软件系统优化

异构计算与编程

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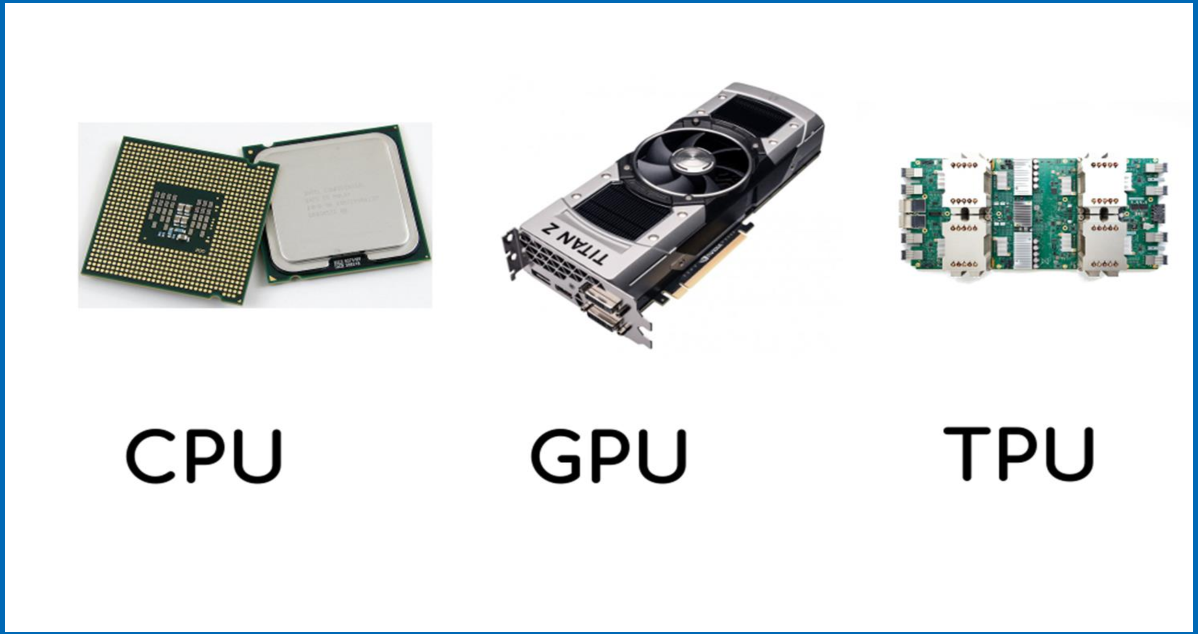
课程大纲

- 异构计算概述
- 并行编程框架
  - 多核编程：Pthread/OpenMP
  - 多节点编程：MPI
  - 异构编程： DPC++
- 作业与练习

异构计算



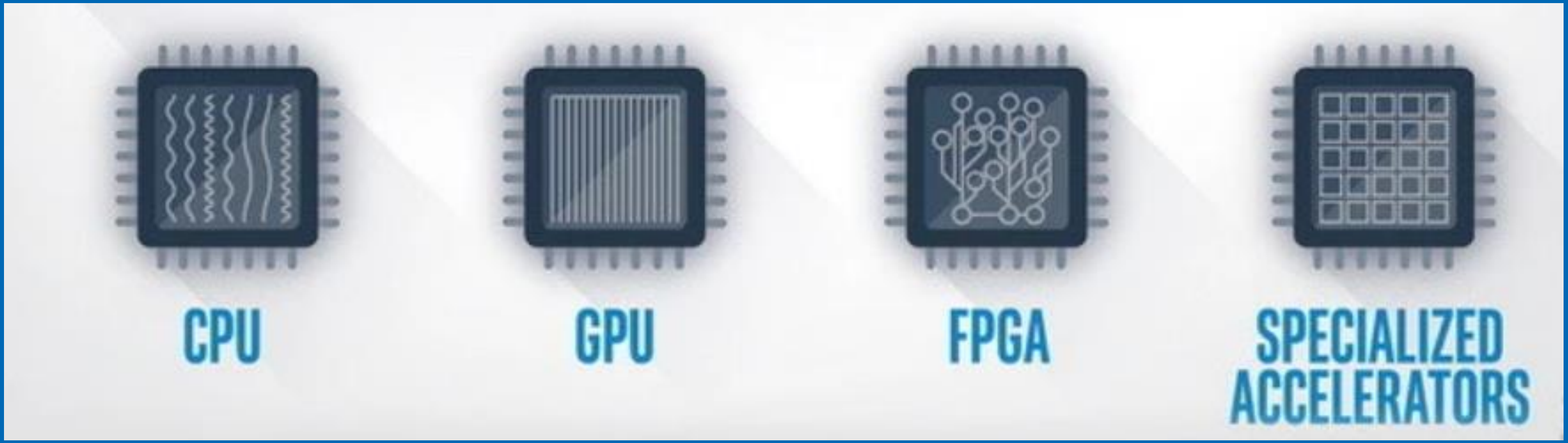
https://www.geekboots.com/story/cpu-vs-gpu-vs-tpu

简介

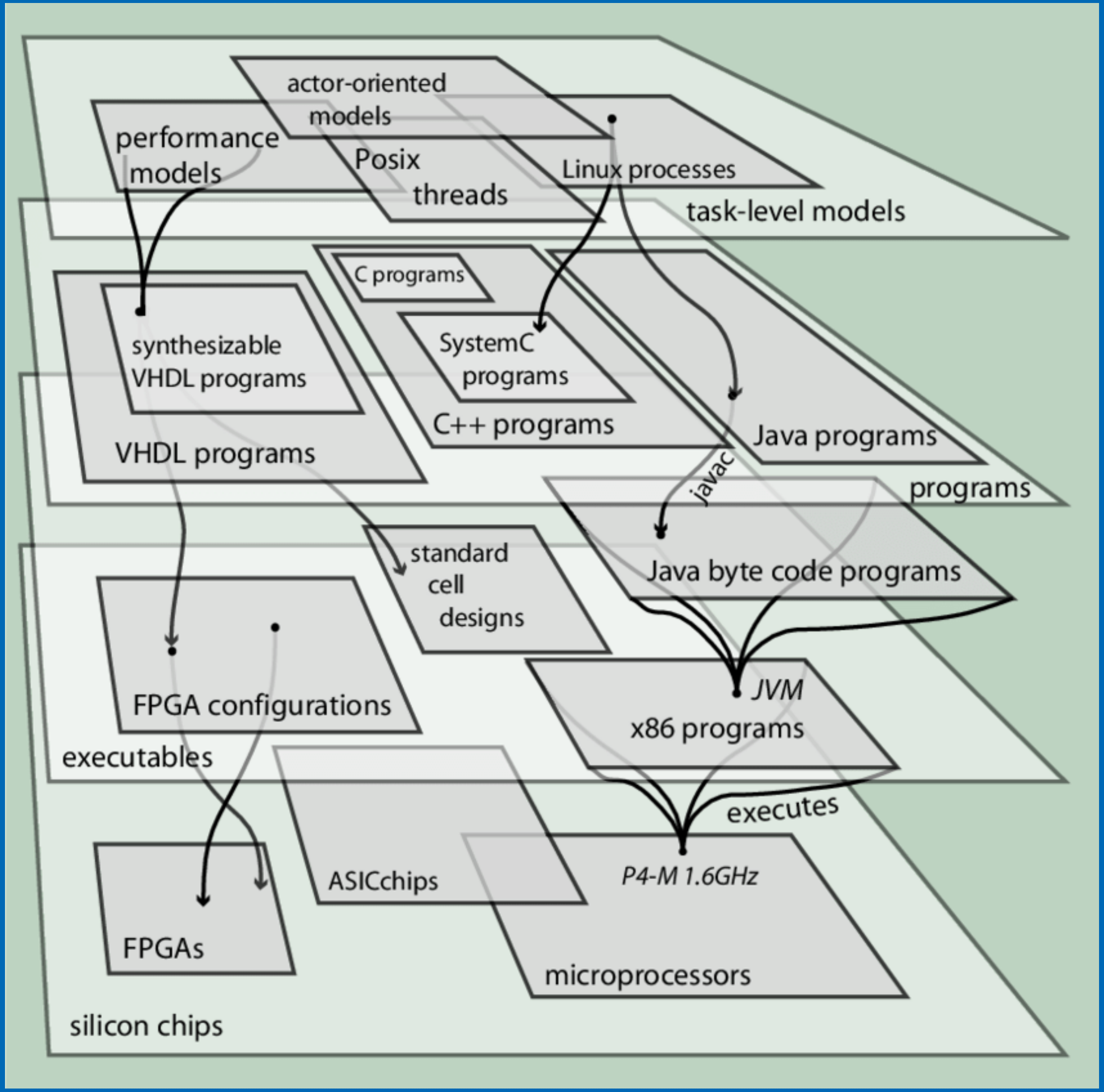
同构计算：相同类型指令集和体系架构的硬件，只是数量上的扩展，通常的同构计算指**多核计算**，即CPU中有更多的硬件核心。

异构计算：是指使用不同类型指令集和体系架构的计算单元组成系统的计算方式。

常见的计算单元类别包括CPU、GPU等协处理器、DSP、ASIC、FPGA等。



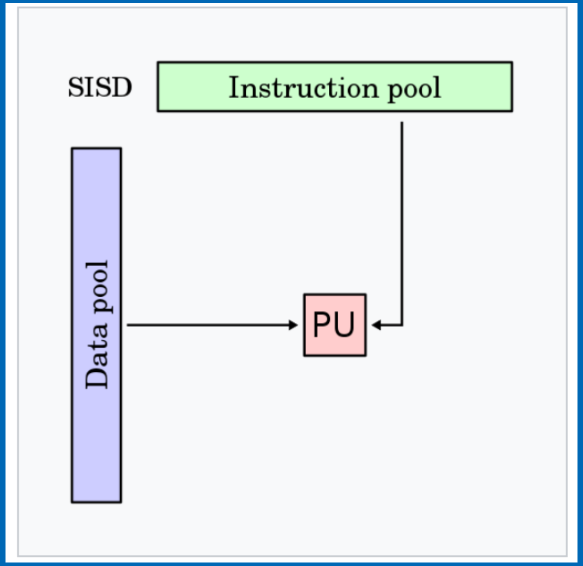
体系结构



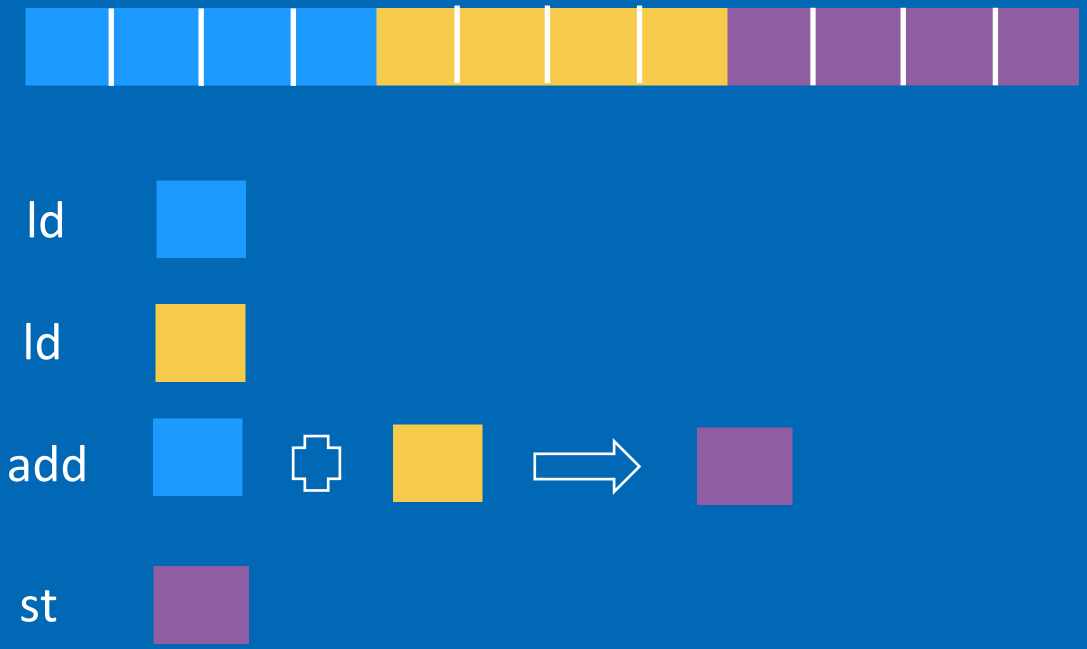
actor-oriented models
performance models
Posix threads
Linux processes
task-level models
C programs
synthesizable VHDL programs
SystemC programs
C++ programs
Java programs
VHDL programs
javac
programs
standard cell designs
Java byte code programs
FPGA configurations
JVM
x86 programs
executables
executes
ASICchips
P4-M 1.6GHz
FPGAs
microprocessors
silicon chips

异构计算硬件使用了不同的体系架构，我们首先要了解体系结构的分类方式。

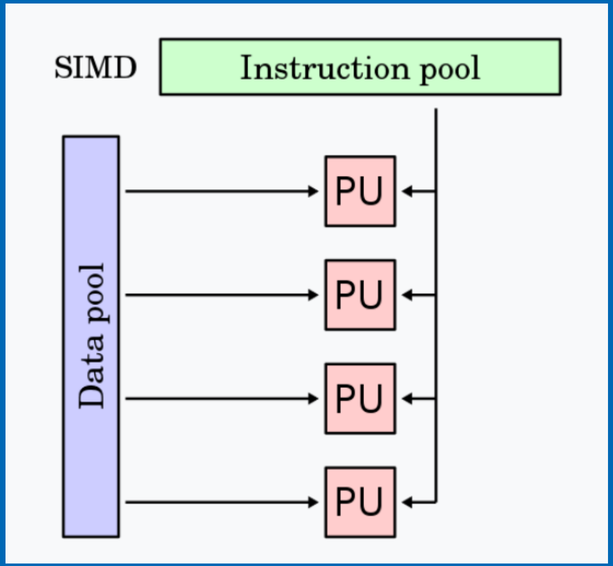
弗林（Flynn）分类法是最为广泛使用的抽象表达方法，其按照指令和数据的处理方式来分类。



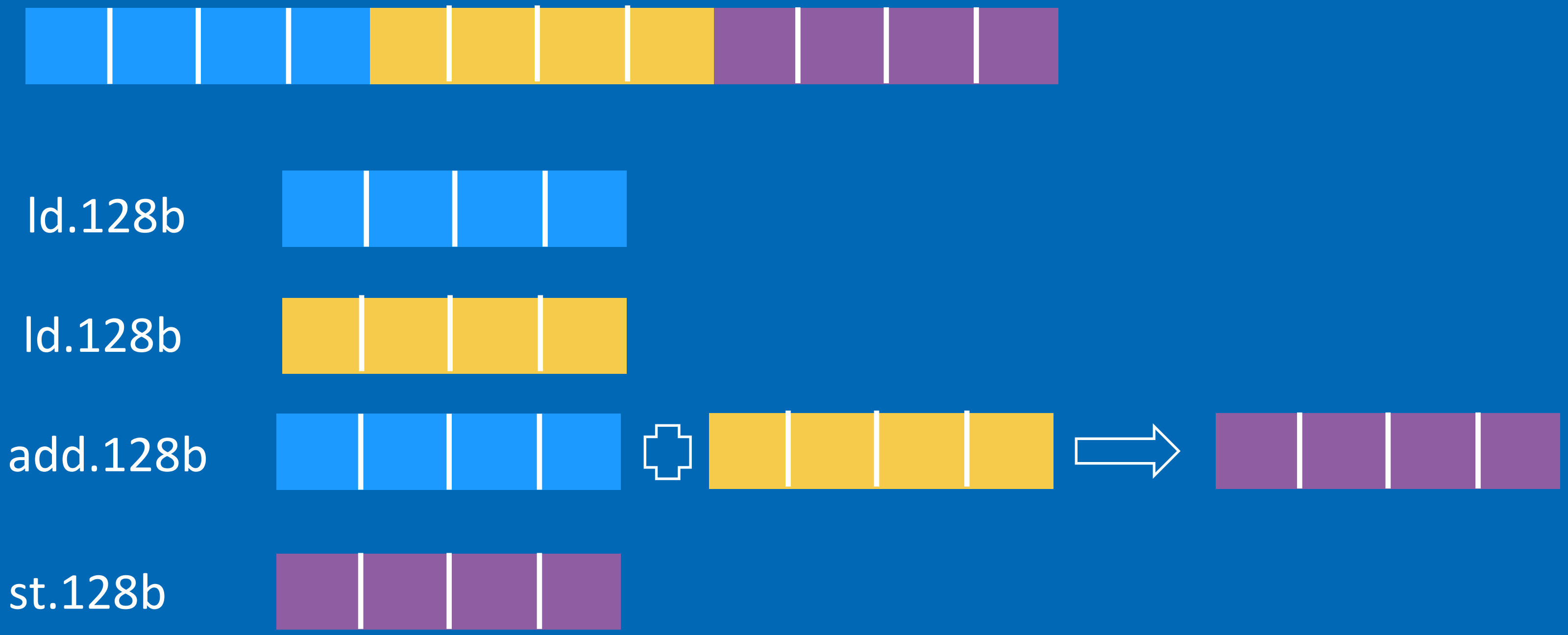
SISD： 单核CPU模式



单指令多数据（SIMD），向量化的执行模式，是现在CPU中主要的并行化方法之一，也同时广泛应用在各种加速卡上。提高数据吞吐量，但是对数据的连续性要求较高，不适合处理分散数据。

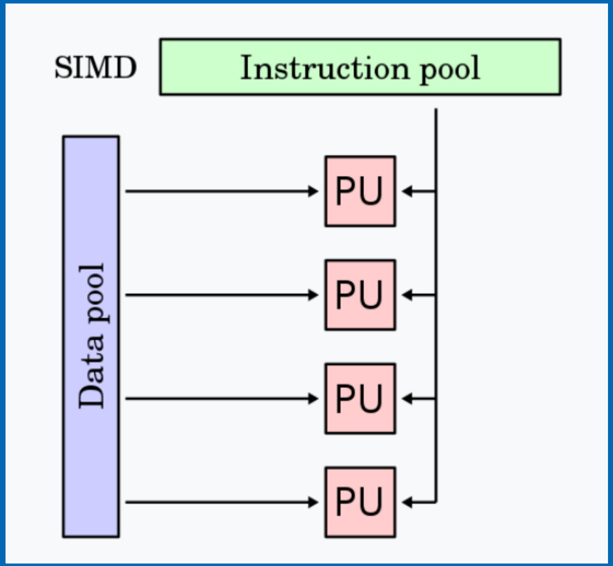


SIMD:向量化执行模式

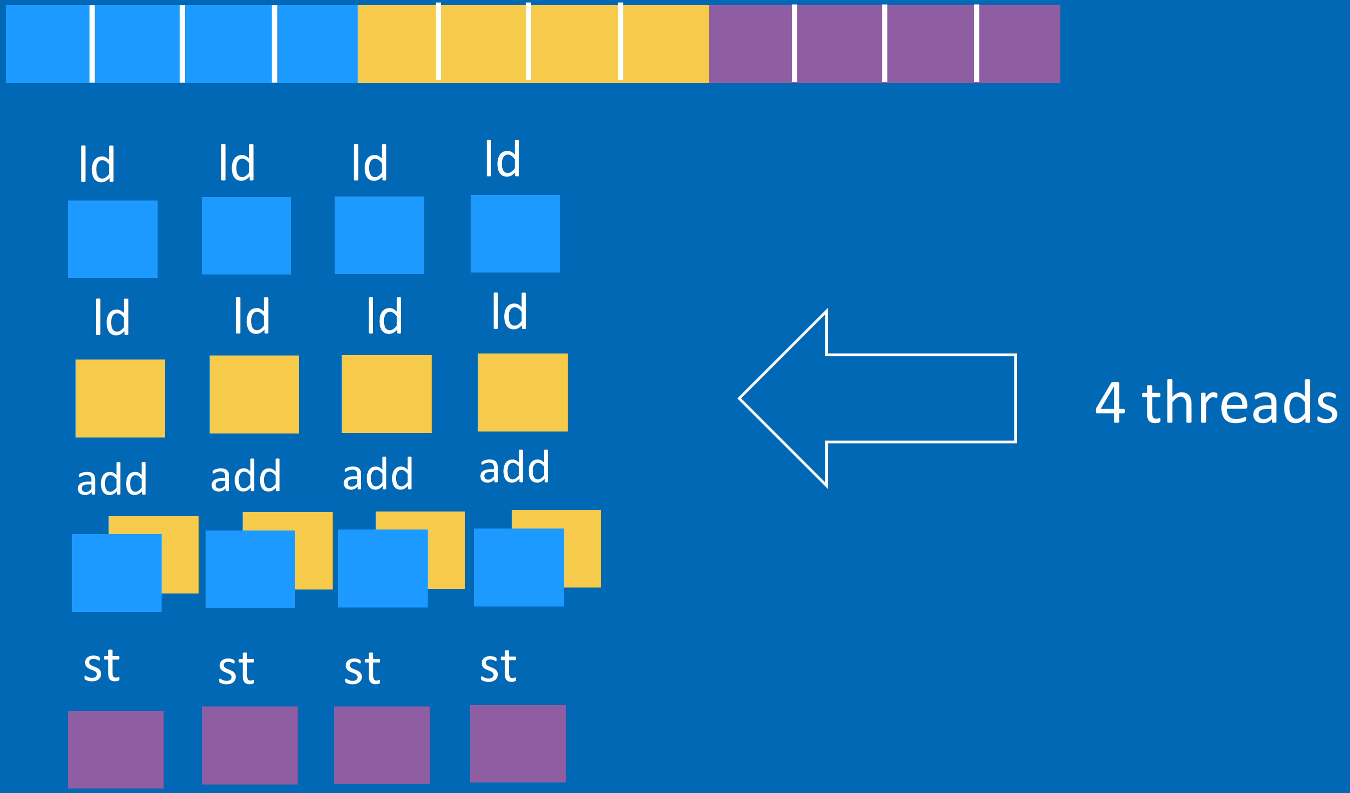


SIMD -> SIMT

单指令多线程（SIMT），一种基于线程视角的数据处理模式，每个线程处理一个数据，但是这些线程共享同一条指令。优点是多线程模式更加灵活，不需要数据的连续性，适合做数据的收集和分发（gather/scatter）操作，但是如果线程中有分支，效率会收到很大影响。

