

Transistor count

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The **transistor count** is the number of transistors on an integrated circuit chip. Transistor count is the most common measure of semiconductor integrated circuit complexity. As of 2016, the highest transistor count in a commercially available CPU (in one chip) is over 7.2 billion transistors, in Intel's 22-core Xeon Broadwell-EP.

According to Moore's law the transistor count of the integrated circuits doubles approximately every two years. On most modern microprocessors, the majority of transistors are contained in caches. In fact, IBM's Storage Controller at 7.1 billion transistors with 480 MB L4 cache in 2015, is bigger than any microprocessor before, on both counts; it is however not a CPU until combined with one (or more) of its companion IBM z13 microprocessor chip. That chip holds the rest of the cache, 64 MB L3 (and the other smaller levels) and processor logic, and while having the same dimensions has only 3.9 billion transistors (near record breaking for a microprocessor on its own). To date, combined, this mainframe is the biggest general purpose processor when only one Storage Controller is used, let alone when two are used.

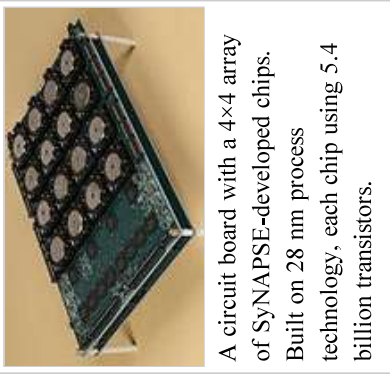
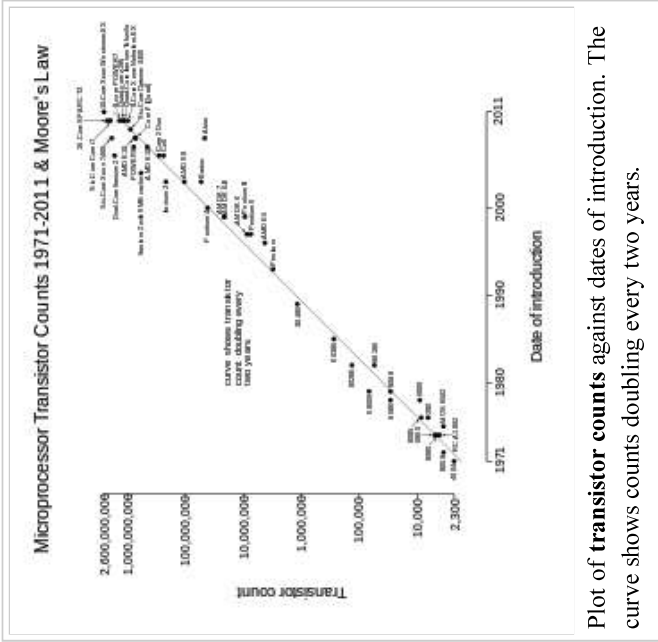
On August 7, 2014, IBM announced their neuromorphic TrueNorth chip; their second generation chip backed by the SyNAPSE program, which, with 5.4 billion transistors (in 4096 cores), has more transistors than any chip IBM has ever made^[1] (until their Storage Controller, mentioned above) and is the "second largest (CMOS) chip in the world"^{[2][3][4]} (and therefore the largest "neuromorphic" one, as a GPU chip is bigger, but sixteen can be connected together).

Altera currently holds the "world-record" for a FPGA containing more than 30 billion transistors overtaking Xilinx's 20 billion transistor count.^[5] [6]

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A circuit board with a 4×4 array of SyNAPSE-developed chips. Built on 28 nm process technology, each chip using 5.4 billion transistors.

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Microprocessors

A microprocessor incorporates the functions of a computer's central processing unit on a single integrated circuit. It is a multipurpose, programmable device that accepts digital data as input, processes it according to instructions stored in its memory, and provides results as output.

