GPU Programming

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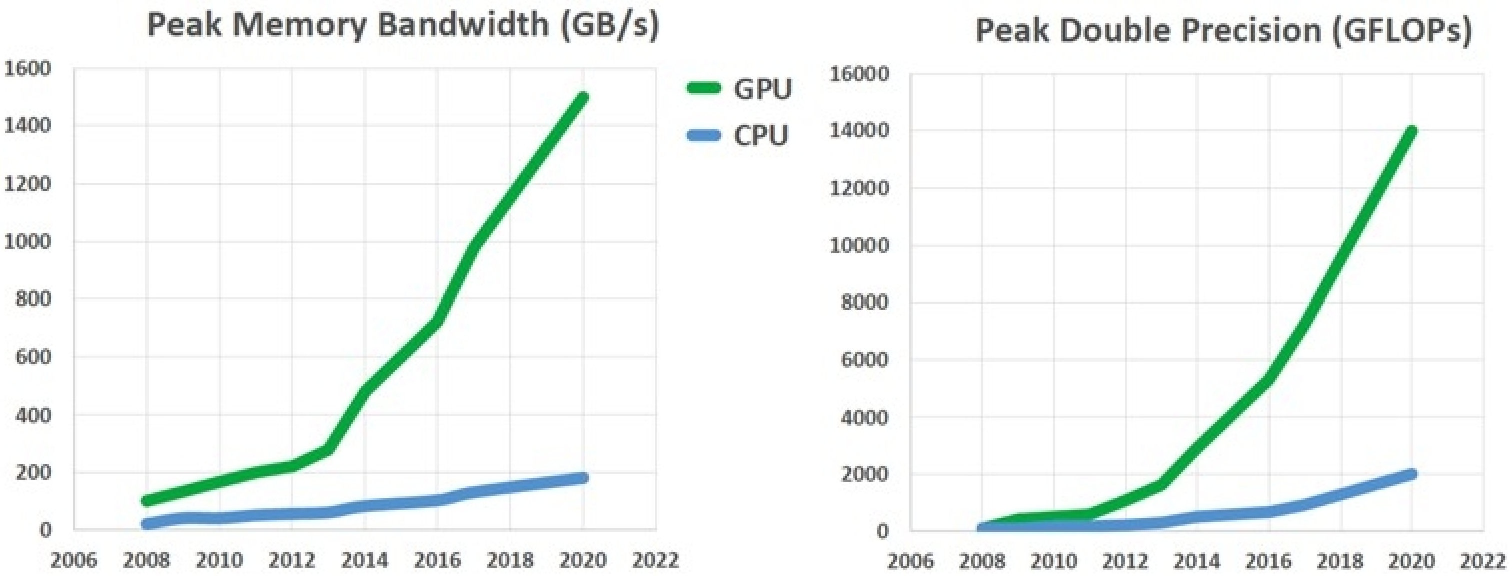
Motivation

- The insatiable market demand for real-time, high-definition 3D graphics capability.
- Led the development of Programmable Graphics Processing Units (GPU, Graphics Processor Unit)

Motivation

- Today's GPUs have evolved into devices with sophisticated capabilities:
  - Parallel processing.
  - Multi threads.
  - High bandwidth communication to RAM.
  - Huge amount of processor units.

