Parallel Design

Models and Paradigms

Goals & Outline

- Outline the design process of a parallel program.
- Introduce metrics for judging performance.
- Build a vocabulary of parallel programming.
- Show basic design patterns.
- Present metrics used for measuring parallelism.

Implicit / Explicit Parallelism

- Implicit: Parallelism as a result of language design, or by way of a compiler, which is transparent to the programmer.

+ Programmers do not worry about communication or task division.

- Less than optimal code, harder to debug.

- Explicit: Parallelism by way of deliberate language constructs or annotation on top of existing languages. The programmer specifies where and when parallel constructs take place.

+ Potentially very efficient code.

- Unique parallel bugs (ie. deadlock), longer development time.

Types of Parallelism

- Hardware
  - Instruction Level
  - Thread Level
    - Shared Memory/Cache (SMP)
  - Cluster Level
    - Message Passing
- Software
  - Task Parallelism
  - Data Parallelism
  - Hybrid Task/Data

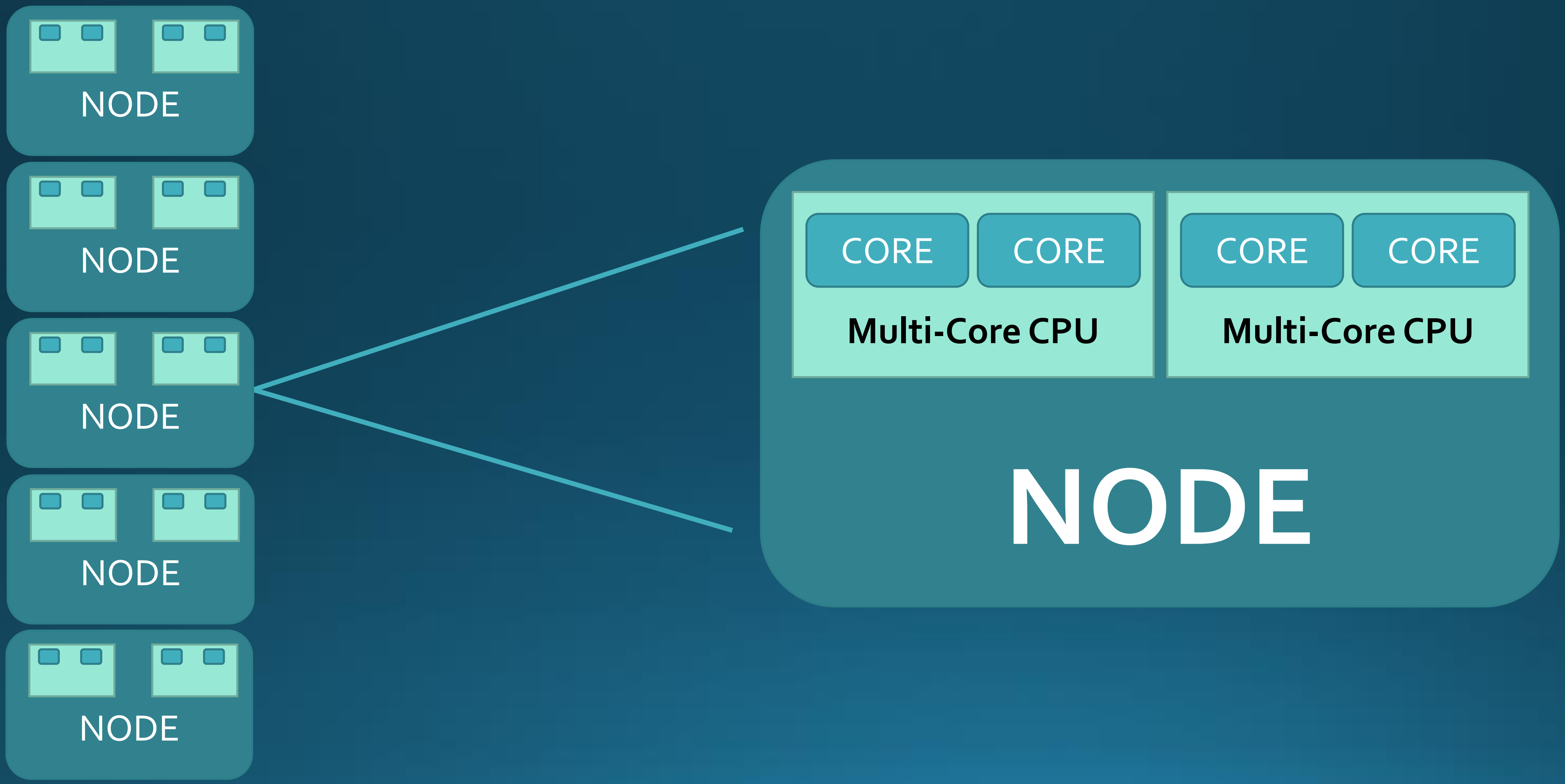
Flynn Taxonomy of Parallelism

	Single Data	Multiple Data
Single Instruction	**SISD**	**SIMD**
Multiple Instruction	**MISD**	**MIMD**

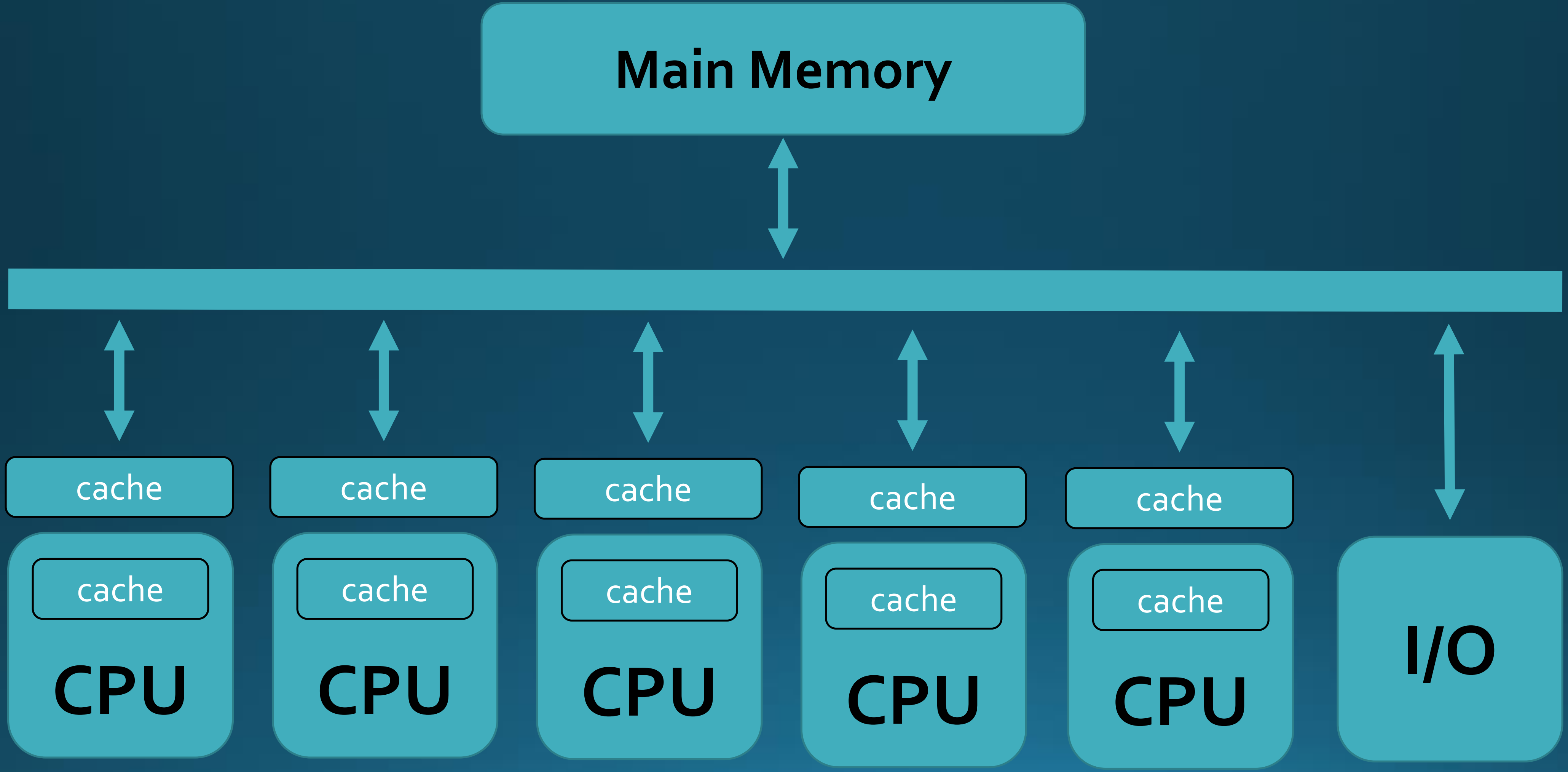
- SISD : Standard single core CPU.
- SIMD : Standard GPU processing model.
- MISD : Not commonly found in practice.
- MIMD: Standard Multi-Core model.

SISD	SIMD
MISD	MIMD

Target Hardware: Cluster Computing

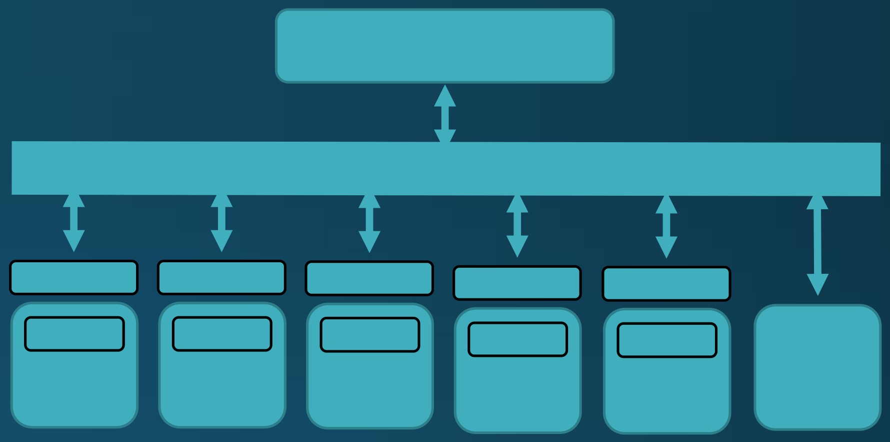


Symmetric Multiprocessor (SMP)



Shared Memory/SMP

- Global address space for intuitive memory access.
  - Synchronization can be a tricky concept to grasp.
- Data sharing is fast, also consistent in UMA* systems.
- Memory consistency model.
  - Cache coherence .
- Lacks scalability.
  - Have to wait for hardware advances.
  - More CPUs = more memory traffic.



