Concurrent Systems (ComS 527)

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PARALLEL PROGRAMMING MODELS

Parallel programing model

Abstraction of the underlying computer system that allows for the expression of parallel algorithms and data structures

Adapted from McCormick et al.

Implementation via

Languages or language extensions

APIs

Compiler directives

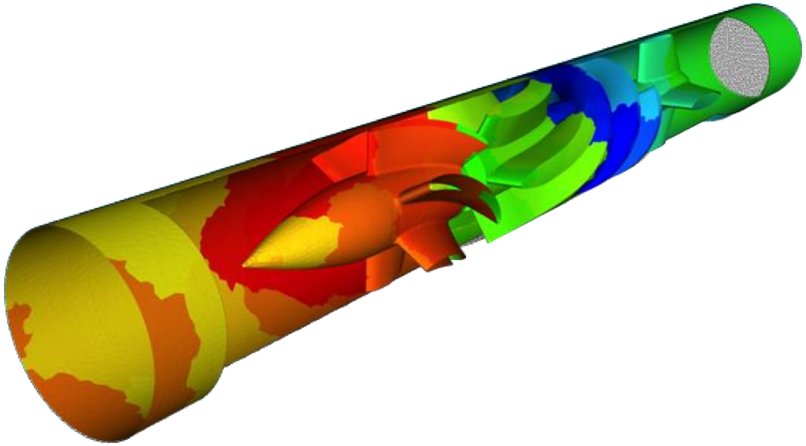
Objectives

Performance	Maximize parallel speedup
Productivity	Minimize time needed for • Writing code • Debugging • Performance optimization
Portability	Compiles & runs on another system Achieves comparable performance

Parallel programming model

Example

- Ventricular assist device
- FEM method
- Parallelization via geometric domain decomposition



Key abstractions

Concurrency

Memory

Communication

Synchronization

Single Program Multiple Data

- The same program is executed on multiple processors
- Underlying principle of most programming models
- Processes or threads are enumerated
- Each process or thread knows
  - Its own number (ID)
  - The total number

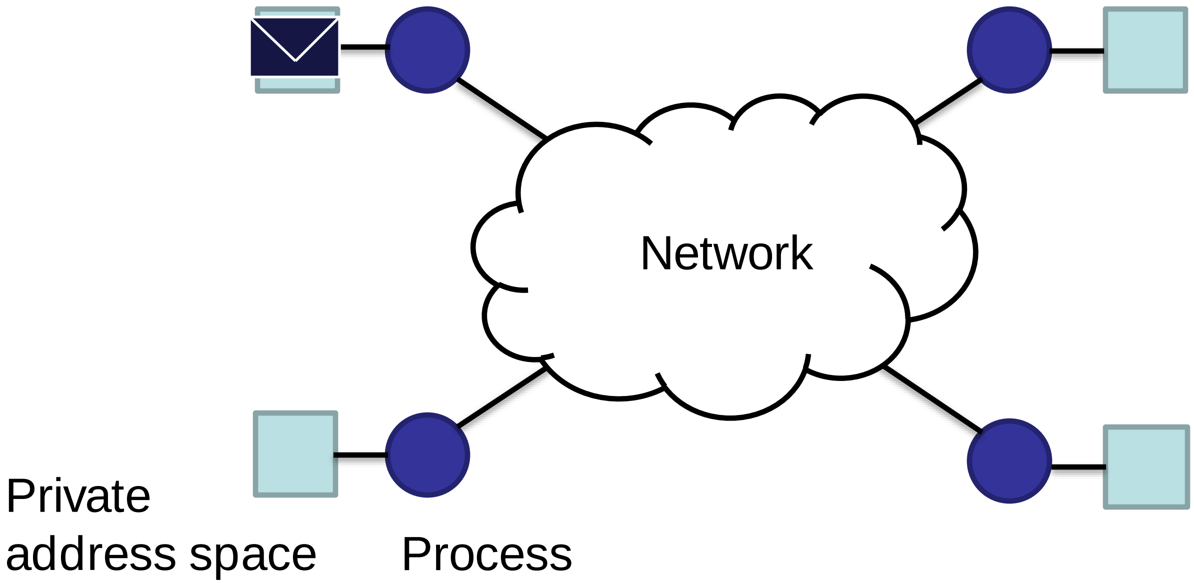
```
if (process_id == 42) then
  call do_something()
else
  call do_something_else()
endif
```