Motivation



Source: https://www.nextplatform.com

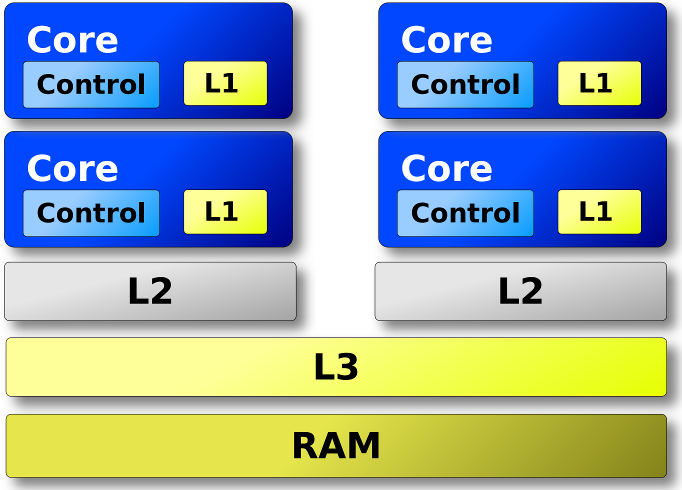
Parallel Systems are very Common Today

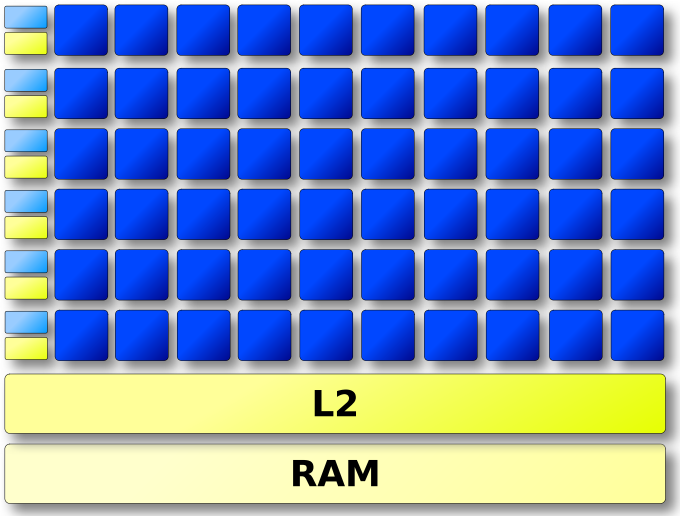
- Currently, any system has more than one processor (multi-core systems) in the same silicon chip.

- GPUs have a big amount of cores (many core systems).

Hardware Specifications

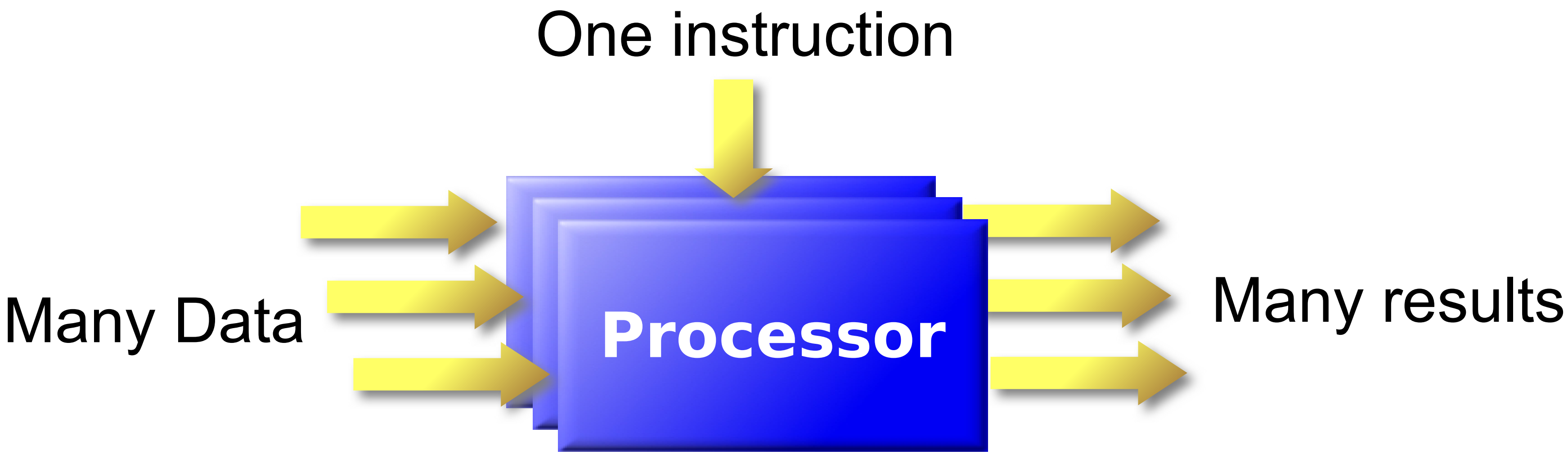
- The performance difference is due to:
  - In a GPU most of the transistors are dedicated to processing.
  - In a CPU there are many transistors dedicated to control: data and instruction flow, cache memory, etc.





Hardware Specifications

- GPUs are designed for problems where data parallelism is the best approach.



