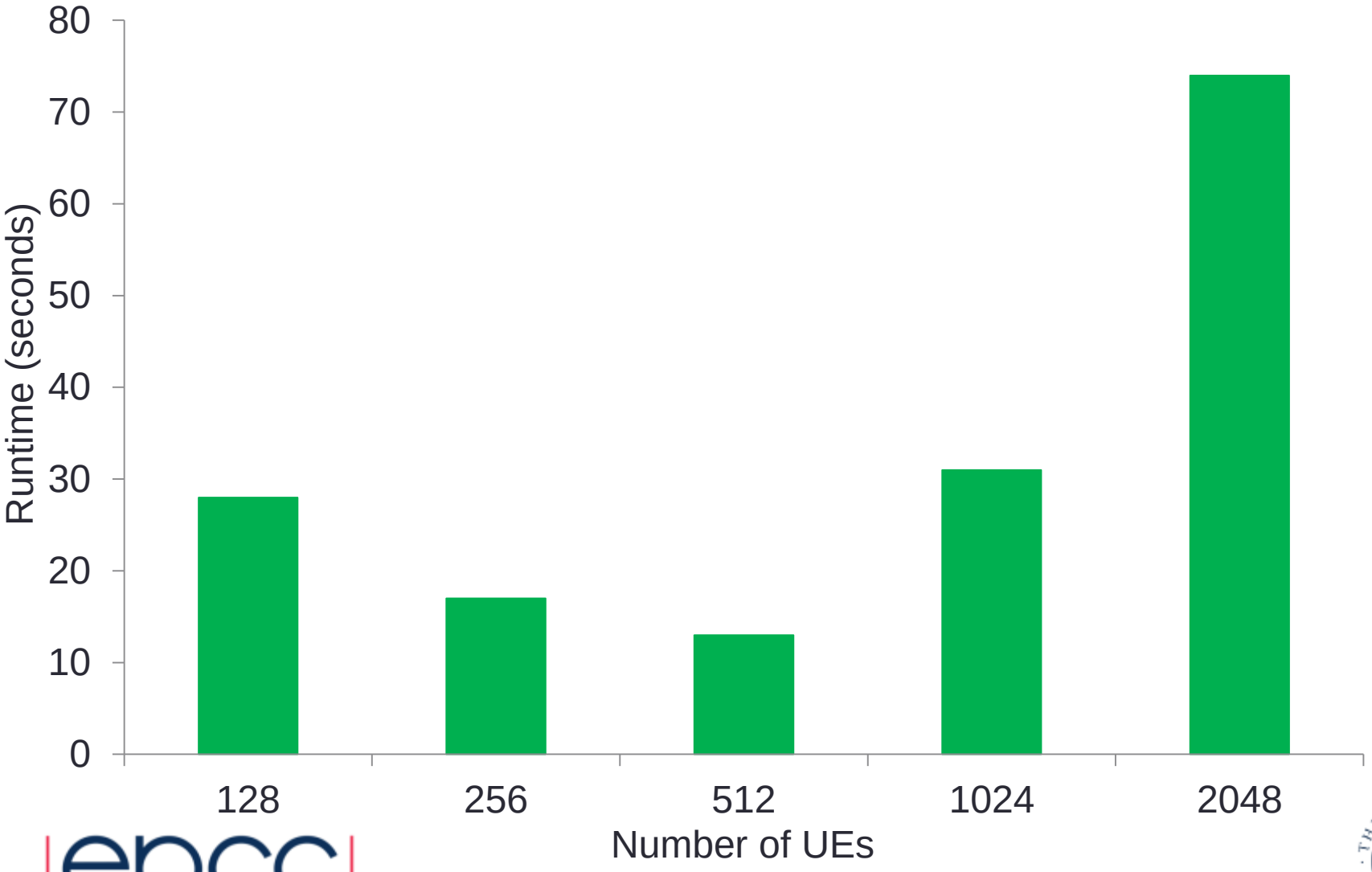
Parallel design patterns ARCHER course

Comparing parallel algorithms

Reusing this material

What's the problem?



