TECHNISCHE
UNIVERSITÄT
DARMSTADT

System and Parallel Programming

Prof. Dr. Felix Wolf

PARALLEL PROGRAMMING MODELS

Parallel programing model

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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

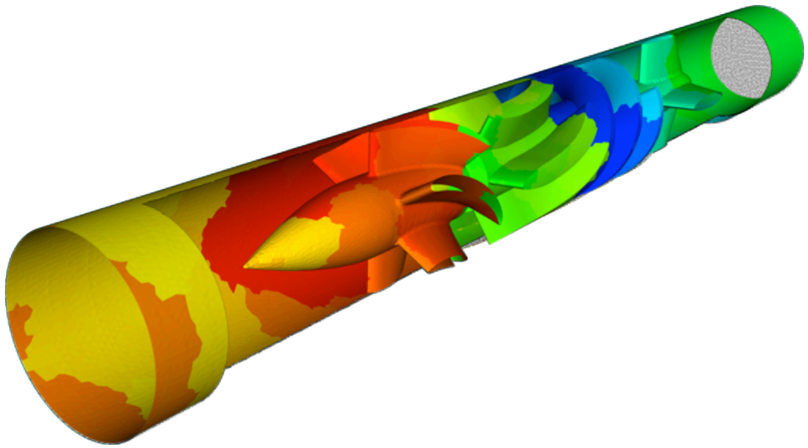
Objectives

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

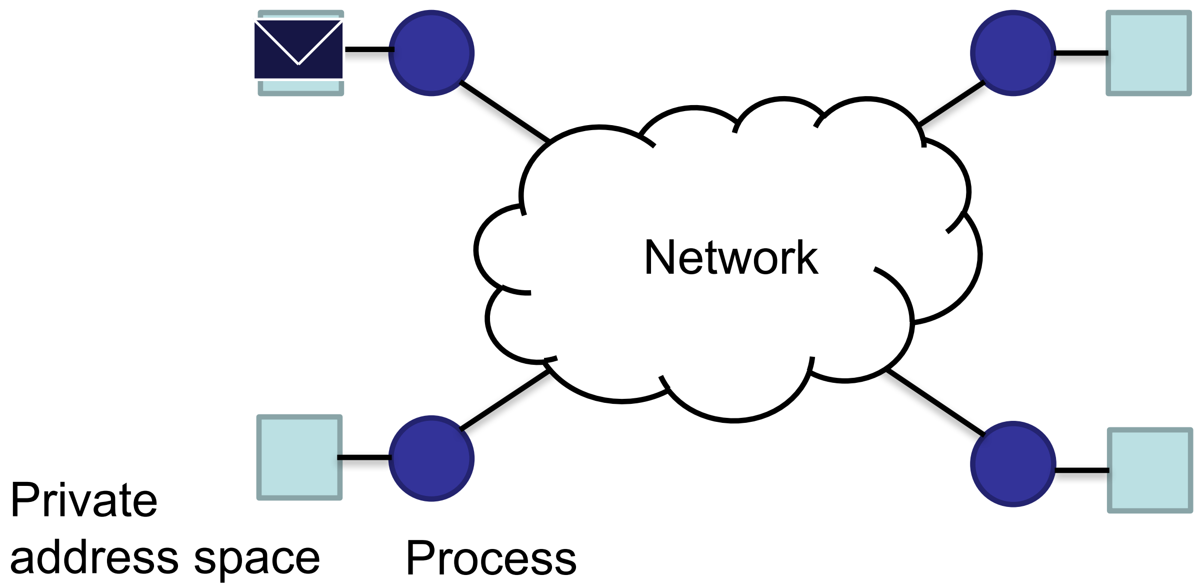
```
if (process_id == 42) then
  call do_something()
else
  call do_something_else()
endif
```