Same program but different control flows

Popular parallel programming models

Programming model	Primary target	Specific examples
Message passing	Compute cluster 	**MPI,** Julia
Multithreading	Multicore server 	**OpenMP**, C++11, OpenACC
GPGPU computing	GPU/TPU 	**CUDA**, OpenCL, Vulkan, OpenACC **OpenMP**

Message Passing Interface (MPI)



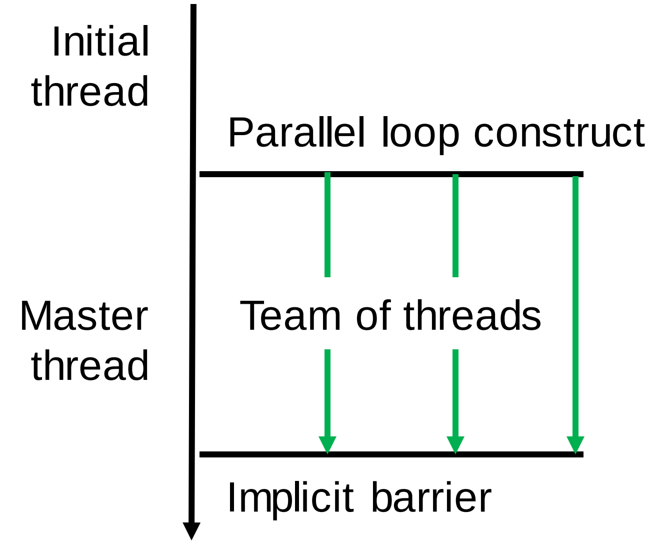

```
if (my_rank == SENDER)
  MPI_Send(buffer, count, datatype, RECEIVER, …);

if (my_rank == RECEIVER)
  MPI_Recv(buffer, count, datatype, SENDER, …);
```

OpenMP

```
void saxpy(…)
{
  int i;

#pragma omp parallel for
  for ( i = 0; i < n; i++ )
    z[i] = a * x[i] + y[i];
}
```

