CUDA API & Multi-GPU

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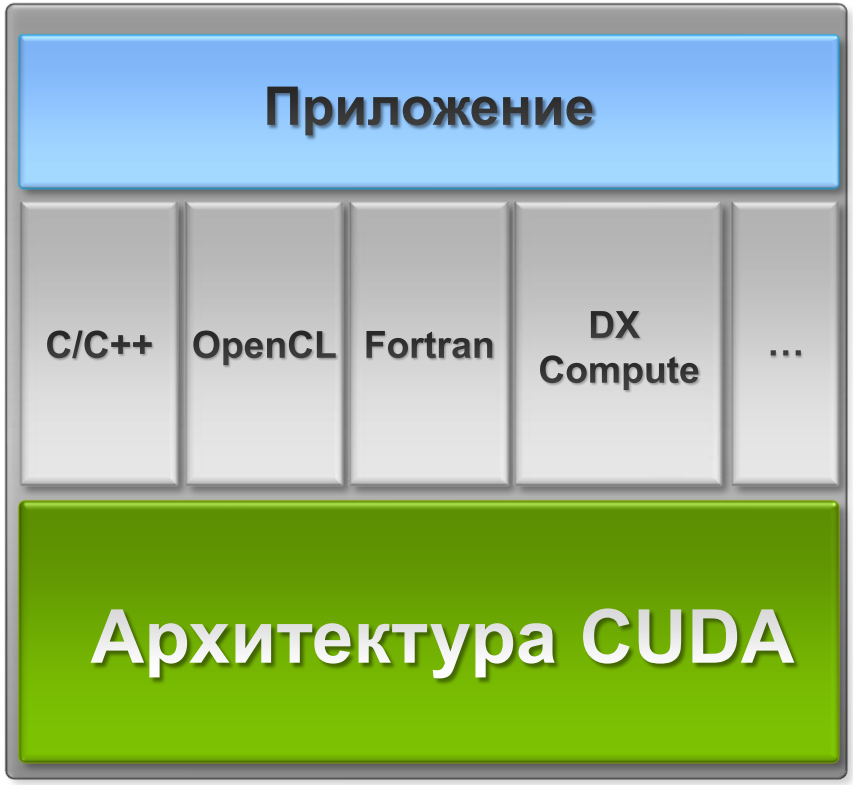
CUDA API

- CUDA C
- CUDA Driver API
- OpenCL
- DirectX Compute



CUDA C (Runtime API)

- Расширение языка C
- CUDA API:
  - Расширения языка C
  - Runtime библиотека

CUDA C Runtime

```
float * a   = new float [N];
float * dev = NULL;

cudaMalloc( (void**)&dev, N * sizeof ( float ) );

dim3 threads = dim3( 512, 1 );
dim3 blocks  = dim3( N / threads.x, 1 );


kernel<<<blocks, threads>>> ( dev );
cudaThreadSynchronize();

cudaMemcpy(a, dev, N*sizeof(float), cudaMemcpyDeviceToHost);

cudaFree( dev );
```

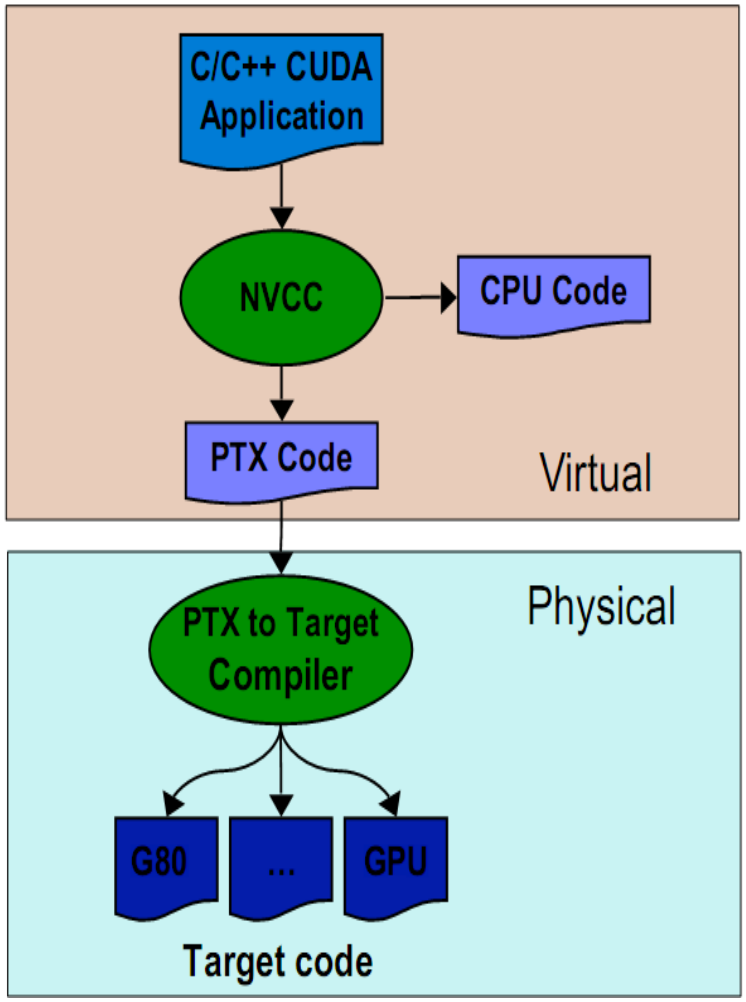
CUDA C Runtime

```
__global__ void kernel ( float * data )
{
   int idx = blockIdx.x * blockDim.x + threadIdx.x ;

   data [idx] = idx;
}
```

