CUDA高性能科学计算

2023-2024-1 秋季

公选-06110

Lecture 7

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授课平台/讨论QQ群

CUDA高性能科学计算(GX)
课程编号:107016


加速计算基础——CUDA C/C++
8 学时 | 中文 | 90 美元 | C/C++，CUDA ®
有培训证书

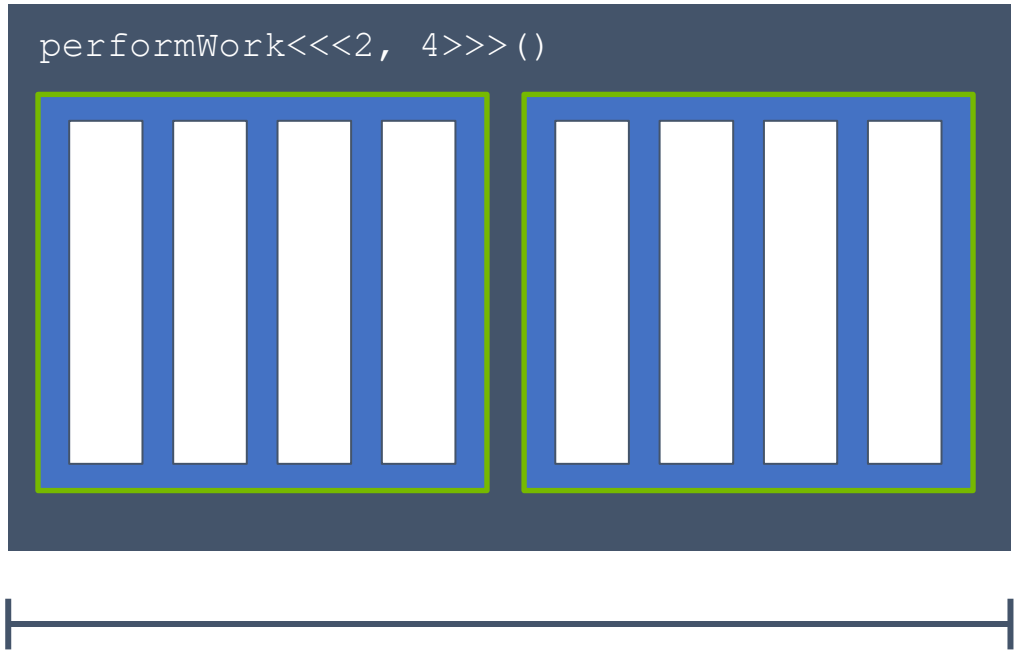
复习

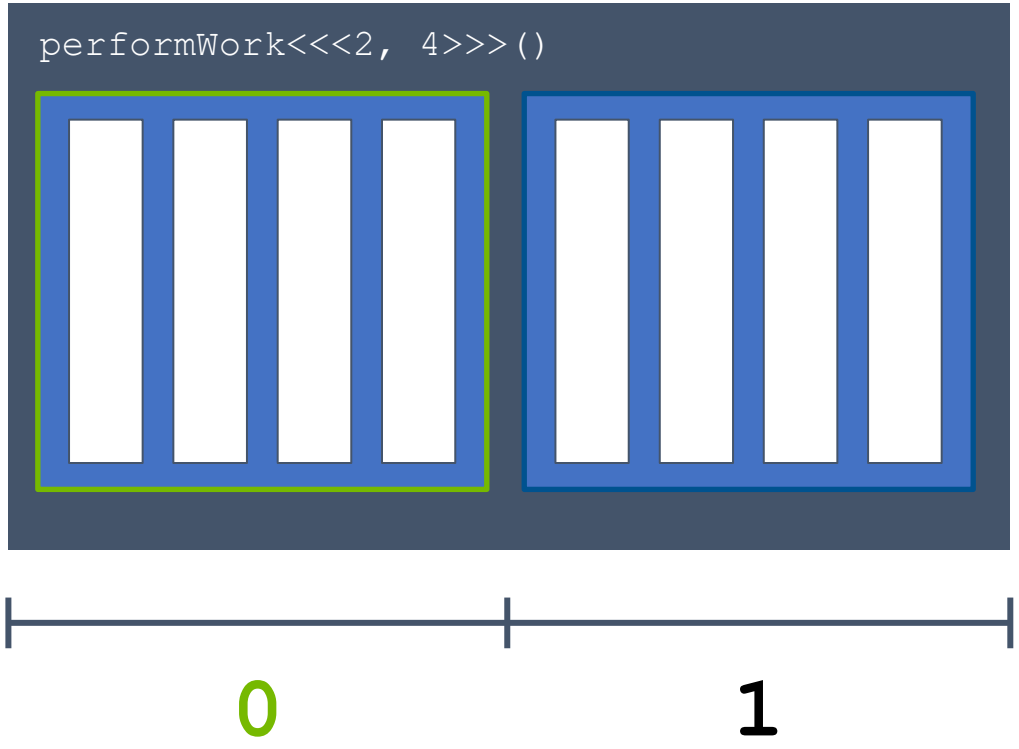
- 核函数 __global__
- 内存分配 cudaMallocManaged
- 执行启动配置
- 跨网格循环
- 改写CPU循环为GPU循环
- 错误处理

复习

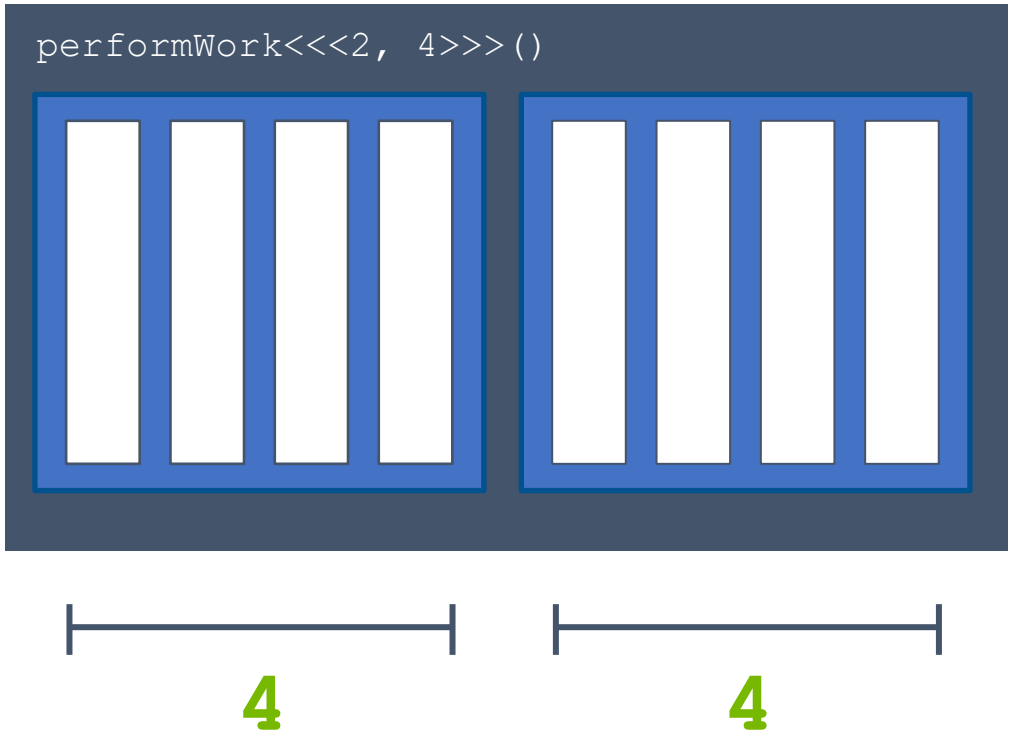
- CUDA 提供的线程层次结构变量
- 协调并行线程
- 网格大小工作量不匹配
- 网格跨度循环
- 错误处理