Processor	Transistor count	Date of introduction	Designer	Process	Area
TMS 1000	8,000	1971	Texas Instruments	8,000 nm	
Intel 4004	2,300	1971	Intel	10,000 nm	12 mm²
Intel 8008	3,500	1972	Intel	10,000 nm	14 mm²
MOS Technology 6502	3,510 ^[7]	1975	MOS Technology	8,000 nm	21 mm²
Motorola 6800	4,100	1974	Motorola	6,000 nm	16 mm²
Intel 8080	4,500	1974	Intel	6,000 nm	20 mm²
RCA 1802	5,000	1974	RCA	5,000 nm	27 mm²
Intel 8085	6,500	1976	Intel	3,000 nm	20 mm²
Zilog Z80	8,500	1976	Zilog	4,000 nm	18 mm²
Motorola 6809	9,000	1978	Motorola	5,000 nm	21 mm²
Intel 8086	29,000	1978	Intel	3,000 nm	33 mm²
Intel 8088	29,000	1979	Intel	3,000 nm	33 mm²
WDC 65C02	11,500 ^[8]	1981	WDC	3,000 nm	6 mm²
Intel 80186	55,000	1982	Intel	3,000 nm	60 mm²
Motorola 68000	68,000	1979	Motorola	3,500 nm	44 mm²
Intel 80286	134,000	1982	Intel	1,500 nm	49 mm²
WDC 65C816	22,000 ^[9]	1983	WDC		9 mm²
Motorola 68020	190,000 ^[10]	1984	Motorola	2,000 nm	85 mm²
Intel 80386	275,000	1985	Intel	1,500 nm	104 mm²
ARM 1	25,000 ^[10]	1985	Acorn	3,000 nm	50 mm²
Novix NC4016	16,000 ^[11]	1985 ^[12]	Harris Corporation	3,000 nm ^[13]	
ARM 2	30,000 ^[10]	1986	Acorn	2,000 nm	30 mm²
TI Explorer's 32-bit Lisp machine chip	553,000 ^[14]	1987	Texas Instruments		
DEC WRL MultiTitan	180,000 ^[15]	1988	DEC WRL	1,500 nm	61 mm²
Intel i960	250,000 ^[16]	1988	Intel	600 nm	
Intel 80486	1,180,235	1989	Intel	1000 nm	173 mm²
ARM 3	300,000	1989	Acorn		

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R4000	1,350,000	1991	MIPS	1,000 nm	213 mm²
ARM 6	35,000	1991	ARM		
Pentium	3,100,000	1993	Intel	800 nm	294 mm²
ARM700	578,977 ^[17]	1994	ARM		68.51 mm²
SA-110	2,500,000 ^[10]	1995	Acorn/DEC/Apple	350 nm	50 mm²
ARM 9TDMI	111,000 ^[10]	1999	Acorn	350 nm	4.8 mm²
Pentium Pro	5,500,000 ^[18]	1995	Intel	500 nm	307 mm²
AMD K5	4,300,000	1996	AMD	500 nm	251 mm²
Pentium II Klamath	7,500,000	1997	Intel	350 nm	195 mm²
Pentium II Deschutes	7,500,000	1998	Intel	250 nm	113 mm²
AMD K6	8,800,000	1997	AMD	350 nm	162 mm²
Pentium III Katmai	9,500,000	1999	Intel	250 nm	128 mm²
Pentium III Coppermine	21,000,000	2000	Intel	180 nm	80 mm²
Pentium II Mobile Dixon	27,400,000	1999	Intel	180 nm	180 mm²
Pentium III Tualatin	45,000,000	2001	Intel	130 nm	81 mm²
AMD K6-III	21,300,000	1999	AMD	250 nm	118 mm²
AMD K7	22,000,000	1999	AMD	250 nm	184 mm²
Pentium 4 Willamette	42,000,000	2000	Intel	180 nm	217 mm²
Pentium 4 Northwood	55,000,000	2002	Intel	130 nm	145 mm²
Pentium 4 Prescott	112,000,000	2004	Intel	90 nm	110 mm²
Pentium 4 Prescott-2M	169,000,000	2005	Intel	90 nm	143 mm²
Pentium 4 Cedar Mill	184,000,000	2006	Intel	65 nm	90 mm²
Pentium D Smithfield	228,000,000	2005	Intel	90 nm	206 mm²
Pentium D Presler	362,000,000	2006	Intel	65 nm	162 mm²
Atom	47,000,000	2008	Intel	45 nm	24 mm²
Barton	54,300,000	2003	AMD	130 nm	101 mm²
AMD K8	105,900,000	2003	AMD	130 nm	193 mm²
Itanium 2 McKinley	220,000,000	2002	Intel	180 nm	421 mm²
Cell	241,000,000	2006	Sony/IBM/Toshiba	90 nm	221 mm²

