Performance metrics

How is my parallel code performing and scaling?

Engineering and Physical Sciences Research Council
Natural Environment Research Council
a Hewlett Packard Enterprise company

Reusing this material

Performance metrics

- A typical program has two categories of components
  - Inherently sequential sections: can't be run in parallel
  - Potentially parallel sections

- Speed up
  - typically $S(N,P) < P$

$$S(N,P) = \frac{T(N,1)}{T(N,P)}$$

- Parallel efficiency
  - typically $E(N,P) < 1$

$$E(N,P) = \frac{S(N,P)}{P} = \frac{T(N,1)}{P\,T(N,P)}$$

- Serial efficiency
  - typically $E(N) <= 1$

$$E(N) = \frac{T_{best}(N)}{T(N,1)}$$

where N is the size of the problem and P the number of processors

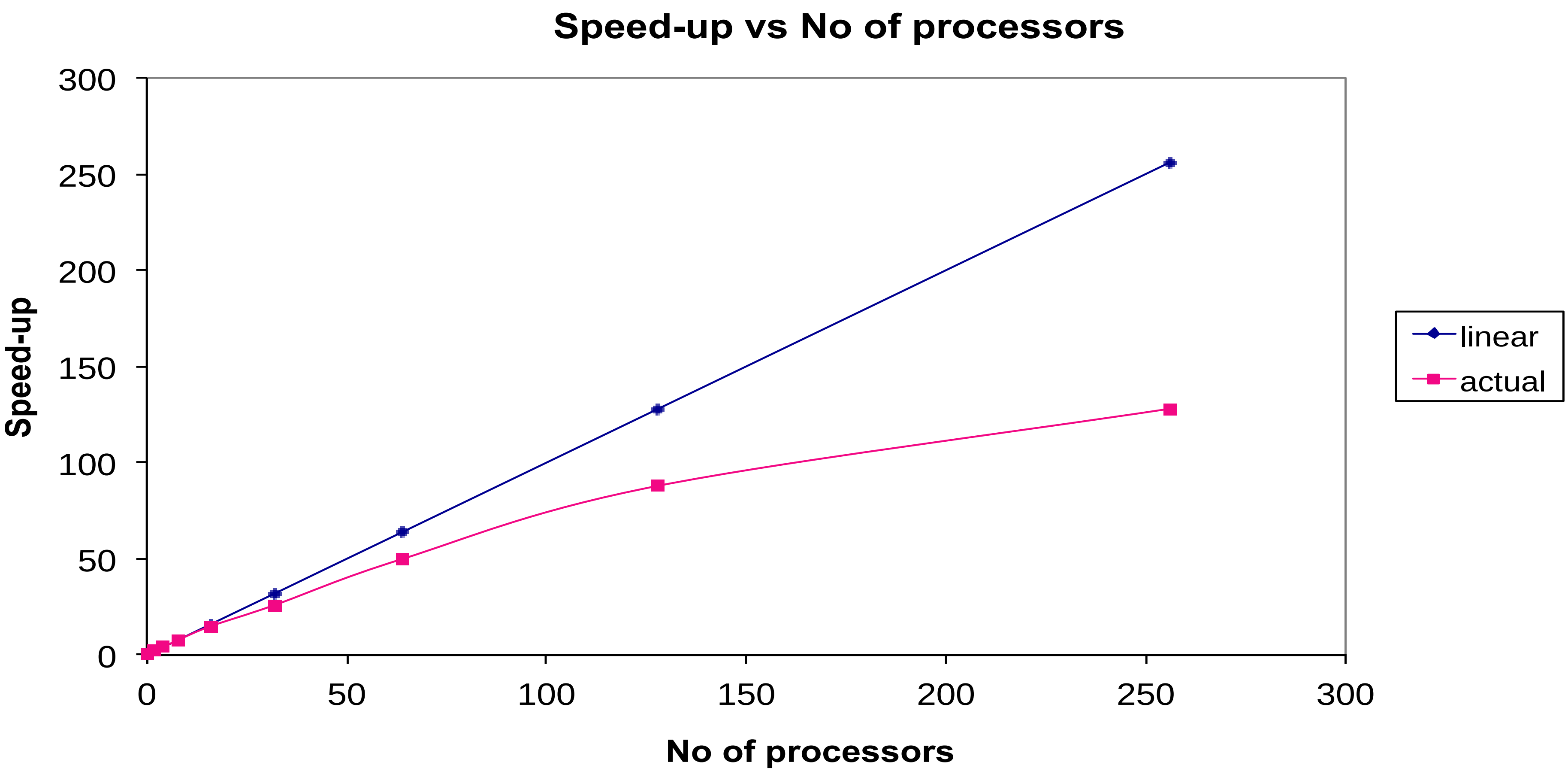
Scaling

- *Scaling* is how the performance of a parallel application changes as the number of processors is increased

