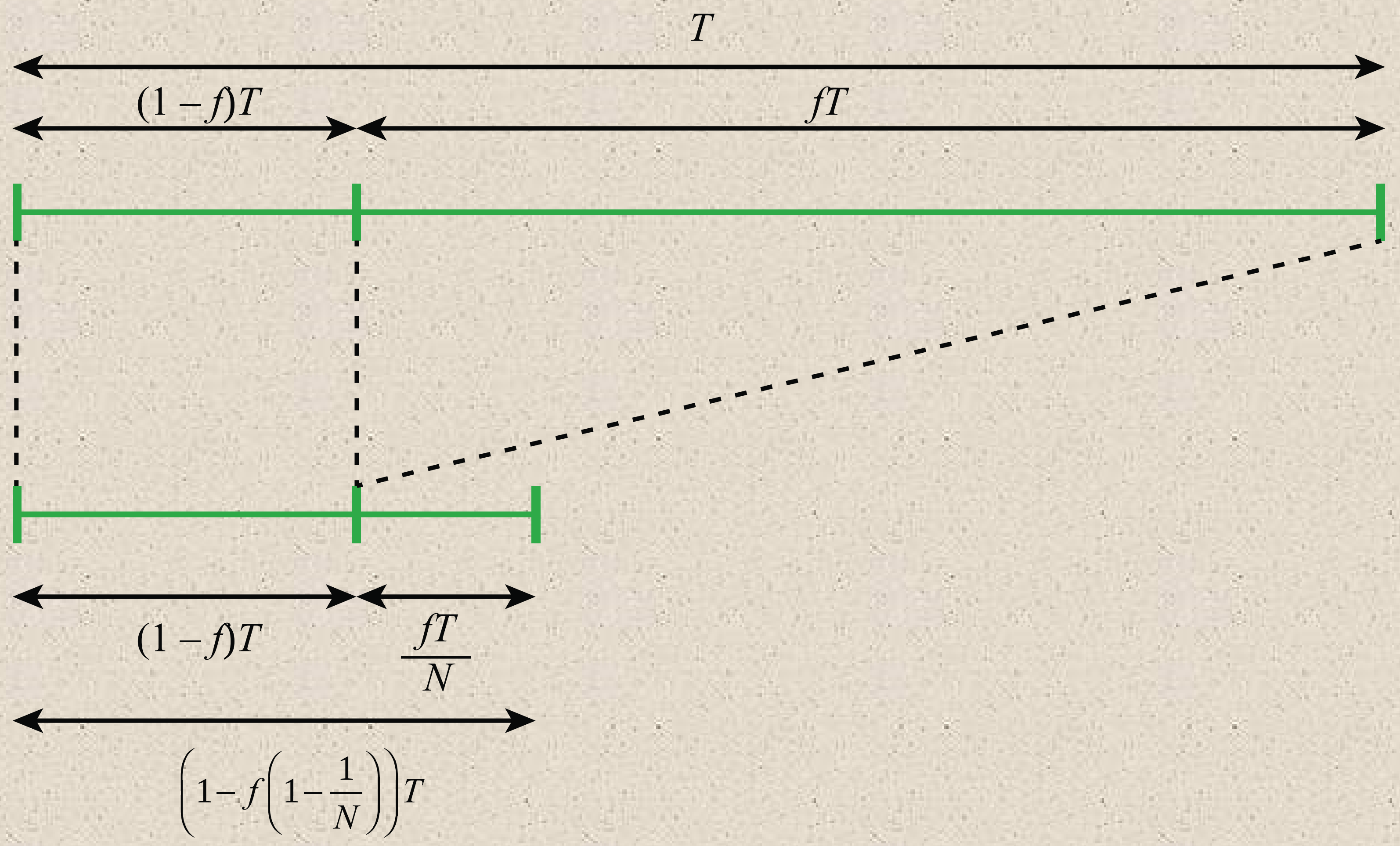


Figure 2.3 