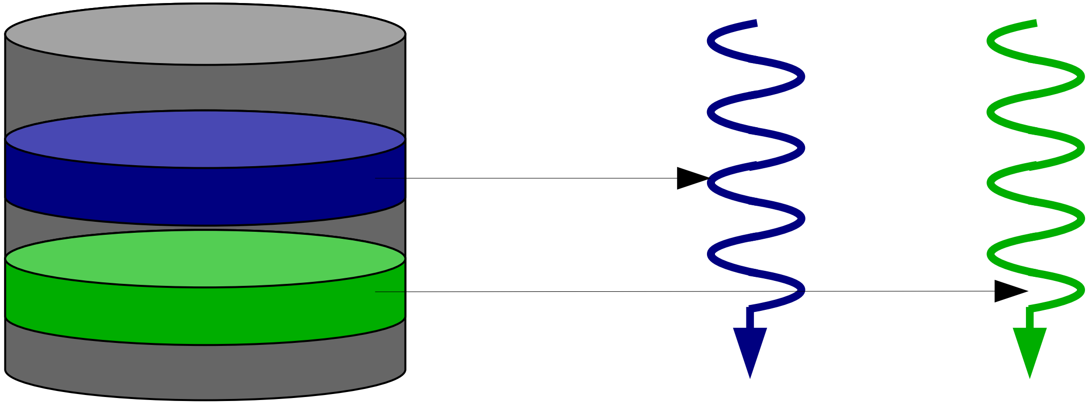
Programming Characteristics.

- Programs running on a GPU are generally arithmetic expression intensive.

- Thus, memory latency can be compensated with computations instead of large caches.

Parallel Processing

- It maps each data element to threads



Data Parallelism

$$\begin{bmatrix} a_{00} & a_{01} & a_{02} \\ a_{10} & a_{11} & a_{12} \\ a_{20} & a_{21} & a_{22} \end{bmatrix} \times \begin{bmatrix} b_{00} & b_{01} & b_{02} \\ b_{10} & b_{11} & b_{12} \\ b_{20} & b_{21} & b_{22} \end{bmatrix} = \begin{bmatrix} c_{00} & c_{01} & c_{02} \\ c_{10} & c_{11} & c_{12} \\ c_{20} & c_{21} & c_{22} \end{bmatrix}$$

Data Parallelism

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Data Parallelism

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Data Parallelism

$$c_{00} = a_{00}b_{00} + a_{01}b_{10} + a_{02}b_{20}$$

$$c_{01} = a_{00}b_{01} + a_{01}b_{11} + a_{02}b_{21}$$

$$c_{02} = a_{00}b_{02} + a_{01}b_{12} + a_{02}b_{22}$$

....

$$c_{22} = a_{20}b_{02} + a_{21}b_{12} + a_{22}b_{22}$$

Data Parallelism

$$c_{00} = a_{00}b_{00} + a_{01}b_{10} + a_{02}b_{20}$$

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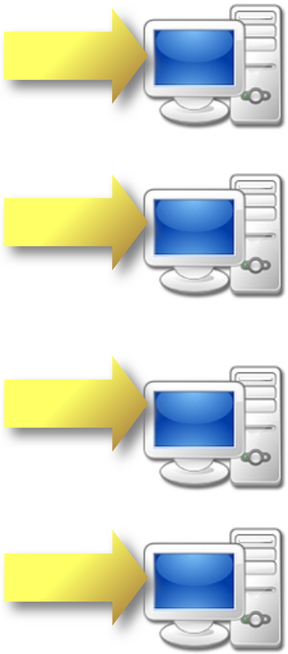

Application Areas

- Image processing.
- Video encoding.
- Patterns recognition.
- Artificial intelligence.
- Scientific computing.

Compute Unified Device Architecture (CUDA)

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Programación Paralela y Distribuida

Definition

- CUDA is a technology that enables the massively parallel processing power of NVIDIA GPUs.
- It is a programming model developed by NVIDIA for its GPUs.

CUDA comes with a software environment that allows developers to use C++ as a high-level programming language.

Compute Unified Device Architecture

- CUDA was introduced in November 2006 with a new programming model and a particular set of instructions.

Characteristics

- No knowledge of APIs is needed for GPU programming.
- Minimum effort in learning new programming elements.
- Provides access to the GPU instruction set

Characteristics

- Provides direct access to the GPU memory.
- The programming model is designed to take advantage of the parallel resources of current systems

Requirements

- Programming in CUDA requires an NVIDIA graphics card.
  - A100
  - HDR100
  - Tesla V100

Requirements

- Corresponding driver for the graphics card.
- CUDA toolkit (compiler and libraries).

CUDA Toolkit

CUDA driver

Operating System support

NVIDIA Hardware

CUDA Goals

CUDA was developed with the following goals in mind:

- Provide a small set of extensions for traditional languages like C.
- Support for heterogeneous computations so that applications can use both the GPU and the CPU.
  - The serial portion in the CPU
  - The parallel portion on the GPU

Introduction

- The CPU and GPU are treated as separate devices, each with their own memory space.