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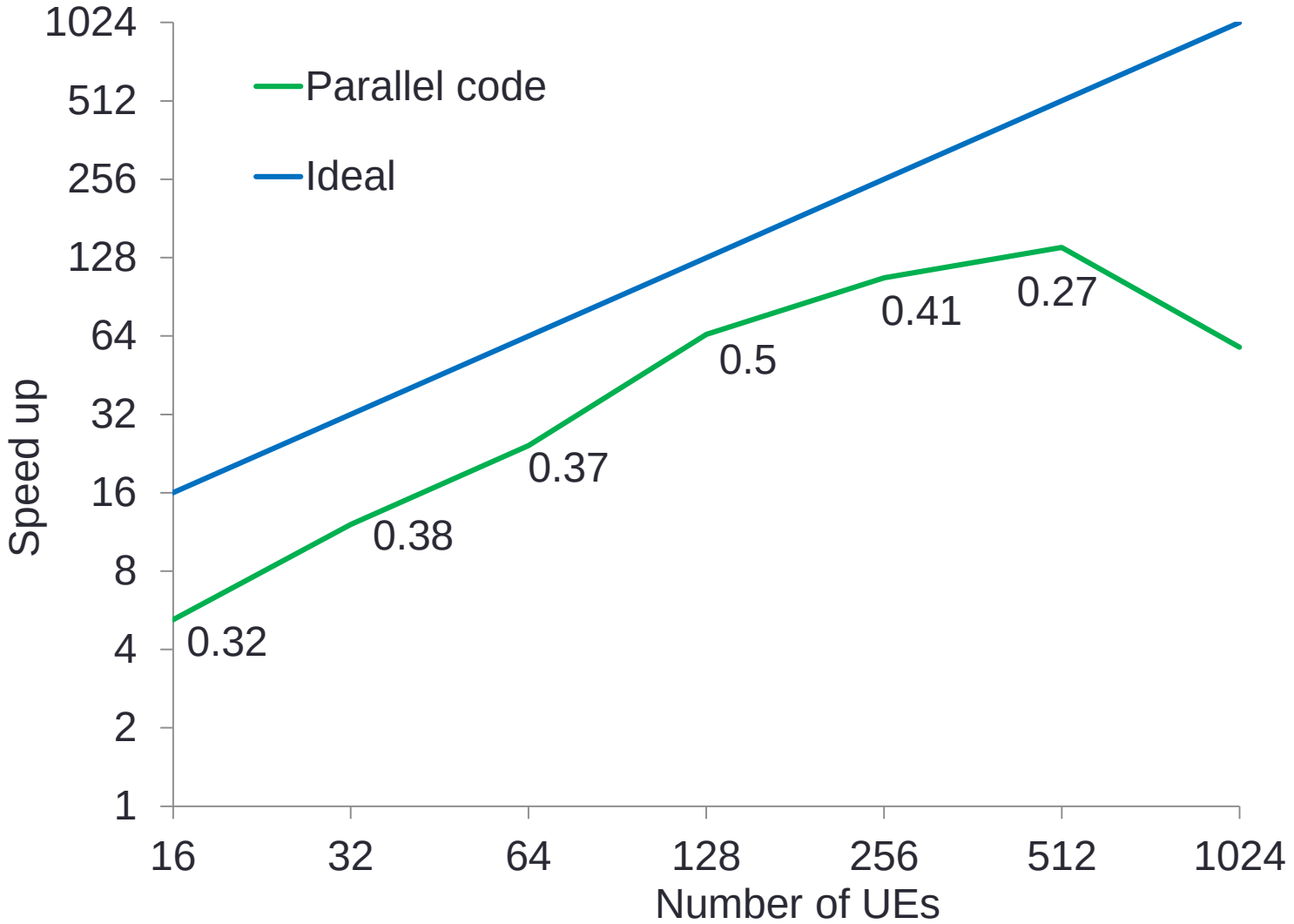
Speed up and parallel efficiency



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$$S(n) = \frac{T1}{Tn} \qquad E(n) = \frac{S(n)}{P}$$

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So what's the issue?

- Empirical studies are fine, but it requires an existing parallel code to benchmark and study

- Be careful what you claim, how many data points is enough to make certain claims?
- How can we predict performance and scalability at higher core counts or with certain modifications made to the algorithm?
- How much insight can we really get (i.e. where is my bottleneck?)

So how can we talk sensibly about parallel algorithms (i.e. compare them) without explicit measurement?

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Amdahl's law

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

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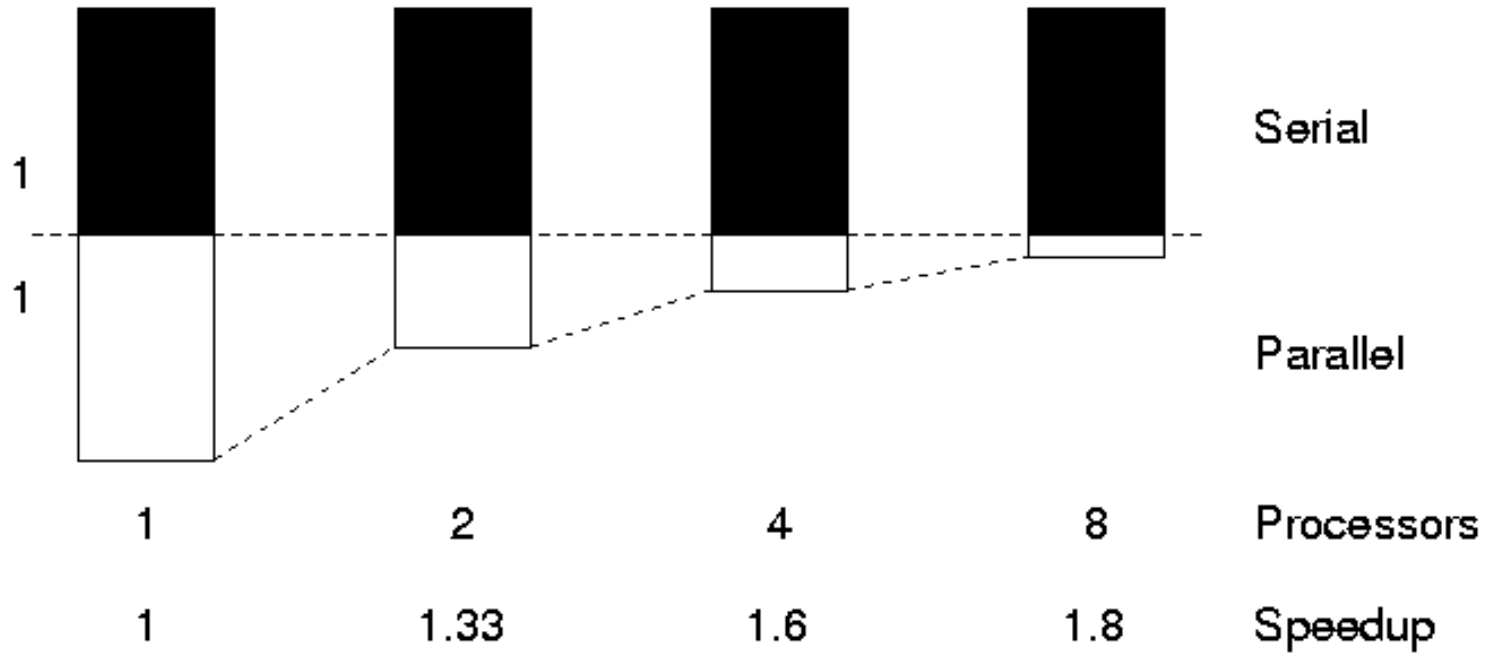
The serial section of code

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

Gene Amdahl, 1967



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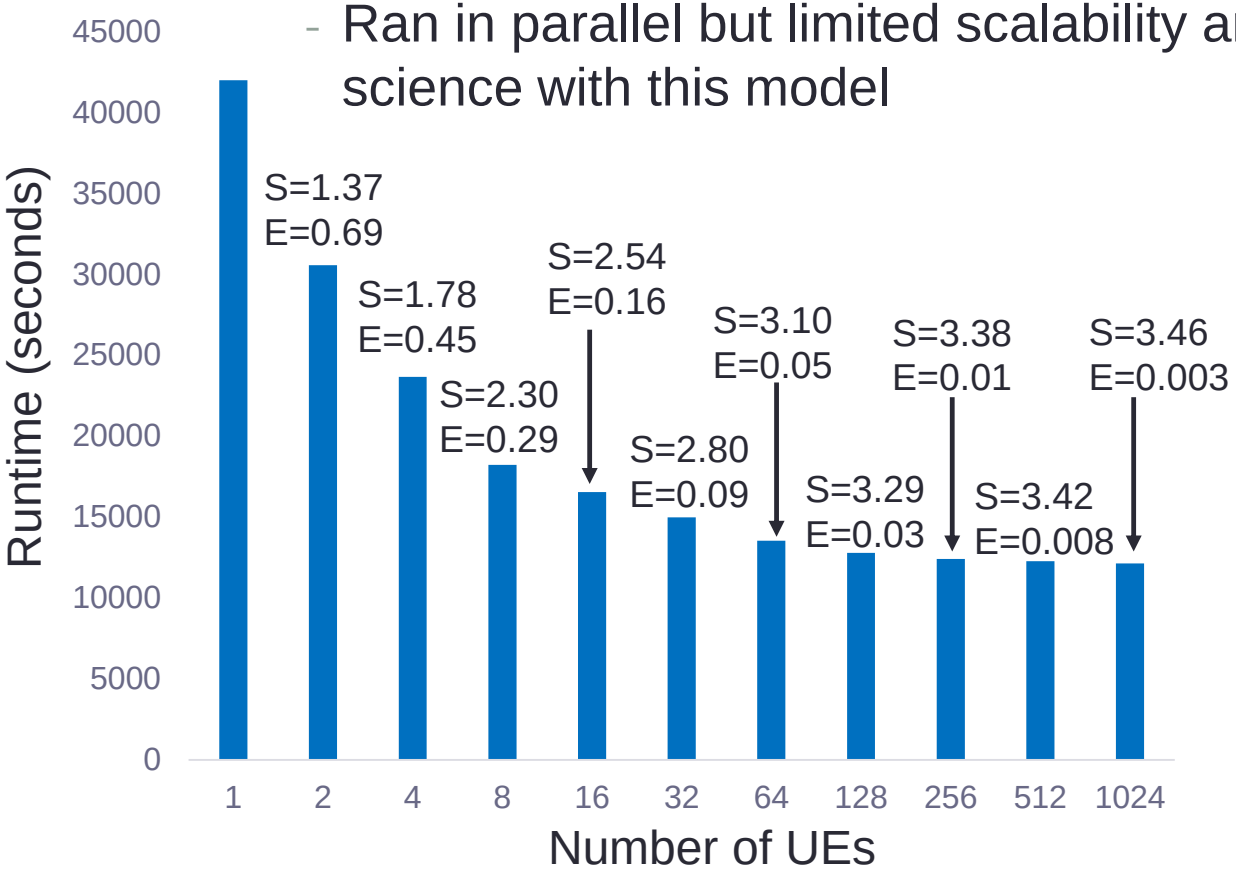
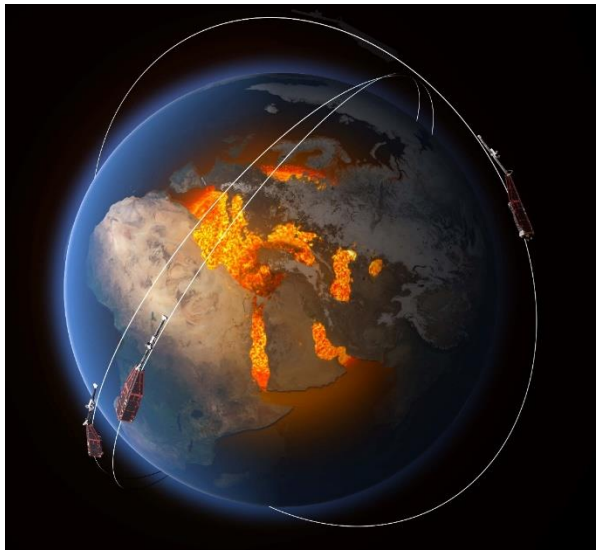
eCSE project on BGS spline model

- Model for predicting the geomagnetic field lines of the earth
  - Ran in parallel but limited scalability and wanted to do more science with this model