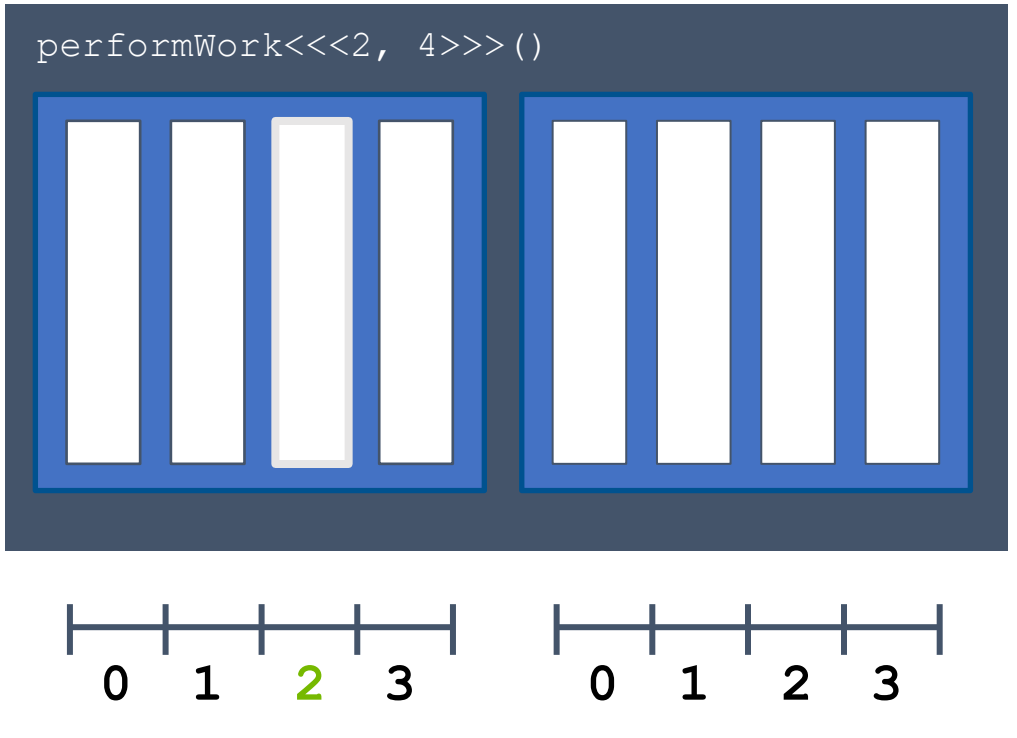
CUDA 提供的线程层次结构变量





CUDA 提供的线程层次结构变量





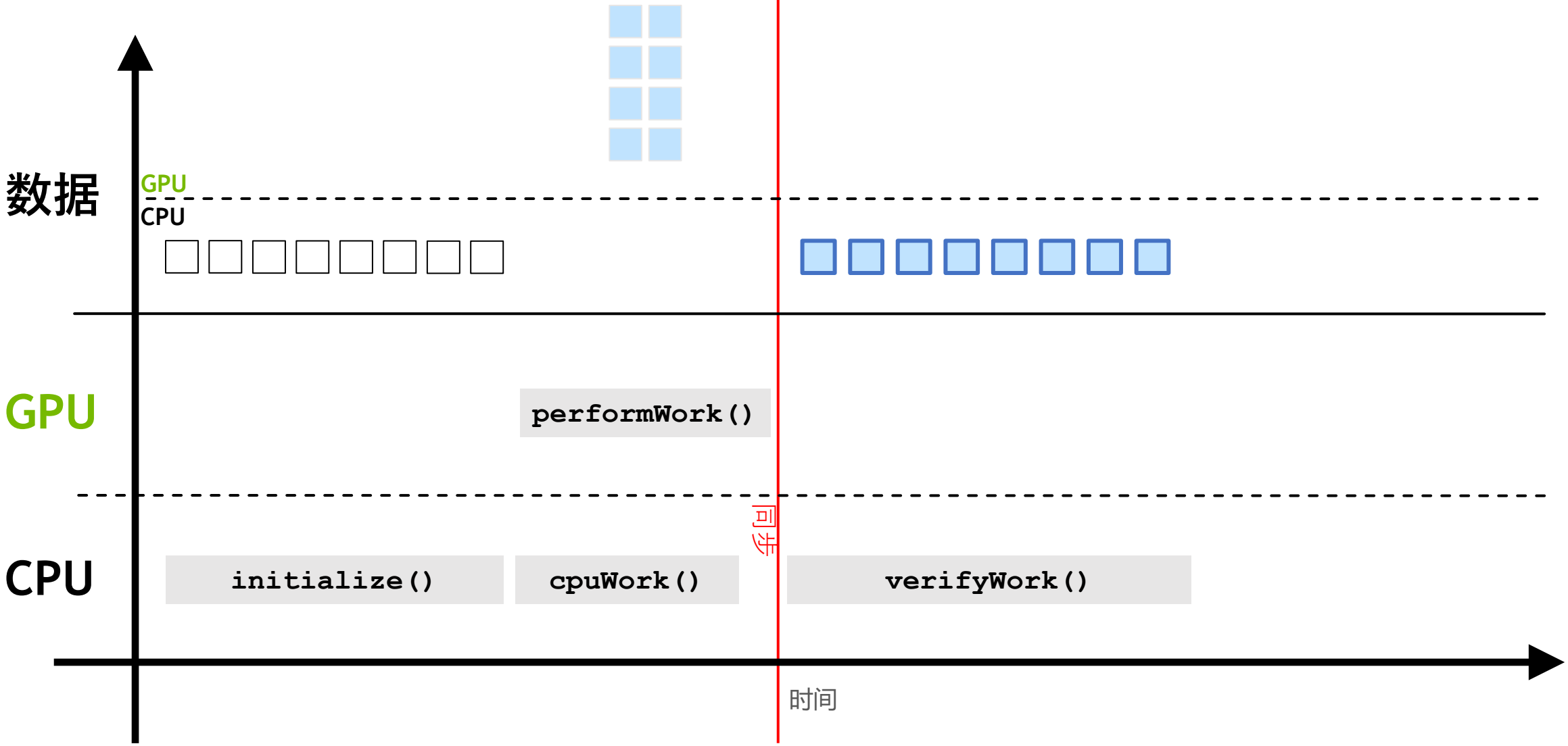
blockDim.x

threadIdx.x

blockIdx.x*blockDim.x + threadIdx.x


协调并行线程

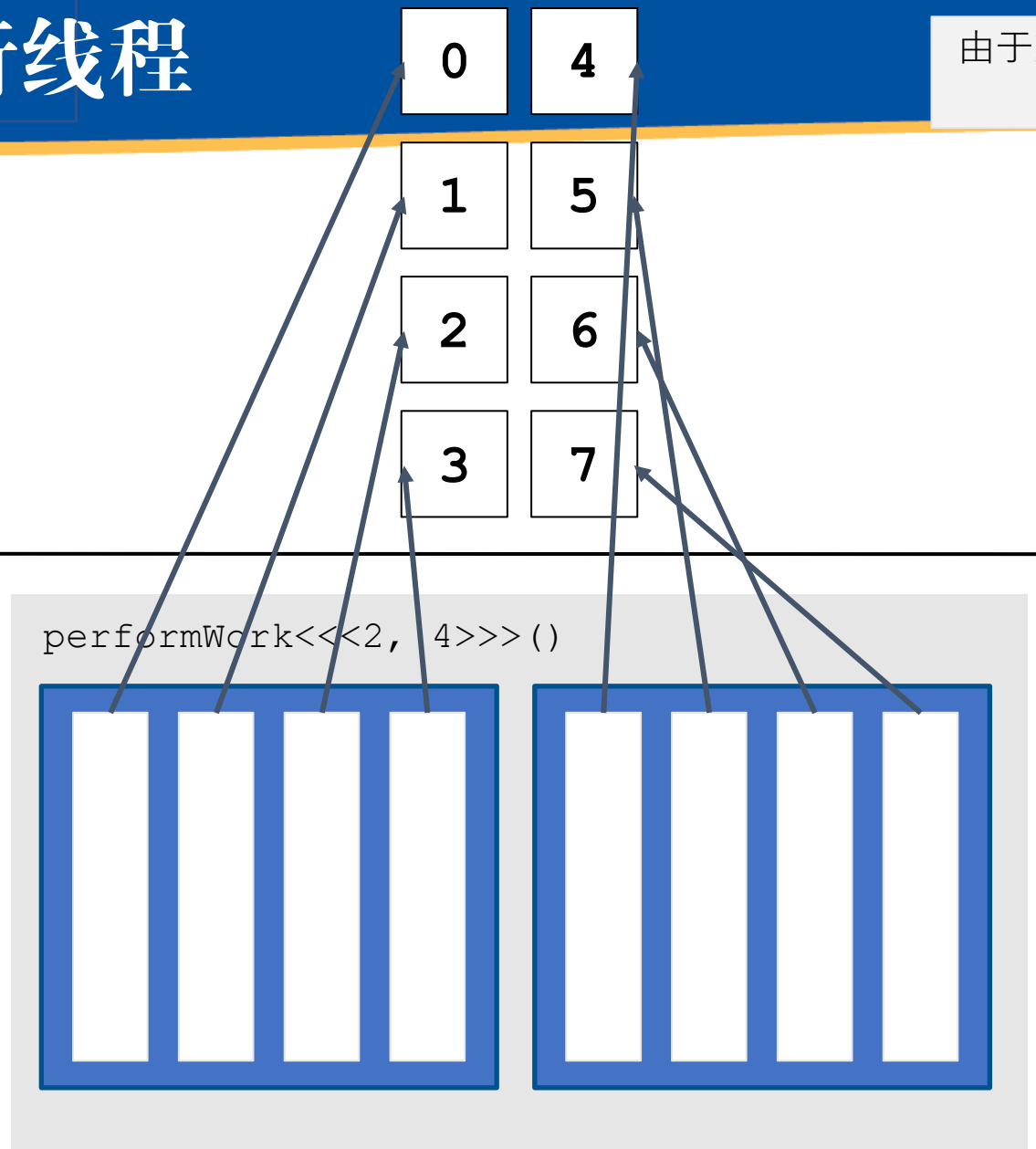
协调并行线程


数据
GPU
CPU
GPU
performWork()
同步
CPU
initialize()
cpuWork()
verifyWork()
时间

协调并行线程

由于某种未知原因，必须映射每个线程以处理向量中的元素

GPU
数据



GPU

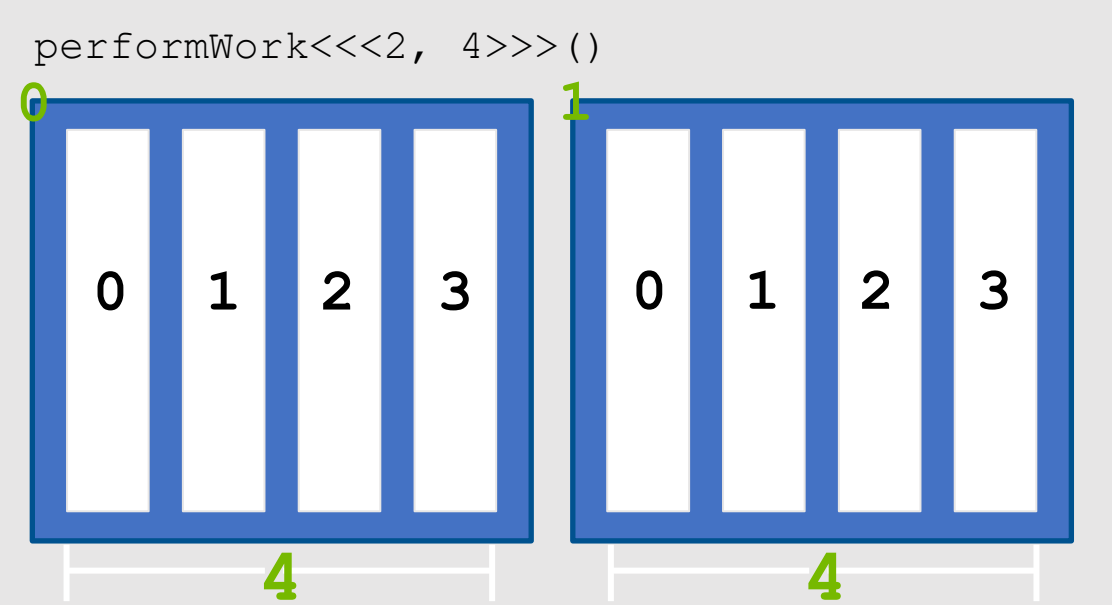
协调并行线程

GPU
数据

0	4
1	5
2	6
3	7

通过这些变量，公式 **threadIdx.x + blockIdx.x * blockDim.x** 可将每个线程映射到向量的元素中

GPU

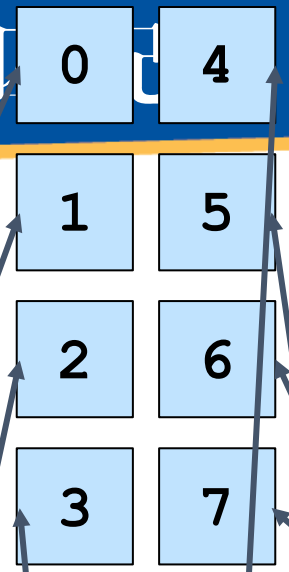


网格大小工作量不匹配

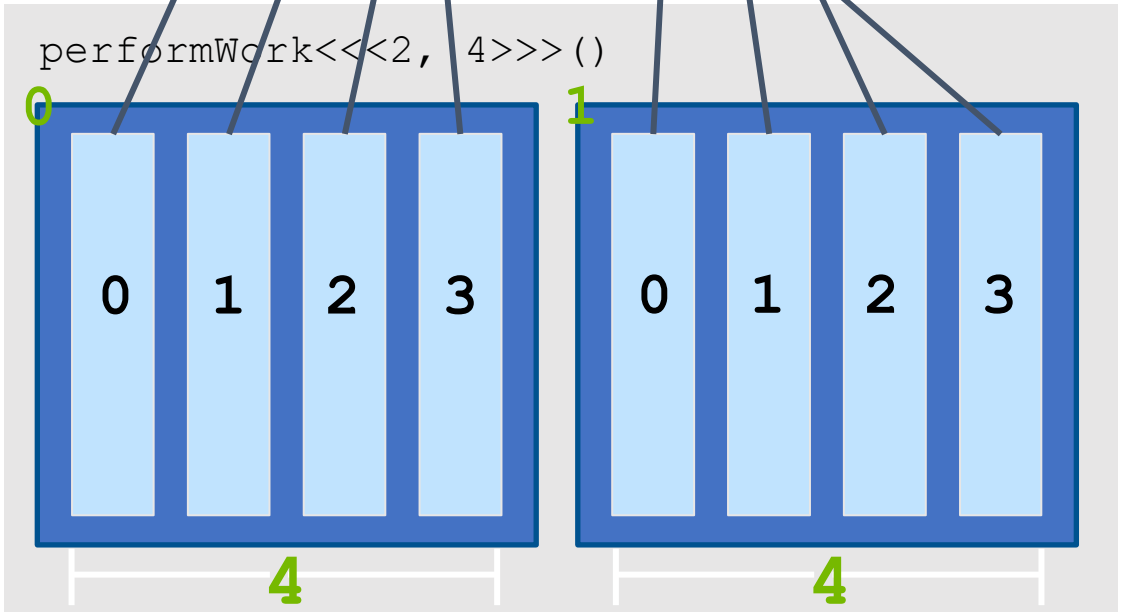
网格大小工作量不匹配

在先前场景中，网络中的线程数与元素数量完全匹配

GPU
数据



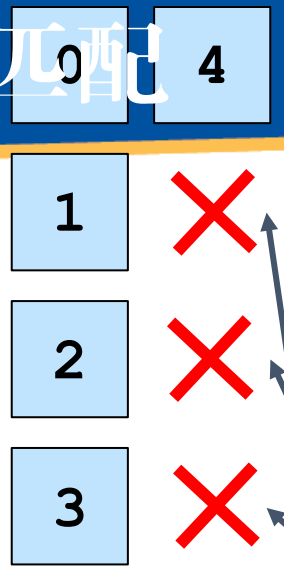
GPU



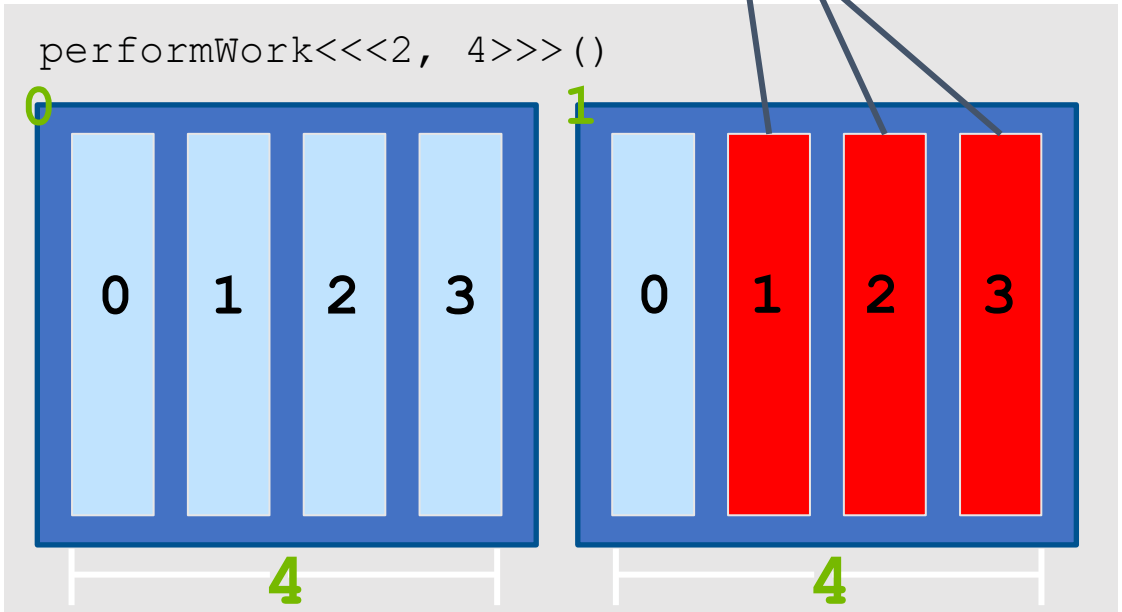
网格大小工作量不匹配

必须使用代码检查并确保经由公式 **threadIdx.x + blockIdx.x * blockDim.x** 计算出的 **dataIndex** 小于 **N**（数据元素数量）。

