Parallel Programming

Overview and Concepts

Outline

- Why use parallel programming?
- Parallel models for HPC
  - Shared memory (thread-based)
  - Message-passing (process-based)
  - Other models
- Assessing parallel performance: scaling
  - Strong scaling
  - Weak scaling
- Limits to parallelism
  - Amdahl’s Law
  - Gustafson’s Law

Why use parallel programming?

It is harder than serial so why bother?

Drivers for parallel programming

- Traditionally, the driver for parallel programming was that a single core alone could not provide the time-to-solution required for complex simulations
  - Multiple cores were tied together as a HPC machine
  - This is the origin of HPC and explains the symbiosis of HPC and parallel programming
- Recently, due to the physical limits on the increase in power of single cores, the driver is due to the fact that **all** modern processors are parallel
  - In effect, parallel programming is required for all computing, not just HPC

Focus on HPC

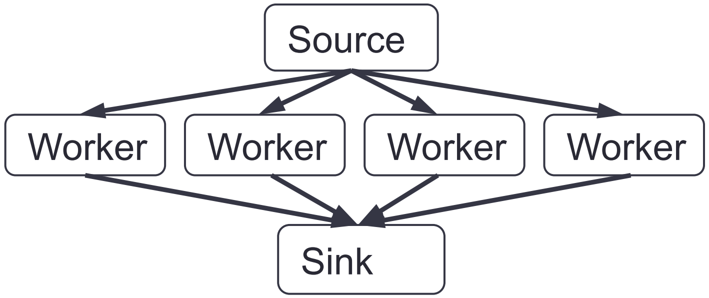
- In HPC, the driver is the same as always
  - Need to run complex simulations with a reasonable time to solution
  - Single core or even single/multiple processors in a workstation do not provide the compute/memory/IO performance required
- Solution is to harness the power of multiple cores/ memory/storage simultaneously
- In order to do this we require concepts to allow us to exploit the resources in a parallel manner
  - Hence, parallel programming
- Over time a number of different parallel programming models have emerged.

Parallel models

How can we write parallel programs

Embarrassingly Parallel/Task Farm

- Use large computers to run many small programs at once
  - run multiple copies of a program with different input parameters
  - Monte Carlo simulations
- Simple structure
  - **Source:** passes out tasks to workers
  - **Workers:** repeatedly process tasks
  - **Sink:** collates results
- No parallel programming required
- Cannot exploit multiple resources for individual programs

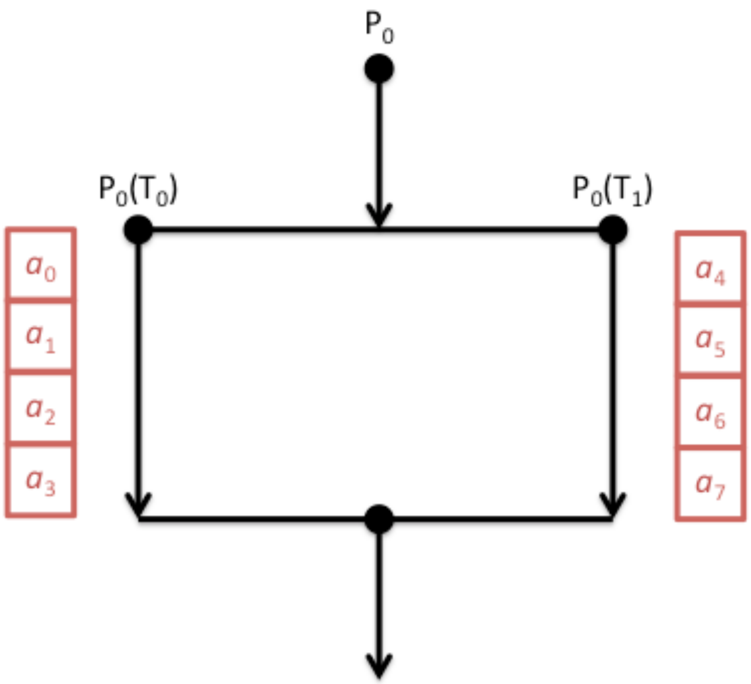


Shared-memory programming

- Shared memory programming is usually based on threads
  - Although some hardware/software allows processes to be programmed as if they share memory
  - Sometimes known as Symmetric Multi-processing (SMP) although this term is now a little old-fashioned
- Most often used for *Data Parallelism*
  - Each thread operates the same set of instructions on a separate portion of the data
- More difficult to use for *Task Parallelism*
  - Each thread performs a different set of instructions