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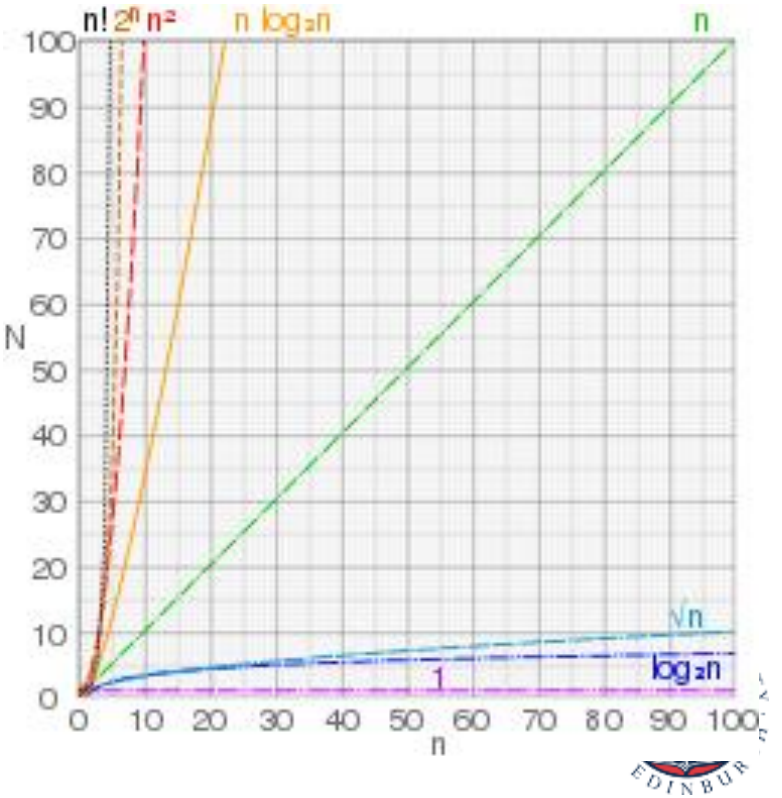
In the serial world

- Algorithm time complexity - The rough growth rate of resources (specifically runtime) with respect to the input size
- Estimated by counting the number of elementary operations the algorithm is required to perform
  - i.e. $8n + 12n^2$ where n is the number of input elements
  - The worst case time complexity is most commonly used and here it would be $O(n^2)$
- Provides a way to evaluate and compare sequential algorithms



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Algorithm time complexity examples

```
for (i=0;i<50;i++) {
   result=result+a[0]
}
```

*50 * (2 + 3 + 1) = O(1)*

```
for (i=0;i<n;i++) {
  result=result+a[i]
}
```

*n * (2 + 3 + 1) = O(n)*

```
for (i=0;i<n;i++) {
  for (j=0;j<n;j++) {
    result=result+a[i]
  }
}
```

*n * (2 + n* (2 + 3 + 1)) = O(n*n)=O(n^2)*

- *Concerned with how the runtime grows as a function of the input size (n)*

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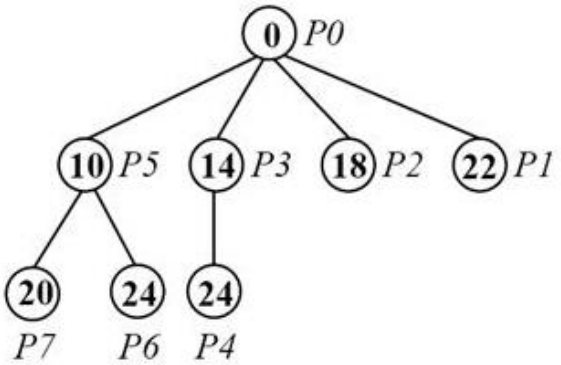
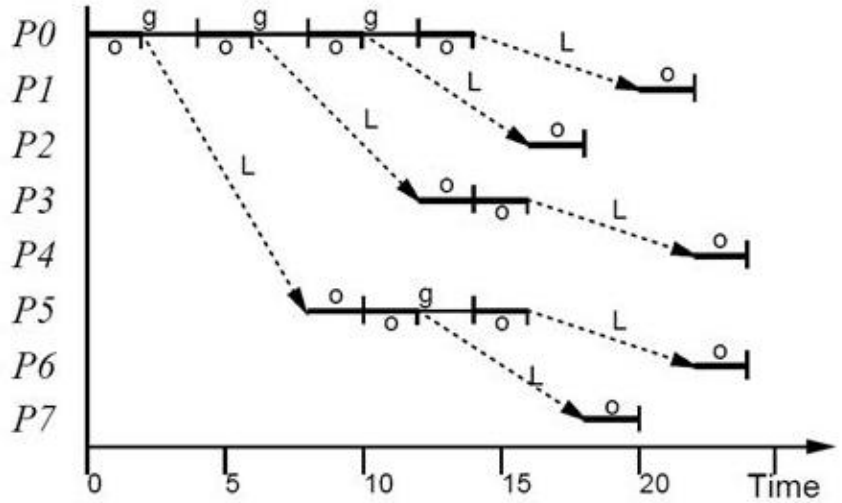
But much more complex in the parallel world!