Introduction

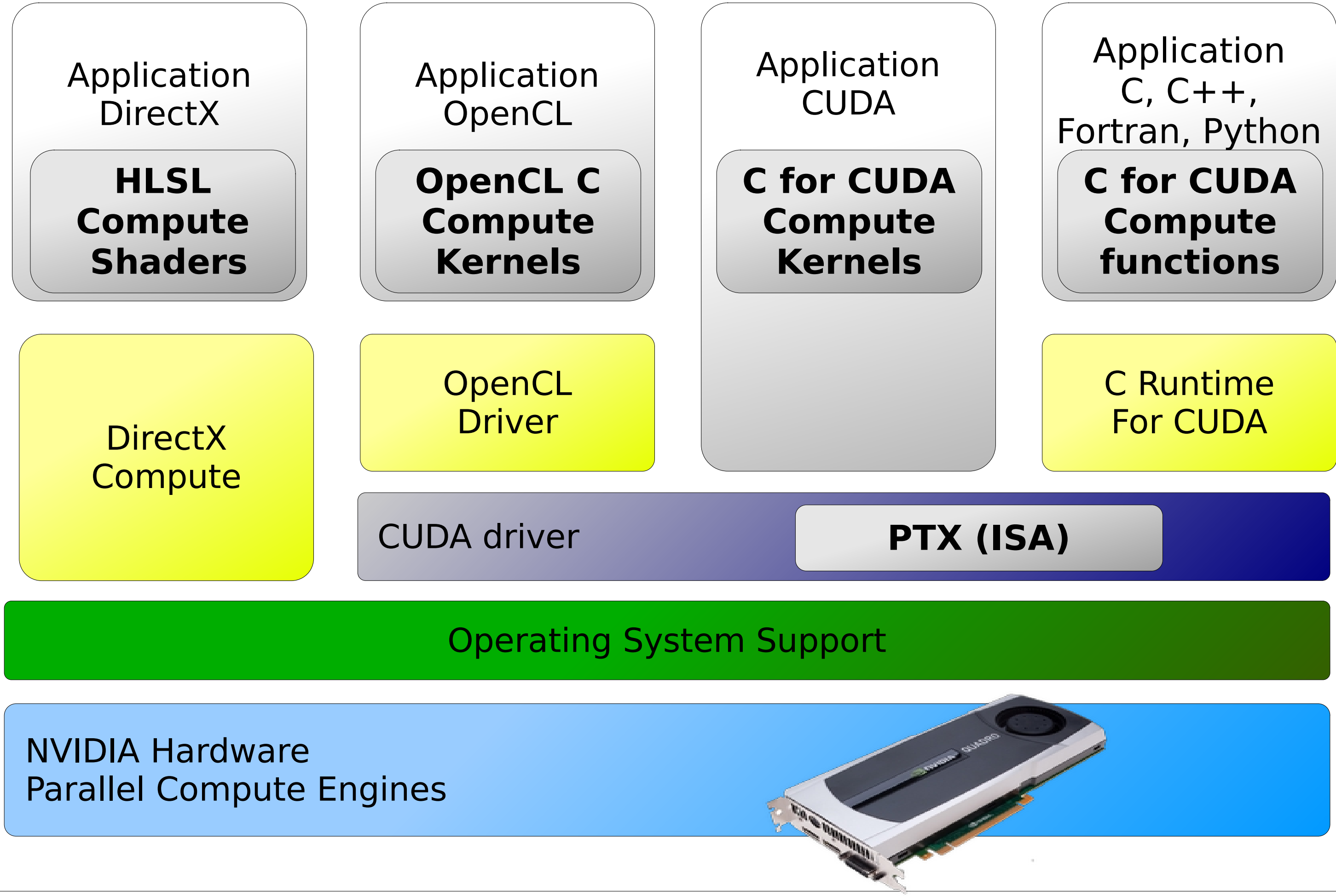
CUDA enables the computing power of graphics cards through APIs such as:

- OpenCL
- DirectX Compute

Or through high level languages like:

- C/C++
- Fortran
- Python, etc.

Architecture



Programming Model

CUDA poses three fundamental abstractions:

- A hierarchy of groups of threads (threads).
- Shared memory.
- Synchronization barrier.