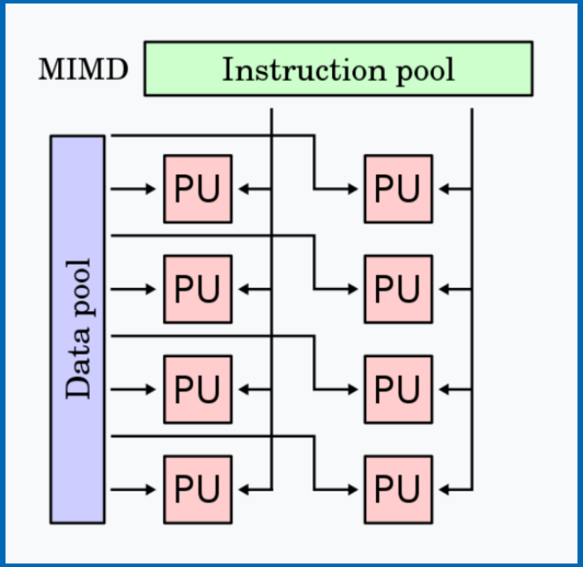


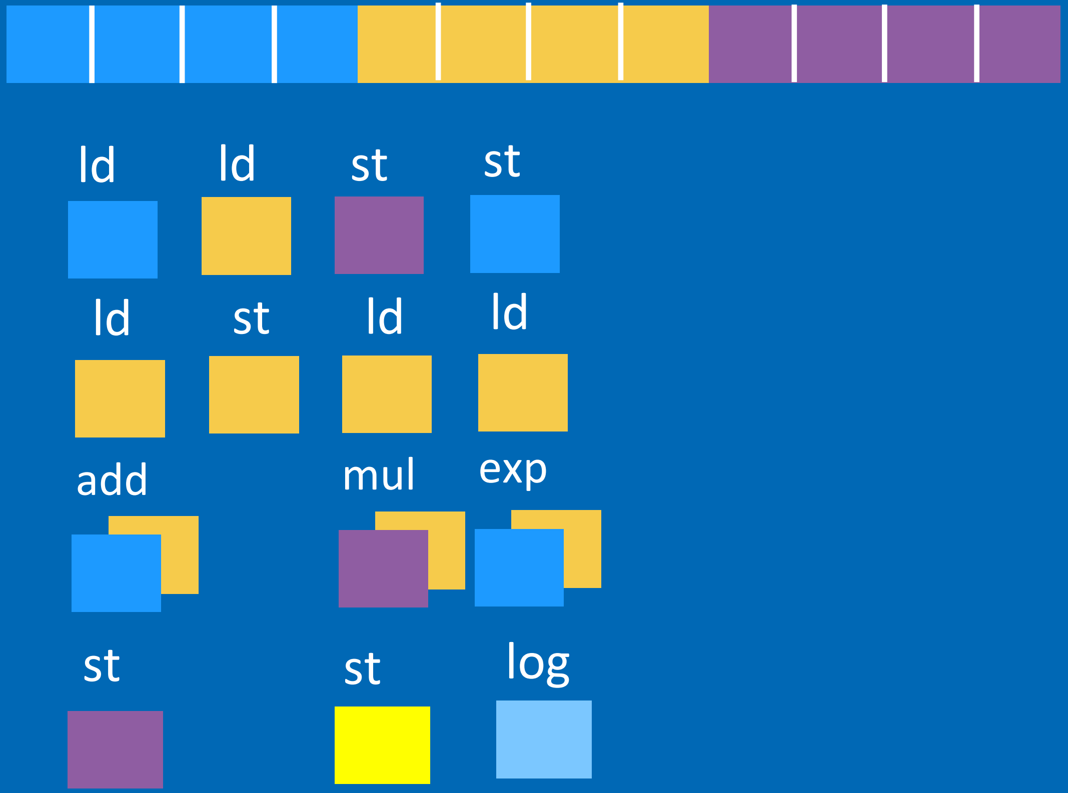
SIMT:单指令多线程



MIMD

多指令多数据流，一般用于多任务的并行模式。每一个计算单元都做各自独立的任务，并且读取各自独立的数据。其任务和数据之间都没有依赖性，所以并行程序设计方面较为简单。



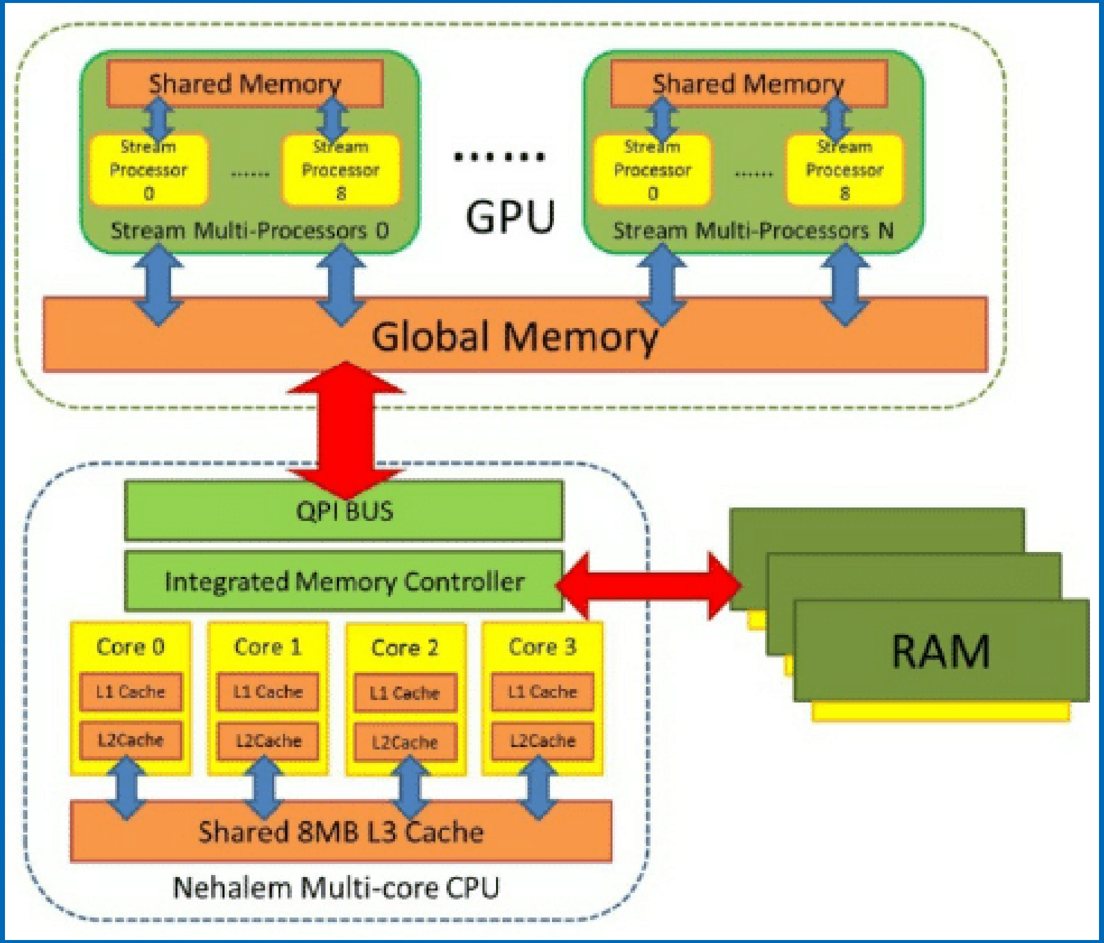


执行模型

GLOBALS
LOCALS
exec( )
EXECUTING...
COMPILE
SECURITY
Real Python

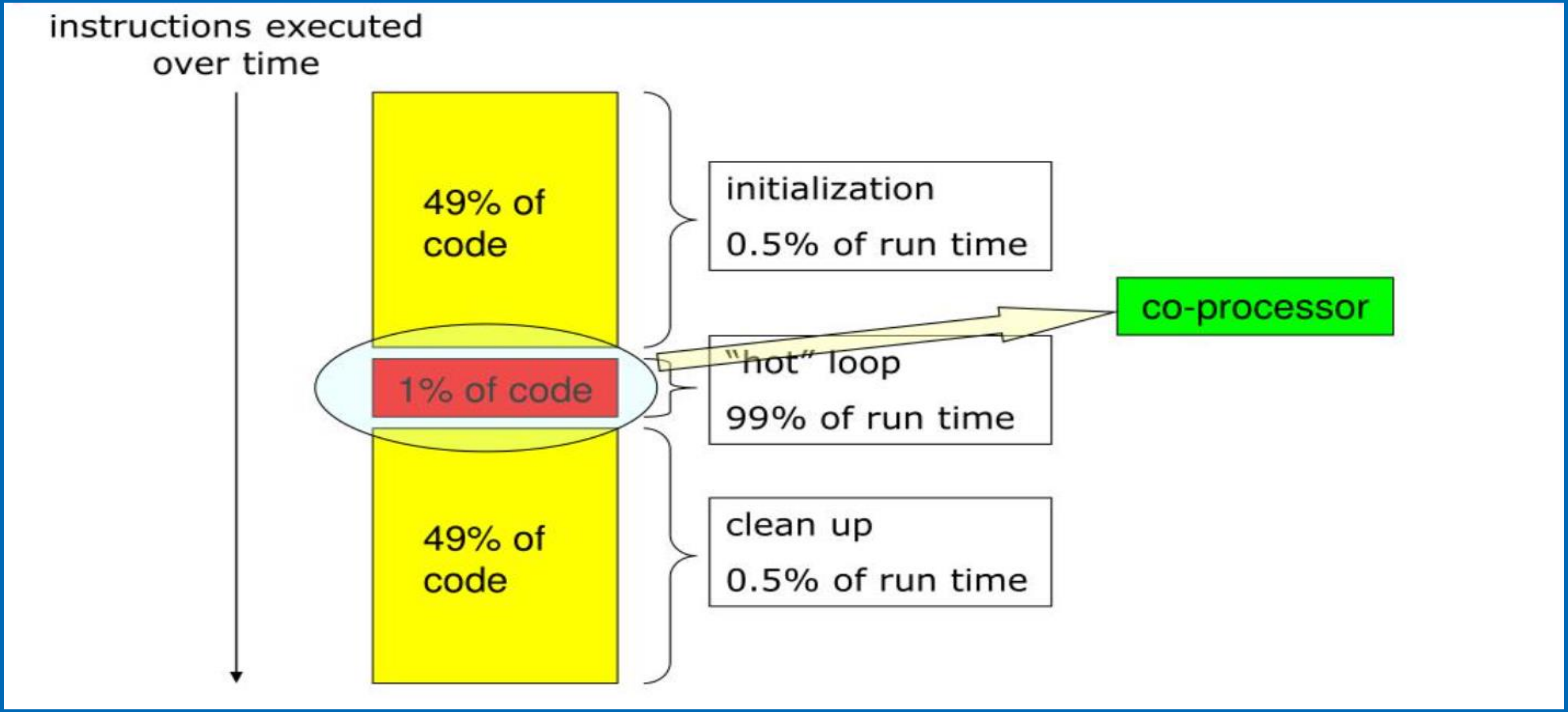
独立性

- 物理上分割，主板连接
- 独立的内存空间
- 不同的计算逻辑以及指令



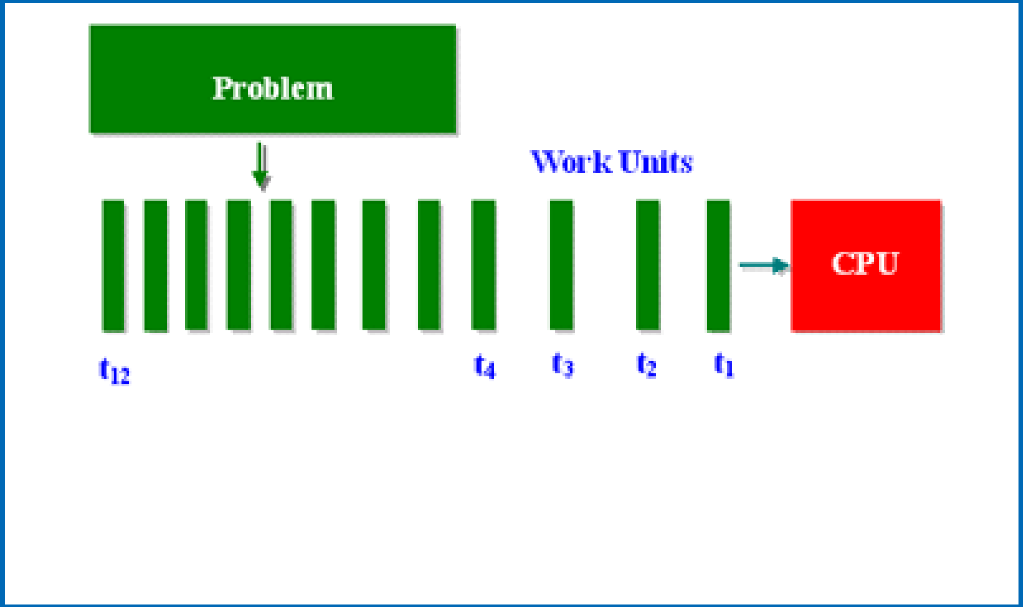
https://bmcsystbiol.biomedcentral.com/articles/10.1186/1752-0509-6-S1-S16/figures/3

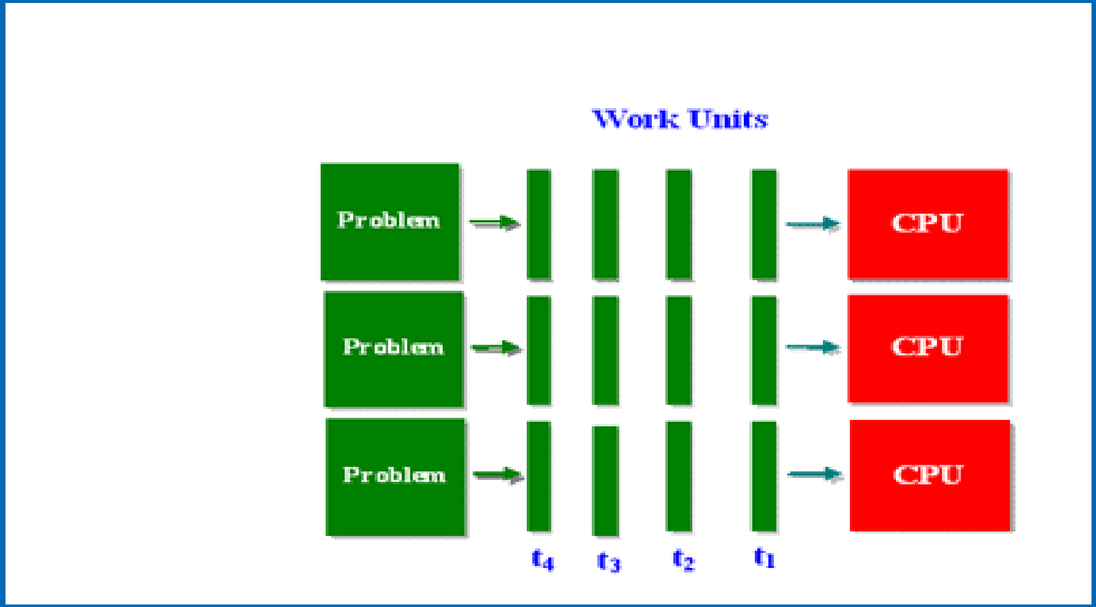
相关性


instructions executed over time
49% of code
1% of code
49% of code
initialization
0.5% of run time
"hot" loop
99% of run time
clean up
0.5% of run time
co-processor

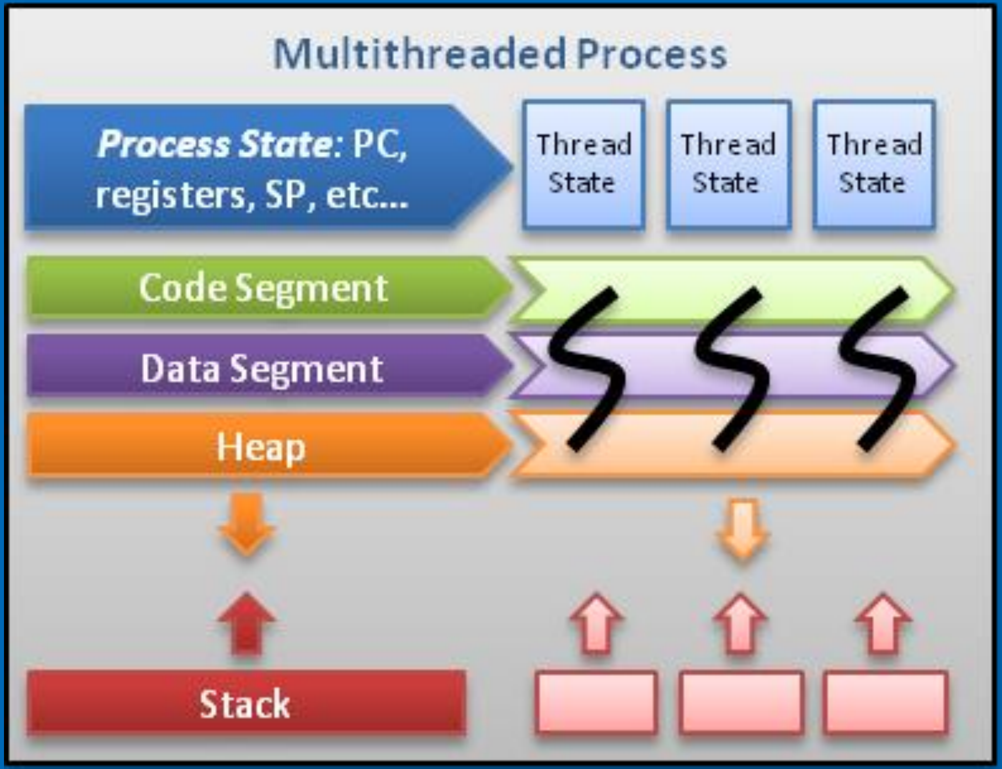
并行性

- 异构计算其实是并行计算的一个扩展，其核心内容仍然是做并行计算。
- 不同之处只是在不同的指令集和硬件架构下进行并行计算。
- 并行计算的核心是如何将任务分配到不同的计算核心。





并行编程框架


Multithreaded Process
Process State: PC, registers, SP, etc...
Thread State
Thread State
Thread State
Code Segment
Data Segment
Heap
Stack

- 多核编程： pthread， openMP
- 多节点编程： MPI
- 异构编程： CUDA， OpenCL， DPC++

多核编程

POSIX线程，简称Pthread，它定义了创建和操纵线程的一阵套API。

线程在相同的进程中共享：

- 进程中的全局变量
- 文件描述符
- 信号
- 工作目录
- 用户和组编号

线程特有的属性：

- 线程编号
- 寄存器，栈指针
- 局部变量，返回地址

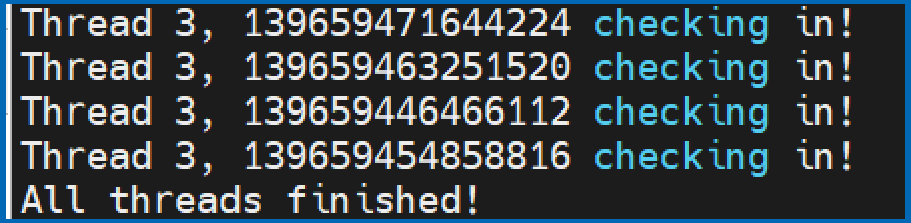
Pthread *Hello World*

1. 头文件<pthread.h>
2. 设置线程数目以及独立空间
3. 定义线程函数，需void类型
4. 创建线程，pthread_create
5. 每个线程独立执行函数f
6. 等待每个线程完成，pthread_join

```
#include <pthread.h>
#include <stdio.h>

#define THREADS 4

void *f(void* id) {
   int tid = * (int*) id;
   printf("Thread %d, %ld checking in!\n", tid, pthread_self());
   return NULL;
}

int main() {

   pthread_t threads[THREADS];
   int tid[THREADS];

   for (int i = 0; i < THREADS; i++) {
      tid[i] = i;
      pthread_create(&threads[i], NULL, f, &tid[i]);
   }

    for (int i = 0; i < THREADS; i++) {
       pthread_join(threads[i], NULL);
   }

   printf("All threads finished!\n");

   return 0;
}
```

提示：

使用Pthread，开发者有很大的控制权限，非常灵活，但是也非常容易出错。



```
Thread 3, 139659471644224 checking in!
Thread 3, 139659463251520 checking in!
Thread 3, 139659446466112 checking in!
Thread 3, 139659454858816 checking in!
All threads finished!
```

```
#include <pthread.h>
#include <stdio.h>

#define THREADS 4

void *f(void* id) {
   int tid = * (int*) id;
   printf("Thread %d, %ld checking in!\n", tid, pthread_self());
   return NULL;
}

int main() {

   pthread_t threads[THREADS];
   int tid；

   for (int i = 0; i < THREADS; i++) {
      tid = i;
      pthread_create(&threads[i], NULL, f, &tid);
   }

    for (int i = 0; i < THREADS; i++) {
       pthread_join(threads[i], NULL);
   }

   printf("All threads finished!\n");

   return 0;
}
```

Pthread：向量加

```
#define THREADS 4
#define N 100

// global data, every thread can see it
int A[N];
int B[N];
int C[N];

void *vecAdd(void* id) {
   int tid = * (int*) id;
   int tnum = N / THREADS;
   printf("Thread %d, %ld checking in!\n", tid, pthread_self());
   for(int i = tid * tnum; i < (tid +1)*tnum; i++) {
         C[i] = A[i] + B[i];
   }
   return NULL;
}
```

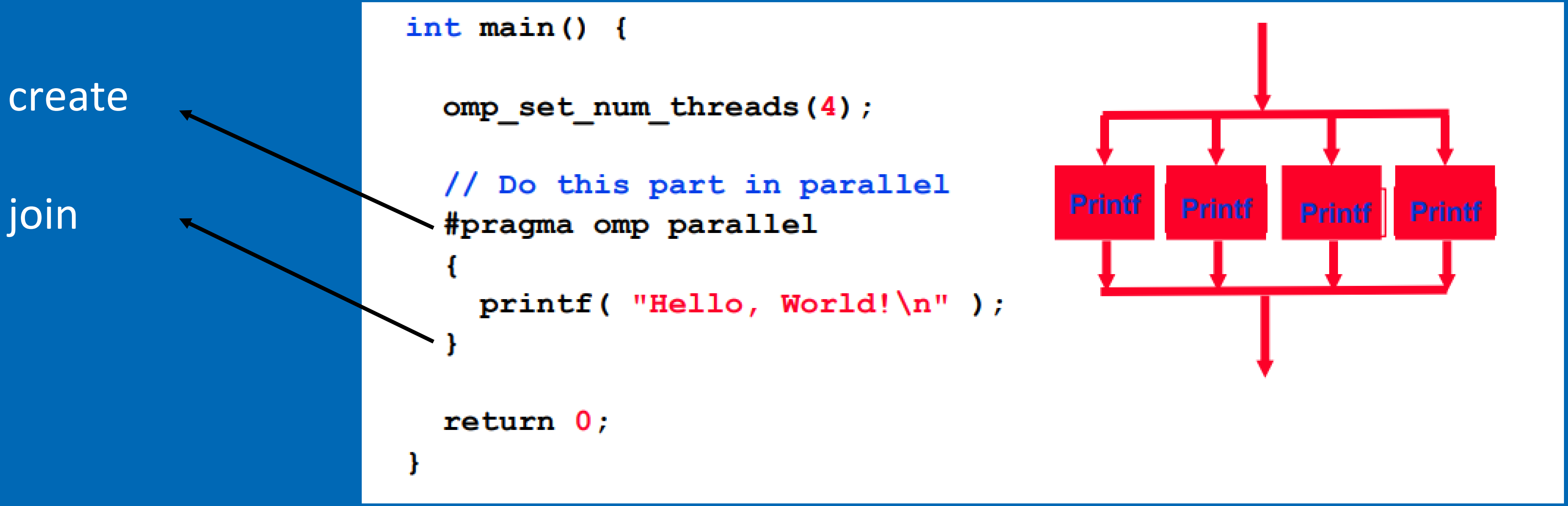
```
int main() {

   pthread_t threads[THREADS];
   int index[THREADS];

   int workload_per_thread = N / THREADS;
   for(int i = 0; i < N; i++) {
      A[i] = 1;
      B[i] = 2;
      C[i] = 0;
   }

   for (int i = 0; i < THREADS; i++) {
      index[i] = i;
      pthread_create(&threads[i], NULL, vecAdd, &index[i]);
   }

   for (int i = 0; i < THREADS; i++) {
       pthread_join(threads[i], NULL);
   }

}
```

OpenMP

- 一种基于编译指导的并行化方法
- 基于共享内存的轻量级并行化方法
- 无需线程的创建，同步，销毁等细粒度控制
- 开发者需要指定并行区域
- 编译器自动生成并行代码

OpenMP Hello World

- #pragma 为线程创建起始标志，线程自动回收当退出当前区域
- parallel 编译指导语句，表明下面区域可以进行并行化



```
int main() {

  omp_set_num_threads(4);

  // Do this part in parallel
  #pragma omp parallel
  {
    printf( "Hello, World!\n" );
  }

  return 0;
}
```

OpenMP：向量加

- 语法结构

#pragma omp parallel [clause [clause] ...]