Illustration of Amdahl's Law

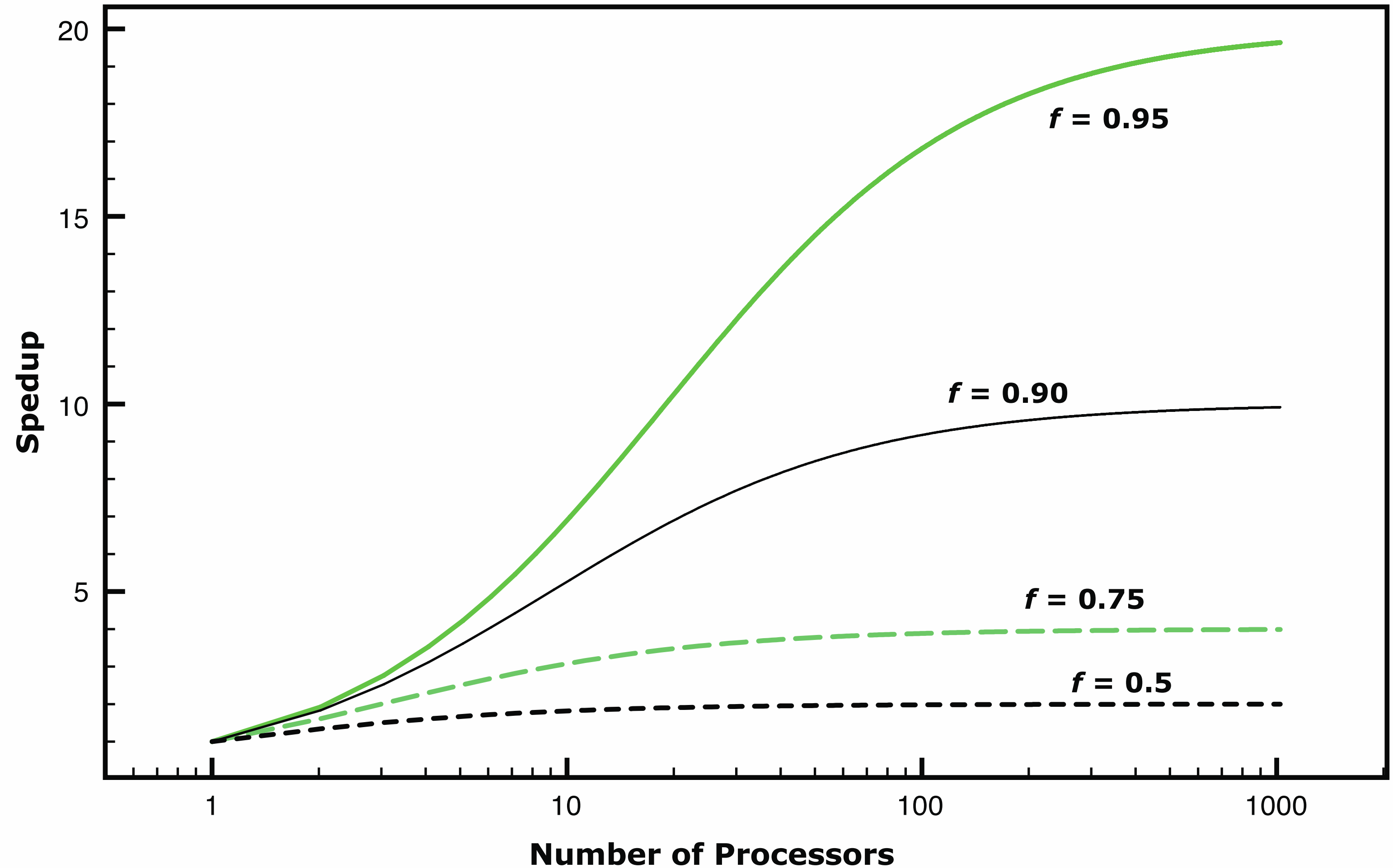
