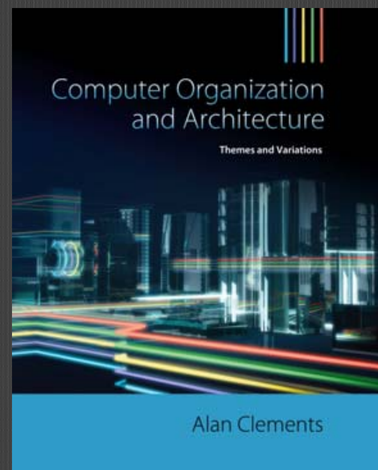
CHAPTER 6

Performance– Meaning and Metrics



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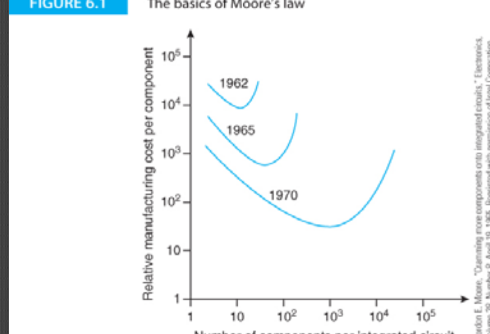

FIGURE 6.1 The basics of Moore's law

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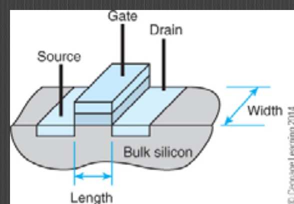

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FIGURE 6.2 The number of devices on a circuit

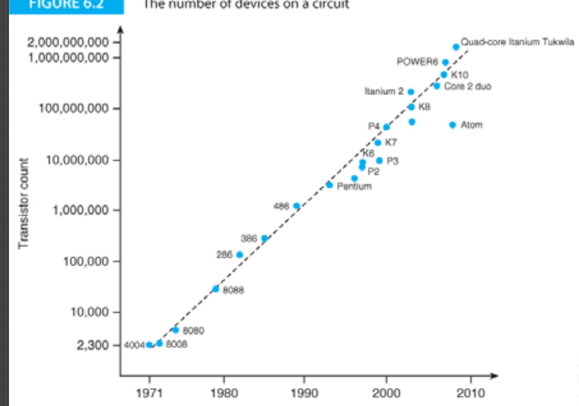

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FIGURE 6.3 Intel's progress in chip design and manufacturing

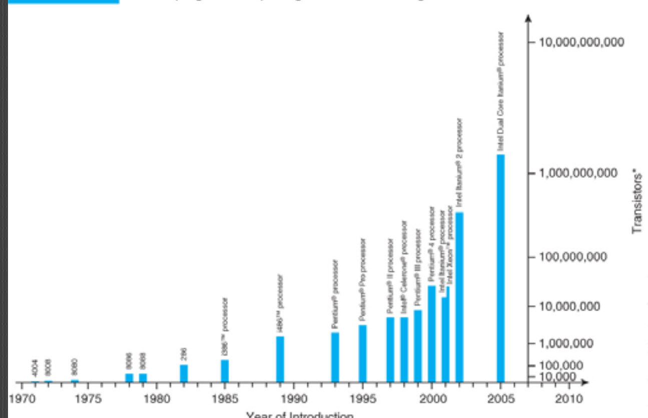

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FIGURE 6.4 3D illustration of microprocessor progress. "De-Mystifying Software Performance Optimization," Intel® Software Network, http://software.intel.com/en-us/articles/de-mystifying-software-performance-optimization/. Reprinted with permission of Intel Corporation.

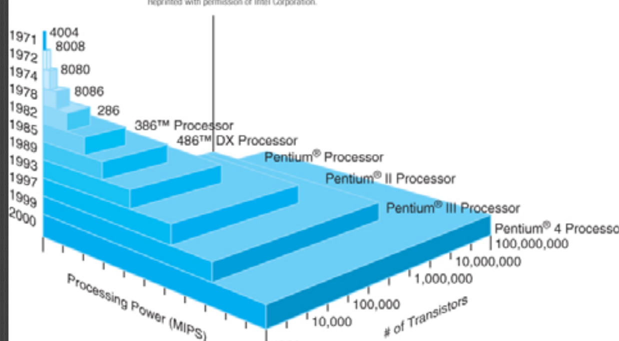

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FIGURE 6.5 The growth of memory capacity