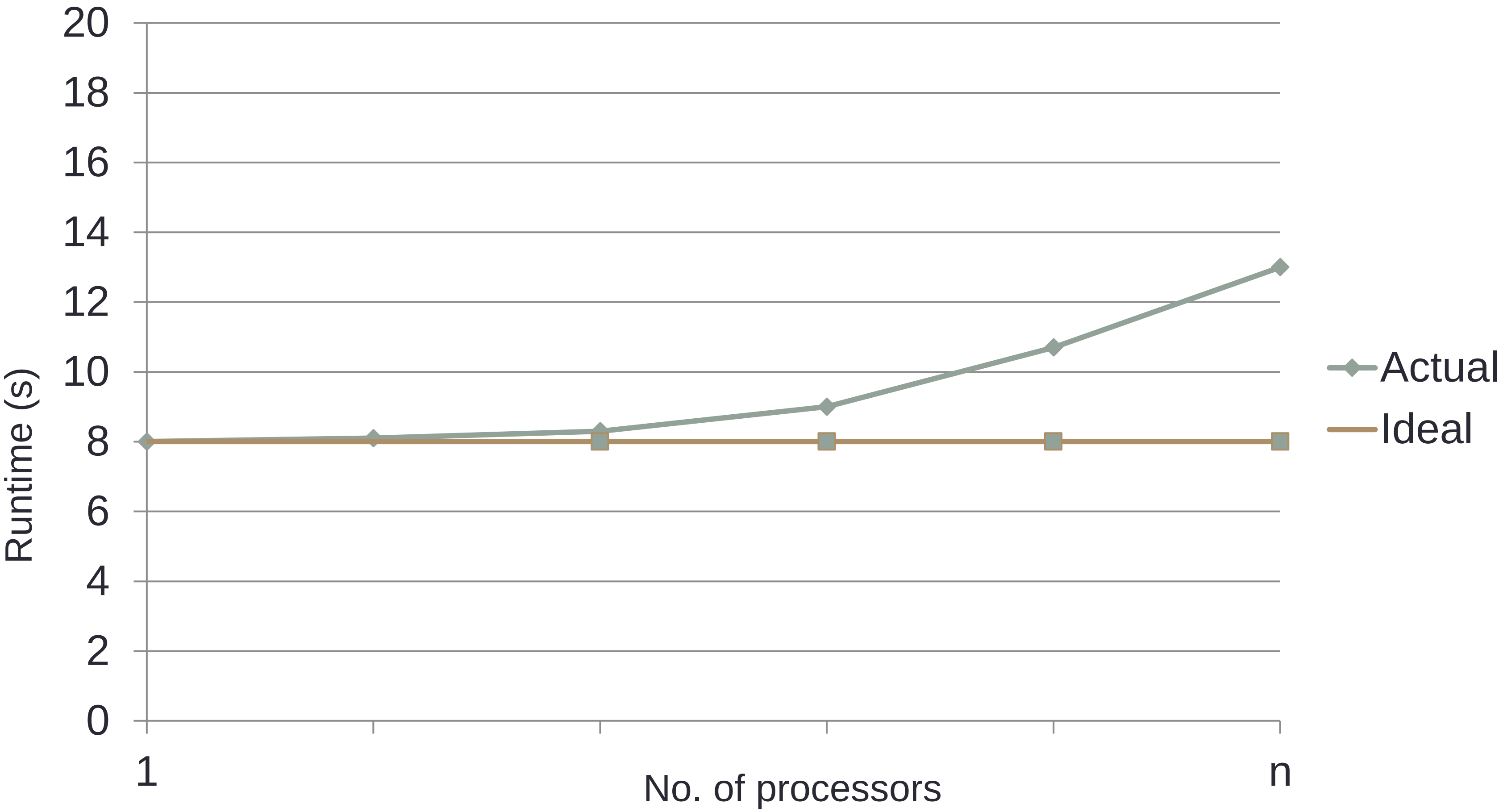
- There are two different types of scaling:
  - *Strong Scaling* – total problem size stays the same as the number of processors increases
  - *Weak Scaling* – the problem size increases at the same rate as the number of processors, keeping the amount of work per processor the same

- Strong scaling is generally more useful and more difficult to achieve than weak scaling

Strong scaling



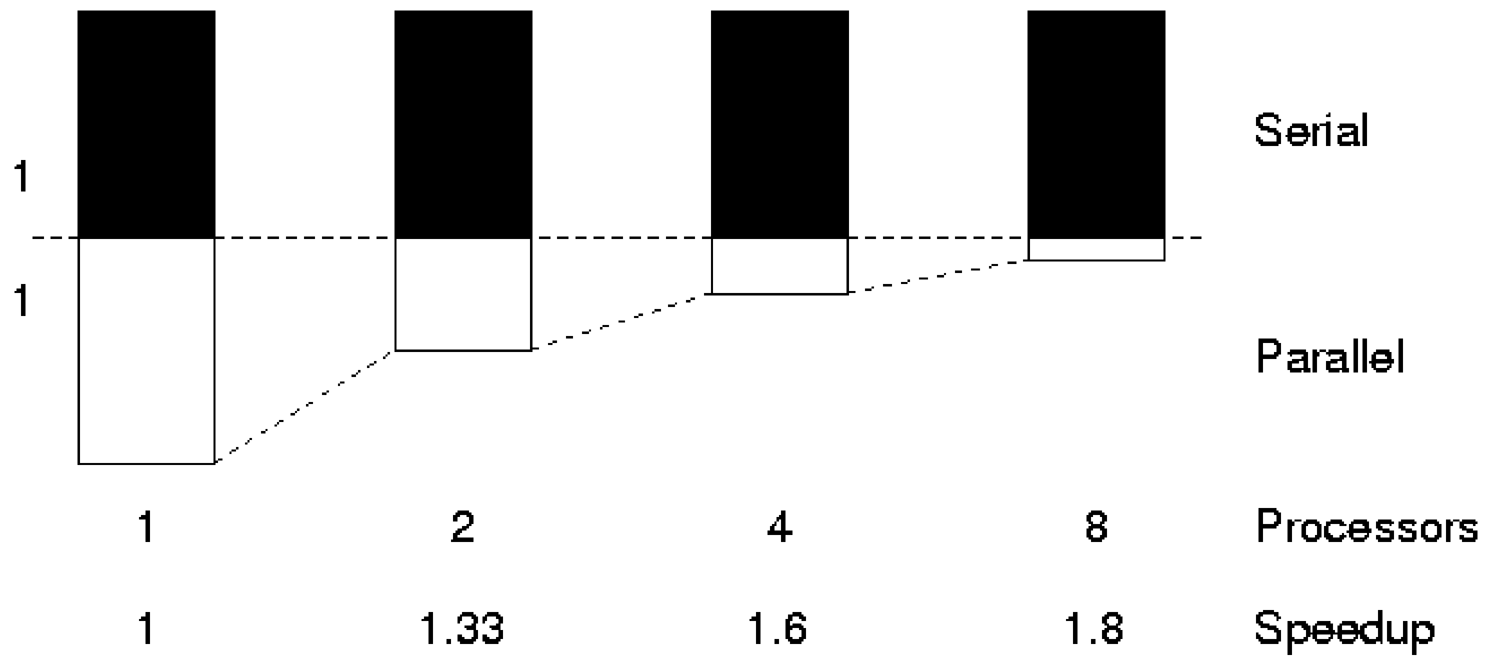
Weak scaling



The serial section of code

"The performance improvement to be gained by parallelisation is limited by the proportion of the code which is serial"

