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64-bit version of x86 architecture "Intel 64" redirects here. For the Intel 64-bit architecture in Itanium chips, see IA-64. "x64" redirects here. For the New York City bus route, see X64 (New York City bus). AMD Opteron, the first CPU to introduce the x86-64 extensions in April 2003 The five-volume set of the x86-64 Architecture Programmer's Manual, as published and distributed by AMD in 2002 x86-64 (also known as x64, x86_64, AMD64, and Intel 64)[note 1] is a 64-bit extension of the x86 instruction set. It was announced in 1999 and first available in the AMD Opteron family in 2003. It introduces two new operating modes: 64-bit mode and compatibility mode, along with a new four-level paging mechanism. In 64-bit mode, x86-64 supports significantly larger amounts of virtual memory and physical memory compared to its 32-bit predecessors, allowing programs to utilize more memory for data storage. The architecture expands the number of general-purpose registers from 8 to 16, all fully general-purpose, and extends their width to 64 bits. Floating-point arithmetic is supported through mandatory SSE2 instructions in 64-bit mode. While the older x86 and x87 registers are still available, they are generally superseded by a set of sixteen 128-bit vector registers (XMM registers). Each of these vector registers can store one of two double-precision floating-point numbers, up to four single-precision floating-point numbers, or 16 32-bit integers. In 64-bit mode, instructions are modified to support 64-bit operations and 64-bit addressing. Mode. The x86-64 architecture is defined as compatibility mode that allows 32-bit user applications to run unmodified alongside 64-bit applications, provided the 64-bit operating system supports them.[11][note 2] Since the full x86-32 instruction sets remain implemented in hardware without the need for emulation, these older executables can run with little or no performance penalty.[13] While newer or modified applications can take advantage of new features of the processor design to achieve performance improvements. Also, processors supporting x86-64 still power on in real mode to maintain backward compatibility with the original 8086 processor, as has been the case with x86 processors since the introduction of protected mode with the 80286. The original specification, created by AMD and released in 2000, has been implemented by AMD, Intel, and VIA. The AMD K8 microarchitecture, in the Opteron and Athlon 64 processors, was the first to implement it. This was the first significant addition to the x86 architecture designed by a company other than Intel. Intel was forced to follow suit and introduced a modified NetBurst family which was software-compatible with AMD's specification. VIA Technologies introduced x86-64 in their VIA Isaiah architecture, with the VIA Nano. The x86-64 architecture was quickly adopted for desktop and laptop personal computers and servers which were commonly configured for 16 GiB (gibibytes) of memory or more. It has effectively replaced the discontinued Intel Itanium architecture (formerly IA-64), which was originally intended to replace the x86 architecture. x86-64 and Itanium are not compatible on the native instruction set level, and operating systems and applications compiled for one architecture cannot be run on the other natively. AMD64 logo AMD64 (also variously referred to by AMD in their literature and documentation as "AMD 64-bit Technology" and "Physical Address Extension") was created as an alternative to the AMD64 name used by Intel and Hewlett-Packard, which was later withdrawn. The AMD64 architecture was positioned by AMD from the beginning as an evolutionary rather than a revolutionary name, to add 64-bit computing capabilities to the existing x86 architecture while supporting legacy 32-bit x86 code as opposed to Intel's approach of creating an entirely new, completely x86-incompatible 64-bit architecture with IA-64. The first AMD64-based processor, the Opteron, was released in April 2003. AMD's processors implementing the AMD64 architecture include Opteron, Athlon 64, Athlon 64 X2, Athlon 64 FX, Athlon II (followed by "X2", "X3", "or "X4" to indicate the number of cores, and XLT models), Turion 64, Turion 64 X2, Sempron ("Palermo" E6 stepping and all "Manila" models), Phenom (followed by "X3" or "X4" to indicate the number of cores), Phenom II (followed by "X2", "X3", "X4" or "X6" to indicate the number of cores), FX, Fusion/APU and Ryzen/Epyc. The primary defining characteristic of AMD64 is the availability of 64-bit general-purpose processor registers (for example, rax), 64-bit integer arithmetic and logical operations, and 64-bit virtual addresses.[16] The designers took the opportunity to make other improvements as well. Notable changes in the 64-bit extensions include: 64-bit integer capability All general-purpose registers (GPRs) are expanded from 32 bits to 64 bits, and all arithmetic and logical operations, memory-to-register and register-to-memory operations, etc., can operate directly on 64-bit integers. Pushes and pops on the stack default to 8-byte strides, and pointers are 8 bytes wide. Additional registers in addition to increasing the size of the general-purpose registers, the number of named general-purpose registers is increased from eight (i.e. eax, ebx, ecx, edx, esi, edi, ebx, esp, ebp) in x86 to 16 (i.e. rax, rcx, rdx, rsi, rdi, rsp, rbp, r8, r9, r10, r11, r12, r13, r14, r15). It is therefore possible to keep more local variables in registers rather than on the stack, and to let registers hold frequently accessed constants.

Registers for small and fast subroutines can be passed in registers to a greater extent than AMD64 still has fewer registers than most RISC instruction sets (e.g. PowerPC has 32 GPRs, 68k has 32 registers, ARM, RISC-V, SPARC, Alpha, Mips, IA-RISCV has 31) or VLIW-like machines such as the Cray T3E (which has 28 registers). However, AMD64 implementation may have far more internal registers than the number of architectural registers exposed by the instruction set (see register renaming). (For example, AMD Zen 1 cores have 168 64-bit integer and 160 128-bit vector floating-point physical internal registers.) Additional XMM (SSE) registers Similarly, the number of 128-bit XMM registers (used for Streaming SIMD instructions) is also increased from 8 to 16. The traditional x87 FPU register stack is not included in the register file size extension in 64-bit mode, compared with the XMM registers used with SSE2, which did get extended. The x87 register stack is not a simple register file although it does allow direct access to individual registers by low cost exchange operations. Larger virtual address space The AMD64 architecture defines a 64-bit virtual address format, of which the low-order 48 bits are used in current implementations.[11]:120 This allows up to 256 TiB (248 bytes) of virtual address space. The architecture definition allows this limit to be raised in future implementations to the full 64 bits,[11]:2,3:13:117:120 extending the virtual address space to 16 EiB (264 bytes).[17] This is compared to just 4 GiB (232 bytes) for the x86.[18] This means that very large files can be operated on by mapping the entire file into the process's address space (which is often much faster than working with file read/write calls), rather than having to map regions of the file into and out of the address space. Larger physical address space The original implementation of the AMD64 architecture implemented 40-bit physical addresses and so could address up to 1 TiB (240 bytes) of RAM.[11]:24 Current implementations of the AMD64 architecture (starting from AMD 10h microarchitecture) extend this to 48-bit physical addresses[19] and therefore can address up to 256 TiB (248 bytes) of RAM. The architecture permits extending this to 52 bits in the future[11]:24[20] (limited by the page table entry format).[11]:131 This would allow addressing of up to a PiB of RAM. For comparison, 32-bit x86 processors are limited to 4 GiB of RAM. Intel has implemented a scheme with a 5-level page table, which allows Intel 64 processors to support 37-bit addresses and, in turn, a 128 PiB virtual address space.[24] Further extensions may allow full 64-bit virtual address space and physical memory with 12-bit page table descriptors and 16- or 21-bit memory offsets for 64 KiB and 2 MiB page allocation sizes; the page table entry would be expanded to 128 bits to support additional hardware flags for page size and virtual address space size.[25] The operating system can also limit the virtual address space. Details, where applicable, are given in the "Operating system compatibility and characteristics" section. Current AMD64 processors support a physical address space of up to 248 bytes of RAM, or 256 TiB.[19] However, as of 2020[update], there were no known x86-64 motherboards that support 256 TiB of RAM.[26][27][28][29][failed verification] The operating system may place additional limits on the amount of RAM that is usable or supported. Details on this point are given in the "Operating system compatibility and characteristics" section of this article. The architecture has two primary modes of operation: long mode and legacy mode. Operating Operating system required[Type of code being run Size (in bits) No. of general-purpose registers Mode Sub-mode Addresses Operands (default in italics) Long mode 64-bit mode 64-bit OS, 64-bit UEFI firmware, or the previous two interacting via a 64-bit firmware's UEFI interface 64-bit 64, 16, 32, 16 32 16 2 Legacy mode Protected mode 16, 16, 32 8 2 Legacy mode Protected mode Bootloader, 32-bit OS, 32-bit UEFI firmware, or the latter two interacting via the firmware's UEFI interface 32-bit 32, 8, 16, 32 8 16-bit protected mode OS 16-bit protected mode 16, 8, 16, 32m 11 8 Virtual 8086 mode 16-bit protected mode or 32-bit OS subset of real mode 16, 8, 16, 32m 11 8 Unreal mode Bootloader or real mode OS real mode 16, 20, 32, 8, 16, 32m 11 8 Real mode Bootloader, real mode OS, or any OS interfacing with a firmware's BIOS interface[30] real mode 20, 21, 8, 16, 32m 11 8 a b c N/A that 16-bit code written for the 80286 and below does not use 32-bit operand instructions. Protected mode 16-bit code written for the 80386 and above can use 32-bit operand instructions. Normally this prefix is used by protected and long mode code for the purpose of using 16-bit operands, as that code would be running in a code segment of size 32 bits. In real mode, the default operand size is 16 bits, so the 0x66 prefix is interpreted differently; changing operand size to 32 bits. State descriptors of the x86-64 operating modes. Main article: Long mode Long mode is the architecture's intended primary mode of operation; it is a combination of the processor's native 64-bit and a combined 32-bit and 16-bit compatibility mode. It is used by 64-bit operating systems. Under a 64-bit operating system, 64-bit programs run under 64-bit mode, and 16-bit protected mode applications (that do not need to use either real mode or virtual 8086 mode in order to execute at any time) run under compatibility mode. Real-mode programs and programs that use virtual 8086 mode at any time cannot be run in long mode unless those modes are emulated in software.[11]:11 However, such programs may be started from an operating system running in long mode on processors supporting VT-x or AMD-V by creating a virtual processor running in the desired mode. Since the basic instruction set is the same, there is almost no performance penalty for executing protected mode x86 code. This is unlike Intel's IA-64, where differences in the underlying instruction set mean that running 32-bit code must be done either in emulation of x86 (making the process slower) or with a dedicated x86 coprocessor. However, on the x86-64 platform, many x86 applications could benefit from a 64-bit recompile, due to the additional registers in 64-bit code and guaranteed SSE2-based FPU support, which a compiler can use for optimization. However, applications that regularly handle integers wider than 32 bits, such as cryptographic algorithms, will need a rewrite of the code handling the huge integers in order to take advantage of the 64-bit registers. Legacy mode is the mode that the processor is in when it is not in long mode.[11]:14 In this mode, the processor acts like an older x86 processor, and only 16-bit and 32-bit code can be executed. Legacy mode allows for a maximum of 32-bit virtual addresses and 4 GiB of virtual RAM. In 2008, Intel 64-bit processors and x86-64 architecture exclude Intel Pentium 4, Pentium D, Pentium E, Pentium G, Pentium H, Pentium J, Pentium K, Pentium L, Pentium M, Pentium N, Pentium Q, Pentium R, Pentium S, Pentium T, Pentium U, Pentium V, Pentium W, Pentium X, Pentium Y, Pentium Z, Pentium AA, Pentium AB, Pentium AC, Pentium AD, Pentium AE, Pentium AF, Pentium AG, Pentium AH, Pentium AI, Pentium AJ, Pentium AK, Pentium AL, Pentium AM, Pentium AN, Pentium AO, Pentium AP, Pentium AQ, Pentium AR, Pentium AS, Pentium AT, Pentium AU, Pentium AV, Pentium AW, Pentium AX, Pentium AY, Pentium AZ, Pentium BA, Pentium BB, Pentium BC, Pentium BD, Pentium BE, Pentium BF, Pentium BG, Pentium BH, Pentium BI, Pentium BJ, Pentium BK, Pentium BL, Pentium BM, Pentium BN, Pentium BO, Pentium BP, Pentium BQ, Pentium BR, Pentium BS, Pentium BT, Pentium BU, Pentium BV, Pentium BW, Pentium BX, Pentium BY, Pentium BZ, Pentium CA, Pentium CB, Pentium CC, Pentium CD, Pentium CE, Pentium CF, Pentium CG, Pentium CH, Pentium CI, Pentium CJ, Pentium CK, Pentium CL, Pentium CM, Pentium CN, Pentium CO, Pentium CP, Pentium CQ, Pentium CR, Pentium CS, Pentium CT, Pentium CU, Pentium CV, Pentium CW, Pentium CX, Pentium CY, Pentium CZ, Pentium DA, Pentium DB, Pentium DC, Pentium DD, Pentium DE, Pentium DF, Pentium DG, Pentium DH, Pentium DI, Pentium DJ, Pentium DK, Pentium DL, Pentium DM, Pentium DN, Pentium DO, Pentium DP, Pentium DQ, Pentium DR, Pentium DS, Pentium DT, Pentium DU, Pentium DV, Pentium DW, Pentium DX, Pentium DY, Pentium DZ, Pentium EA, Pentium EB, Pentium EC, Pentium ED, Pentium EE, Pentium EF, Pentium EG, Pentium EH, Pentium EI, Pentium EJ, Pentium EK, Pentium EL, Pentium EM, Pentium EN, Pentium EO, Pentium EP, Pentium EQ, Pentium ER, Pentium ES, Pentium ET, Pentium EU, Pentium EV, Pentium EW, Pentium EX, Pentium EY, Pentium EZ, Pentium FA, Pentium FB, Pentium FC, Pentium FD, Pentium FE, Pentium FF, Pentium FG, Pentium FH, Pentium FI, Pentium FJ, Pentium FK, Pentium FL, Pentium FM, Pentium FN, Pentium FO, Pentium FP, Pentium FQ, Pentium FR, Pentium FS, Pentium FT, Pentium FU, Pentium FV, Pentium FW, Pentium FX, Pentium FY, Pentium FZ, Pentium GA, Pentium GB, Pentium GC, Pentium GD, Pentium GE, Pentium GF, Pentium GH, Pentium GI, Pentium GJ, Pentium GK, Pentium GL, Pentium GM, Pentium GN, Pentium GO, Pentium GP, Pentium GQ, Pentium GR, Pentium GS, Pentium GT, Pentium GU, Pentium GV, Pentium GW, Pentium GX, Pentium GY, Pentium GZ, Pentium HA, Pentium HB, Pentium HC, Pentium HD, Pentium HE, Pentium HF, Pentium HG, Pentium HH, Pentium HI, Pentium HJ, Pentium HK, Pentium HL, Pentium HM, Pentium HN, Pentium HO, Pentium HP, Pentium HQ, Pentium HR, Pentium HS, Pentium HT, Pentium HU, Pentium HV, Pentium HW, Pentium HX, Pentium HY, Pentium HZ, Pentium IA, Pentium IB, Pentium IC, Pentium ID, Pentium IE, Pentium IF, Pentium IG, Pentium IH, Pentium II, Pentium IJ, Pentium IK, Pentium IL, Pentium IM, Pentium IN, Pentium IO, Pentium IP, Pentium IQ, Pentium IR, Pentium IS, Pentium IT, Pentium IU, Pentium IV, Pentium IW, Pentium IX, Pentium IY, Pentium IZ, Pentium JA, Pentium JB, Pentium JC, Pentium JD, Pentium JE, Pentium JF, Pentium JG, Pentium JH, Pentium JI, Pentium JJ, Pentium JK, Pentium JL, Pentium JM, Pentium JN, Pentium JO, Pentium JP, Pentium JQ, Pentium JR, Pentium JS, Pentium JT, Pentium JU, Pentium JV, Pentium JW, Pentium JX, Pentium JY, Pentium JZ, Pentium KA, Pentium KB, Pentium KC, Pentium KD, Pentium KE, Pentium KF, Pentium KG, Pentium KH, Pentium KI, Pentium KJ, Pentium KK, Pentium KL, Pentium KM, Pentium KN, Pentium KO, Pentium KP, Pentium KQ, Pentium KR, Pentium KS, Pentium KT, Pentium KU, Pentium KV, Pentium KW, Pentium KX, Pentium KY, Pentium KZ, Pentium LA, Pentium LB, Pentium LC, Pentium LD, Pentium LE, Pentium LF, Pentium LG, Pentium LH, Pentium LI, Pentium LJ, Pentium LK, Pentium LL, Pentium LM, Pentium LN, Pentium LO, Pentium LP, Pentium LQ, Pentium LR, Pentium LS, Pentium LT, Pentium LU, Pentium LV, Pentium LW, Pentium LX, Pentium LY, Pentium LZ, Pentium MA, Pentium MB, Pentium MC, Pentium MD, Pentium ME, Pentium MF, Pentium MG, Pentium MH, Pentium MI, Pentium MJ, Pentium MK, Pentium ML, Pentium MM, Pentium MN, Pentium MO, Pentium MP, Pentium MQ, Pentium MR, Pentium MS, Pentium MT, Pentium MU, Pentium MV, Pentium MW, Pentium MX, Pentium MY, Pentium MZ, Pentium NA, Pentium NB, Pentium NC, Pentium ND, Pentium NE, Pentium NF, Pentium NG, Pentium NH, Pentium NI, Pentium NJ, Pentium NK, Pentium NL, Pentium NM, Pentium NO, Pentium NP, Pentium NQ, Pentium NR, Pentium NS, Pentium NT, Pentium NU, Pentium NV, Pentium NW, Pentium NX, Pentium NY, Pentium NZ, Pentium OA, Pentium OB, Pentium OC, Pentium OD, Pentium OE, Pentium OF, Pentium OG, Pentium OH, Pentium OI, Pentium OJ, Pentium OK, Pentium OL, Pentium OM, Pentium ON, Pentium OO, Pentium OP, Pentium OQ, Pentium OR, Pentium OS, Pentium OT, Pentium OU, Pentium OV, Pentium OW, Pentium OX, Pentium OY, Pentium OZ, Pentium PA, Pentium PB, Pentium PC, Pentium PD, Pentium PE, Pentium PF, Pentium PG, Pentium PH, Pentium PI, Pentium PJ, Pentium PK, Pentium PL, Pentium PM, Pentium PN, Pentium PO, Pentium PP, Pentium PQ, Pentium PR, Pentium PS, Pentium PT, Pentium PU, Pentium PV, Pentium PW, Pentium PX, Pentium PY, Pentium PZ, Pentium QA, Pentium QB, Pentium QC, Pentium QD, Pentium QE, Pentium QF, Pentium QG, Pentium QH, Pentium QI, Pentium QJ, Pentium QK, Pentium QL, Pentium QM, Pentium QN, Pentium QO, Pentium QP, Pentium QQ, Pentium QR, Pentium QS, Pentium QT, Pentium QU, Pentium QV, Pentium QW, Pentium QX, Pentium QY, Pentium QZ, Pentium RA, Pentium RB, Pentium RC, Pentium RD, Pentium RE, Pentium RF, Pentium RG, Pentium RH, Pentium RI, Pentium RJ, Pentium RK, Pentium RL, Pentium RM, Pentium RN, Pentium RO, Pentium RP, Pentium RQ, Pentium RR, Pentium RS, Pentium RT, Pentium RU, Pentium RV, Pentium RW, Pentium RX, Pentium RY, Pentium RZ, Pentium SA, Pentium SB, Pentium SC, Pentium SD, Pentium SE, Pentium SF, Pentium SG, Pentium SH, Pentium SI, Pentium SJ, Pentium SK, Pentium SL, Pentium SM, Pentium SN, Pentium SO, Pentium SP, Pentium SQ, Pentium SR, Pentium SS, Pentium ST, Pentium SU, Pentium SV, Pentium SW, Pentium SX, Pentium SY, Pentium SZ, Pentium TA, Pentium TB, Pentium TC, Pentium TD, Pentium TE, