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Lecture 8: Introduction to distributed me

Previous lectures

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In the last six lectures we looked at **shared memory parallelism** (SMP) relevant to *e.g.* multi-core CPUs:

- ory.
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- g
- Without proper **synchronisation**, r
non-deterministic.

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- Dependencies can lead to **data rac**
- Can reach **deadlock** if threads wait for synchronisation events that never occur.

This lecture

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This lecture is the first of six on **distributed memory parallelism**, and we will see that some (but not all) of these issues remain relev

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- ry.
- **tion**.
  - No **data races**.

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- Performance considerations remain th
  primary parallel overhead is **com**
- Improper synchronisation can still lead to **non-determinism** and **deadlock**.

Distributed memory systems

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Multiple **processes** (rather than threads) that communicate *via* an **interconnection network** or **'interconnect'**.

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- F
n
- Each process has its own **heap memory**.
- If a process needs data currently held on another node's memory, must **communicate** over the network.

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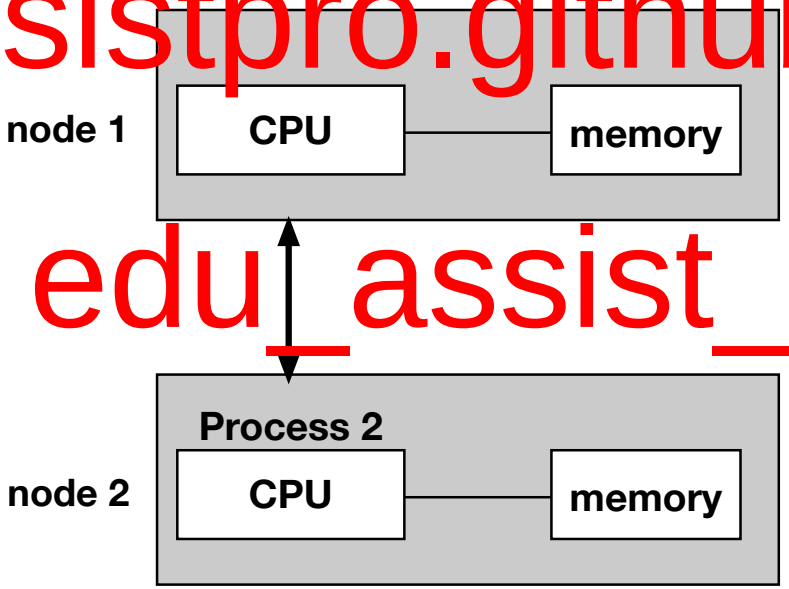

Current fastest supercomputer[1]

Fujitsu Fugaku, RIKEN, Kobe, Japan

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- ARM-based A64FX CPU.
- 4
  as
- Thttps://eduassistpro.github.i
- No GPUs.
- Draws nearly 30MW of power.Add WeChat edu_assist_pr
- Benchmarked $\approx$ 442 PFLOPS.
- 1 PFLOPS $= 10^{15}$ FLOPS.
- 1 FLOPS $=$ 1 floating point operation per second.

[1] As of Nov. 2021; `top500.org`.

Clusters as distributed systems

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Supercomputers share features with other **distributed systems** such as data centres:

-
-
- May have high energy demand and cooling r

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Here focus on **High Performance Co**

- Individual cluster nodes use the same **operating system**.
- Cannot usually be **addressed individually**.
- Requires a special **job scheduler**.

The interconnection network or 'interconnect'

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For the local area networks within HPC clusters, communication between nodes is carried over high performance **interconnects**.

- [1].
- :
- :

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These numbers are improving with time but **CPU performance**.

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The need to reduce communication overhea
more important in the foreseeable future.

[1] As of Nov. 2021; see `top500.org`.

Network topology

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- If data sent *via* intermediate nodes, latency is increased.
  - Each node must parse data packet and decide where to send.

Ther

Net

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- G = nodes *(processors)*.
- E = connections *(edges)*.

Want G with smallest **diameter** δ *(largest path length between nodes)*.