Same program but different control flows

Popular parallel programming models

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

Message Passing Interface



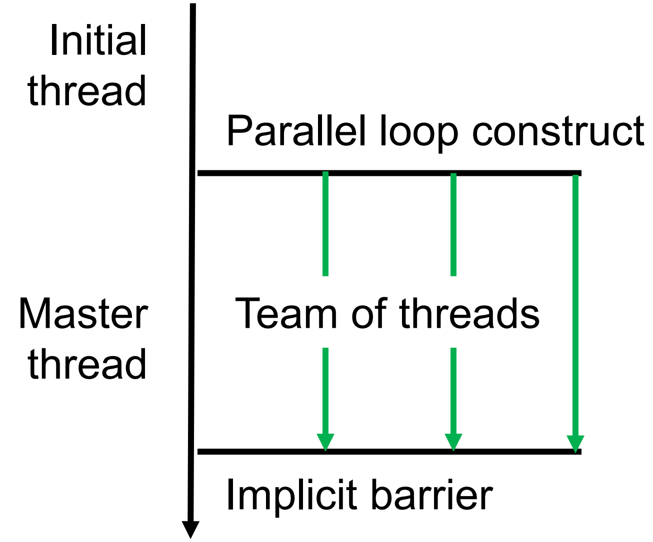

```
if (my_rank == SENDER)
   MPI_Send(buffer, count, datatype, RECEIVER, …);

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];
}
```

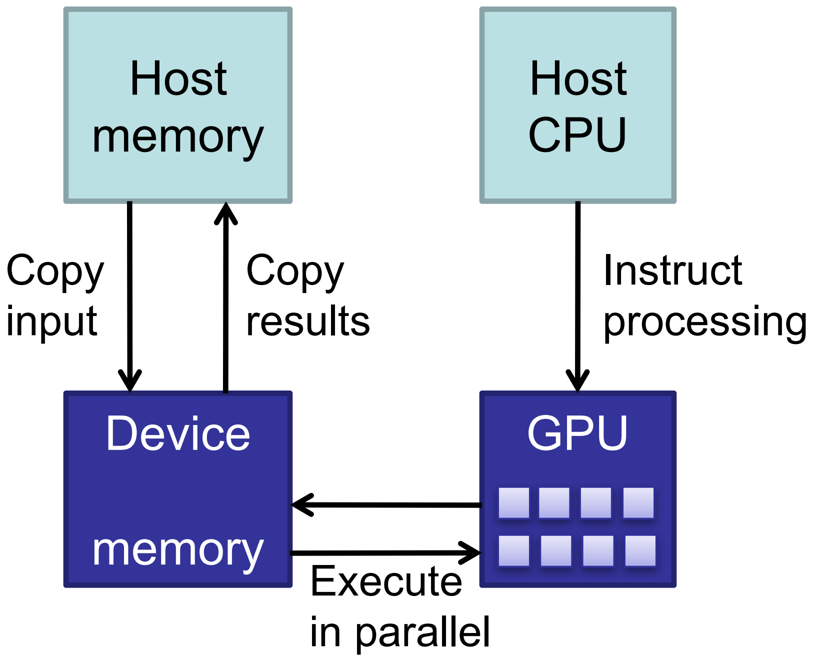


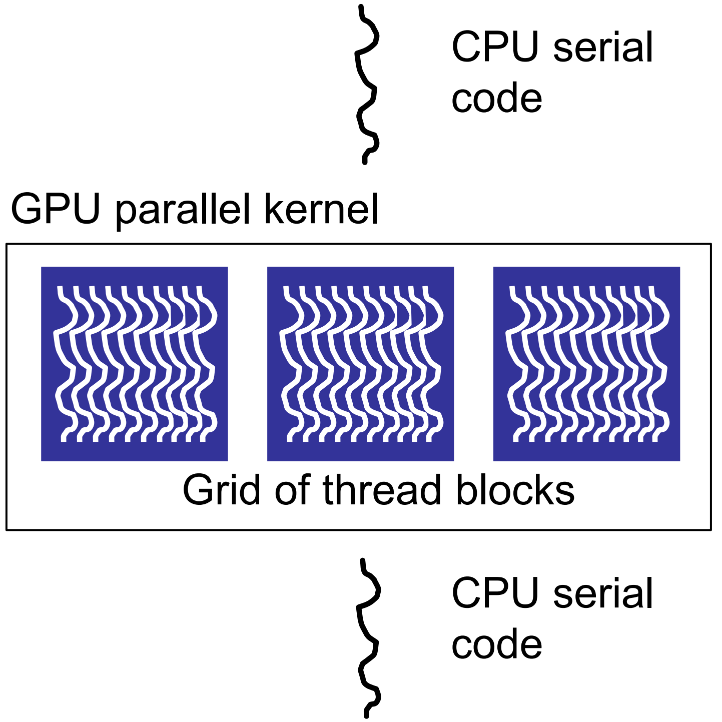
- Multiple threads communicate via shared variables
- Synchronization through barriers, lock-style methods, and atomic operations

