

# Performance metrics

---

How is my parallel code performing and scaling?



# Reusing this material



This work is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License.

[http://creativecommons.org/licenses/by-nc-sa/4.0/deed.en\\_US](http://creativecommons.org/licenses/by-nc-sa/4.0/deed.en_US)

This means you are free to copy and redistribute the material and adapt and build on the material under the following terms: You must give appropriate credit, provide a link to the license and indicate if changes were made. If you adapt or build on the material you must distribute your work under the same license as the original.

Acknowledge EPCC as follows: “© EPCC, The University of Edinburgh, [www.epcc.ed.ac.uk](http://www.epcc.ed.ac.uk)”

Note that this presentation contains images owned by others. Please seek their permission before reusing these images.

# 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  $E(N) \leq 1$

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

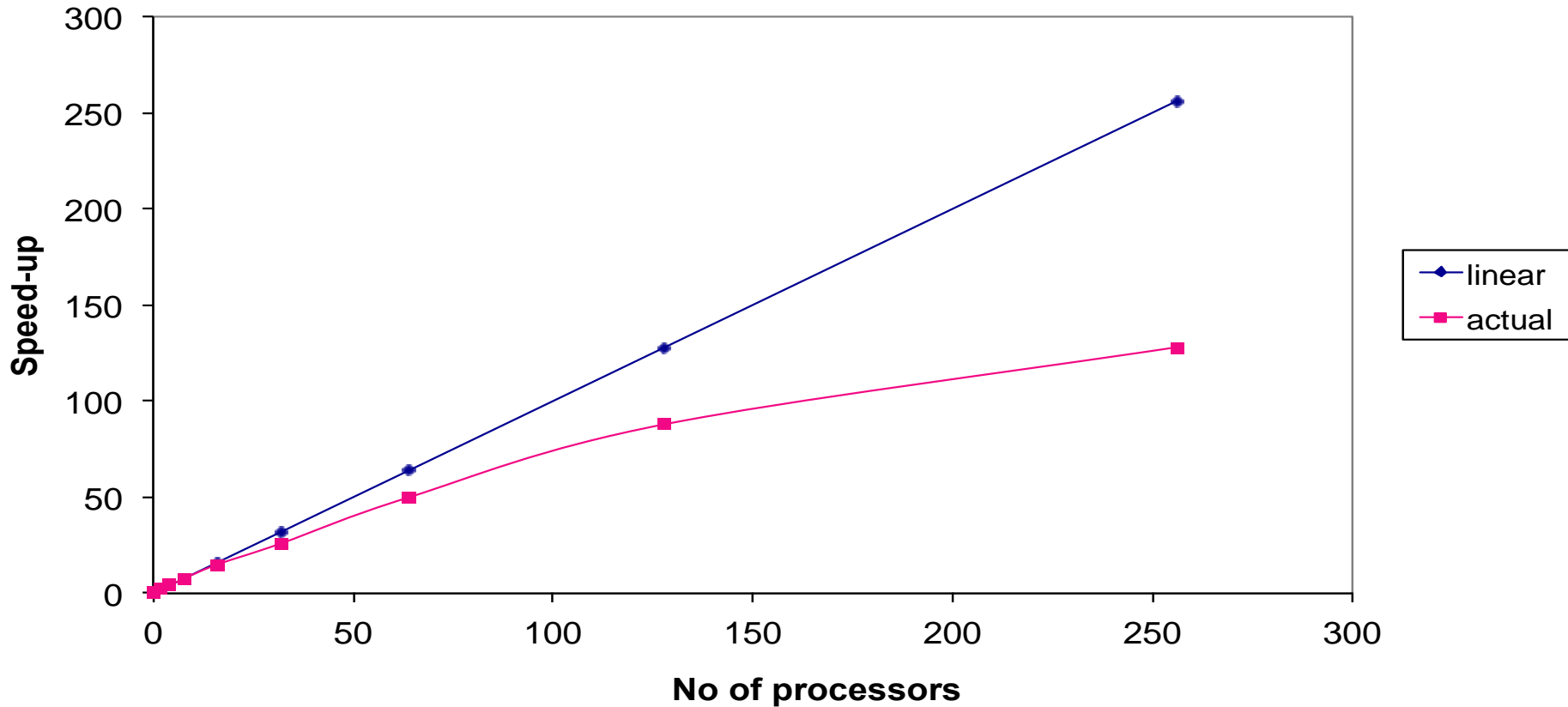
where  $N$  is the size of the problem and  $P$  the number of processors