GPU
数据



GPU



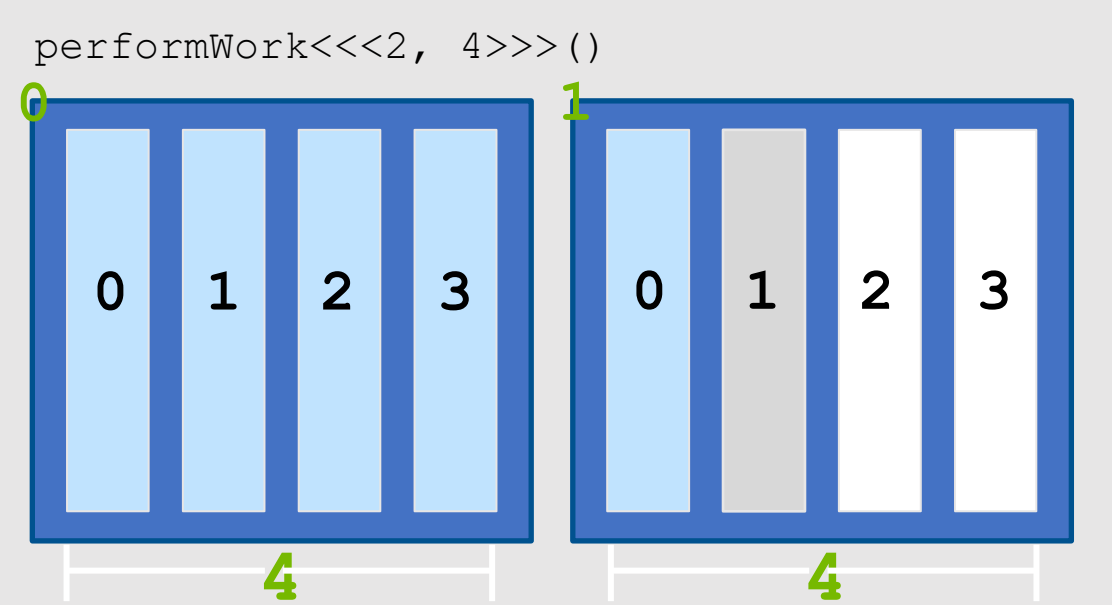
网格大小工作量不匹配

GPU
数据

0	4
1	
2	
3	

threadIdx.x	+	blockIdx.x	*	blockDim.x
1		1		4
dataIndex	<	N	=	可以运行
5		5		false

GPU



如何处理块配置与所需线程数不匹配

- 1000**数据**　1000/256 = 3.9　　3+1=4　　4*256=1024
- 1024**数据**　1024/256 = 4
- 1025**数据**　1025/256 = 4.01　4+1=5　　5*256=1280
- size_t number_of_blocks = (N + threads_per_block - 1) / threads_per_block;

网格跨度循环

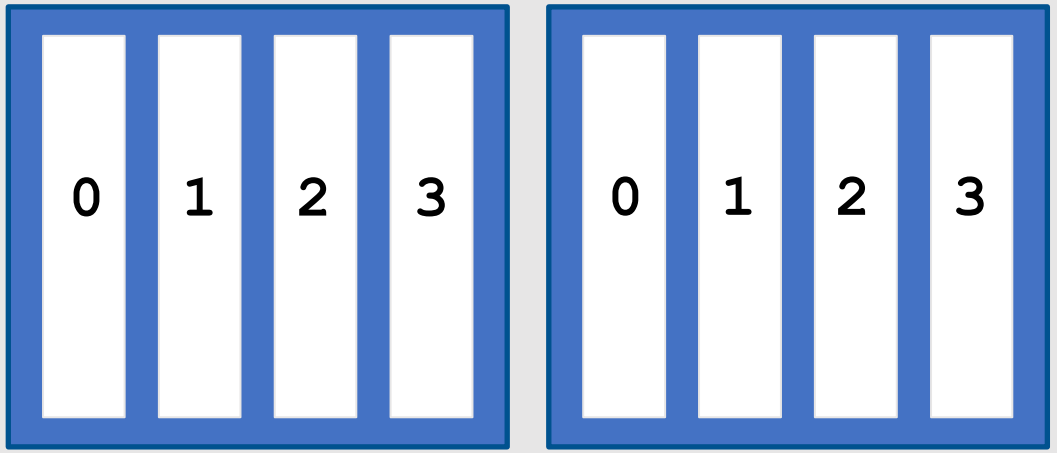
GPU
数据

0	4	8	12	16	20	24	28
1	5	9	13	17	21	25	29
2	6	10	14	18	22	26	30
3	7	11	15	19	23	27	31

数据元素数量往往会大于网格中的线程数

GPU

```
performWork<<<2, 4>>>()
```



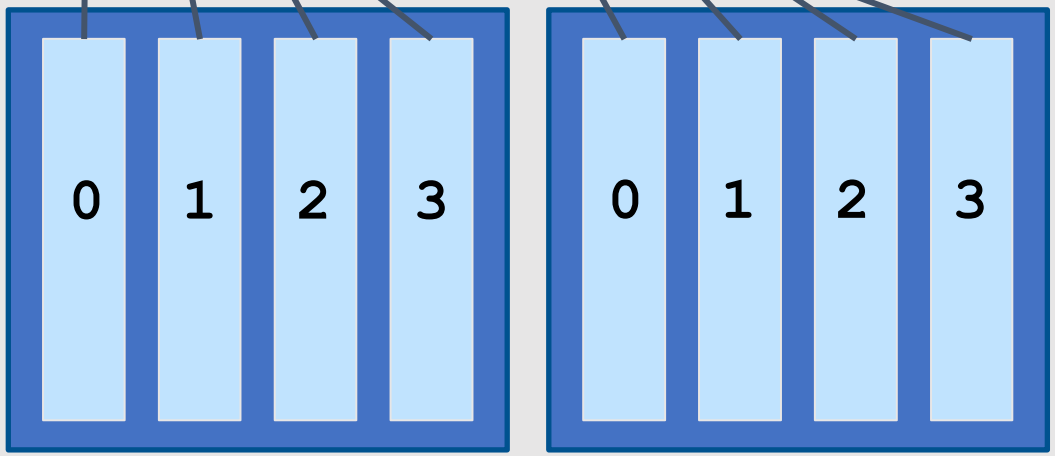
GPU
数据

0	4	8	12	16	20	24	28
1	5	9	13	17	21	25	29
2	6	10	14	18	22	26	30
3	7	11	15	19	23	27	31

在此类情况下，线程无法只处理一个元素

```
performWork<<<2, 4>>>()
```

GPU



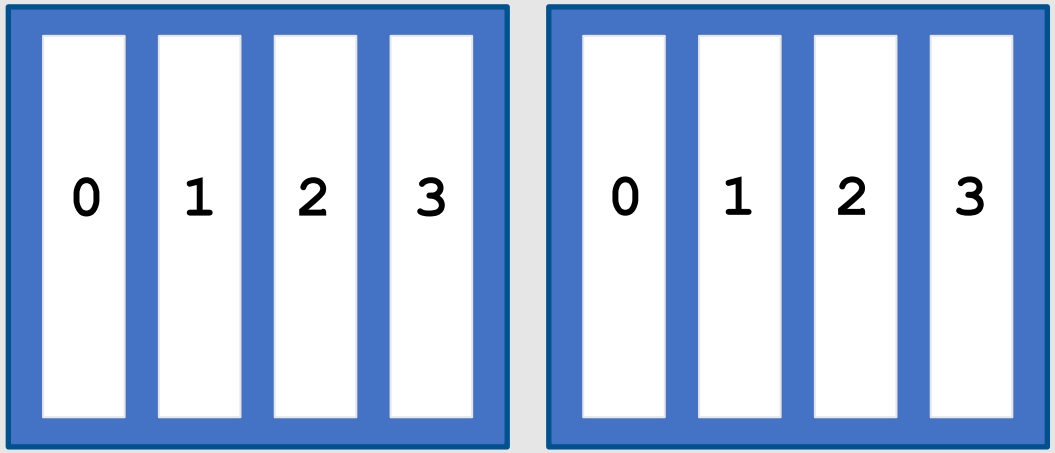
GPU
数据

0	4	8	12	16	20	24	28
1	5	9	13	17	21	25	29
2	6	10	14	18	22	26	30
3	7	11	15	19	23	27	31

以编程方式解决此问题的其中一种方法是使用**网格跨度循环**

GPU

```
performWork<<<2, 4>>>()
```



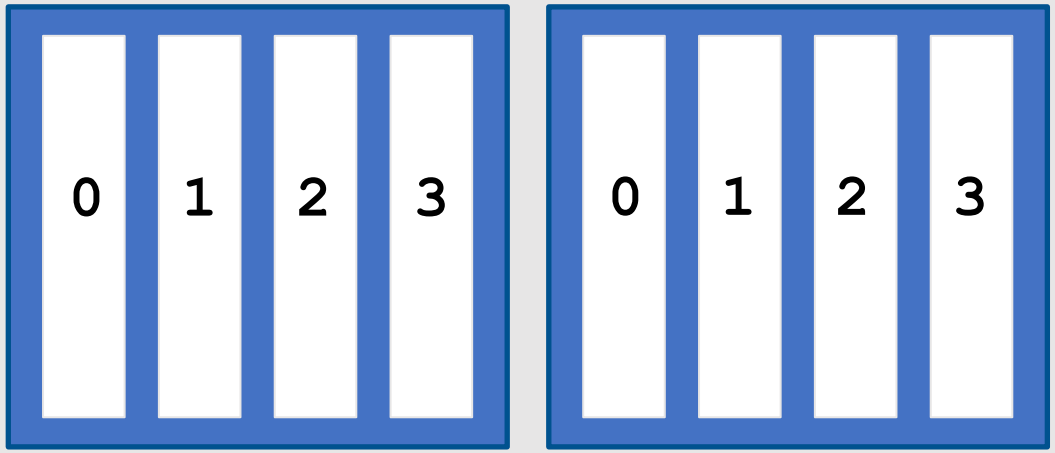
GPU
数据

0	4	8	12	16	20	24	28
1	5	9	13	17	21	25	29
2	6	10	14	18	22	26	30
3	7	11	15	19	23	27	31