* UMA: Uniform Memory Access, NUMA: Non-Uniform Memory Access

Message Passing Interface (MPI)

- Distributed memory model (will run on shared memory systems).
  - Memory addresses are not mapped.
  - No globally accessible memory.
  - Hybrid systems will also use threads.
- Memory is local & scalable.
  - No need for local memory synchronization.
- You may require specialized data structures.
- Non-Uniform memory access times on remote nodes.
  - Access times affected by the network (could be Ethernet).

Challenges

- non-determinism
- communication
- synchronization
- data/task partitioning

Challenges

- non-determinism
  - race conditions
- communication
- synchronization

```
transfer(Account from, Account to, double amount)
{
    from = from – amount;
    to = to + amount;
}
```

Challenges

- non-determinism
  - race conditions
- communication
- synchronization

```
transfer(Account from, Account to, double amount)
{
    temp = from;
    temp -= amount
    from = temp;

    temp = to;
    temp -= amount
    to = temp;
}

MyAccount = 500;
ClerkA.transfer(B, MyAccount, 200);
ClearB.transfer(MyAccount, C, 50);
```

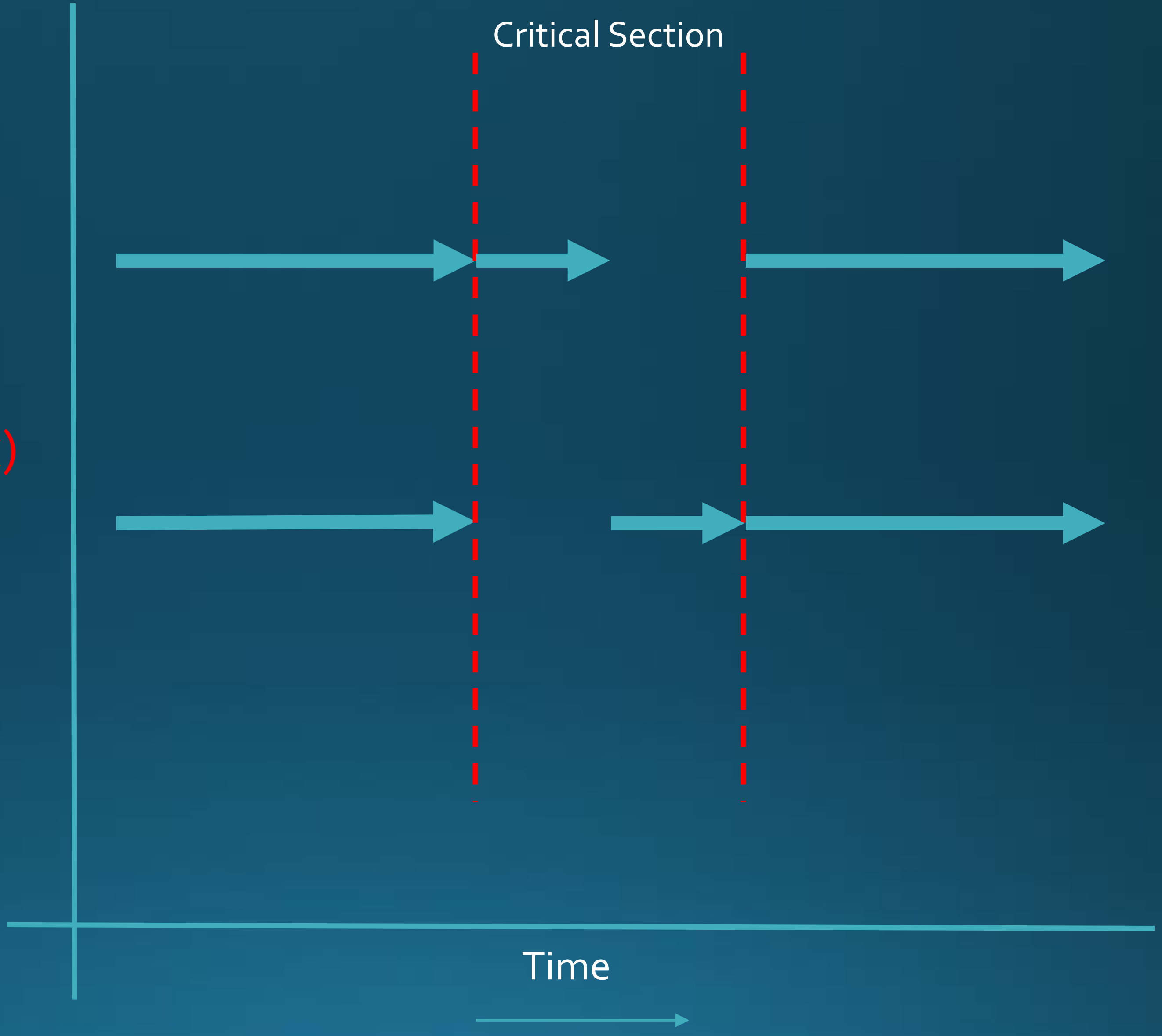
Challenges

- non-determinism
  - race conditions
- communication
- synchronization

`ClerkA.transfer (B, MyAccount, 200);`	`ClearB.transfer (MyAccount, C, 50);`
temp = \$300 (temp = from)	temp = \$500 (temp = from)
temp = \$100 (`temp -= amount`)	temp = \$450 (temp -= amount)
B = \$100 (`from = temp`)	=== delay ===
temp = \$500 (temp = to)	…
temp = \$700\$ (temp += amount)	…
MyAccount = \$700 (to = temp)	…
	MyAccount = \$450 (from = temp)