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(…);
```

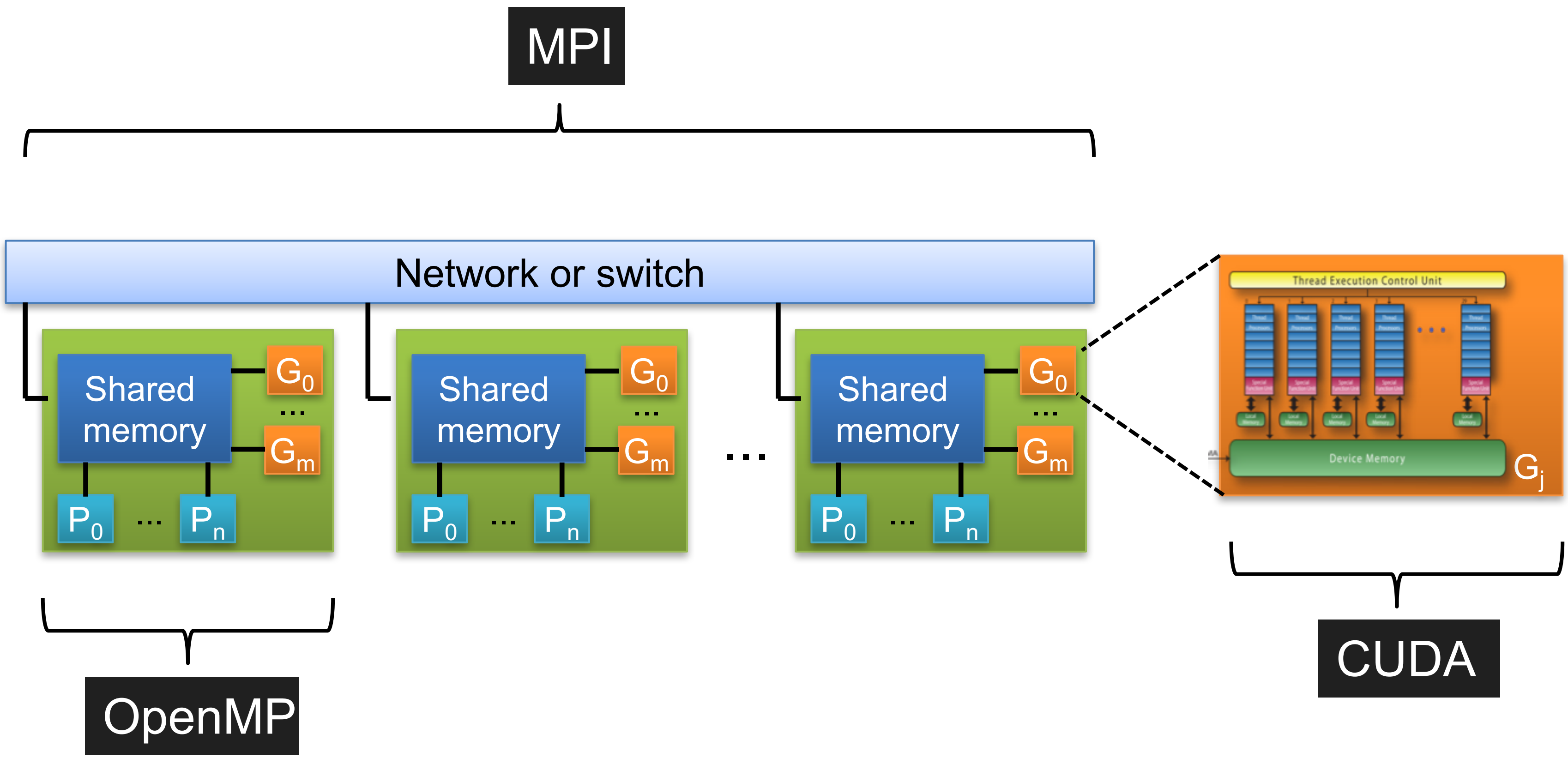
Example: saxpy (2)

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>>>(…);
```

Hybrid programming: MPI + X



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