所有**线**程均按此种方式运作，
如此便会涵盖所有元素

GPU

```
performWork<<<2, 4>>>()
```



GPU
数据

0	4	8	12	16	20	24	28
1	5	9	13	17	21	25	29
2	6	10	14	18	22	26	30
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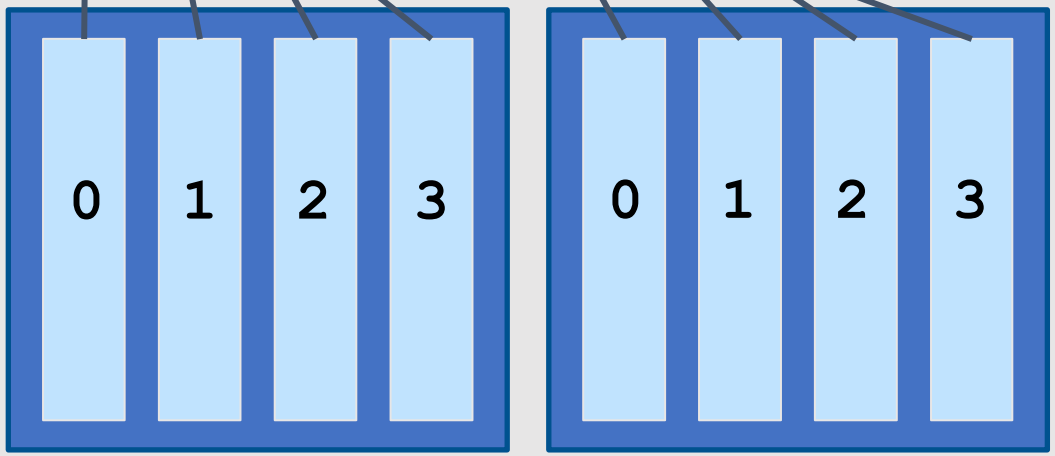
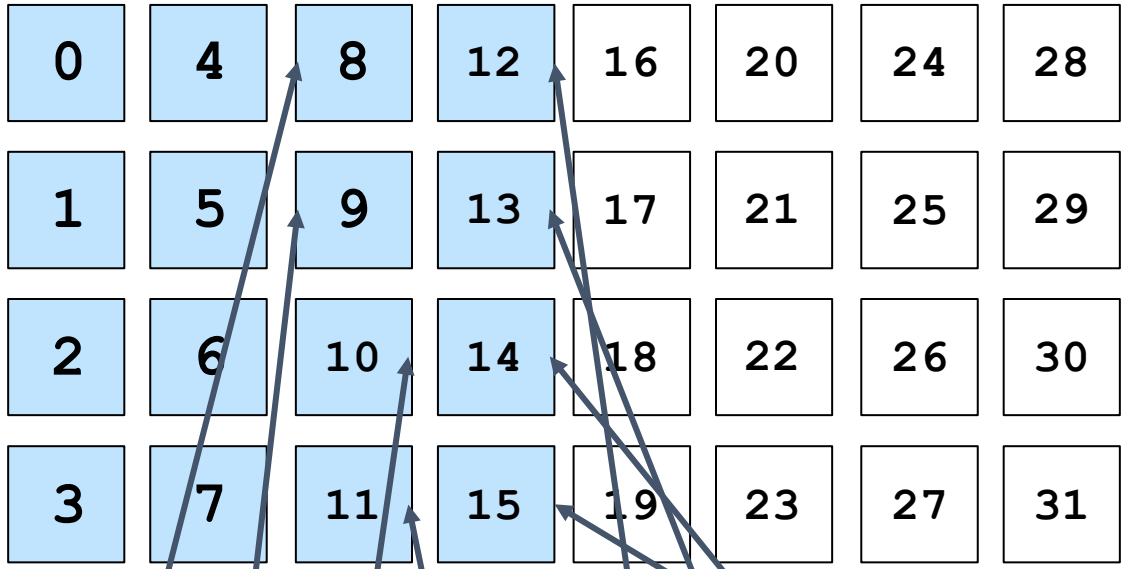
```



GPU
数据



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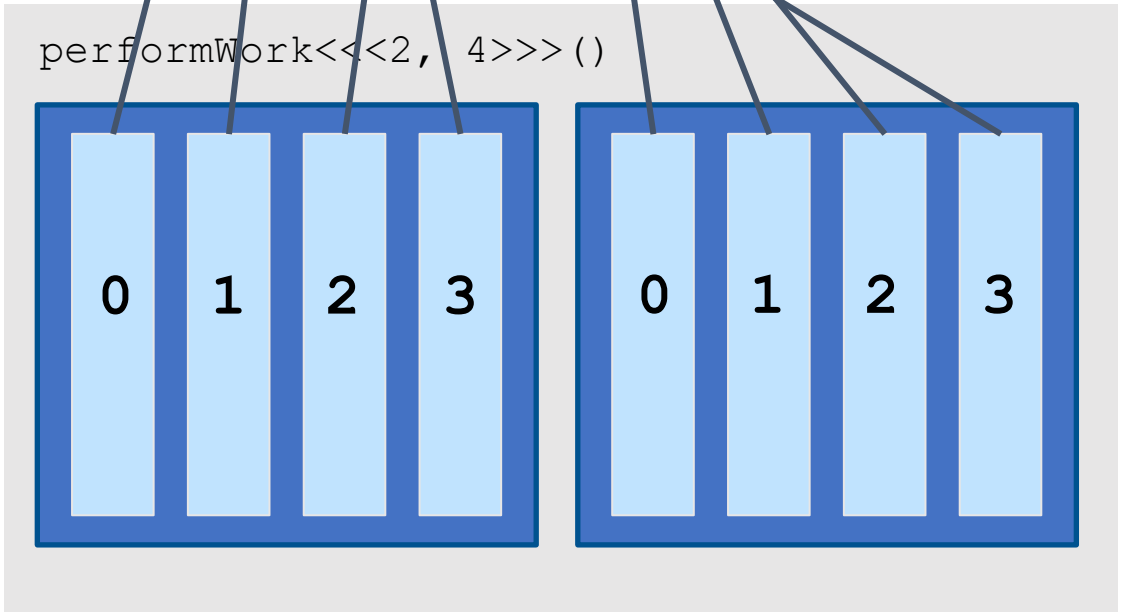
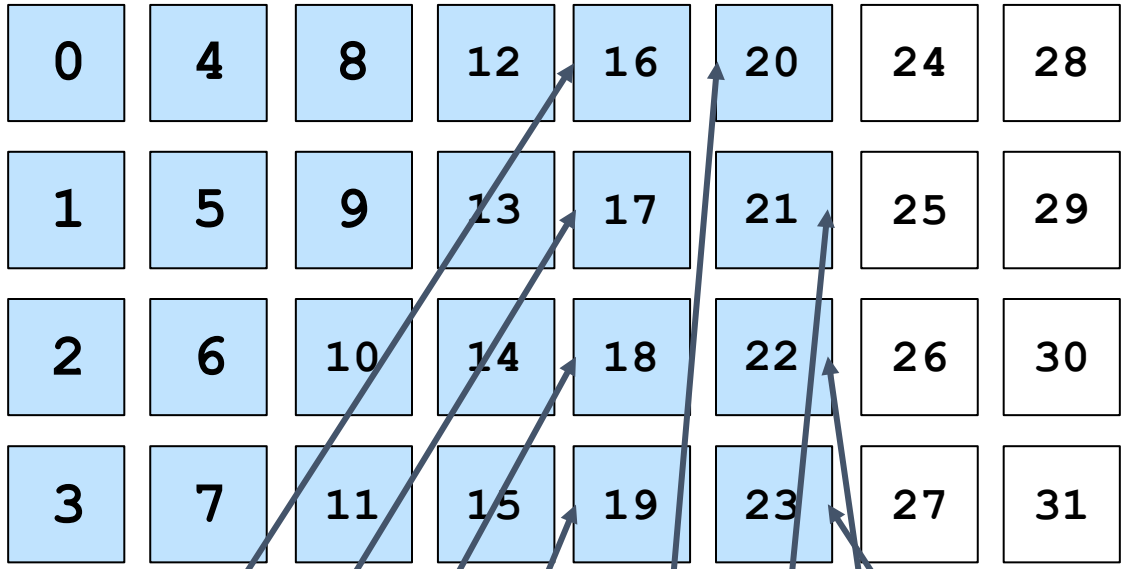
GPU



GPU
数据



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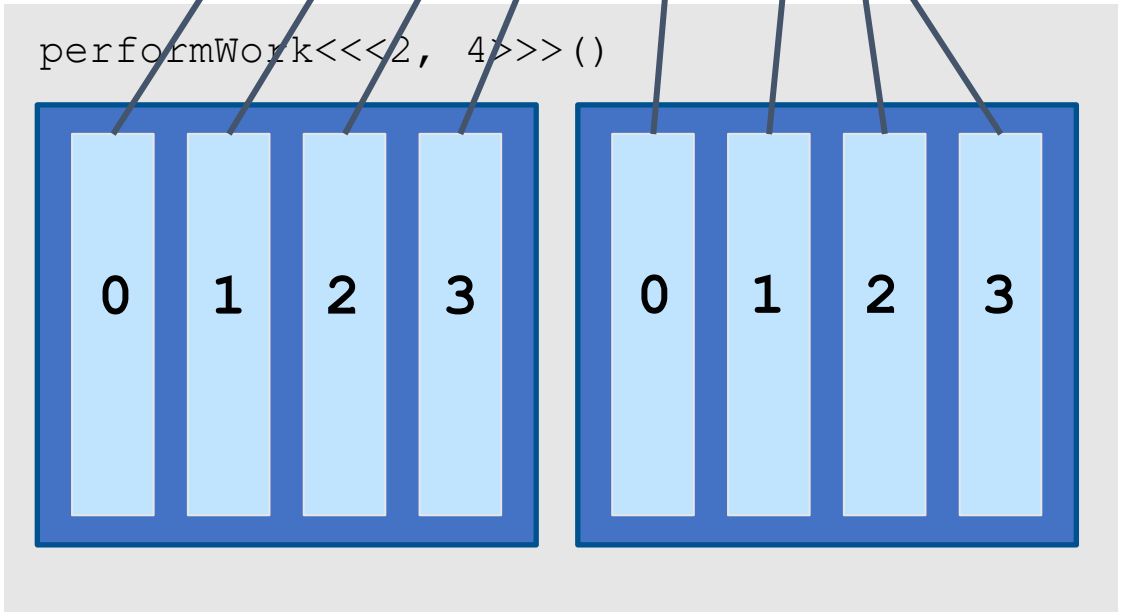
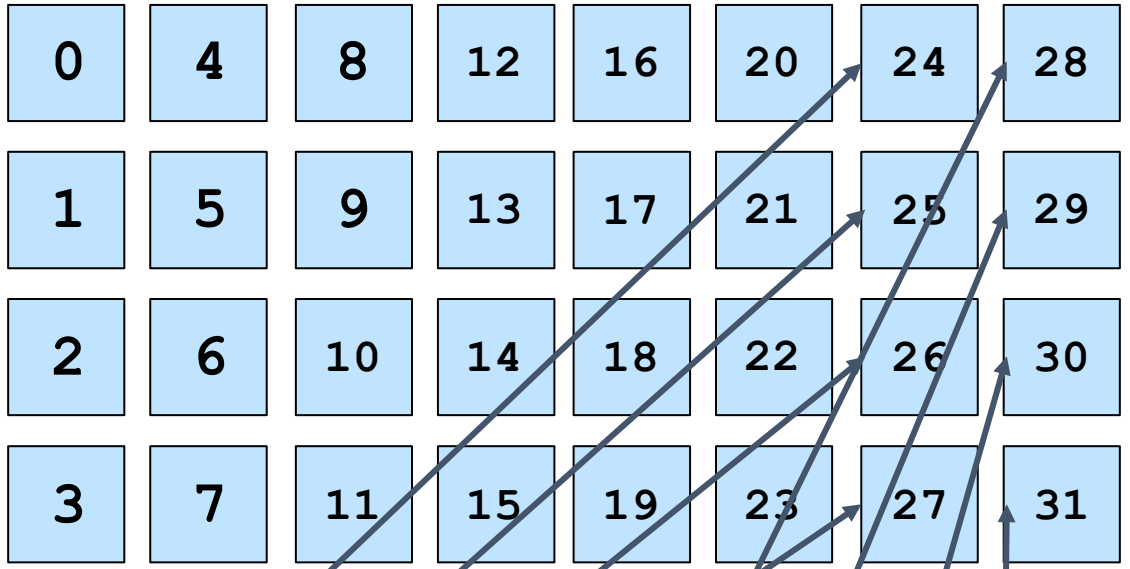
GPU



GPU
数据



所有线程均按此种方式运作，
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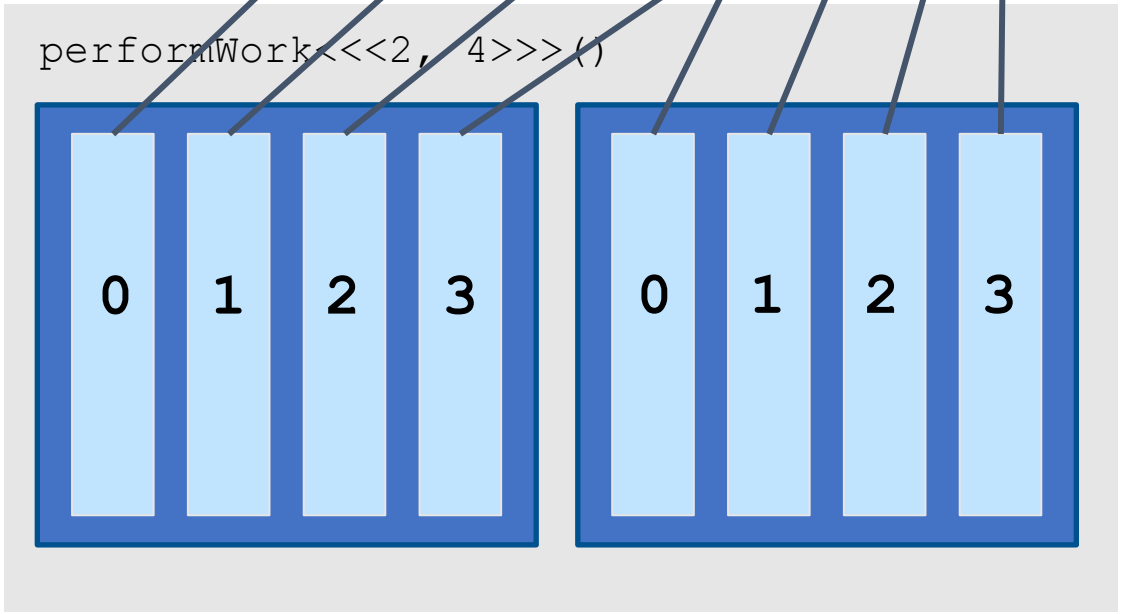
GPU



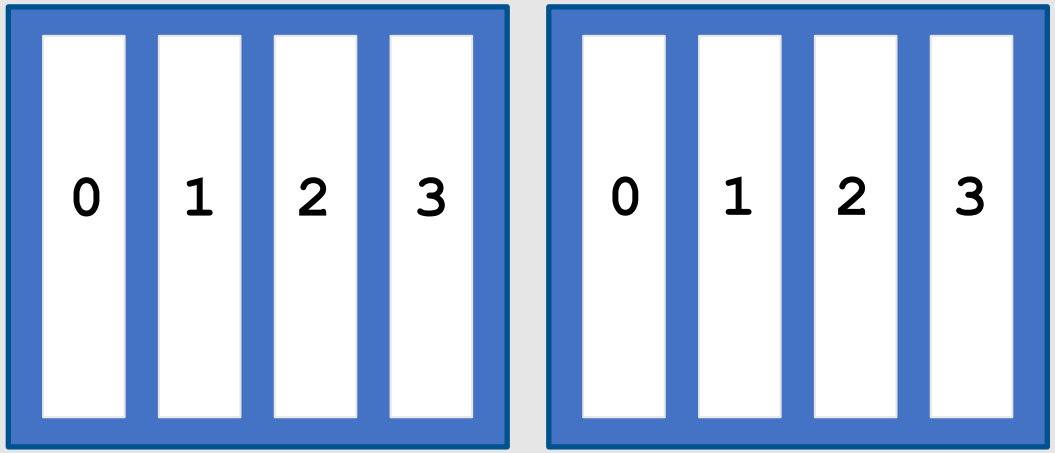
GPU
数据

0	4	8	12	16	20	24	28
1	5	9	13	17	21	25	29
2	6	10	14	18	22	26	30
3	7	11	15	19	23	27	31

所有**线**程均按此种方式运作，
如此便会涵盖所有元素

GPU