- A number of different ways of modelling this
- Log P is one common approach in the literature
  - L is the latency of the communication medium (cycles)
  - o is the overhead of sending and receiving messages (cycles)
  - g is the gap required between messages due to bandwidth limitations (cycles)
  - P is the number of UEs





Example taken from http://slideplayer.com/slide/8123828/ where P=8, L=6, g=4, o=2

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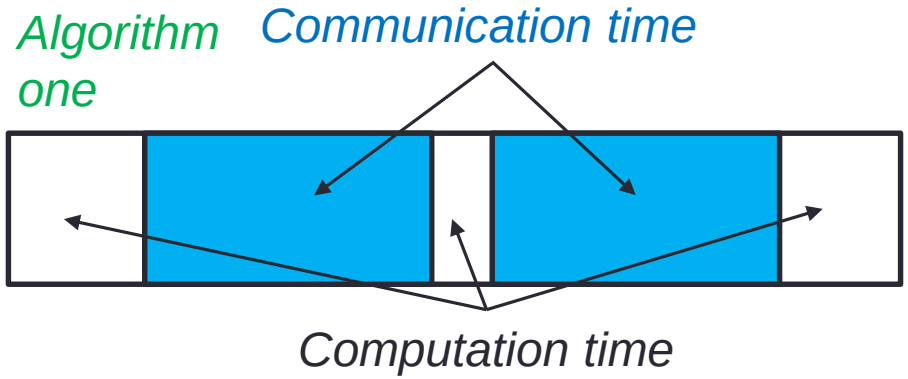
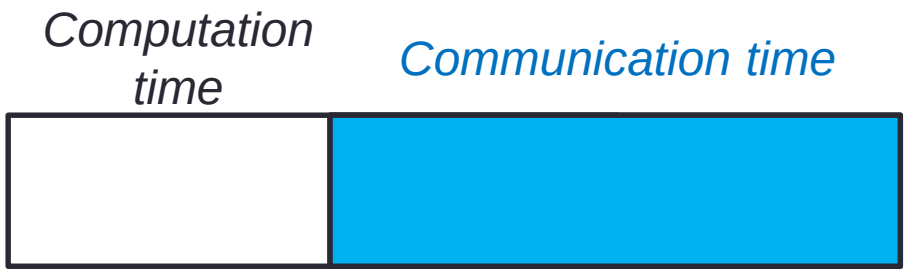
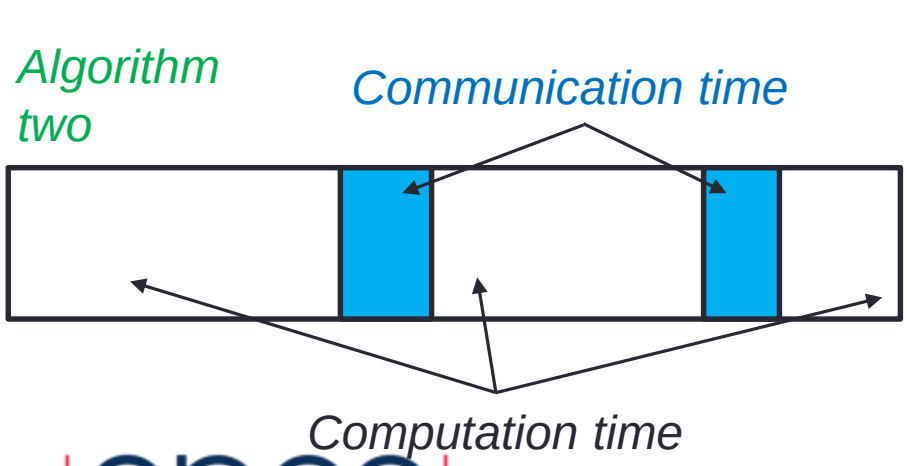
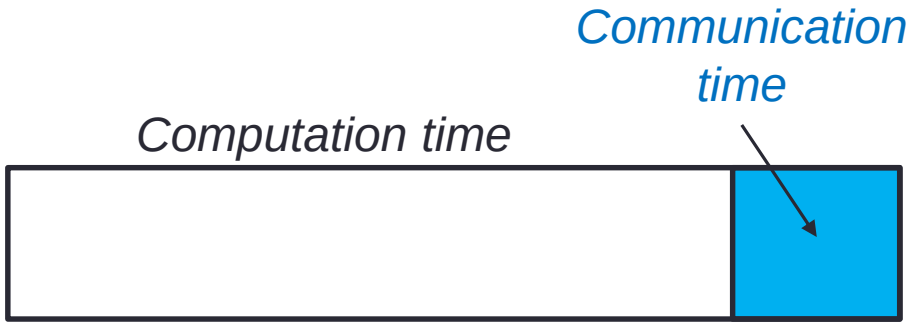
What are we looking to optimise