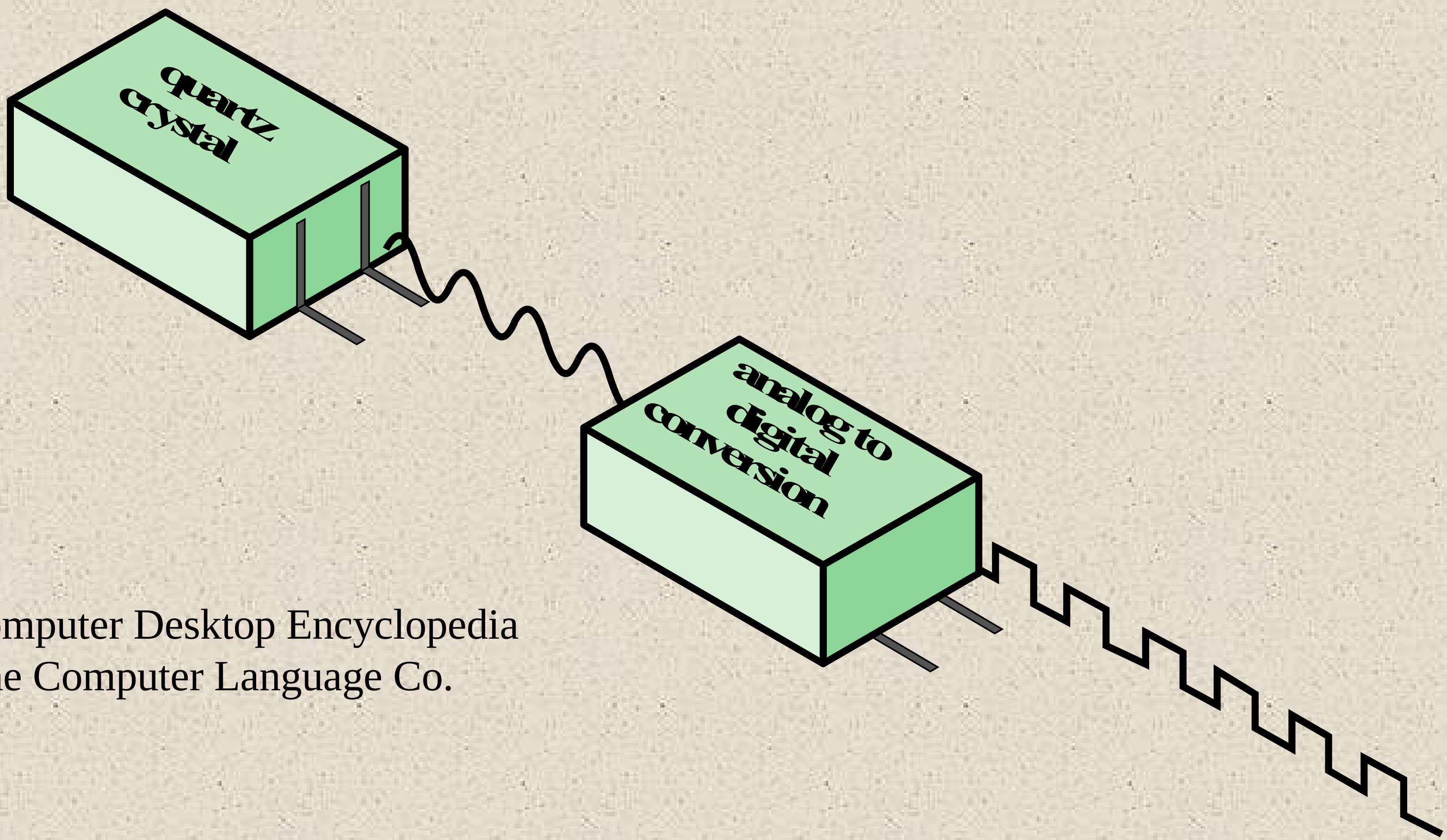


