

    表示一个block中包含多少个线程



CUDA的线程索引

- 如何确定线程执行地数据




```
int index = threadIdx.x + blockIdx.x * blockDim.x;
          =         5   +        2    * 8;
          = 21;
```

线程层次

- 我们写的程序:

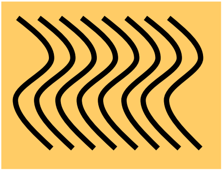
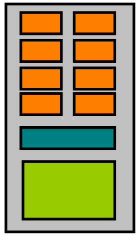
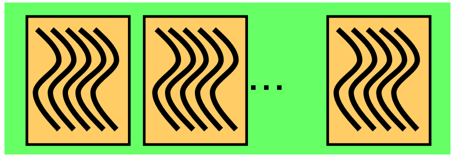
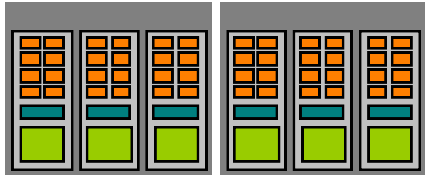
```
__global__ void add( int *a, int *b, int *c ) {
    c[threadIdx.x] = a[threadIdx.x] + b[threadIdx.x];
}
add<<<1,4>>>( a, b, c);
```

- 实际上在设备上运行的样子:

Thread 0	Thread 1
c[0] = a[0] + b[0];	c[1] = a[1] + b[1];

Thread 2	Thread 3
c[2] = a[2] + b[2];	c[3] = a[3] + b[3];

线程层次

Software	GPU	
 Thread	 CUDA Core	Threads are executed by cuda core
	 SM	Thread blocks are executed on SM
 Grid	 Device	A kernel is launched as a grid of thread blocks

线程层次

- 硬件调度：
  - Grid： GPU(GPC)级别的调度单位
  - Block(CTA)：SM级别的调度单位
  - Threads/Warp：CUDA core级别的调度单位
- 资源和通信：
  - Grid：共享同样的kernel 和 Context
  - Block(CTA)：同一个SM(Streaming Multiprocessor)，同一个SM(Shared Memory)
  - Threads/Warp: 允许同一个warp中的thread读取其他thread的值

线程层次

- 硬件调度：
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CUDA的线程索引

```
__global__ void add(const double *x, const double
*y, double *z)
{
    const int n = blockDim.x * blockIdx.x + threadIdx.x;
    z[n] = x[n] + y[n];
}
```

每个线程都执行相同的命令

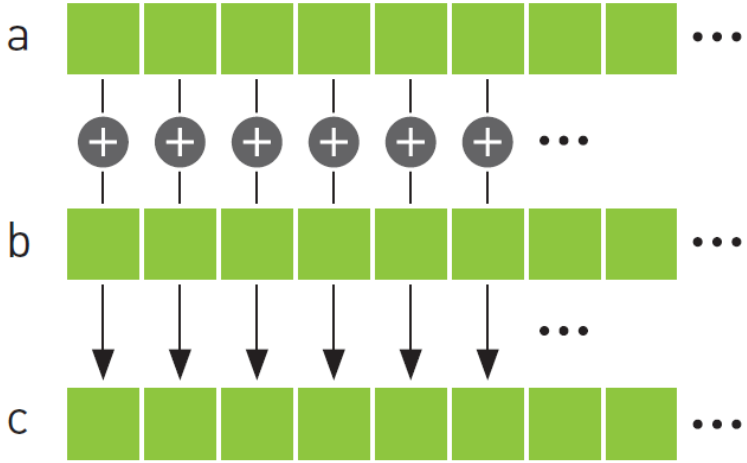
CUDA PROGRAMMING BY EXAMPLE

Case: Vector Add

- Parallelizable problem:
  - c = a + b
  - a, b, c are vectors of length N
- CPU implementation:

```
void main(){
   int size = N * sizeof(int);
   int *a, *b, *c;
   a = (int *)malloc(size);
   b = (int *)malloc(size);
   c = (int *)malloc(size);
   memset(c, 0, size);
   init_rand_f(a, N);
   init_rand_f(b, N);

   vecAdd(N, a, b, c);
}
```




```
void vecAdd (int n, int *a,
             int *b, int *c)
{
   for(int i = 0; i < n; i++)
   {
      c[i] = a[i] + b[i];
   }
}
```