1. Communication to computation ratio









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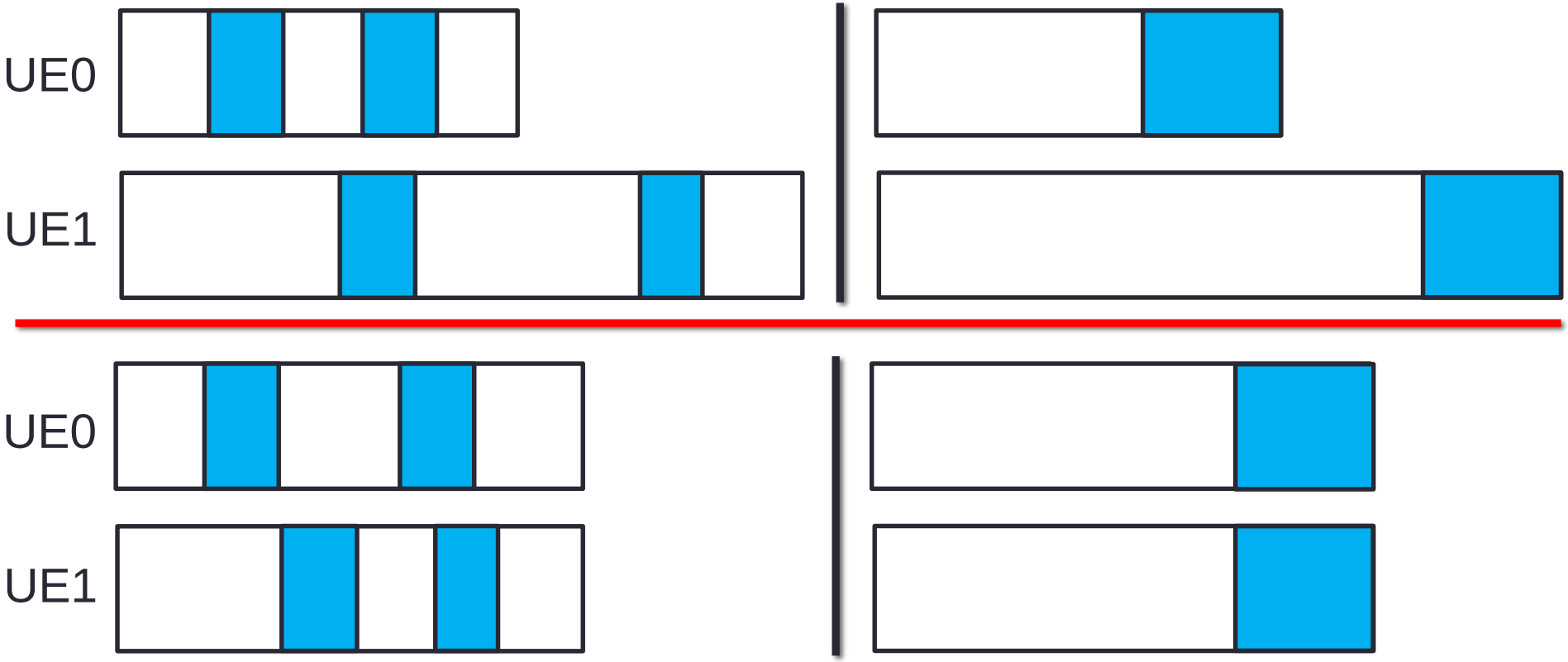
What are we looking to optimise

2. Load balance between processes



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Load Imbalance Factor (LIF):
maximum load / average load

Where 1 is ideal

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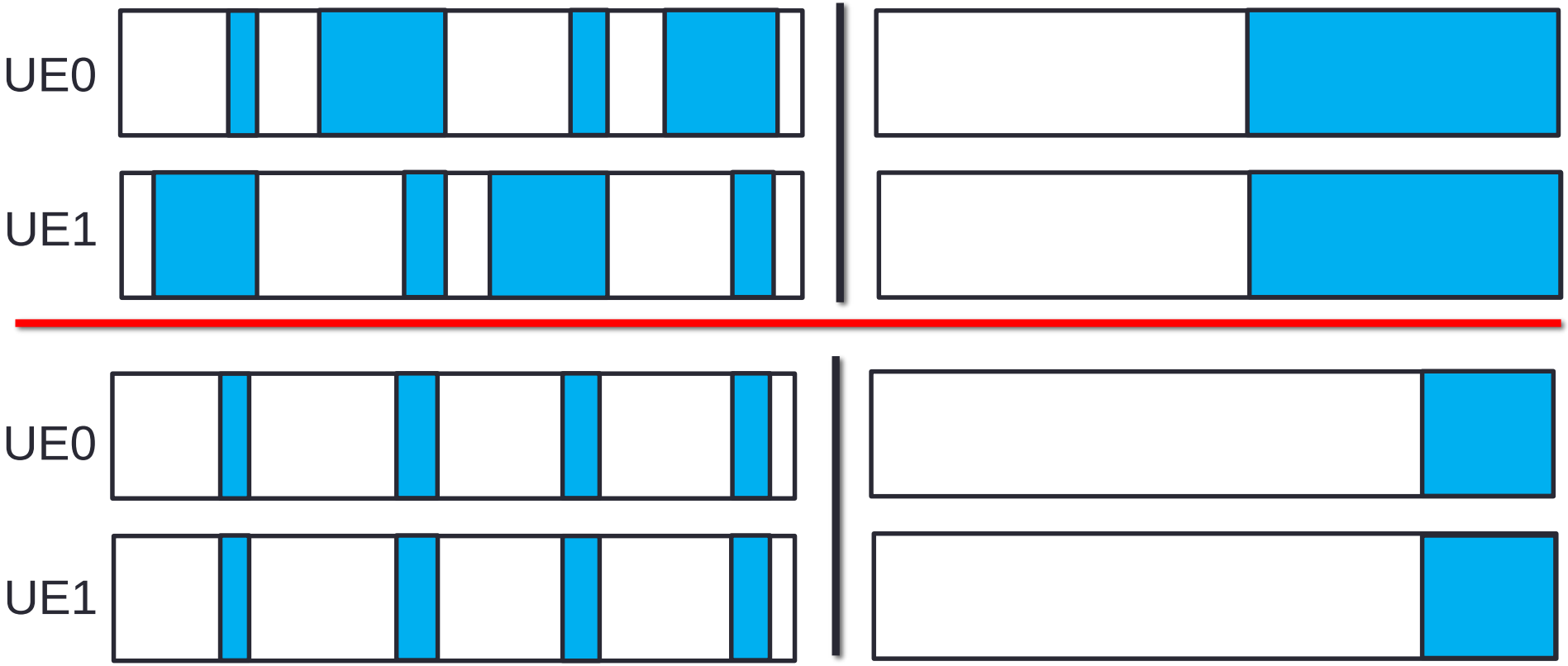
What are we looking to optimise

