Panorama des modèles et outils de programmation parallèle

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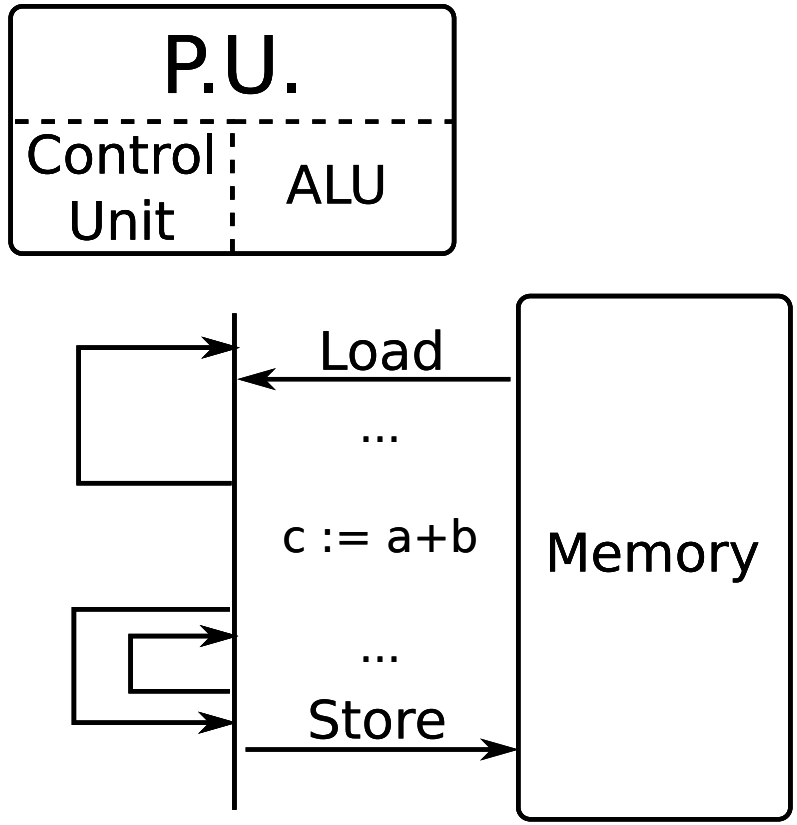
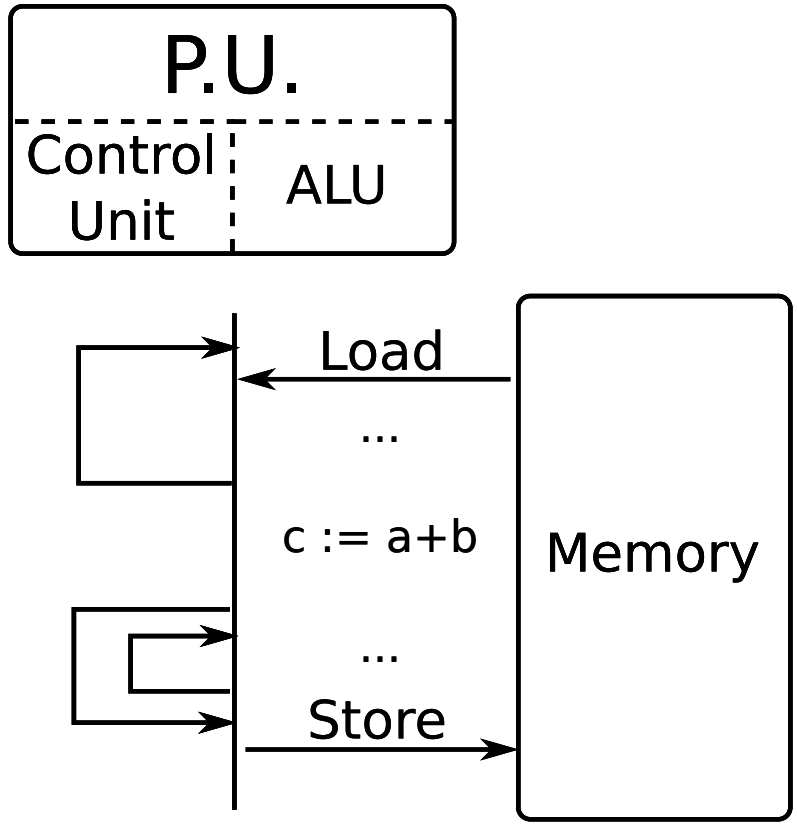
Outline

Introduction

Unicore



Unicore

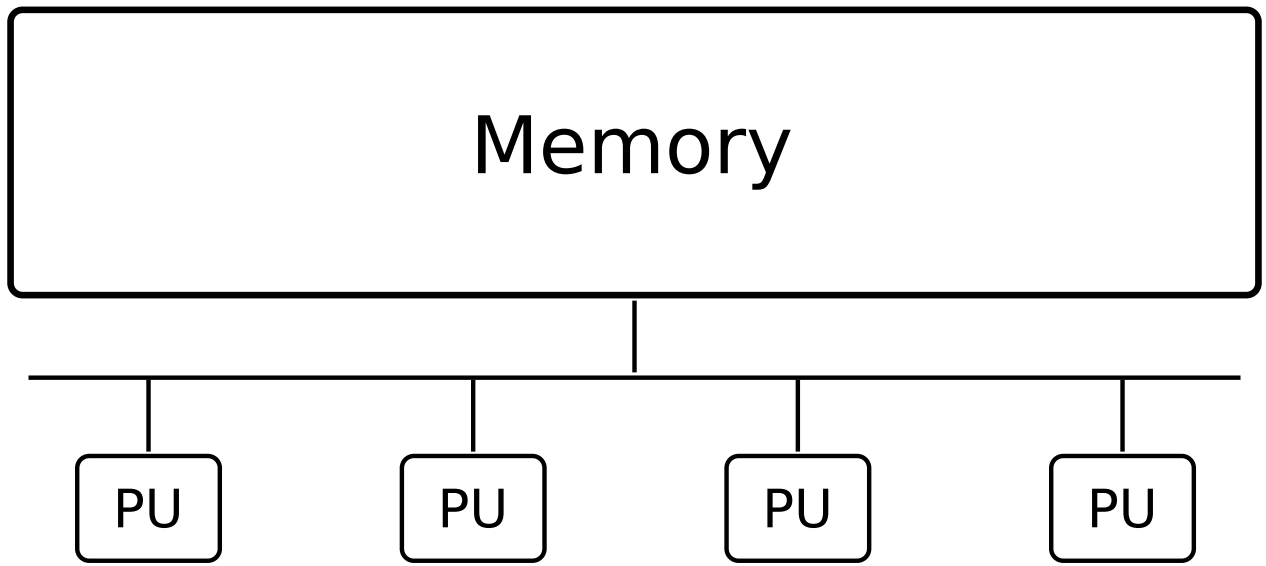


- asm (x86...), C, Fortran, C++...

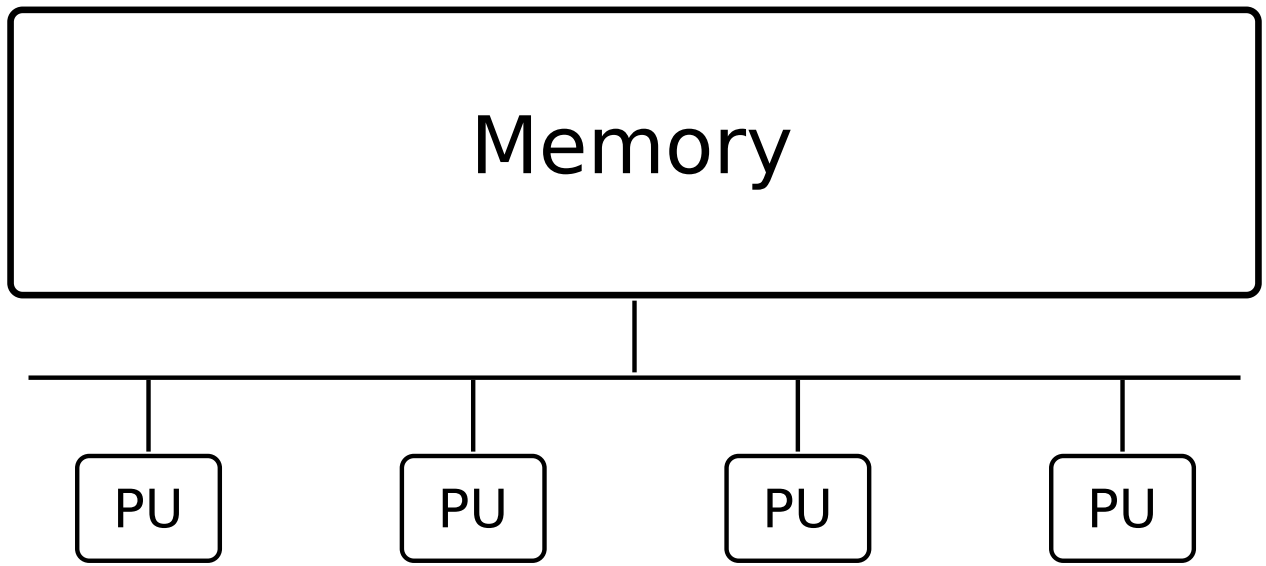
Moore's Law + Frequency Wall = Parallelism

(mandatory slide)

Multicore



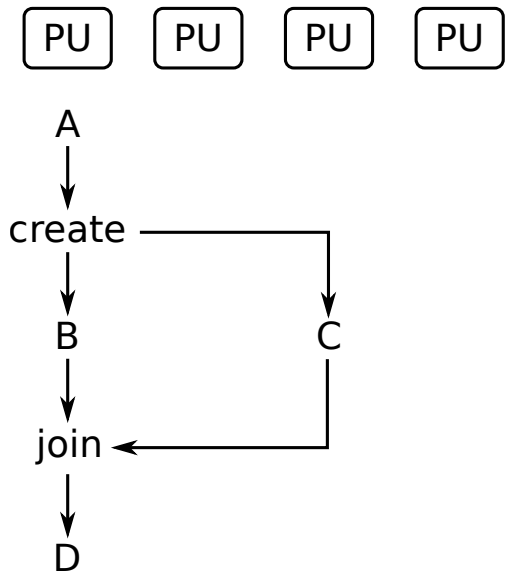
Multicore



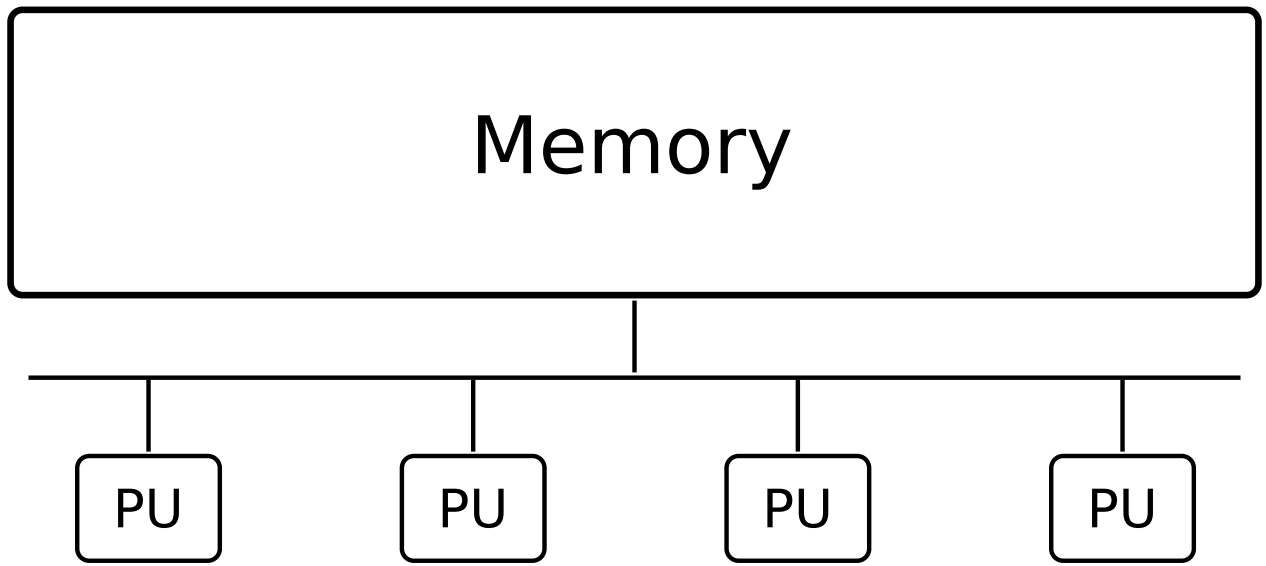
- PThread

POSIX Threads (PThread)

```c
#include <pthread.h>

void * mythread(void * arg) {
    // C
}

int main() {
    pthread_t tid;

    // A

    pthread_create(&tid, NULL, &mythread, NULL);

    // B

    pthread_join(tid, NULL);

    // D
}
```



Multicore

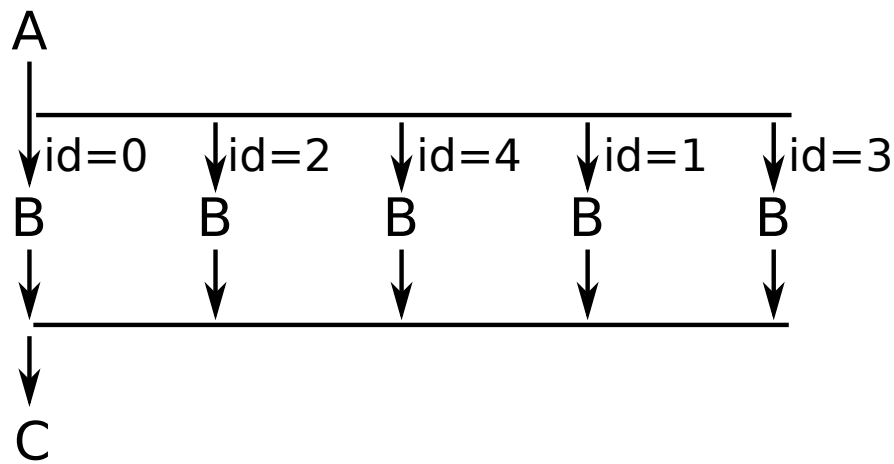


- PThread
- OpenMP

OpenMP

```c
#include <omp.h>

int main() {

    // A

    #pragma omp parallel num_threads(5)
    {
        int id = omp_get_thread_num();
        printf("My id: %d\n", id); // B
    }

    // C
}
```

```
% gcc -fopenmp test.c
% ./a.out
My id: 1
My id: 3
My id: 0
My id: 2
My id: 4
```

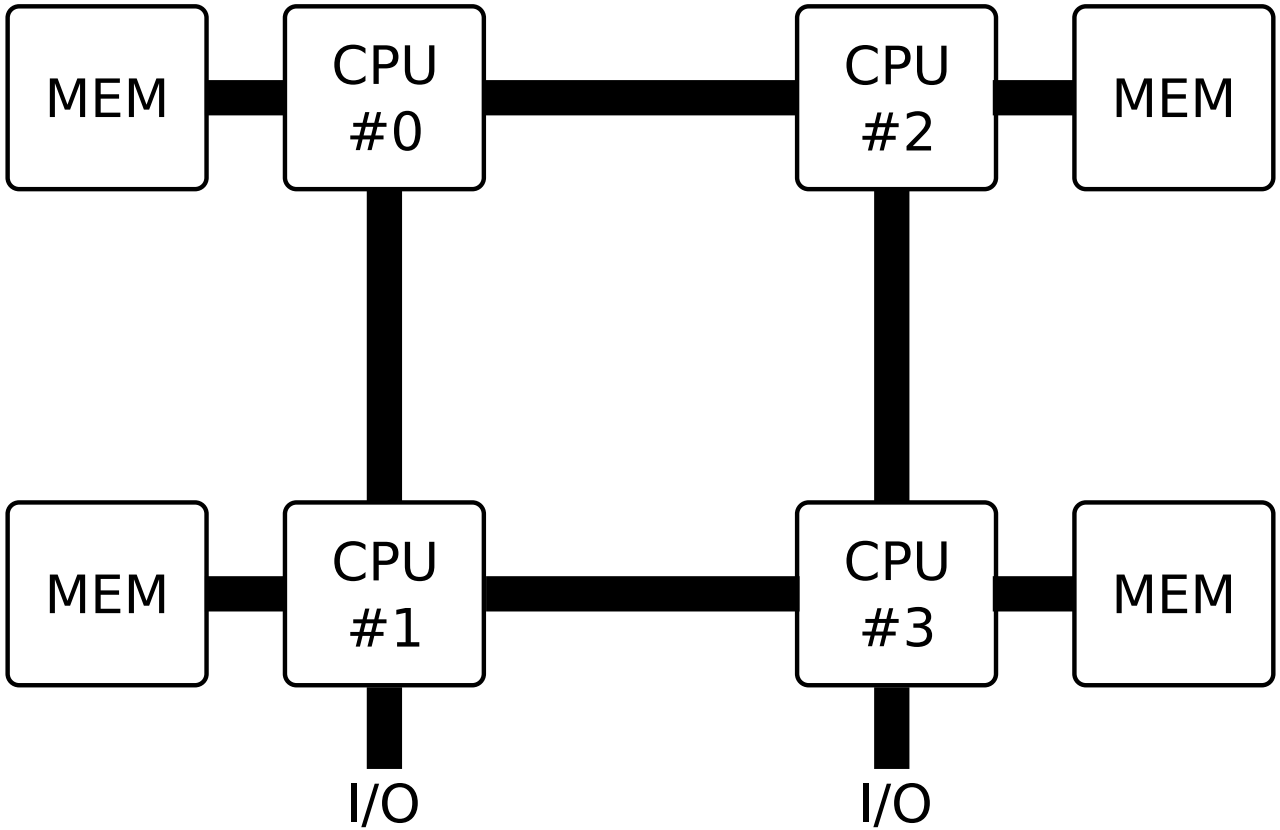


OpenMP

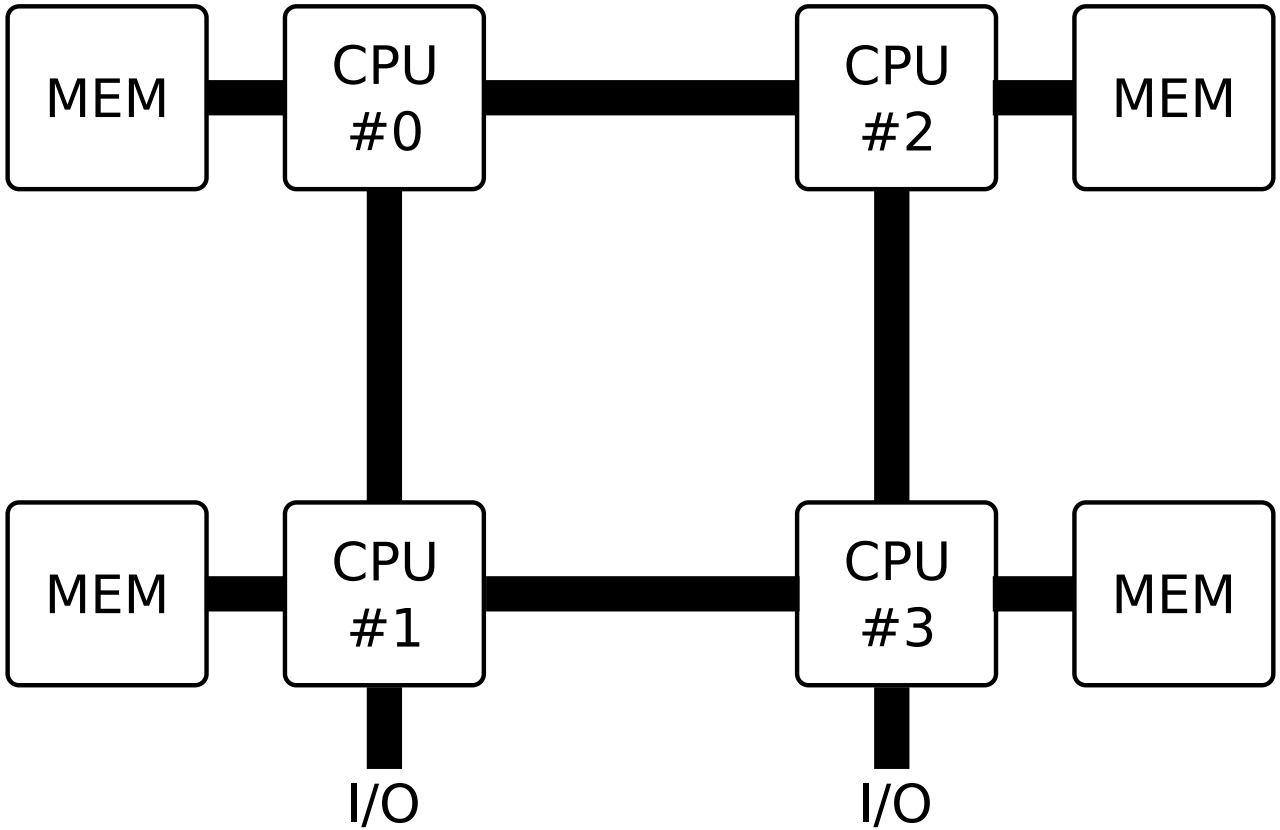
```
#pragma omp parallel for num_threads(3)
for (int i=0; i<10; i++) {
    int id = omp_get_thread_num();
    printf("%d: %d\n", id, i);
}
```

```
% ./a.out
2: 7
2: 8
2: 9
1: 4
1: 5
1: 6
0: 0
0: 1
0: 2
0: 3
```

Multicore with NUMA

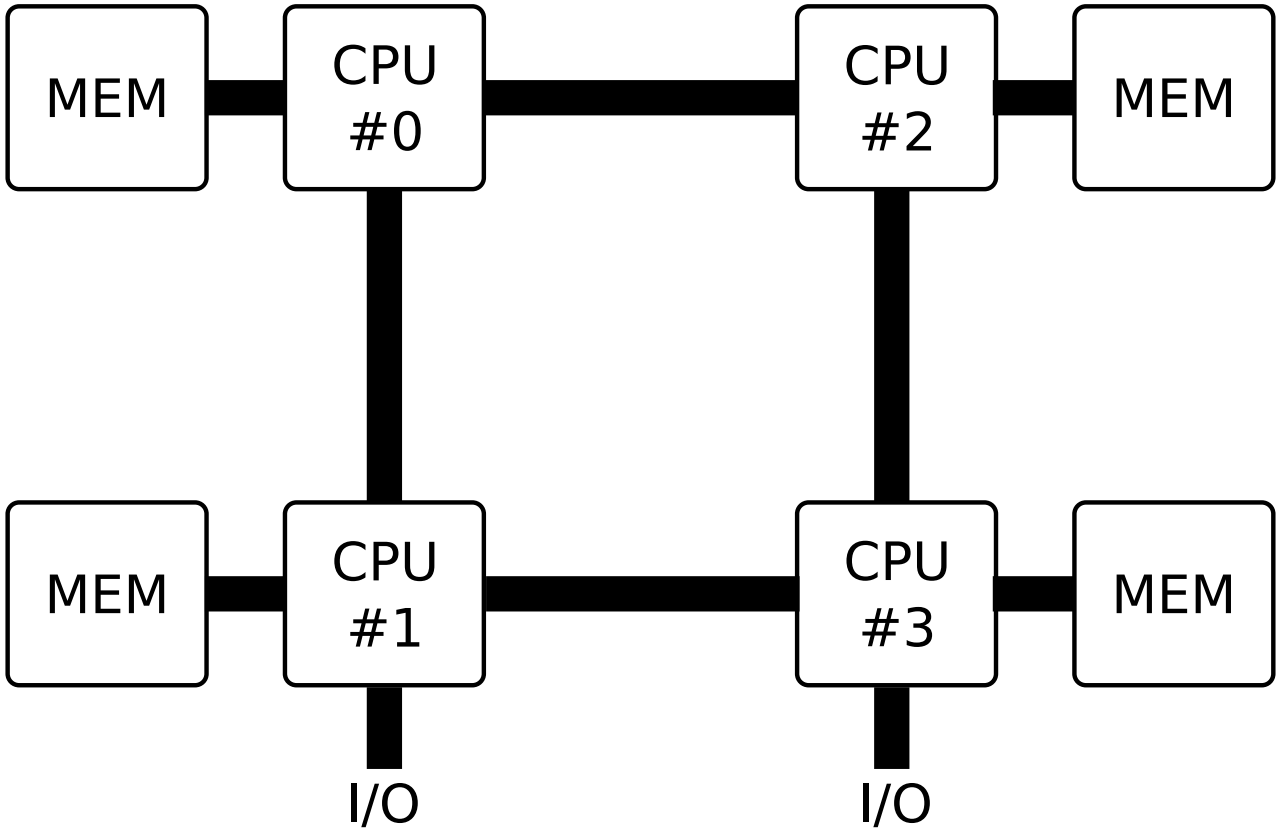


Multicore with NUMA



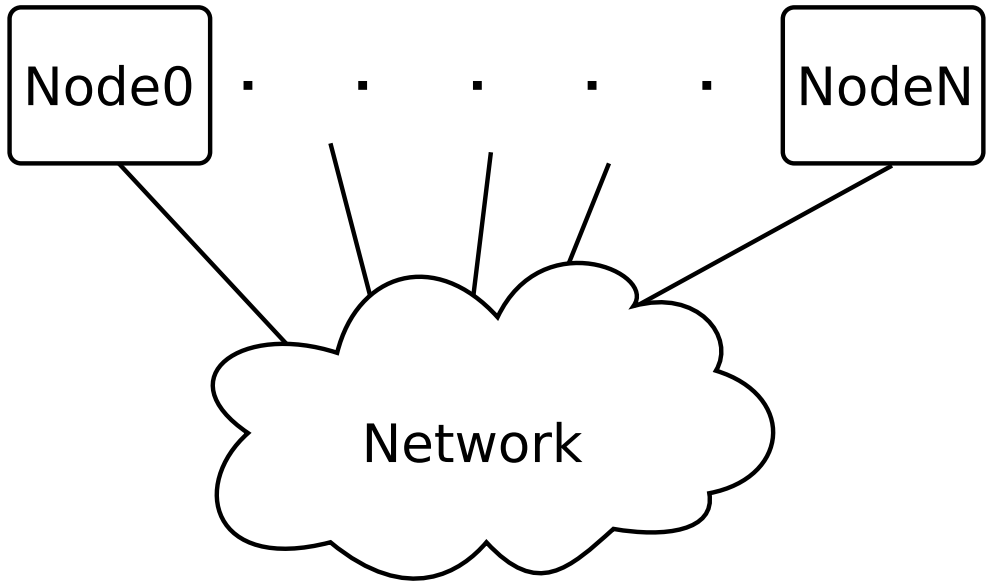
- Issues: thread scheduling (data affinity...), data migration...

Multicore with NUMA

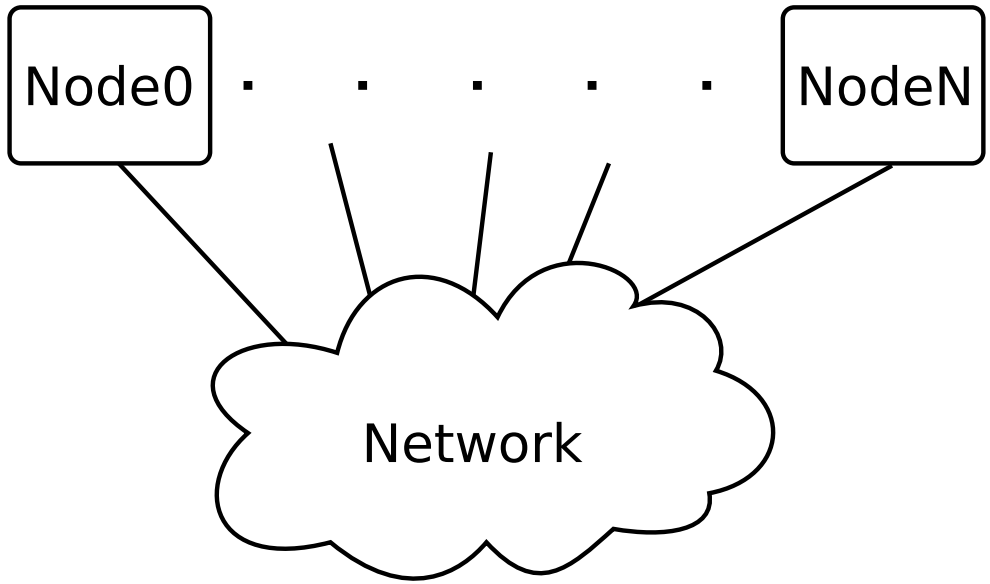


- Issues: thread scheduling (data affinity...), data migration...
- e.g. OpenMP: ForestGomp