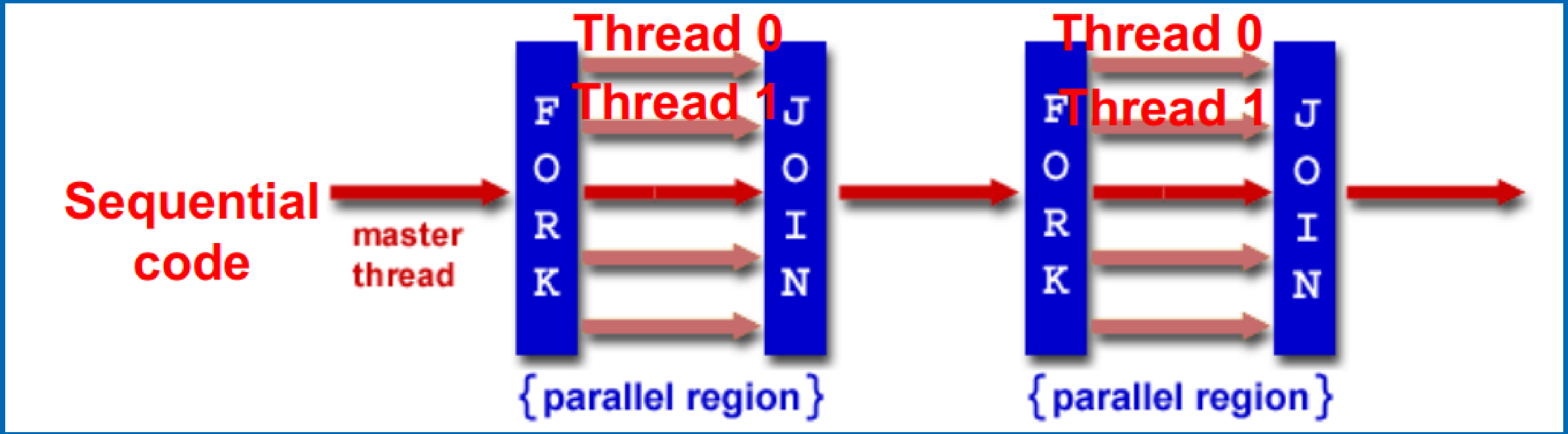
structured-block

- Clause包括：private，shared，…

```
#include <omp.h>
#include <stdio.h>

#define N 100

int main() {
   int A[N];
   int B[N];
   int C[N];

   for(int i = 0; i < N; i++) {
      A[i] = 1;
      B[i] = 2;
      C[i] = 0;
   }

#pragma omp parallel for
   for(int i = 0; i < N; i++) {
         C[i] = A[i] + B[i];
   }

   for(int i =0; i < N; i++) {
      if( C[i] != 3 ) printf("\nError in %d, %d", i, C[i]);
   }

   printf("All threads finished!\n");

   return 0;
}
```

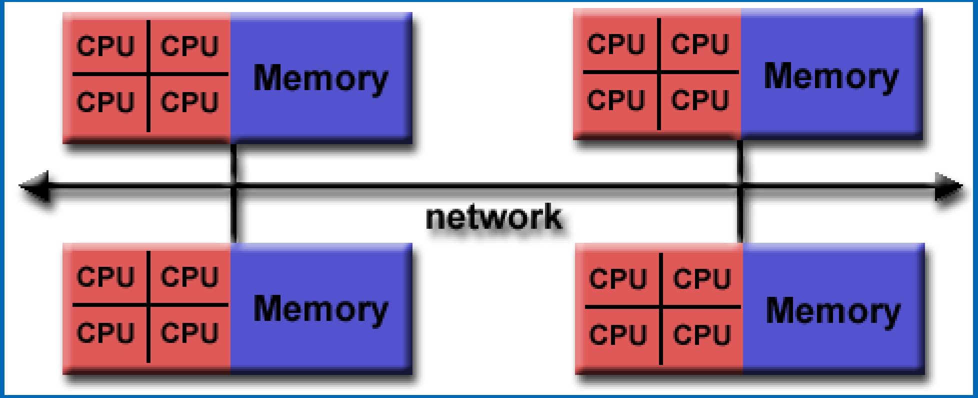
Fork-Join模型

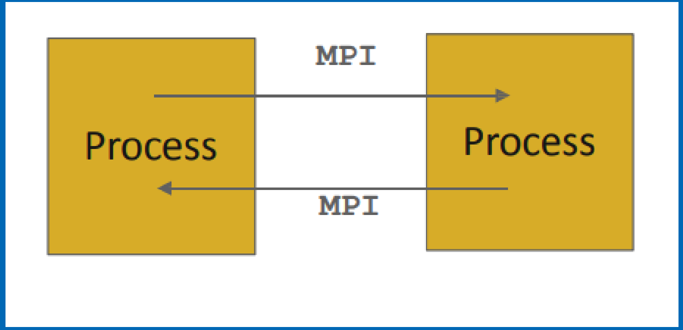
- OpenMP的编程模型是一种基于创建（fork），合并（join）的方式
- 仅在需要的地方进行并行化，线程创建和销毁的成本低

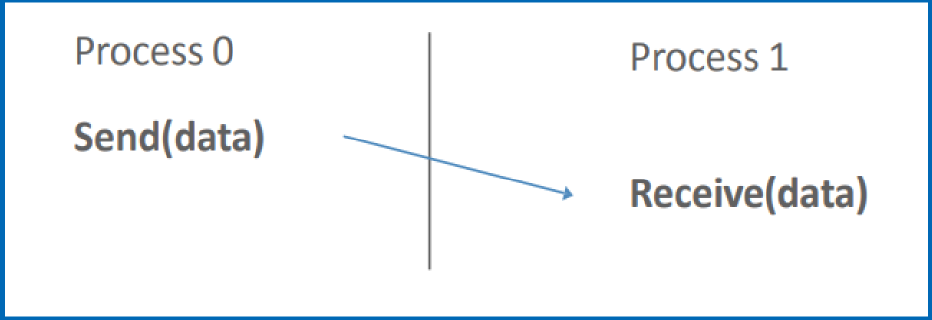


MPI: 消息传递模型

- 基于分布式内存的并行计算模式
- 进程之间进行显式的通信
- 消息发送和接收







如何运行一个MPI程序?

普通程序编译和执行:

- gcc test.c -o test
- ./test

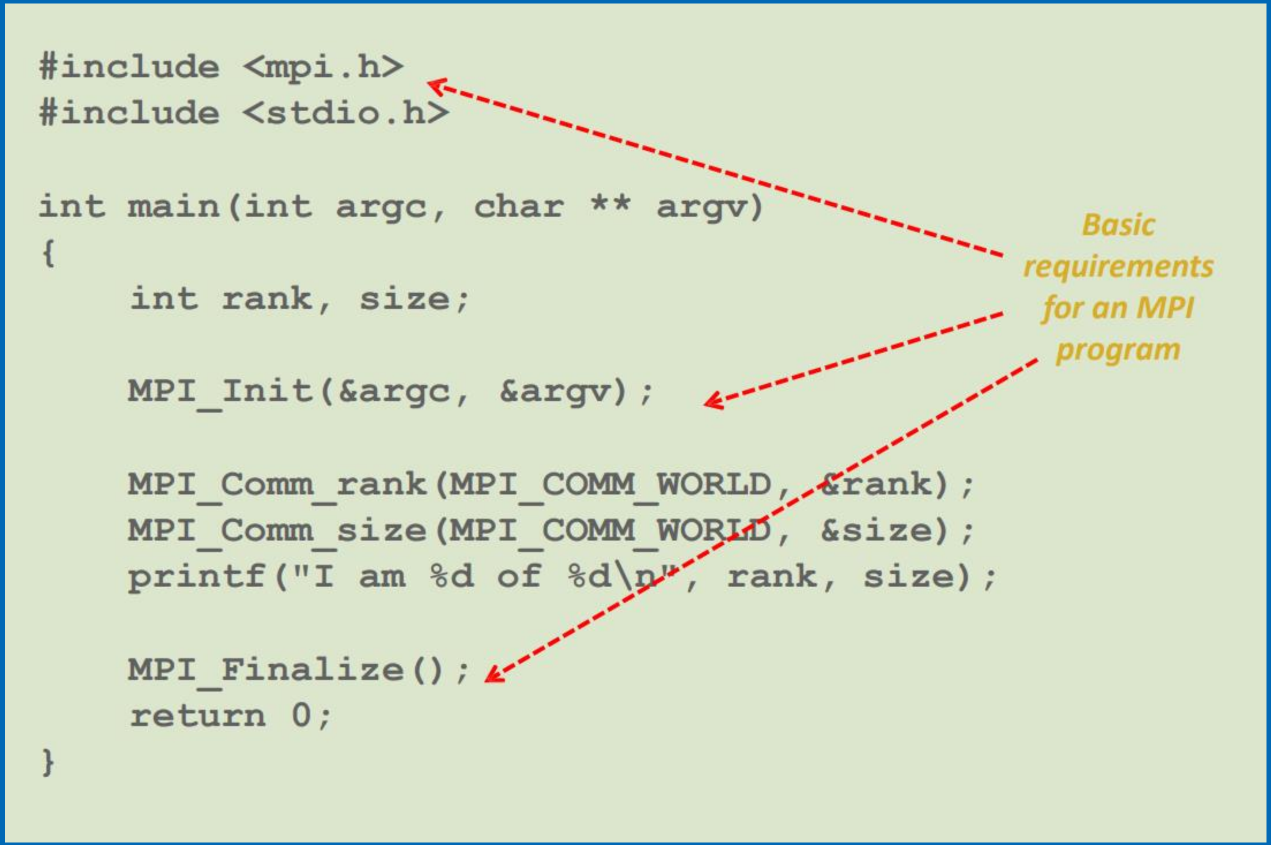
MPI程序编译和执行:

- mpicc test.c -o test
- mpiexec –np 4 ./test

- 通过mpiexec 会创建新的进程
- Np指定number of processor

MPI Hello World

1. 头文件<mpi.h>
2. MPI初始化和结束
3. 通信域，MPI_COMM_WORLD
4. 得到当前通信域整体进程数，size
5. 得到当前进程对应的序号，rank



```
#include <mpi.h>
#include <stdio.h>

int main(int argc, char ** argv)
{
    int rank, size;

    MPI_Init(&argc, &argv);

    MPI_Comm_rank(MPI_COMM_WORLD, &rank);
    MPI_Comm_size(MPI_COMM_WORLD, &size);
    printf("I am %d of %d\n", rank, size);

    MPI_Finalize();
    return 0;
}
```

MPI send/receive

MPI_SEND(buf, count, datatype, dest, tag, comm)

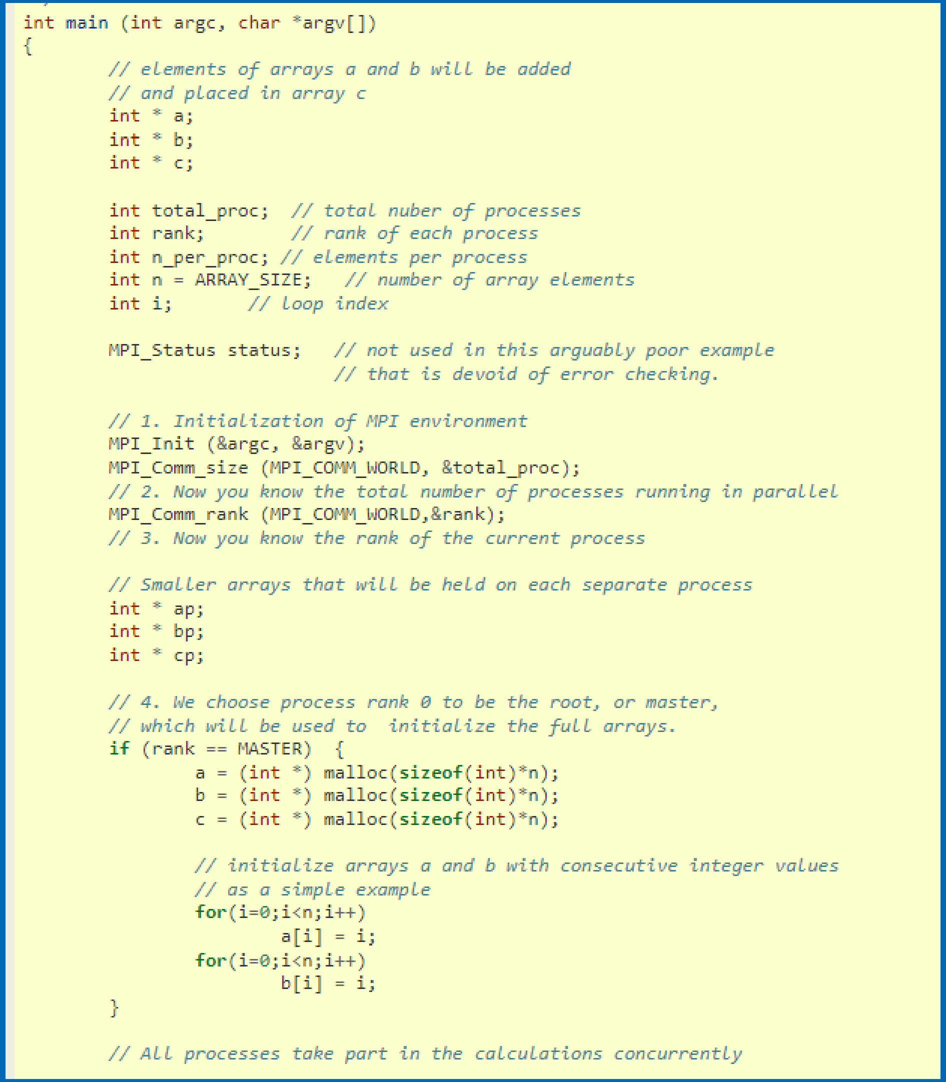
MPI_RECV(buf, count, datatype, source, tag, comm, status)

```
#include <mpi.h>
#include <stdio.h>

int main(int argc, char ** argv)
{
    int rank, data[100];

    MPI_Init(&argc, &argv);

    MPI_Comm_rank(MPI_COMM_WORLD, &rank);

    if (rank == 0)
        MPI_Send(data, 100, MPI_INT, 1, 0, MPI_COMM_WORLD);
    else if (rank == 1)
        MPI_Recv(data, 100, MPI_INT, 0, 0, MPI_COMM_WORLD, MPI_STATUS_IGNORE);

    MPI_Finalize();
    return 0;
}
```

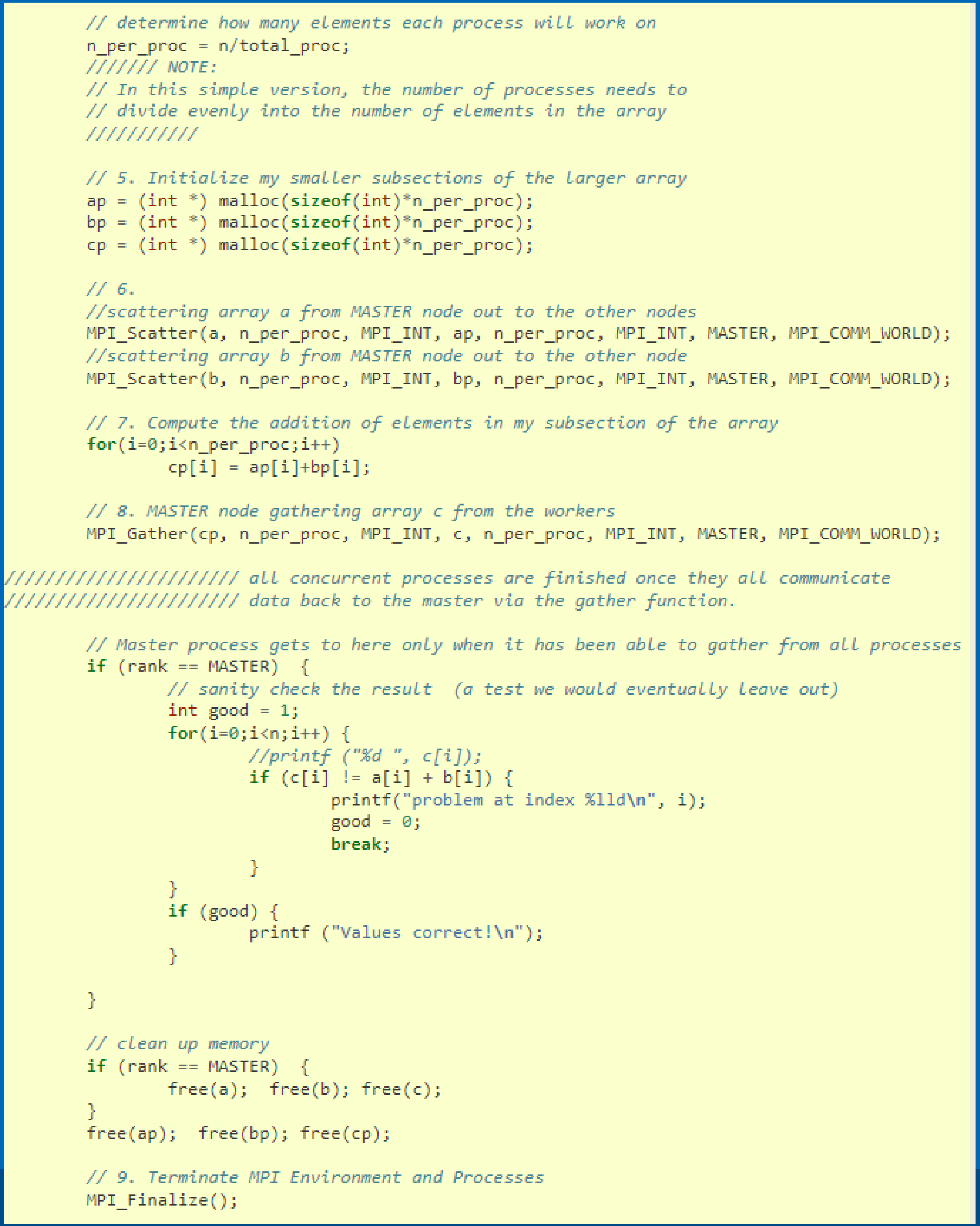
- MPI的工作模式就像发短信，一方发一发接收。
- 发送和接收的数据用（buf，count，datatype）描述
- tag是用户定义的类型
- Comm是定义的通讯域
- 对于SEND/RECV是阻塞型API，会一直等待到彼此之间数据传输完成