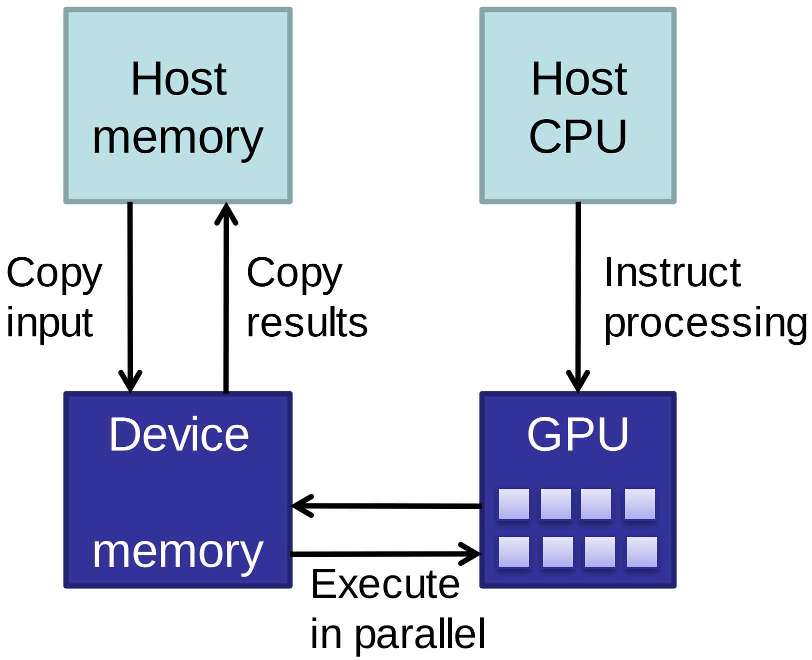


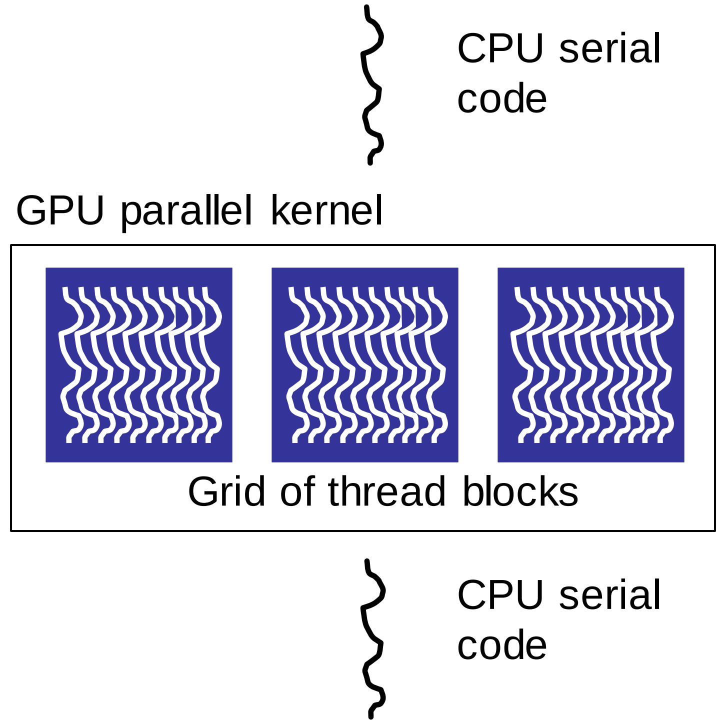
- Multiple threads communicate via shared variables
- Synchronization through barriers, lock-style methods, and atomic operations

CUDA

C with NVIDIA extensions

- Suitable for data-parallel workloads





Example: saxpy

Computing z = ax + y with serial loop

```
void saxpy_serial(…)
{
  int i;
  for (i=0; i<n; i++)
    z[i]= a * x[i] + y[i];
}
```

```
/* invoke serial saxpy kernel */
saxpy_serial(…);
```

Example: saxpy – CUDA

Computing z = ax + y with parallel loop

```
__global__
void saxpy_parallel(…)
{
  int i = blockIdx.x * blockDim.x + threadIdx.x;
  if (i<n) z[i]= a * x[i] + y[i];
}
```

```
/* invoke parallel saxpy kernel with n threads */
/* organized in 256 threads per block */
int nblocks = (n + 255) / 256;
saxpy_parallel<<<nblocks, 256>>>(…);
```