Figure 2.4 Amdahl's Law for Multiprocessors

Little's Law

- Fundamental and simple relation with broad applications
- Can be applied to almost any system that is statistically in steady state, and in which there is no leakage
- Queuing system
  - If server is idle an item is served immediately, otherwise an arriving item joins a queue
  - There can be a single queue for a single server or for multiple servers, or multiple queues with one being for each of multiple servers
- Average number of items in a queuing system equals the average rate at which items arrive multiplied by the time that an item spends in the system
  - Relationship requires very few assumptions
  - Because of its simplicity and generality it is extremely useful



From Computer Desktop Encyclopedia
1998, The Computer Language Co.

Figure 2.5 System Clock

	I_c	p	m	k	t
Instruction set architecture	**X**	**X**			
Compiler technology	**X**	**X**	**X**		
Processor implementation		**X**			**X**
Cache and memory hierarchy				**X**	**X**

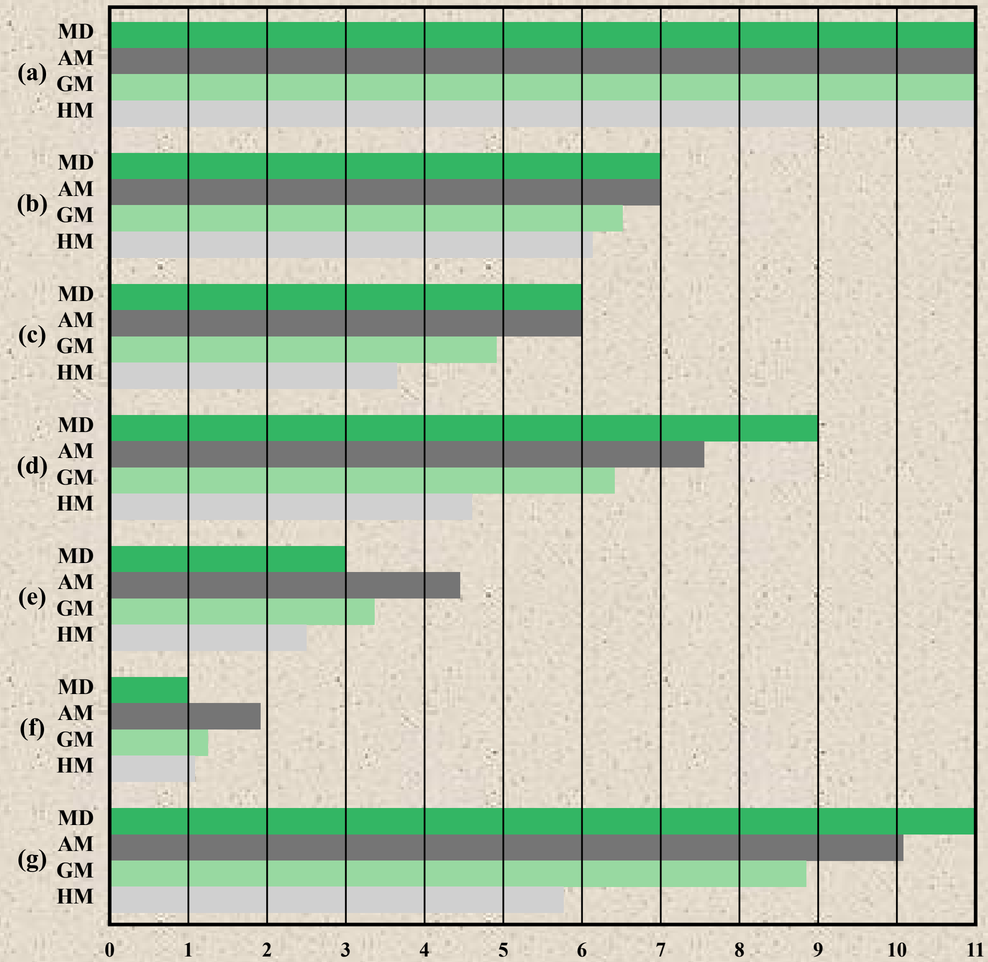
Table 2.1 Performance Factors and System Attributes