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Core 2 Duo Conroe	291,000,000	2006	Intel	65 nm	143 mm²
Core 2 Duo Allendale	169,000,000	2007	Intel	65 nm	111 mm²
Itanium 2 Madison 6M	410,000,000	2003	Intel	130 nm	374 mm²
AMD K10 quad-core 2M L3	463,000,000 ^[19]	2007	AMD	65 nm	283 mm²
ARM Cortex-A9	26,000,000 ^[20]	2007	ARM	45 nm	31 mm²
Core 2 Duo Wolfdale 3M	230,000,000	2008	Intel	45 nm	83 mm²
Itanium 2 with 9 MB cache	592,000,000	2004	Intel	130 nm	432 mm²
Core 2 Duo Wolfdale	411,000,000	2007	Intel	45 nm	107 mm²
Core i7 (Quad)	731,000,000	2008	Intel	45 nm	263 mm²
AMD K10 quad-core 6M L3	758,000,000 ^[19]	2008	AMD	45 nm	258 mm²
POWER6	789,000,000	2007	IBM	65 nm	341 mm²
Six-core Opteron 2400	904,000,000	2009	AMD	45 nm	346 mm²
16-core SPARC T3	1,000,000,000 ^[21]	2010	Sun/Oracle	40 nm	377 mm²
Apple A7 (dual-core ARMv8 "mobile SoC")	1,000,000,000	2013	Apple	28 nm	102 mm²
Quad-core + GPU Core i7	1,160,000,000	2011	Intel	32 nm	216 mm²
Six-core Core i7 (Gulftown)	1,170,000,000	2010	Intel	32 nm	240 mm²
8-core POWER7 32M L3	1,200,000,000	2010	IBM	45 nm	567 mm²
8-core AMD Bulldozer	1,200,000,000 ^[22]	2012	AMD	32 nm	315 mm²
Quad-core + GPU AMD Trinity	1,303,000,000	2012	AMD	32 nm	246 mm²
Quad-core z196 ^[23]	1,400,000,000	2010	IBM	45 nm	512 mm²
Quad-core + GPU Core i7 Ivy Bridge	1,400,000,000	2012	Intel	22 nm	160 mm²
Quad-core + GPU Core i7 Haswell	1,400,000,000 ^[24]	2014	Intel	22 nm	177 mm²
Dual-core Itanium 2	1,700,000,000 ^[25]	2006	Intel	90 nm	596 mm²
Quad-core + GPU GT2 Core i7 Skylake K	cca 1,750,000,000	2015	Intel	14 nm	122 mm²
Six-core Core i7 Ivy Bridge E	1,860,000,000	2013	Intel	22 nm	256 mm²
Duo-core + GPU Iris Core i7 Broadwell-U	1,900,000,000 ^[26]	2015	Intel	14 nm	133 mm²
Six-core Xeon 7400	1,900,000,000	2008	Intel	45 nm	503 mm²
Quad-core Itanium Tukwila	2,000,000,000 ^[27]	2010	Intel	65 nm	699 mm²