Shared-memory concepts

- Threads "communicate" by having access to the same memory space
  - Any thread can alter any bit of data
  - No explicit communications between the parallel tasks



Advantages and disadvantages

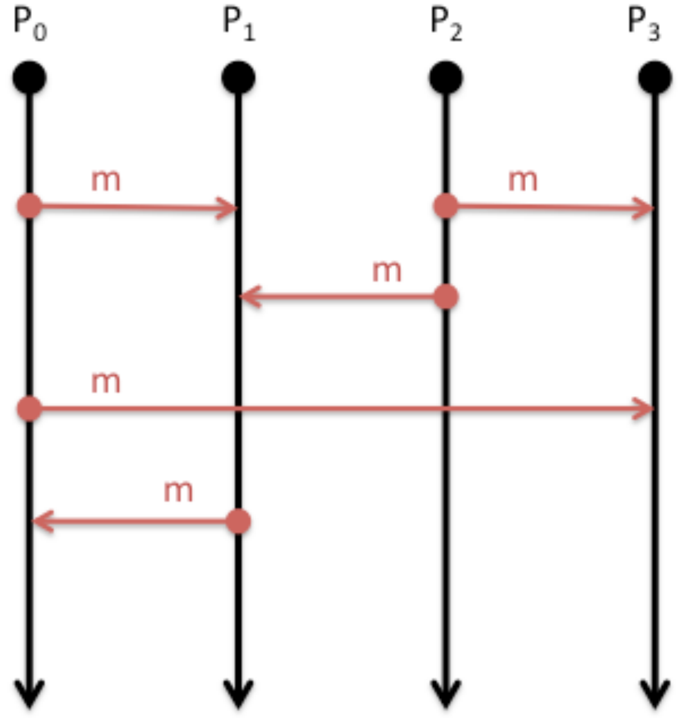
- Advantages:
  - Conceptually simple
  - Usually minor modifications to existing code
  - Often very portable to different architectures
- Disadvantages
  - Difficult to implement task-based parallelism – lack of flexibility
  - Often does not scale very well
  - Requires a large amount of inherent data parallelism (e.g. large arrays) to be effective
  - Can be surprisingly difficult to get good performance

Message-passing programming

- Message passing programming is process-based
- Processes running simultaneously communicate by exchanging messages
  - Messages can be 2-sided – both sender and receiver are involved in the process
  - Or they can be 1-sided – only the sender or receiver is involved
- Used for both data and task parallelism
  - In fact, most message passing programs employ a mixture of data and task parallelism

Message-passing concepts

- Each process does not have access to another process's memory
- Communication is usually explicit



Advantages and disadvantages

- Advantages:
  - Flexible – almost any parallel algorithm imaginable can be implemented
  - Scaling usually only limited by your choice of algorithm
  - Portable – MPI library is provided on all HPC platforms
- Disadvantages
  - Parallel routines usually become part of the program due to explicit nature of communications
    - Can be a large task to retrofit into existing code
  - May not give optimum performance on shared-memory machines
  - Can be difficult to scale to very large numbers of processes (>100,000) due to overheads

Scaling

Assessing parallel performance

Scaling

- *Scaling* is how the performance of a parallel application changes as the number of parallel processes/threads is increased
- There are two different types of scaling:
    - *Strong Scaling* – total problem size stays the same as the number of parallel elements increases
    - *Weak Scaling* – the problem size increases at the same rate as the number of parallel elements, keeping the amount of work per element the same
- Strong scaling is generally more useful and more difficult to achieve than weak scaling

Limits to parallel performance

How much can you gain from parallelism

Performance improvement

- Two theoretical descriptions of the limits to parallel performance improvement are useful to consider:
  - Amdahl's Law – how much improvement is possible for a fixed problem size given more cores
  - Gustafson's Law – how much improvement is possible given a fixed amount of time and given more cores