CUDA C Runtime

- NVCC
- .ptx
  - -keep



CUDA C Runtime

- NVCC
- .ptx
  - -keep

```
__global__ void kernel ( float * data )
{
   int idx = blockIdx.x * blockDim.x + threadIdx.x ;

   data [idx] = idx;
}
```

CUDA C Runtime

```
.entry _Z6kernelPf (.param .u32 __cudaparm__Z6kernelPf_data)
{
  .reg .u16 %rh<4>;
  .reg .u32 %r<8>;
  .reg .f32 %f<3>;
  .loc 14      6       0
  $LBB1__Z6kernelPf:
  .loc 14      10      0
  mov.u16      %rh1, %ctaid.x;  //
  mov.u16      %rh2, %ntid.x;   //
  mul.wide.u16         %r1, %rh1, %rh2;       //
  cvt.u32.u16  %r2, %tid.x;           //
  add.u32      %r3, %r2, %r1;   //
  cvt.rn.f32.s32       %f1, %r3;      //
  ld.param.u32         %r4, [__cudaparm__Z6kernelPf_data]; // id:14
  mul.lo.u32   %r5, %r3, 4;     //
  add.u32      %r6, %r4, %r5;   //
  st.global.f32        [%r6+0], %f1;          // id:15
  .loc 14      11      0
  exit;
  $LDWend__Z6kernelPf:
} // _Z6kernelPf
```

CUDA C Driver

```
CUdevice    device;
CUcontext   context;
CUmodule    module;
CUfunction  function;
CUdeviceptr pData;

float * pHostData = new float[N];

cuInit(0);

cuDeviceGetCount(&device_count);
cuDeviceGet( &device, 0 );

cuCtxCreate( &context, 0, device );

cuModuleLoad( &module, "hello.cuda_runtime.ptx" );
cuModuleGetFunction( &function, module, "_Z6kernelPf" );

cuMemAlloc( &pData, N * sizeof(float) );

// ...
```

CUDA C Driver

```
// ...
cuFuncSetBlockShape( function, N, 1, 1 );
cuParamSeti( function, 0, pData );
cuParamSetSize( function, sizeof(void *) );
cuLaunchGrid( function, 1, 1 );
cuMemcpyDtoH( pHostData, pData, N * sizeof( float) );
cuMemFree( pData );
```

OpenCL

- Кроссплатформенный стандарт
  - GPU, CPU, Cell, …
- Проблема: **функциональность, но не производительность**
  - Разный код для разных платформ
  - Разные расширения openGL-style

CUDA vs OpenCL Терминология

- CUDA C
  - Поток (thread)
  - Блок потоков (thread block)
  - Сеть (grid)
  - Ядро
- OpenCL
  - Элемент работы (work-item)
  - Группа работы (work-group)
  - N-мерное пространство индексов (ND-Range index space)
  - Ядро

CUDA vs OpenCL
Спецификаторы функций

- CUDA C
  - __global__
  - __host__
  - __device__
- OpenCL
  - __kernel
  - `n/a`
  - `n/a`

CUDA vs OpenCL Пространство памяти

- CUDA C
  - __device__
  - __shared__
  - __constant__
  - local
- OpenCL
  - __global
  - __local
  - __constant
  - __private

OpenCL

```
cl_context ctx;
cl_command_queue cmd_q;
cl_program program;
cl_kernel kernel;
cl_device_id * pDevId = NULL;
```

```
ctx = clCreateContextFromType(0,CL_DEVICE_TYPE_GPU,0,0,0);
```

```
clGetContextInfo(ctx,CL_CONTEXT_DEVICES,0,0,&dev_cnt);
clGetContextInfo(ctx,CL_CONTEXT_DEVICES,dev_cnt,pDevId,0);
```

```
cmd_q= clCreateCommandQueue(ctx,pDevId[0],0,0);
```

```
program = clCreateProgramWithSource(ctx,1,pText,0,0);
clBuildProgram(program, 0,0,0,0,0);
```

```
kernel = clCreateKernel(program, "simple", 0);
```

OpenCL

```
cl_mem mem = clCreateBuffer(ctx,CL_MEM_WRITE_ONLY,
                            N*sizeof(float),0,0);
```

```
clSetKernelArg(kernel, 0, sizeof(cl_mem),(void*) &mem);
clSetKernelArg(kernel, 1, sizeof(int),   (void*) &N);
```

```
clEnqueueNDRangeKernel(cmd_q,kernel,1,0,&N,&N,0,0,0);
```

```
clEnqueueReadBuffer(cmd_q, mem, CL_TRUE, 0,
                    N*sizeof(float), pData,0,0,0);
```

```
clReleaseMemObject(mem);
clReleaseKernel(kernel);
clReleaseProgram(program);
clReleaseCommandQueue(cmd_q);
clReleaseContext(ctx);
```

DirectX Compute

- Microsoft API
- Тесно интегрирован с Direct3D
- Доступен
  - CS 4.x: DirectX 10 HW
  - CS 5.x: DirectX 11 HW

DirectX

- ID3D11Device
  - ID3D11Resource
  - ID3D11View
- ID3D11DeviceContext

CUDA vs DirectX
Спецификаторы функций

- CUDA C
  - __global__
  - __host__
  - __device__
- DirectX
  - Compute Shader
  - `n/a`
  - `n/a`

CUDA vs DirectX Compute Пространство памяти

- CUDA C
  - __device__
  - __shared__
  - __constant__
  - local
- DirectX
  - [Structured]Buffer
  - groupshared
  - Constant Buffer
  - n/a

DirectX

- ID3D11Device
  - ID3D11Resource
  - ID3D11View
- ID3D11DeviceContext
- ID3D11Asynchronous
  - ID3D11Query
- ID3D11ComputeShader
- ID3DX11Effect

DirectX

- ID3D11Device
  - ID3D11Resource
    - Buffer
    - StructuredBuffer
    - Texture
  - ID3D11View
    - ShaderResourceView
    - UnorderedAccessView
    - RenderTargetView

DirectX

- ID3D11DeviceContext
  - Dispatch(bx, by, bz)
  - DispatchIndirect(pBuffer, offset)
  - End(pQuery)
  - GetData(g_pQuerry, NULL, 0, 0)

DirectX

ID3D11ComputeShader

- ConstantBuffer
- ShaderResourceView
- UnorderedAccessView

ID3D11Effect

- ConstantBuffer
- ShaderResourceView
- UnorderedAccessView

DirectX

ID3D11ComputeShader

```
pContext->CSSetShader(pCS, NULL, 0);
pContext->CSSetUnorderedAccessViews(0, 1, &pRWBufUAV, NULL);
```

ID3D11Effect

```
pEffect->GetVariableByName("tSimple")->AsUnorderedAccessView()-
   >SetUnorderedAccessView(pRWBufUAV);

pEffect->GetTechniqueByName("tSimple")->GetPassByName("pSimple")-
   >Apply(0, pContext);
```

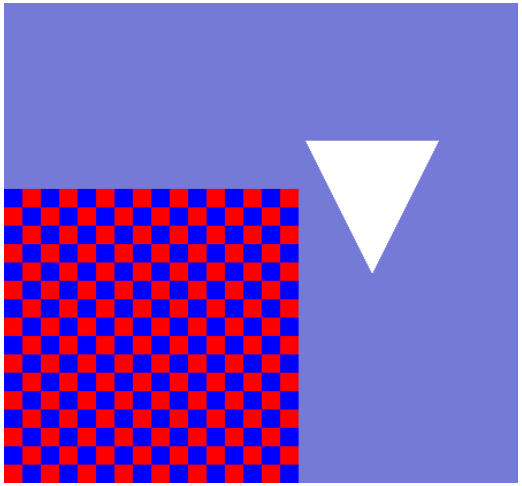
```
20  #define GROUP_SIZE 16
21
22  unsigned int    g_bufPitch = 0;
23  unsigned int    g_bufWidth = 3;
24  unsigned int    g_bufHeight = 0;
25
26  RWBuffer<float4>  g_bufResult : register ( u0 );
27
28  [numthreads( GROUP_SIZE, GROUP_SIZE, 1 )]
29  void CS_Main_RWBuffer(uint3 gid : SV_GroupID,
30                        uint3 tid : SV_GroupThreadID,
31                        uint3 id : SV_DispatchThreadID)
32  {
33    if (id.x > g_bufWidth || id.y > g_bufHeight) return;
34
35    float4 pos[3] = { {0.0, 1.0, 0.0, 1.0}, {-1.0, -1.0, 0.0, 1.0}, {1.0, -1.0, 0.0, 1.0}};
36
37    int index = id.x % 3;
38
39    g_bufResult[id.x + id.y * g_bufPitch] = pos[index];
40  }
41
```

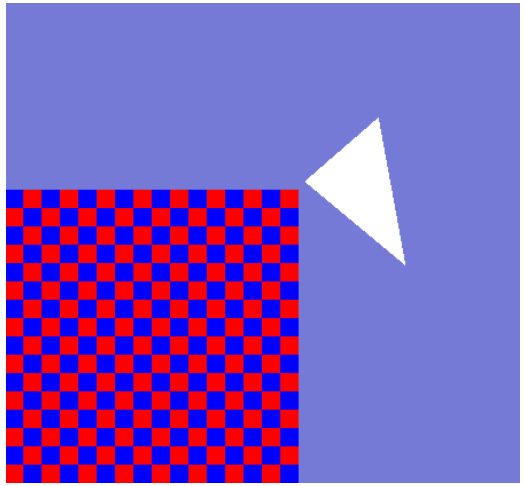
DirectX Compute

```
41  unsigned int     g_t2dWidth = 512;
42  unsigned int     g_t2dHeight = 512;
43  RWTexture2D<float4> g_t2dResult : register ( u1 );
44
45  [numthreads( GROUP_SIZE, GROUP_SIZE, 1 )]
46  void CS_Main_RWTexture2D(uint3 gid : SV_GroupID,
47                           uint3 tid : SV_GroupThreadID,
48                           uint3 id : SV_DispatchThreadID)
49  {
50    if (id.x > g_t2dWidth || id.y > g_t2dHeight) return;
51
52    if ((gid.x % 2 == 0 && gid.y % 2 == 0) || (gid.x % 2 == 1 && gid.y % 2 == 1))
53      g_t2dResult[id.xy] = float4(1, 1, 0, 1);
54    else
55      g_t2dResult[id.xy] = float4(1, 0, 1, 1);
56  }
57
```

DirectX Compute

```
59  technique11 tFillUAV
60  {
61      pass pFillRWTexture2D
62      {
63          SetComputeShader(CompileShader(cs_5_0, CS_Main_RWTexture2D()));
64      }
65
66      pass pFillRWBuffer
67      {
68          SetComputeShader(CompileShader(cs_5_0, CS_Main_RWBuffer()));
69      }
70  };
```