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Apple A8 (dual-core ARM64 "mobile SoC")	2,000,000,000	2014	Apple	20 nm	89 mm²
8-core POWER7+ 80 MB L3 cache	2,100,000,000	2012	IBM	32 nm	567 mm²
Six-core Core i7/8-core Xeon E5 (Sandy Bridge-E/EP)	2,270,000,000 ^[28]	2011	Intel	32 nm	434 mm²
8-core Xeon Nehalem-EX	2,300,000,000 ^[29]	2010	Intel	45 nm	684 mm²
8-core Core i7 Haswell-E	2,600,000,000 ^[30]	2014	Intel	22 nm	355 mm²
10-core Xeon Westmere-EX	2,600,000,000	2011	Intel	32 nm	512 mm²
Six-core zEC12	2,750,000,000	2012	IBM	32 nm	597 mm²
Apple A8X (tri-core ARM64 "mobile SoC")	3,000,000,000 ^[31]	2014	Apple	20 nm	128 mm²
8-core Itanium Poulson	3,100,000,000	2012	Intel	32 nm	544 mm²
IBM z13	3,990,000,000	2015	IBM	22 nm	678 mm²
12-core POWER8	4,200,000,000	2013	IBM	22 nm	650 mm²
15-core Xeon Ivy Bridge-EX	4,310,000,000 ^[32]	2014	Intel	22 nm	541 mm²
61-core Xeon Phi	5,000,000,000 ^[33]	2012	Intel	22 nm	350 mm²
Xbox One main SoC	5,000,000,000	2013	Microsoft/AMD	28 nm	363 mm²
18-core Xeon Haswell-E5	5,560,000,000 ^[34]	2014	Intel	22 nm	661 mm²
IBM z13 Storage Controller	7,100,000,000	2015	IBM	22 nm	678 mm²
22-core Xeon Broadwell-E5	~7,200,000,000 ^[35]	2016	Intel	14 nm	456 mm²
SPARC M7	10,000,000,000 ^[36]	2015	Oracle	20 nm	

Transistorized computers

The "second generation" of computers (transistor computers) featured boards filled with discrete transistors and magnetic memory cores.

Processor ⇄	Transistor count ⇄	Date of introduction ⇄	Manufacturer ⇄	Process ⇄	Area ⇄
"Transistor Computer" (full size)	200 discrete point-contact transistors	1955	University of Manchester	?	?
"Metrovick 950"	200 discrete junction transistors	1956	Metropolitan-Vickers	?	?
PDP-1	2,700 discrete transistors	1959	Digital Equipment Corporation		
PDP-8/s	? discrete transistors (519 logic gates)	1971 ?	Digital Equipment Corporation	?	?
M18 FADAC	1,600 discrete transistors	1960	Autonetics	?	?
D-17B	1,521 discrete transistors	1962	Autonetics	?	?
Apollo Guidance Computer	12,300 (4,100 ICs, each containing a single 3-input NOR gate)	1966	Raytheon / MIT Instrumentation Laboratory	?	?

GPUs

A graphics processing unit (GPU) is a specialized electronic circuit designed to rapidly manipulate and alter memory to accelerate the building of images in a frame buffer intended for output to a display.