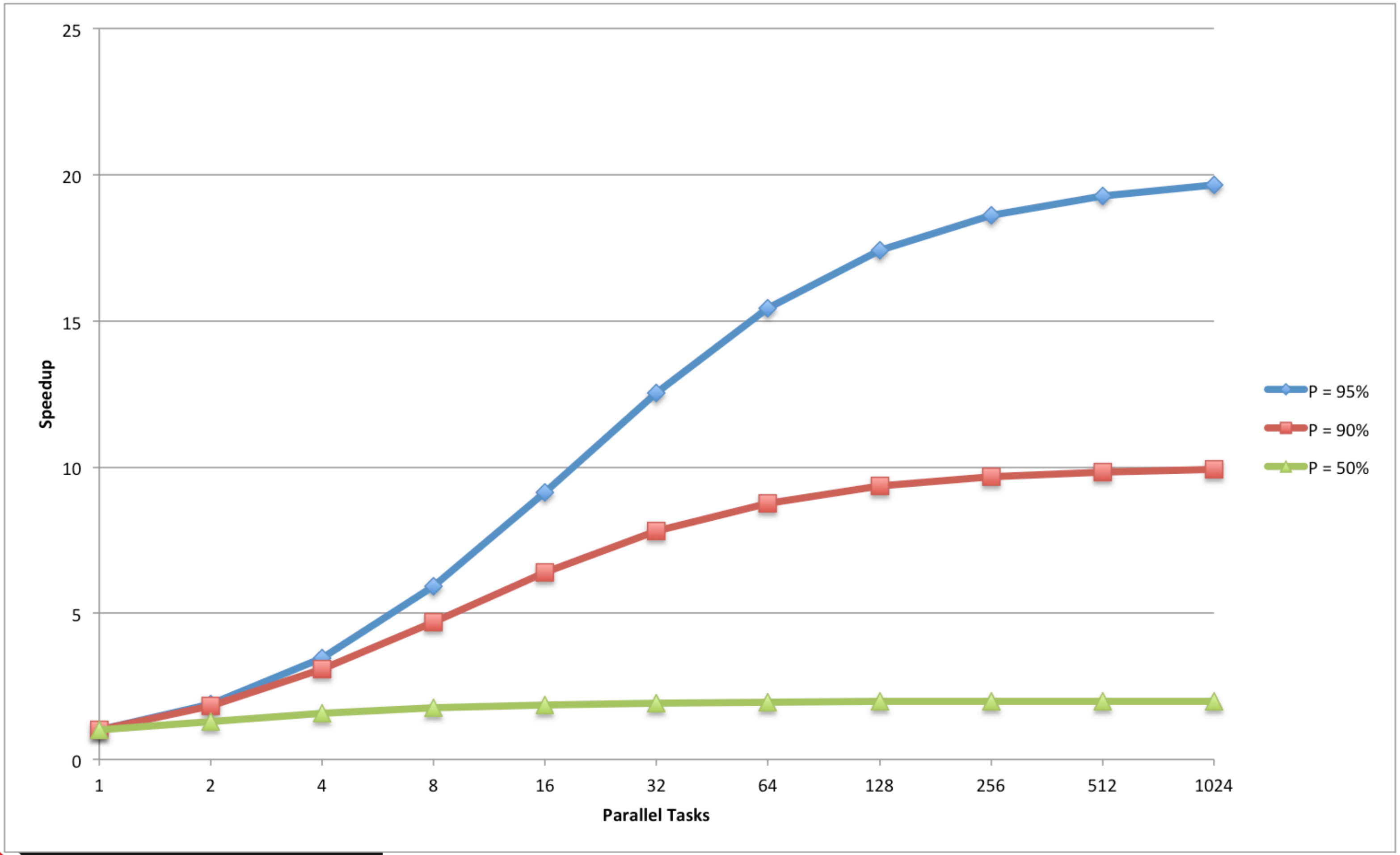
Amdahl's Law

- Performance improvement from parallelisation is strongly limited by serial portion of the code
  - As the serial part's performance is not increased by adding more processes/threads
  - Based on having a fixed problem size

$$S(N) = \frac{1}{(1-P) + \frac{P}{N}}$$

- For example, 90% parallelisable (*P*=0.9):
  - S(16) = 6.4
  - S(1024) = 9.9

Amdahl's Law



25
20
15
10
5
0
Speedup
1
2
4
8
16
32
64
128
256
512
1024
Parallel Tasks
P = 95%
P = 90%
P = 50%

Gustafson's Law

- If you can increase the amount of work done by each process/task then the serial component will not dominate
  - Increase the problem size to maintain scaling
  - This can be in terms of adding extra complexity or increasing the overall problem size.

$$S(N) = N - (1 - P)(N - 1)$$

- For example, 90% parallelisable (P=0.9):
  - S(16) = 14.5
  - S(1024) = 921.7

Gustafson's Law