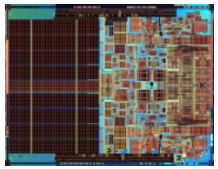




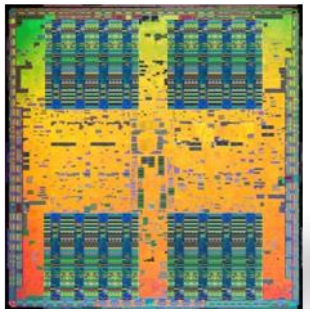
Multi-GPU

- CUDA
- OpenMP
- MPI
- OS Threads

Multi-GPU



CPU

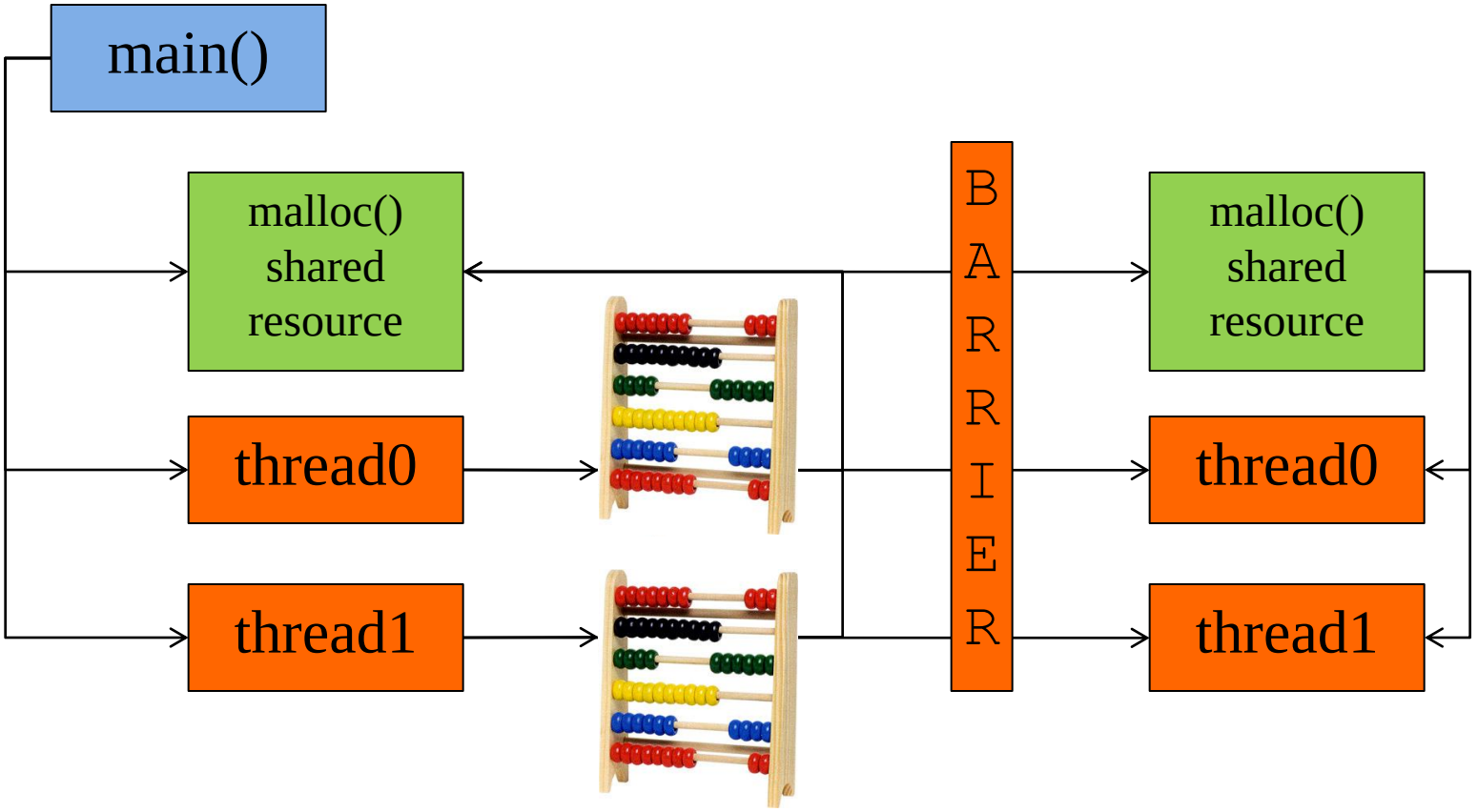


GPU

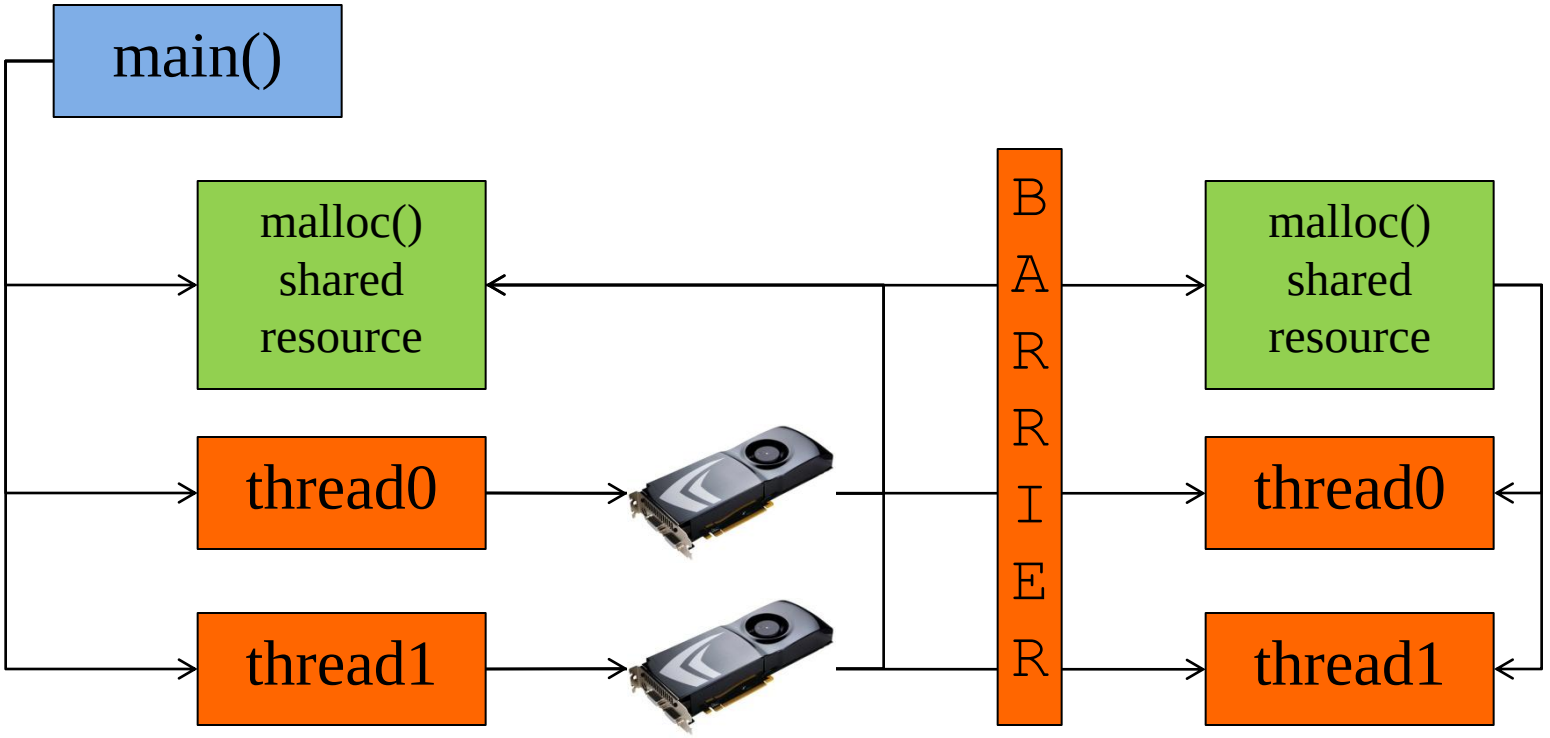
CUDA

Кластер

Пример


main()
malloc()
shared
resource
thread0
thread1
BARRIER
malloc()
shared
resource
thread0
thread1