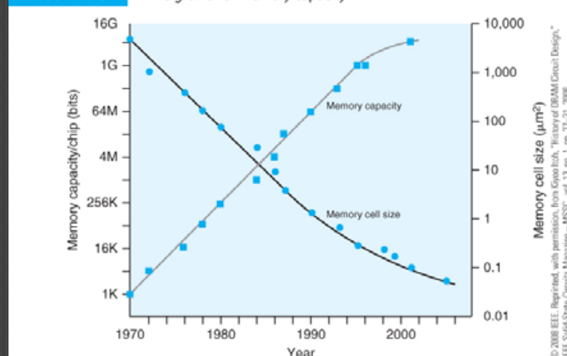

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FIGURE 6.6 Hard disk trends – areal density growth by year

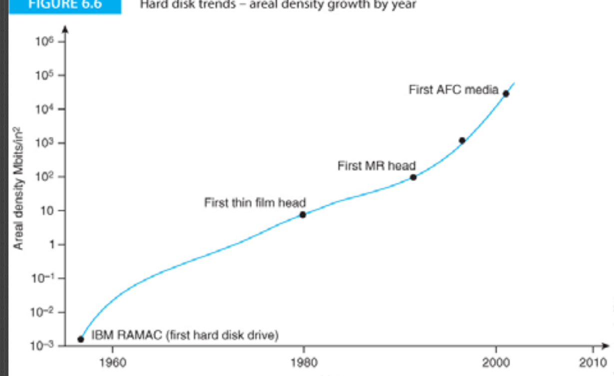

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FIGURE 6.7 Disk improvement as a function of price

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FIGURE 6.8 Performance, the computer, and the designer

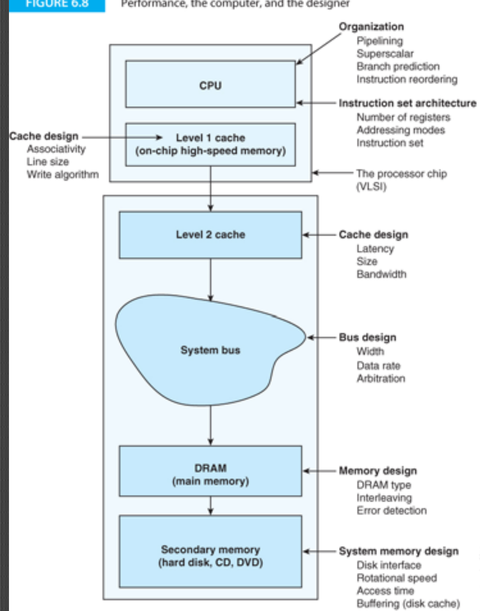

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FIGURE 6.9 The CPU's clock

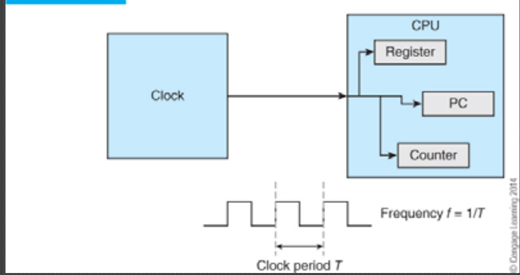

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FIGURE 6.10 Clock doubling

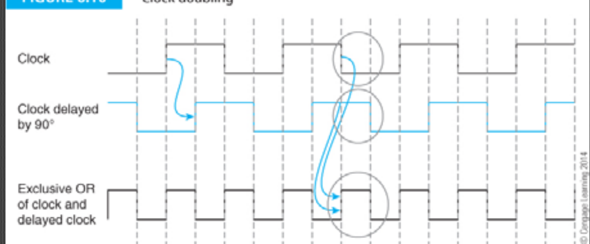

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FIGURE 6.11 Demonstrating the non-scalability of clocks

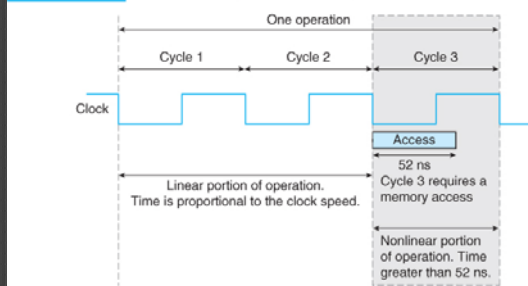

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FIGURE 6.12 The effect of introducing wait states

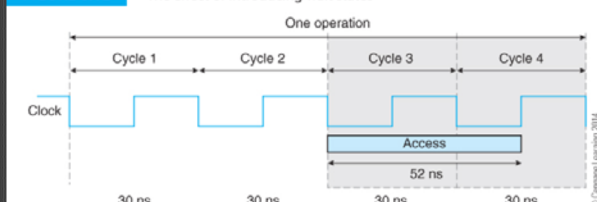

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TABLE 6.1 Total Time Required to Execute the Operation of Figure 6.11 as a Function of Clock Cycle Time