```
performWork<<<2, 4>>>()
```



错误处理

```
cudaError_t err;
err = cudaMallocManaged(&a, N)                    // Assume the existence of `a` and `N`.

if (err != cudaSuccess)                           // `cudaSuccess` is provided by CUDA.
{
  printf("Error: %s\n", cudaGetErrorString(err)); // `cudaGetErrorString` is provided by CUDA.
}
```

错误处理

```
someKernel<<<1, -1>>>();  // -1 is not a valid number of threads.

cudaError_t err;
err = cudaGetLastError(); // `cudaGetLastError` will return the error from above.
if (err != cudaSuccess)
{
  printf("Error: %s\n", cudaGetErrorString(err));
}
```

已经完成以下列出的所有实验学习目标

- 编写、编译及运行既可调用 CPU 函数也可启动GPU核函数的 C/C++ 程序。
- 使用执行配置控制并行线程层次结构。
- 重构串行循环以在 GPU 上并行执行其迭代。
- 分配和释放可用于 CPU 和 GPU 的内存。
- 处理 CUDA 代码生成的错误。

目标

- 加速 CPU 应用程序
  - 练习：加速向量加法
- 进阶内容
  - 2维和3维的网格和块
  - 练习：加速2D矩阵乘法应用
  - 练习：给热传导应用程序加速

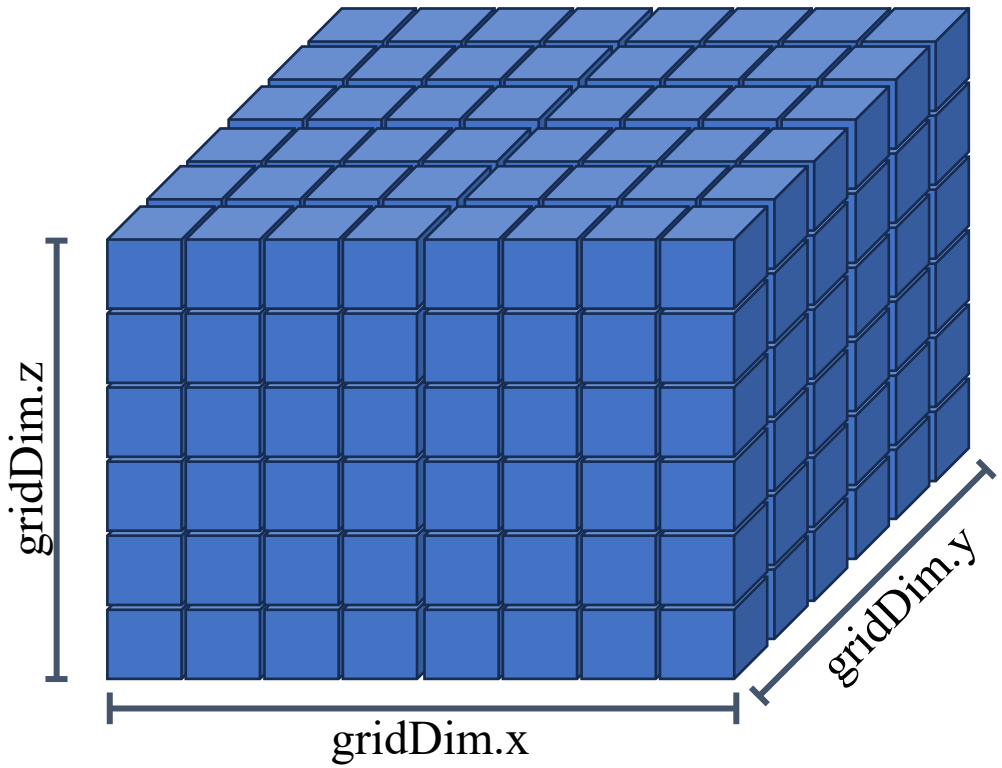
练习：加速向量加法

- 核函数 __global__
- 内存分配 cudaMallocManaged
- 执行启动配置
- 跨网格循环
- 改写CPU循环为GPU循环
- 错误处理

网格与线程（二维和三维）

- gridDim.x
- gridDim.y
- gridDim.z

- blockIdx.x
- blockIdx.y
- blockIdx.z



- blockDim.x
- blockDim.y
- blockDim.z

- threadIdx.x
- threadIdx.y
- threadIdx.z

练习：加速2D矩阵乘法应用

- 您将需创建执行配置，其参数均为 dim3 值，且 x 和 y 维度均设为大于 1。
- 在核函数主体内部，您将需要按照惯例在网格内建立所运行线程的唯一索引，但应为线程建立两个索引：一个用于网格的 x 轴，另一个用于网格的 y 轴。

```
void matrixMulCPU( int * a, int * b, int * c )
{
  int val = 0;

  for( int row = 0; row < N; ++row )
    for( int col = 0; col < N; ++col )
    {
      val = 0;
      for ( int k = 0; k < N; ++k )
        val += a[row * N + k] * b[k * N + col];
      c[row * N + col] = val;
    }
}
```

练习：加速2D矩阵乘法应用

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```
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{
  int val = 0;

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    for( int col = 0; col < N; ++col )
    {
      val = 0;
      for ( int k = 0; k < N; ++k )
        val += a[row * N + k] * b[k * N + col];
      c[row * N + col] = val;
    }
}
```

练习：加速2D矩阵乘法应用

```
__global__ void matrixMulGPU( int * a, int * b, int * c )
{
  int val = 0;

  int row = blockIdx.x * blockDim.x + threadIdx.x;
  int col = blockIdx.y * blockDim.y + threadIdx.y;

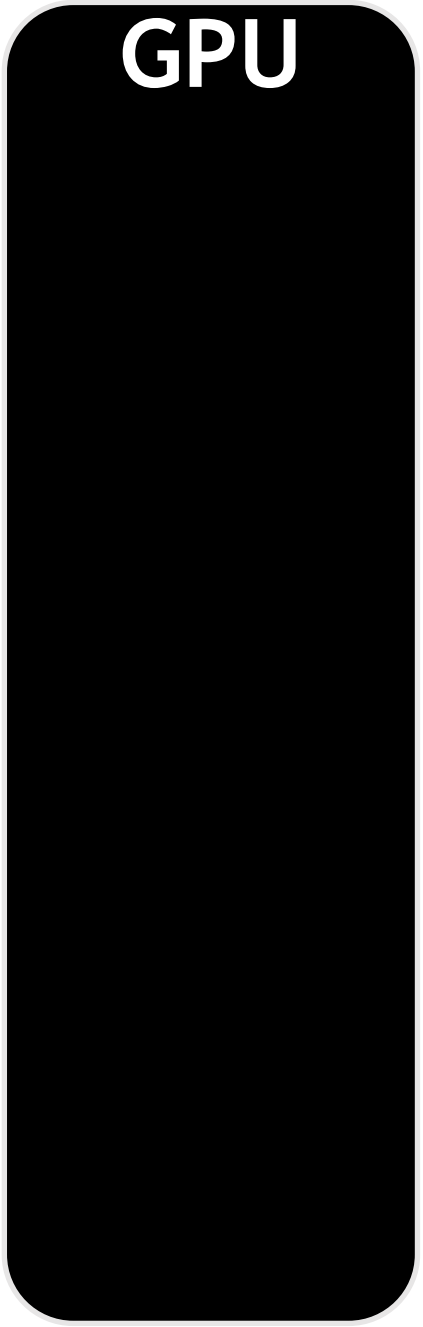
  if (row < N && col < N)
  {
    for ( int k = 0; k < N; ++k )
      val += a[row * N + k] * b[k * N + col];
    c[row * N + col] = val;
  }
}
```

```
void matrixMulCPU( int * a, int * b, int * c )
{
  int val = 0;

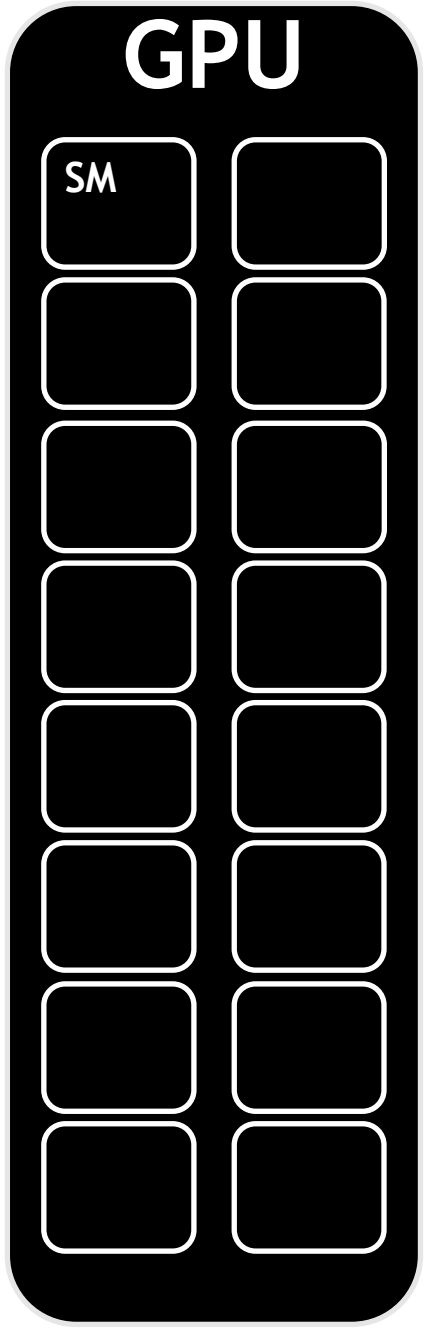
  for( int row = 0; row < N; ++row )
    for( int col = 0; col < N; ++col )
    {
      val = 0;
      for ( int k = 0; k < N; ++k )
        val += a[row * N + k] * b[k * N + col];
      c[row * N + col] = val;
    }
}
```


利用基本的 CUDA 内存管理技术来优化加速应用程序

流处理器



NVIDIA GPU 包含称为**流多处理器**或 **SM** 的功能单元



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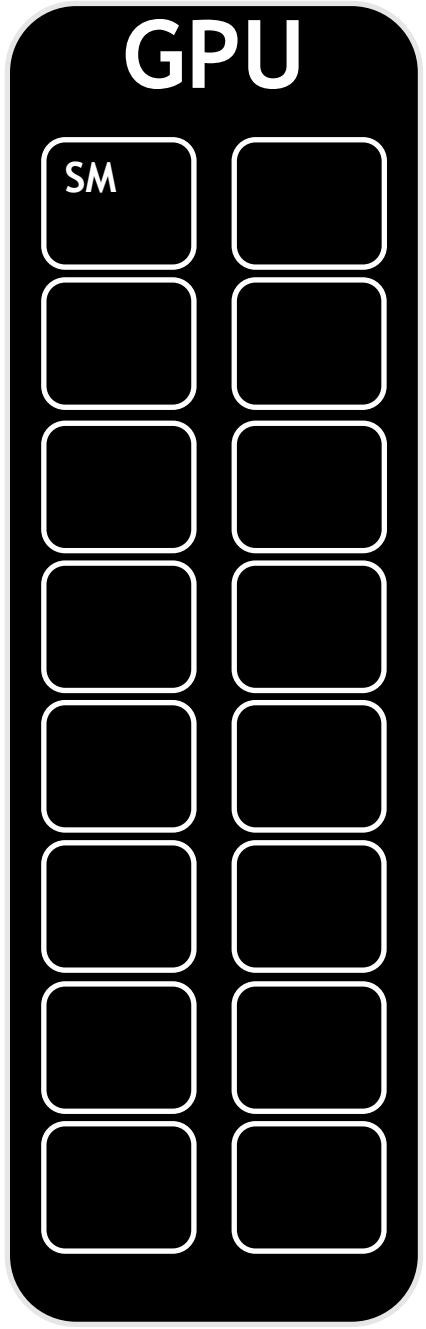
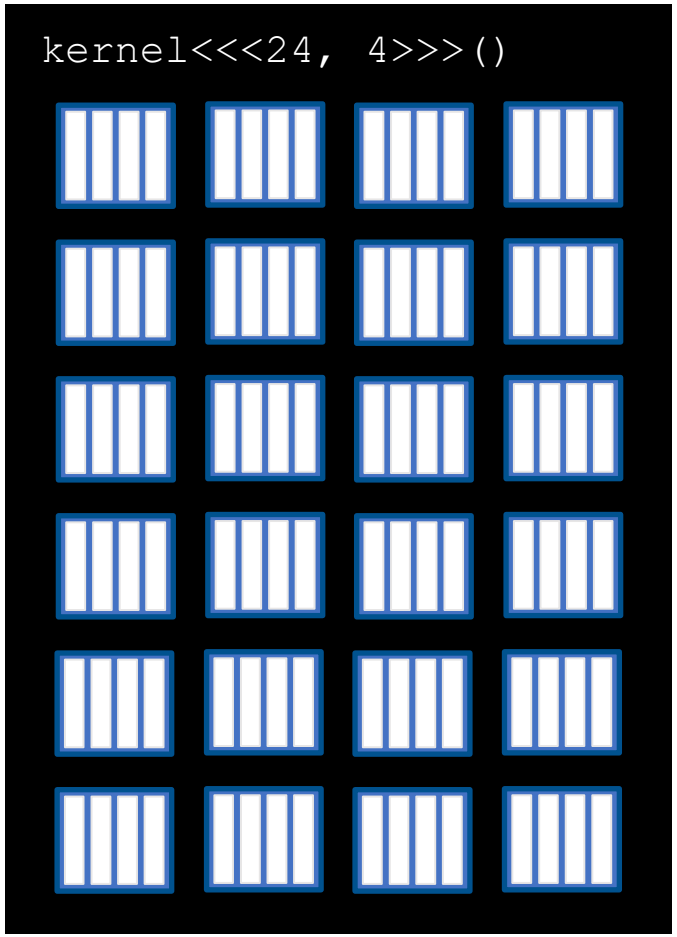
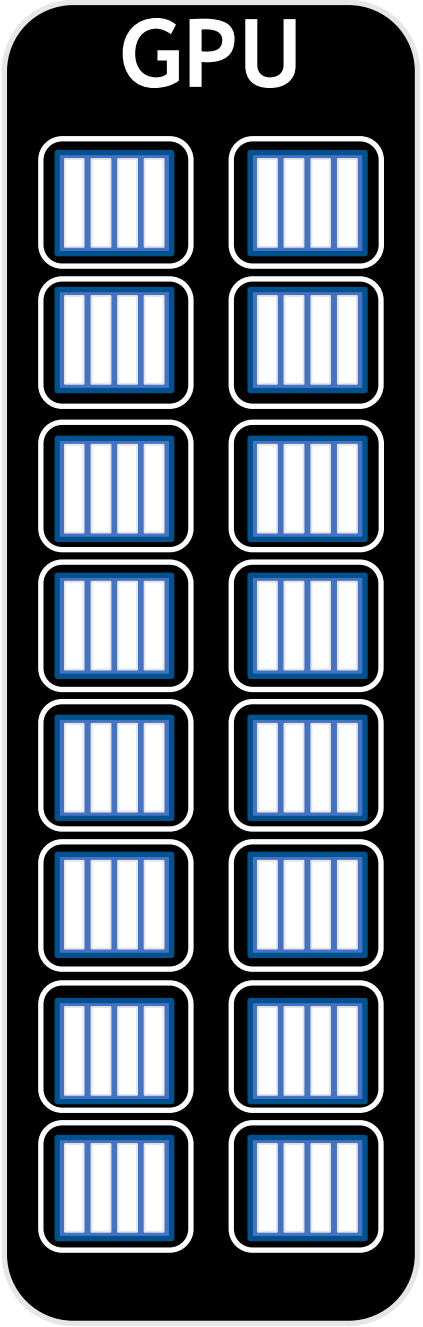