Пример


main()
malloc()
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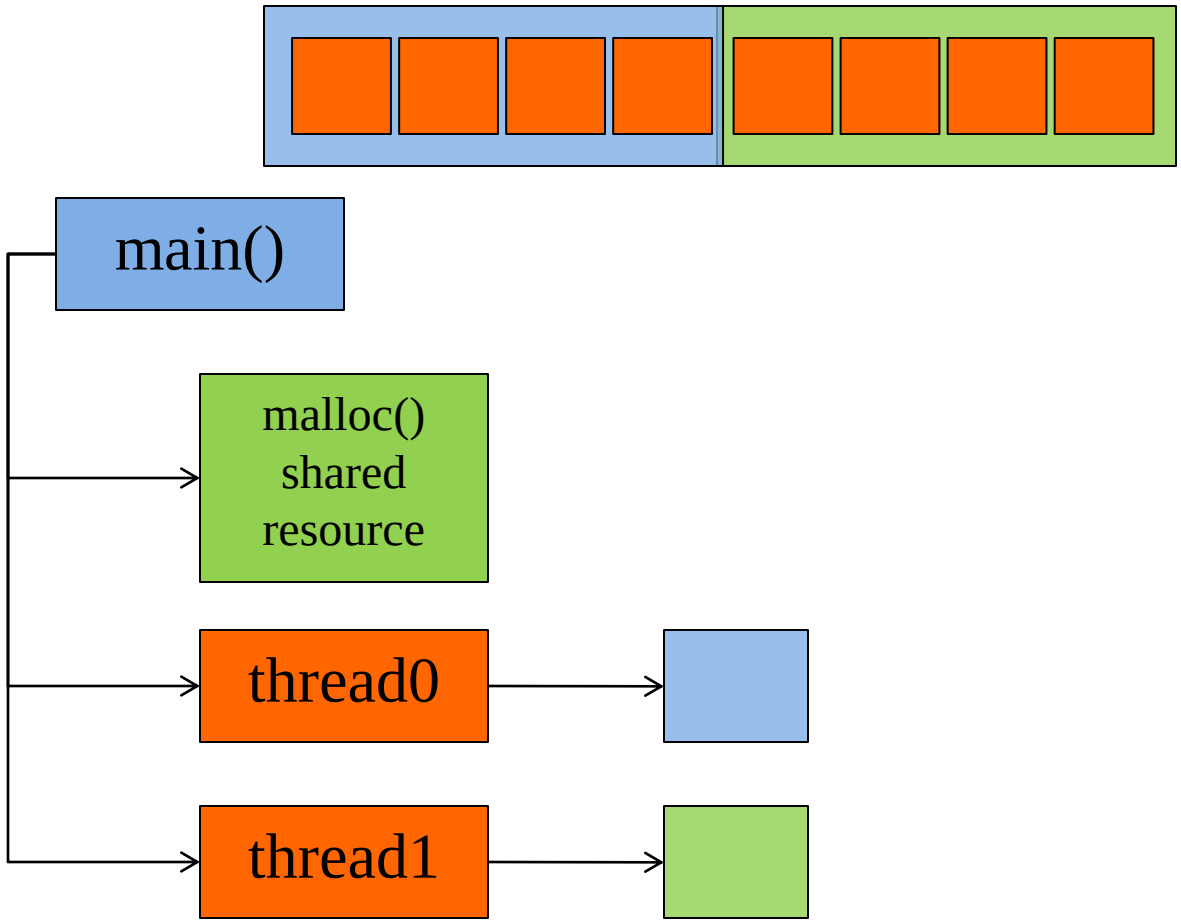
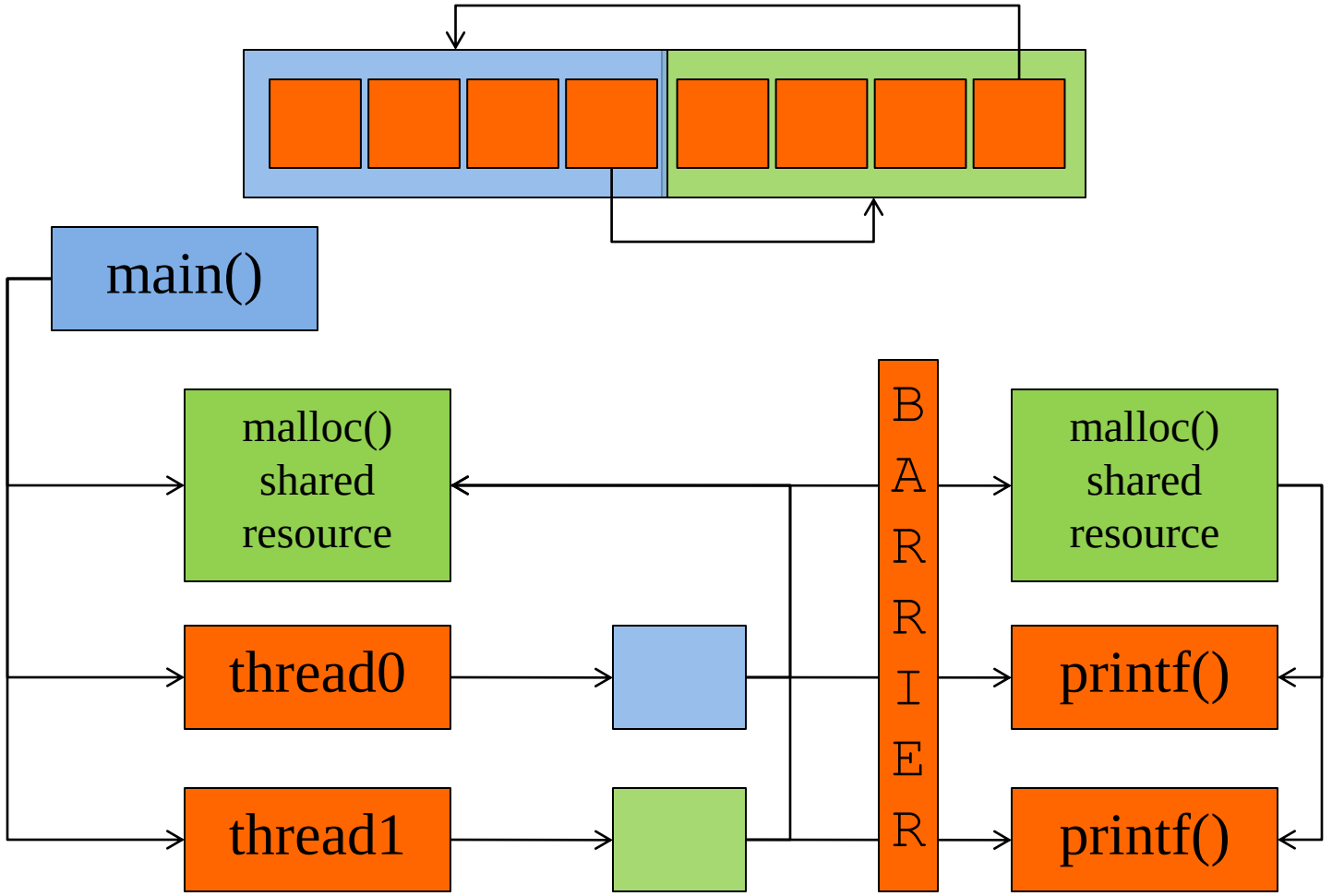
Модельная задача