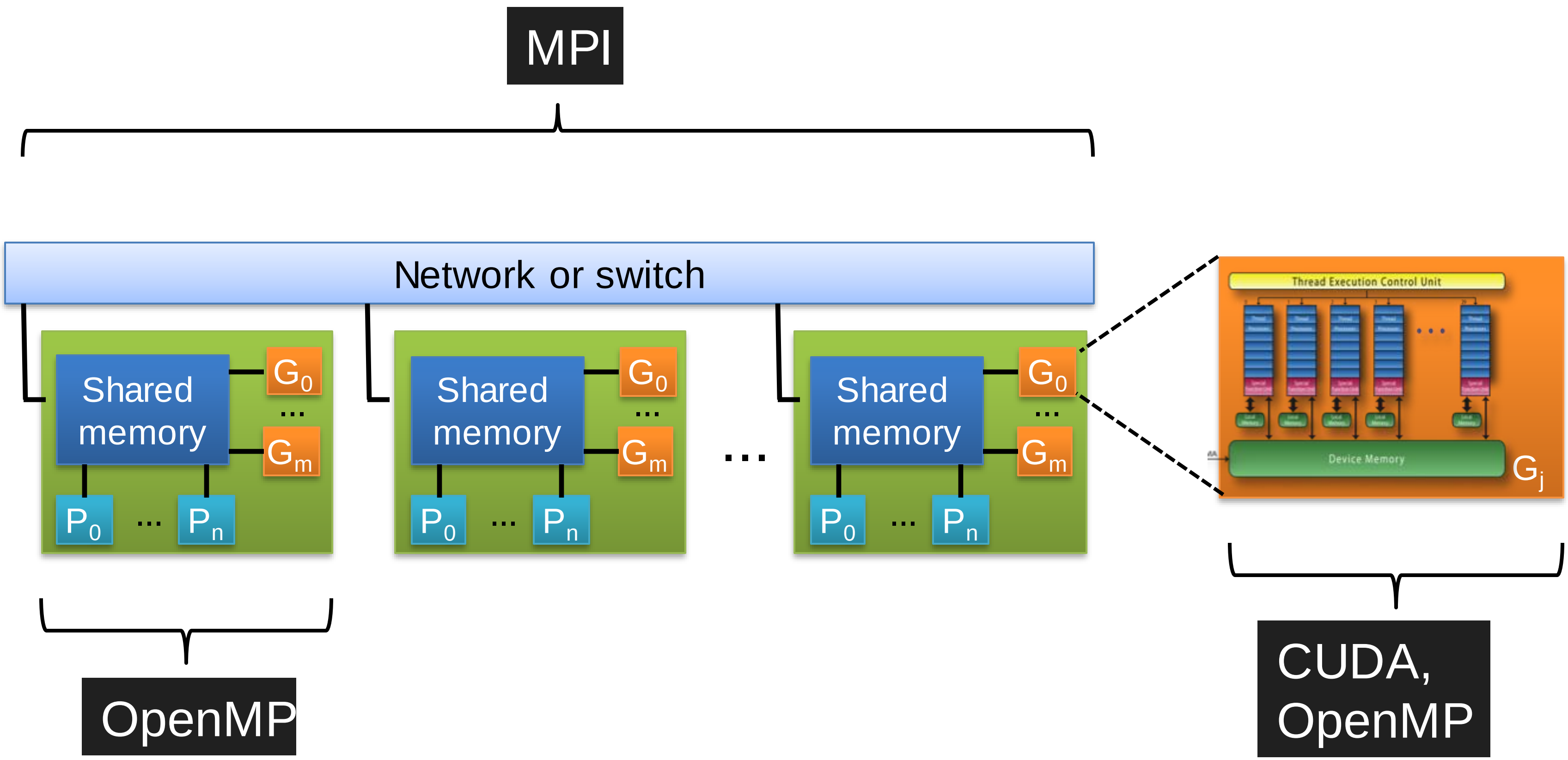
Example: saxpy – OpenMP for GPU

```
double x[N], y[N], s[N], a; /* calculate z=a*x+y  */

/* Compiler generates code for GPU */
/* Runtime runs code on device, copies data from/to GPU */
#pragma omp target
{
#pragma omp parallel for
for (int i=0; i<N; i++)
        s[i] = a*x[i] + y[i];
}
```

- Code is unmodified except for the pragma
- Data is **implicitly** copied
  - Moves this region of code to the GPU and implicitly maps data
- All calculation done on **device (GPU)**

Hybrid programming: MPI + X



Numba: High-Performance **Python** with CUDA Acceleration

Comparison

Programming model	Advantage	Disadvantage
MPI	Scalable	Parallelization requires major re-design
OpenMP	Incremental parallelization	Limited scalability Hard to debug
CUDA	Efficient & scalable for data-parallel workloads	High code complexity, laborious optimization

Summary

- Mainstream parallel programming models
  - MPI
  - OpenMP
  - CUDA