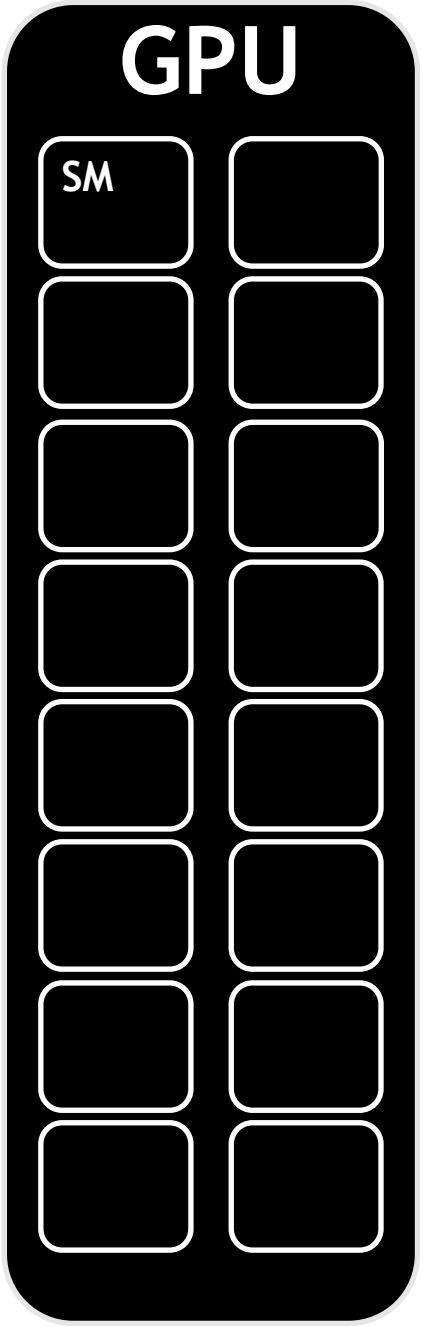


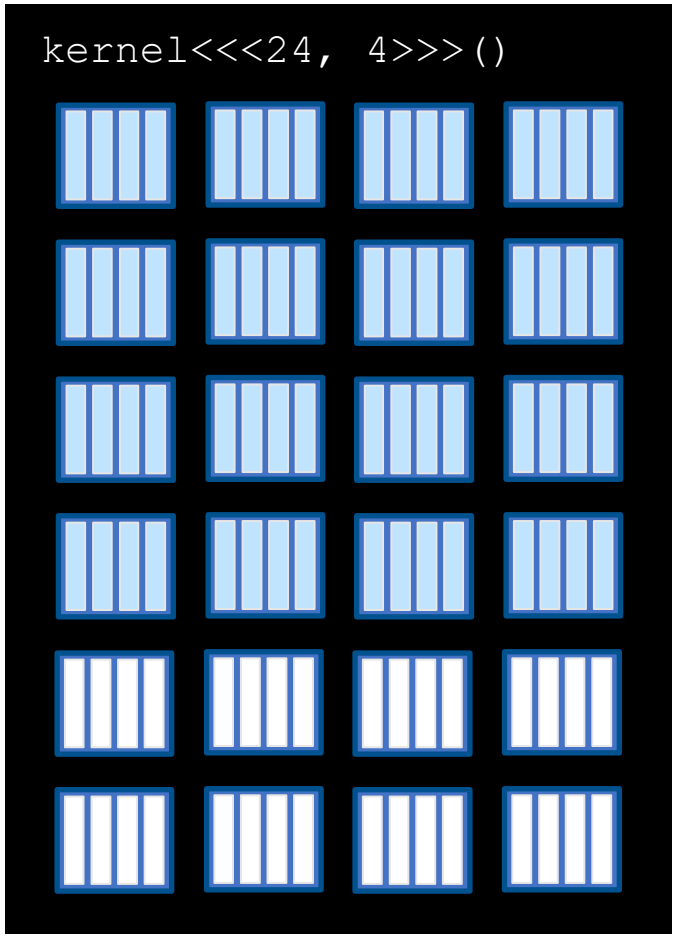
线程块均可安排在 SM 上运行



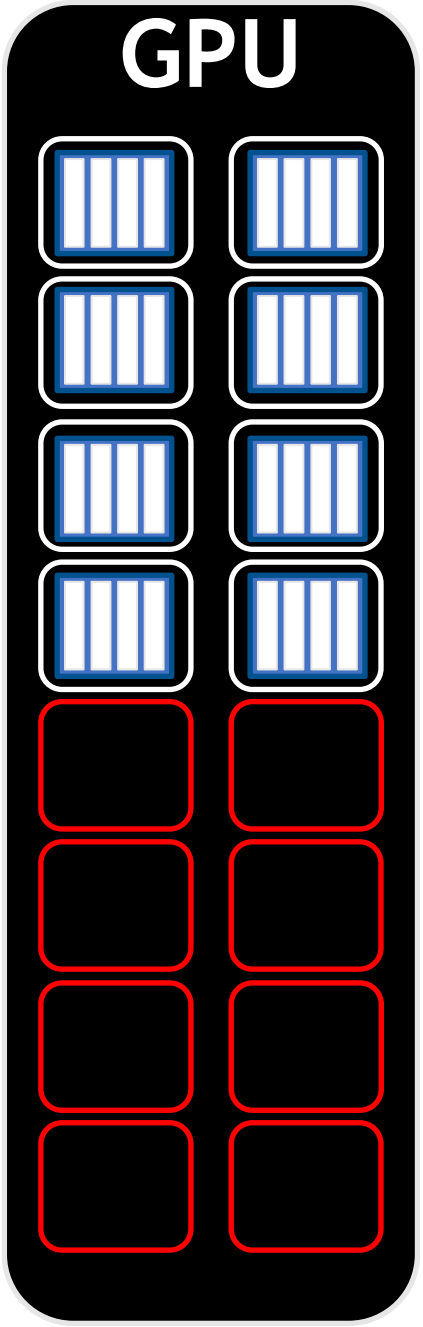

```
kernel<<<24, 4>>>()
```

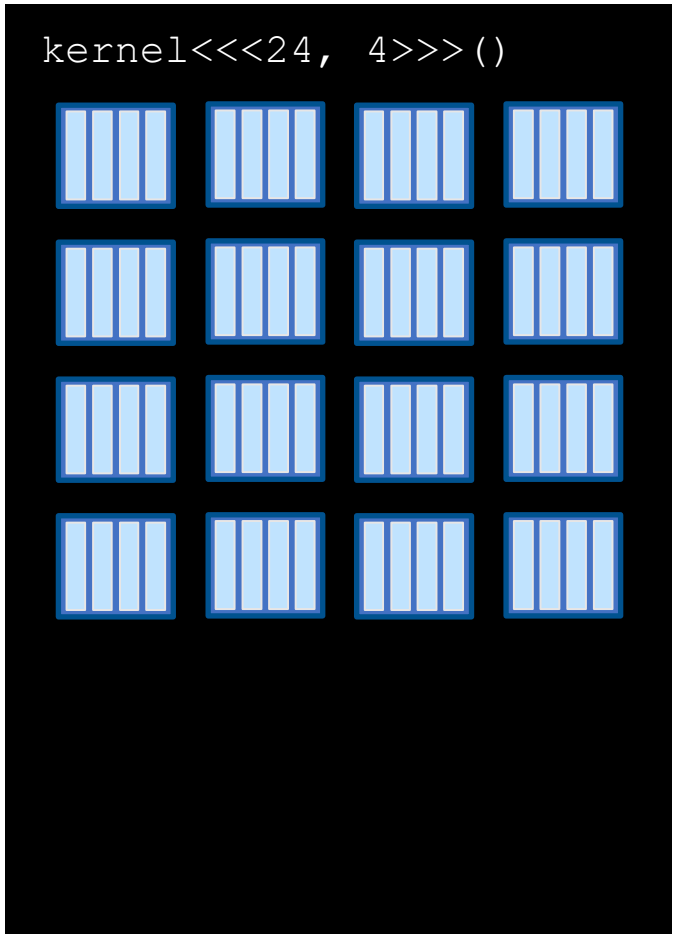
根据 GPU 上的 SM 数量以及线程块要求，可在 SM 上安排运行多个线程块



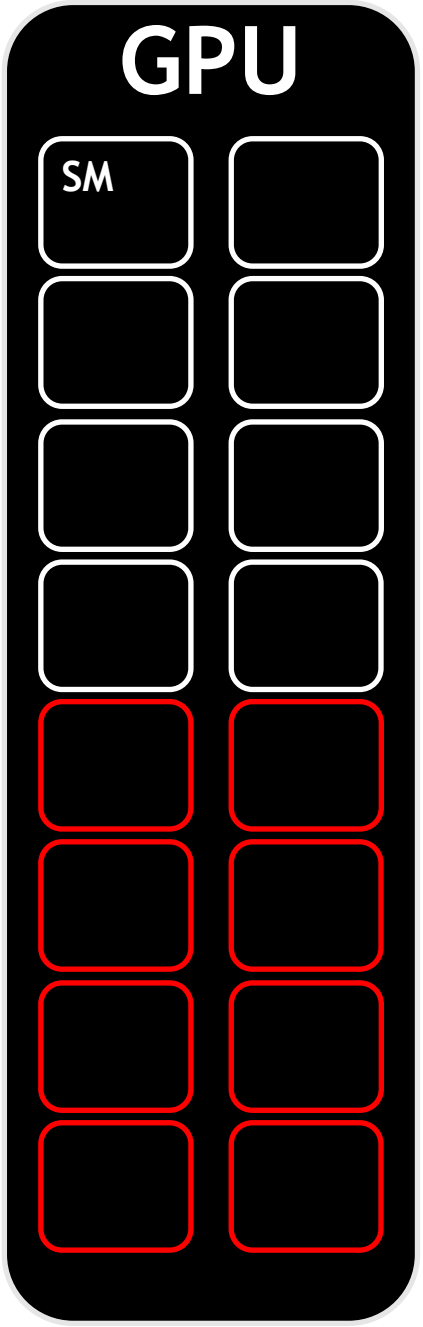


根据 GPU 上的 SM 数量以及**线程块**要求，可在 SM 上安排运行多个**线程块**