Challenges

- non-determinism
- communication
  - mutual exclusion (mutex)
- synchronization



Challenges

- non-determinism
- communication
  - mutual exclusion (mutex)
- synchronization

```
foo()
{
    do stuff before
    lock();
    …
    critical code section
    ….
    release();
    do stuff after
}
```

Thread 1	Thread 2
do stuff before	do stuff before
lock	lock
critical code	…
release	…
do stuff after	critical code
	release
	do stuff after

Challenges

- non-determinism
- communication
- synchronization
  - deadlocks

```
transfer(Account from, Account to, double amount)
{
    sync(from);
    sync(to);
    from.withdraw(amount);
    to.deposit(amount);
    release(to);
    release(from);
}

Thread1 -> transfer(A, B, 10.0);
Thread2 -> transfer(B, A, 10.0);
```

Performance Metrics

- Serial Runtime : T_1
- Parallel Runtime at n Processes: T_n
- Speedup (times faster): $S_n=T_1/T_n$
- Efficiency: $E_n=S_n/n$

Performance Metrics : Presentation

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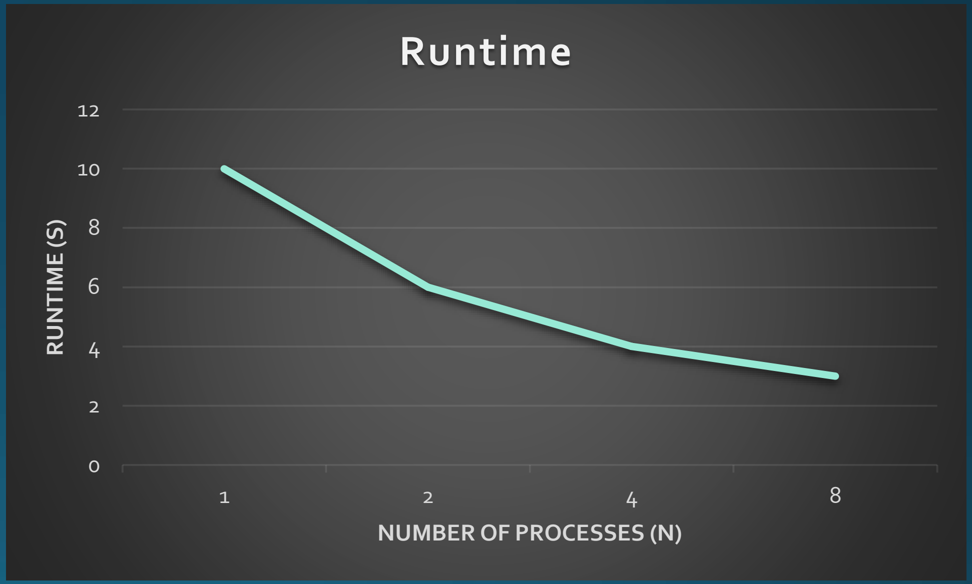

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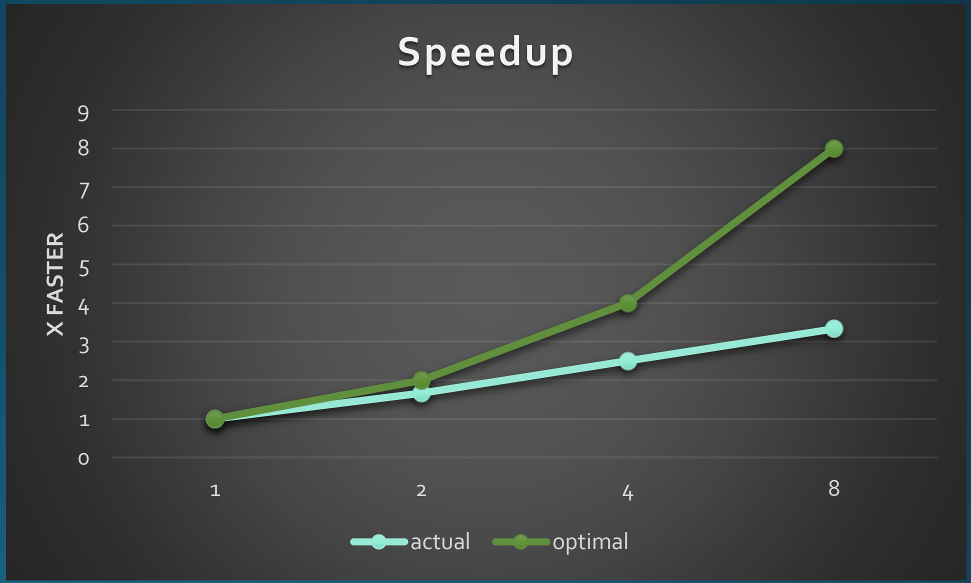