Gene Amdahl, 1967

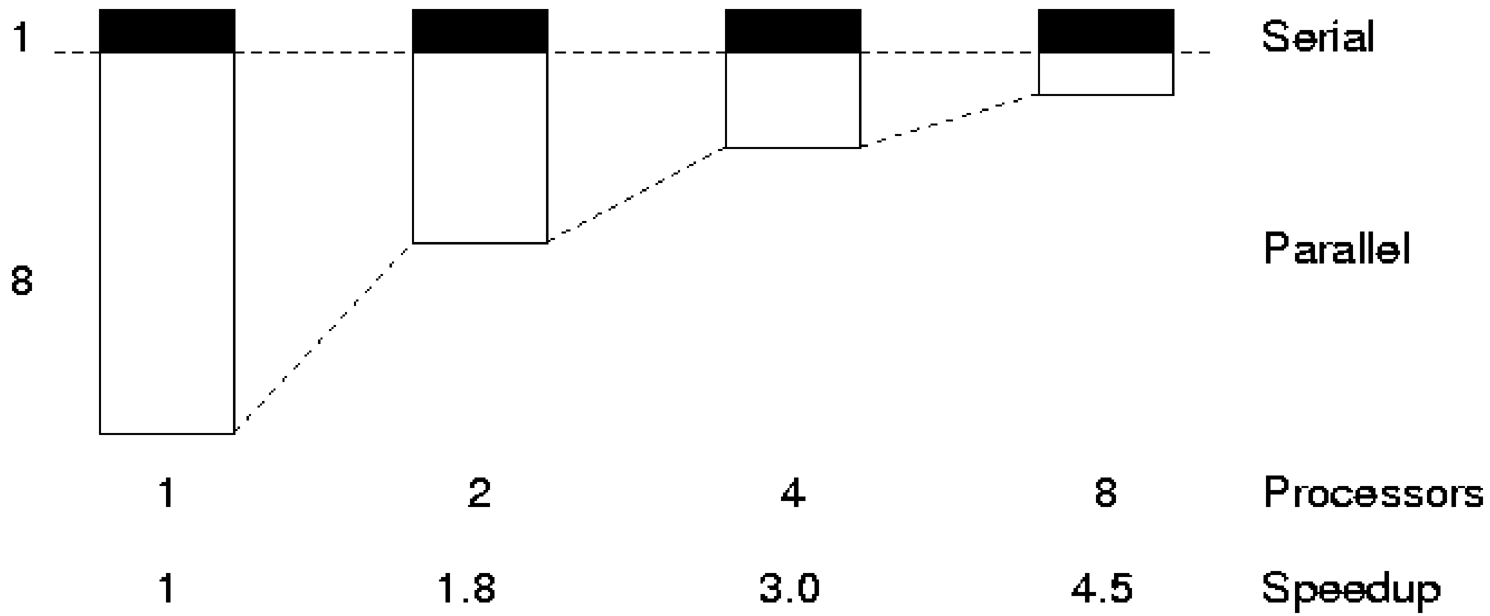


Amdahl's law

- Assume that a fraction, α, is completely serial
- Parallel runtime $$T(N,P) = \alpha\, T(N,1) + \frac{(1-\alpha)\, T(N,1)}{P}$$
  - Assuming parallel part is 100% efficient
- Parallel speedup $$S(N,P) = \frac{T(N,1)}{T(N,P)} = \frac{P}{\alpha P + (1-\alpha)}$$
- We are fundamentally limited by the serial fraction
  - For $\alpha = 0$, *S* = *P* as expected (i.e. *efficiency* = 100%)
  - Otherwise, speedup limited by $1/\alpha$ for any *P*
    - *For* $\alpha = 0.1$; 1/0.1 = 10 therefore 10 times maximum speed up
    - *For* $\alpha = 0.1$; S(N, 16) = 6.4, S(N, 1024) = 9.9

Gustafson's Law

- We need larger problems for larger numbers of CPUs



- Whilst we are still limited by the serial fraction, it becomes less important

Utilising Large Parallel Machines

- Assume parallel part is O(*N*), serial part is O(1)
  - time

$$
\begin{aligned}
T(N,P) &= T_{serial}(N,P) + T_{parallel}(N,P) \\
&= \alpha T(1,1) + \frac{(1-\alpha)NT(1,1)}{P}
\end{aligned}
$$

  - speedup

$$
S(N,P) = \frac{T(N,1)}{T(N,P)} = \frac{a + (1-a)N}{a + (1-a)\dfrac{N}{P}}
$$

- Scale problem size with CPUs, i.e. set *N* = *P* (weak scaling)
  - speedup $S(P,P) = a + (1-a)P$
  - efficiency $E(P,P) = \frac{a}{P} + (1-a)$

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.