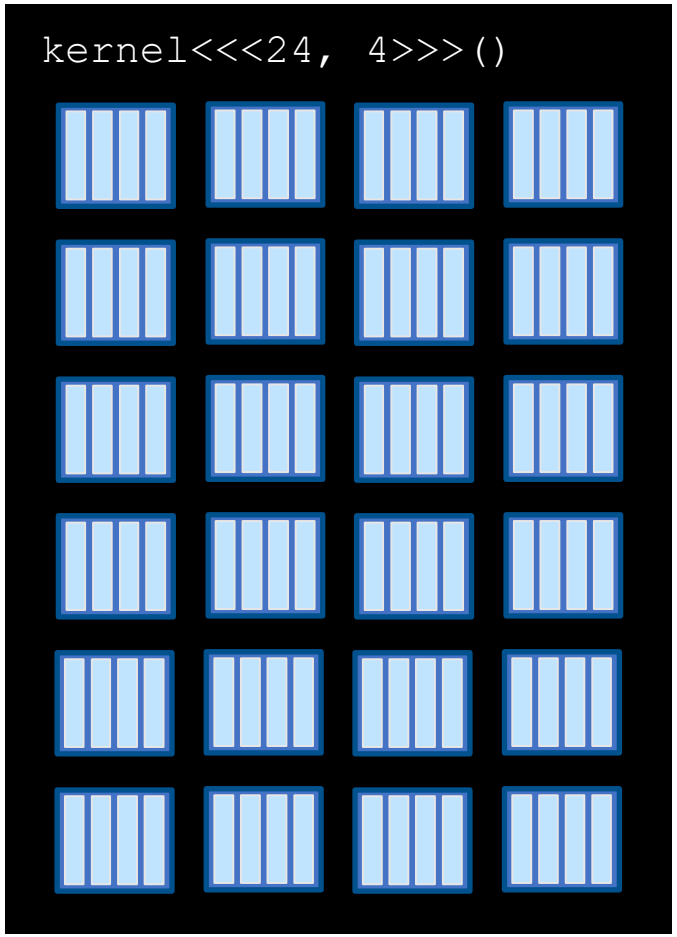




如果网格维度能被 GPU 上的 SM 数量整除，则可充分提高 SM 的利用率

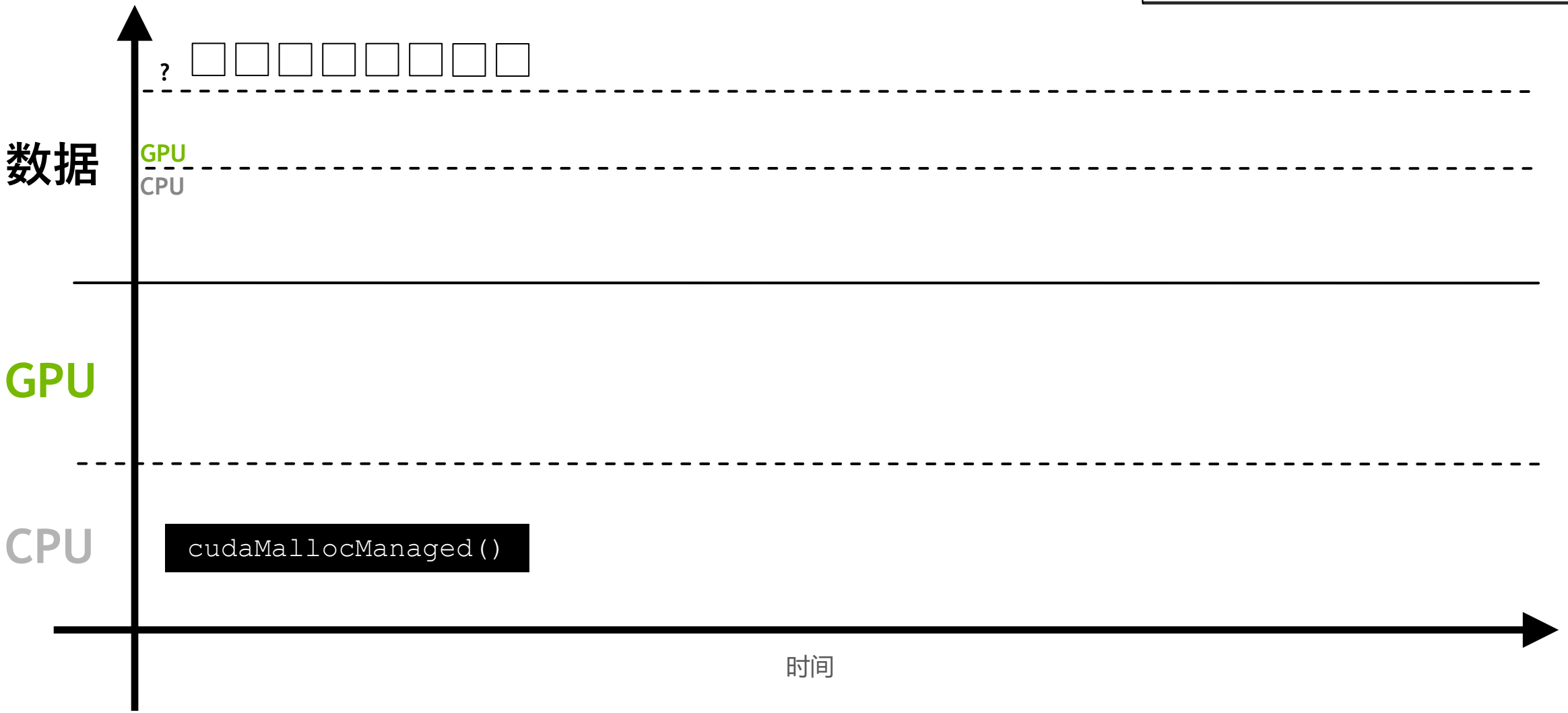


以下是闲置的 SM

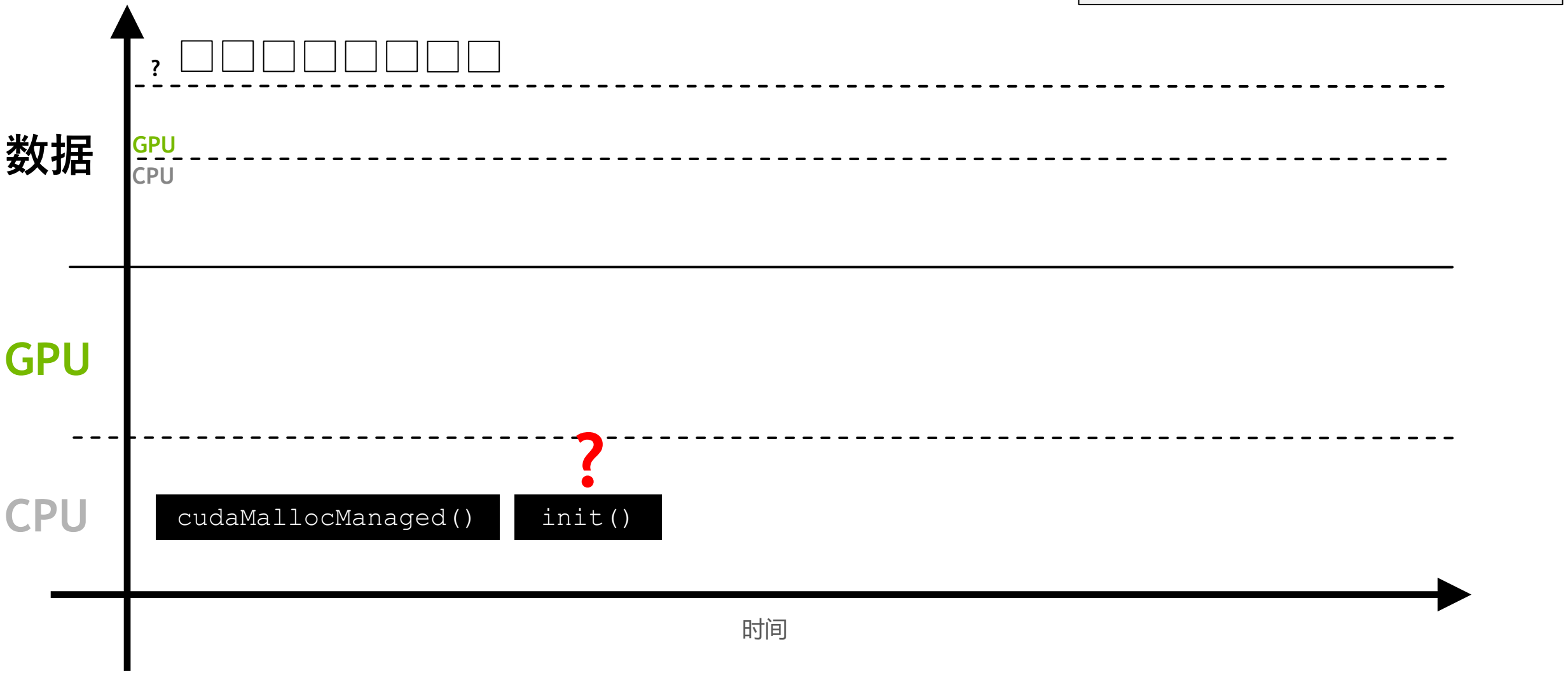


统一内存行为

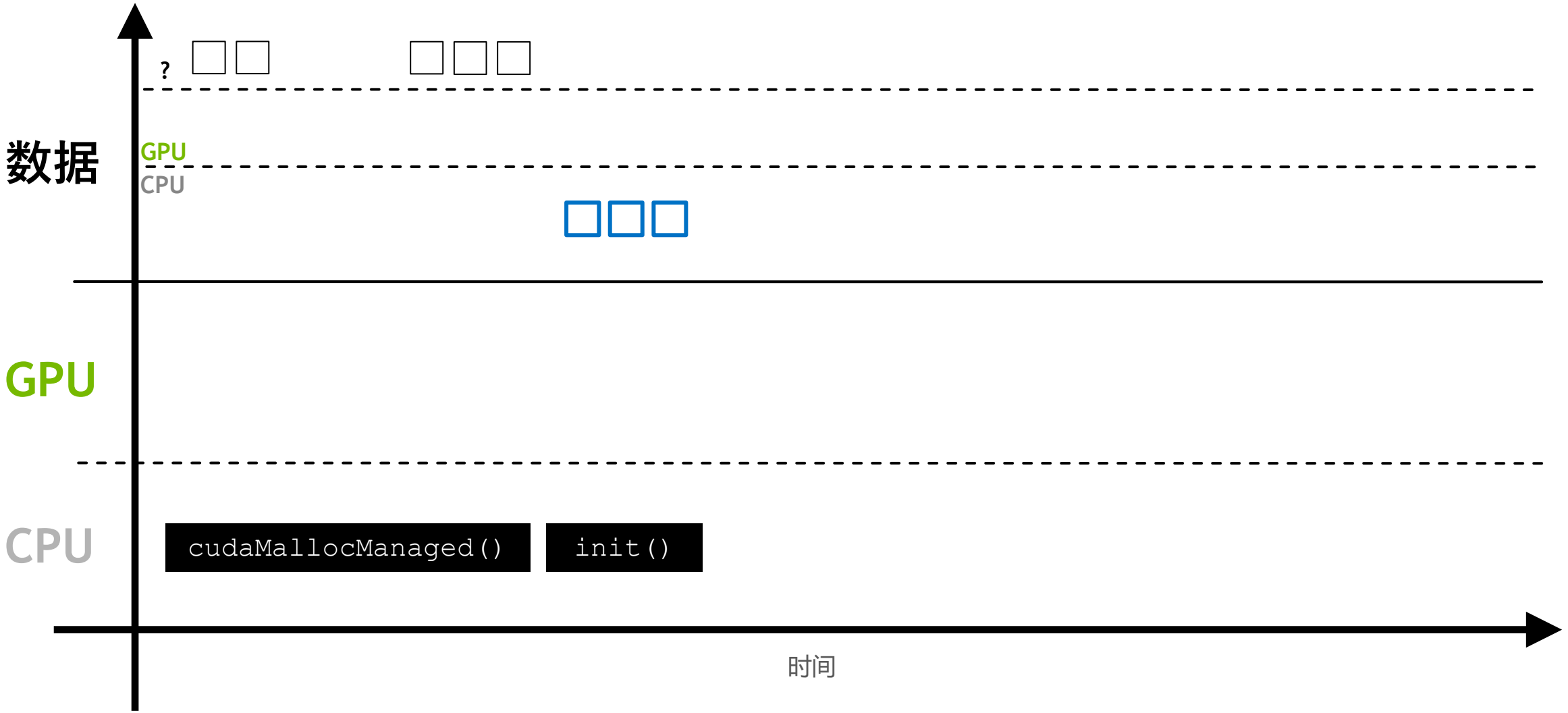
分配 **UM 时**，它最初可能并未**驻留**在 CPU 或 GPU 上



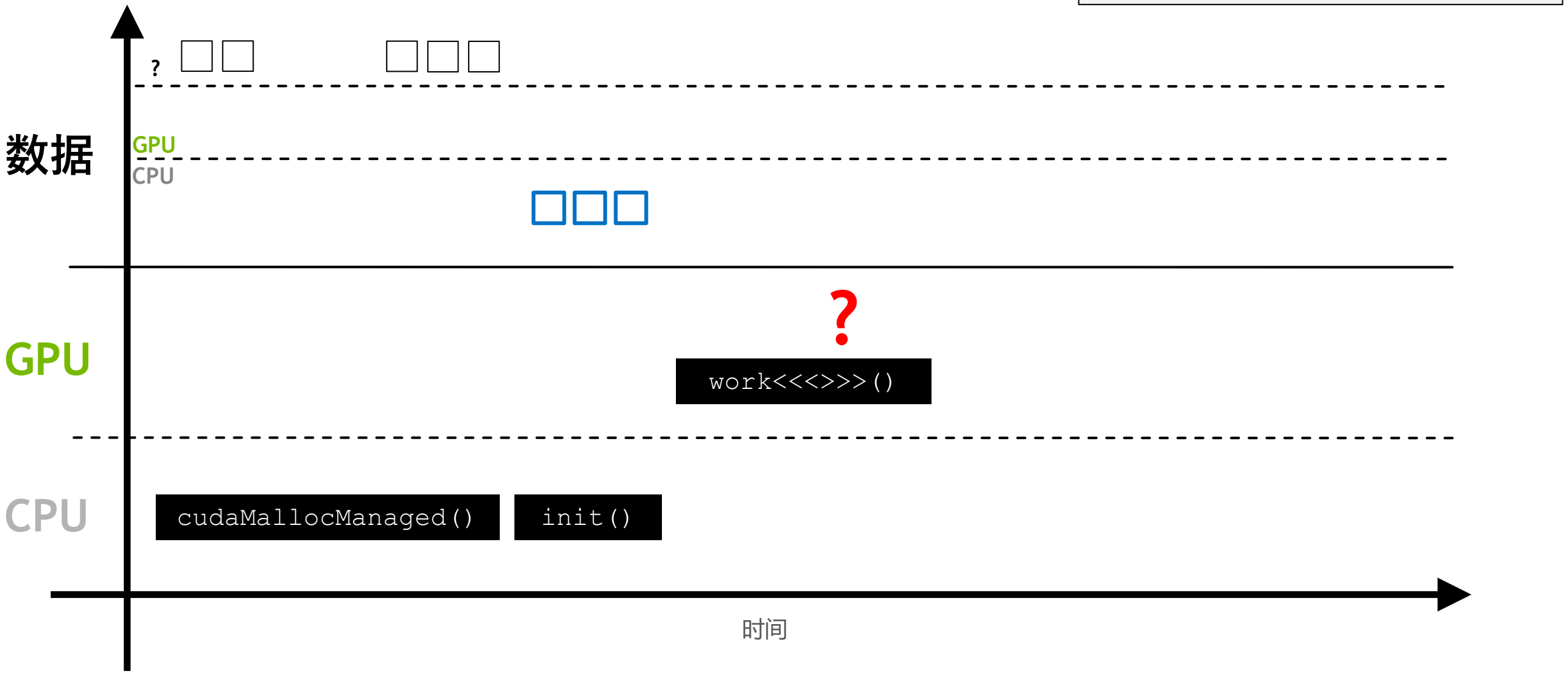
当某些工作首次请求内存时，将会发生