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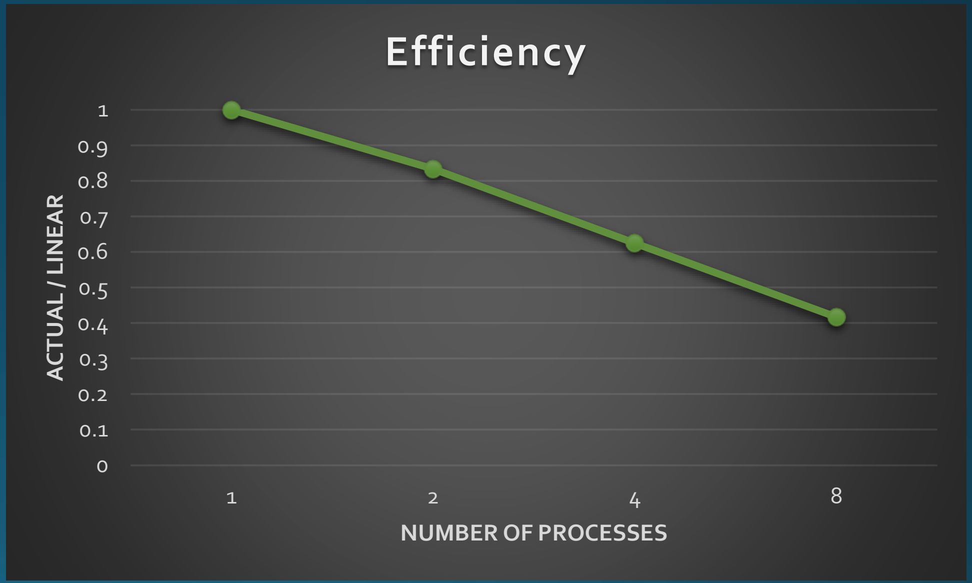


Amdahl's law

Percentage of the program which can be parallelized: p

Percentage of the program which is serial only: 1-p

Serial runtime: $T_1=(1-p)\,T_1+p\,T_1$

Theoretical parallel runtime: $T_n=(1-p)\,T_1+p\,T_1/n$

Tn/T1=(1-p) +p/n

Sn=T1/Tn=1/((1-p)+pn) note: Amdahl calls this 'speedup in latency'.

Amdahl's law

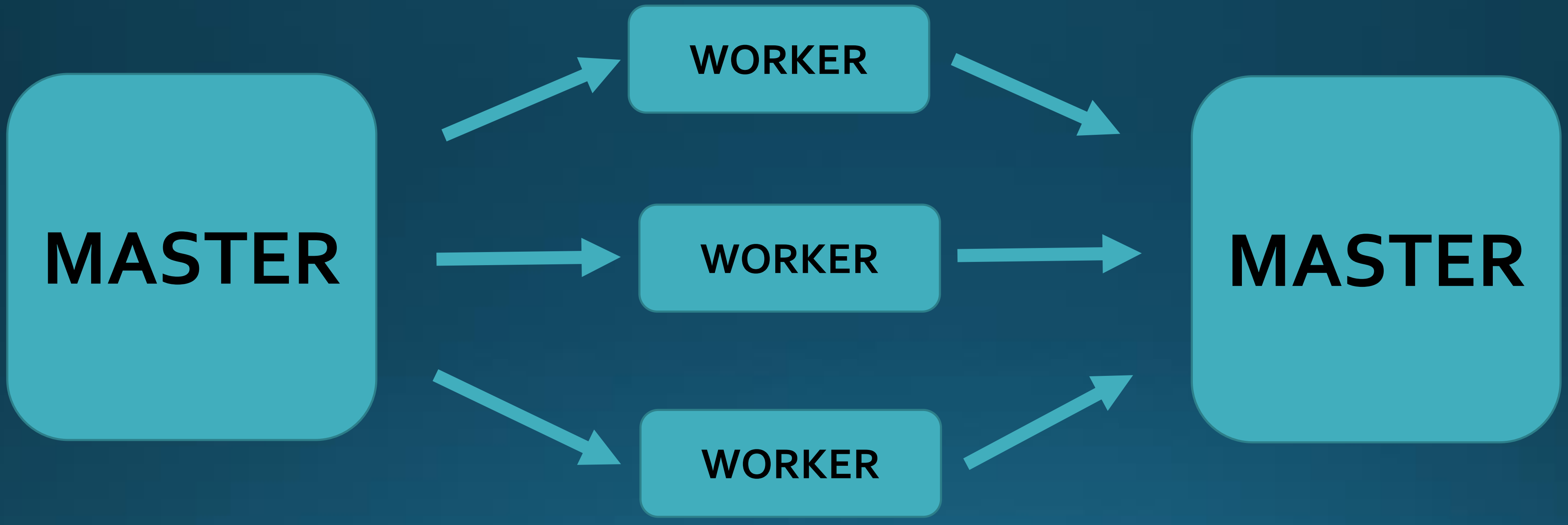
States that the minimum execution time of a parallel program is dictated by the execution time of the serial portion of the program.

- disk I/O
- inter-process communication
- critical code segments
- lock overhead
- context switching
- latency (p) can change in ratio to the number of processes.