Calculating the Mean

The use of benchmarks to compare systems involves calculating the mean value of a set of data points related to execution time

The three common formulas used for calculating a mean are:

- Arithmetic
- Geometric
- Harmonic



(a) Constant (11, 11, 11, 11, 11, 11, 11, 11, 11, 11, 11)
(b) Clustered around a central value (3, 5, 6, 6, 7, 7, 7, 8, 8, 9, 1 1)
(c) Uniform distribution (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 1 1)
(d) Large-number bias (1, 4, 4, 7, 7, 9, 9, 10, 10, 1 1, 11)
(e) Small-number bias(1, 1, 2, 2, 3, 3, 5, 5, 8, 8, 1 1)
(f) Upper outlier (11, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1)
(g) Lower outlier (1, 11, 11, 11, 11, 11, 11, 11, 11, 11, 11)

MD = median
AM = arithmetic mean
GM = geometric mean
HM = harmonic mean

Figure 2.6 Comparison of Means on Various Data Sets (each set has a maximum data point value of 1 1)

- An Arithmetic Mean (AM) is an appropriate measure if the sum of all the measurements is a meaningful and interesting value

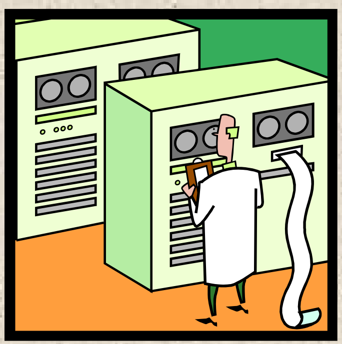
- The AM is a good candidate for comparing the execution time performance of several systems

For example, suppose we were interested in using a system for large-scale simulation studies and wanted to evaluate several alternative products. On each system we could run the simulation multiple times with different input values for each run, and then take the average execution time across all runs. The use of multiple runs with different inputs should ensure that the results are not heavily biased by some unusual feature of a given input set. The AM of all the runs is a good measure of the system's performance on simulations, and a good number to use for system comparison.

Arithmetic Mean

+

- The AM used for a time-based variable, such as program execution time, has the important property that it is directly proportional to the total time
  - If the total time doubles, the mean value doubles



	Computer A time (secs)	Computer B time (secs)	Computer C time (secs)	Computer A rate (MFLOPS)	Computer B rate (MFLOPS)	Computer C rate (MFLOPS)
Program 1 (10^8 FP ops)	2.0	1.0	0.75	50	100	133.33
Program 2 (10^8 FP ops)	0.75	2.0	4.0	133.33	50	25
Total execution time	2.75	3.0	4.75			
Arithmetic mean of times	1.38	1.5	2.38			
Inverse of total execution time (1/sec)	0.36	0.33	0.21			
Arithmetic mean of rates				91.67	75.00	79.17
Harmonic mean of rates				72.72	66.67	42.11

Table 2.2

A Comparison of Arithmetic and Harmonic Means for Rates

Table 2.3 A Comparison of Arithmetic and Geometric Means for Normalized Results

(a) Results normalized to Computer A

	Computer A time	Computer B time	Computer C time
Program 1	2.0 (1.0)	1.0 (0.5)	0.75 (0.38)
Program 2	0.75 (1.0)	2.0 (2.67)	4.0 (5.33)
Total execution time	2.75	3.0	4.75
Arithmetic mean of normalized times	1.00	1.58	2.85
Geometric mean of normalized times	1.00	1.15	1.41

(b) Results normalized to Computer B

	Computer A time	Computer B time	Computer C time
Program 1	2.0 (2.0)	1.0 (1.0)	0.75 (0.75)
Program 2	0.75 (0.38)	2.0 (1.0)	4.0 (2.0)
Total execution time	2.75	3.0	4.75
Arithmetic mean of normalized times	1.19	1.00	1.38
Geometric mean of normalized times	0.87	1.00	1.22