Clock	Cycles 1 & 2	Clocks/cycle 3	Cycle 3	Total Time	Linear Time	Ratio: LT/TT
100	200	1	100	300	300	1.000
80	160	1	80	240	240	1.000
60	120	1	60	180	180	1.000
50	100	2	100	200	150	0.750
40	80	2	80	160	120	0.750
30	60	2	60	120	90	0.750
20	40	3	60	100	60	0.600
10	20	6	60	80	30	0.325
8	16	7	56	72	24	0.333
6	12	9	54	66	18	0.273
4	8	13	52	60	12	0.200
0	0	∞	52	52	0	0.000

FIGURE 6.13 Relationship between clock period and throughput for the system of Figure 6.11

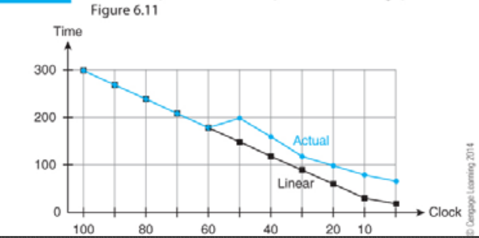

TABLE 6.2 The Expression $z = 4(x + y)$ Executed on Two Hypothetical Computers

Computer *A* (LOAD/STORE)	Computer *B* (Memory-Register)
`LDR r1,(r0) ;load x`	`LDR r1,(r0) ;load x`
`LDR r2,(4,r0) ;load y`	`ADD r1,(4,r0) ;x+y`
`ADD r2,r1,r2 ;x+y`	`MUL r1,#4 ;4(x+y)`
`ADD r2,r2,r2 ;2(x+y)`	`STR r1,(8,r0) ;store z`
`ADD r2,r2,r2 ;4(x+y)`	
`STR r2,(8,r0) ;store z`	

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TABLE 6.3 Relative Instruction Frequency and Cycle Count for a Computer

Machine Operation	Relative Frequency	Cycles per Instruction
Arithmetic/logical instruction	53%	1
Register load operation	20%	4
Register store operation	7%	2
Unconditional branch instruction	12%	1
Conditional branch instruction	8%	2

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TABLE 6. 4 Calculating the Average CPI for the System in Table 6.3

Machine Operation	Frequency	Cycles	CPI
Arithmetic/logical instruction	53%	1	0.53
Register load operation	20%	4	0.80
Register store operation	7%	2	0.14
Unconditional branch instruction	12%	1	0.12
Conditional branch instruction	8%	2	0.16
Average cycles per instruction			1.75

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TABLE 6.5 Calculating the Average Time Spent Executing Each Instruction Class

Machine Operation	Frequency	Average Cycles	Average Time
Arithmetic/logical instruction	53%	$1 \times .53 = 0.53$	30.29%
Register load operation	20%	$4 \times .2 = 0.80$	45.71%
Register store operation	7%	$2 \times .07 = 0.14$	8.00%
Unconditional branch instruction	12%	$1 \times 0.12 = 0.12$	6.86%
Conditional branch instruction	8%	$2 \times .08 = 0.16$	9.14%

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FIGURE 6.14 Factors affecting computer performance

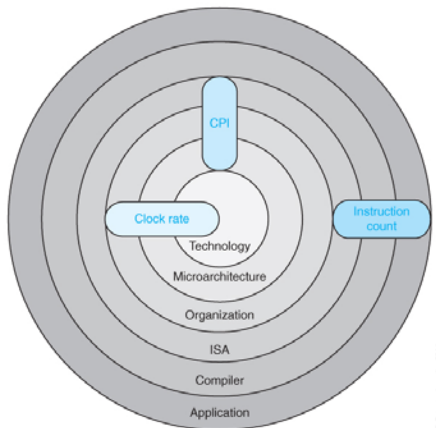

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TABLE 6. 6 Metrics for Seven Machines. © 1996 IEEE. Reprinted, with permission, from Ran Giladi, "Evaluating the Mflops Measure," IEEE Micro, vol. 16 no. 4, pp. 69–75, 1996.

Vendor	MIPS	MFLOPS	SPECfp92	Clock
HP 755/125	213	45.4	195.7	125
DEC 10000/610	202	42	193.6	200
Sun SPARCstation 20/61	167.4	35.3	102.8	60
Sanar Sunar WS 10/51	135.5	27.3	65.2	50
SGI R4400 Indigo2 Ex	120	22.6	93.6	75
Intel Xpress/MX	112	11.4	58.7	66.7
IBM RS5000/220/M20	36.4	6.5	29.1	33

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TABLE 6.7 Comparing Machines of Nearly Equal MIPS Ratings. © 1996 IEEE. Reprinted, with permission, from Ran Giladi, "Evaluating the Mflops Measure," IEEE Micro, vol. 16 no. 4, pp. 69–75, 1996.