Clusters



Clusters

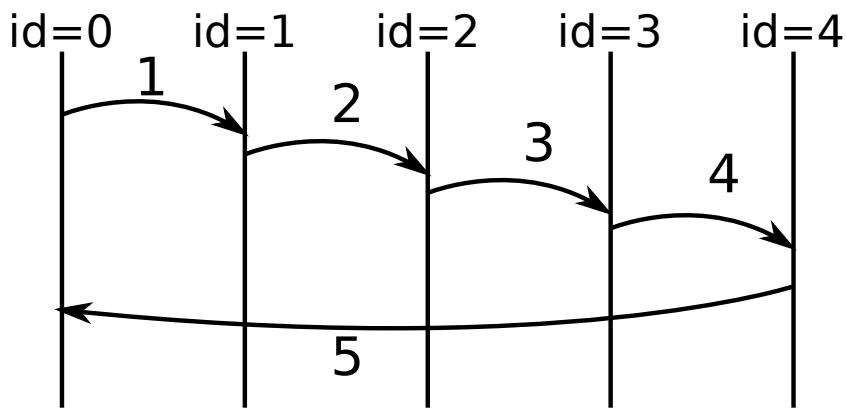


- Synchronous Message Passing: MPI

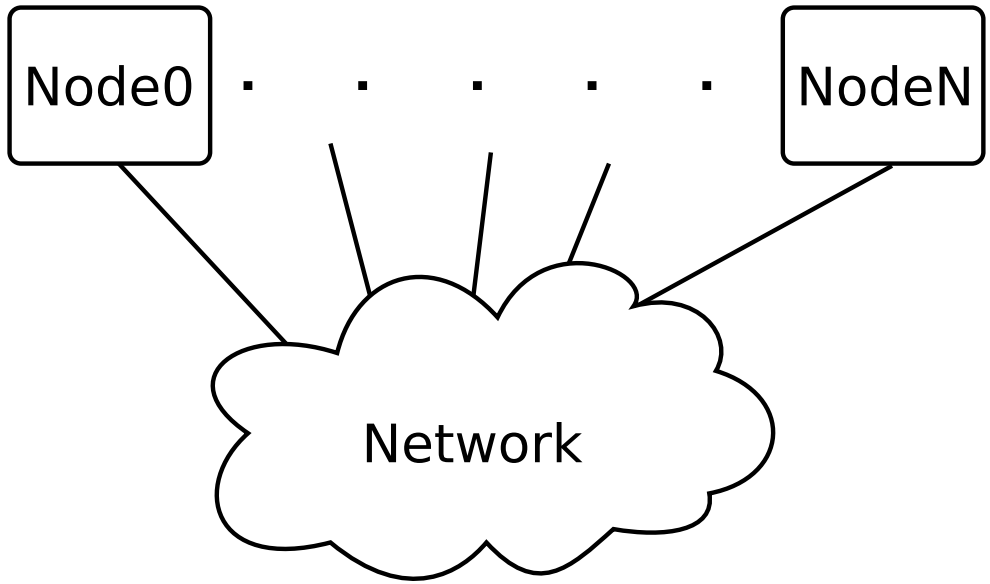
MPI

```c
int cnt = 1;

if (id == 0) {
 MPI_Send(&cnt, 1, MPI_INT, id+1, 0, MPI_COMM_WORLD);
 MPI_Recv(&cnt, 1, MPI_INT, N-1, 0, MPI_COMM_WORLD, NULL);
 printf("Counter: %d\n", cnt);
}
else {
 MPI_Recv(&cnt, 1, MPI_INT, id-1, 0, MPI_COMM_WORLD, NULL);
 cnt += 1;
 MPI_Send(&cnt, 1, MPI_INT, (id+1) % N, 0, MPI_COMM_WORLD);
}
```

```
% mpicc test.c
% mpirun -n 5 --hostfile hosts ./a.out
Counter: 5
```

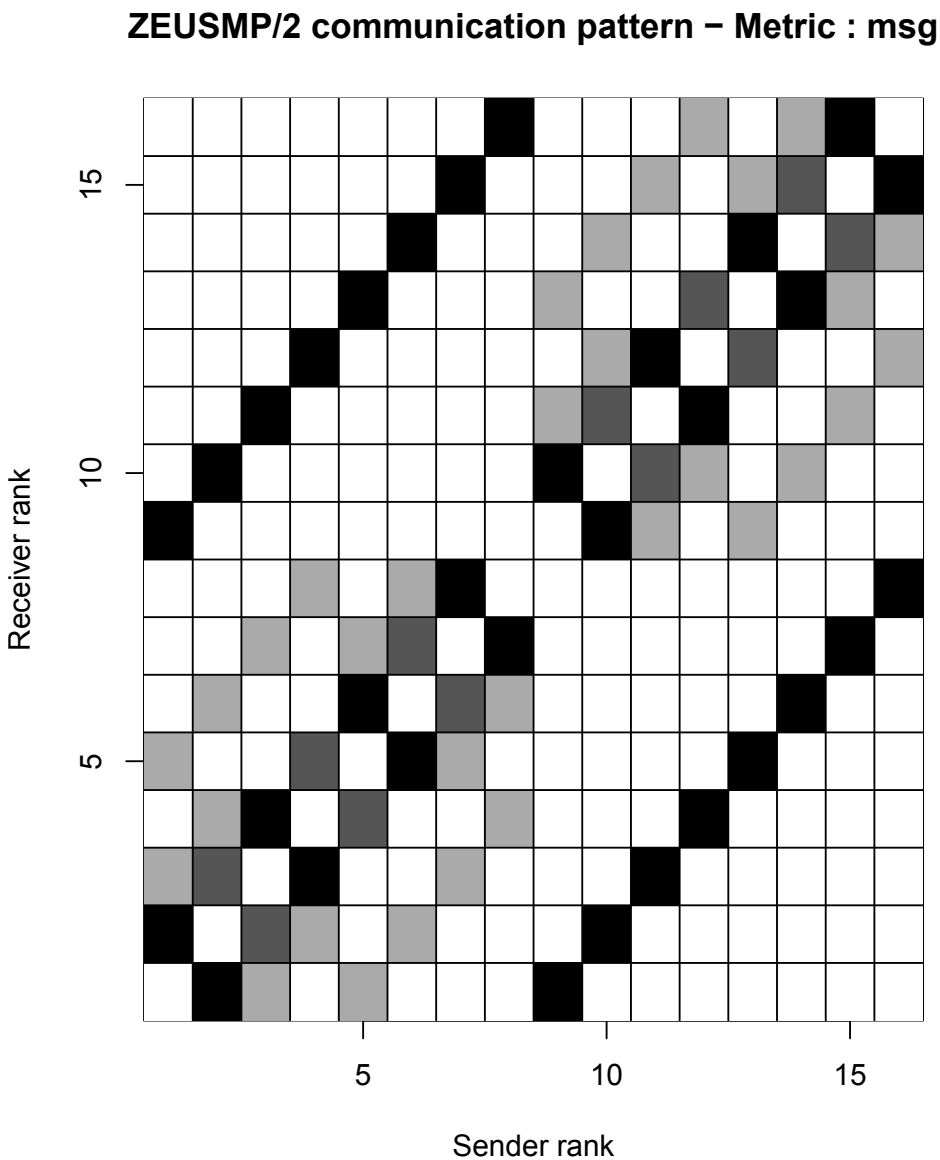


Clusters



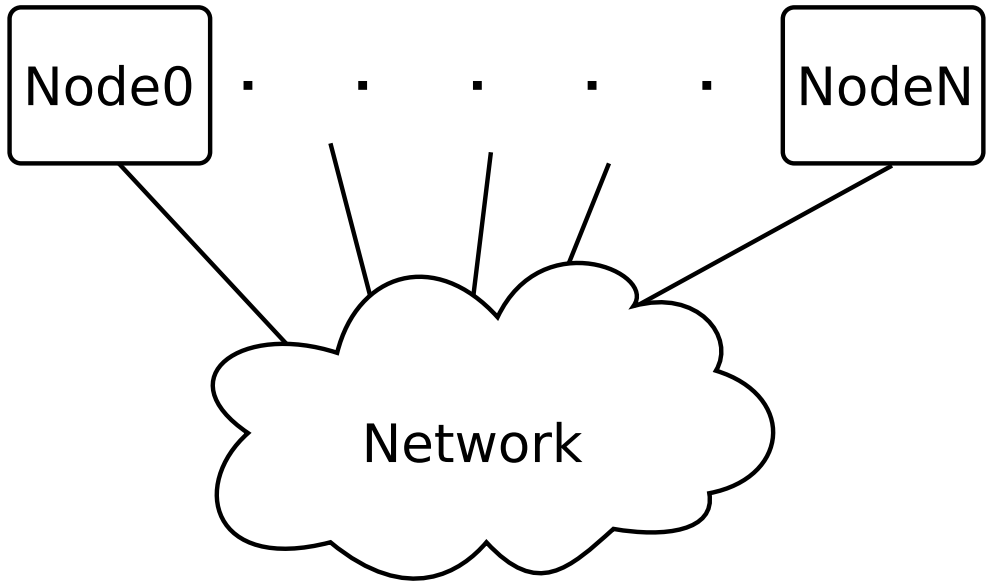
- Synchronous Message Passing: MPI
  - Process placement issue
    - Depends on network topology
    - e.g. TreeMatch

TreeMatch



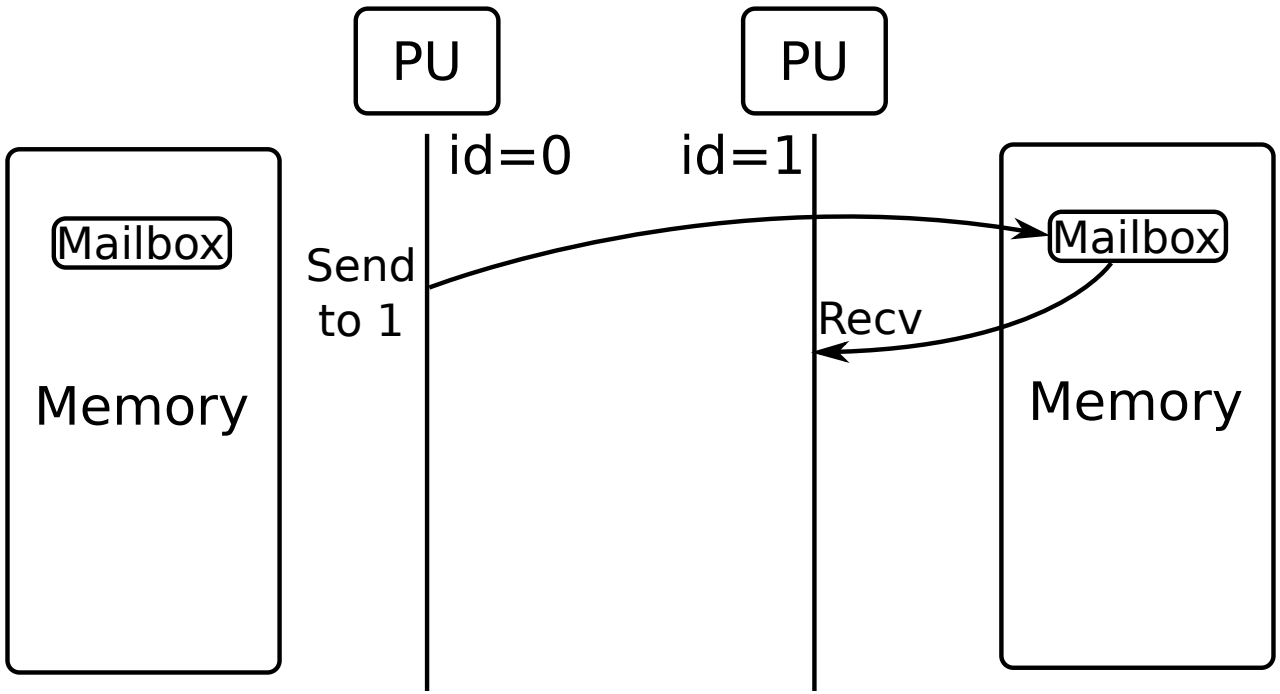
- Trace communications between processes
- Algorithm to map processes to network topology

Clusters



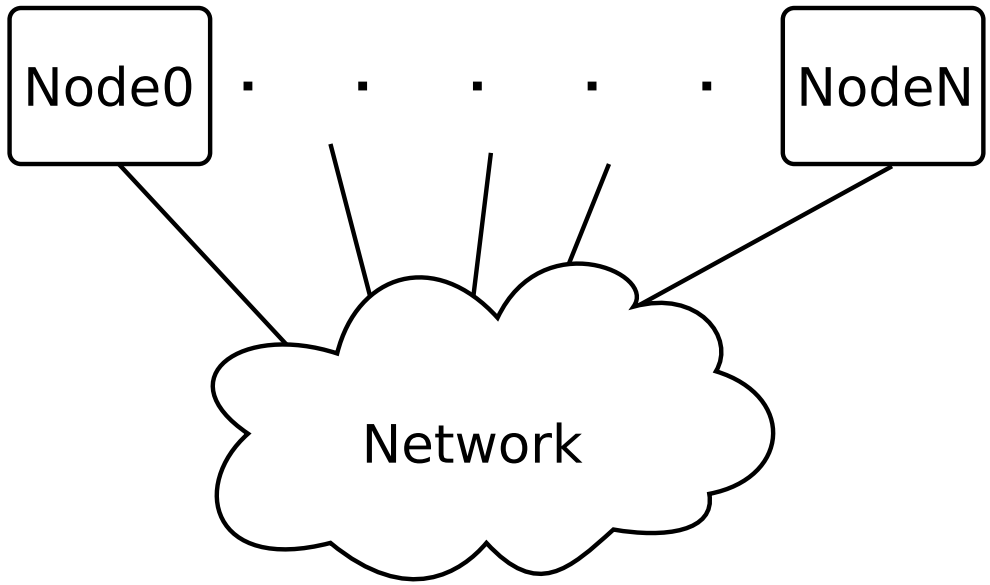
- Synchronous Message Passing: MPI
- Actor model / Active Objects: Charm++, Erlang...

Actor model



- Asynchronous message passing
- Dynamic actor creation

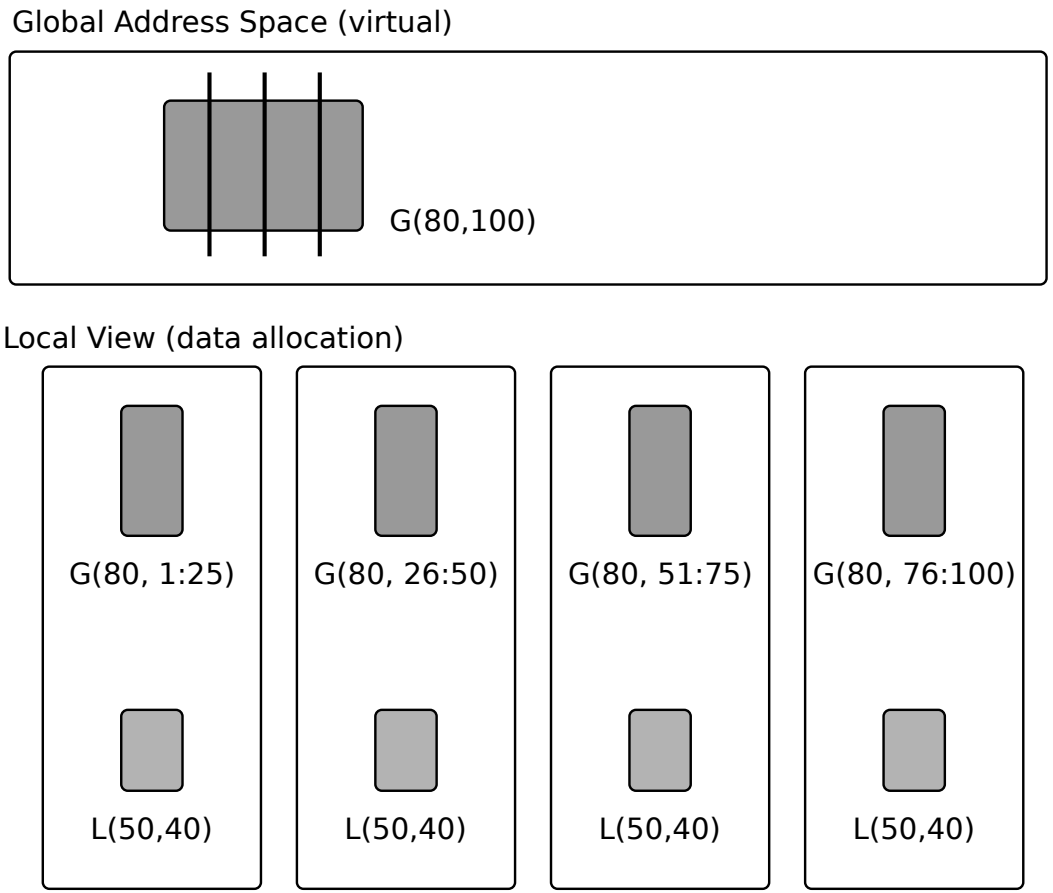
Clusters



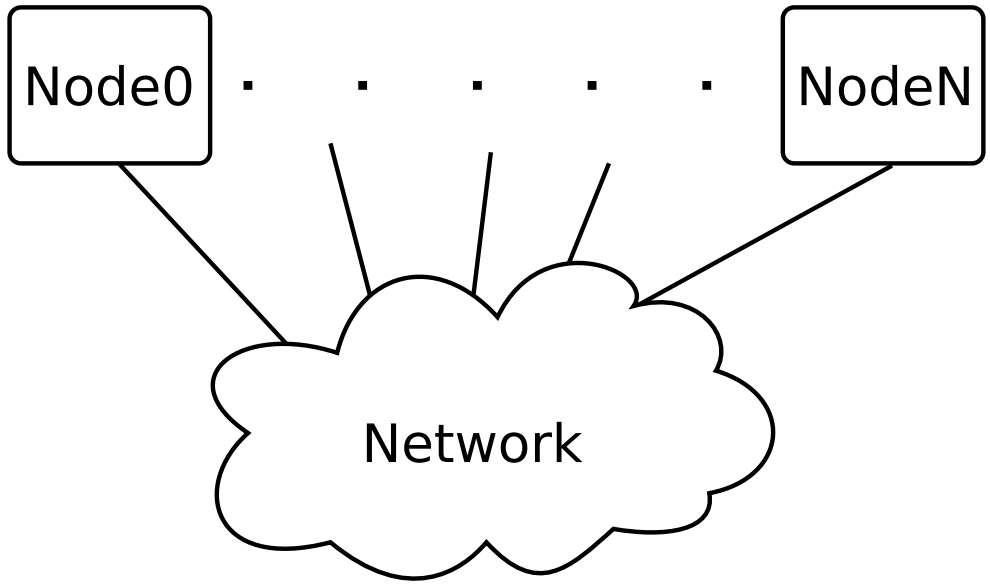
- Synchronous Message Passing: MPI
- Actor model / Active Objects: Charm++, Erlang...
- PGAS: HPF, XcalableMP, x10, ZPL/Chapel...
  - PGAS = Partitioned Global Address Space

PGAS: XcalableMP

```
!$xmp nodes P(4)
!$xmp template T(100)
!$xmp distribute T(block) onto P
      real G(80, 100)              ! global variable
!$xmp align G(*, i) with T(i)
      real L(50, 40)               ! local variable (default)
```

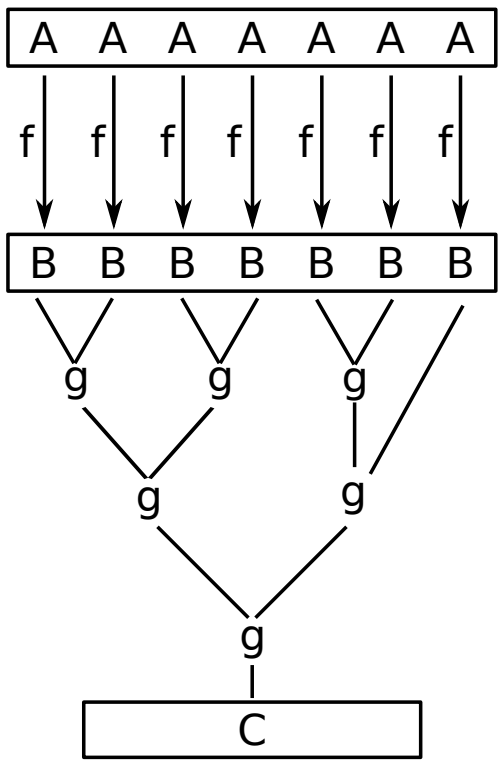


Clusters



- Synchronous Message Passing: MPI
- Actor model / Active Objects: Charm++, Erlang...
- PGAS: HPF, XcalableMP, x10, ZPL/Chapel...
- MapReduce: Google MapReduce, Hadoop...

MapReduce



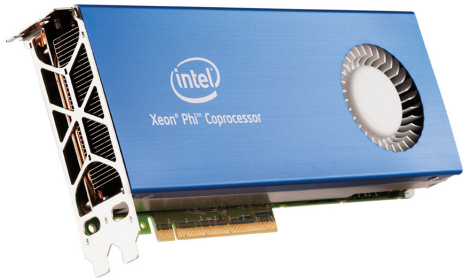
- reduce g . map f
  - Most operations on collections can be written this way
  - Easily parallelizable
- Users only have to provide f and g
- The runtime system provides
  - Task distribution
  - Communications
  - Fault tolerance
  - ...

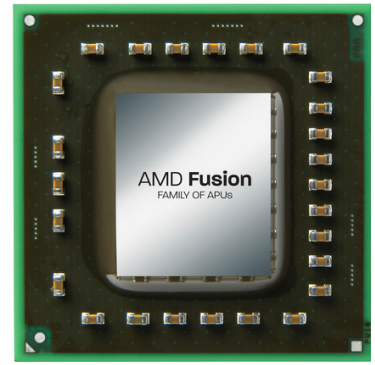
Keywords: Bird-Meertens Formalism, Catamorphism

Summary

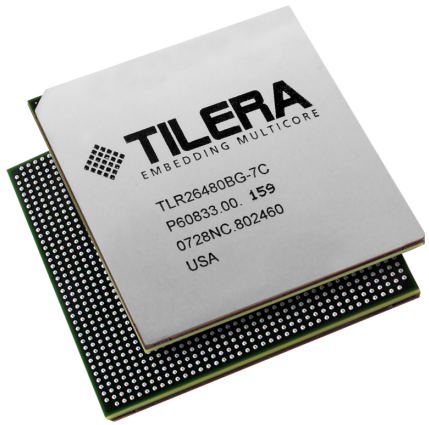
Architecture	Programming models
Multicore (NUMA)	OpenMP, PThread...
Cluster	MPI, PGAS, Actors, MapReduce...

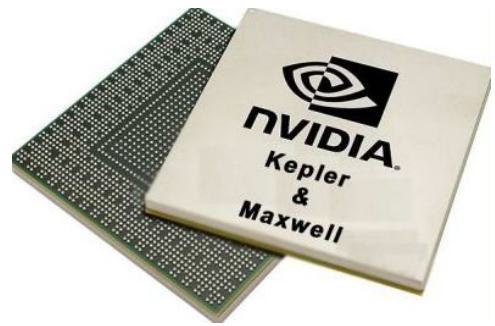
- They all assume homogeneous architectures
  - Same (or similar) architecture duplicated





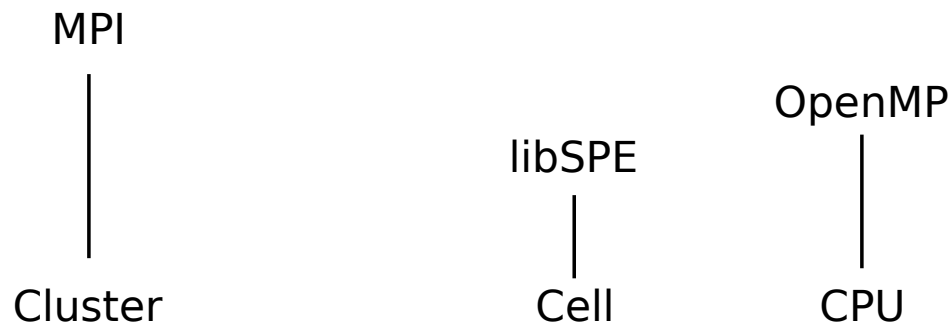
Accelerators & Many-Core





Frameworks...

Frameworks...



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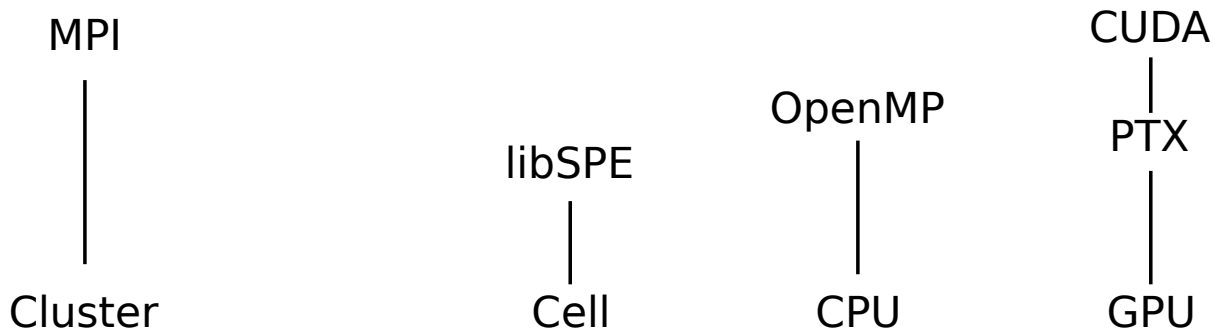

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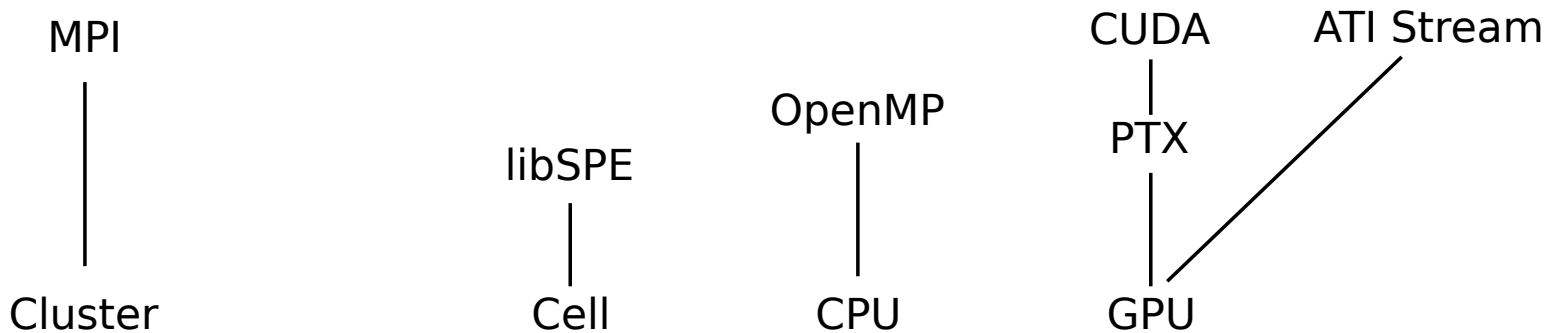

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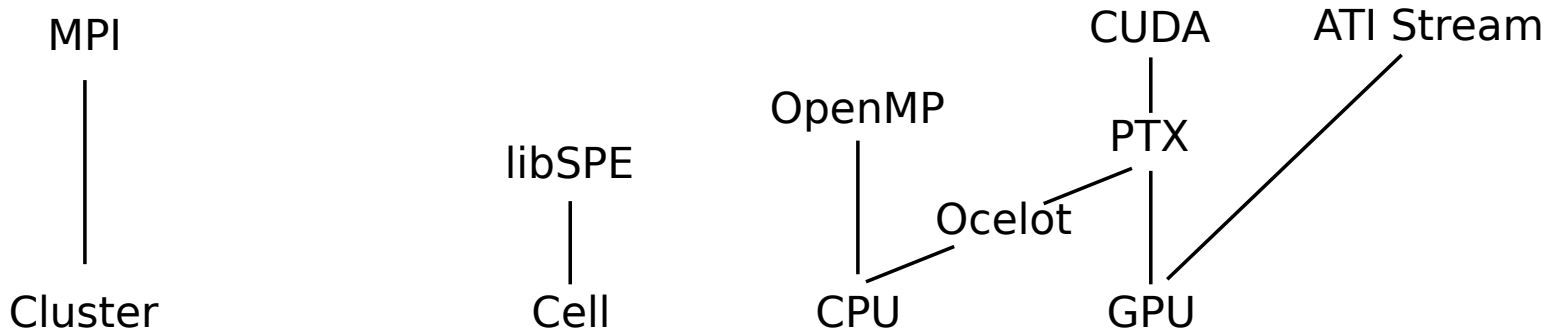
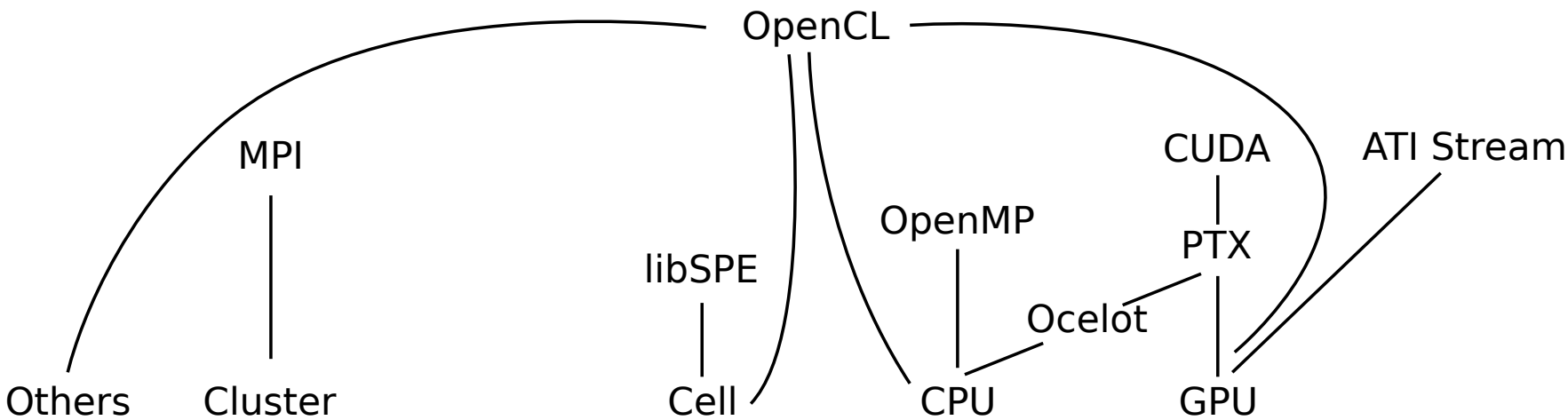