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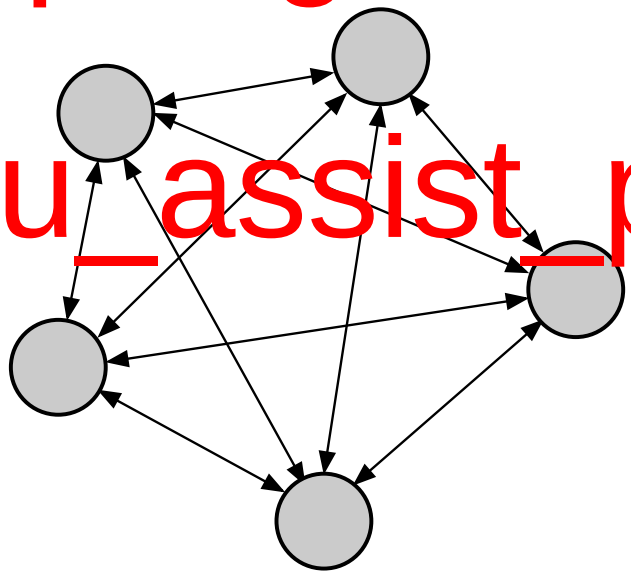
A **complete graph** *(right)* has $\delta = 1$, but is impractical *(too many connections for each machine)*.



Example topologies for p nodes

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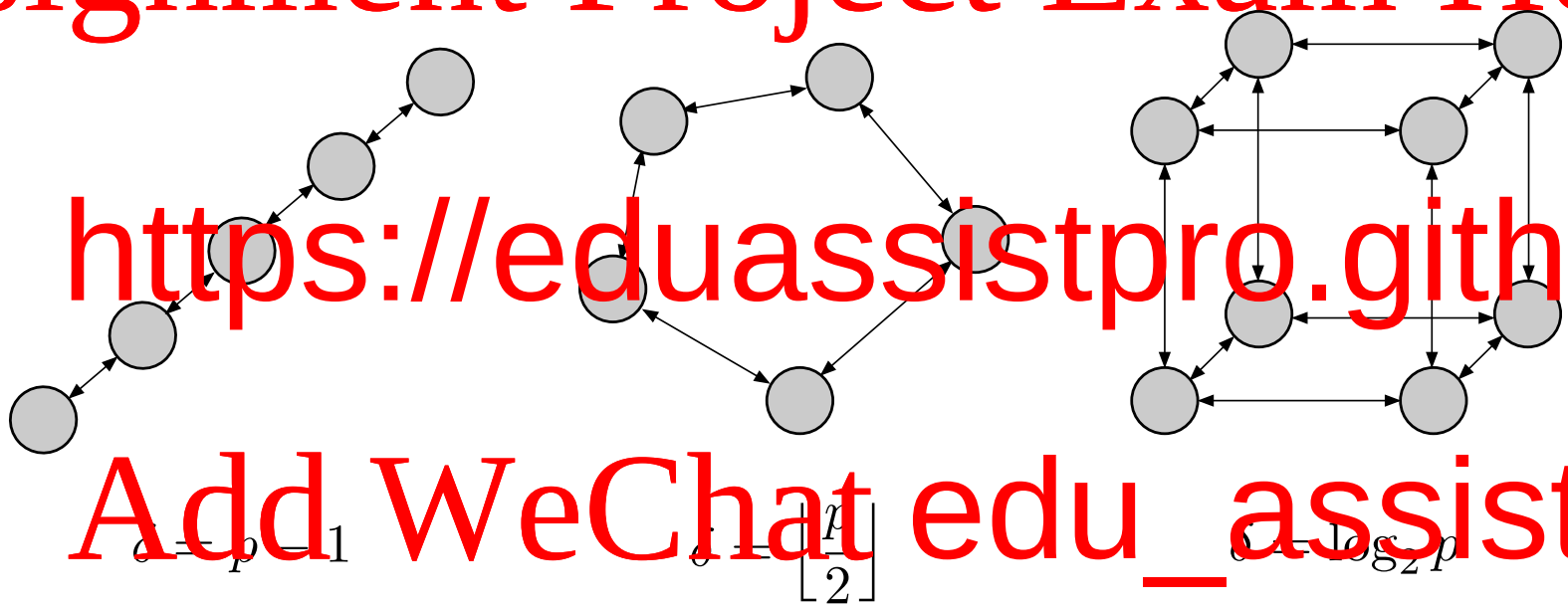

Hypercube topology preferred due to its short path lengths[1].

[1] Rauber and Rünger, *Parallel programming for multicore and cluster systems* (Springer, 2013).

Processes *versus* threads

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Recall from Lecture 2 that **processes** communicate with other processes using *e.g.* sockets.

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For m **ss** per node, with one thread per core.

- Avoids communication **within** a no
- Combination of OpenMP and MPI is quite c *ld*)

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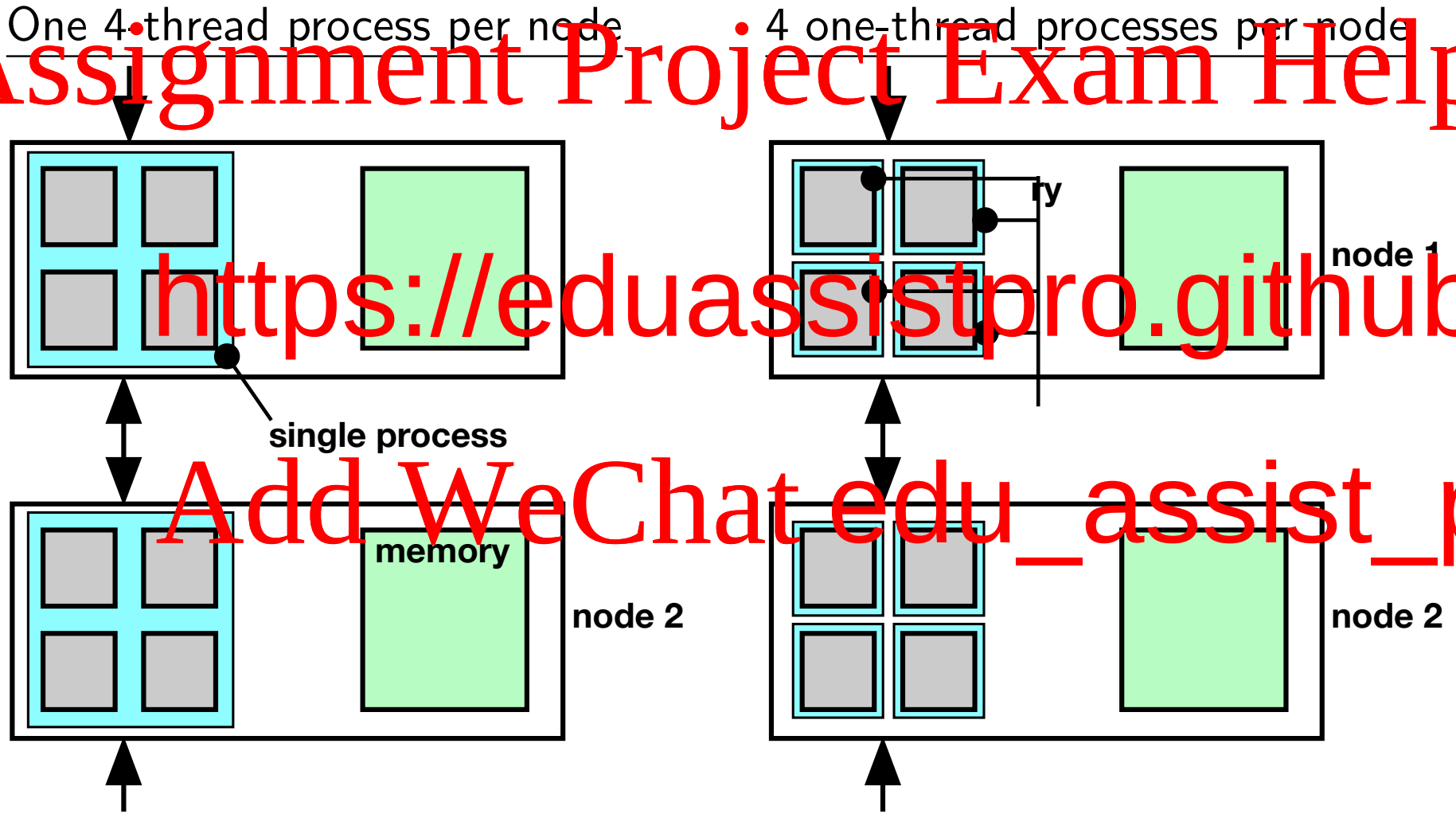
For simplicity, we consider one **single-threaded process per core**, and therefore **multiple processes per node**.

Example for quad core nodes



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Books

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Wilkinson and Allen *[Lecture 1]* covers distributed memory parallelism (MPI), and a little OpenMP, but no GPU.

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A more practical book for MPI coding is:

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- **Parallel Programming with MPI** (Morgan-Kauffman).
  - Old (1997), only covers distributed memory systems and MPI.
  - Many code examples and snippets.