分页错误



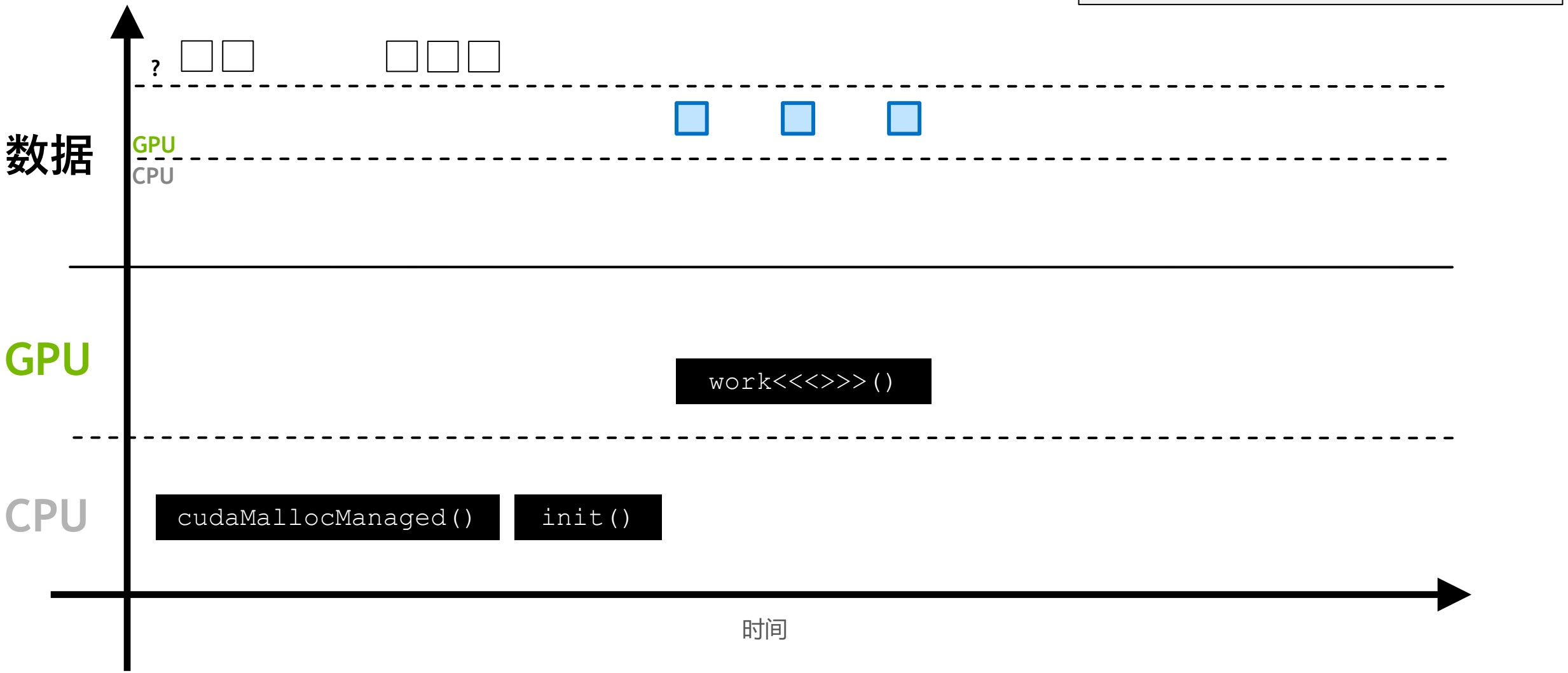
分页错误将触发所请求的内存发生迁移



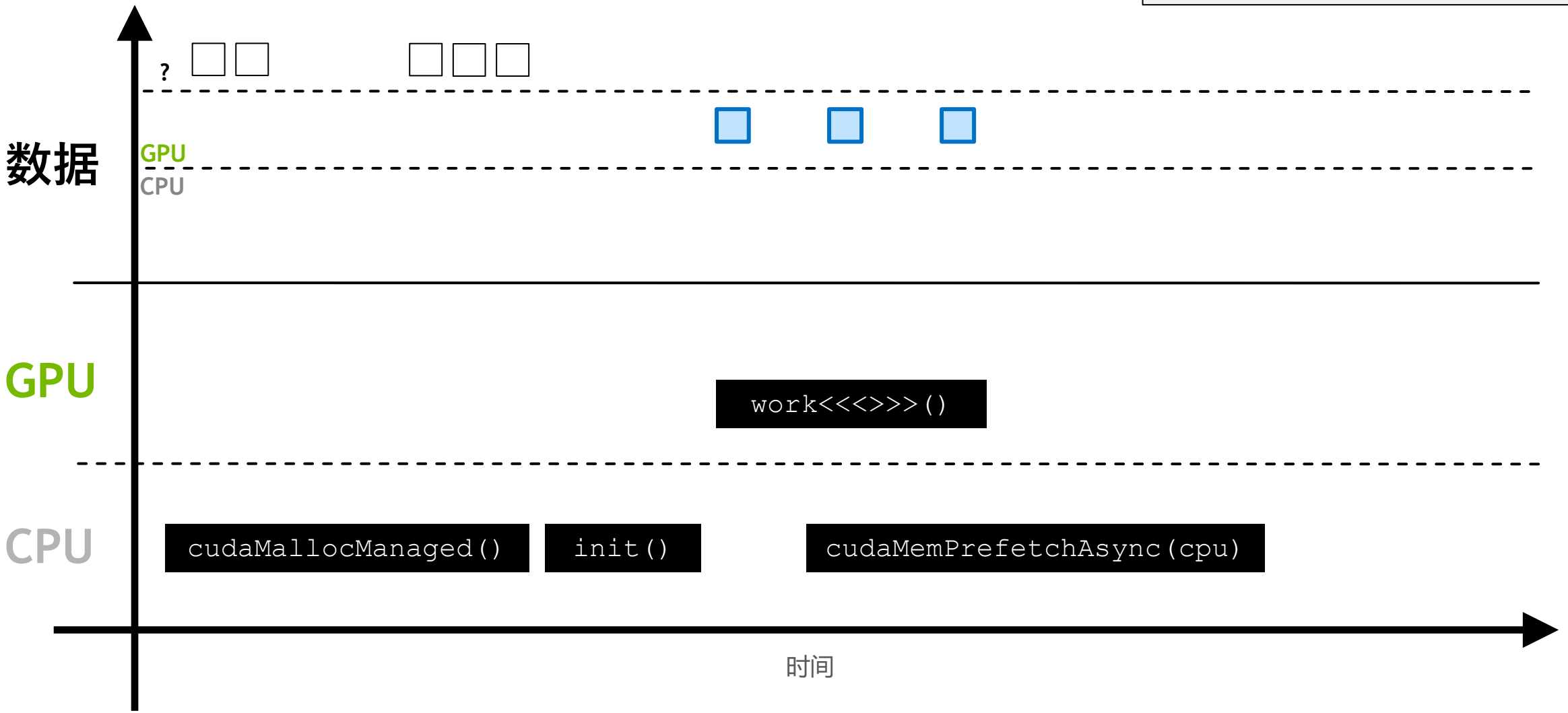
只要在系统中并未驻留内存的位置请求内存，此过程便会重复



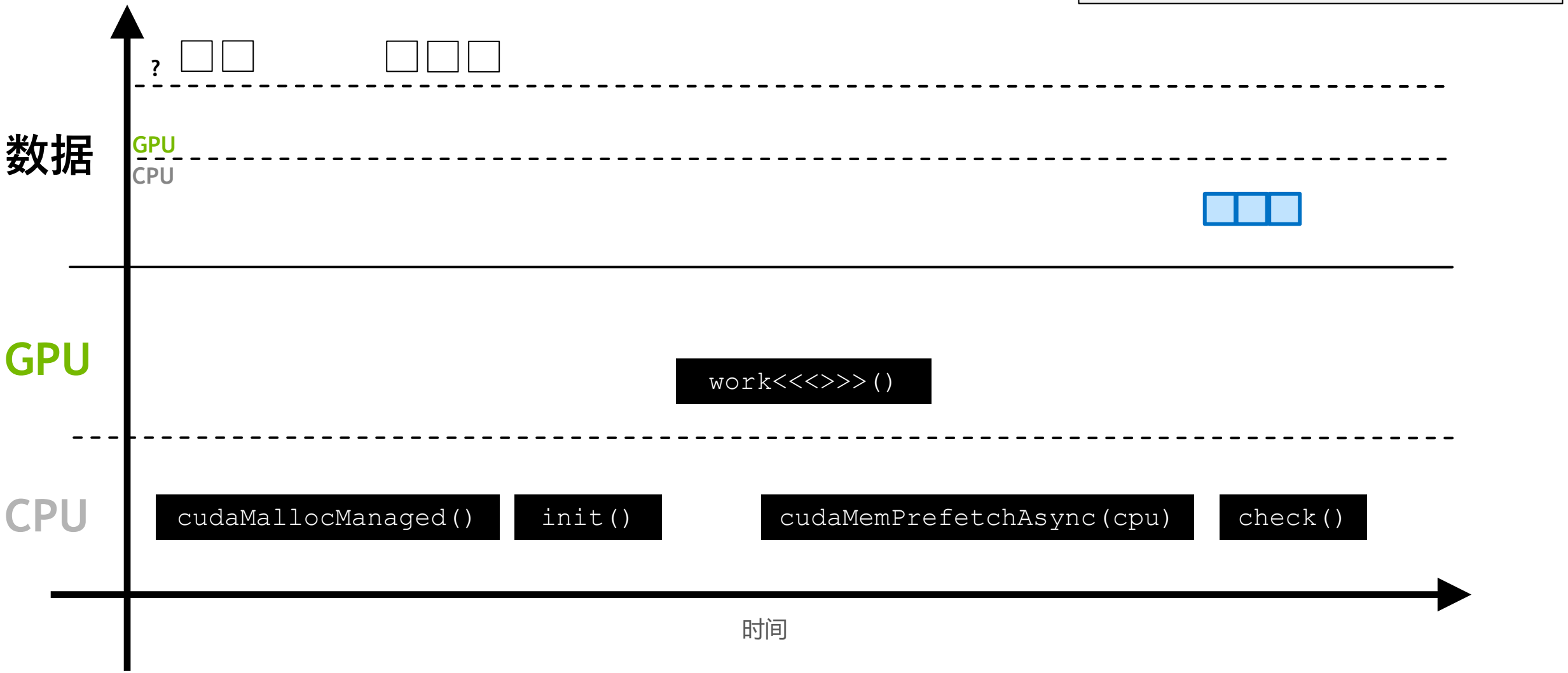
只要在系统中并未驻留内存的位置请求内存，此过程便会重复



如果已知**将在**未驻留内存的位置**访问**内存，**则**可使用异步**预**取



异步预取能以更大批量移动内存，
并会防止发生分页错误

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