MPI
Cluster
libSPE
Cell
OpenMP
CPU
CUDA
PTX
Ocelot
ATI Stream
GPU

Frameworks...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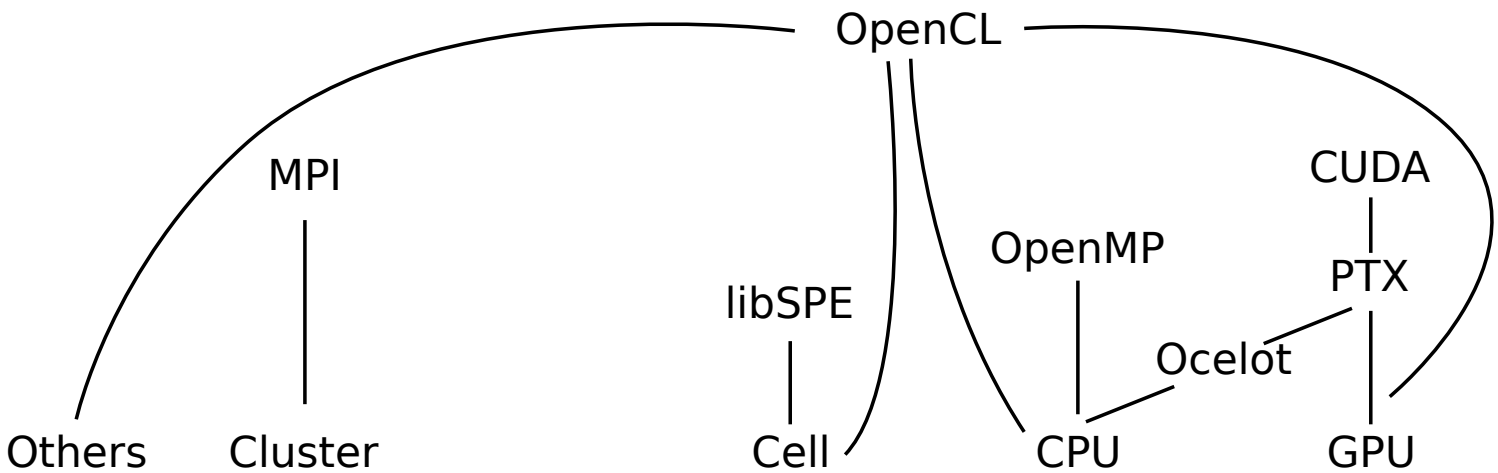
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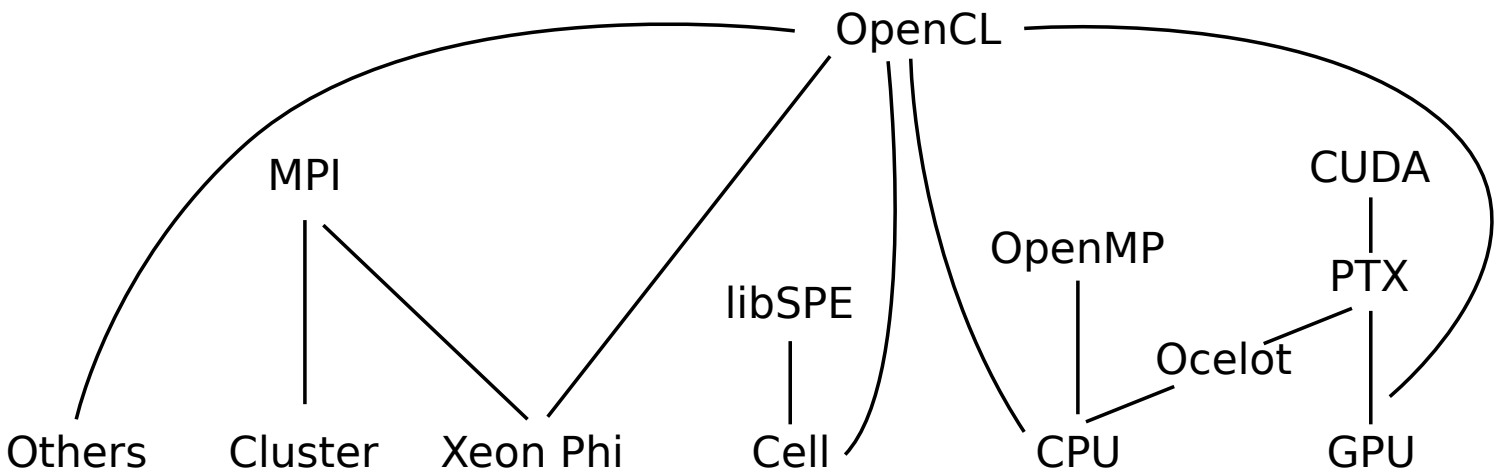
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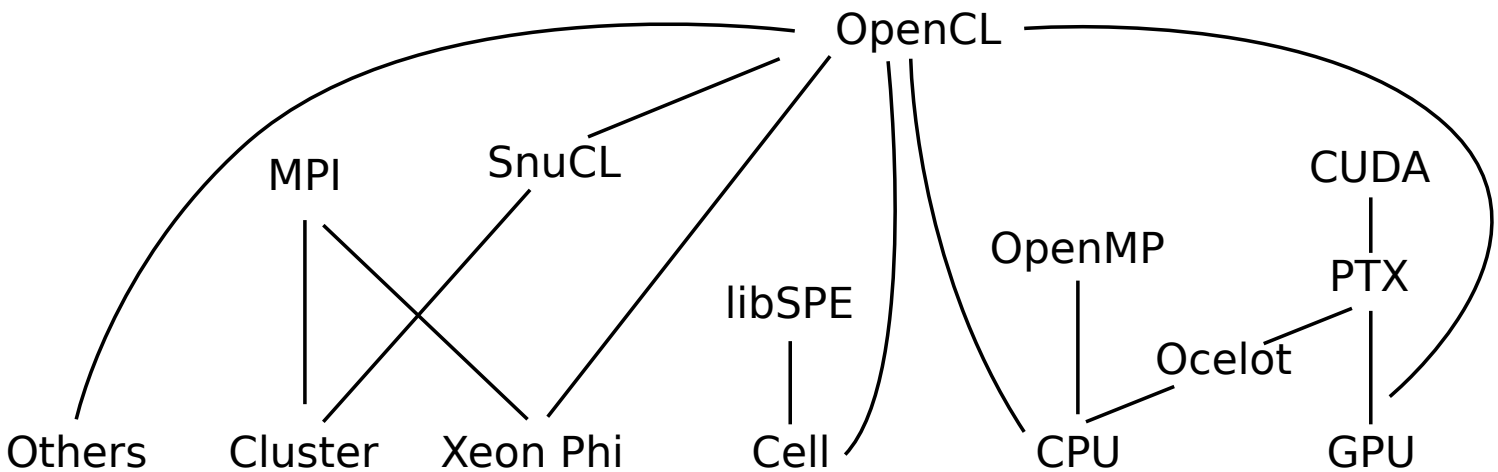
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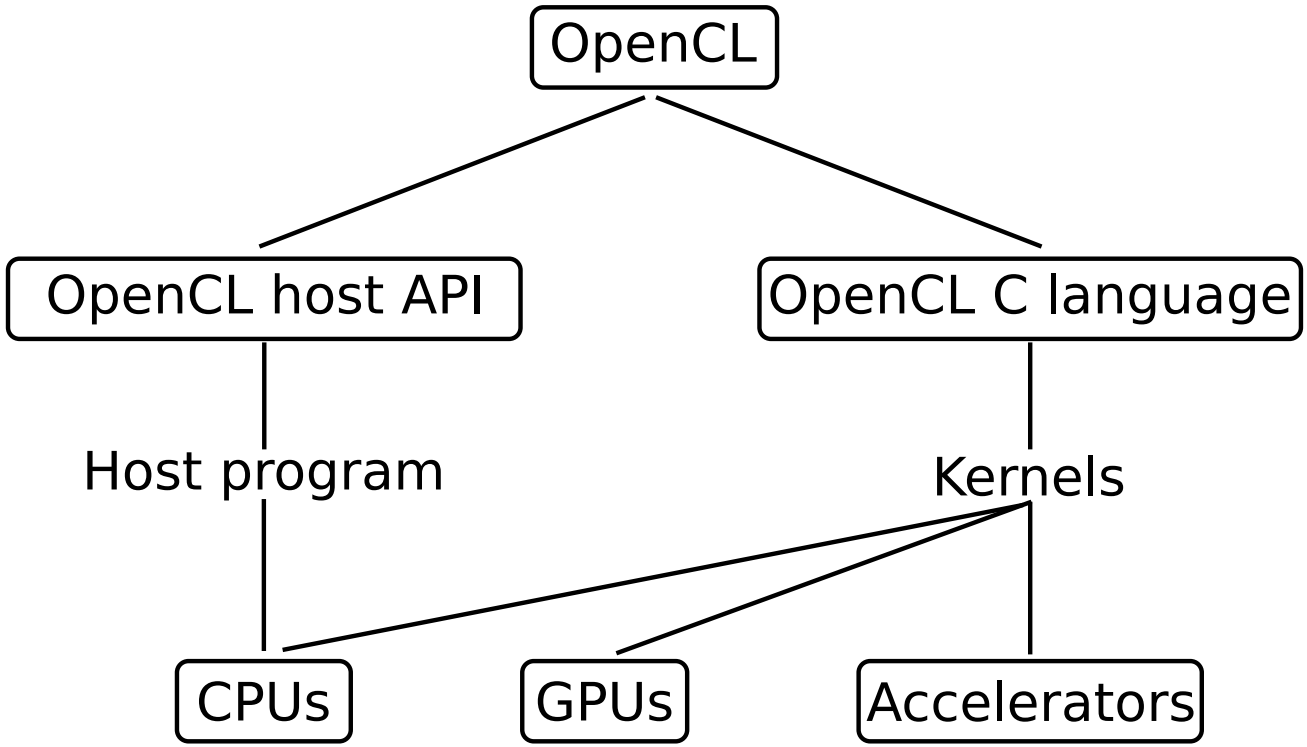
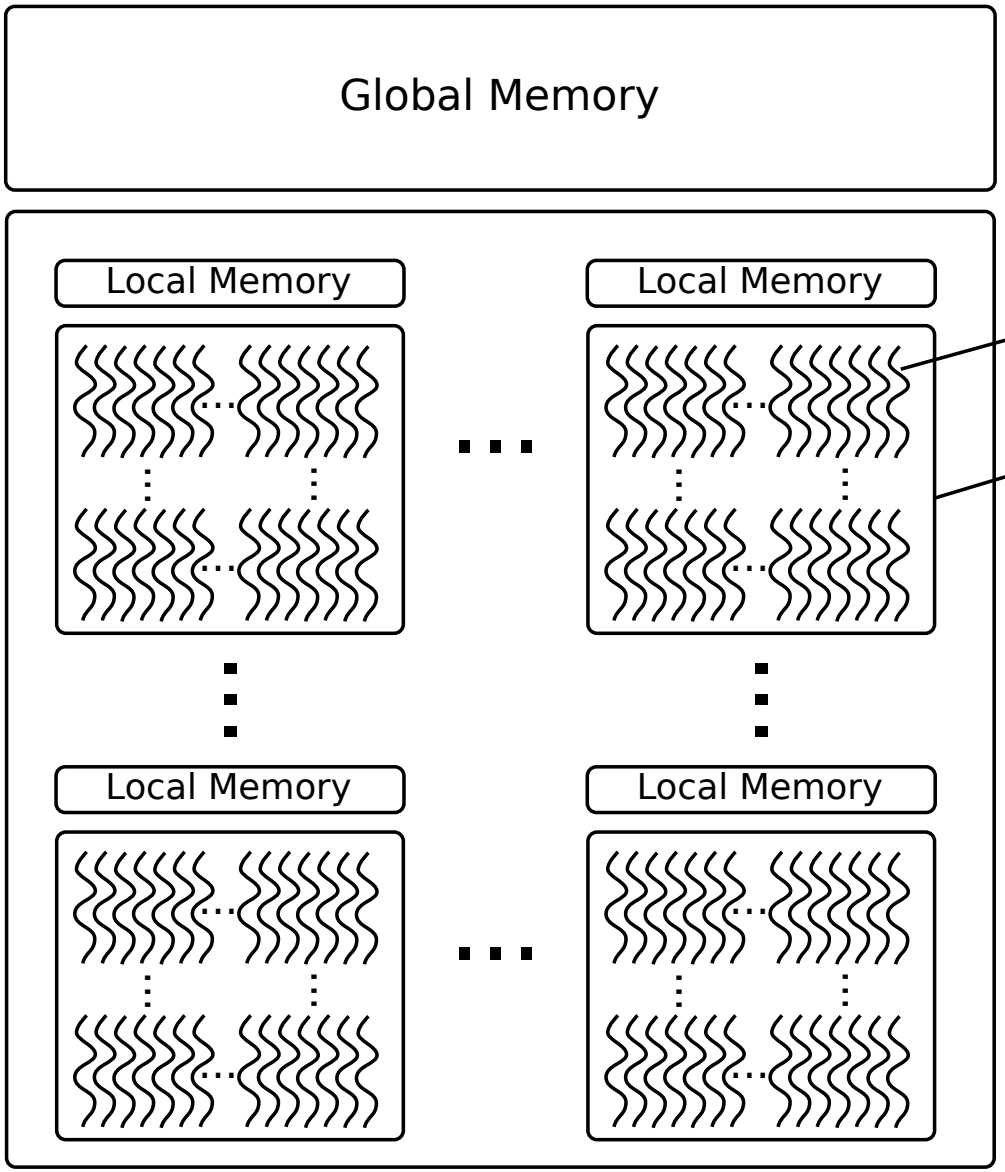
OpenCL


OpenCL
OpenCL host API
OpenCL C language
Host program
Kernels
CPUs
GPUs
Accelerators

OpenCL C Language



- SPMD
- get_local_id(int dim)
- get_global_id(int dim)

- __local, __global
- work-group barrier

OpenCL Host API

Device management

- Query available devices and their capabilities

Memory management

- Allocate/release buffers in device memory
- Transfer data between host memory and devices

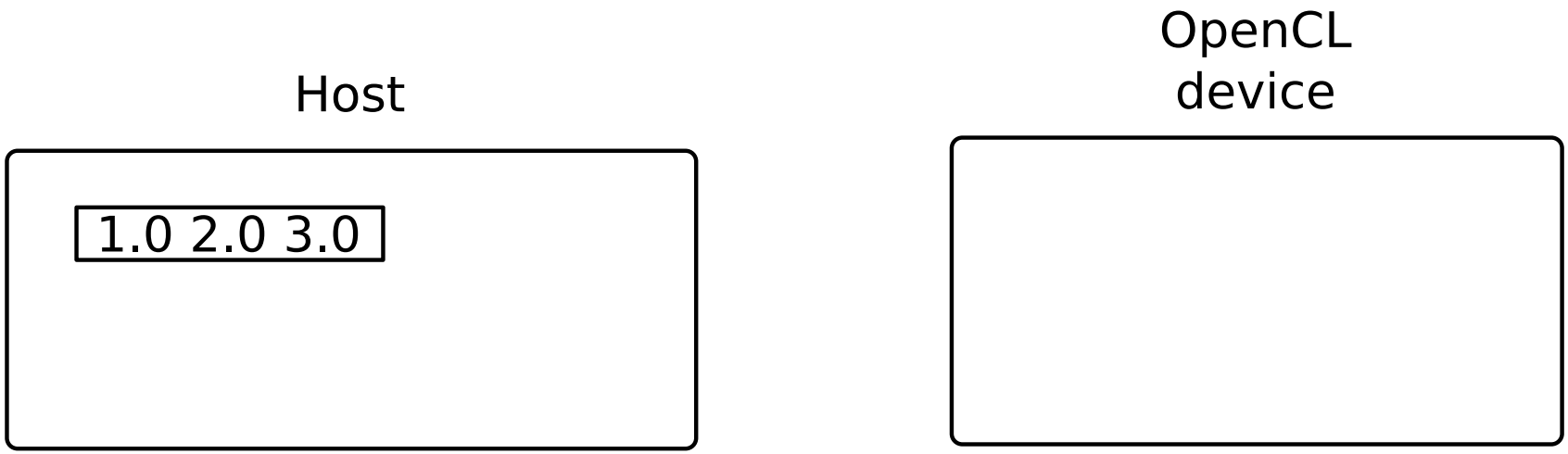
Kernel management

- Compilation
- Scheduling on devices

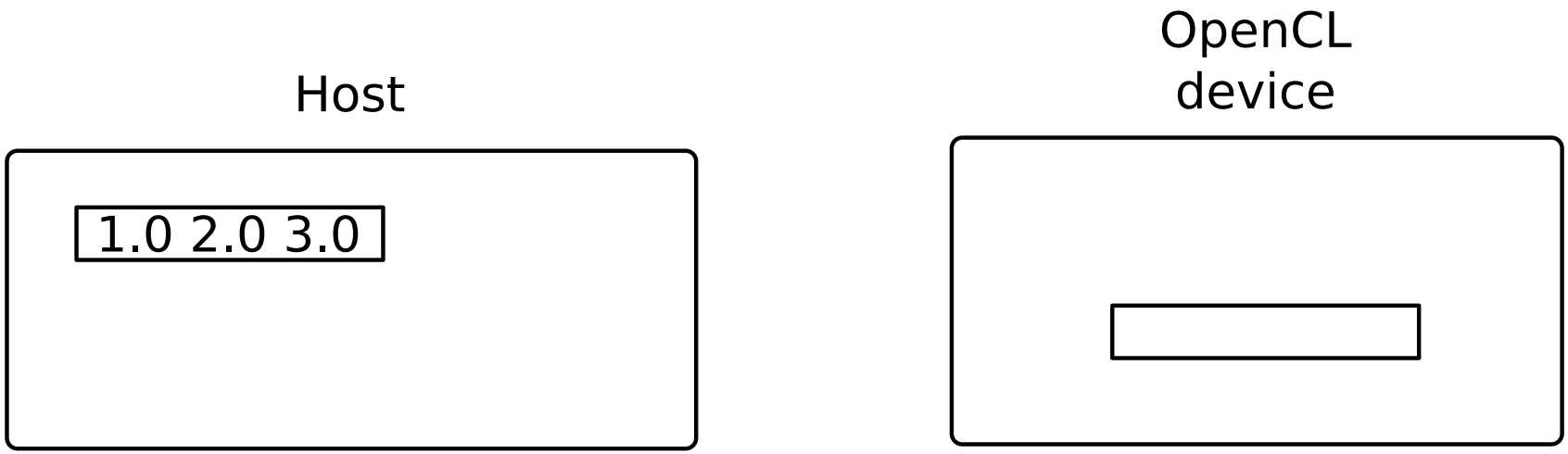
Synchronizations

- Command graph: events...
- With the host program: barriers...

OpenCL example



OpenCL example



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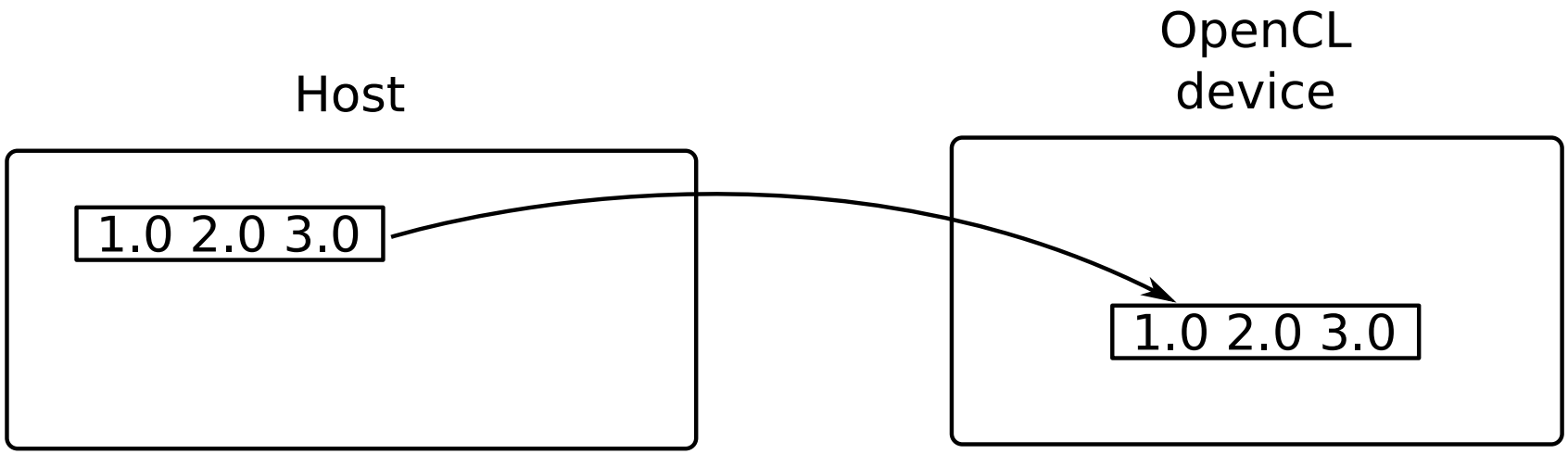

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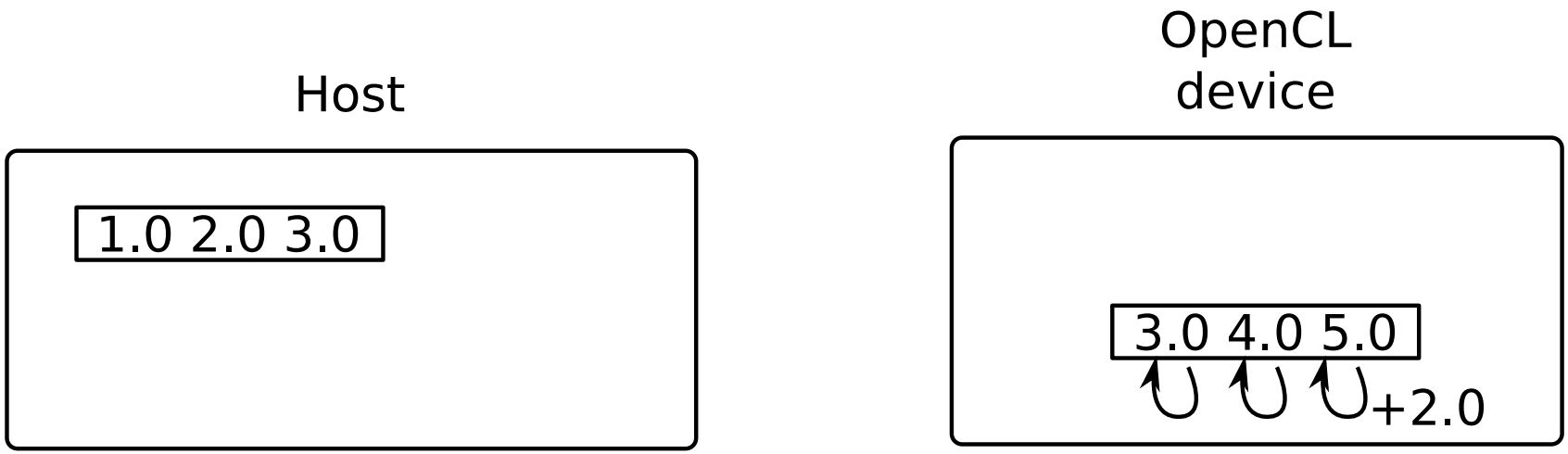

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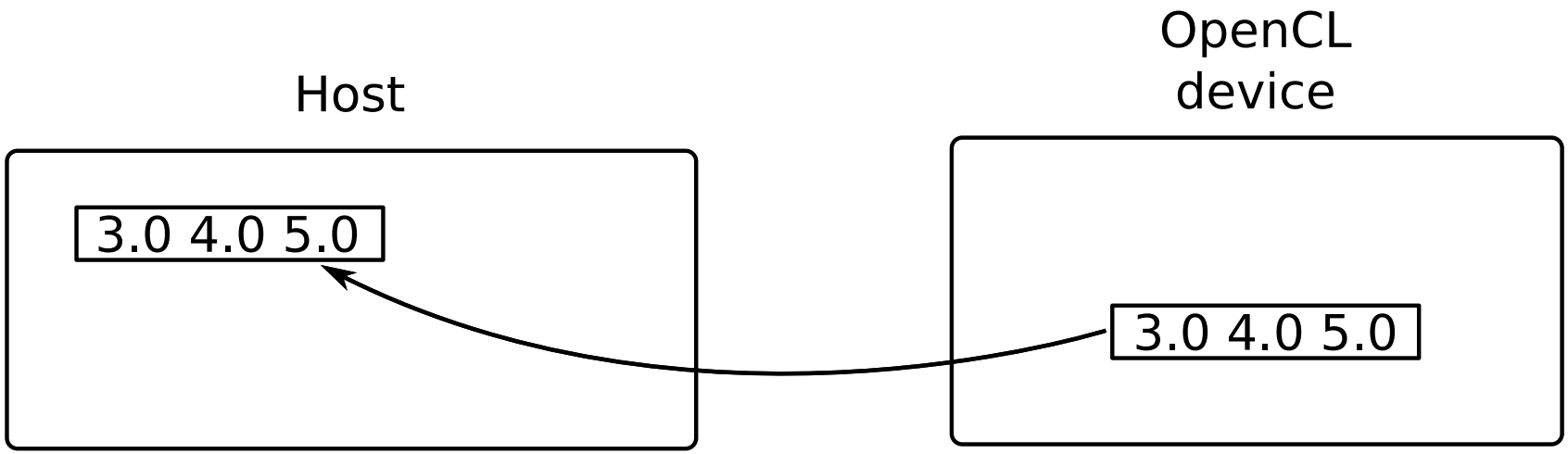


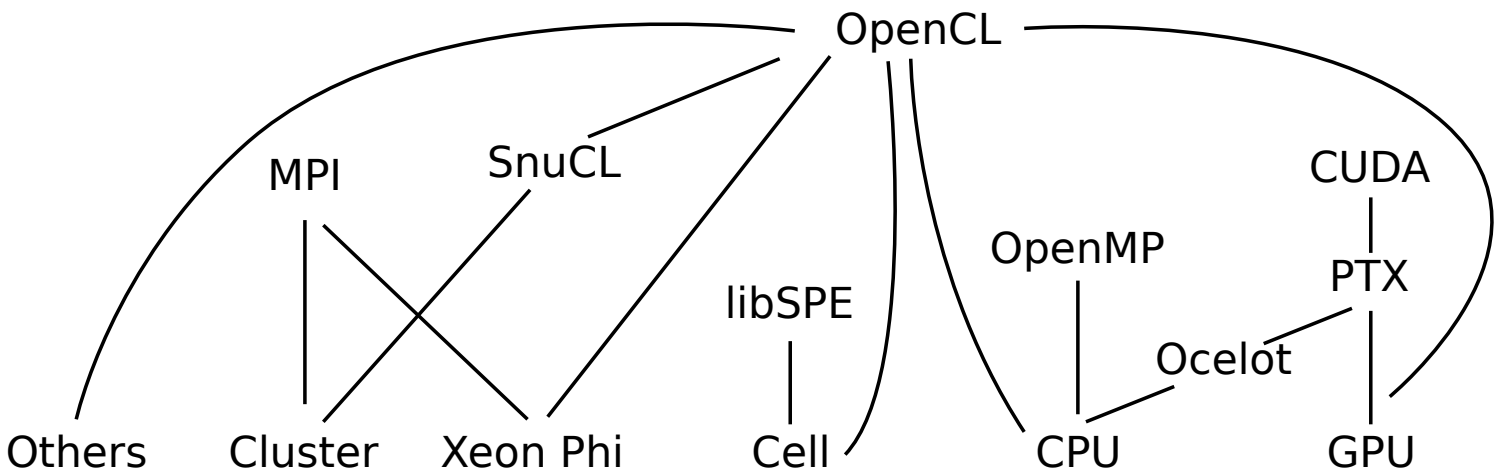
OpenCL example: kernel

```
__kernel void add2(__global float *out)
{
    size_t id = get_global_id(0);

    out[id] += 2.0;
}
```

OpenCL example: host API

```
float data[256] = {...};

clGetPlatformIDs(max_pfs, pfs, NULL);
clGetDeviceIDs(pfs[0],CL_DEVICE_TYPE_ALL,1,devs,NULL);
ctx = clCreateContext(NULL, 1, devs[0], NULL,NULL,NULL);
cq = clCreateCommandQueue(ctx, devs[0], 0, NULL);

buf = clCreateBuffer(ctx,CL_MEM_READ_WRITE,1024,NULL,NULL);

clEnqueueWriteBuffer(cq,buf,CL_FALSE,0,1024,data,0,NULL,NULL);

program = clCreateProgramWithSource(ctx,1,&src,NULL,NULL);
clBuildProgram(program, 0, NULL, NULL, NULL, NULL);
ker = clCreateKernel(program, "add2", NULL);

clSetKernelArg(ker, 0, sizeof(cl_mem), &buf);
size_t group[3] = {32, 1, 1};
size_t grid[3] = {256, 1, 1};
clEnqueueNDRangeKernel(cq,ker,3,NULL,grid,group,0,NULL,NULL);

clEnqueueReadBuffer(cq,buf,CL_FALSE,0,1024,data,0,NULL,NULL);

clFinish(cq);
```

Frameworks...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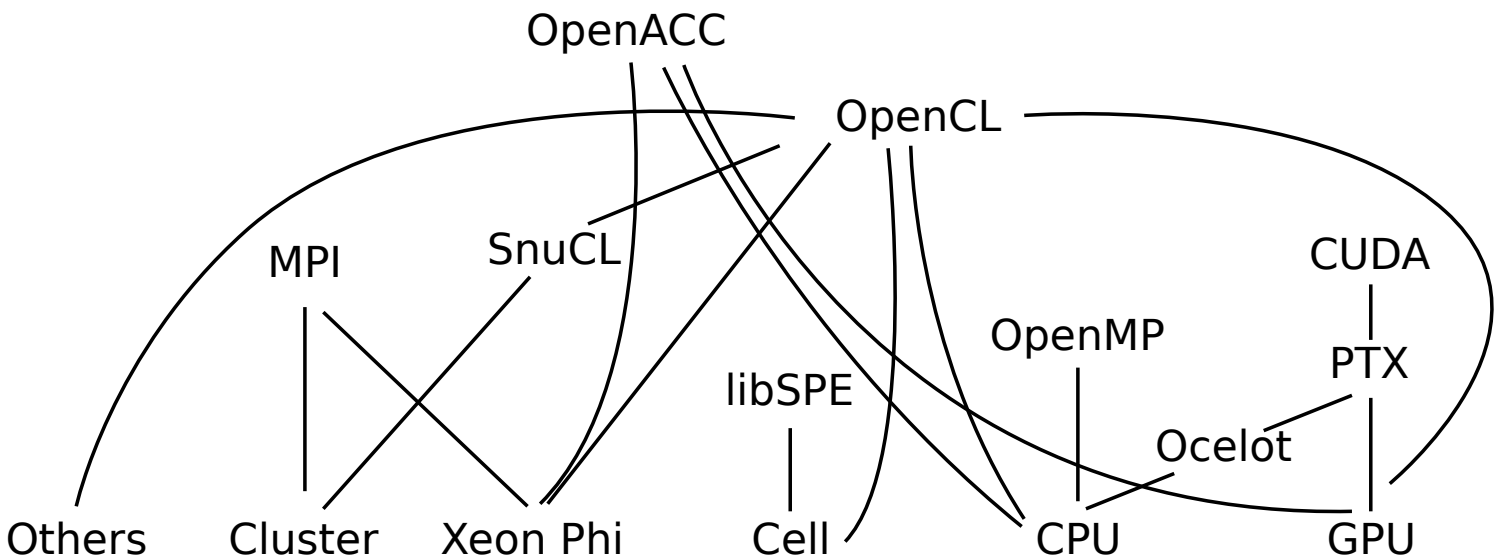
Frameworks...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MPI
SnuCL
CUDA
OpenMP
PTX
libSPE
Ocelot
Others
Cluster
Xeon Phi
Cell
CPU
GPU