Distributed HPC programming

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- For distributed HPC, there is essentially only one option[1]: **MPI**
  - Stands for **Message Passing Interface**.
  - *ing').*
  - https://eduassistpro.github.i
  - Fully supports C, C++ and FORTRAN.
    - Most online examples are in one of these lan
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  - Unofficial bindings for Java, MATLAB, P

[1] Has superseded PVM = Parallel Virtual Machine (1989). Others such as Spark, Chapel *etc.* not (yet?) widely used in HPC.

Implementations

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The MP standard only defines the **interface**, it is still down to a vendor to provide an **implementation**.

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There

- **MPICH**: `www.mpich.org`
- **OpenMPI**: `www.open-mpi.org`
- Don't confuse OpenMPI with OpenMP . . . !

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There are also commercial implementations:

- *e.g.* Intel MPI, Spectrum MPI (IBM).

Installing MPI

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The system `cloud-hpc1.leeds.ac.uk` has OpenMPI[1] installed:

```
module load mpi/openmpi-x86_64
```

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For pe
(cf. lin

- Mac users might like to try `home`

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On Windows machines, Microsoft MPI[2]

- Based on MPICH.

[1] Note the linux command "`module avail`" shows what modules are installed.

[2] `https://docs.microsoft.com/en-us/message-passing-interface/microsoft-mpi`

Building an MPI program

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Need to use a **special compiler** for MPI programs:

- Standard installation includes `mpicc`, `mpic++`, `mpifort`.
-
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For example, to compile a file `helloW`

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```
mpicc -Wall -o helloWorld helloW
```

- Will generate the executable `hel`
- All warnings on ('`-Wall`').
- Add *e.g.* `-lm` for the maths library.

Executing an MPI program

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Also need a special **launcher** to execute an MPI program[1].
For multiple processes all on the **same local machine**:

```
mpiexec -n 2 ./helloWorld
```

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- `mpirun` is the same/very similar to

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Best to develop/debug code on a single machine (
of `cloud-hpc1.leeds.ac.uk`), then r
batch mode for *e.g.* timing runs.

[1] Executing as usual ('`./helloWorld`') will launch *one* process, *i.e.* serial.
[2] With OpenMPI, can override with the argument `-oversubscribe`.

Launching via the batch queue

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The system cloud-hpc1.leeds.ac.uk has been set up to allow access to two 8-core nodes via `slurm`.

- enMP:
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```
#!/bin/bash
#Request a single node, and 8 cores (adjust as n
#SBATCH -N1 -n8

module add mpi/openmpi3-x86_64
mpiexec -n 8 ./helloWorld
```

A 'Hello World' example

```
1  #include "stdio.h"
2  #include "stdlib.h"
3  #include "mpi.h"                    // Need to include mpi.h
4
5  int main
6  {
7    int n;
8
9    MPI_Init( &argc, &argv );
10   MPI_Comm_size( MPI_COMM_WORLD, &numprocs );
11   MPI_Comm_rank( MPI_COMM_WORLD, &rank );
12
13   printf( "Process %d of %d.\n", rank, numprocs );
14
15   MPI_Finalize();
16   return EXIT_SUCCESS;
17 }
```

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Initialising and finalising

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The first MPI call **must** be `MPI_Init()`:

- Pass command line arguments `argc` and `argv`.
-
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The final MPI call **must** be `MPI_Fina`

- Note the US spelling; *finalize* not

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Any MPI calls before `MPI_Init()` or after `MPI_Finalize()` will result in a runtime error.

Number of processes and rank

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```
MPI_Comm_size(MPI_COMM_WORLD,&numprocs)
```

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```
MPI_Comm_rank(MPI_COMM_WORLD,&ra
```

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- Sets `rank` to the process number, know i
- Ranges from `0` to `numprocs-1` inclusive.
- Similar to `omp_get_thread_num()`.

Communicators

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For our purposes, whenever you see an MPI call with the argument **communicator**, just use `MPI_COMM_WORLD`:

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In general, communicators allow processes to be

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- *e.g.* when developing a parallel library, to prevent processes to accidentally communicate processes.
- An advanced feature we won't consider.

Summary and next lecture

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Today we have started looking at **distributed memory parallelism**:

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- For HPC, use **MPI = Message Passing Interface.**
- Seen how to build and execute a 'Hello World

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Next time we will see how MPI supports communication between processes, and use this to solve real problems.