# Scaling

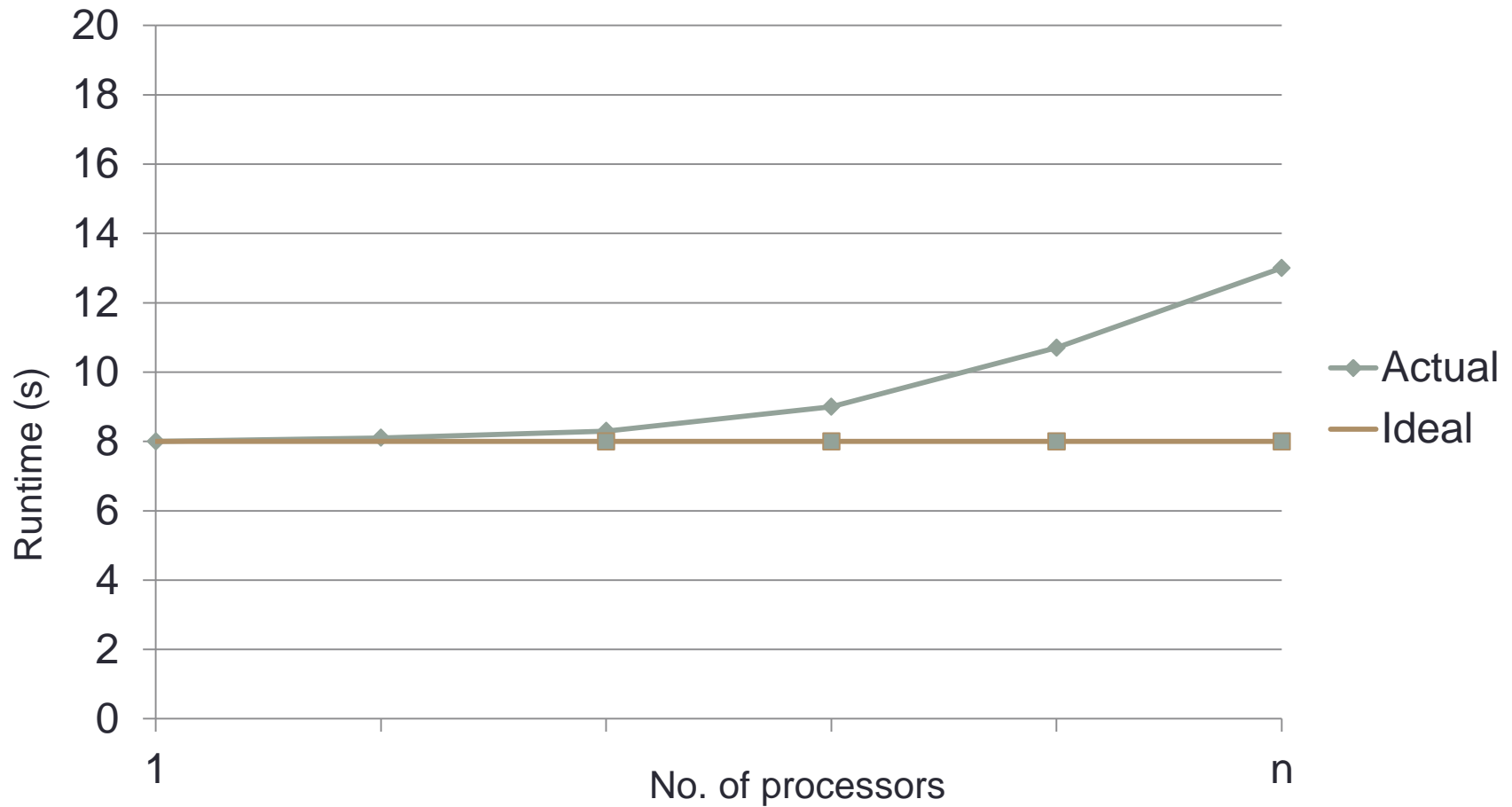
- *Scaling* is how the performance of a parallel application changes as the number of processors is increased
- There are two different types of scaling:
  - *Strong Scaling* – total problem size stays the same as the number of processors increases
  - *Weak Scaling* – the problem size increases at the 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

Speed-up vs No of processors



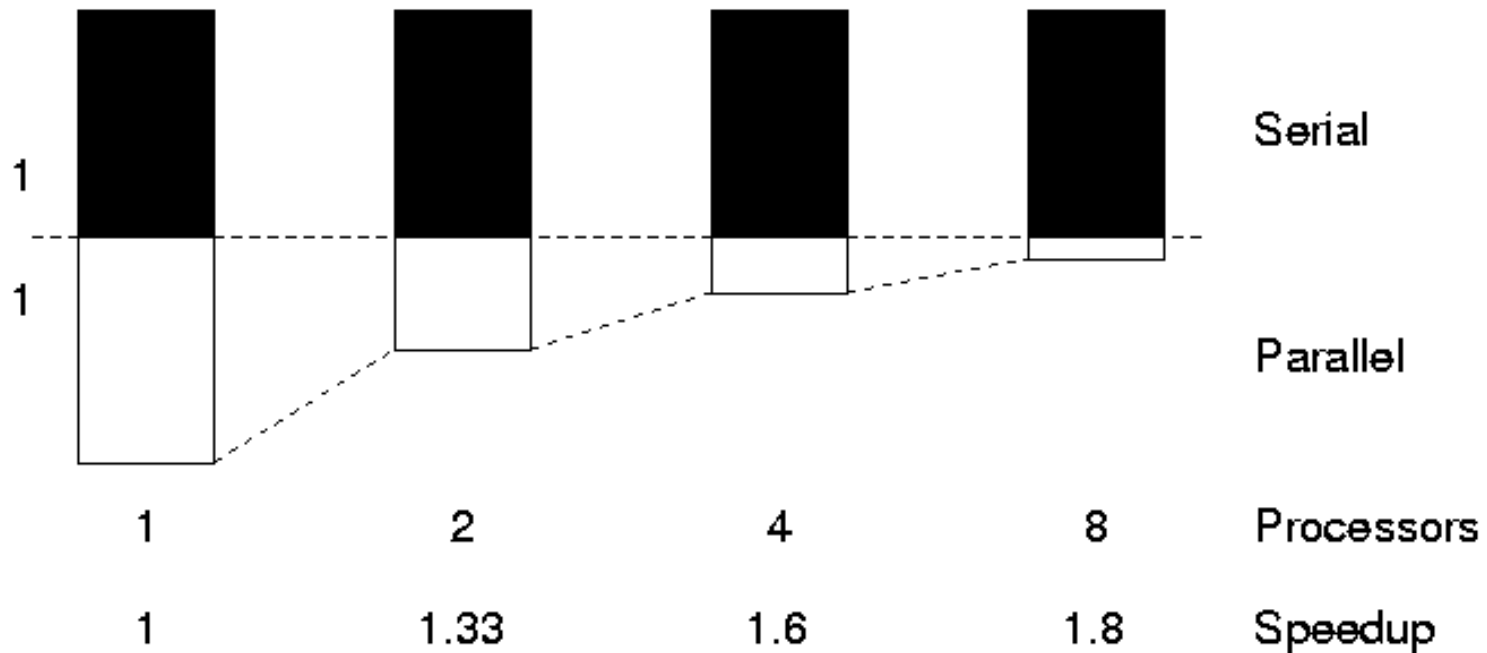
# Weak scaling



# 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

- A fraction,  $a$ , is completely serial

- Parallel runtime 
$$T(N, P) = a T(N, 1) + \frac{(1 - a) T(N, 1)}{P}$$
  - Assuming parallel part is 100% efficient

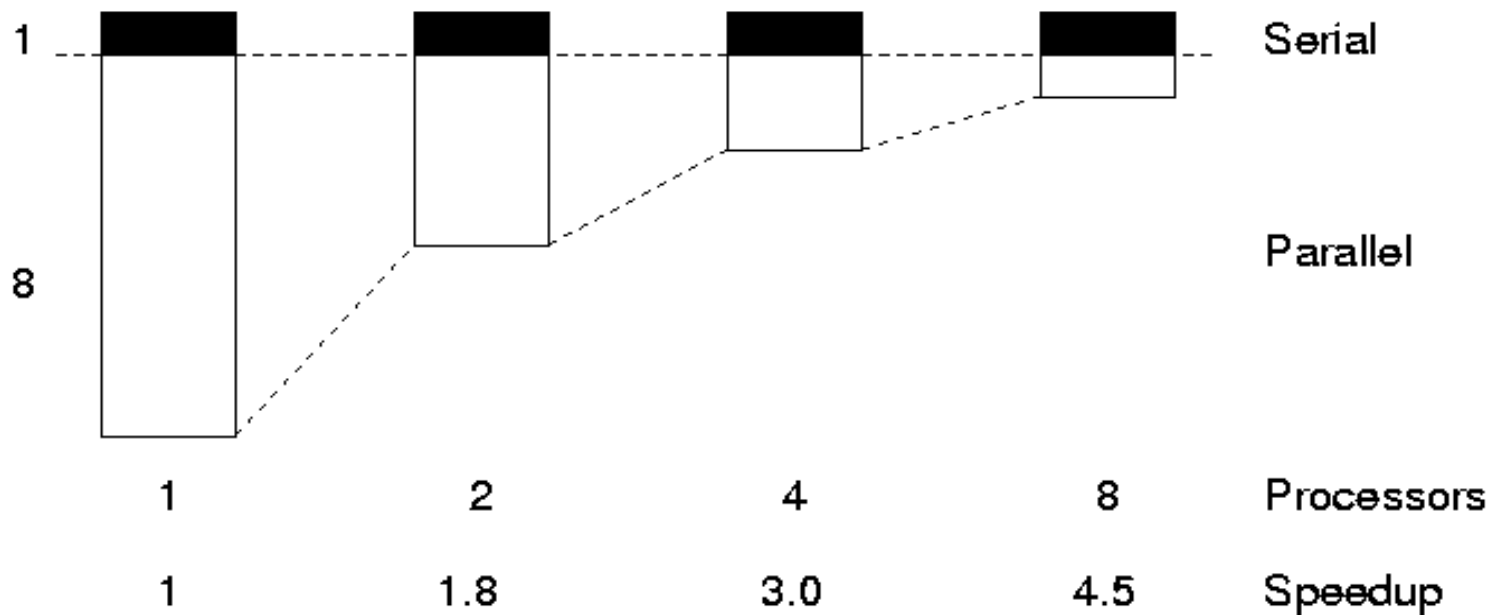
- Parallel speedup 
$$S(N, P) = \frac{T(N, 1)}{T(N, P)} = \frac{P}{aP + (1 - a)}$$