Processor	Transistor count	Date of introduction	Manufacturer	Process	Area
NV3	3,500,000	1997	NVIDIA	350 nm	90 mm ²
Rage 128	8,000,000	1999	AMD	250 nm	70 mm ²
NV5	15,000,000	1999	Nvidia	250 nm	
NV10	23,000,000	1999	Nvidia	220 nm	111 mm ²
NV11	20,000,000	2000	Nvidia	180 nm	65 mm ²
NV15	25,000,000	2000	Nvidia	180 nm	81 mm ²
R100	30,000,000	2000	AMD	180 nm	97 mm ²
NV20	57,000,000	2001	Nvidia	150 nm	128 mm ²
R200	60,000,000	2001	AMD	150 nm	68 mm ²
NV25	63,000,000	2002	Nvidia	150 nm	142 mm ²
R300	107,000,000	2002	AMD	150 nm	218 mm ²
R360	117,000,000	2003	AMD	150 nm	218 mm ²
NV38	135,000,000	2003	Nvidia	130 nm	207 mm ²
R480	160,000,000	2004	AMD	130 nm	297 mm ²
NV40	222,000,000	2004	Nvidia	130 nm	305 mm ²
G70	303,000,000	2005	Nvidia	110 nm	333 mm ²
R520	321,000,000	2005	AMD	90 nm	288 mm ²
R580	384,000,000	2006	AMD	90 nm	352 mm ²
G80	681,000,000	2006	Nvidia	90 nm	480 mm ²
R600	700,000,000	2007	AMD	80 nm	420 mm ²
G92	754,000,000	2007	Nvidia	65 nm	324 mm ²
RV790	959,000,000 ^[37]	2008	AMD	55 nm	282 mm ²
GT200 Tesla	1,400,000,000 ^[38]	2008	Nvidia	65 nm	576 mm ²
Cypress RV870	2,154,000,000 ^[39]	2009	AMD	40 nm	334 mm ²
Cayman RV970	2,640,000,000	2010	AMD	40 nm	389 mm ²
GF100 Fermi	3,200,000,000 ^[40]	Mar 2010	Nvidia	40 nm	526 mm ²
GF110 Fermi	3,000,000,000 ^[40]	Nov 2010	Nvidia	40 nm	520 mm ²

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GK104 Kepler	3,540,000,000 ^[41]	2012	Nvidia	28 nm	294 mm²
Tahiti	4,312,711,873 ^[42]	2011	AMD	28 nm	365 mm²
GK110 Kepler	7,080,000,000 ^[43]	2012 ^[44]	Nvidia	28 nm	561 mm²
Hawaii	6,300,000,000	2013	AMD	28 nm	438 mm²
GM204 Maxwell	5,200,000,000	2014	Nvidia	28 nm	398 mm²
GM200 Maxwell	8,100,000,000	2015	Nvidia	28 nm	601 mm²
Fiji	8,900,000,000	2015	AMD	28 nm	596 mm²
GP100 Pascal	15,300,000,000 ^[45]	2016	Nvidia	16 nm	610 mm²

FPGA

A field-programmable gate array (FPGA) is an integrated circuit designed to be configured by a customer or a designer after manufacturing.

	FPGA	↕	Transistor count	↕	Date of introduction	↕	Manufacturer	↕	Process	↕	Area	↕
Virtex			~70,000,000		1997		Xilinx					
Virtex-E			~200,000,000		1998		Xilinx					
Virtex-II			~350,000,000		2000		Xilinx		130 nm			
Virtex-II PRO			~430,000,000		2002		Xilinx					
Virtex-4			1,000,000,000		2004		Xilinx		90 nm			
Virtex-5			1,100,000,000 ^[46]		2006		Xilinx		65 nm			
Stratix IV			2,500,000,000 ^[47]		2008		Altera		40 nm			
Stratix V			3,800,000,000 ^[48]		2011		Altera		28 nm			
Virtex-7			6,800,000,000 ^[49]		2011		Xilinx		28 nm			
Virtex-Ultrascale XCVU440			20,000,000,000+ ^[50]		2014		Xilinx		20 nm			
Stratix 10 Family device, 10GX5500/10SX5500			30,000,000,000+ ^[5]		2015		Altera		14 nm			

Logic functions

Transistor count for generic logic functions is based on static CMOS implementation.^[51]

Function	Transistor count
NOT	2
Buffer	4
NAND 2-input	4
NOR 2-input	4
AND 2-input	6
OR 2-input	6
NAND 3-input	6
NOR 3-input	6
XOR 2-input	6
XNOR 2-input	8
MUX 2-input with TG	6
MUX 4-input with TG	18
NOT MUX 2-input	8
MUX 4-input	24
1-bit Adder full	28
1-bit Adder-subtractor	48
AND-OR-INVERT [52]	6
Latch, D gated	8
Flip-flop, edge triggered dynamic D with reset	12
8-bit multiplier[53]	3,000
16-bit multiplier[53]	9,000
32-bit multiplier[54]	21,000
small-scale integration	2–100[55]
medium-scale integration	100–500[55]
large-scale integration	500–20,000[55]
very-large-scale integration	20,000–1,000,000[55]
ultra-large scale integration	>1,000,000

Memory

Semiconductor memory is an electronic data storage device, often used as computer memory, implemented on integrated circuit.

We know that in order to store a single bit (which may be 1 or 0), one flip-flop is required, made of around eight transistors. Typical CMOS Static random-access memory (SRAM) consists of 6 transistors. For Dynamic random-access memory (DRAM), 1T1C, which means one transistor and one capacitor structure is common. Capacitor charged or not is used to store 1 or 0. For flash memory, the data is stored in floating gate, and the resistance of the transistor is sensed to interpret the data stored. Depending on how fine scale the resistance could be separated, one transistor could store up to 3-bits, meaning eight distinctive level of resistance possible per transistor. However, the fine the scale comes with cost of repeatability therefore reliability. Typically, low grade 2-bits MLC flash is used for flash drive, so a 16 GB flash drive contains roughly 64 billion transistors.

Chip	↕	Capacity & type	↕	Transistor count	↕	Date of introduction	↕	Manufacturer	↕	Process	↕	Area
?		256-bit ROM bipolar TTL		?		1965		Sylvania		?		?
?		1024-bit ROM MOS		?		1965		General Microelectronics		?		?
SP95		16-bit SRAM bipolar		?		1965		IBM		?		?
?		128-bit RAM		?		1969		IBM		?		?
		512-bit PROM bipolar TTL		?		1970		Radiation Inc.		?		?
93400		256-bit RAM		?		1970		Fairchild		?		?
1103 ^{[56][57]}		1 kb DRAM		?1,024		1970		Intel		?		?
1702 Erasable PROM		2 kb EPROM		?		1971		Intel		?		?
?		8 Mb DRAM		28,388,608		January 6, 1984 (1986)		Hitachi		?		?
ϕ ^{[58][59]}		64 Mb DRAM		267,108,864		1994		NEC, Samsung		320 nm		?
ϕ ^{[60][61]}		256 Mb DRAM		2268,435,456		June 12, 1995		IBM, SIEMENS AG, Toshiba Corp.		250 nm		286 mm²
ϕ ^[62]		1 Gb DRAM		?1,073,741,824		January 9, 1995 (2001)		Hitachi		?		?
?		64 Gb DRAM		268,719,476,736		2007(9)?		?		?		?
ϕ ^[63]		128 Gb DRAM		?137,438,953,472		July 5, 2012		Samsung		30 nm		?

Parallel systems

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Historically, each processing element in earlier parallel systems—like all CPUs of that time—was a serial computer built out of multiple chips. As transistor counts per chip increases, each processing element could be built out of fewer chips, and then later each multi-core processor chip could contain more processing elements.^[64]

Goodyear MPP: (1983?) 8 pixel processors per chip, 3,000 to 8,000 transistors per chip.^[64]

Brunel University Scape (single-chip array-processing element): (1983) 256 pixel processors per chip, 120,000 to 140,000 transistors per chip.^[64]

Cell Broadband Engine: (2006) 9 cores per chip, 234 million transistors per chip.^[65]

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- Evolution of FPGA Architecture (http://www.xilinx.com/company/press/kits/asmb/asmb_arch_pres.pdf)

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