Patterns

- Master-Worker
- Multi-Walk
- Pipeline
- Hybrid
- Loop Parallelism

Master-Worker

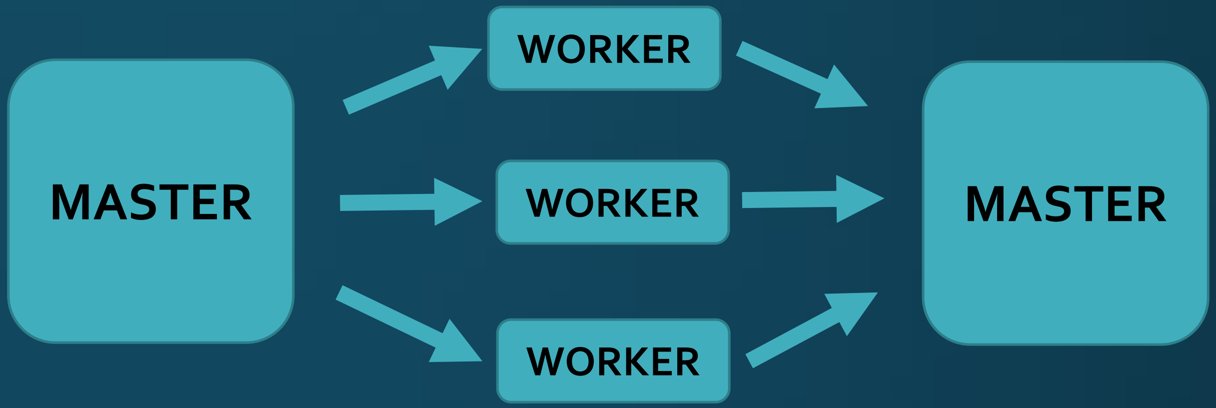


Assigns Tasks

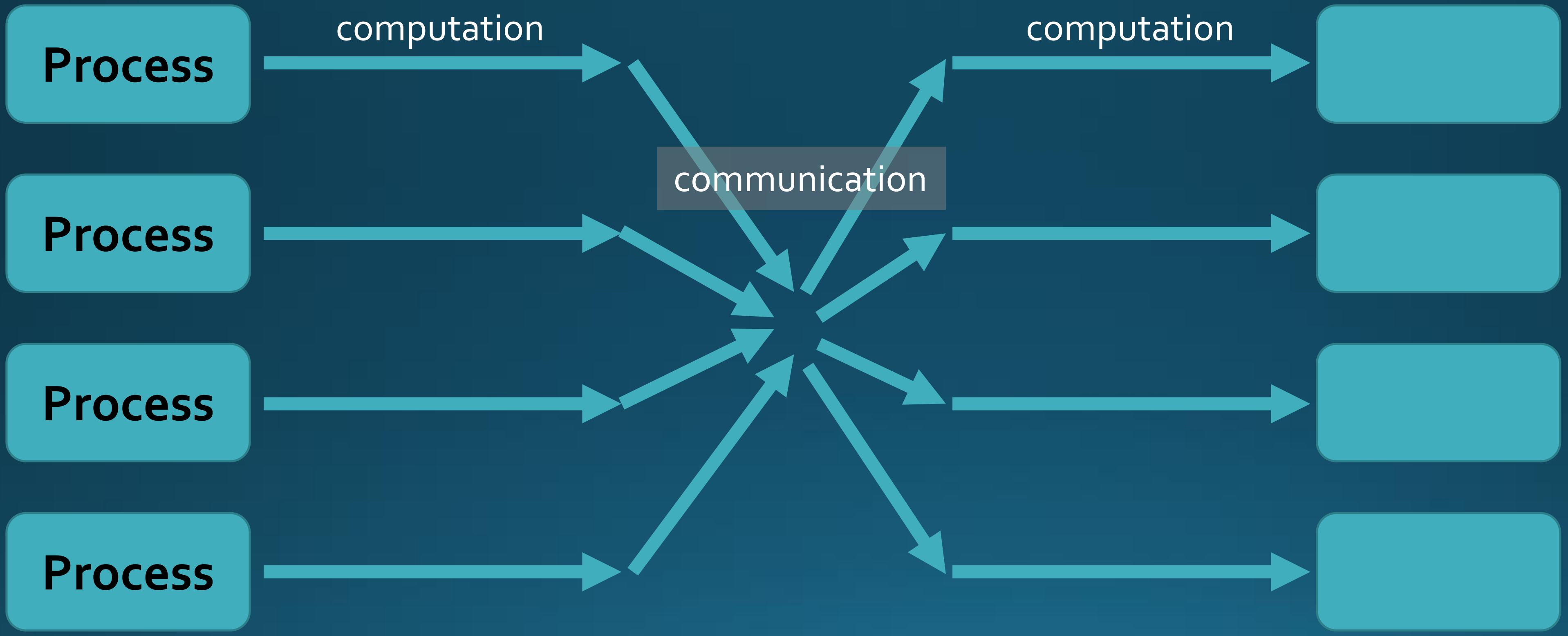
Performs Computation

Collects Results

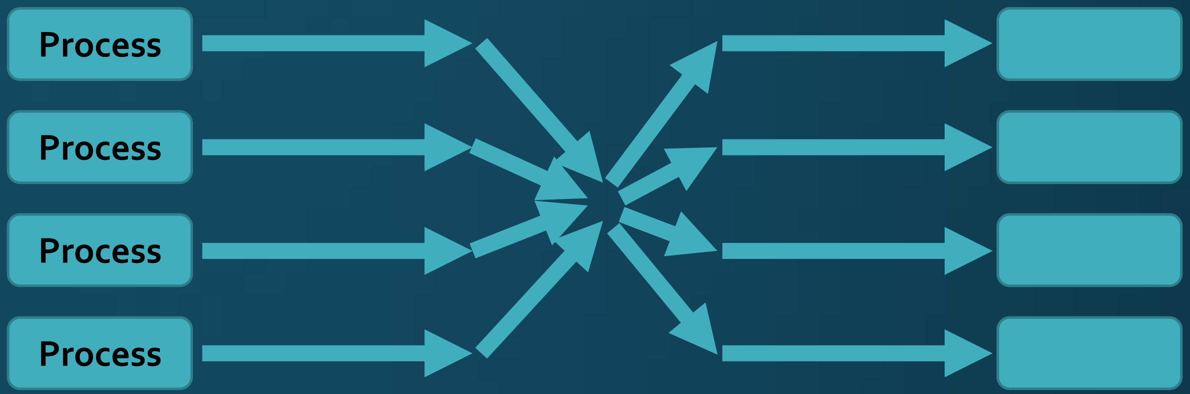
- All communication is between the master and a worker.
- The master can either wait (block) or perform computation.
- Scalability (see Hadoop).
- Simple to code.
- No inter-worker communication.
- Singe point of failure.