Programming Model

- These abstractions provide two specific types of parallelism embedded within two other types of parallelism:

CPU

- Data parallelism. (Coarse grain)
- Functional parallelism

GPU

- Data parallelism (Fine grain)
- Thread parallelism

Programming Model

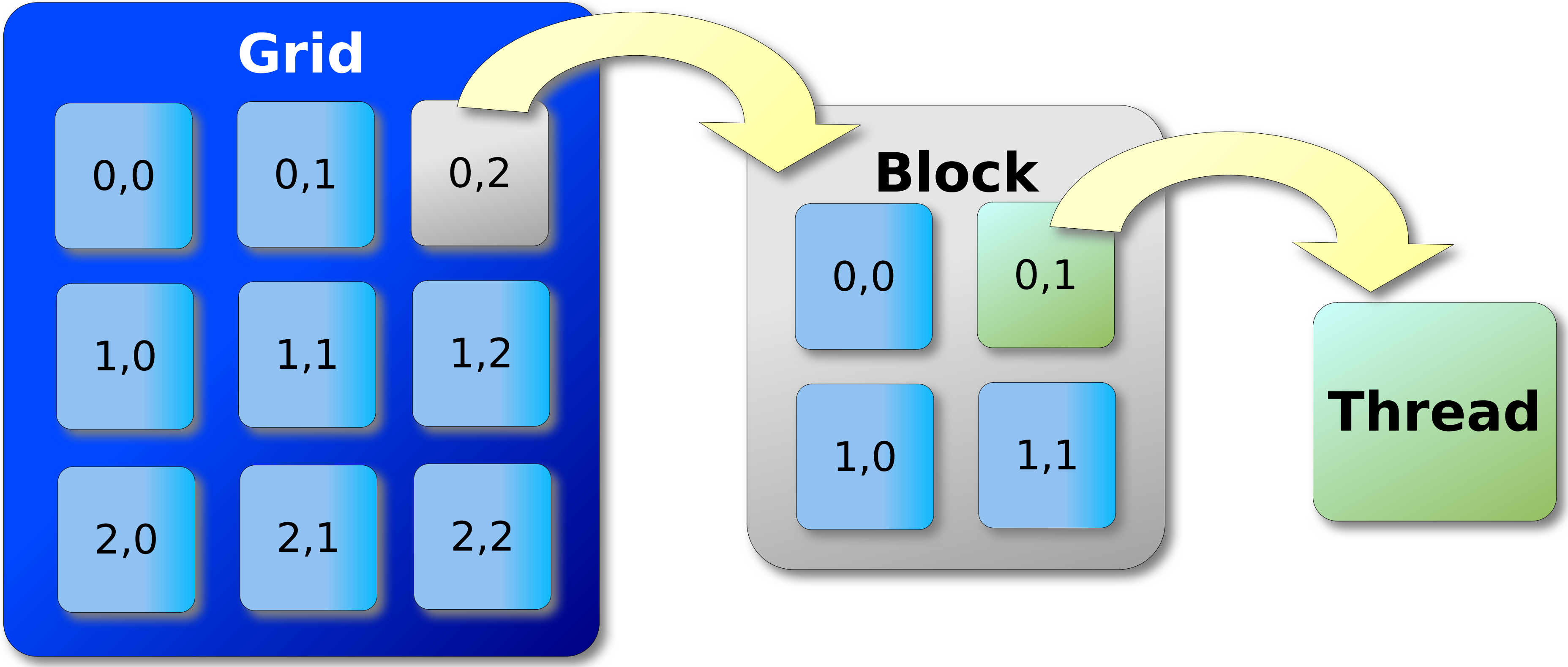
- This provides the programmer with a guide to the process of partitioning the problem into relatively thick subproblems.

- Each subproblem can be solved independently by using thread blocks.