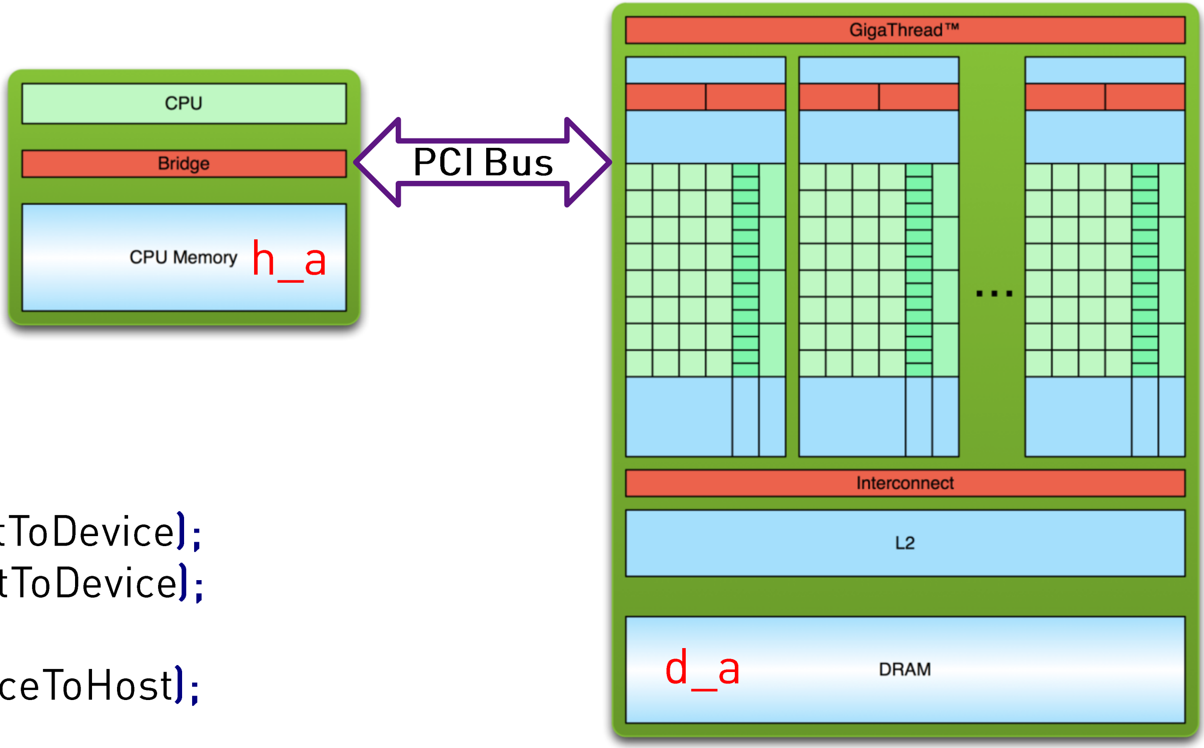
GPU CODE WORKFLOW

Allocate GPU Memories

```
int main(void) {
    size_t size = N * sizeof(int);
    int *h_a, *h_b; int *d_a, *d_b, *d_c;
    h_a = (int *)malloc(size);
    h_b = (int *)malloc(size);
    ...
    cudaMalloc((void **)&d_a, size);
    cudaMalloc((void **)&d_b, size);
    cudaMalloc((void **)&d_c, size);

    cudaMemcpy(d_a, h_a, size, cudaMemcpyHostToDevice);
    cudaMemcpy(d_b, h_b, size, cudaMemcpyHostToDevice);
    vectorAdd<<<grid, block>>>(d_a, d_b, d_c, N);
    cudaMemcpy(h_c, d_c, size, cudaMemcpyDeviceToHost);

    cudaFree(d_a); cudaFree(d_b); cudaFree(d_c);
    free(h_a); free(h_b);
    return 0;}
```