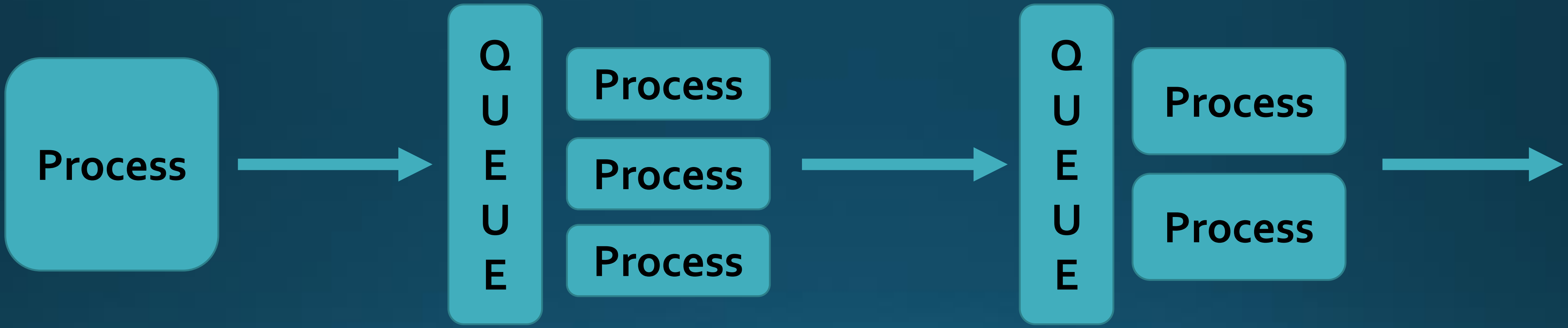
Multi-Walk (single program multiple data)



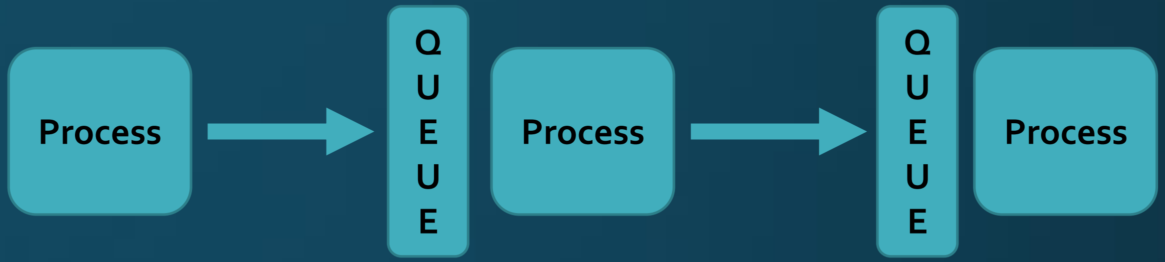
- Communication is between processes, as opposed to facilitated such as in Master-Worker.
- Barrier points (communication).
- Not suited for large variation in process runtime.
- Prone to communication delays.