Vendor	MIPS	MFLOPS	SPECfp92	Clock
HP T500	100	35	170.2	90
DEC 3000/300L	100.1	12.2	63.6	100
Sun SPARCstation 5/70	100.3	13.1	47.3	70
Intel Xpress/MX	112	11.4	58.7	66.7

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TABLE 6.8 Contradictory Benchmarks. © 1996 IEEE. Reprinted, with permission, from Ran Giladi, "Evaluating the Mflops Measure," IEEE Micro, vol. 16 no. 4, pp. 69–75, 1996.

Vendor	MIPS	MFLOPS	SPECfp92	Clock
DEC 3000/300L	100.1	12.2	63.6	100
HP 750	76	22	92	66
Sun SPARCstation 5/70	100.3	13.1	47.3	70
Sun SPARCstation 20/61	129.4	29.6	84.8	50

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FIGURE 6.15 Illustration of Amdahl's law

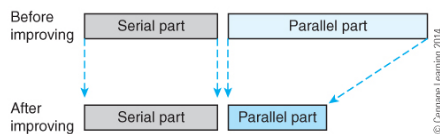

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TABLE 6.9 Effect of Amdahl's Law

Processors	Speedup Ratio $f_s = 0.2$	Speedup Ratio $f_s = 0.1$
1	1	1
2	1.667	1.818
3	2.143	2.500
4	2.500	3.077
5	2.778	3.571
10	3.571	5.263
100	4.808	9.174
∞	5.000	10.00

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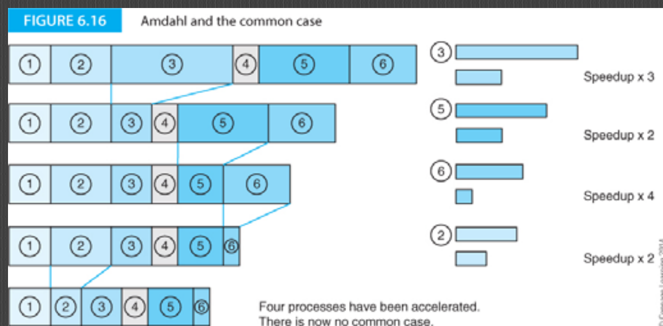

FIGURE 6.16 Amdahl and the common case

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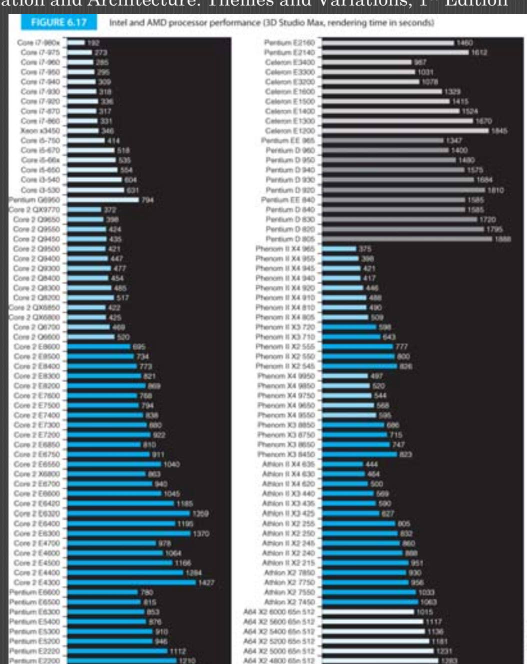

FIGURE 6.17 Intel and AMD processor performance (3D Studio Max, rendering time in seconds)

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FIGURE 6.18 Benchmarks for games

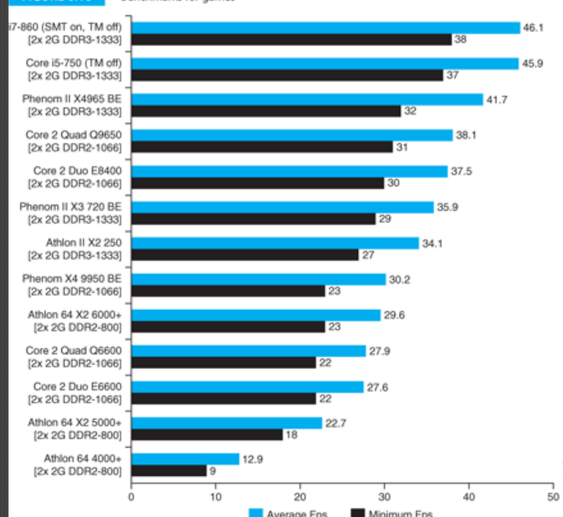

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FIGURE 6.19 Benchmarks reported by a commercial benchmarking tool