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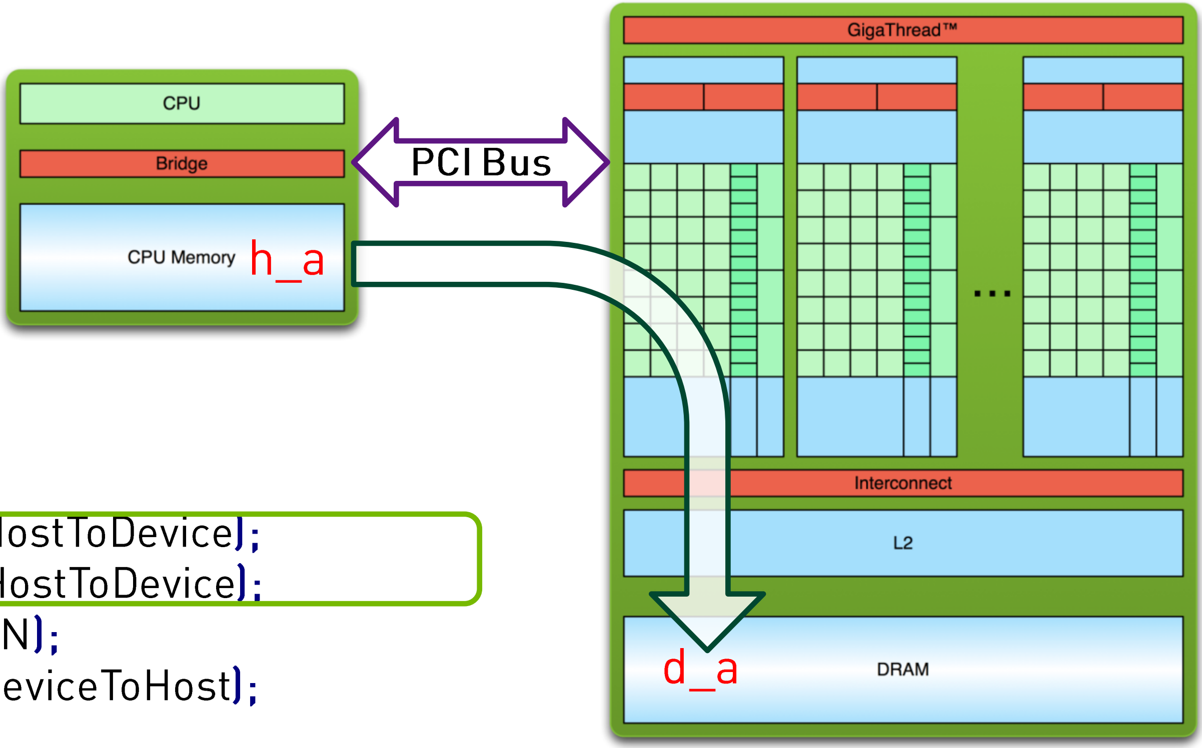
GPU CODE WORKFLOW

Copy data from CPU to GPU

```
int main(void) {
    size_t size = N * sizeof(int);
    int *h_a, *h_b; int *d_a, *d_b, *d_c;
    h_a = (int *)malloc(size);
    h_b = (int *)malloc(size);
    ...
    cudaMalloc((void **)&d_a, size);
    cudaMalloc((void **)&d_b, size);
    cudaMalloc((void **)&d_c, size);

    cudaMemcpy(d_a, h_a, size, cudaMemcpyHostToDevice);
    cudaMemcpy(d_b, h_b, size, cudaMemcpyHostToDevice);
    vectorAdd<<<grid, block>>>(d_a, d_b, d_c, N);
    cudaMemcpy(h_c, d_c, size, cudaMemcpyDeviceToHost);

    cudaFree(d_a); cudaFree(d_b); cudaFree(d_c);
    free(h_a); free(h_b);
    return 0;}
```