intel

MPI：向量加

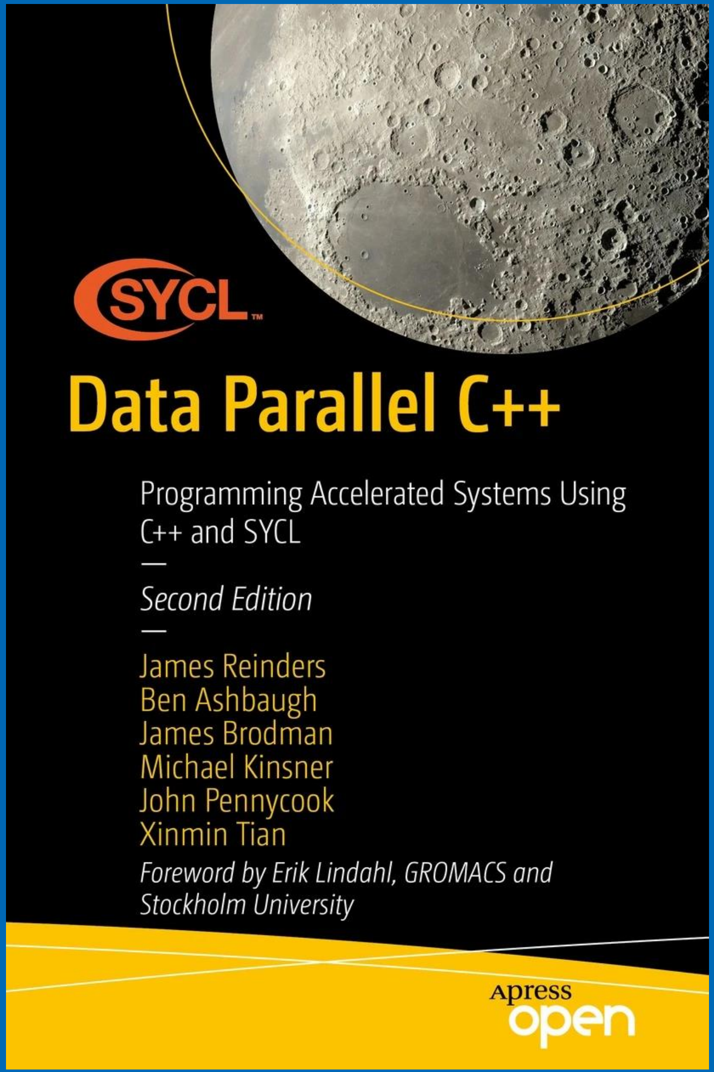


```c
int main (int argc, char *argv[])
{
	// elements of arrays a and b will be added
	// and placed in array c
	int * a;
	int * b;
	int * c;

	int total_proc;	// total nuber of processes
	int rank;		// rank of each process
	int n_per_proc;	// elements per process
	int n = ARRAY_SIZE;	// number of array elements
	int i;		// loop index

	MPI_Status status;	// not used in this arguably poor example
				// that is devoid of error checking.

	// 1. Initialization of MPI environment
	MPI_Init (&argc, &argv);
	MPI_Comm_size (MPI_COMM_WORLD, &total_proc);
	// 2. Now you know the total number of processes running in parallel
	MPI_Comm_rank (MPI_COMM_WORLD,&rank);
	// 3. Now you know the rank of the current process

	// Smaller arrays that will be held on each separate process
	int * ap;
	int * bp;
	int * cp;

	// 4. We choose process rank 0 to be the root, or master,
	// which will be used to  initialize the full arrays.
	if (rank == MASTER)  {
		a = (int *) malloc(sizeof(int)*n);
		b = (int *) malloc(sizeof(int)*n);
		c = (int *) malloc(sizeof(int)*n);

		// initialize arrays a and b with consecutive integer values
		// as a simple example
		for(i=0;i<n;i++)
			a[i] = i;
		for(i=0;i<n;i++)
			b[i] = i;
	}

	// All processes take part in the calculations concurrently
```



```c
	// determine how many elements each process will work on
	n_per_proc = n/total_proc;
	/////// NOTE:
	// In this simple version, the number of processes needs to
	// divide evenly into the number of elements in the array
	//////////

	// 5. Initialize my smaller subsections of the larger array
	ap = (int *) malloc(sizeof(int)*n_per_proc);
	bp = (int *) malloc(sizeof(int)*n_per_proc);
	cp = (int *) malloc(sizeof(int)*n_per_proc);

	// 6.
	//scattering array a from MASTER node out to the other nodes
	MPI_Scatter(a, n_per_proc, MPI_INT, ap, n_per_proc, MPI_INT, MASTER, MPI_COMM_WORLD);
	//scattering array b from MASTER node out to the other node
	MPI_Scatter(b, n_per_proc, MPI_INT, bp, n_per_proc, MPI_INT, MASTER, MPI_COMM_WORLD);

	// 7. Compute the addition of elements in my subsection of the array
	for(i=0;i<n_per_proc;i++)
		cp[i] = ap[i]+bp[i];

	// 8. MASTER node gathering array c from the workers
	MPI_Gather(cp, n_per_proc, MPI_INT, c, n_per_proc, MPI_INT, MASTER, MPI_COMM_WORLD);

///////////////////// all concurrent processes are finished once they all communicate
///////////////////// data back to the master via the gather function.

	// Master process gets to here only when it has been able to gather from all processes
	if (rank == MASTER)  {
		// sanity check the result  (a test we would eventually leave out)
		int good = 1;
		for(i=0;i<n;i++) {
			//printf ("%d ", c[i]);
			if (c[i] != a[i] + b[i]) {
				printf("problem at index %lld\n", i);
				good = 0;
				break;
			}
		}
		if (good) {
			printf ("Values correct!\n");
		}

	}

	// clean up memory
	if (rank == MASTER)  {
		free(a);  free(b); free(c);
	}
	free(ap);  free(bp); free(cp);

	// 9. Terminate MPI Environment and Processes
	MPI_Finalize();
```

Data Parallel C++


SYCL

Data Parallel C++

Programming Accelerated Systems Using C++ and SYCL

—

Second Edition

—

James Reinders
Ben Ashbaugh
James Brodman
Michael Kinsner
John Pennycook
Xinmin Tian

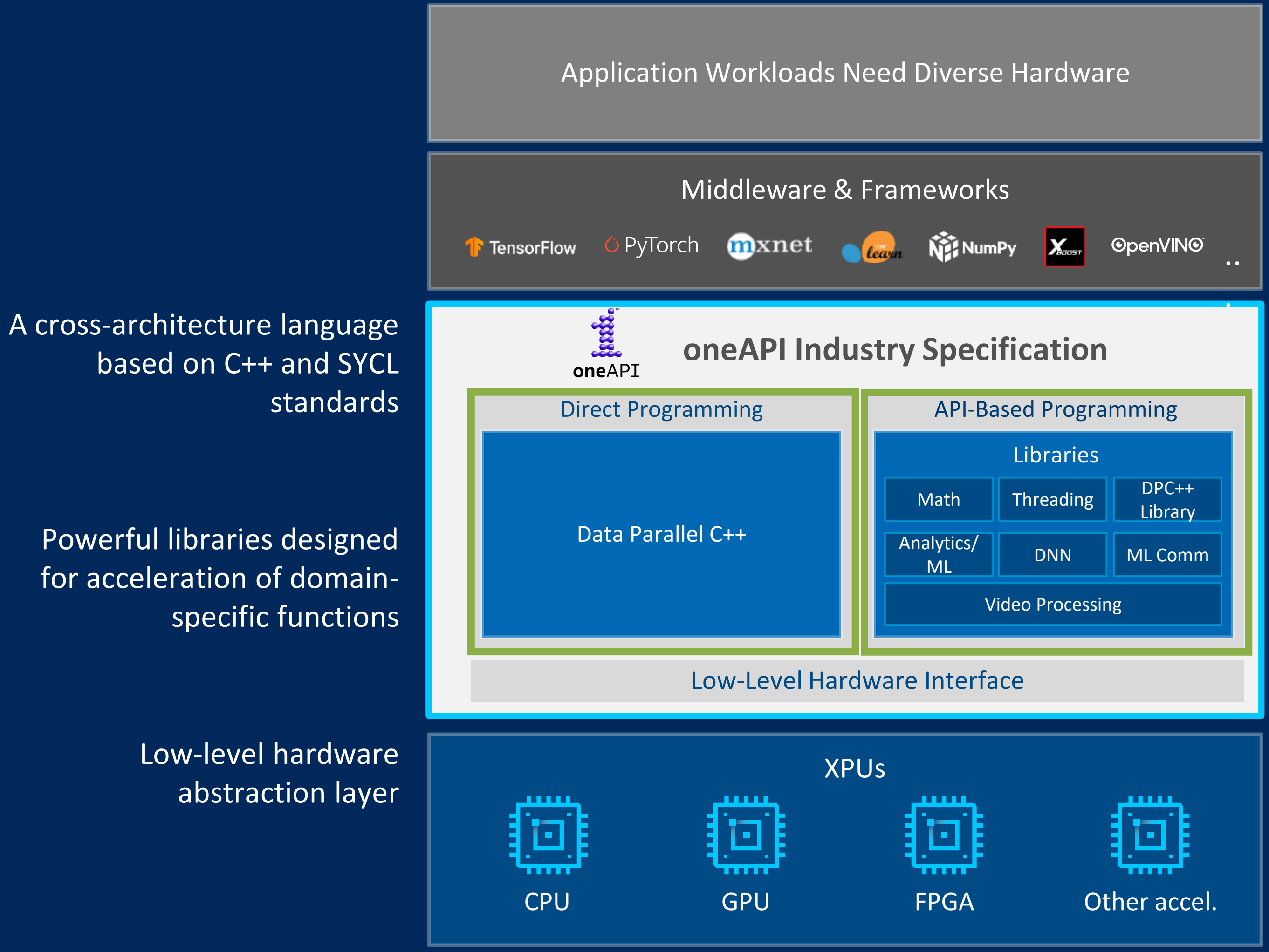
Foreword by Erik Lindahl, GROMACS and Stockholm University

Apress open

https://github.com/Apress/data-parallel-CPP

编程模型

- Low-Level Hardware Interface
- Programming Language
- High Performance Library



Application Workloads Need Diverse Hardware
Middleware & Frameworks
TensorFlow
PyTorch
mxnet
learn
NumPy
OpenVINO
oneAPI
oneAPI Industry Specification
Direct Programming
Data Parallel C++
API-Based Programming
Libraries
Math
Threading
DPC++ Library
Analytics/ ML
DNN
ML Comm
Video Processing
Low-Level Hardware Interface
XPUs
CPU
GPU
FPGA
Other accel.
A cross-architecture language based on C++ and SYCL standards
Powerful libraries designed for acceleration of domain-specific functions
Low-level hardware abstraction layer

oneAPI

The productive, smart path to freedom for accelerated computing from the economic and technical burdens of proprietary programming models

intel.

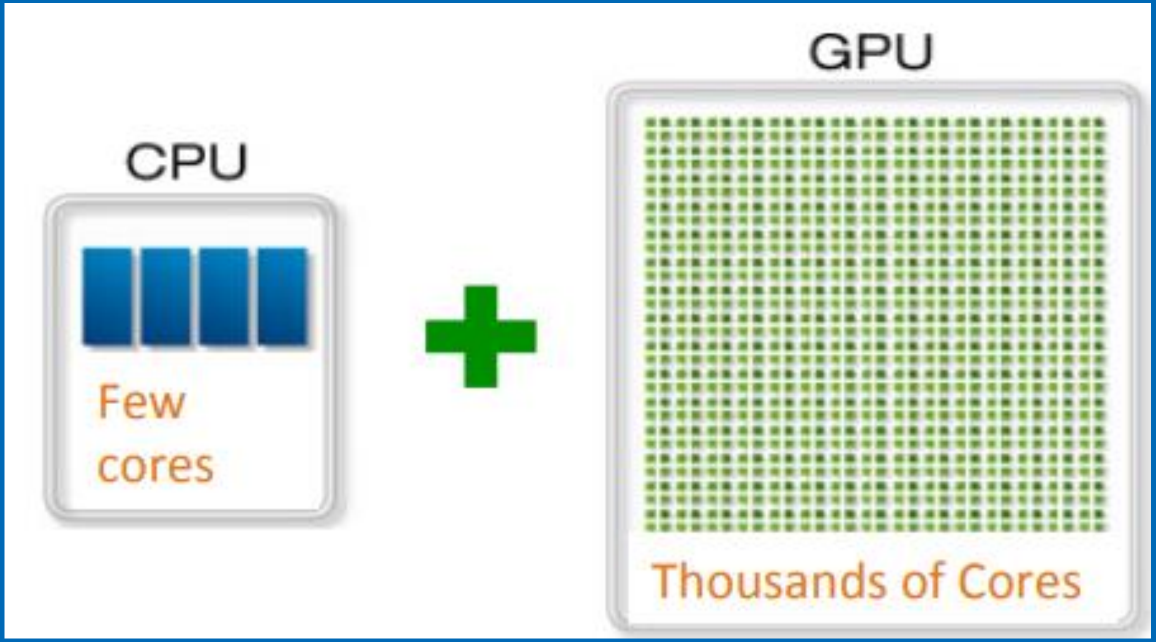
通用处理器： CPU + GPU来进行加速

CPU

- General Purpose Tasks
- Most Common App
- Compute Intensive

GPU

- Specialized tasks
- Most visual app
- Data processing in parallel



本课程重点：

- 教会同学们如何使用DPC++编写程序
- 理解串行程序和并行程序设计的区别
- 实现自己的并行算法 == 能完成作业☺

本课程将略过：

- 非关键路径的功能
- 非必要的语言特性和细节
- 各种用法的变化

Data Parallel C++ 是什么？

基于C++语言的扩展，它提供了：

- 访问硬件设备的抽象
- 数据访问的方法
- 表达并行性的方法

设备

- **设备,** 表示 OneAPI 系统中的各种硬件

  设备类是预定义的设备选择和查询的方法

  包含用于查询设备信息的成员函数,

  支持创建不同硬件， CPU/GPU/FPGA/…

- **device_selector** 类支持运行时选择特定设备

  default_selector、 cpu_selector、 gpu_selector.....

Code Example

```
 #include <CL/sycl.hpp>
#include <iostream>
using namespace sycl;
int main() {
  queue my_gpu_queue( gpu_selector{} );
```

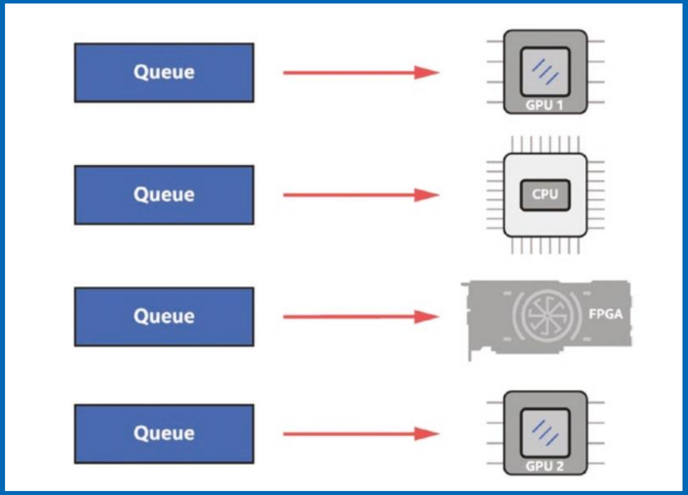
```
patric@gpu:~$ dpcpp gpu_selector.cpp
patric@gpu:~$ ./a.out
Selected GPU device: Intel(R) Iris(R) Xe MAX Graphics [0x4905]
```

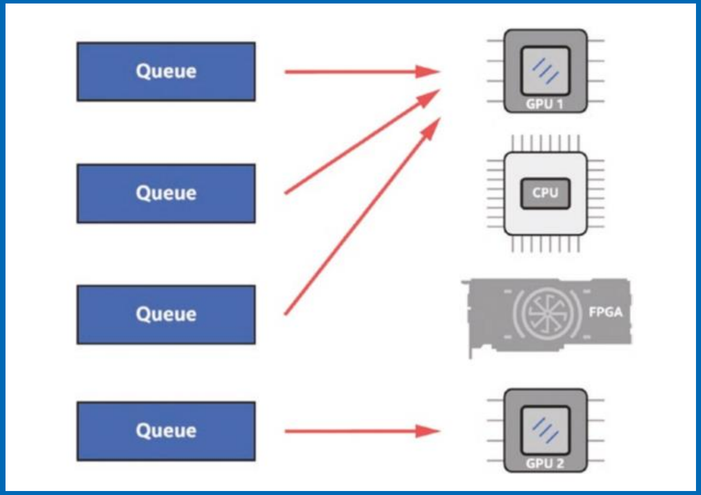
```
}
```

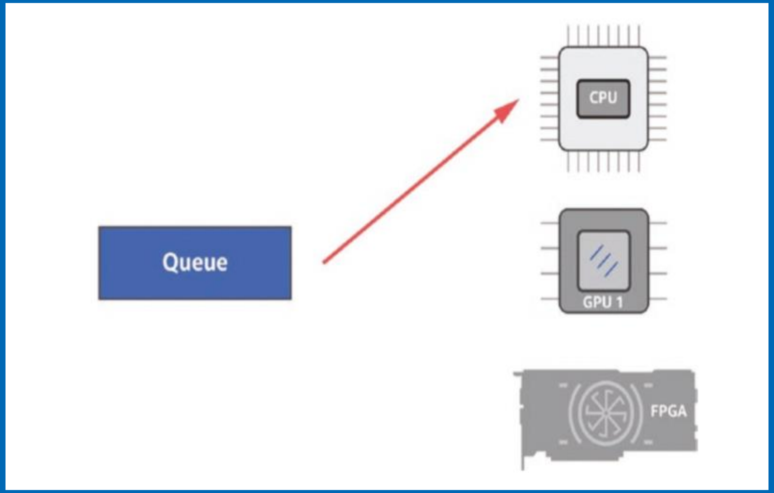
https://github.com/pengzhao-intel/oneAPI_course/blob/main/code/gpu_selector.cpp

队列

- 队列是一种将工作提交到设备的机制
- 主程序将任务推入队列，异构设备从队列中获得执行任务
- 一个队列映射到一个设备，多个队列可以映射到同一设备。





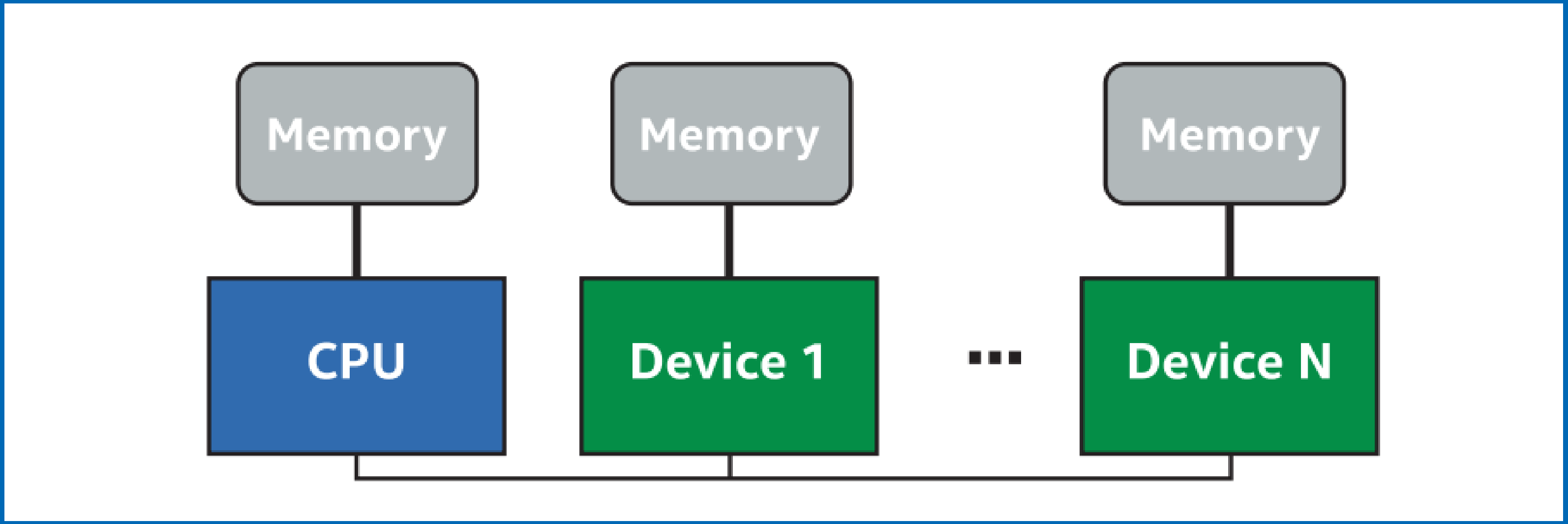


Code Example

```
int main() {
  queue my_gpu_queue( gpu_selector{} );
  std::cout << "Selected GPU device: " <<
    my_gpu_queue.get_device().get_info<info::device::name>() ";
  return 0;
}
```

数据移动

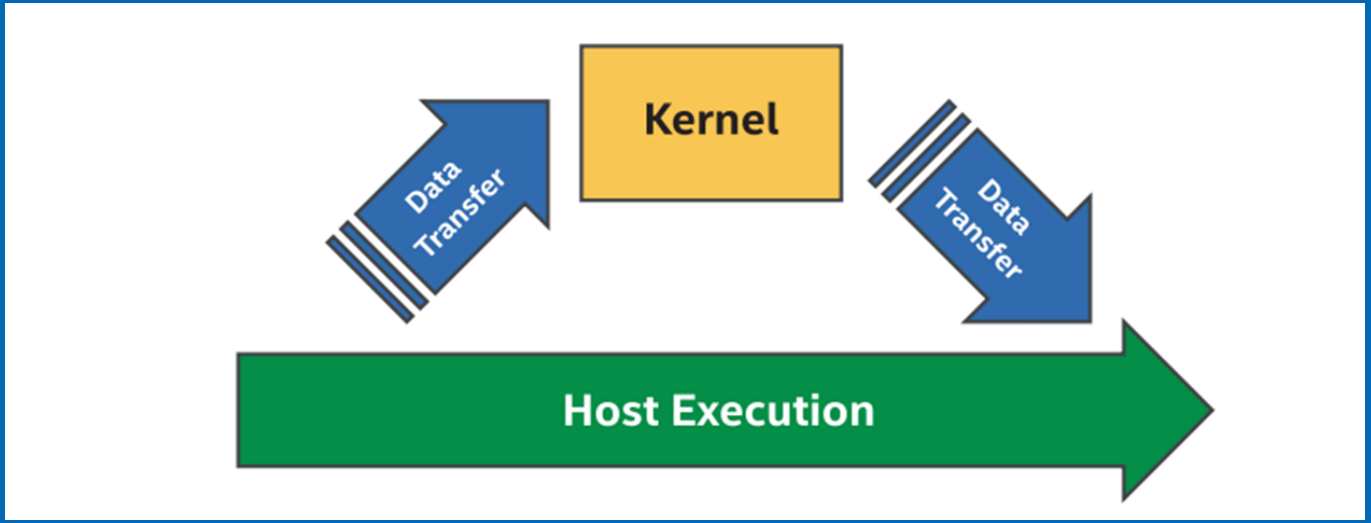
- CPU和GPU具有独立的存储空间



- 程序员需要考虑如何在不同设备之间移动数据

- 显式的数据移动，CPU->GPU，计算， GPU -> CPU

- 隐式的数据移动， 数据在被访问的时候，系统自动进行数据迁移



• 显式内存申请

Traditional C/C++

void* malloc (size_t size);

Allocate memory block

Allocates a block of *size* bytes of memory, returning a pointer to the beginning of the block.

Data Parallel C++

void* malloc_host(size_t size, const sycl::queue& q);

void* malloc_device(size_t size, const sycl::queue& q);

void* malloc_shared(size_t size, const sycl::queue& q);

• 显式内存拷贝

Traditional C/C++

void * memcpy (void * destination, const void * source, size_t num);

Copy block of memory

Copies the values of *num* bytes from the location pointed to by *source* directly to the memory block pointed to by *destination*.

Data Parallel C++

void * queue.memcpy (void * destination, const void * source, size_t num);

• 内存释放

Traditional C/C++

void free (void* ptr);

Deallocate memory block

A block of memory previously allocated by a call to malloc, calloc or realloc is deallocated,

making it available again for further allocations.

Data Parallel C++

void free(void* ptr, sycl::queue& q);

Free memory allocated by sycl::malloc_device, sycl::malloc_host, or sycl::malloc_shared.

代码

```
constexpr int N = 10;

  int *host_mem   = malloc_host<int>(N, my_gpu_queue);
  int *device_mem = malloc_device<int>(N, my_gpu_queue);
```

编译：

```
patric@gpu:~/course$ dpcpp data_movement_ex.cpp -o data_move
```

运行输出：

```
patric@gpu:~/course$ ./data_move
Selected GPU device: Intel(R) Iris(R) Xe MAX Graphics [0x4905]

Data Result
0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
Task Done!
```

https://github.com/pengzhao-intel/oneAPI_course/blob/main/code/data_movement_ex.cpp

内核

- 什么地方需要并行化?

计算量最大，最耗时的地方，通常是循环内的部分

串行的执行方式

```
for(int i=0; i < 1024; i++){
    a[i] = b[i] + c[i];
});
```

并行的执行方式

```
launch N kernel instances {
    int id = get_instance_id();
    c[id] = a[id] + b[id];
}
```

parallel_for

- 并行化 for-loop是并行计算的核心

  在该循环中，每个迭代应该是完全独立的，并且不分顺序。
- 并行内核使用 parallel_for 函数表示

串行的执行方式

```
for(int i=0; i < 1024; i++){
    a[i] = b[i] + c[i];
});
```

使用 **parallel_for** 卸载到加速器

```
h.parallel_for(range<1>(1024), [=](id<1> i){
    A[i] =  B[i] + C[i];
});
```

基础并行内核

基本并行内核的功能通过 range、id 和 item 类提供。

- range 用于描述任务空间的大小
- item 代表内核函数的单个实例，向执行范围的查询属性公开其他函数
- 利用item的信息来将每个线程对应到整体的任务空间

```
h.parallel_for(range<1>(1024), [=](item<1> item){
            auto idx = item.get_id();
            auto R = item.get_range();
            // CODE THAT RUNS ON DEVICE
});
```

代码实例

```
// Copy from host(CPU) to device(GPU)
my_gpu_queue.memcpy(device_mem, host_mem, N * sizeof(int)).wait();

// do some works on GPU
// submit the content to the queue for execution
my_gpu_queue.submit([&](handler& h) {
```

运行输出：

```
patric@gpu:~/course$ ./basic_parafor
Selected GPU device: Intel(R) Iris(R) Xe MAX Graphics [0x4905]

Data Result
0, 2, 4, 6, 8, 10, 12, 14, 16, 18,
Task Done!
```

```
my_gpu_queue.memcpy(host_mem, device_mem, N * sizeof(int)).wait();
```

https://github.com/pengzhao-intel/oneAPI_course/blob/main/code/basic_parafor.cpp

性能评价

https://www.constructioninsure.co.uk/high-risk-trade-insurance-most-beneficial/

Q: 我的程序快了吗？

如何衡量我们的程序是否运行的更快，更有效了？

- 时间： wall time
- 带宽： GBytes/sec
- 计算： Gflops

时间

CPU

Start timer

Code

End timer

duration =   end – start

```
float duration_cpu = 0.0;
std::chrono::high_resolution_clock::time_point s, e;
s = std::chrono::high_resolution_clock::now();
// CPU code here
e = std::chrono::high_resolution_clock::now();
duration_cpu =
std::chrono::duration<float, std::milli>(e - s).count();
```

```
// CPU computation
 printf("\n Start CPU Computation, Number of Elems = %d \n", N);
```

代码

编译：

```
patric@gpu:~/course$ dpcpp timer.cpp -o time
```

运行输出：

```
patric@gpu:~/course$ ./time
Selected GPU device: Intel(R) Iris(R) Xe MAX Graphics [0x4905]

 Start CPU Computation, Number of Elems = 10000000
 End CPU Computation, Time = 5.333

Task Done!
```

如何测量GPU时间?

GPU

Start timer

GPU Code

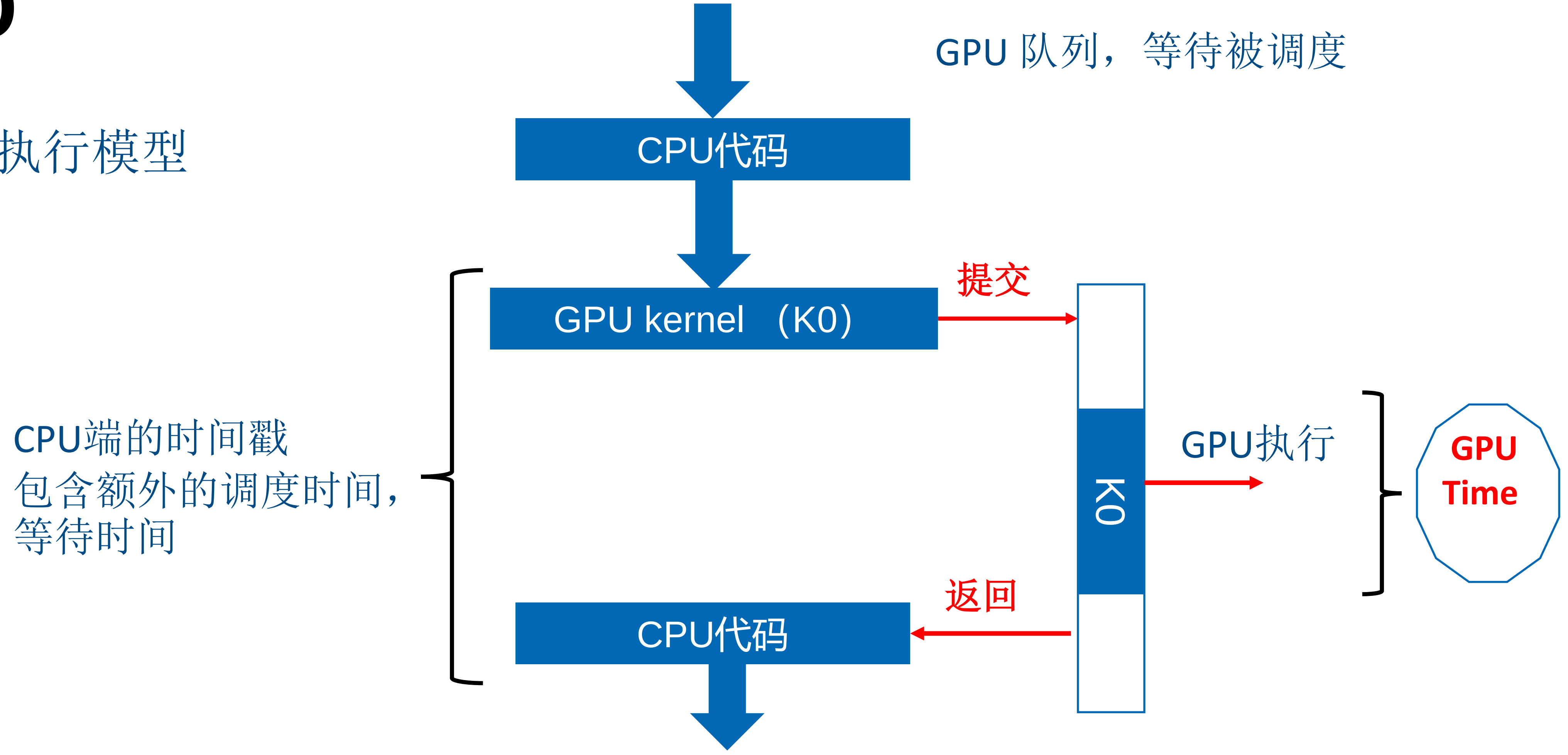
End timer

duration = end – start

Correct ?

NO

异构执行模型

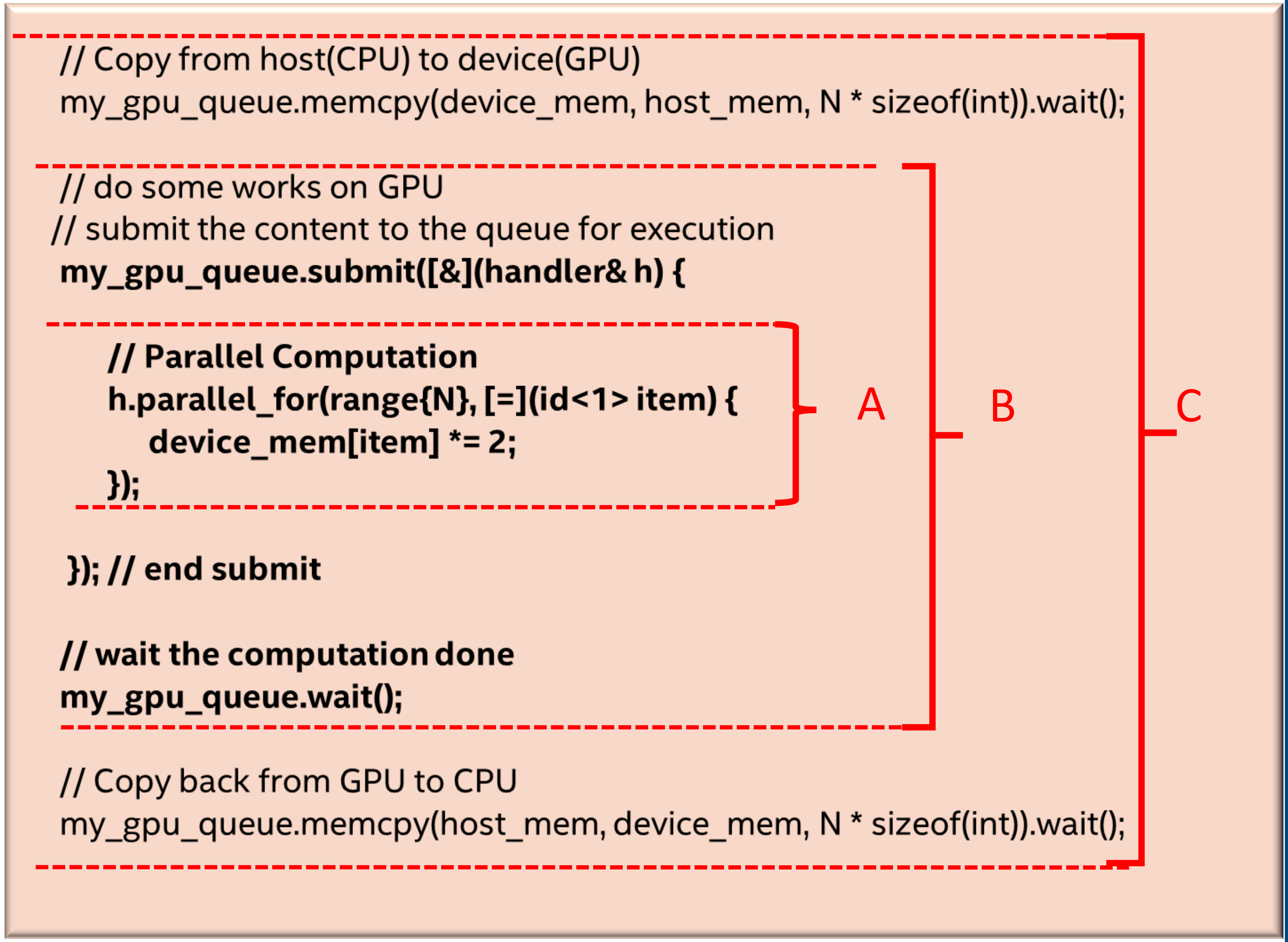

GPU 队列，等待被调度
CPU代码
提交
GPU kernel （K0）
K0
GPU执行
GPU Time
CPU端的时间戳
包含额外的调度时间，
等待时间
返回
CPU代码

GPU: add profiling in Queue

```
auto propList = cl::sycl::property_list {cl::sycl::property::queue::enable_profiling()};

queue my_gpu_queue(gpu_selector{}, propList);


// submit the content to the queue for execution
 auto event = my_gpu_queue.submit([&](handler& h) {
      // Parallel Computation
       ….
 });


 double gpu_time_ns =
  event.get_profiling_info<info::event_profiling::command_end>() -
  event.get_profiling_info<info::event_profiling::command_start>();
```

YES

从CPU的角度来看代码执行了多长时间



```
// Copy from host(CPU) to device(GPU)
my_gpu_queue.memcpy(device_mem, host_mem, N * sizeof(int)).wait();

// do some works on GPU
// submit the content to the queue for execution
my_gpu_queue.submit([&](handler& h) {

    // Parallel Computation
    h.parallel_for(range{N}, [=](id<1> item) {
        device_mem[item] *= 2;
    });

});  // end submit

// wait the computation done
my_gpu_queue.wait();

// Copy back from GPU to CPU
my_gpu_queue.memcpy(host_mem, device_mem, N * sizeof(int)).wait();
```

https://github.com/pengzhao-intel/oneAPI_course/blob/main/code/timer.cpp

Compare Results

```
Selected GPU device: Intel(R) Iris(R) Xe MAX Graphics [0x4905]

 Start CPU Computation, Number of Elems = 10000000

 CPU Computation,          Time =     5.474415

 GPU Computation, GPU Time A = 1.083385

 GPU Computation, GPU Time B = 1.605373

 GPU Computation, GPU Time C = 20.106045
```

Review Code Structure Again!

```
// Copy from host(CPU) to device(GPU)
my_gpu_queue.memcpy(device_mem, host_mem, N * sizeof(int)).wait();

// do some works on CPU
for(.... )  {  ....  };

// do some works on GPU
   my_gpu_queue.submit([&](handler& h)
     parallel_for( ) { ..... }
 }); // end submit
my_gpu_queue.wait();

// Copy back from GPU to CPU
my_gpu_queue.memcpy(host_mem, device_mem, N * sizeof(int)).wait();
```

CPU time1

GPU time1

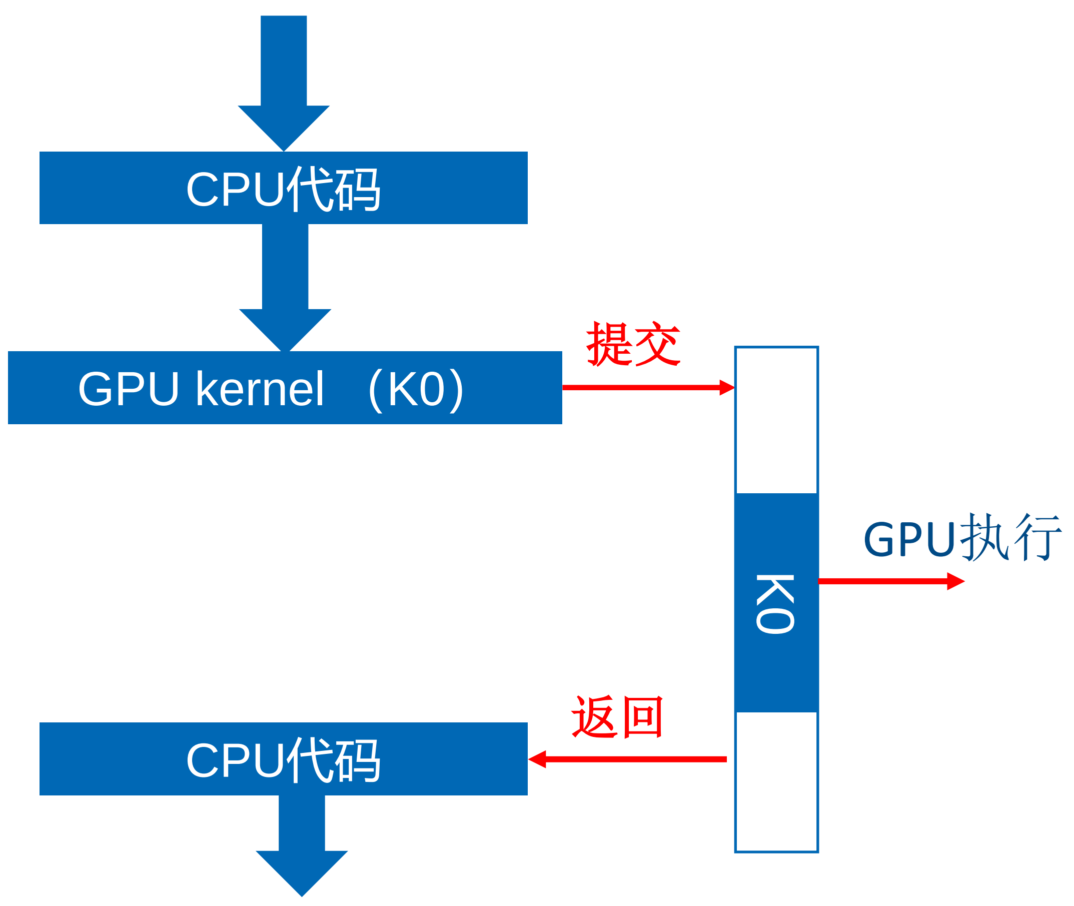
异构计算与异步计算

```
// Copy from host(CPU) to device(GPU)
my_gpu_queue.memcpy(device_mem, host_mem, N * sizeof(int)).wait();
```

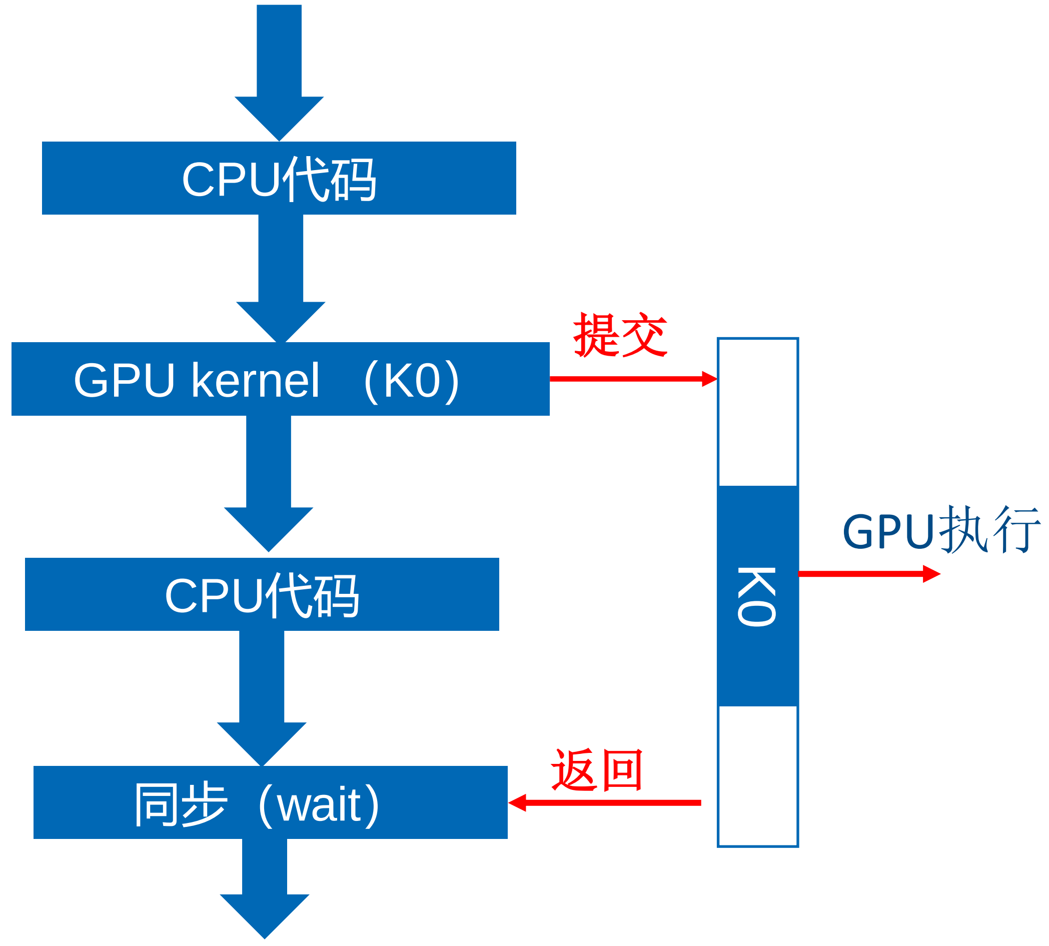
```
Selected GPU device: Intel(R) Iris(R) Xe MAX Graphics [0x4905]

 Start CPU Computation, Number of Elems = 10000000

 CPU Computation,   Time = 5.699950

 GPU Computation,   Time = 1.552332

 Total Computation, TIme = 7.252606
```

```
// Copy back from GPU to CPU
my_gpu_queue.memcpy(host_mem, device_mem, N * sizeof(int)).wait();
```

异构计算 + 异步计算



Time = CPU + GPU



Time = max(CPU, GPU)

Async Results

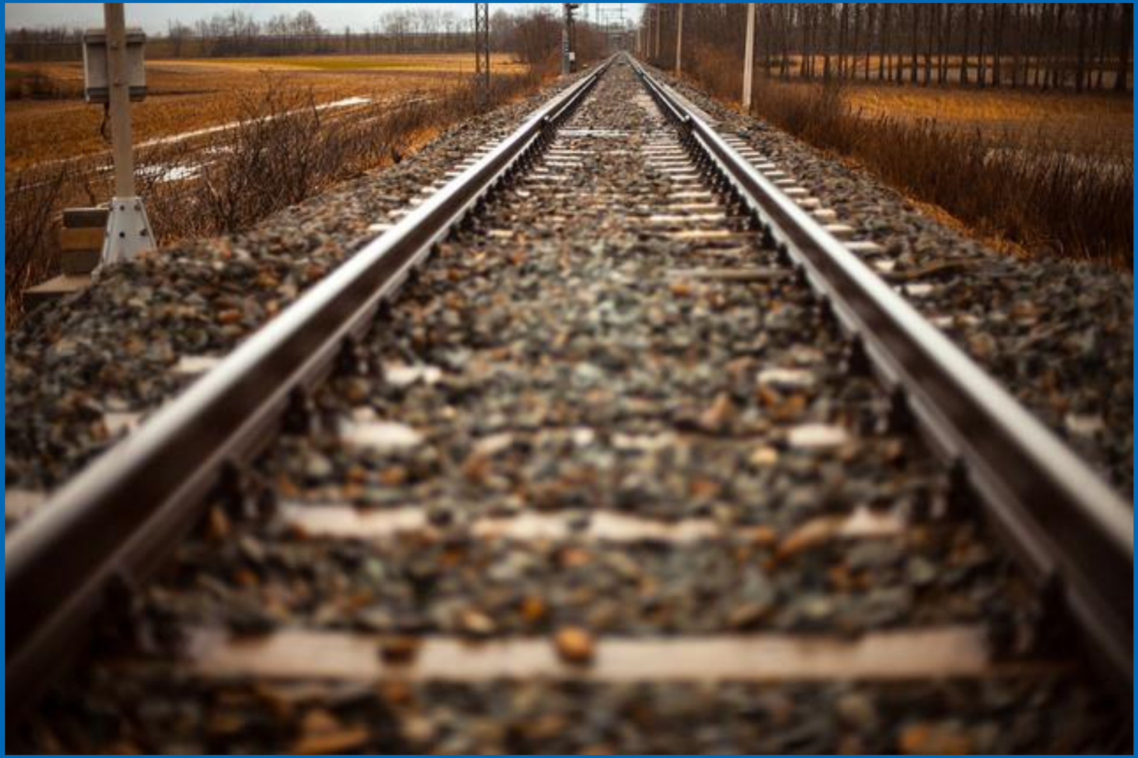
```
Selected GPU device: NVIDIA A100-PCIE-40GB

Start CPU Computation, Number of Elems = 10000000

CPU Computation, Time = 3.116137

GPU Computation, Time = 3.141288

Total Computation, TIme = 3.141403

Task Done!
```

Why?