OpenACC

Concepts

- Generate kernels from annotated C/Fortran code
- Simpler memory model (one accelerator)
- Ensure memory coherence with annotations

OpenACC example

```
float data[256] = {...};

#pragma acc kernels copy(data)
for (int i=0; i<256; i++)
    data[i] += 2.0;
```

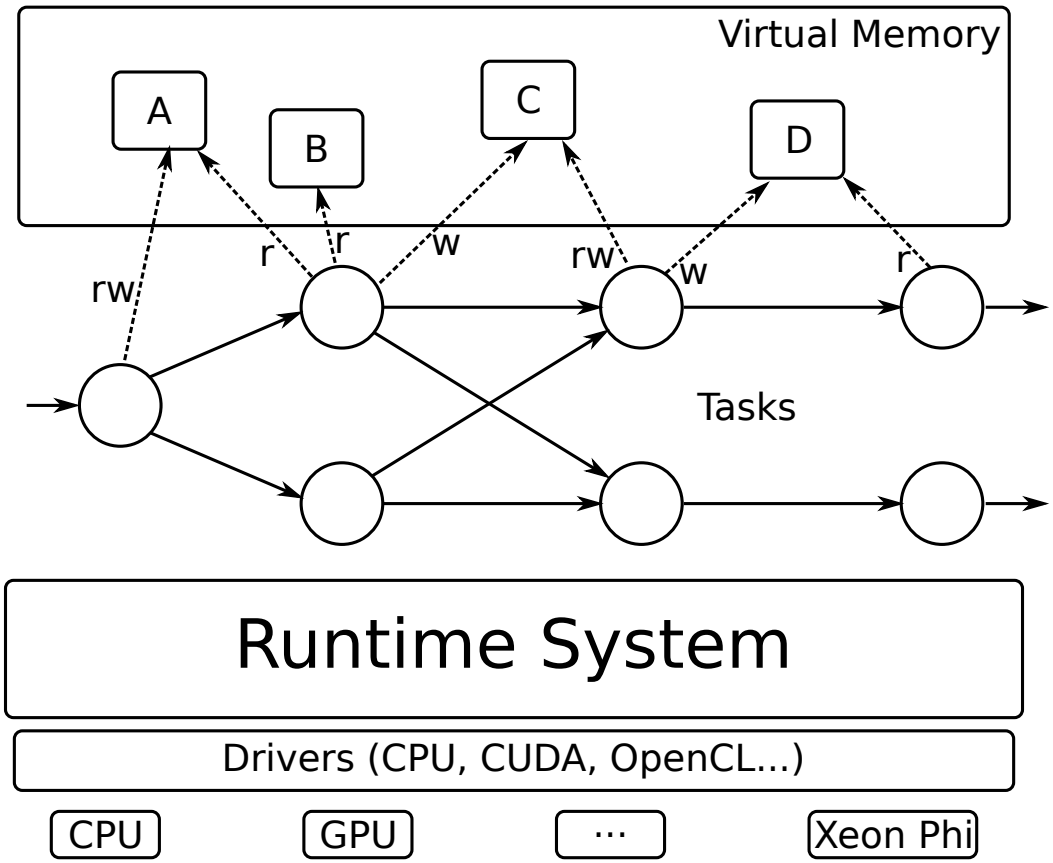
Limitations

Low-level approaches

- No support for multi-accelerator (OpenACC)
- Hard to manage several accelerators (OpenCL)

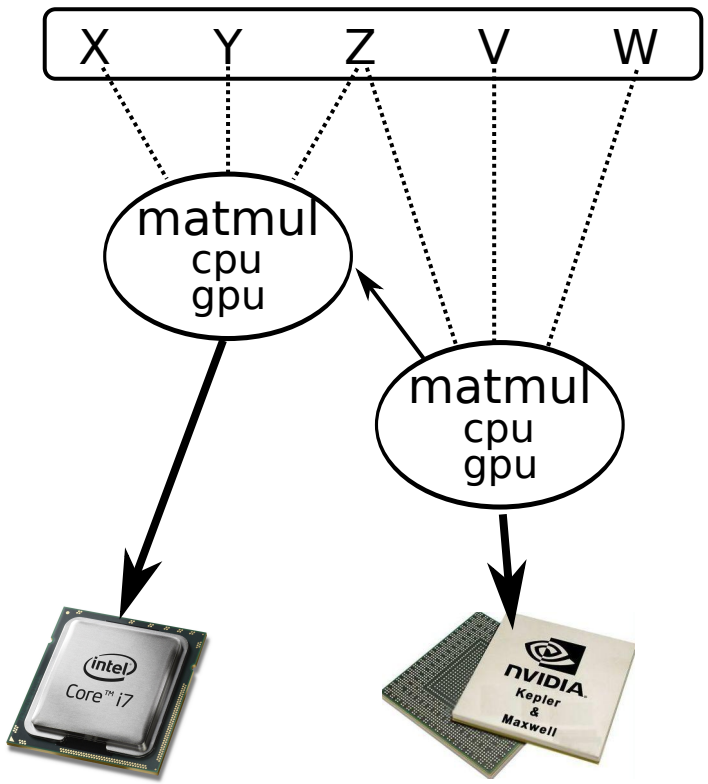
Runtime Systems

Runtime Systems



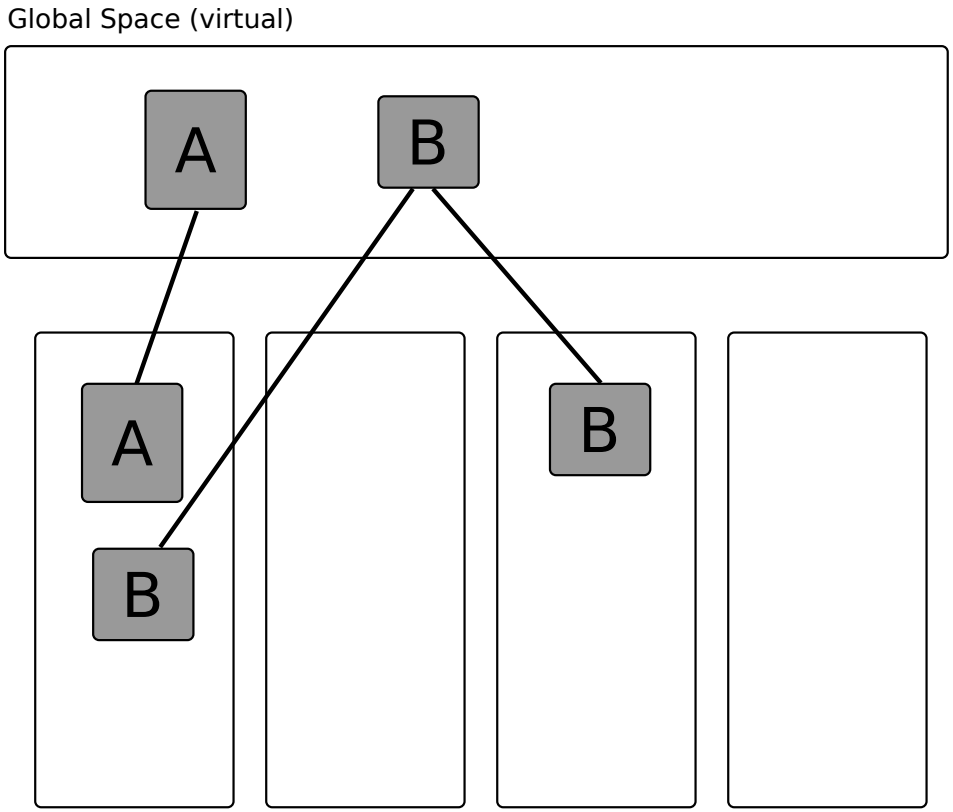
- Automatically schedule kernels on available accelerators
- Automatically manage distributed memory
- e.g. StarSS, StarPU...

Runtime Systems



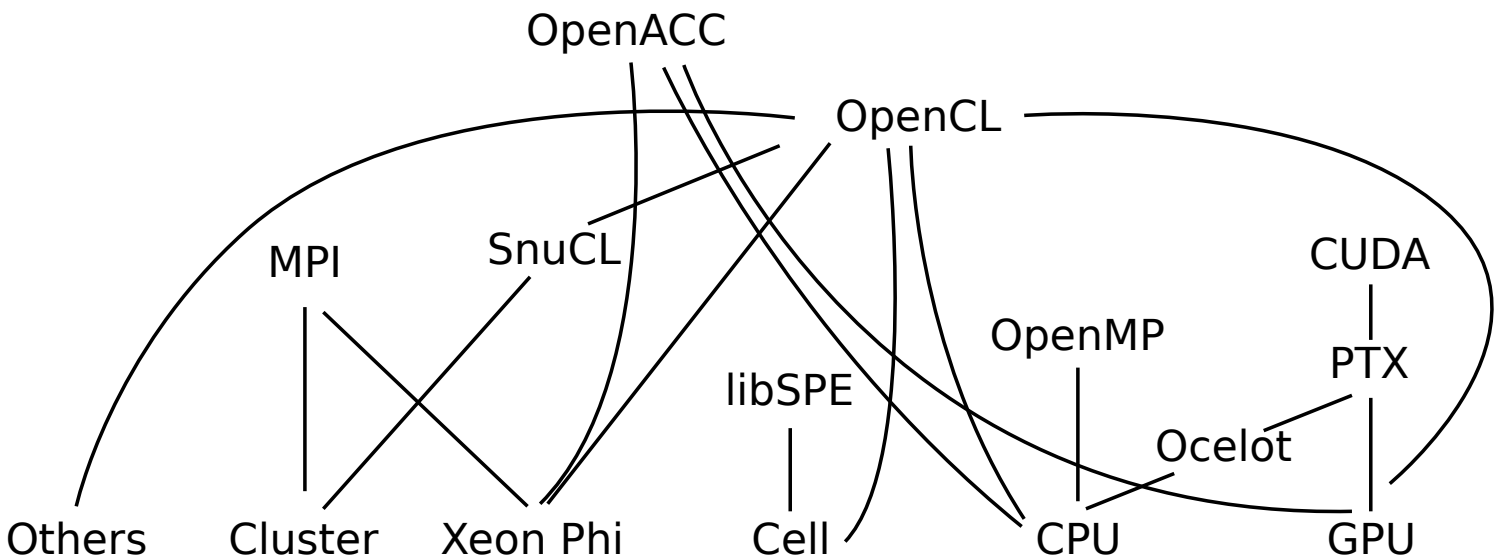
- Automatically schedule kernels on available accelerators
- Automatically manage distributed memory
- e.g. StarSS, StarPU...

Runtime Systems

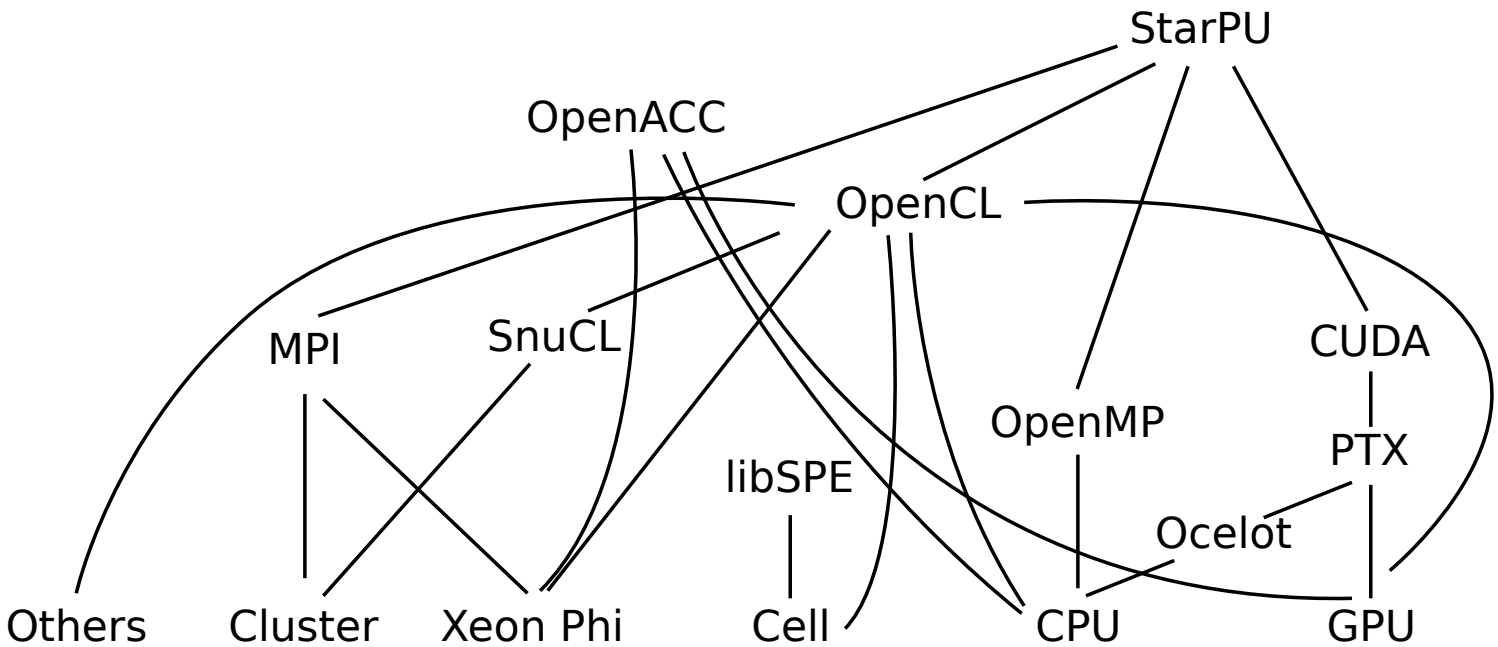


- Automatically schedule kernels on available accelerators
- Automatically manage distributed memory
- e.g. StarSS, StarPU...

Frameworks...


OpenACC
OpenCL
MPI
SnuCL
CUDA
OpenMP
PTX
libSPE
Ocelot
Others
Cluster
Xeon Phi
Cell
CPU
GPU

Frameworks...


StarPU
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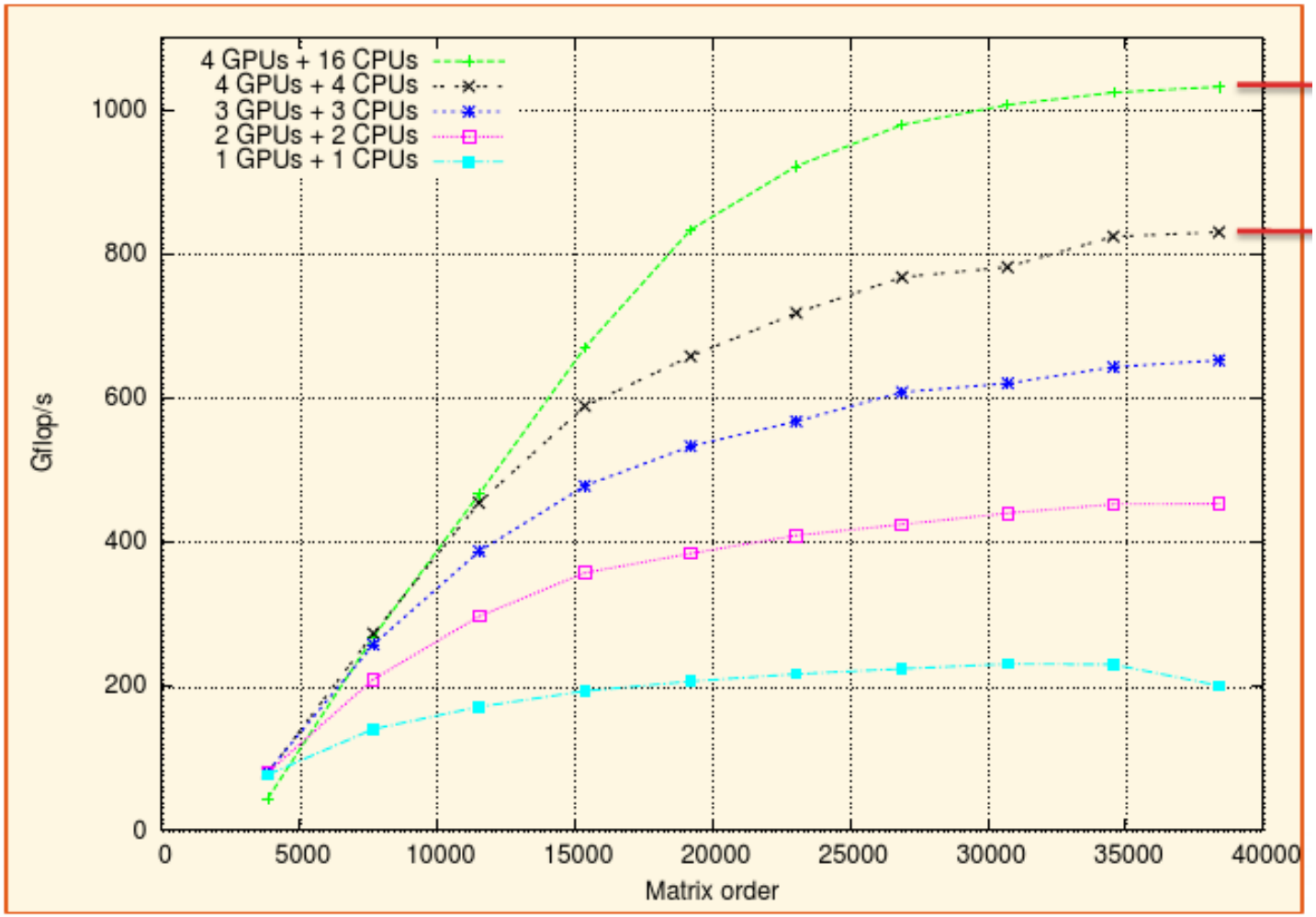
CPU
GPU

StarPU example

```
void scal_cpu_func(void * buffers[], vois *args);
void scal_cuda_func(void * buffers[], vois *args);

starpu_codelet scal_cl = {
    .where = STARPU_CPU | STARPU_CUDA,
    .cpu_func = {scal_cpu_func, NULL},
    .cuda_func = {scal_cuda_func, NULL},
    .nbuffers = 1,
    .modes = {STARPU_RW}
}

float vector[N];

starpu_data_handle vector_handle;

starpu_vector_data_register(&vector_handle, 0,
          vector, N, sizeof(float));

starpu_insert_task(&scal_cl, STARPU_RW, vector_handle, 0);

starpu_task_wait_for_all();
starpu_data_unregister(vector_handle);
```

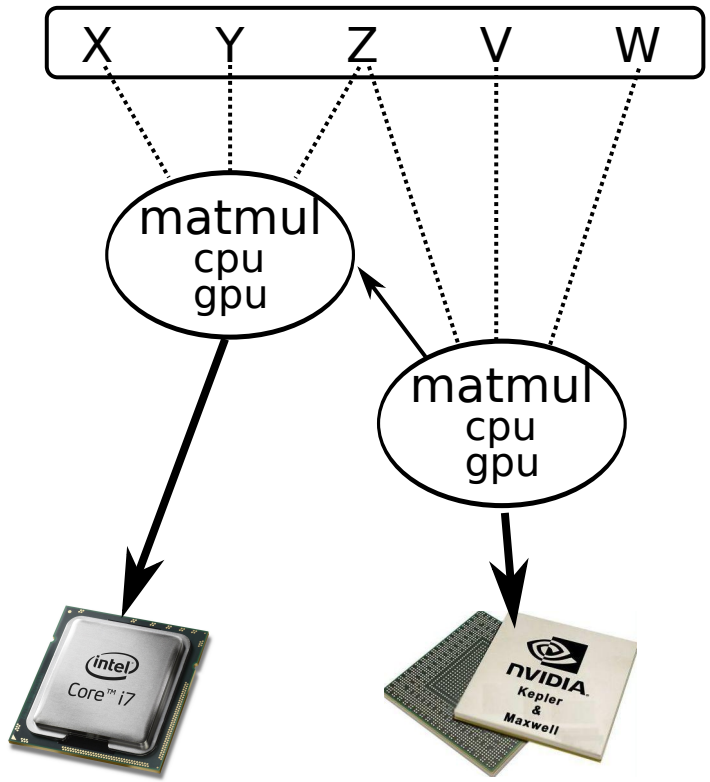
StarPU performance



UTK Magma (linear algebra) - QR factorization
16 CPUs (AMD) + 4 GPUs (C1060)

Limitations

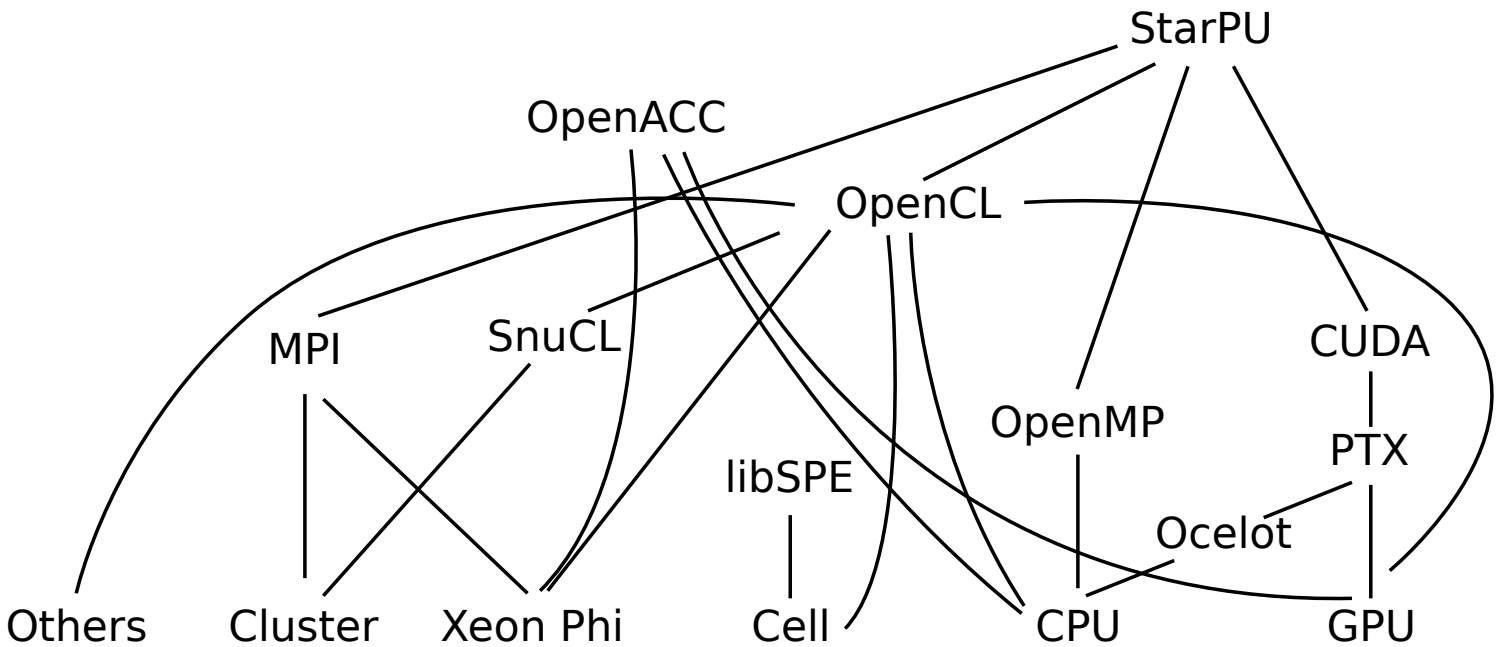
- Task/data granularity adaptation
- Task graph optimizations



What I am working on

- Use a functional language to describe the task graph
- More amenable to optimizations
  - Granularity adaptation expected
- e.g. HaskellPU, ViperVM

Frameworks...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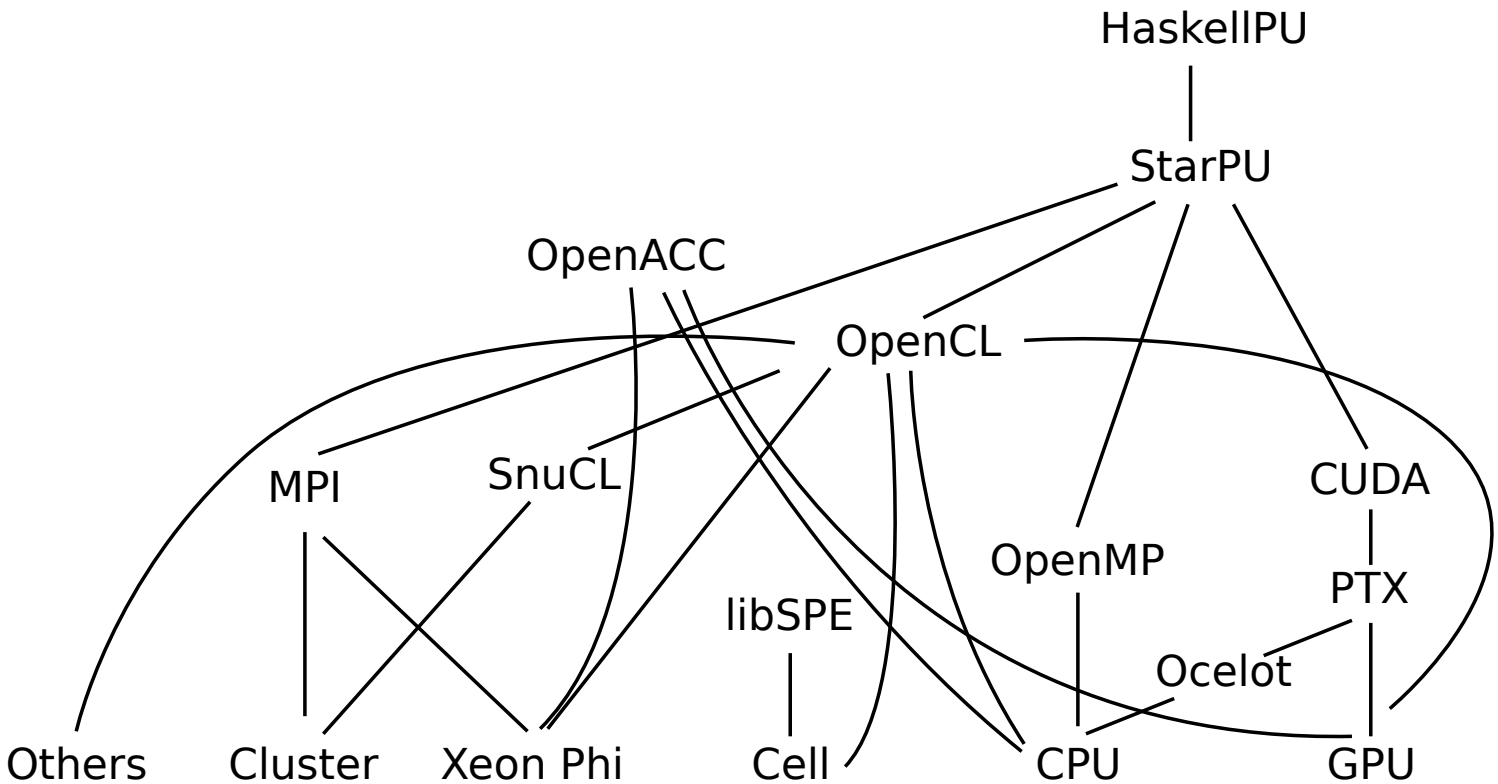
Frameworks...


HaskellPU
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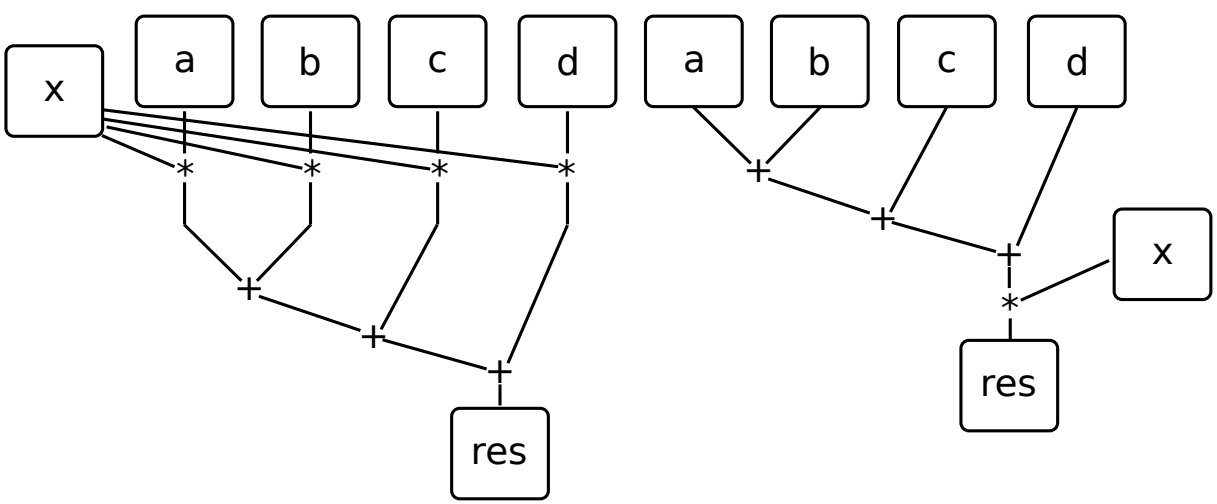
HaskellPU

```
let res = a*x + b*x + c*x + d*x
computeSync res
```

```
let res = (a + b + c + d) * x
computeSync res
```

```
let res = (reduce (+) [a,b,c,d]) * x
computeSync res
```



Conclusion

- Things are evolving quickly!
  - Architectures
  - Programming models
- Runtime systems are now accepted in the HPC community
  - Ensure portability and performance
- New challenges
  - Fault tolerance
  - Power management
  - Collaboration with the programming language community (FP...)

Thank you!