GPU CODE WORKFLOW

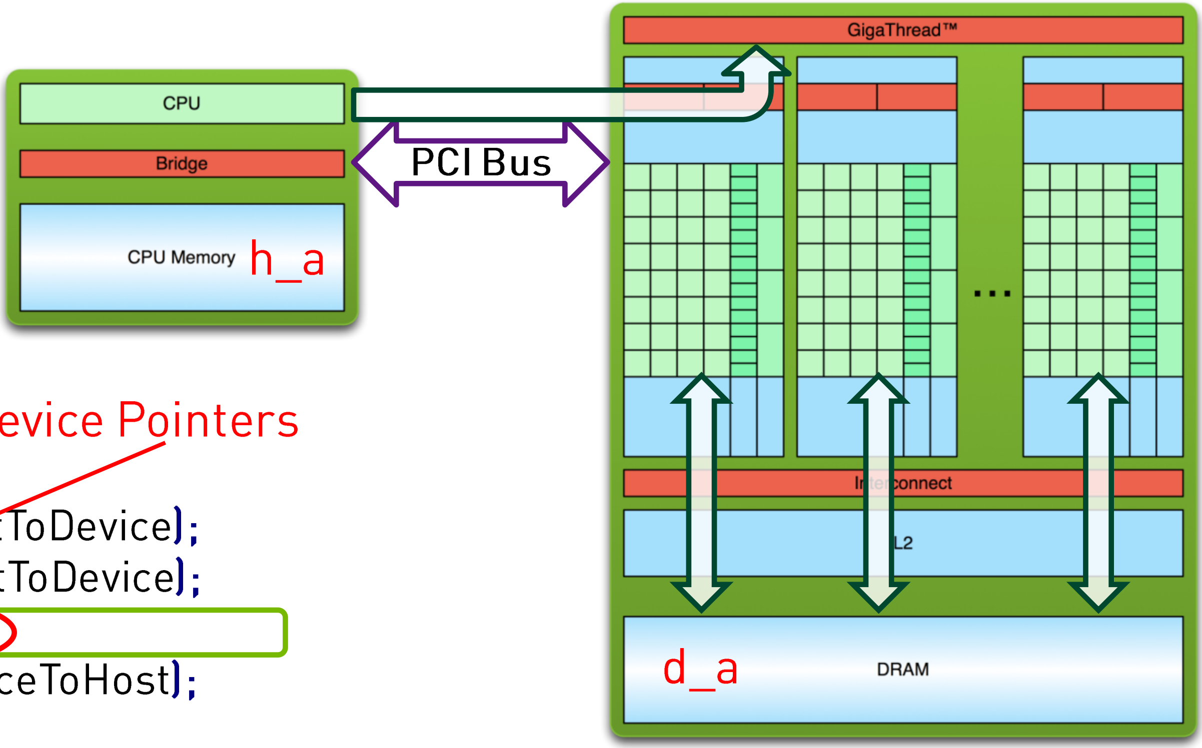
Invoke the CUDA Kernel

```
int main(void) {
    size_t size = N * sizeof(int);
    int *h_a, *h_b; int *d_a, *d_b, *d_c;
    h_a = (int *)malloc(size);
    h_b = (int *)malloc(size);
    ...
    cudaMalloc((void **)&d_a, size);
    cudaMalloc((void **)&d_b, size);
    cudaMalloc((void **)&d_c, size);

    cudaMemcpy(d_a, h_a, size, cudaMemcpyHostToDevice);
    cudaMemcpy(d_b, h_b, size, cudaMemcpyHostToDevice);
    vectorAdd<<<grid, block>>>(d_a, d_b, d_c, N);
    cudaMemcpy(h_c, d_c, size, cudaMemcpyDeviceToHost);

    cudaFree(d_a); cudaFree(d_b); cudaFree(d_c);
    free(h_a); free(h_b);
    return 0;}
```

Device Pointers



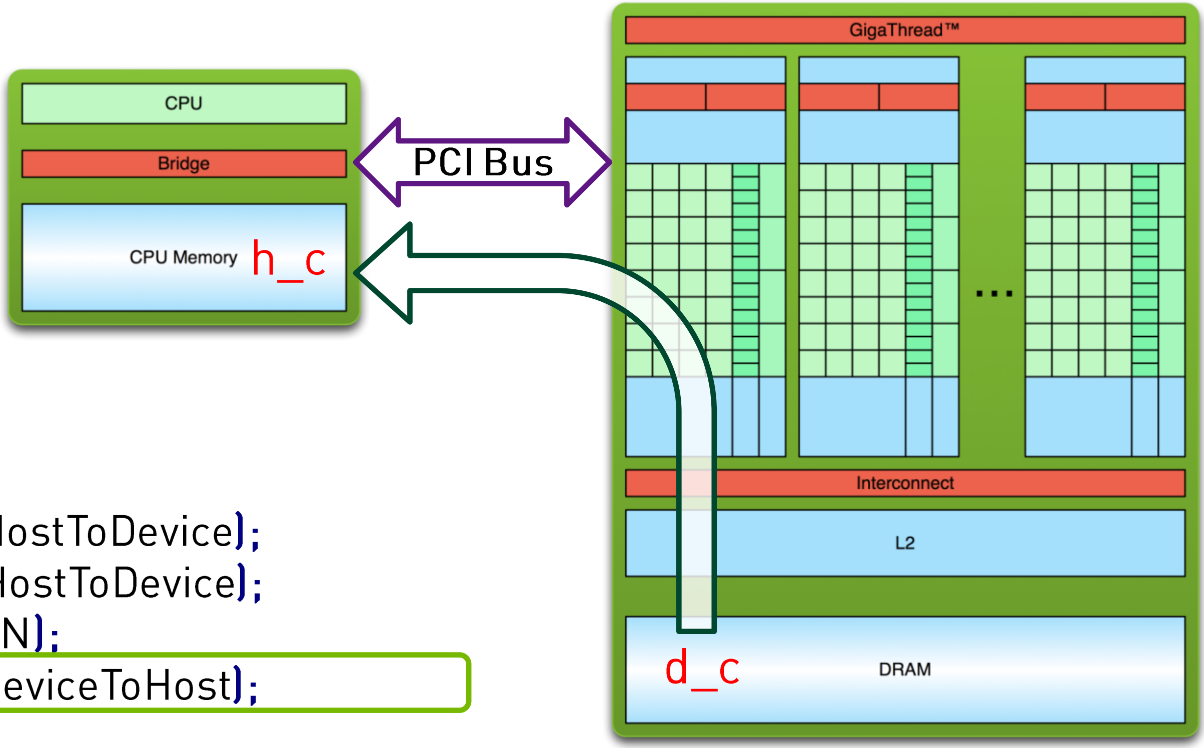
GPU CODE WORKFLOW

Copy result from GPU to CPU

```
int main(void) {
    size_t size = N * sizeof(int);
    int *h_a, *h_b; int *d_a, *d_b, *d_c;
    h_a = (int *)malloc(size);
    h_b = (int *)malloc(size);
    ...
    cudaMalloc((void **)&d_a, size);
    cudaMalloc((void **)&d_b, size);
    cudaMalloc((void **)&d_c, size);

    cudaMemcpy(d_a, h_a, size, cudaMemcpyHostToDevice);
    cudaMemcpy(d_b, h_b, size, cudaMemcpyHostToDevice);
    vectorAdd<<<grid, block>>>(d_a, d_b, d_c, N);
    cudaMemcpy(h_c, d_c, size, cudaMemcpyDeviceToHost);

    cudaFree(d_a); cudaFree(d_b); cudaFree(d_c);
    free(h_a); free(h_b);
    return 0;}
```