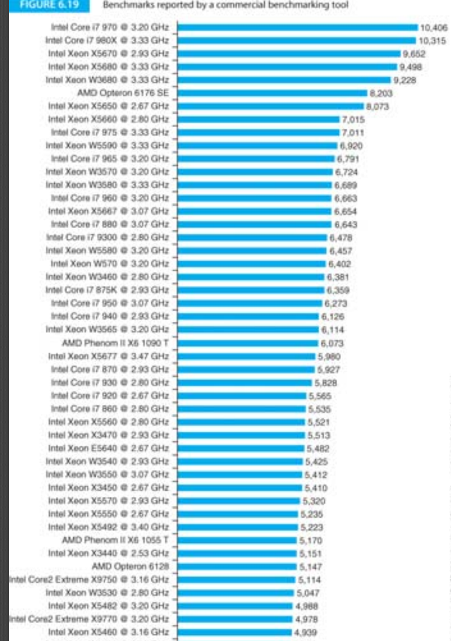

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TABLE 6.10 Details of Eleven Processors in a Review by HEXUS

Model Number	Cores / Threads	GHz Clock	Turbo Boost (max)	Process	Die Size	Cache	Memory Support	TDP
Phenom II X4 965 BE	4/4	3.40	N/A	45 nm (Deneb)	258 mm²	2 MB 6 MB L3	L2 DDR3-1,333+	95 W
Phenom II X6 1055T	6/6	2.80	3.30	45 nm (Thuban)	346 mm²	3 MB 6 MB L3	L2 DDR3-1,600+	125 W 95 W
Phenom II X6 1090T	6/6	3.20	3.60	45 nm (Thuban)	346 mm²	3 MB 6 MB L3	L2 DDR3-1,600+	125 W
Core i5 661 (IGP)	2/4	3.33	3.60	32 nm (Clarkdale)	81 mm²	512 KB 4 MB L3	L2 DDR3-1,333	87 W
Core i5 750	4/4	2.67	3.20	45 nm (Lynnfield)	296 mm²	1 MB 8 MB L3	L2 DDR3-1,333	95 W
Core i7 860	4/8	2.80	3.46	45 nm (Lynnfield)	296 mm²	1 MB 8 MB L3	L2 DDR3-1,333	95 W
Core i7 870	4/8	2.93	3.60	45 nm (Lynnfield)	296 mm²	1 MB 8 MB L3	L2 DDR3-1,333	95 W
Core i7 920	4/8	2.67	2.93	45 nm (Bloomfield)	263 mm²	1 MB 8 MB L3	L2 DDR3-1066	130 W
Core i7 975 EE	4/8	3.33	3.60	45 nm (Bloomfield)	263 mm²	1 MB 8 MB L3	L2 DDR3-1066	130 W
Core i7 970	6/12	3.20	3.46	32 nm (Westmere)	248 mm²	1.5 MB 12 MB L3	L2 DDR3-1066	130 W
Core i7 980X EE	6/12	3.33	3.60	32 nm (Westmere)	248 mm²	1.5 MB 12 MB L3	L2 DDR3-1066	130 W

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FIGURE 6.20 Power consumption by processor in both idle and load modes

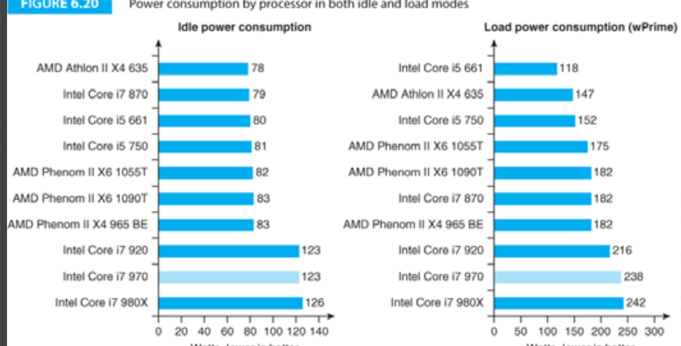

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FIGURE 6.21 Performance by processor. The left-hand parameters are rates and the right-hand parameters are times