3. Synchronisation costs



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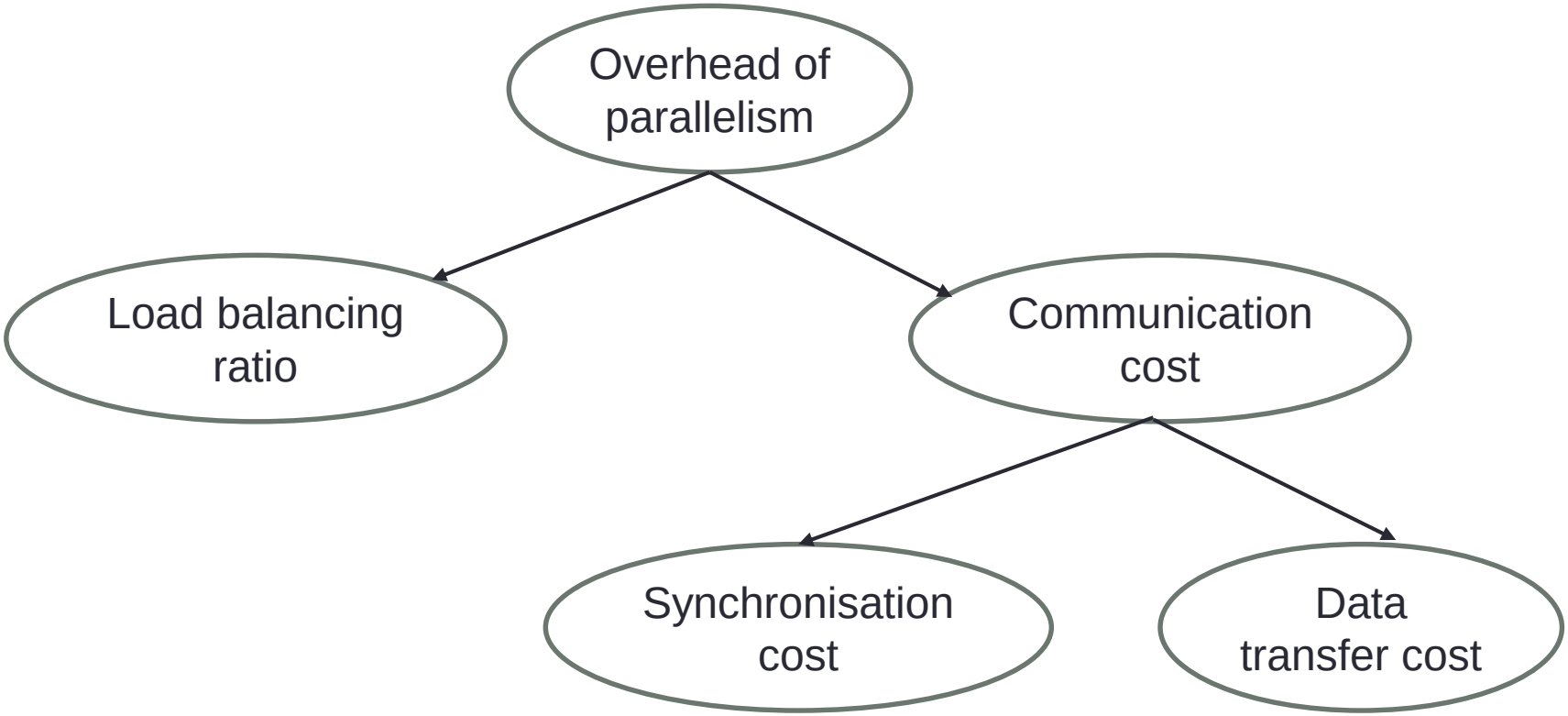
Parallelism overhead



- Needs to be balanced against the computational complexity
- Need to consider code maintainability

Can be obvious from code

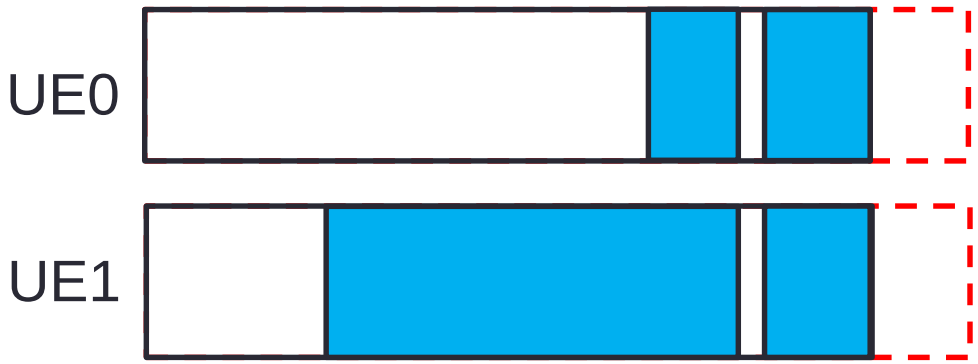
```
if (rank == 0) {
  for (i=0;i<1000;i++) {
      a[i]=……
  }
  send a to rank 1
  b=recv from rank 1
}
```

```
if (rank == 1) {
  b=recv from rank 0
  for (i=0;i<100;i++) {
      a[i]=……
  }
  send a to rank 0
}
```