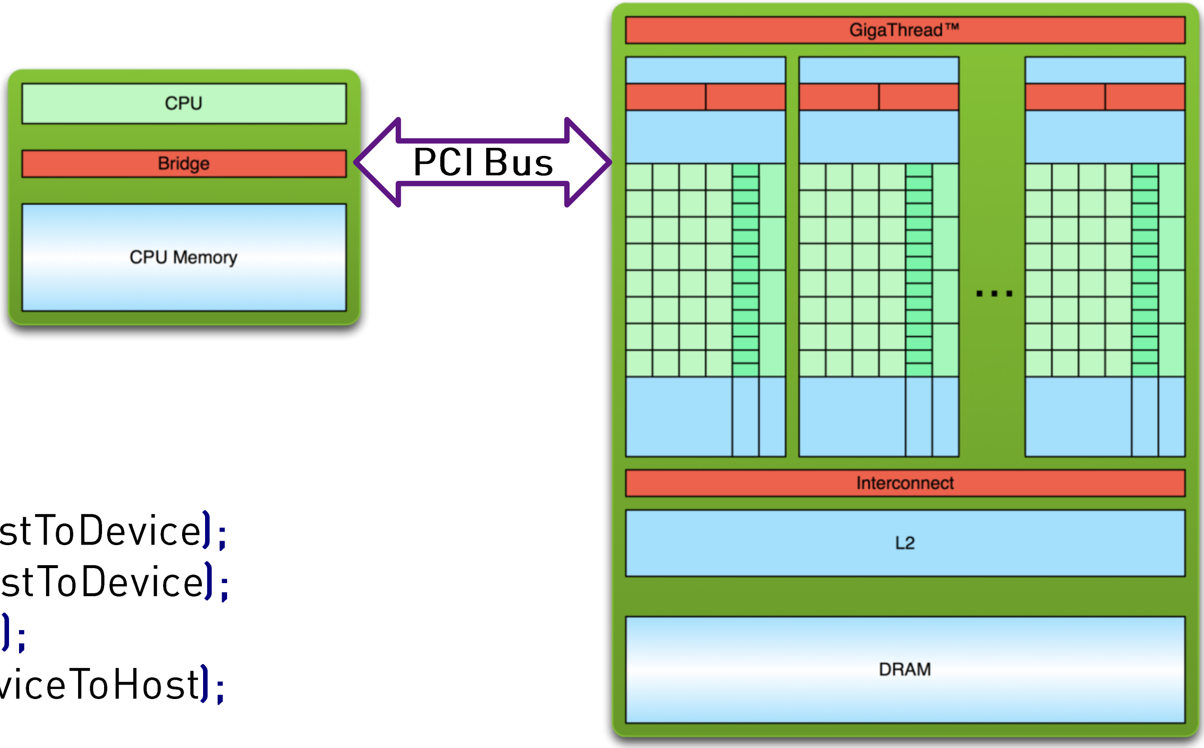
GPU CODE WORKFLOW

Release GPU Memories

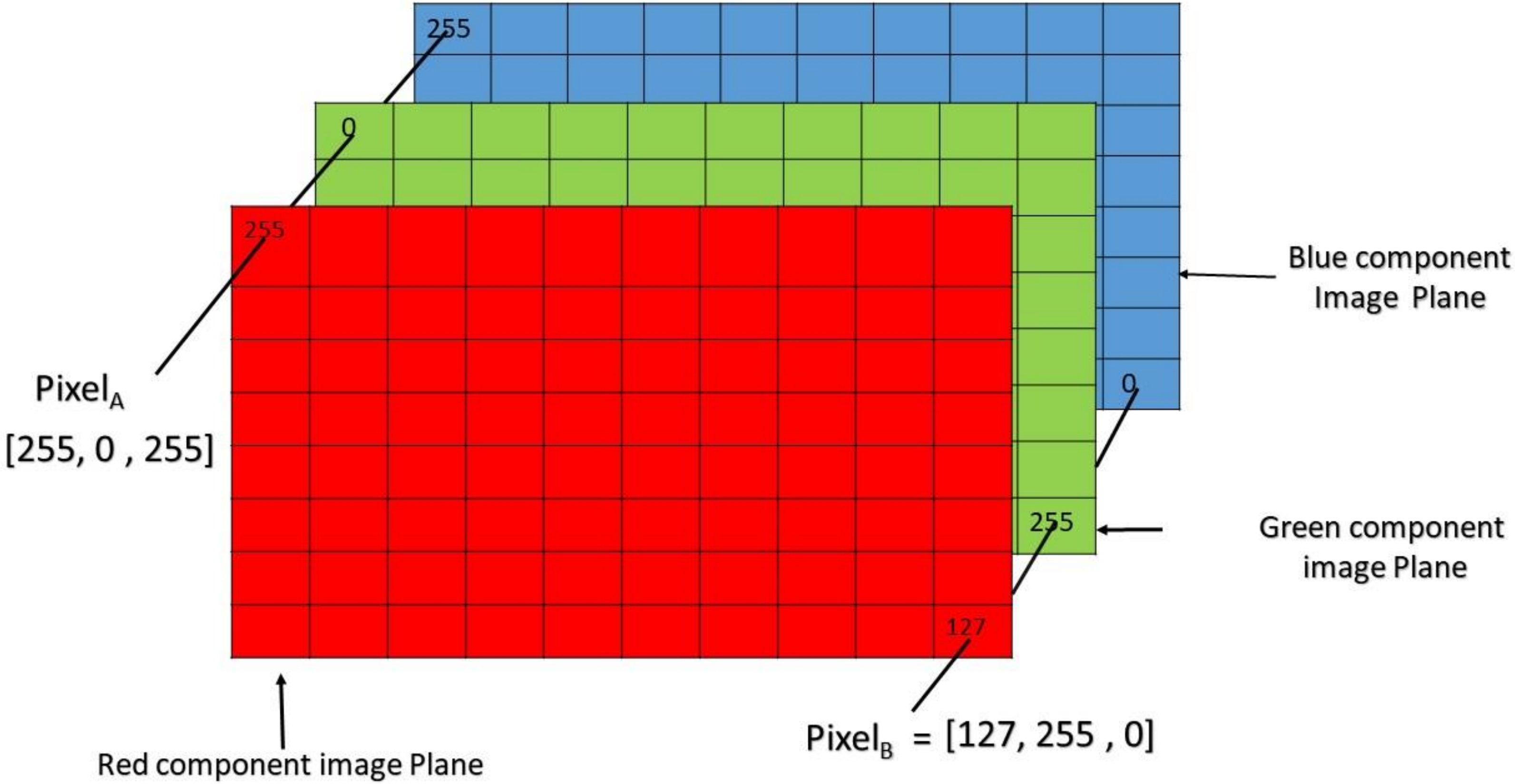
```
int main(void) {
    size_t size = N * sizeof(int);
    int *h_a, *h_b; int *d_a, *d_b, *d_c;
    h_a = (int *)malloc(size);
    h_b = (int *)malloc(size);
    ...
    cudaMalloc((void **)&d_a, size);
    cudaMalloc((void **)&d_b, size);
    cudaMalloc((void **)&d_c, size);

    cudaMemcpy(d_a, h_a, size, cudaMemcpyHostToDevice);
    cudaMemcpy(d_b, h_b, size, cudaMemcpyHostToDevice);
    vectorAdd<<<grid, block>>>(d_a, d_b, d_c, N);
    cudaMemcpy(h_c, d_c, size, cudaMemcpyDeviceToHost);

    cudaFree(d_a); cudaFree(d_b); cudaFree(d_c);
    free(h_a); free(h_b);
    return 0;}
```