$$S(N*P,P) = P - \alpha(P-1)$$

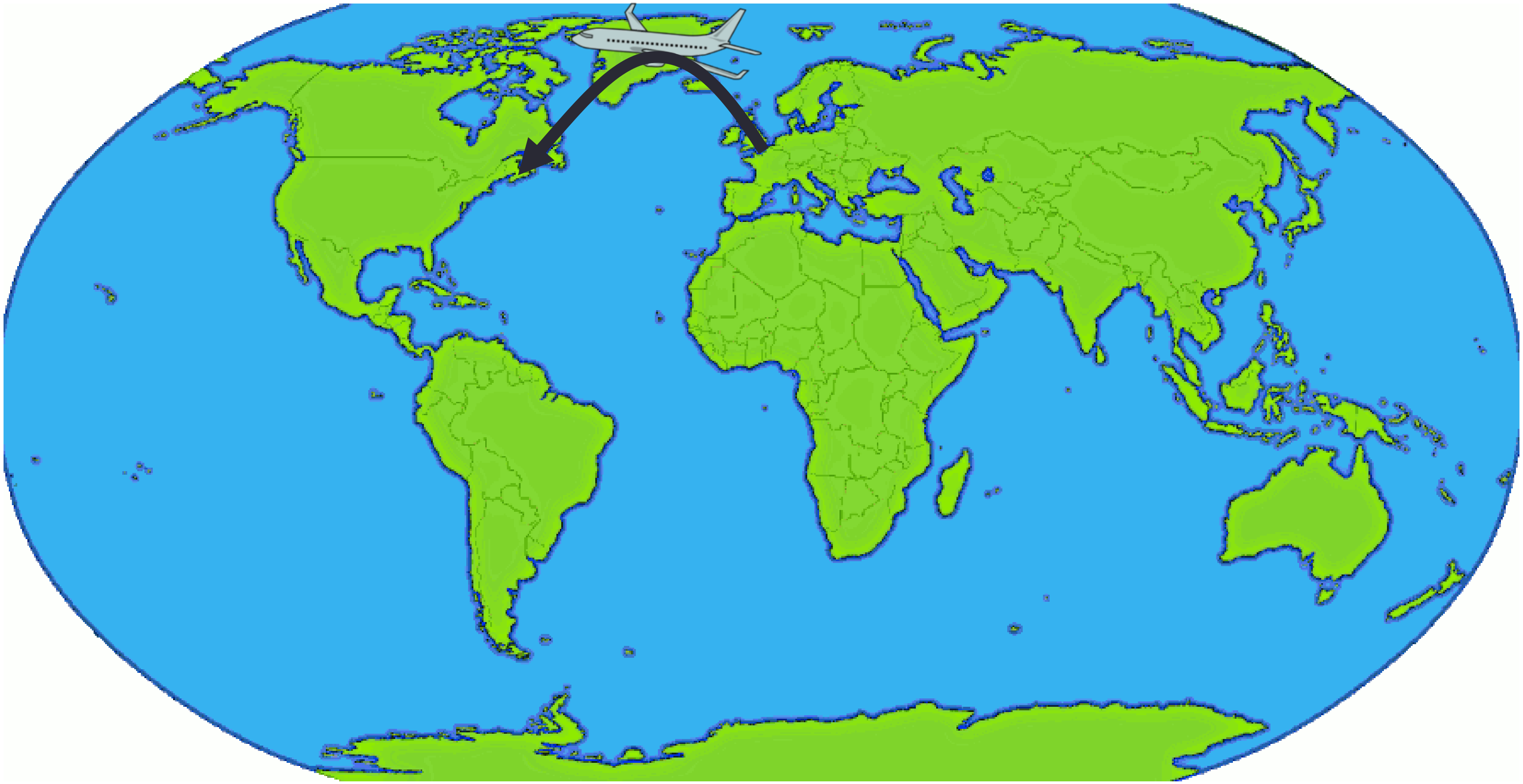
  - Due to the scaling of N, effectively the serial fraction becomes $\frac{\alpha}{P}$