小结

- 理解异构计算的核心思想
- 能够实现简单的并行内核
- 具有系统和内核层性能分析的能力

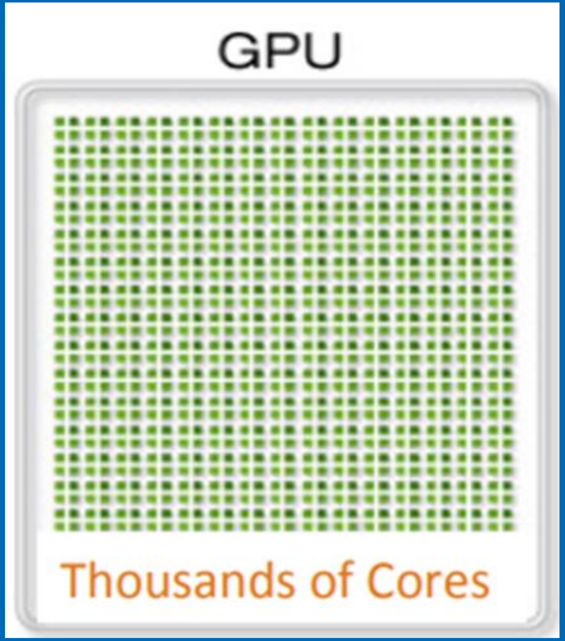
执行模型



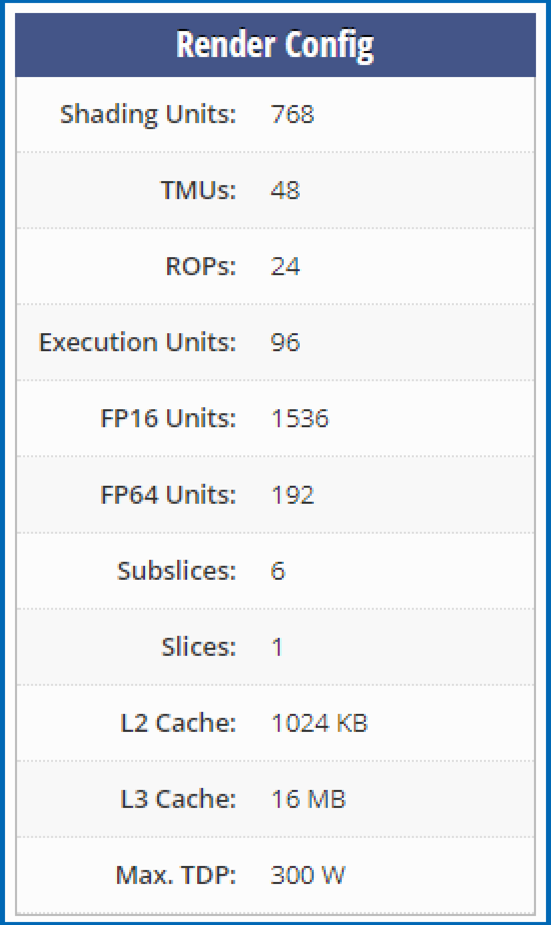
http://alana.io/downloads/rails-3/

深入思考

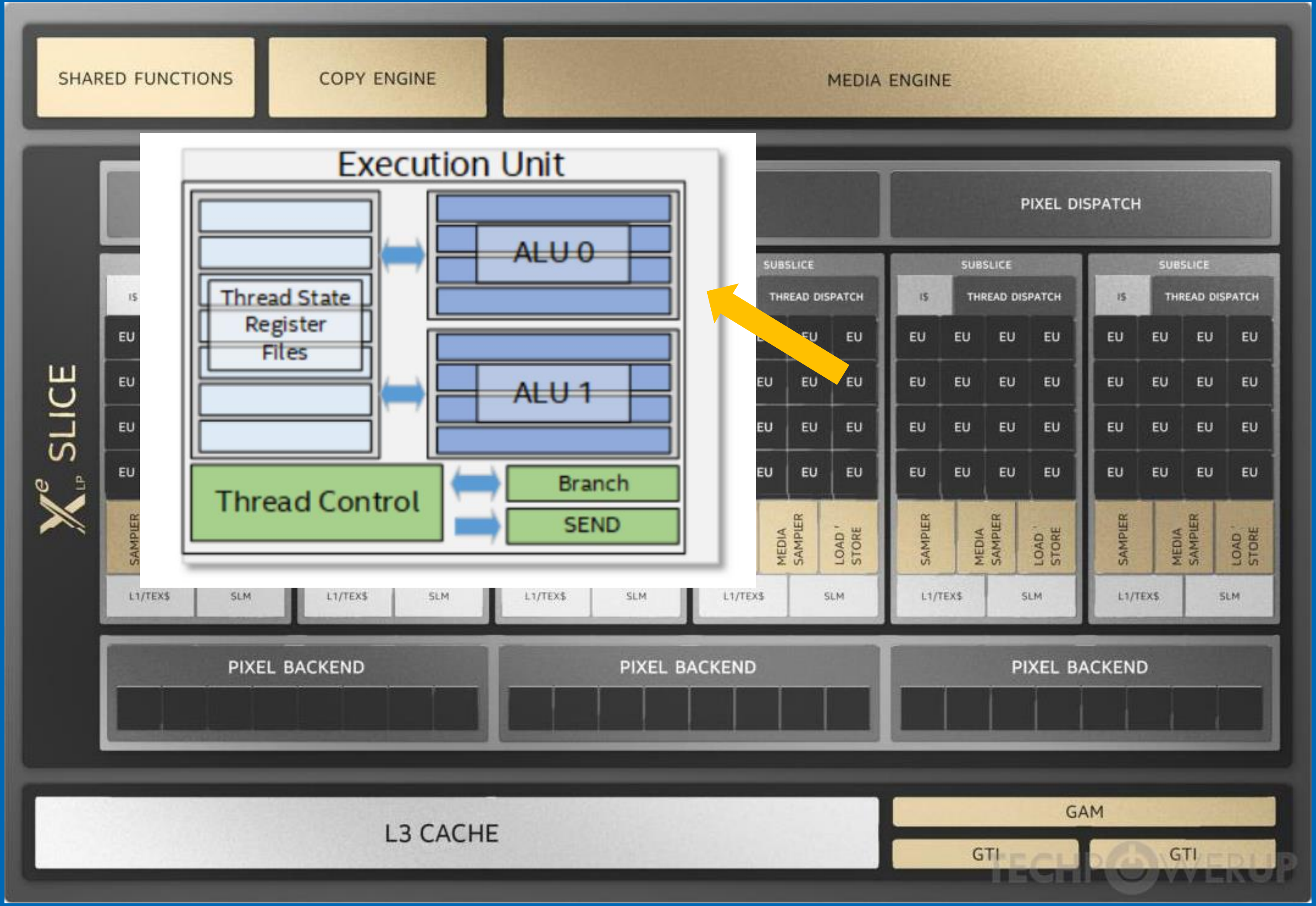
- GPU是如何工作的?
- parallel_for是如何工作的?
- 任务如何映射到GPU上的?
- 我们如何控制任务的划分?



英特尔® DG1 GPU架构



Render Config	
Shading Units:	768
TMUs:	48
ROPs:	24
Execution Units:	96
FP16 Units:	1536
FP64 Units:	192
Subslices:	6
Slices:	1
L2 Cache:	1024 KB
L3 Cache:	16 MB
Max. TDP:	300 W



DPC++任务粒度

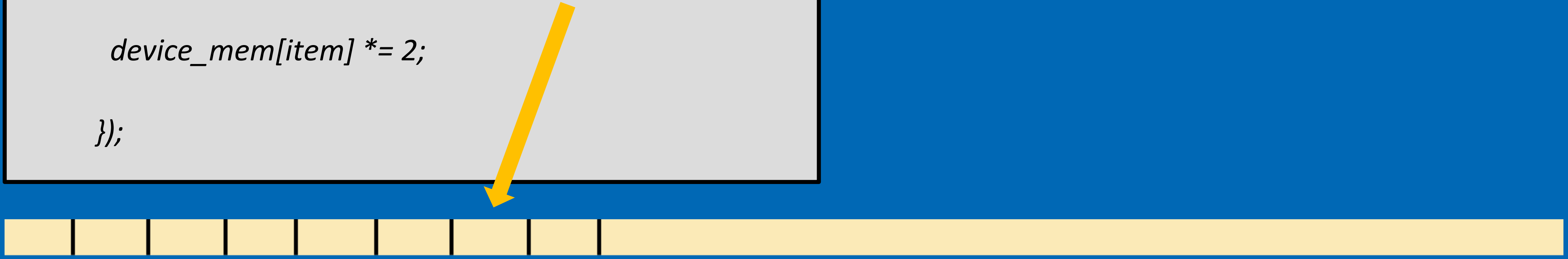
Work-item：

最基本的计算粒度，会被映射到ALU上执行

Work-group：

组织一定数量的work-item同时执行，会被调度到同一个subslice，其中的work-time共享一定的资源，能进行组内协同

```
h.parallel_for(range{N}, [=](id<1> item) {
    device_mem[item] *= 2;
  });
```

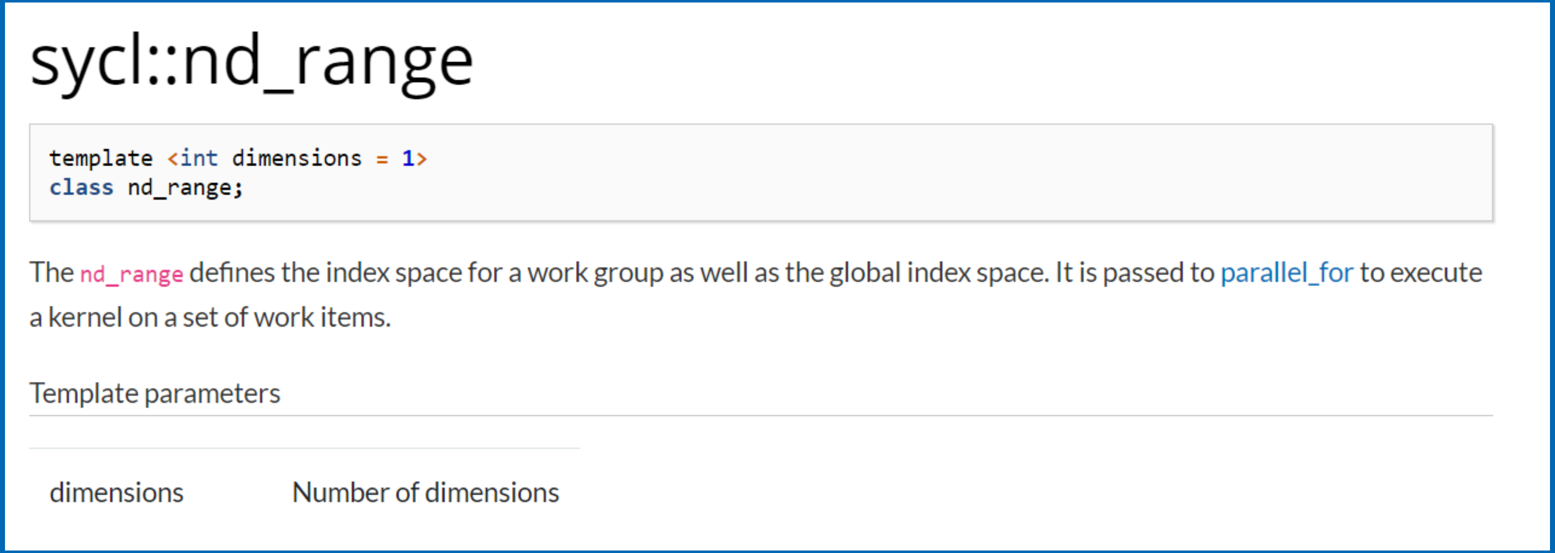


显示设定计算粒度

基本并行内核是实现 for-loop 并行化的简便方法，但缺少精确的控制能力

ND-Range 内核参数是一种增强的并行表达方法

- 更精确的任务划分控制
- 将任务的执行和硬件的计算单元所对应



sycl::nd_range

```
template <int dimensions = 1>
class nd_range;
```

The nd_range defines the index space for a work group as well as the global index space. It is passed to parallel_for to execute a kernel on a set of work items.

Template parameters

dimensions	Number of dimensions

https://docs.oneapi.io/versions/latest/dpcpp/iface/nd_range.html#nd-range

ND-Range 内核

ND_Range 内核的功能通过 nd_range 和 nd_item 展现

- nd_range 类表示使用每个工作组的全局执行范围和本地执行范围的分组执行范围

```
h.parallel_for(range{N}, [=](id<1> item) {

    device_mem[item] *= 2;

  });
```

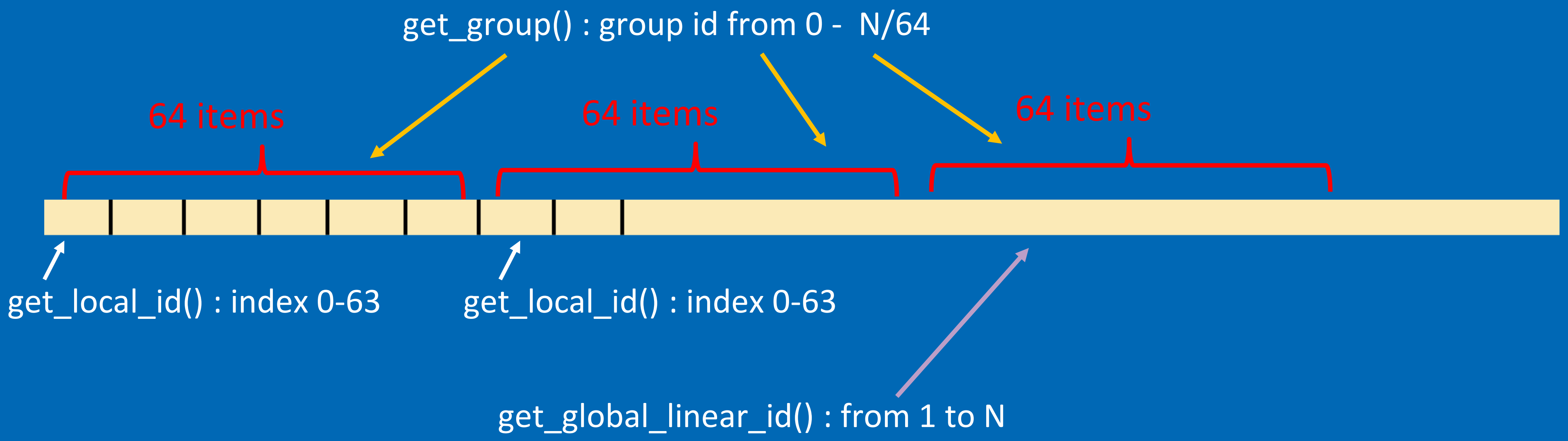
How many work-item in each work-group?

How many work-group will be generated?

```
h.parallel_for(nd_range<1>(N,  64), [=](nd_item<1> item){

   auto idx = item.....;

     device_mem[idx] *= 2;

});
```

nd_item 类表示内核函数的单个实例，并允许查询工作组范围和索引。

```
h.parallel_for(nd_range<1>(N,  64), [=](nd_item<1> item){
      auto idx = item. (    check if you understand );
      device_mem[idx] *= 2;
});
```

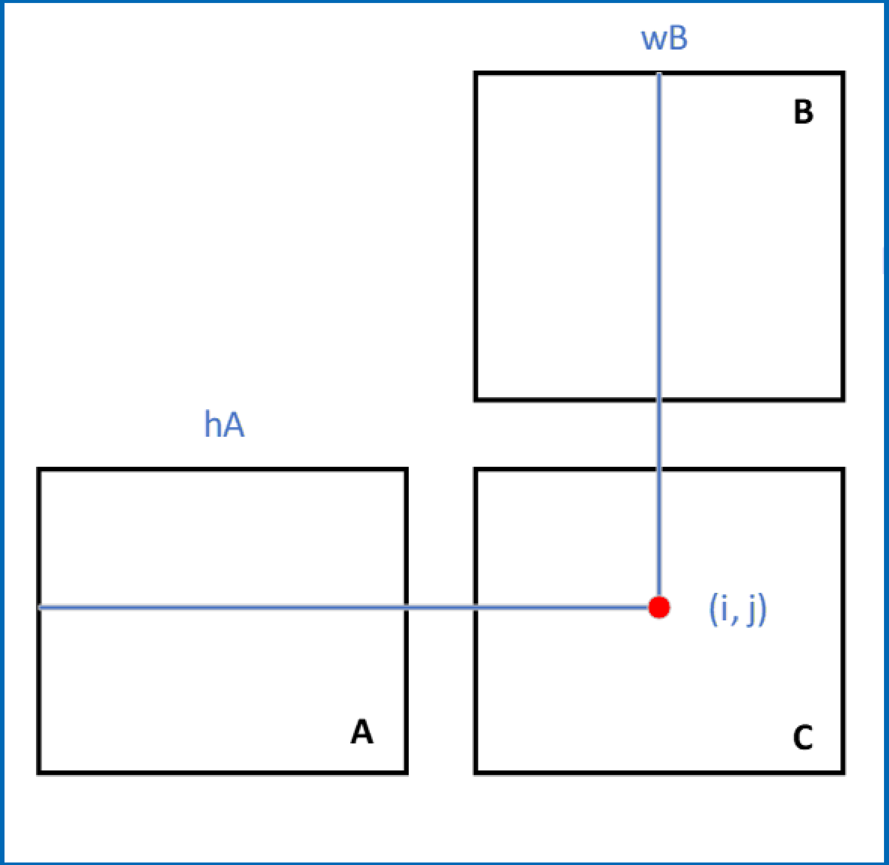

get_group() : group id from 0 - N/64
64 items
64 items
64 items
get_local_id() : index 0-63
get_local_id() : index 0-63
get_global_linear_id() : from 1 to N

Example: GEMM

Let’s show how strong you are!

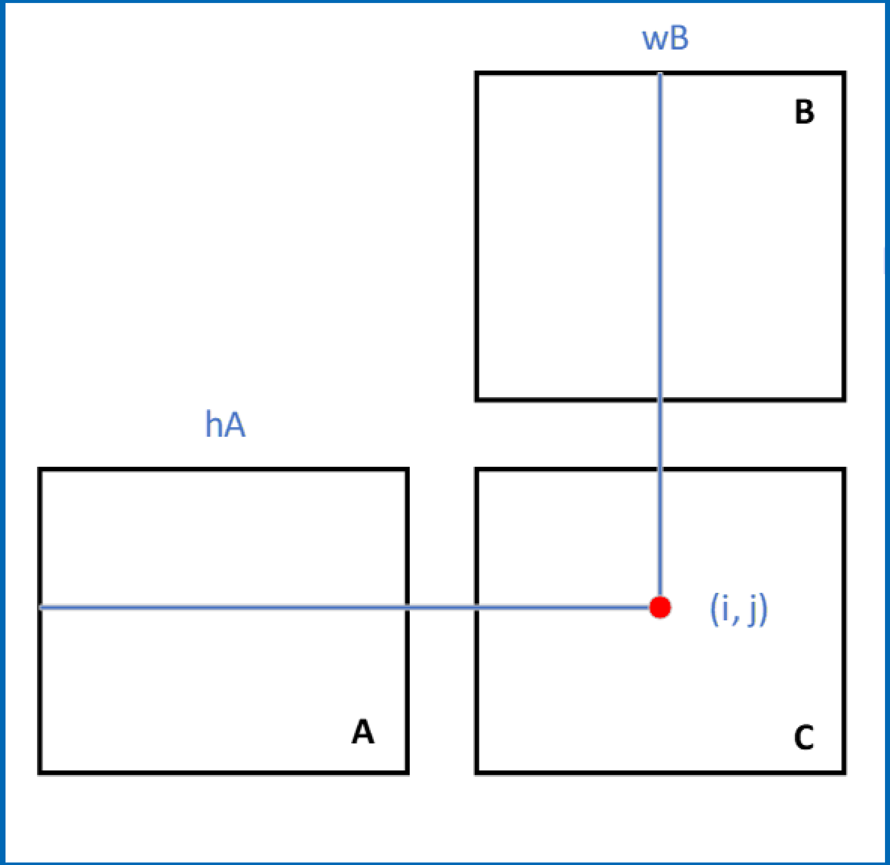
C[i][j] += A[i][hA] * B[hB][j]

```
for (i = 0; i < M; ++i)
    for (j = 0; j < N; ++j)
        for (k = 0; k < L; ++k)
            c[i][j] += a[i][k] * b[k][j];
```

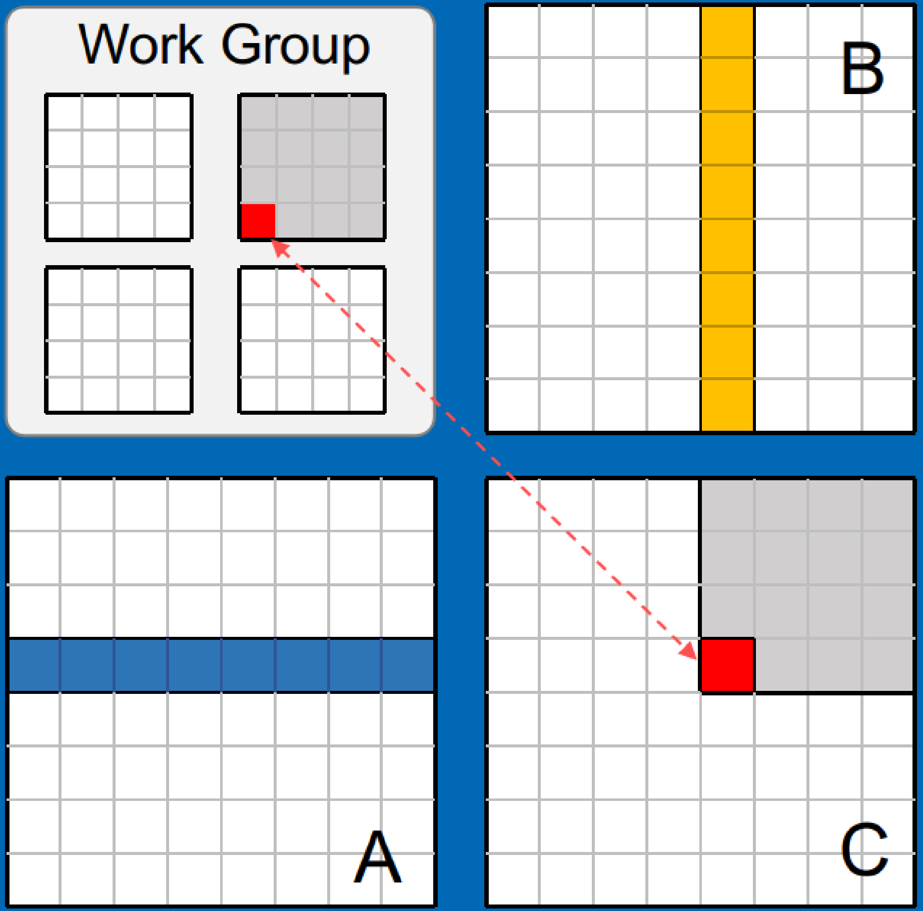


GEMM: CPU Version

```
// Single Thread Computation in CPU
for(int i = 0; i < M; i++) {
   for(int j = 0; j < N; j++) {
      float sum = 0.0f;
      for(int k = 0; k < K; k++) {
         sum +=  cA[i * K + k] * cB[k * N  + j];
      }
      cC[i * N + j] = sum;
   }
}
```