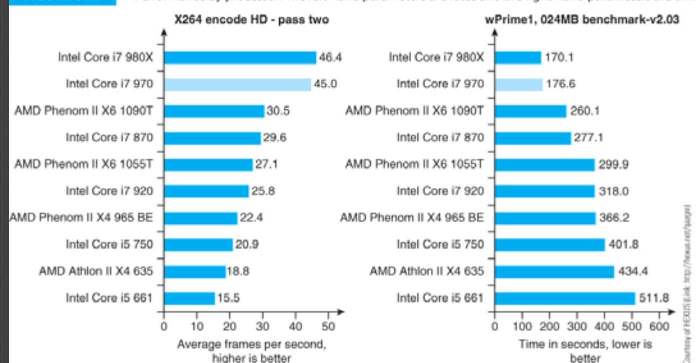

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TABLE 6.11 Test Results for Three Hypothetical Machines

	Task A	Task B	Task C	Total
Reference machine	10	100	5	115
Machine M1	10	200	5	215
Machine M2	20	100	5	125
Machine M3	20	100	20	140

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TABLE 6.12 Test Results for Three Hypothetical Machines after Normalization

	Task A	Task B	Task C	Total
Machine M1	1	2	1	4
Machine M2	2	1	1	4
Machine M3	2	1	4	7

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FIGURE 6.22 The use of SPEC benchmarks in published papers. © 2003 IEEE. Reprinted, with permission, from Hennessy, J.; Citron, D.; Patterson, D.; Sohi, G. "The Use and Abuse of SPEC: An ISCA Panel," IEEE Micro, vol. 23, no. 4, pp. 73–77, July/Aug. 2003.

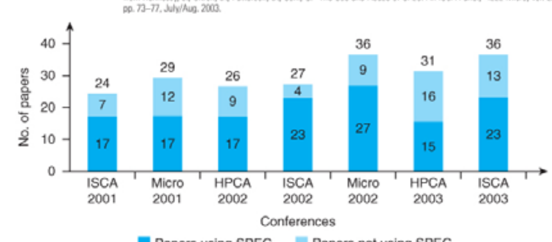

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TABLE 6.13 The SPEC 2006 Integer Reference Benchmarks

Benchmark	Language	Application	Brief Description
400.perlbench	C	Programming Language	Derived from Perl V5.8.7. The workload includes SpamAssassin, MHonArc (an email indexer), and specdiff (SPEC's tool that checks benchmark outputs).
401.bzip2	C	Compression	Julian Seward's bzip2 version 1.0.3, modified to do most work in memory, rather than doing I/O.
403.gcc	C	C Compiler	Based on gcc Version 3.2, generates code for Opteron.
429.mcf	C	Combinatorial Optimization	Vehicle scheduling. Uses a network simplex algorithm (which is also used in commercial products) to schedule public transport.
445.gobmk	C	Artificial Intelligence: Go	Plays the game of Go, a simply described but deeply complex game.
456.hmmer	C	Search Gene Sequence	Protein sequence analysis using profile hidden Markov models (profile HMMs).
458.sjeng	C	Artificial Intelligence: Chess	A highly-ranked chess program that also plays several chess variants.
462.libquantum	C	Physics/Quantum Computing	Simulates a quantum computer, running Shor's polynomial-time factorization algorithm.
464.h264ref	C	Video Compression	A reference implementation of H.264/AVC, encodes a videostream using two parameter sets. The H.264/AVC standard is expected to replace MPEG2.
471.omnetpp	C++	Discrete Event Simulation	Uses the OMNet++ discrete event simulator to model a large Ethernet campus network.
473.astar	C++	Path-Finding Algorithms	Pathfinding library for 2D maps, including the well known A* algorithm.
483.xalancbmk	C++	XML Processing	A modified version of Xalan-C++, which transforms XML documents to other document types.

TABLE 6.14 The SPEC 2006 Floating-Point Reference Benchmarks

Benchmark	Language	Application Area	Brief Description
410.bwaves	Fortran	Fluid Dynamics	Computes 3D transonic transient laminar viscous flow.
416.gamess	Fortran	Quantum Chemistry	Gamess implements a wide range of quantum chemical computations. For the SPEC workload, self-consistent field calculations are performed using the Restricted Hartree Fock method, Restricted open-shell Hartree-Fock, and Multi-Configuration Self-Consistent Field.
433.milc	C	Physics/Quantum Chromodynamics	A gauge field generating program for lattice gauge theory programs with dynamical quarks.
434.zeusmp	Fortran	Physics/CFD	ZEUS-MP is a computational fluid dynamics code developed at the Laboratory for Computational Astrophysics (NCSA, University of Illinois at Urbana-Champaign) for the simulation of astrophysical phenomena.
435.gromacs	C, Fortran	Biochemistry/ Molecular Dynamics	Molecular dynamics, i.e., simulate Newtonian equations of motion for hundreds to millions of particles. The test case simulates protein Lysozyme in a solution.
436.cactus ADM	C, Fortran	Physics/General Relativity	Solves the Einstein evolution equations using a staggered-leapfrog numerical method.