- For instance, $\alpha = 0.1$

$$S(16N,16) = 14.5$$

$$S(1024N,1024) = 921.7$$

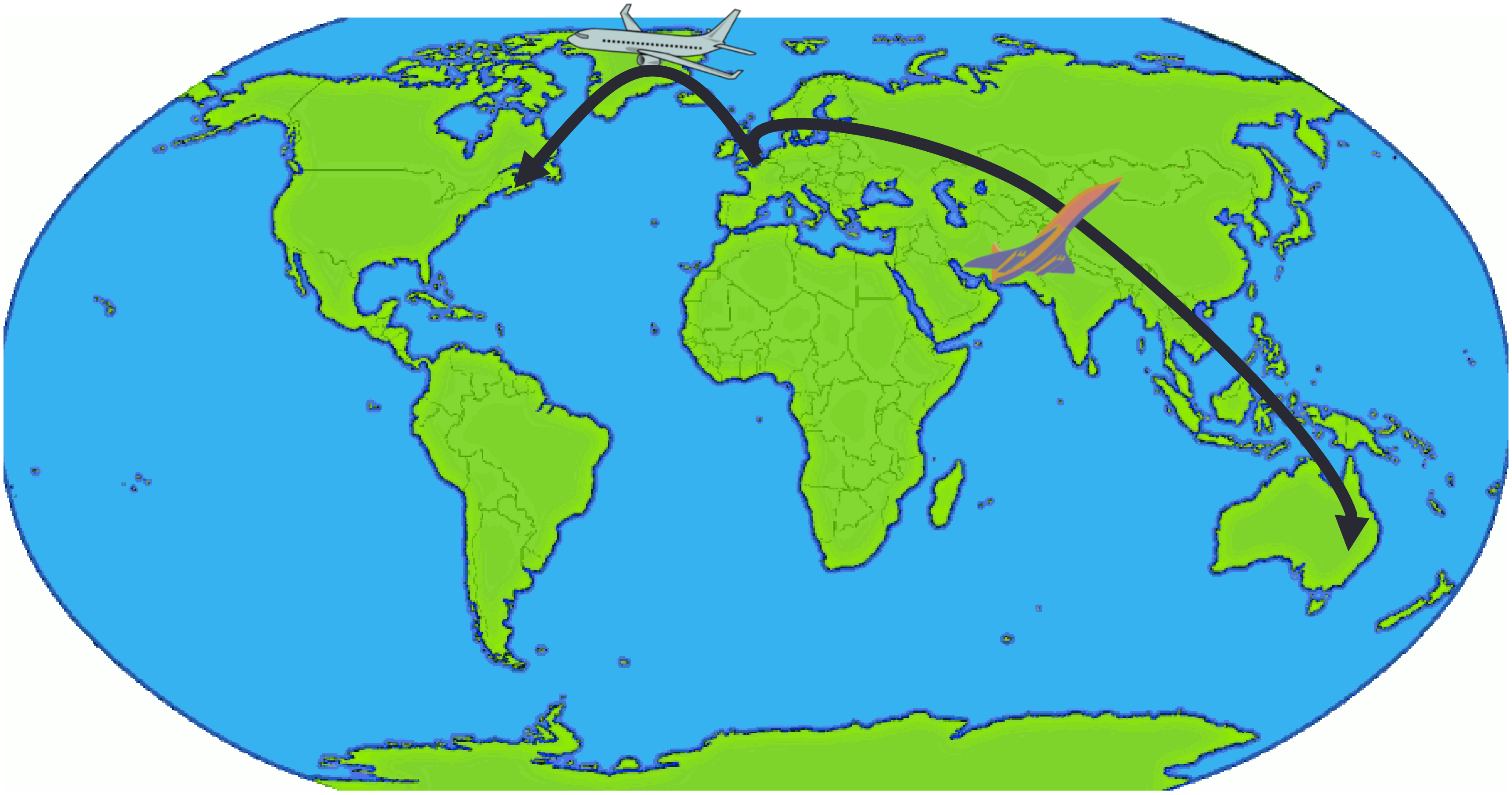
Analogy: Flying London to New York



Buckingham Palace to Empire State

- By Jumbo Jet
  - distance: 5600 km; speed: 700 kph
  - time: 8 hours ?
- No!
  - 1 hour by tube to Heathrow + 1 hour for check in etc.
  - 1 hour immigration + 1 hour taxi downtown
  - fixed overhead of 4 hours; total journey time: 4 + 8 = 12 hours
- Triple the flight speed with Concorde to 2100 kph
  - total journey time = 4 hours + 2 hours 40 mins = 6.7 hours
  - speedup of 1.8 not 3.0
- Amdahl's law!
  - a = 4/12 = 0.33; max speedup = 3 (i.e. 4 hours)

Flying London to Sydney



Buckingham Palace to Sydney Opera

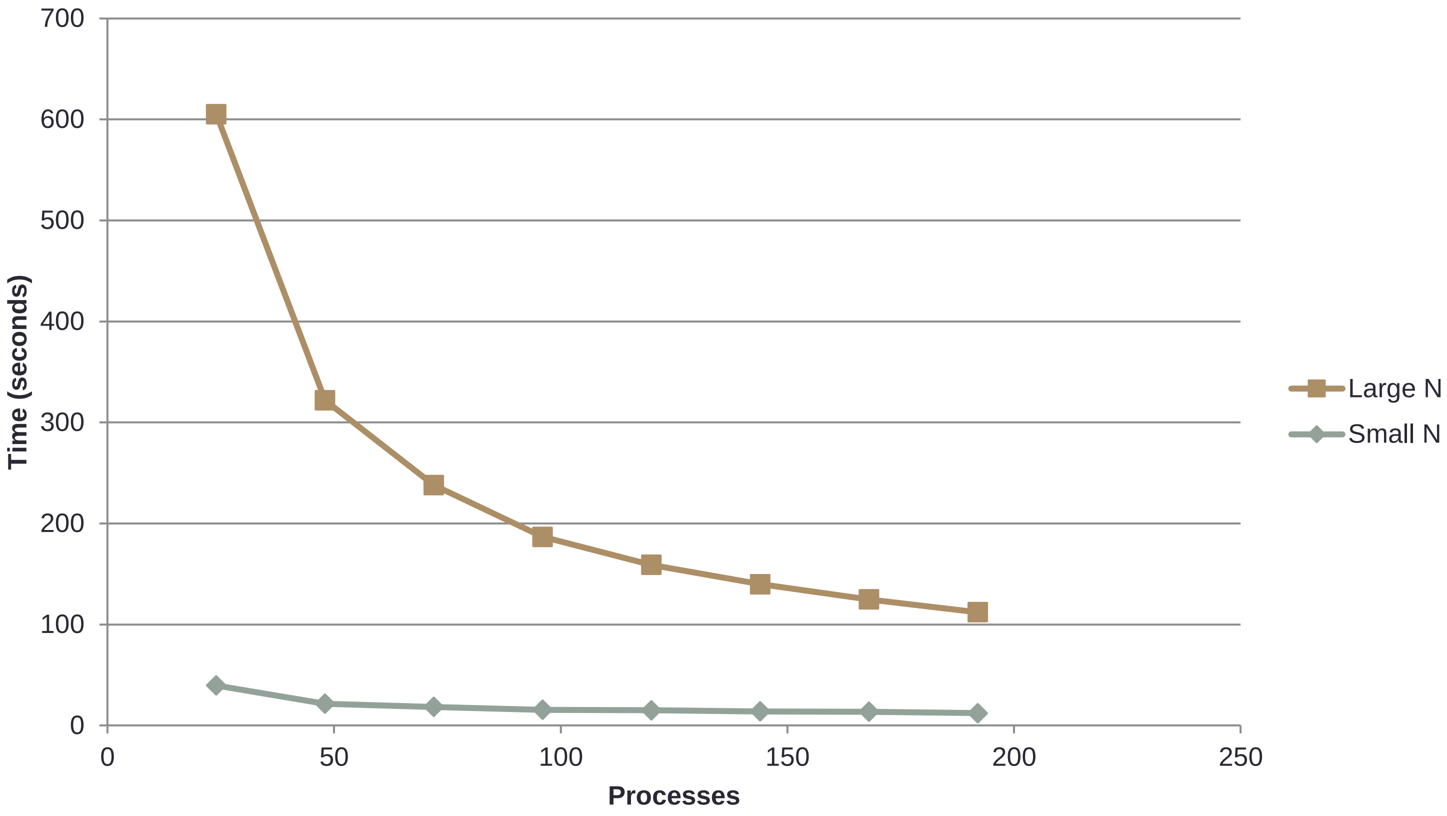
- By Jumbo Jet
  - distance: 16800 km; speed: 700 kph; flight time; 24 hours
  - serial overhead **stays the same:** total time: 4 + 24 = 28 hours
- Triple the flight speed
  - total time = 4 hours + 8 hours = 12 hours
  - speedup = 2.3 (as opposed to 1.8 for New York)
- Gustafson's law!
  - bigger problems scale better
  - increase **both** distance (i.e. *N*) **and** max speed (i.e. *P*) by three
  - maintain same balance: 4 "serial" + 8 "parallel"