Модельная задача

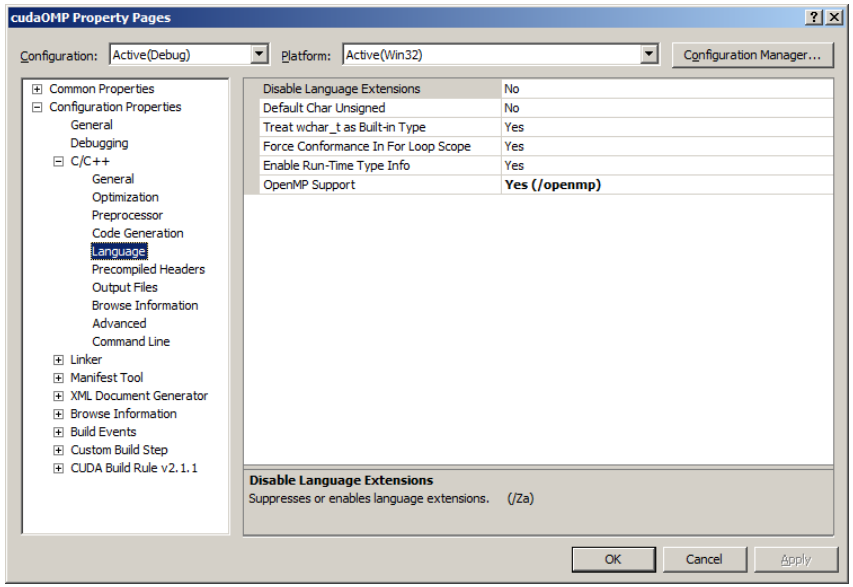


CUDA

- cudaGetDeviceCount()
- cudaSetDevice()

OpenMP

- omp_set_num_threads()
- omp_get_thread_num()
- omp_get_num_threads()
- #pragma omp parallel
- #pragma omp barrier



Модельная задача

```
9   void Kernel_Wrapper(float *, int, int);
10
11  int main(int argc, char * argv[])
12  {
13    int device_count = 0;
14    int N = 32;
15
16    cudaGetDeviceCount(&device_count);
17    omp_set_num_threads(device_count);
18
19    float *shared_mem = new float[device_count];
20
```

Модельная задача

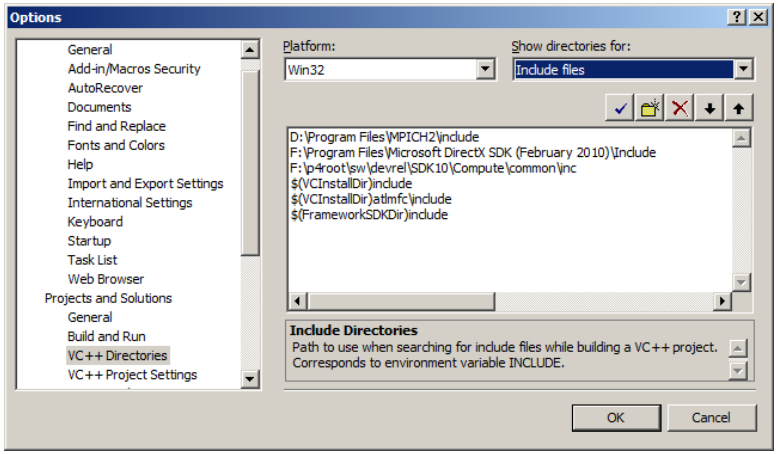
```
21  #pragma omp parallel
22    {
23      unsigned int cpu_thread_id = omp_get_thread_num();
24      unsigned int num_cpu_threads = omp_get_num_threads();
25
26      cudaSetDevice(cpu_thread_id);
27
28      fprintf(stdout, "Rank %d size %d device %d / %d\n",
29        cpu_thread_id, num_cpu_threads, device_count);
30
31      float * dData = NULL;
32      float * hData = NULL;
33
34      cudaMallocHost((void **) &hData, N * sizeof(float));
35      cudaMalloc((void **) &dData, N * sizeof(float));
36
37      Kernel_Wrapper(dData, cpu_thread_id, N);
38
39      cudaMemcpy(hData, dData, N * sizeof(float), cudaMemcpyDeviceToHost);
40
41      fprintf(stdout, "0 : %f | 1 : %f | 2 : %f | 3 : %f\n",
42        hData[0], hData[1], hData[2], hData[3]);
43
44      shared_mem[(cpu_thread_id + 1) % num_cpu_threads] = hData[3];
```

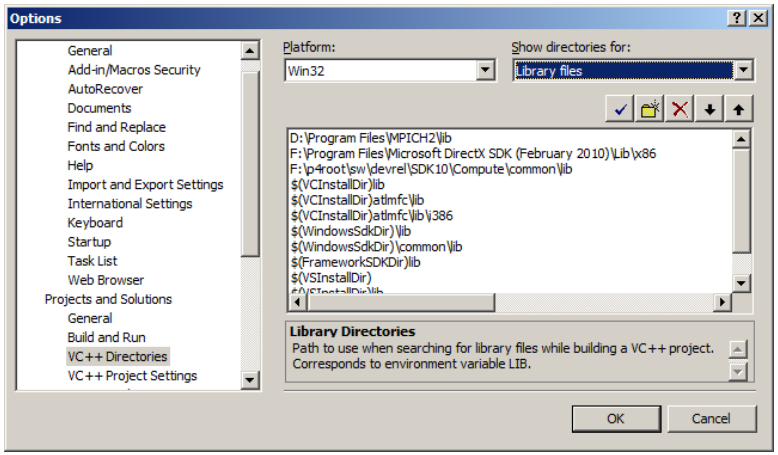
Модельная задача

```
46  #pragma omp barrier
47
48      fprintf(stdout, "Thread %d recv %f\n", cpu_thread_id, shared_mem[cpu_thread_id]);
49
50      cudaFree(dData);
51      cudaFreeHost(hData);
52    }
53
54    delete [] shared_mem;
55
56    return 0;
```