GEMM: GPU version

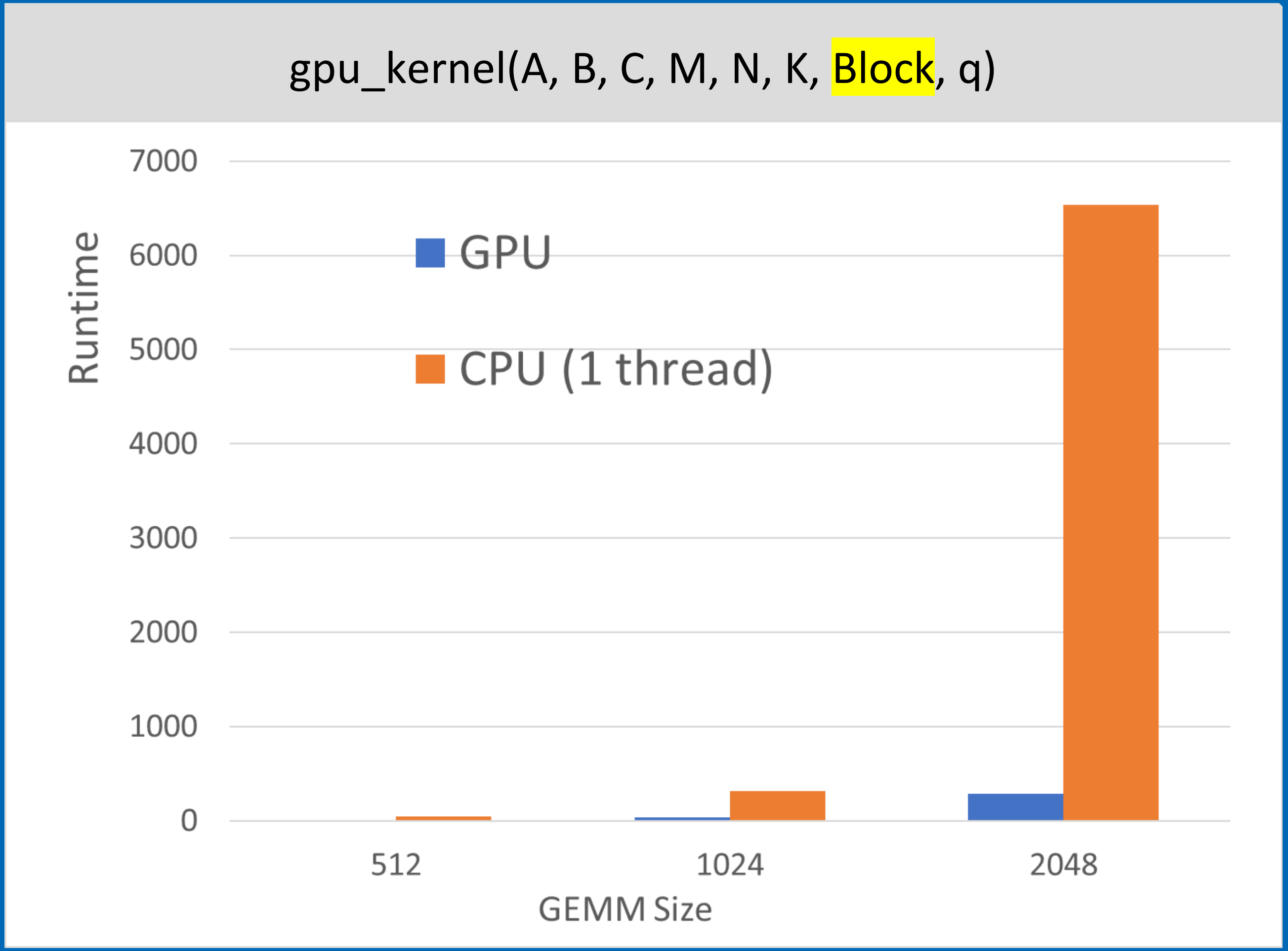


https://github.com/pengzhao-intel/oneAPI_course/blob/main/code/gemm_basic.cpp

```
// define the workgroup size and mapping
 auto grid_rows = (M + block_size - 1) / block_size * block_size;
 auto grid_cols = (N + block_size - 1) / block_size * block_size;
 auto local_ndrange  = range<2>(block_size, block_size);
 auto global_ndrange = range<2>(grid_rows, grid_cols);

 auto e = q.submit([&](sycl::handler &h) {
   h.parallel_for<class k_name_t>(
     sycl::nd_range<2>(global_ndrange, local_ndrange),
                              [=](sycl::nd_item<2> index) {
       int row = index.get_global_id(0);
       int col = index.get_global_id(1);
       float sum = 0.0f;
       for (int i = 0; i < K; i++) {
        sum += A[row * K + i] * B[i * N  + col];
       }
       C[row * N + col] = sum;
     });
 });
 e.wait();
```

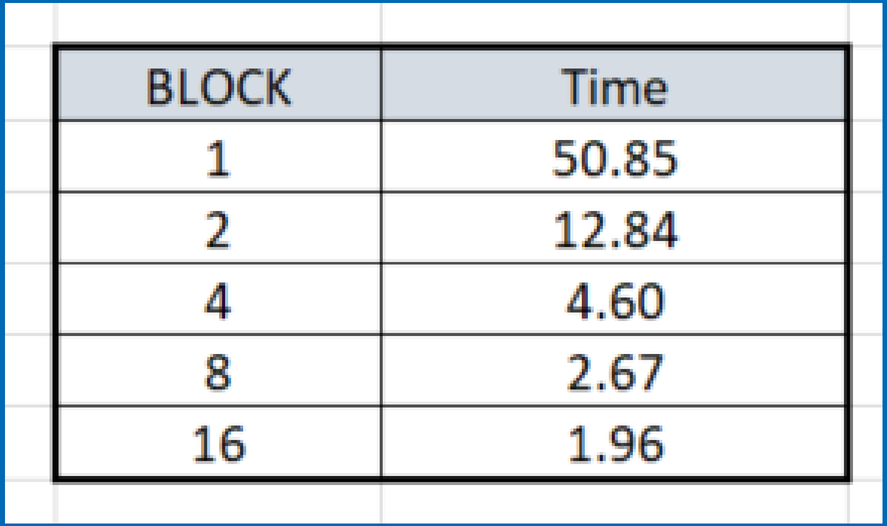
Performance

- GPU kernel used 4x4 Block
- CPU reference code:
  - only 1 thread,
  - could be improved by multi-threads

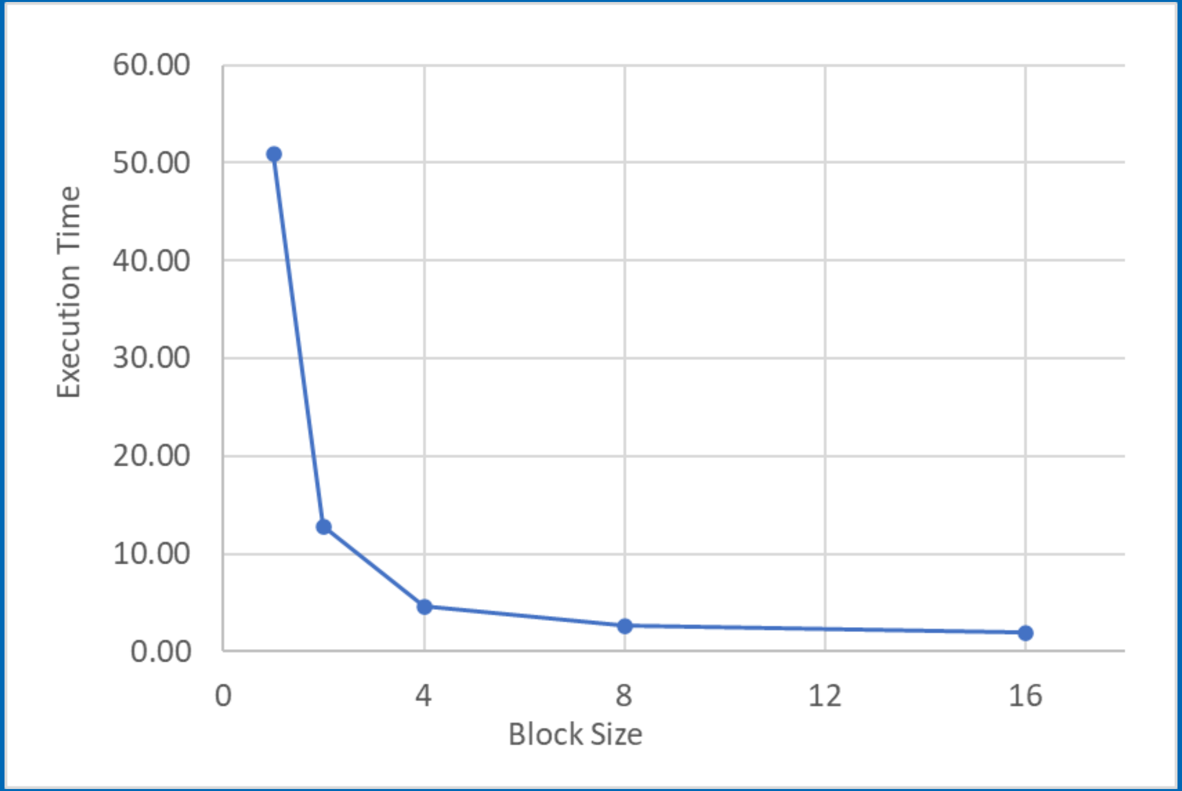


使用率与效率（Occupancy/Efficiency）

Work-group的大小和性能的关系？



BLOCK	Time
1	50.85
2	12.84
4	4.60
8	2.67
16	1.96



Tips

It’s importance to have enough workgroups in GPU

- Scale on different GPUs, say from DG1 to DG2
- Thread switch to make GPU busy

It’s importance to have enough work-item in each Work-group

- Scale on SIMD lane, from 8 to 16, 32
- Better vectorization

Big workgroup ≠ Enough workgroups

实验课

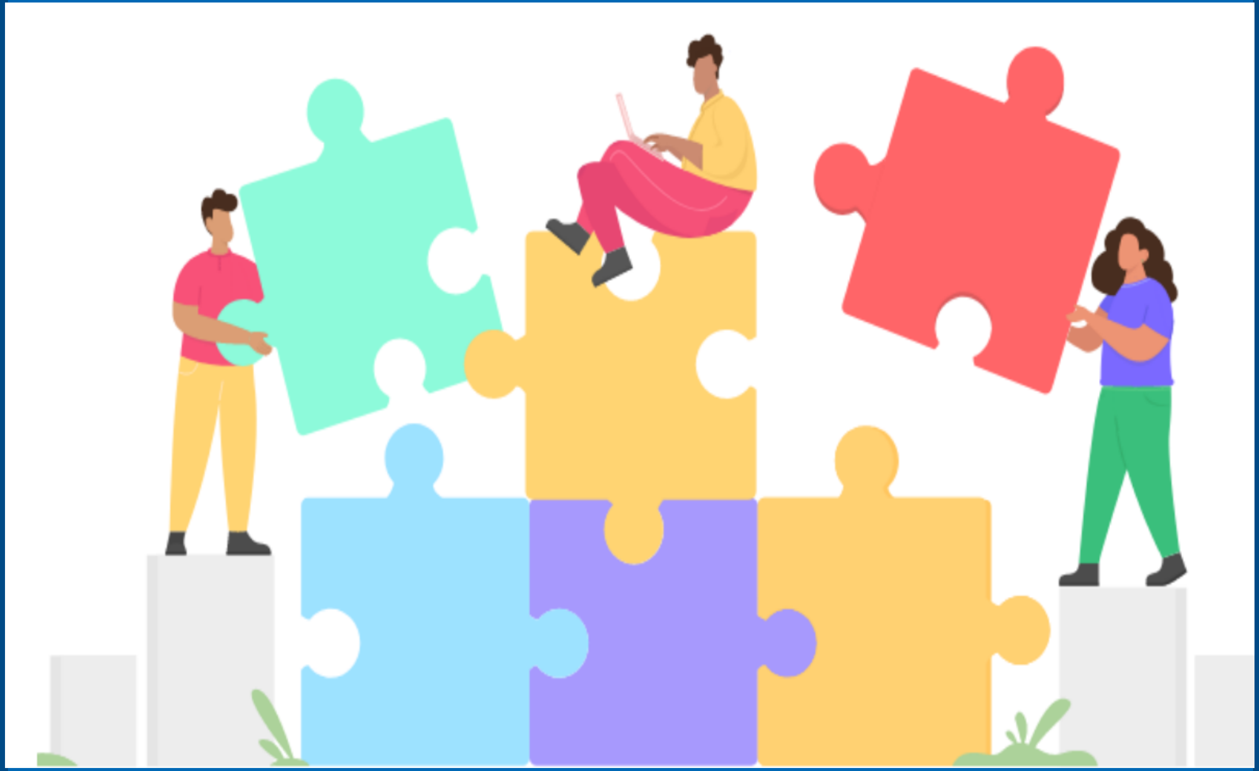
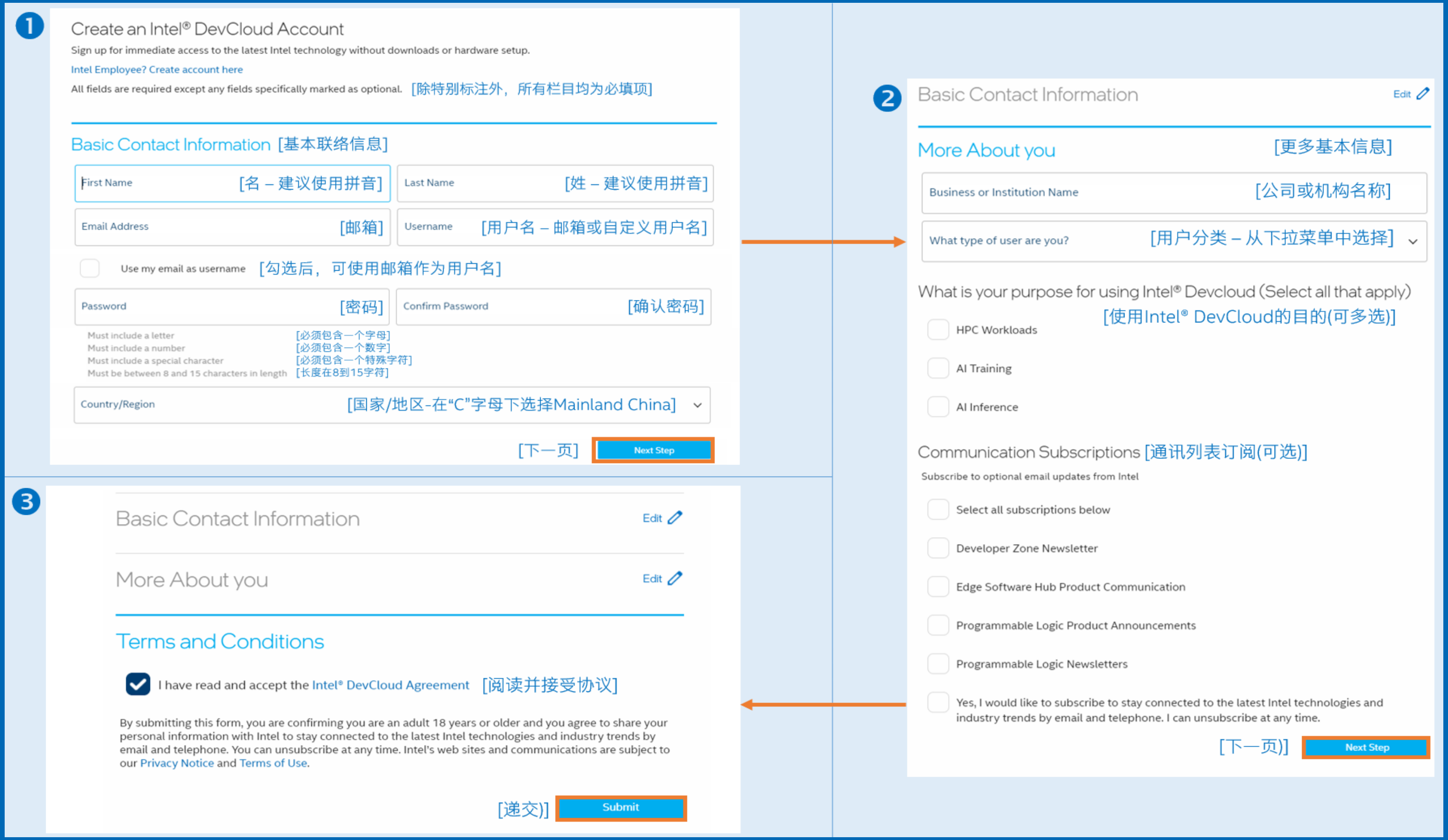


Image Source: https://www.vmaker.com/blog/tags/team-collaboration/

DEVCLOUD环境配置

https://devcloud.intel.com/oneapi/



1

Create an Intel® DevCloud Account

Sign up for immediate access to the latest Intel technology without downloads or hardware setup.

Intel Employee? Create account here

All fields are required except any fields specifically marked as optional. [除特别标注外，所有栏目均为必填项]

Basic Contact Information [基本联络信息]

First Name [名 – 建议使用拼音]	Last Name [姓 – 建议使用拼音]
Email Address [邮箱]	Username [用户名 – 邮箱或自定义用户名]

Use my email as username [勾选后，可使用邮箱作为用户名]

Password [密码]	Confirm Password [确认密码]

Must include a letter	[必须包含一个字母]
Must include a number	[必须包含一个数字]
Must include a special character	[必须包含一个特殊字符]
Must be between 8 and 15 characters in length	[长度在8到15字符]

Country/Region [国家/地区-在“C”字母下选择Mainland China]

[下一页] Next Step

2

Basic Contact Information Edit

More About you [更多基本信息]

Business or Institution Name [公司或机构名称]

What type of user are you? [用户分类 – 从下拉菜单中选择]

What is your purpose for using Intel® Devcloud (Select all that apply) [使用Intel® DevCloud的目的(可多选)]

- HPC Workloads
- AI Training
- AI Inference

Communication Subscriptions [通讯列表订阅(可选)]

Subscribe to optional email updates from Intel

- Select all subscriptions below
- Developer Zone Newsletter
- Edge Software Hub Product Communication
- Programmable Logic Product Announcements
- Programmable Logic Newsletters
- Yes, I would like to subscribe to stay connected to the latest Intel technologies and industry trends by email and telephone. I can unsubscribe at any time.

[下一页)] Next Step

3

Basic Contact Information Edit

More About you Edit

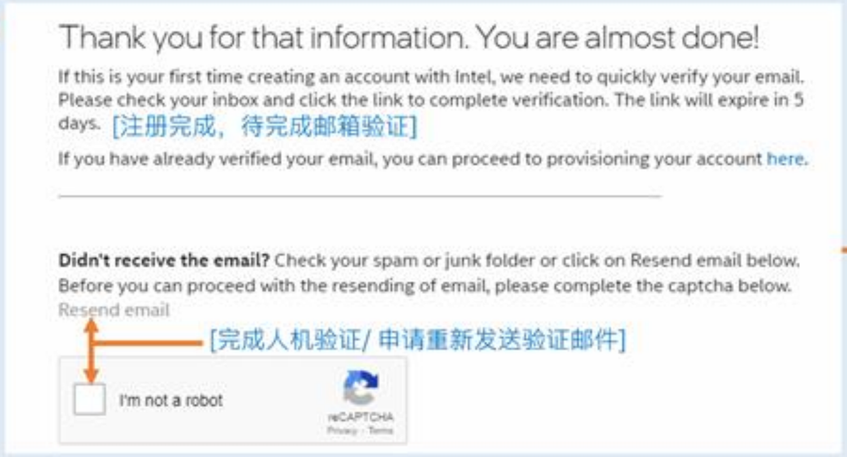
Terms and Conditions

[✓] I have read and accept the Intel® DevCloud Agreement [阅读并接受协议]

By submitting this form, you are confirming you are an adult 18 years or older and you agree to share your personal information with Intel to stay connected to the latest Intel technologies and industry trends by email and telephone. You can unsubscribe at any time. Intel's web sites and communications are subject to our Privacy Notice and Terms of Use.

[递交)] Submit

4



Thank you for that information. You are almost done!

If this is your first time creating an account with Intel, we need to quickly verify your email. Please check your inbox and click the link to complete verification. The link will expire in 5 days. [注册完成，待完成邮箱验证]

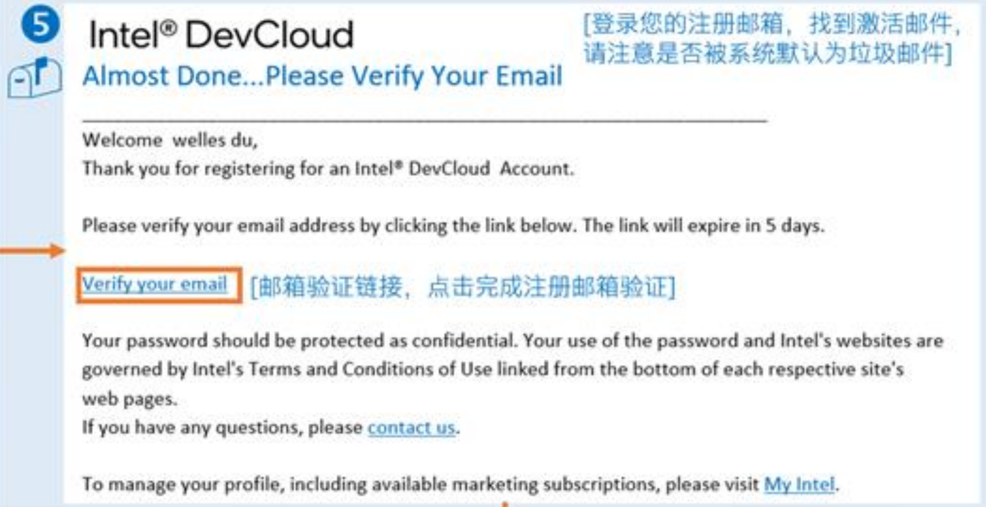
If you have already verified your email, you can proceed to provisioning your account here.