- We are fundamentally limited by the serial fraction
  - For  $a = 0$ ,  $S = P$  as expected (i.e. *efficiency* = 100%)
  - Otherwise, speedup limited by  $1/a$  for any  $P$ 
    - For  $a = 0.1$ ;  $1/0.1 = 10$  therefore 10 times maximum speed up
    - For  $a = 0.1$ ;  $S(N, 16) = 6.4$ ,  $S(N, 1024) = 9.9$



# 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

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

- speedup

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

- 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.

$$S(N * P, P) = P - a(P - 1)$$

- Due to the scaling of N, effectively the serial fraction becomes  $\frac{a}{P}$
- For instance,  $a = 0.1$

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

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

# 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

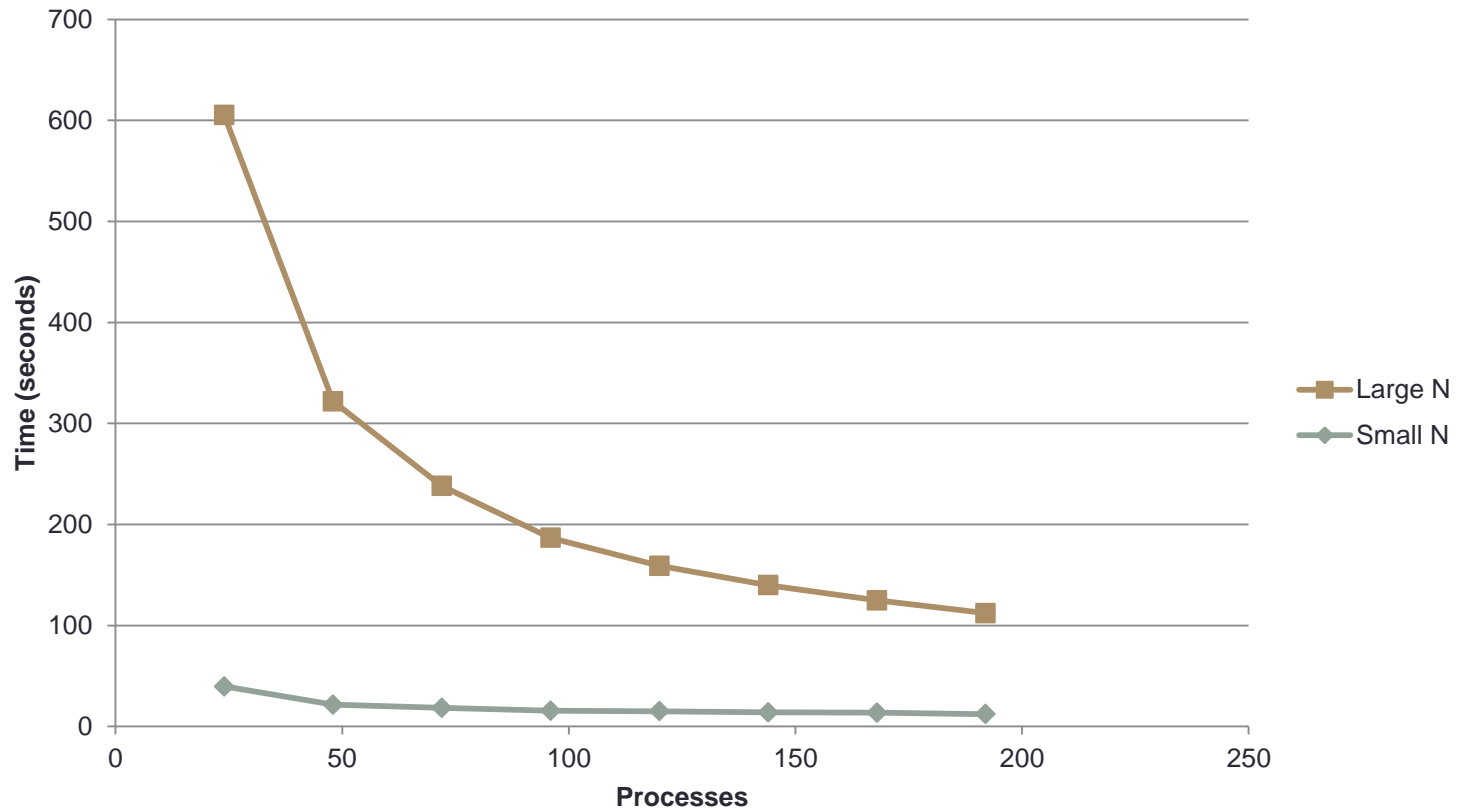
- By Jumbo Jet
  - distance: 16800 km; speed: 700 kph; flight time; 24 hours
  - serial overhead **stays the same**: total time:  $4 + 24 = 28$  hours
- Triple the flight speed
  - total time = 4 hours + 8 hours = 12 hours
  - speedup = 2.3 (as opposed to 1.8 for New York)
- Gustafson's law!
  - bigger 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