A slight improvement….

```
if (rank == 0) {
  for (i=0;i<1000;i++) {
      a[i]=……
  }
  send a to rank 1
  b=recv from rank 1
}
```

```
if (rank == 1) {
  for (i=0;i<100;i++) {
      a[i]=……
  }
  b=recv from rank 0
  send a to rank 0
}
```



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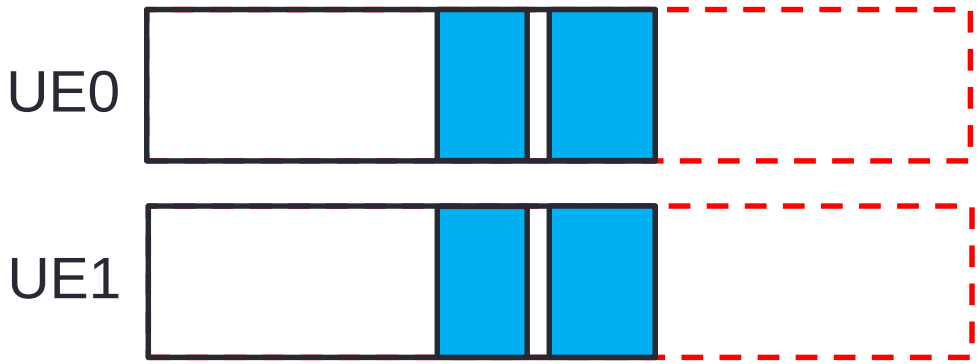
More of an improvement….

```
if (rank == 0) {
  for (i=0;i<550;i++) {
      a[i]=……
  }
  send a to rank 1
  b=recv from rank 1
}
```

```
if (rank == 1) {
  for (i=0;i<550;i++) {
      a[i]=……
  }
  b=recv from rank 0
  send a to rank 0
}
```



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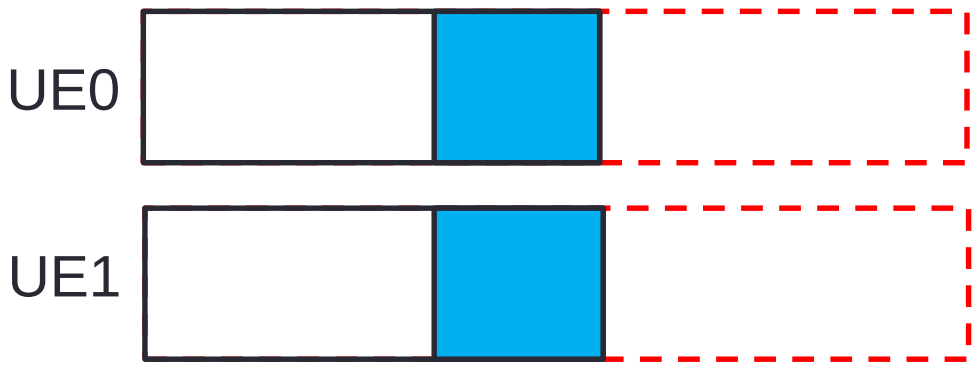
Potentially even better

```
if (rank == 0) {
  b=nonblocking recv from rank 1
  for (i=0;i<550;i++) {
      a[i]=.....
  }
  nonblocking send a to rank 1
  wait on all comms
}
```

```
if (rank == 1) {
  b=nonblocking recv from rank 0
  for (i=0;i<550;i++) {
      a[i]=.....
  }
  nonblocking send a to rank 0
  wait on all comms
}
```



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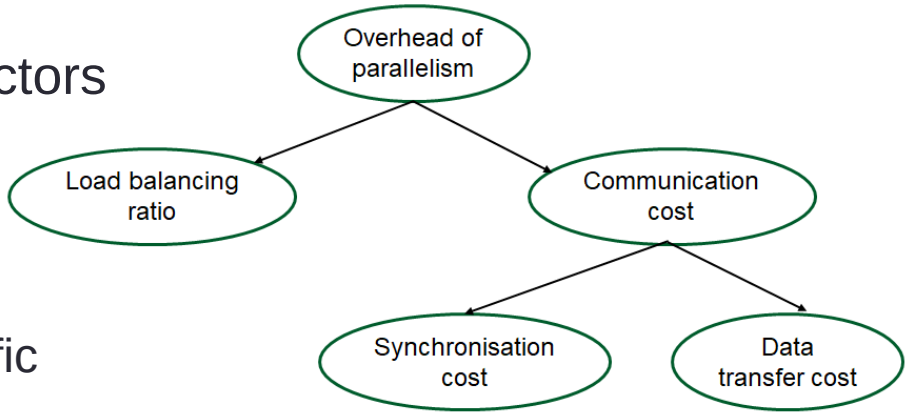
Still requires expertise…..

- Algorithm analysis is not simple and requires programmer insight & reasoning
  - There are very many contributing factors
    - Machine specific factors
    - Compiler optimisations
    - Underlying libraries and runtime
    - Interconnect and current network traffic
    - The time of day and year



- Theoretical ways can be unwieldy in practice, so often intuition is needed
  - Consider what the overhead of parallelism is and how to reduce it

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But we don't get this for free!

- Efficiency
  - Speed, memory, storage
- Scalability
  - Large machines, large problems
- Simplicity of the code
  - Development, debugging, verification, modification, maintenance
- Portability
  - Software nearly always outlives its original target platform

- There is rarely *one right answer* and a good design often boils down to a number of *tradeoffs*
- Parallel optimisations can increase sequential time complexity