(Continued)

TABLE 6.14 Continued

Benchmark	Language	Application Area	Brief Description
437.leslie3d	Fortran	Fluid Dynamics	Computational Fluid Dynamics (CFD) using Large-Eddy Simulations with Linear-Eddy Model in 3D. Uses the MacCormack Predictor-Corrector time integration scheme.
444.namd	C++	Biology / Molecular Dynamics	Simulates large biomolecular systems. The test case has 92,224 atoms of apolipoprotein A-I.
447.dealII	C++	Finite Element Analysis	Deal.II is a C++ program library targeted at adaptive finite elements and error estimation. The test case solves a Helmholtz-type equation with non-constant coefficients.
450.soplex	C++	Linear Programming, Optimization	Solves a linear program using a simplex algorithm and sparse linear algebra. Test cases include railroad planning and military airlift models.
453.povray	C++	Image Ray-Tracing	Image rendering. The test case is a 1280 × 1024 anti-aliased image of a landscape with some abstract objects with textures using a Perlin noise function.
454.calculix	C, Fortran	Structural Mechanics	Finite element code for linear and nonlinear 3D structural applications. Uses the SPOOLES solver library.
459.Gems FDTD	Fortran	Computational Electromagnetics	Solves the Maxwell equations in 3D using the finite-difference time-domain (FDTD) method.
465.tonto	Fortran	Quantum Chemistry	An open source quantum chemistry package, using an object-oriented design in Fortran 95. The test case places a constraint on a molecular Hartree-Fock wavefunction calculation to better match experimental X-ray diffraction data.
470.lbm	C	Fluid Dynamics	Implements the "Lattice-Boltzmann Method" to simulate incompressible fluids in 3D.
481.wrf	C, Fortran	Weather	Weather modeling from scales of meters to thousands of kilometers. The test case is from a 30km area over 2 days.
482.sphinx3	C	Speech recognition	A widely-known speech recognition system from Carnegie Mellon University.

TABLE 6.15 SPEC 2006 Sample Published Benchmarks (actual run times)

	Base						Peak					
Benchmark*	Seconds	Ratio	Seconds	Ratio	Seconds	Ratio	Seconds	Ratio	Seconds	Ratio	Seconds	Ratio
400.perlbench	562	17.4	**540**	**18.1**	539	18.1	455	21.5	475	20.6	**455**	**21.5**
401.bzip2	**733**	**13.2**	732	13.2	764	12.6	729	13.2	765	12.6	**730**	**13.2**
403.gcc	621	13.0	**622**	**12.9**	623	12.9	456	17.7	**473**	**17.0**	474	17.0
429.mcf	395	23.1	396	23.0	**396**	**23.0**	316	28.8	333	27.4	**329**	**27.7**
445.gobmk	595	17.6	**595**	**17.6**	594	17.7	562	18.7	**575**	**18.2**	587	17.9
456.hmmer	**277**	**33.7**	277	33.7	278	33.6	267	34.9	**256**	**36.4**	256	36.5
458.sjeng	**679**	**17.8**	678	17.8	679	17.8	627	19.3	**628**	**19.3**	656	18.5
462.libquantum	151	137	151	137	**151**	**137**	151	137	151	137	**151**	**137**
464.h264ref	799	27.7	**800**	**27.7**	801	27.6	**777**	**28.5**	759	29.2	781	28.3
471.omnetpp	505	12.4	**506**	**12.4**	526	11.9	418	14.9	399	15.7	**417**	**15.0**
473.astar	554	12.7	**554**	**12.7**	577	12.2	**569**	**12.3**	569	12.3	571	12.3
483.xalancbmk	**305**	**22.6**	295	23.4	306	22.5	**305**	**22.6**	295	23.4	306	22.5

*Results appear in the order in which they were run. Bold underlined text indicates a median measurement.

