**Exercise**: You have a task X with two component parts A and B, each of which takes 30 minutes. What is the latency of X?

Suppose that you can speedup part B by a factor of 2. What is the latency now? What is the overall speedup?

**Answer**: It really depends on whether A and B are concurrent or sequential. If sequential, you can answer using *Amdahl’s Law*. 

<table>
<thead>
<tr>
<th>Plane</th>
<th>DC to Paris</th>
<th>Speed</th>
<th>Passengers</th>
<th>Throughput (pmph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boeing 747</td>
<td>6.5 hours</td>
<td>610 mph</td>
<td>470</td>
<td>286,700</td>
</tr>
<tr>
<td>Concorde</td>
<td>3 hours</td>
<td>1350 mph</td>
<td>132</td>
<td>178,200</td>
</tr>
</tbody>
</table>

- **Which has higher performance?**
- **What is performance?**
  - Time to completion (latency)?
  - Throughput?
- We’re concerned with performance, but there are other important metrics:
  - Cost
  - Power
  - Footprint
Amdahl’s Law

How much extra performance can you get if you speed up part of your program? There are two factors:

- How much better is it? \((S, k)\)
- How often is it used? \((\alpha)\)

\[
T_{new} = (1 - \alpha) T_{old} + \left(\frac{\alpha T_{old}}{k}\right) = T_{old}\left[(1 - \alpha) + \frac{\alpha}{k}\right]
\]

\[
S = \frac{T_{old}}{T_{new}} = \frac{1}{(1 - \alpha) + \frac{\alpha}{k}}
\]

Example 1

Your pipeline has one very slow stage that consumes 60% of the time to process an instruction. You discover that you can speed it up by a factor of 3. What is the improvement in the latency?

\[
S = \frac{T_{old}}{T_{new}} = \frac{1}{(1 - \alpha) + \frac{\alpha}{k}}
\]

Hence,

\[
S = \frac{1}{(1 - 0.6) + 0.6/3} = 1.67X
\]

Suppose you could make that stage arbitrarily fast. How would that improve latency?

Example 2

Suppose:

- Floating point instructions could be improved by 2X.
- But, only 10% of instructions are floating point.

\[
T_{new} = T_{old} \times [0.9 + 0.1/2] = 0.95 \times T_{old}
\]

\[
S_{total} = \frac{1}{0.95} = 1.053
\]

Speedup is bounded by:

\[
\frac{1}{\text{fraction of time not enhanced}}
\]

Example 3

Assume you can parallelize some portion of your program to make it 100X faster.

How much faster does the whole program get?

\[
T_1 = T_0 \left[(1 - p) + \frac{d}{S}\right]
\]

Speedup vs. Vector Fraction
Suppose:
- Memory operations currently take 30% of execution time.
- A new L1 cache speeds up 80% of memory operations by a factor of 4.
- A second new L2 cache speeds up 1/2 of the remaining 20% by a factor of 2.

What is the total speedup?

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**Example 4 Answer**

Applying the two optimizations sequentially:

<table>
<thead>
<tr>
<th>L1</th>
<th>L2</th>
<th>Not memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory time</td>
<td>0.24</td>
<td>0.03</td>
</tr>
<tr>
<td>24%</td>
<td>3%</td>
<td>3%</td>
</tr>
</tbody>
</table>

Total = 1.0

<table>
<thead>
<tr>
<th>L1</th>
<th>L2</th>
<th>Not memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>sped up</td>
<td>0.06</td>
<td>0.03</td>
</tr>
<tr>
<td>8.6%</td>
<td>4.2%</td>
<td>4.2%</td>
</tr>
</tbody>
</table>

Total = 0.82

<table>
<thead>
<tr>
<th>L1</th>
<th>L2</th>
<th>Not memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>sped up</td>
<td>0.015</td>
<td>0.03</td>
</tr>
<tr>
<td>0.015</td>
<td>0.03</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Total = 0.805

Speed up = 1.242

---

**Summary Message**

**Make the common case fast!**

**Examples**
- All instructions require instruction fetch, only some require data memory access. *Improve instruction fetch performance first.*
- Programs exhibit locality (spatial and temporal) and smaller memories are faster than larger memories.
  - Incorporate small, fast caches into processor design.
  - Manage caches to exploit locality.

Amdahl provided a quantitative basis for making these decisions.

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**Amdahl’s Non-Corollary**

**Amdahl’s law does not bound slowdown!**

Things can only get so fast, but they can get arbitrarily slow.

*Don’t do things that hurt the non-common case too much!*