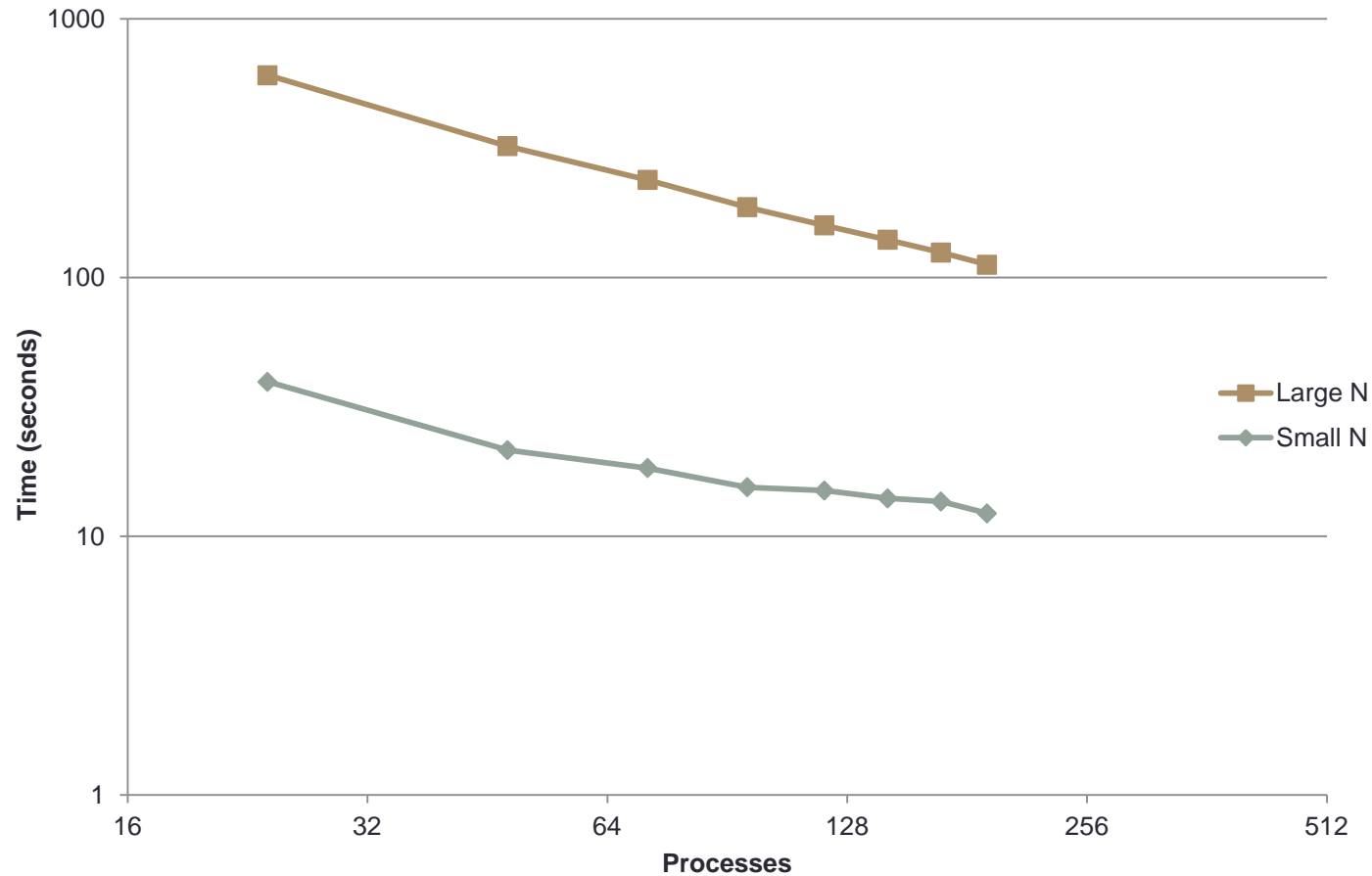
- Think carefully whenever you plot data
  - what am I trying to show with the graph?
  - is it easy to interpret?
  - can it be interpreted quantitatively?
- Default plotting options are rarely what you want
  - default colours can be hard to read (e.g. yellow on white)
  - default axis limits may not be sensible
  - ...
- Test data
  - MPI version of traffic model on multiple nodes of ARCHER