图像处理

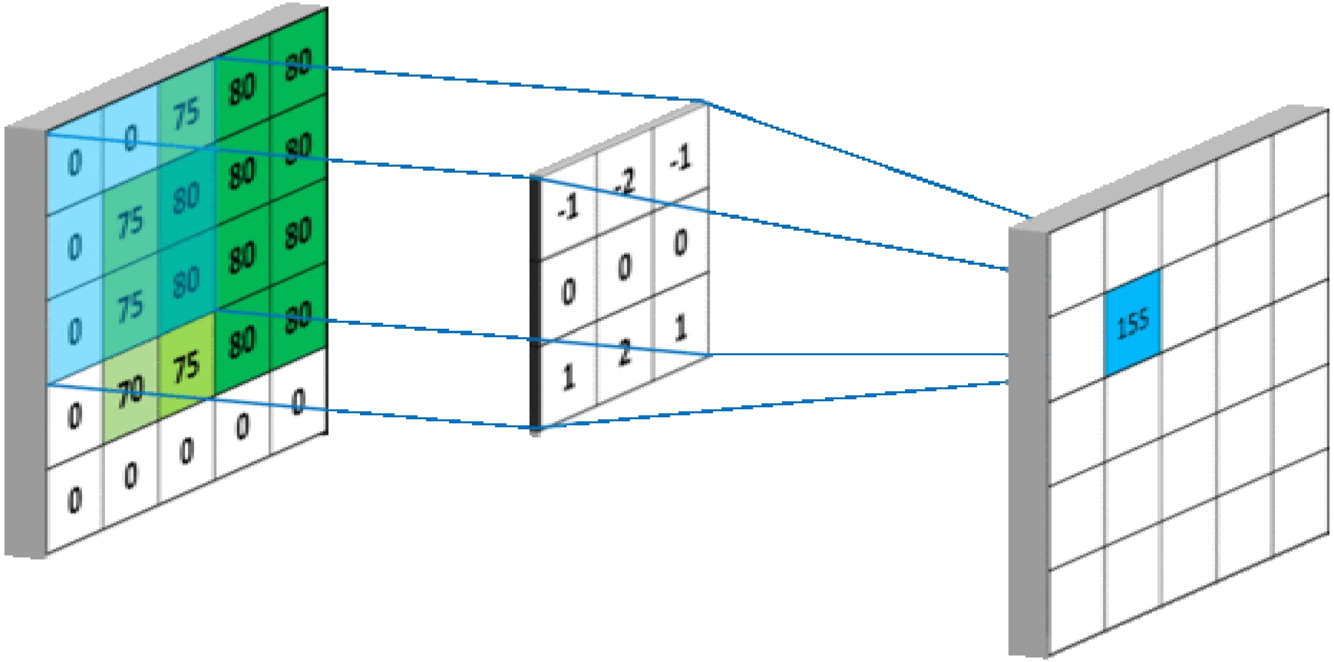


Pixel of an RGB image are formed from the corresponding pixel of the three component images

Sobel 边缘检测

$$\mathbf{G_x} = \begin{bmatrix} +1 & 0 & -1 \\ +2 & 0 & -2 \\ +1 & 0 & -1 \end{bmatrix} * \mathbf{A} \quad \text{and} \quad \mathbf{G_y} = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} * \mathbf{A}$$

Sobel 边缘检测



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1
155

更多资源：

https://developer.nvidia-china.com

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https://www.nvidia.cn/developer/community-training/

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