Plotting

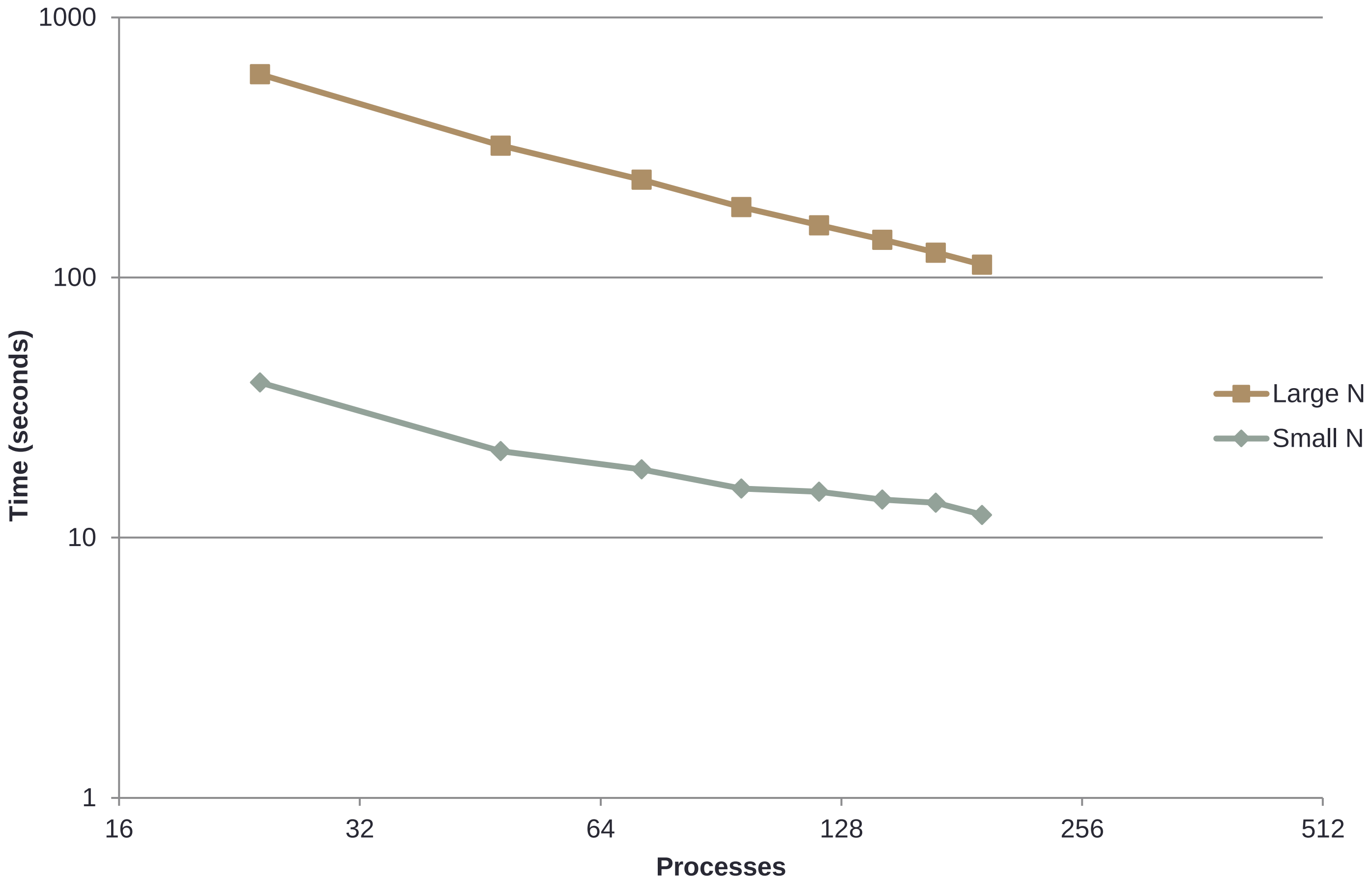
- Think carefully whenever you plot data
  - what am I trying to show with the graph?
  - is it easy to interpret?
  - can it be interpreted quantitatively?

- Default plotting options are rarely what you want
  - default colours can be hard to read (e.g. yellow on white)
  - default axis limits may not be sensible
  - ...
- Test data
  - MPI version of traffic model on multiple nodes of ARCHER

Hard to interpret small N data here

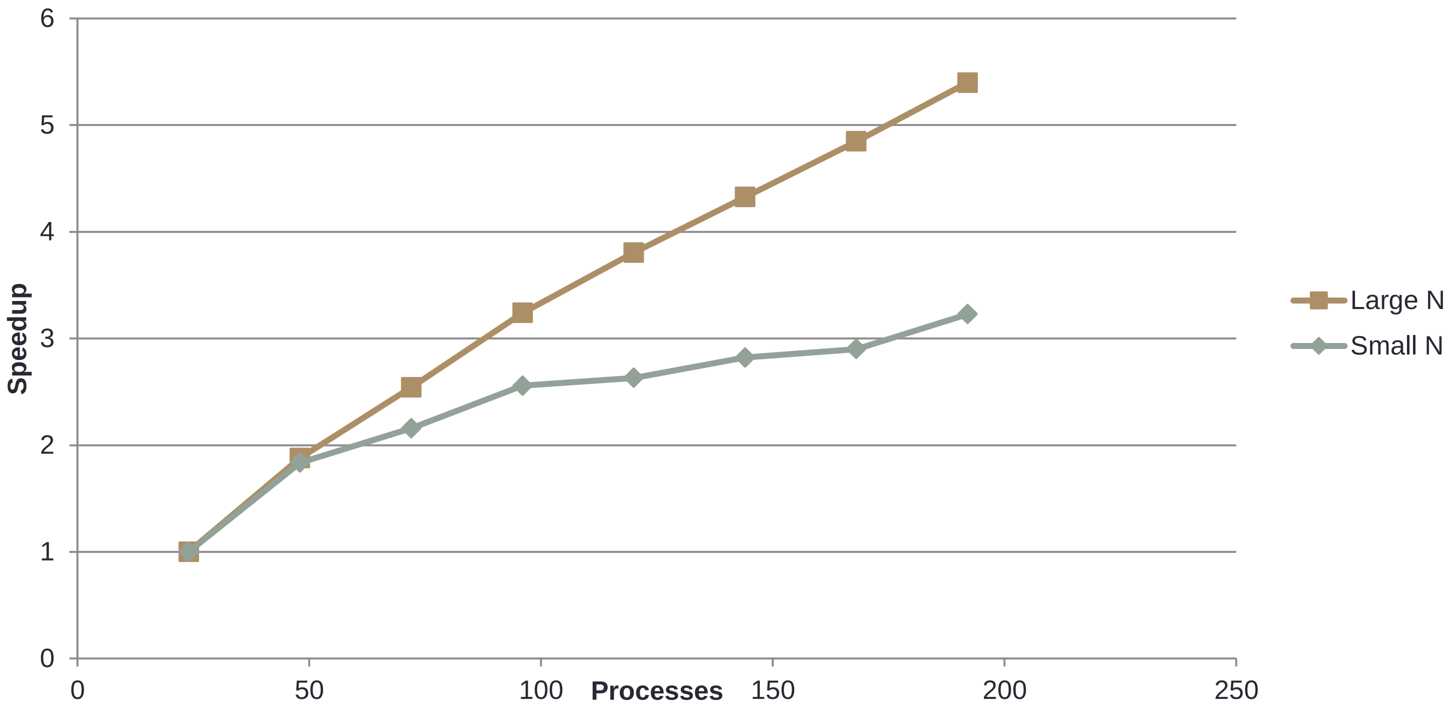


log/log can make trends in data too similar

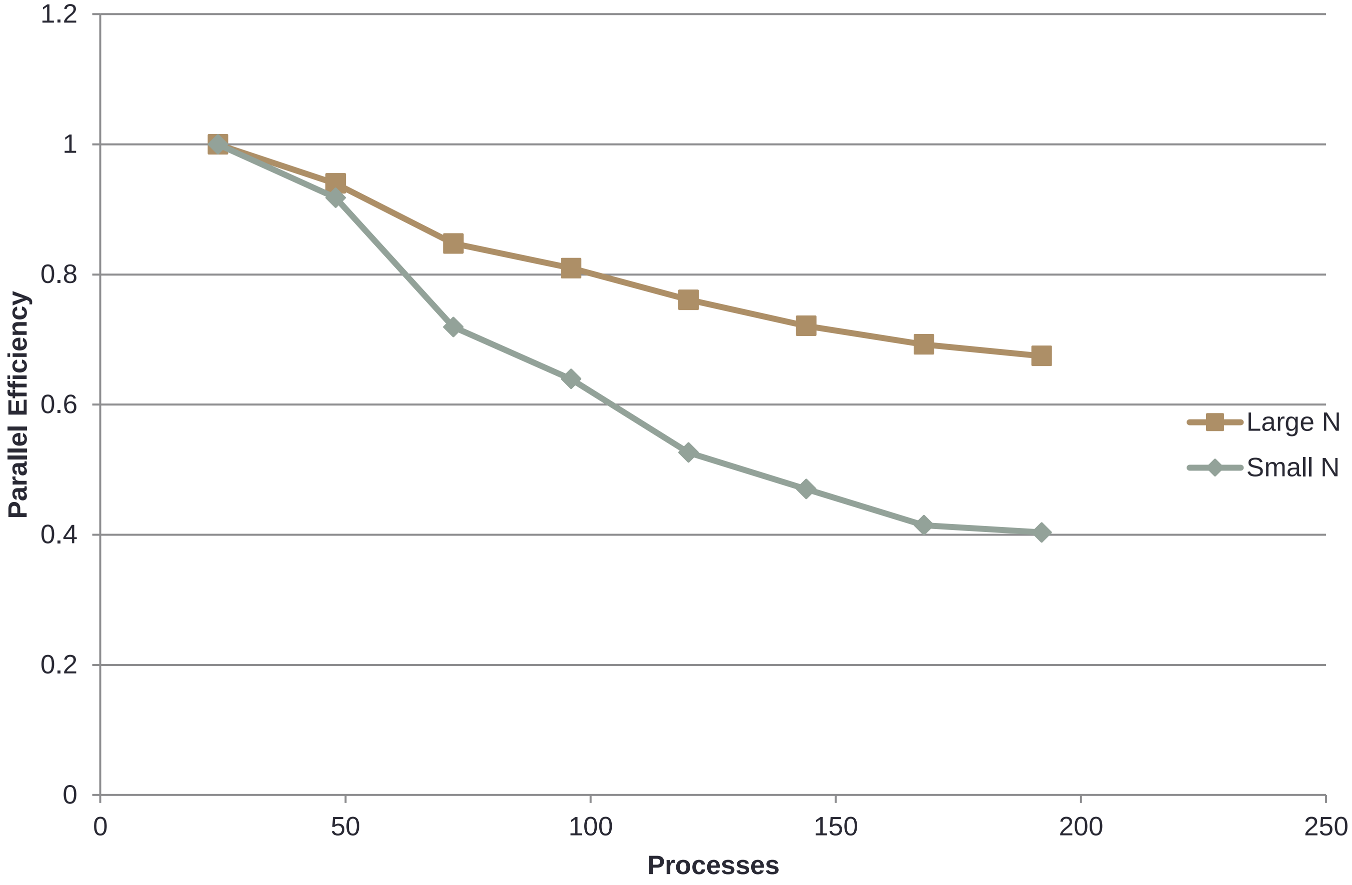


Normalised data easier to compare

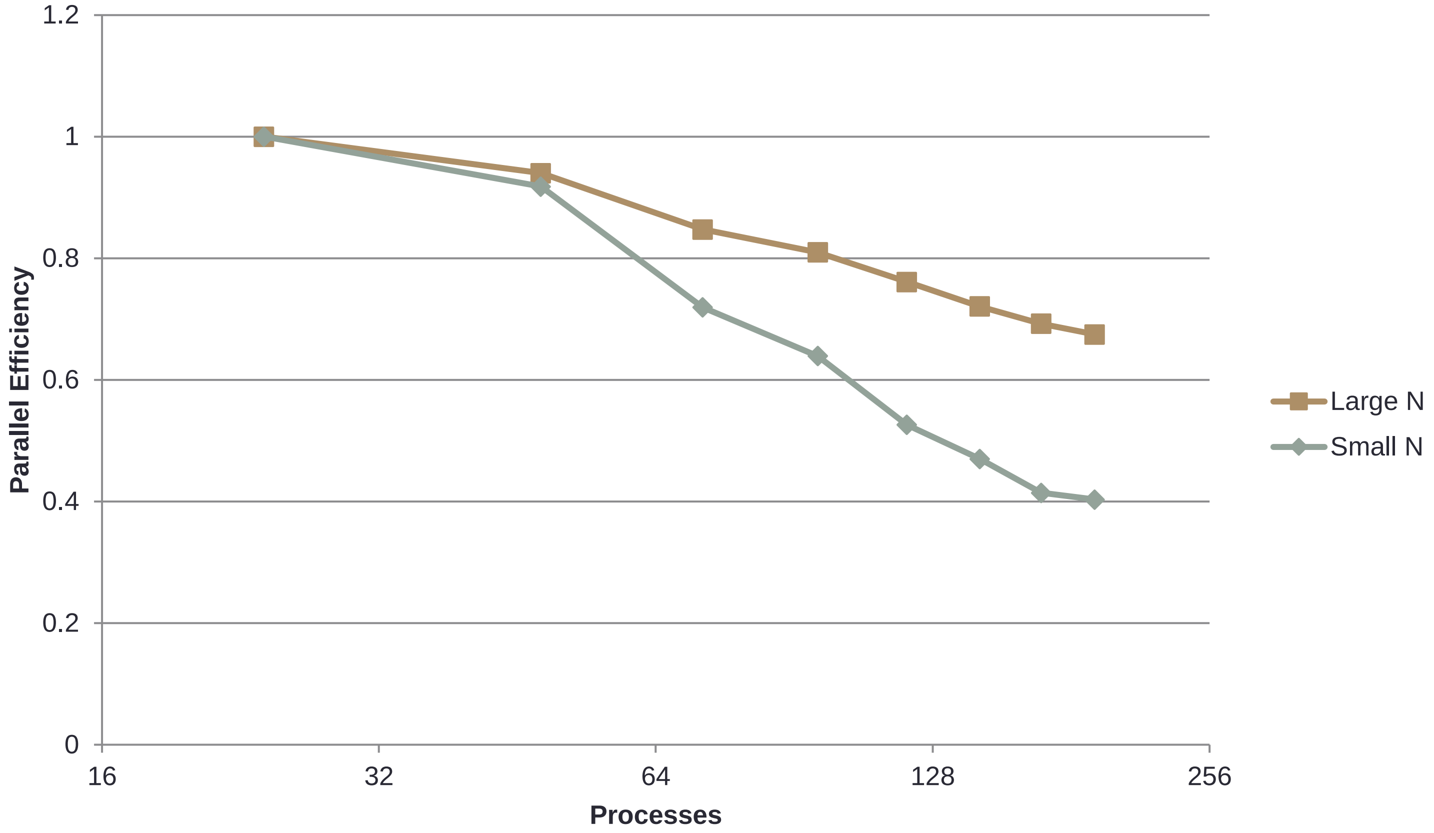
- use single-node (24-core) performance as baseline here



Efficiency plots can be useful too

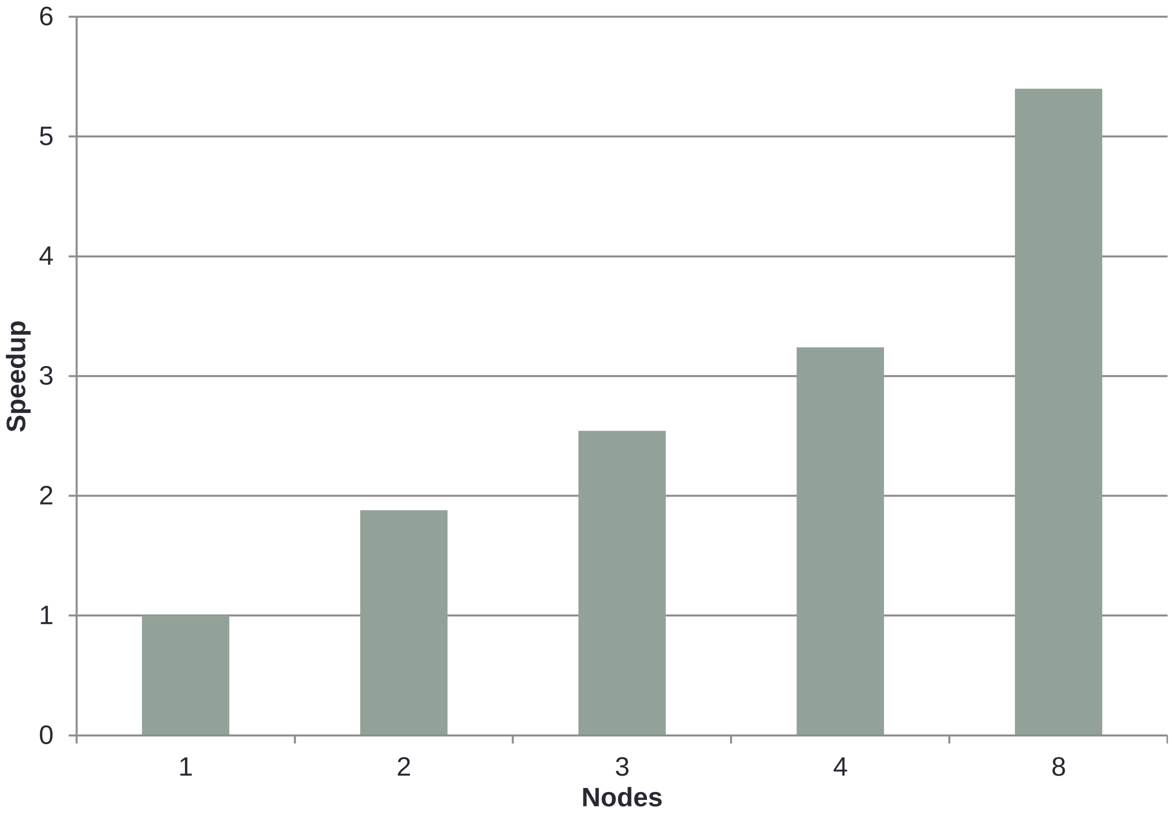


log/linear useful if many points at small P



Don’t just accept the default options

- In this bar chart the x-axis doesn’t have a meaningful scale



Summary

- A variety of considerations when parallelising code
  - serial sections
  - communications overheads
  - load balance
  - ...

- Scaling is important
  - the better a code scales the larger machine it can take advantage of

- Metrics exist to give you an indication of how well your code performs and scales
  - important to plot them appropriately