FIGURE 6.23 SPEC 2006 sample published benchmark (overall results)

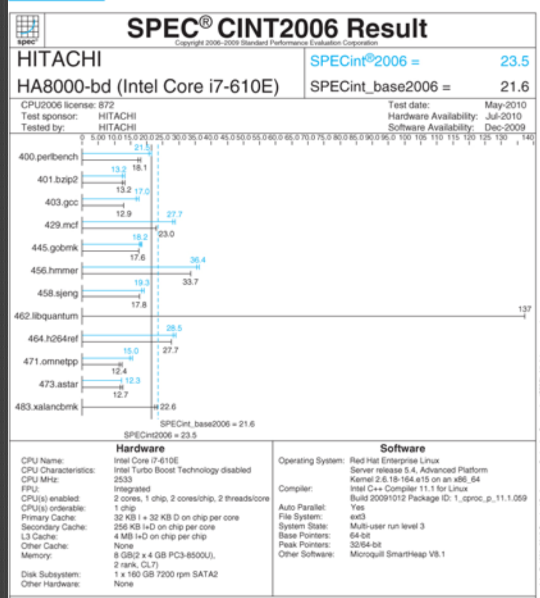

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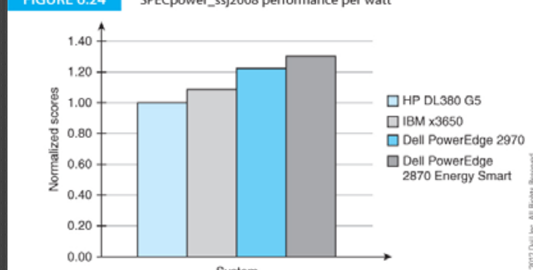
FIGURE 6.24 SPECpower_ssj2008 performance per watt



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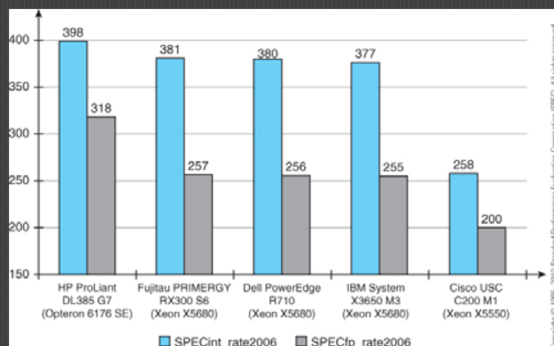

FIGURE 6.25 SPECpower_ssj2008 performance

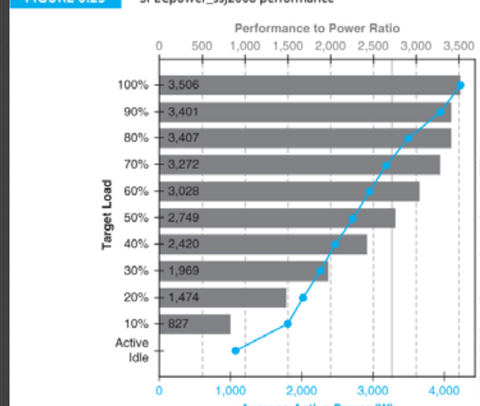

TABLE 6.16 Tests on Two Machines Compared to Two Reference Machines

	Test 1	Test 2	Test 3	Arithmetic Average	Geometric Mean
System 1	10	10	10	10	10
System 2	1	12	17	10	5.89
System 3	10	5	20	11.67	10

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TABLE 6.17 Arithmetic and Geometric Means

System	Test Results	Arithmetic Mean	Geometric Mean
Base	10 10 10 10 10 10	10	10
1	10 10 10 10 10 100	25	14.68
2	10 10 10 10 10 1	8.5	6.81

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TABLE 6.18 Geometric Means

	t_1	t_2	t_3	Geometric Mean
Evaluation machine	2	2	4	2.52
Reference machine	4	6	9	6
Normalized results	2	3	2.26	2.38

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TABLE 6.19 Illustration of the Difficulty of Comparing Means

	Test 1	Test 2	Test 3	Arithmetic	Geometric	Harmonic
Case 1	10	10	10	10	10	10
Case 2	1	12	17	10	5.89	12.392
Case 3	10	5	20	11.67	10	8.571

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TABLE 6.20 Time Taken by a Workstation to Carry Out Various Activities

Operation	Symbol	Time
Orbital dynamic calculations	C_{OD}	50%
Performing aerodynamic calculations	C_{AD}	25%
Image processing	C_{IP}	15%
Microsoft flight simulator	C_{MS}	10%

FIGURE P6.7

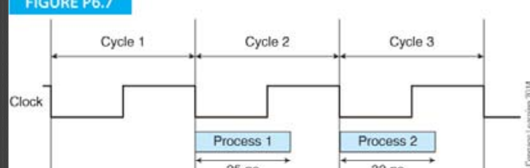
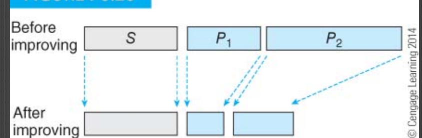


FIGURE P6.20



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