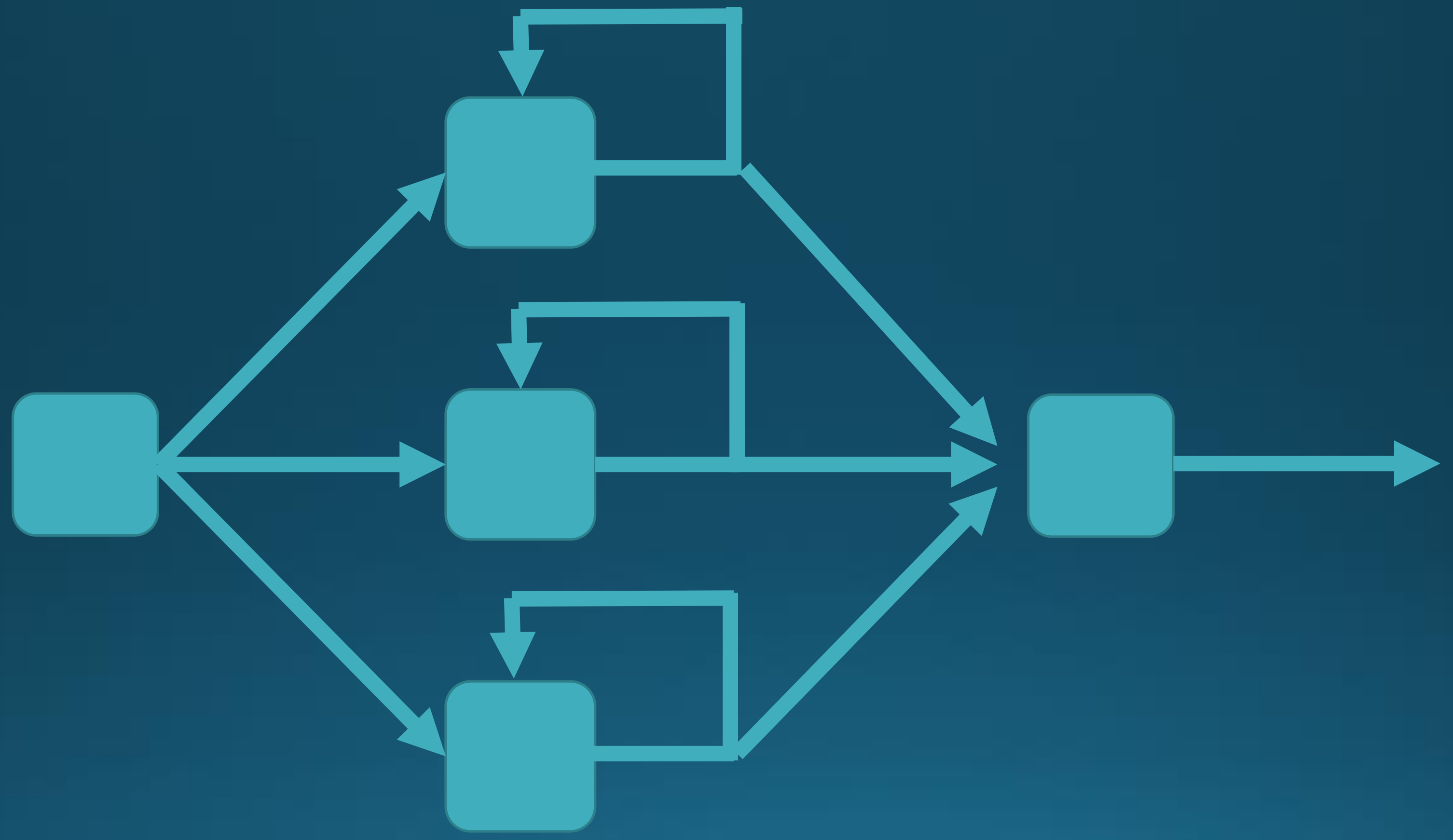
Pipeline


Process
QUEUE
Process
Process
Process
QUEUE
Process
Process

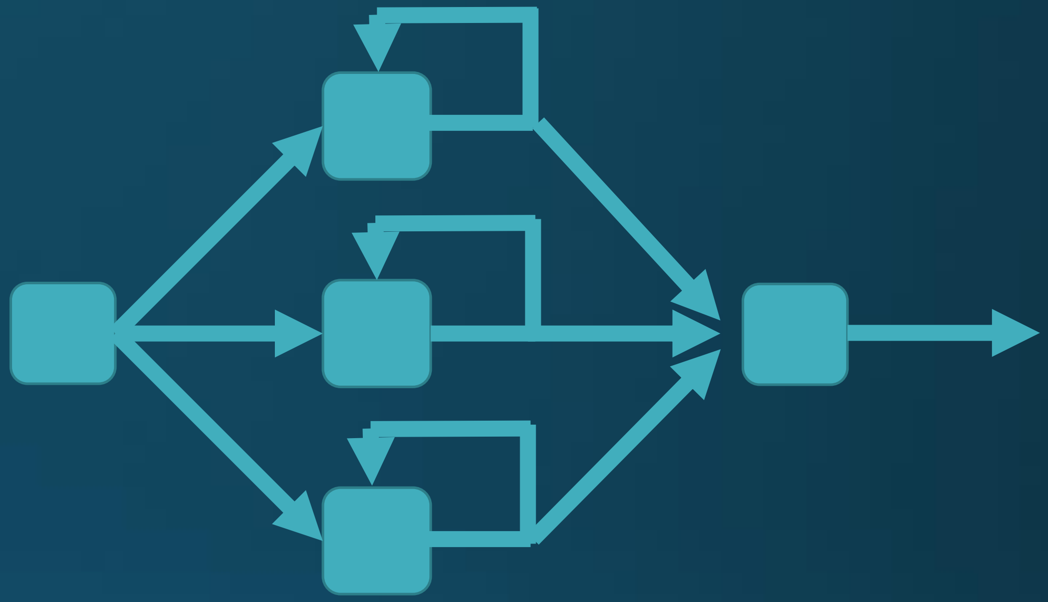
- Data assembly line model.
- Queue driven model.
  - Prone to starvation.
  - Variable sized process pools.
- Instruction pipeline.
- Graphics pipeline.



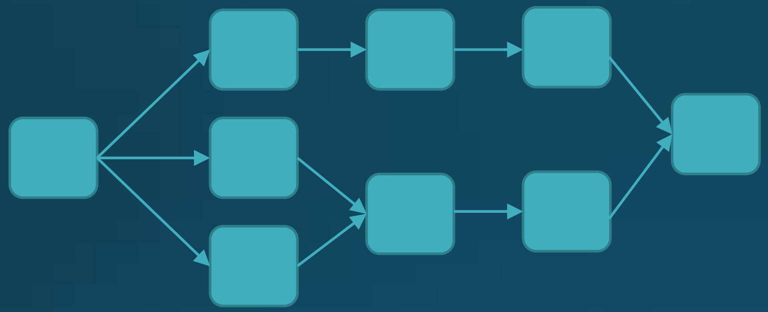
Loop Parallelism



- Data independence between iterations of the loop.
- Easy to implement.
- Susceptible to race conditions from mutex locks on critical code sections.



Hybrid Patterns



Hybrid Patterns (nested, asynchronous): A composition of patterns resulting in a hierarchy of tasks which allows sub-patterns to be replaced with another pattern with matching input-output dependencies.

Thank You.
Questions?