# Hard to interpret small N data here

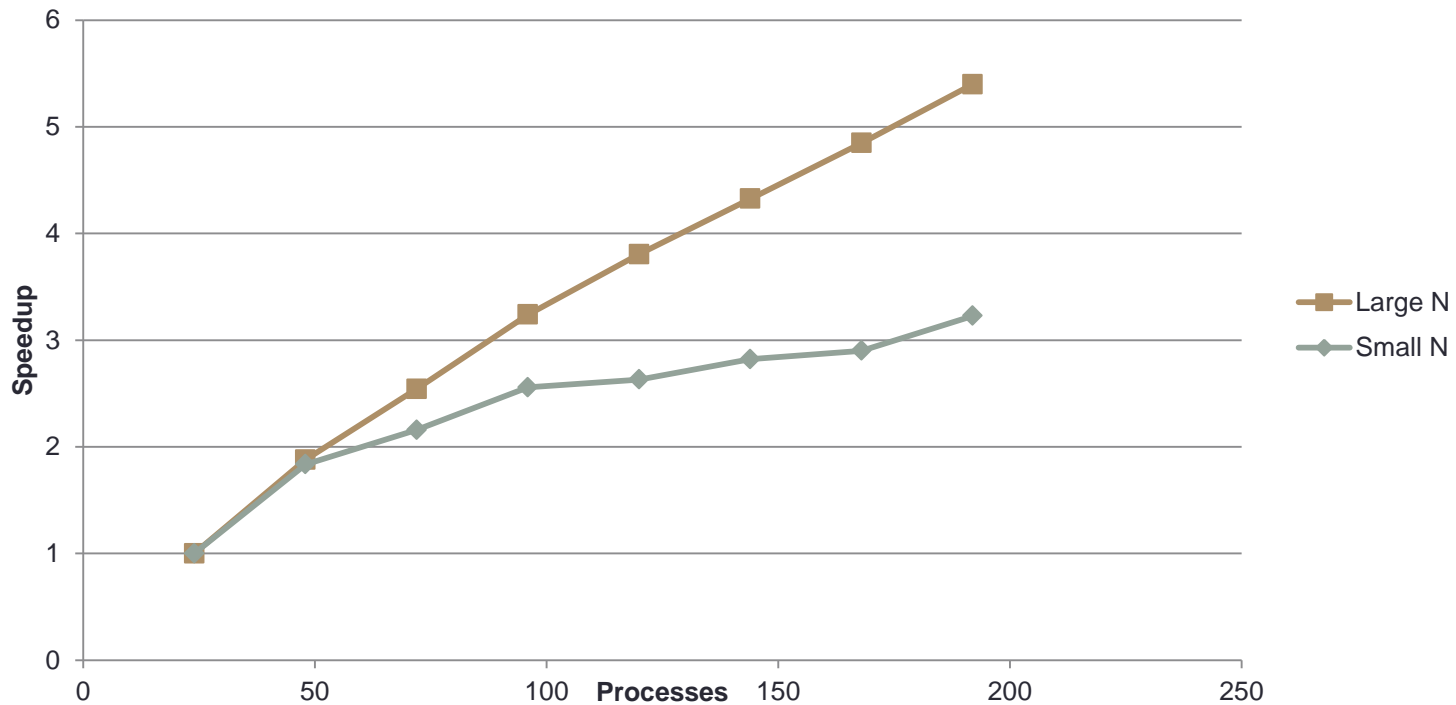


# log/log can make trends in data too similar

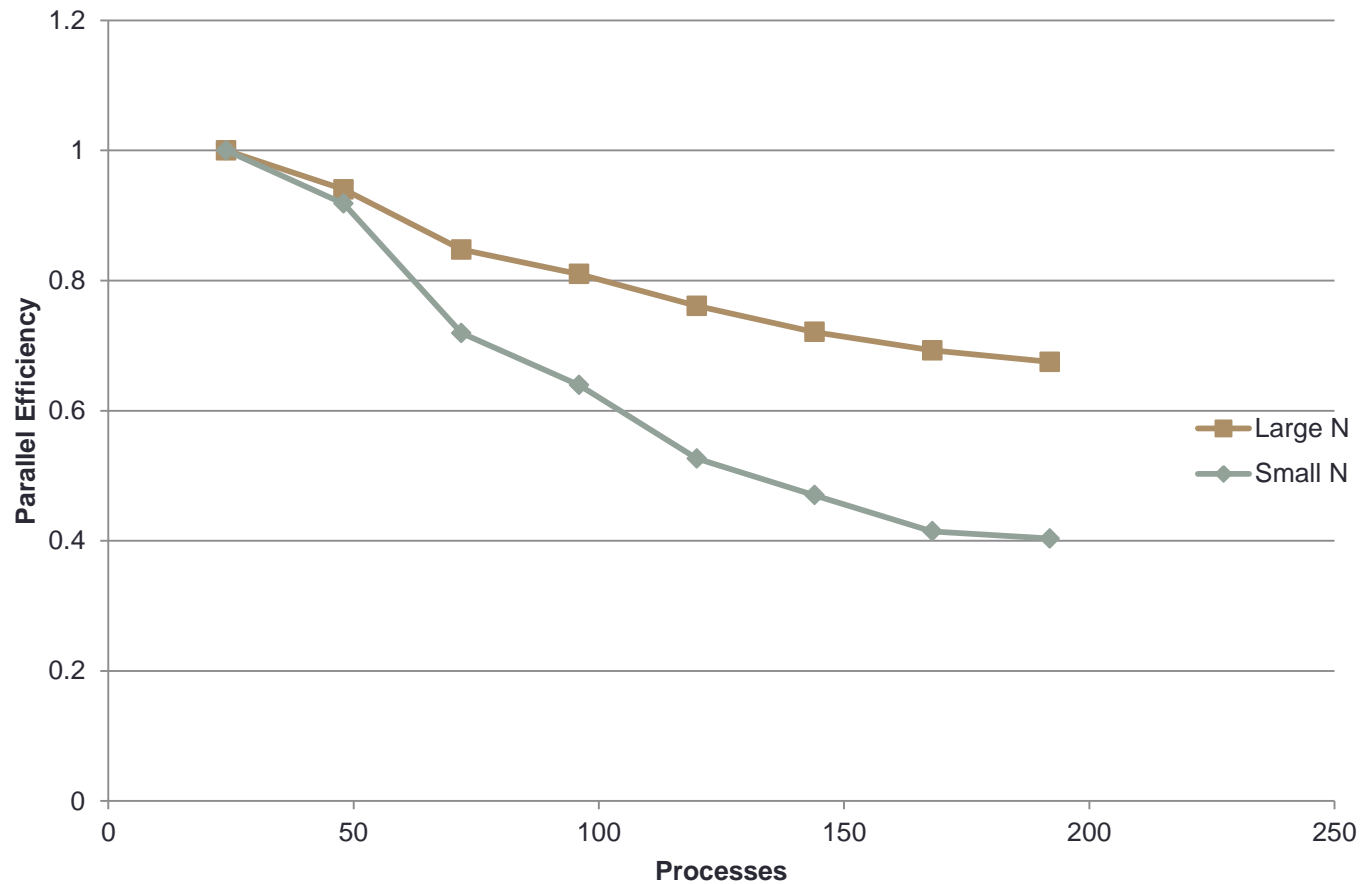