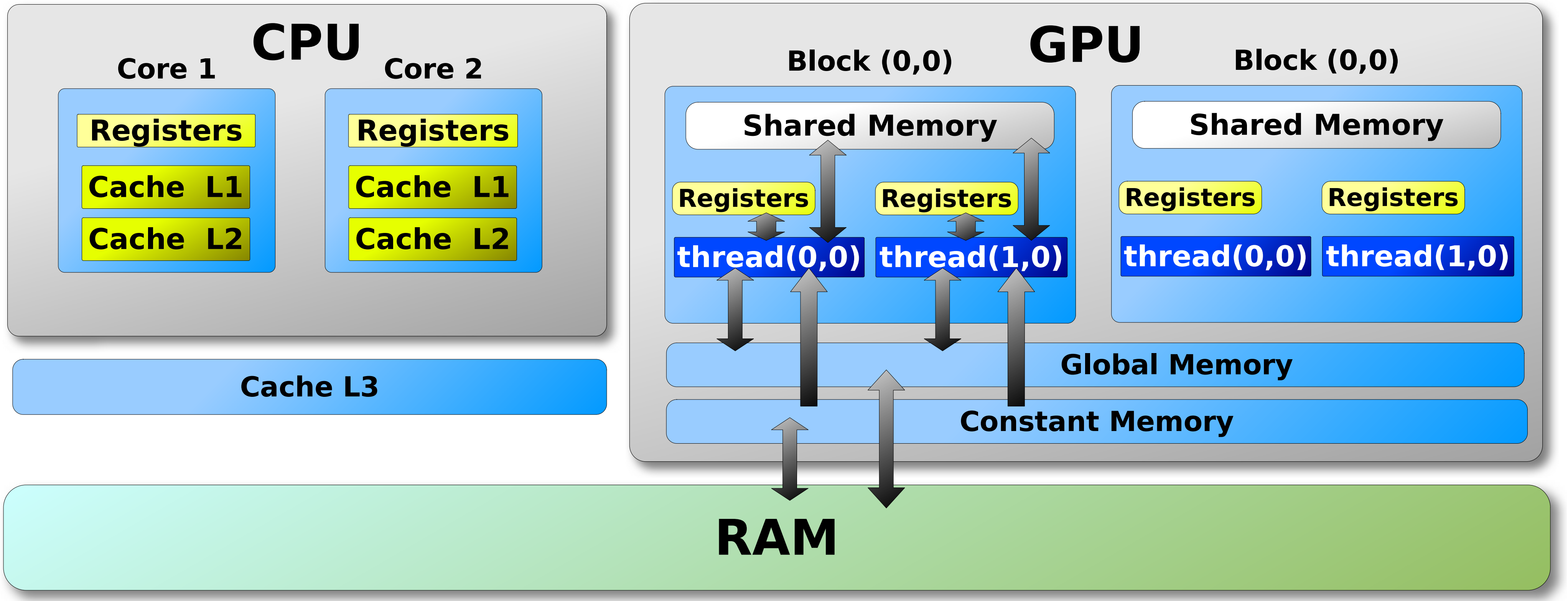
Programming Model

- Then, each subproblem can be divided into smaller pieces.
- That can be solved in parallel, collaboratively, by the threads within each block.

CUDA thread hierarchy



Memory Hierarchy



Variable Types

Variable declaration	Memory	Scope	Lifetime
`int var;`	register	thread	thread
`int array_var[10];`	local	thread	thread
`__shared__ int shared_var;`	shared	block	block
`__device__ int global_var;`	global	grid	application
`__constant__ int constant_var;`	constant	grid	application

Example

```
#define N 20
float c[N][N];

void mulmat(float a[N][N], float b[N][N]){
    int i,j,k;
    for(i=0; i<N; i++)
        for(j=0; j<N; j++)
            for(k=0; k<N; k++)
                c[i][j] = c[i][j] + a[i][k]*b[k][j];
}
```

Example

```
__global__ void MatrixMult(float *Md, float *Nd,
                                              float *Pd, int Width){
    //Cálculo del índice de fila de Pd y M
    int Row blockIdx.y * TILE_WIDTH + threadIdx.y;
    //Cálculo del índice de columna de Pd y N
    Int Col blockIdx.x * TILE_WIDTH + threadIdx.x;
    float Pvalue = 0;
    for( int k = 0; k < Width; ++k )
        Pvalue += Md[Row*Width+k] * Nd[k*Width+Col];
    Pd[Row*Width*Col] = Pvalue;
}
```

CUDA Installation Process

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Programación Paralela y Distribuida

CUDA Installation Process

Download cuda-toolkit.

```
cd /usr/local/src

wget -np -nH https://developer.download.nvidia.com/compute/cuda/12.1.1/local_installers/cuda_12.1.1_530.30.02_linux.run
```

CUDA Installation Process

Install the software

```
./cuda_12.1.1_530.30.02_linux.run

Enter install path (default /usr/local/cuda,
'/cuda' will be appended): ENTER
```

CUDA Installation Process

Add environment variable

/etc/profile (global)
.bashrc (user)

```
export PATH=$PATH:/usr/local/cuda/bin
export LD_LIBRARY_PATH=$LD_LIBRARY_PATH:/usr/local/cuda/lib64:/usr/local/cuda/lib
```

Compiling Programs

```
nvcc sourceCode.cu -o execName

./execName
```