Didn't receive the email? Check your spam or junk folder or click on Resend email below. Before you can proceed with the resending of email, please complete the captcha below.

Resend email

[完成人机验证/ 申请重新发送验证邮件]

5



Intel® DevCloud

Almost Done...Please Verify Your Email

[登录您的注册邮箱，找到激活邮件，请注意是否被系统默认为垃圾邮件]

Welcome welles du,

Thank you for registering for an Intel® DevCloud Account.

Please verify your email address by clicking the link below. The link will expire in 5 days.

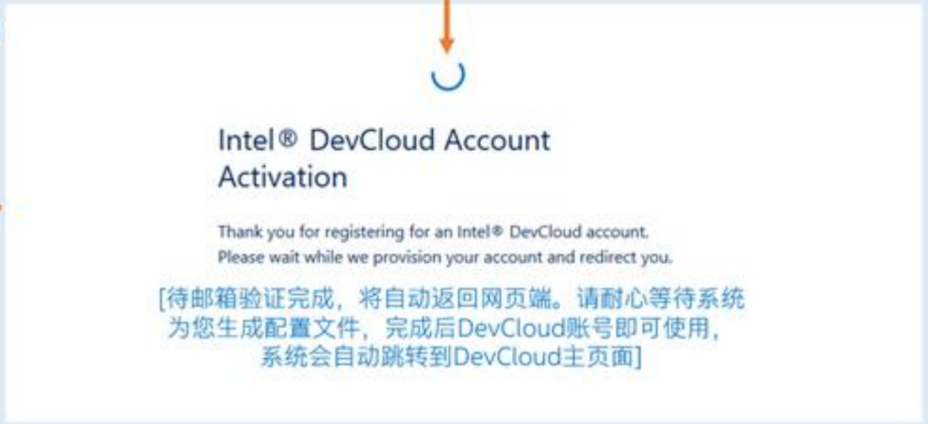
Verify your email [邮箱验证链接，点击完成注册邮箱验证]

Your password should be protected as confidential. Your use of the password and Intel's websites are governed by Intel's Terms and Conditions of Use linked from the bottom of each respective site's web pages.

If you have any questions, please contact us.

To manage your profile, including available marketing subscriptions, please visit My Intel.

6



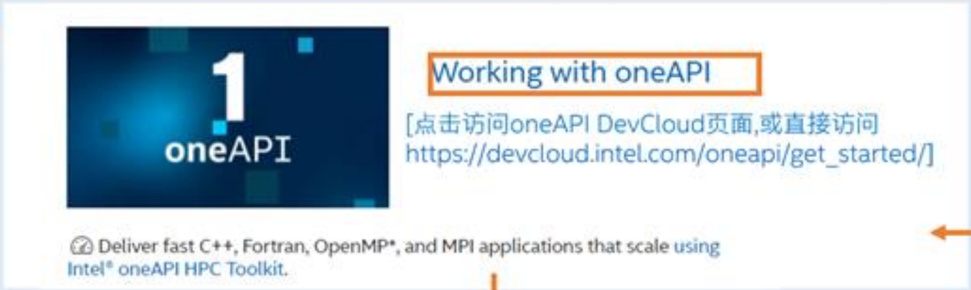
Intel® DevCloud Account Activation

Thank you for registering for an Intel® DevCloud account.

Please wait while we provision your account and redirect you.

[待邮箱验证完成，将自动返回网页端。请耐心等待系统为您生成配置文件，完成后DevCloud账号即可使用，系统会自动跳转到DevCloud主页面]

7

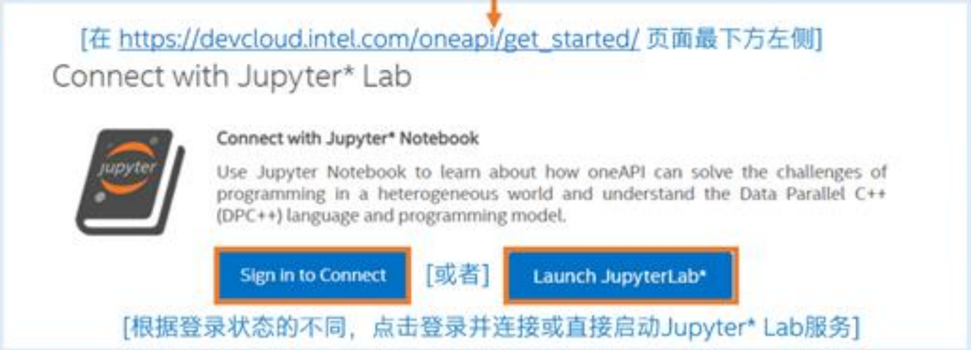


Working with oneAPI

[点击访问oneAPI DevCloud页面,或直接访问 https://devcloud.intel.com/oneapi/get_started/]

Deliver fast C++, Fortran, OpenMP*, and MPI applications that scale using Intel® oneAPI HPC Toolkit.

8



[在 https://devcloud.intel.com/oneapi/get_started/ 页面最下方左侧]

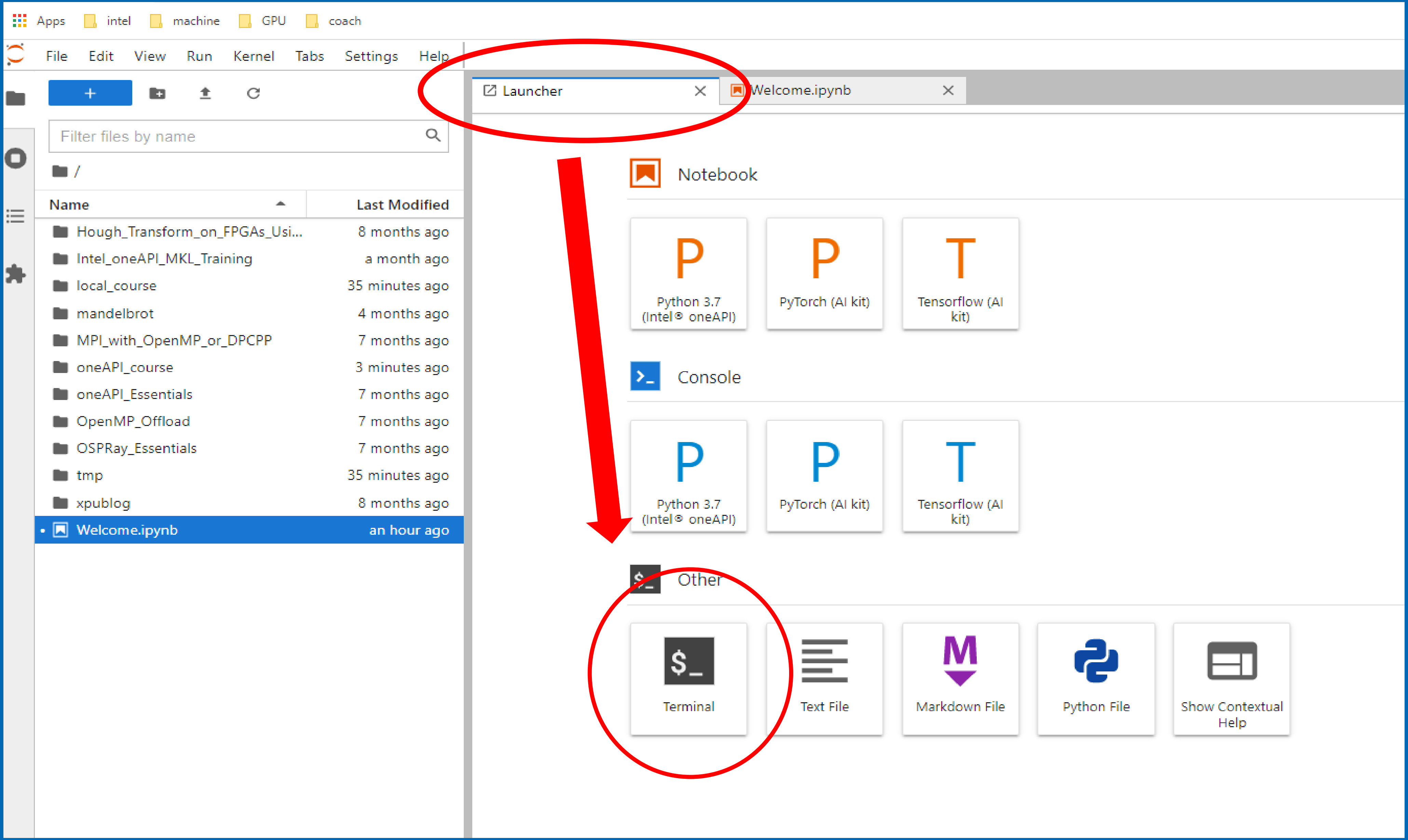
Connect with Jupyter* Lab

Connect with Jupyter* Notebook

Use Jupyter Notebook to learn about how oneAPI can solve the challenges of programming in a heterogeneous world and understand the Data Parallel C++ (DPC++) language and programming model.

Sign in to Connect [或者] Launch JupyterLab*

[根据登录状态的不同，点击登录并连接或直接启动Jupyter* Lab服务]



Apps intel machine GPU coach

File Edit View Run Kernel Tabs Settings Help

Launcher | Welcome.ipynb

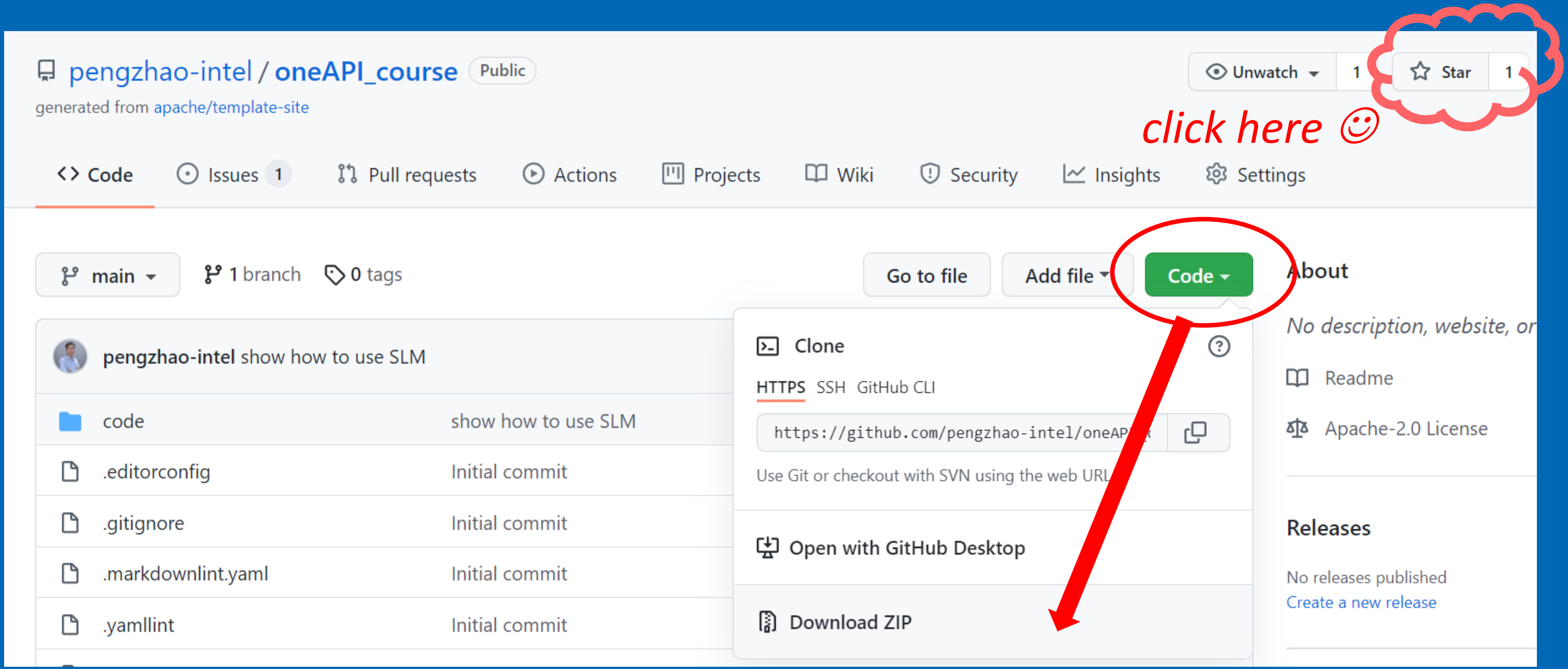
Filter files by name

/

Name	Last Modified
Hough_Transform_on_FPGAs_Usi...	8 months ago
Intel_oneAPI_MKL_Training	a month ago
local_course	35 minutes ago
mandelbrot	4 months ago
MPI_with_OpenMP_or_DPCPP	7 months ago
oneAPI_course	3 minutes ago
oneAPI_Essentials	7 months ago
OpenMP_Offload	7 months ago
OSPRay_Essentials	7 months ago
tmp	35 minutes ago
xpublog	8 months ago
Welcome.ipynb	an hour ago

Download Example Code

https://github.com/pengzhao-intel/oneAPI_course/tree/main/code



pengzhao-intel / oneAPI_course Public

generated from apache/template-site

Unwatch 1 | Star 1

Code | Issues 1 | Pull requests | Actions | Projects | Wiki | Security | Insights | Settings

main | 1 branch | 0 tags | Go to file | Add file | Code

pengzhao-intel show how to use SLM

code	show how to use SLM
.editorconfig	Initial commit
.gitignore	Initial commit
.markdownlint.yaml	Initial commit
.yamllint	Initial commit

Clone

HTTPS SSH GitHub CLI

https://github.com/pengzhao-intel/oneAPI

Use Git or checkout with SVN using the web URL.

Open with GitHub Desktop

Download ZIP

About

No description, website, or

Readme

Apache-2.0 License

Releases

No releases published

Create a new release

Access GPU node

- Download code into DevCloud by git or upload manually

```
git clone https://github.com/pengzhao-intel/oneAPI_course
```

- Compiler Code and Execute

```
dpcpp basic_parafor.cpp –o a.out
```

Access GPU node

- Get machine with interactive mode

```
qsub -I -l nodes=1:iris_xe_max:ppn=2 -d .
```

- Submit Job to node

```
qsub -l nodes=1:iris_xe_max:ppn=2 run.sh
```

Part I, Familiar with DevClould (20 min)

1. clinfo: machine information

2. Basic Linux Commands

3. Compiler first DPC++ Program

   - run local by changing device

4. pbsnodes, check available nodes

5. Create a shell file, submit to GPU and check results

Part II, Modify DPC++ code (30 min)

1. Review basic_parafor.cpp

2. Change memory type to share

3. Create new file, vector_add.cpp

   - change code and complete the kernel

   - using ND_range

实验课练习

1. 改写gemm_basic代码26，27行，利用work group和local work item的坐标来计算global坐标

https://github.com/pengzhao-intel/oneAPI_course/blob/main/code/gemm_basic.cpp#L26

2. 修改程序输入数据的大小，设定非M=N=K=2000，修改程序，并使其通过正确性测试

https://github.com/pengzhao-intel/oneAPI_course/blob/main/code/gemm_basic.cpp#L154

编程作业：Cross Entropy

Log Softmax

$$y_i = \log \frac{\exp(x_i)}{\sum_j \exp(x_j)}$$

$$= \log \frac{\exp(x_i)}{\exp(x_{max}) \sum_j \exp(x_j - x_{max})}$$

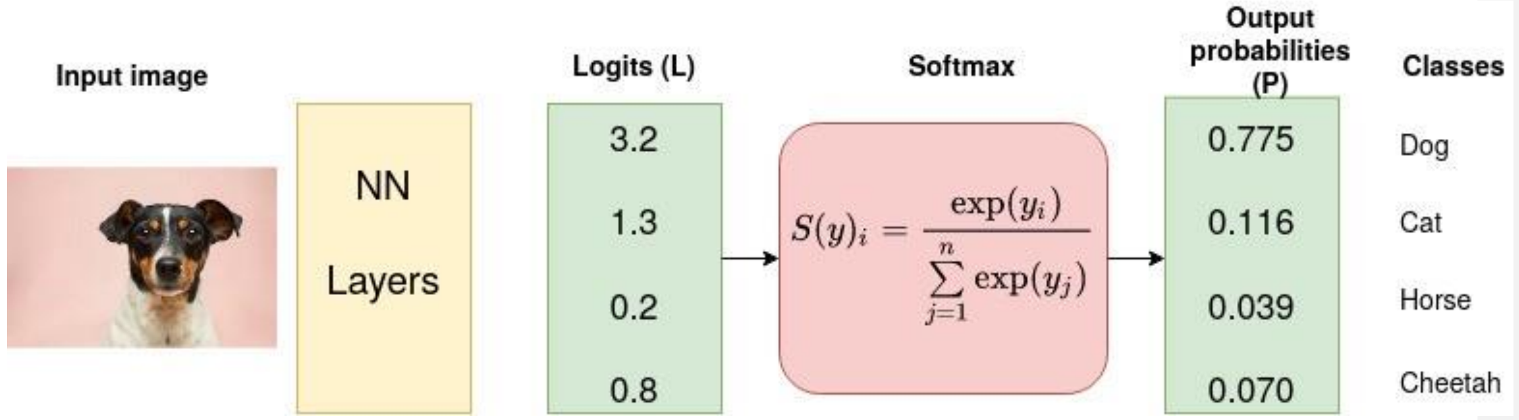
$$= x_i - x_{max} - \log \sum_j \exp(x_j - x_{max})$$

Select

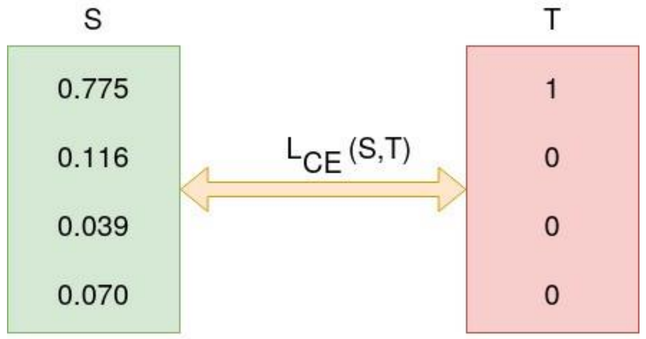
m[i] = y$[mask[i]][i]$

Update

loss[i] = - m[i] * weight[i]

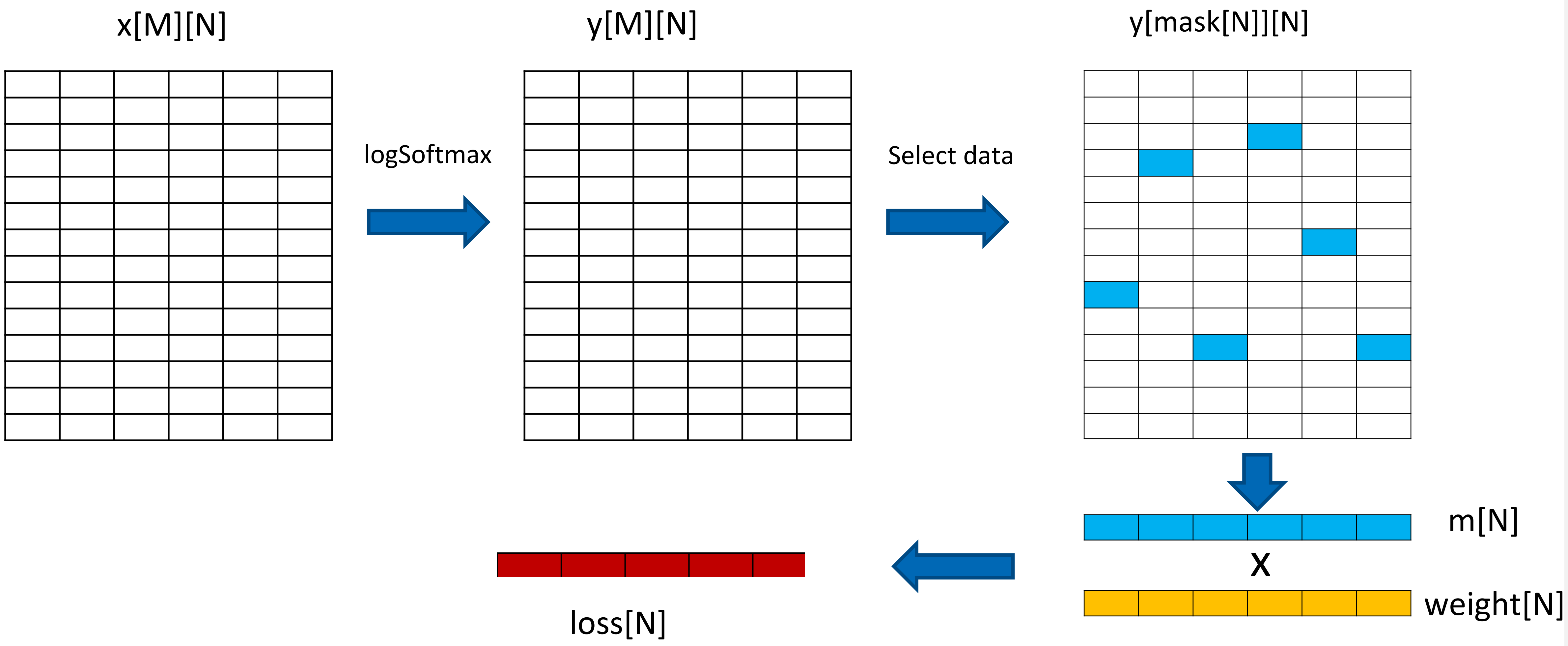


Softmax(X)



Cross Entropy (L)

二维输入X，计算流程如下：



题目

- 输入

  三维输入x[K][M][N]， K=128, M=32, N=8192， 其中K为batchsize，M为category，N为feature

  二维坐标数组mask[K][N], 权重数组weight[K][N]

- K维度相互独立，在每一个面做上述二维的cross entropy计算
- 最终结果为二维数组loss[K][N]
- 设计相应的GPU程序，要求结果和CPU计算结果误差绝对值在0.001之内
- 用时间来衡量程序的性能，越小越好

intel®

SPMD (Single Program Multiple Data)

单指令多线程（SIMT），一种基于线程视角的数据处理模式，每个线程处理一个数据，但是这些线程共享同一条指令。优点是多线程模式更加灵活，不需要数据的连续性，适合做数据的收集和分发（gather/scatter）操作，但是如果线程中有分支，效率会收到很大影响。