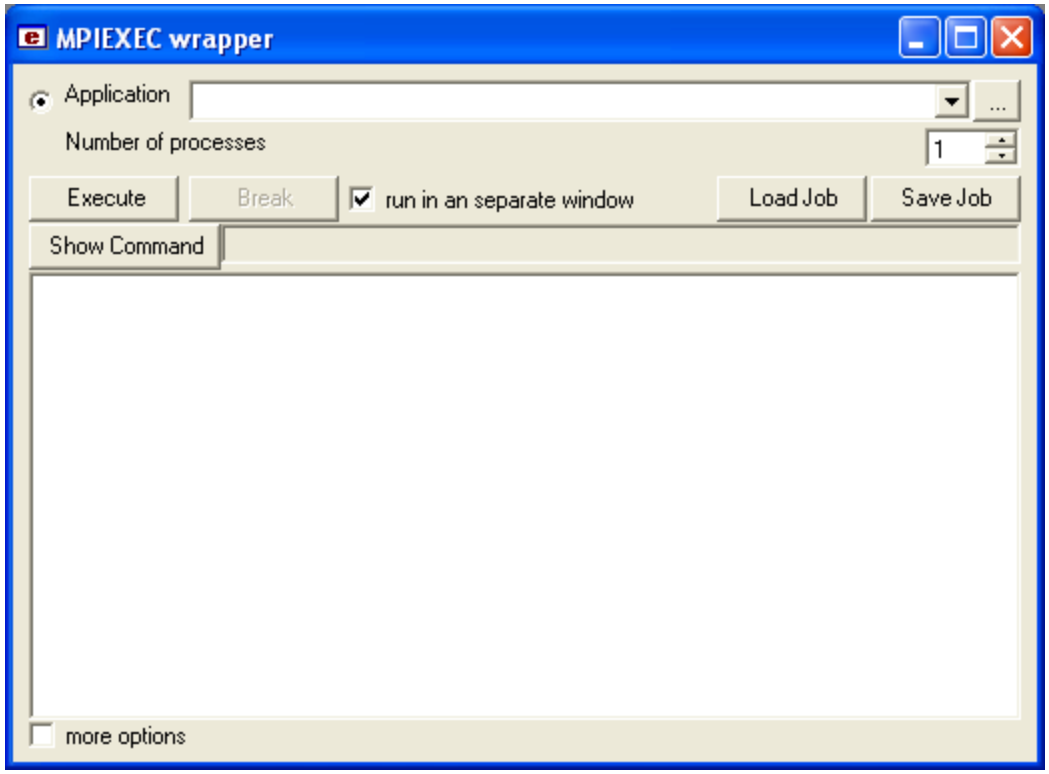
MPI

- MPICH2
- Инструкция по установке
- Programming Guide





Запуск MPI


MPIEXEC wrapper
Application
...
Number of processes
1
Execute
Break
run in an separate window
Load Job
Save Job
Show Command
more options

Модельная задача

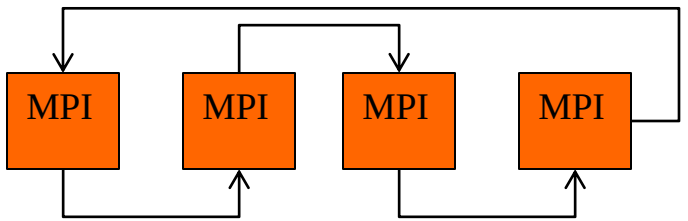
```
9  void Kernel_Wrapper(float *, int, int);
10
11 int main(int argc, char * argv[])
12 {
13   MPI_Init(&argc, &argv);
14   int N = 32;
15   int rank, size;
16
17   MPI_Comm_rank(MPI_COMM_WORLD, &rank);
18
19   MPI_Comm_size(MPI_COMM_WORLD, &size);
20
21   int device_count = 0;
22
23   cudaGetDeviceCount(&device_count);
24
25   int set_device = min(device_count-1, rank % size);
26
27   cudaSetDevice(set_device);
28
29   fprintf(stdout, "Rank %d size %d device %d / %d\n",
30     rank, size, set_device, device_count);
```

Модельная задача

```
32    float * dData = NULL;
33    float * hData = NULL;
34
35    cudaMallocHost((void **) &hData, N * sizeof(float));
36    cudaMalloc((void **) &dData, N * sizeof(float));
37
38    Kernel_Wrapper(dData, rank, N);
39
40    cudaMemcpy(hData, dData, N * sizeof(float),
41      cudaMemcpyDeviceToHost);
42
43    fprintf(stdout, "0 : %f | 1 : %f | 2 : %f | 3 : %f\n",
44      hData[0], hData[1], hData[2], hData[3]);
45
```

Модельная задача

```
46    float recvbuf = 0.0f;
47    MPI_Status st;
48
49    MPI_Send(&hData[3], 1, MPI_FLOAT, (rank+1) % size,
50      0, MPI_COMM_WORLD);
51    MPI_Recv(&recvbuf, 1, MPI_FLOAT, (size + rank-1) % size,
52      0, MPI_COMM_WORLD, &st);
53
54    fprintf(stdout, "Rank %d rec %f\n", rank, recvbuf);
55
56    cudaFree(dData);
57    cudaFreeHost(hData);
58
59    MPI_Finalize();
60
61    return 0;
62  }
```



Ссылки

- http://iproc.ru/programming/openmp-visual-studio/
- http://iproc.ru/programming/mpich-windows/
- http://www.mcs.anl.gov/research/projects/mpich2/

Ресурсы нашего курса

- CUDA.CS.MSU.SU
  - Место для вопросов и дискуссий
  - Место для материалов нашего курса
  - Место для ваших статей!
    - Если вы нашли какой-то интересный подход!
    - Или исследовали производительность разных подходов и знаете, какой из них самый быстрый!
    - Или знаете способы сделать работу с CUDA проще!
- Steps3d.narod.ru
- www.nvidia.ru