# Normalised data easier to compare

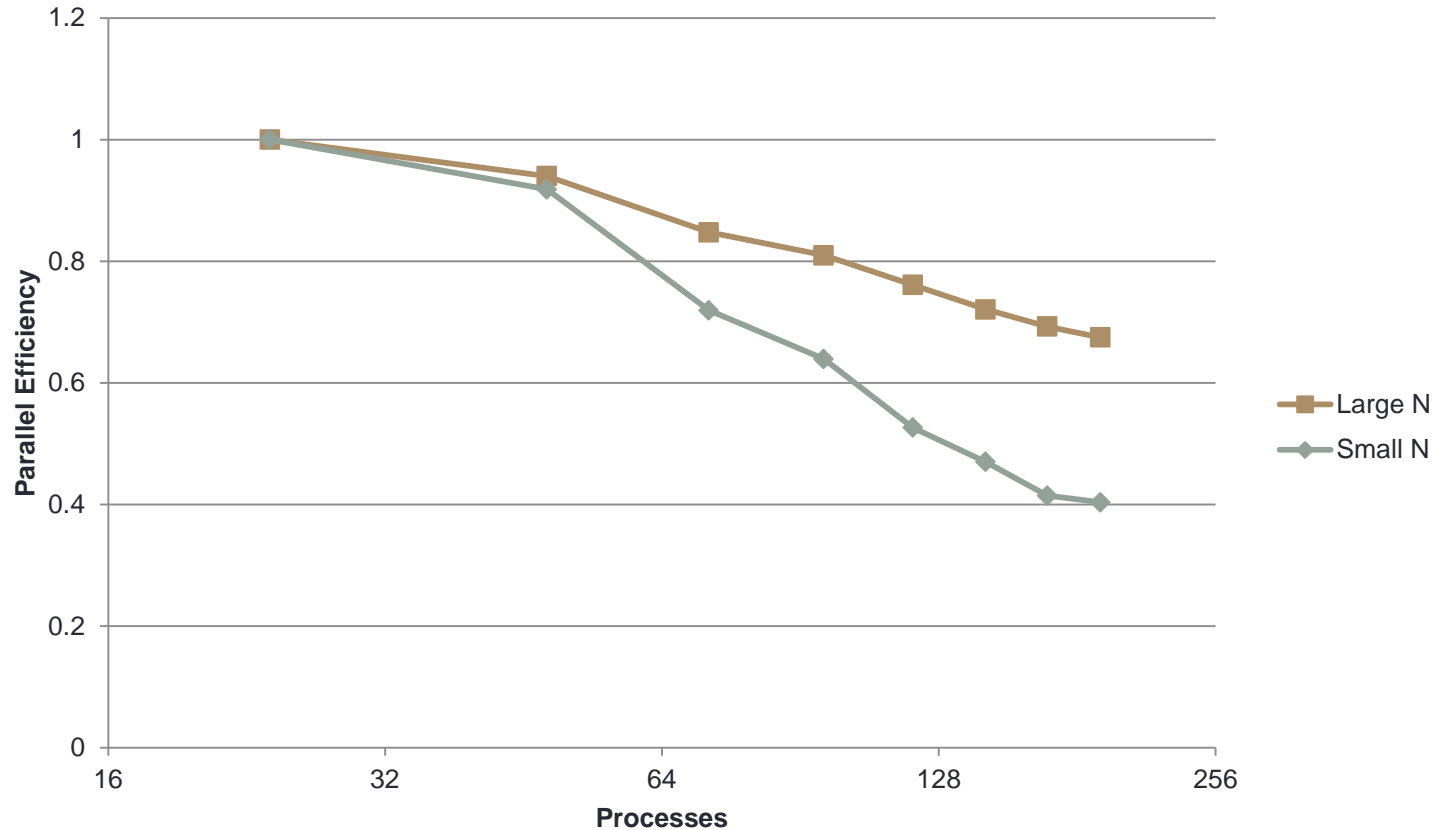
- use single-node (24-core) performance as baseline here



# Efficiency plots can be useful too

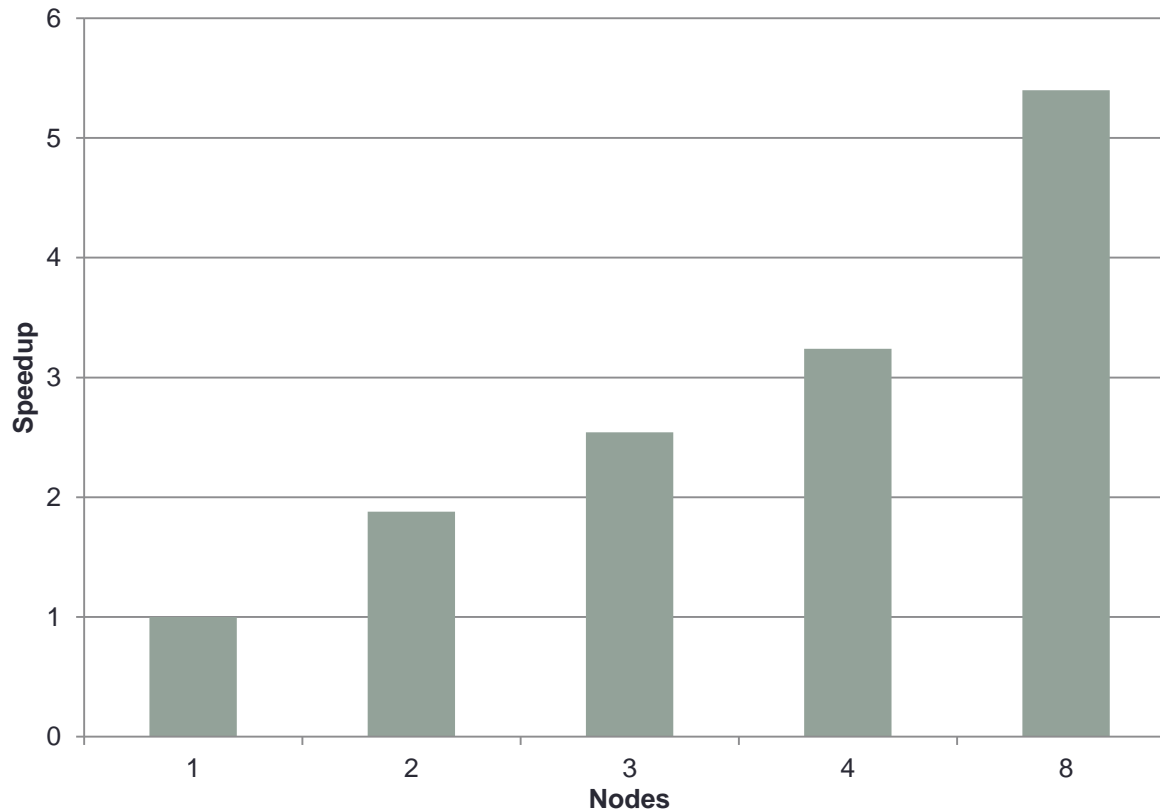


# log/linear useful if many points at small P



# 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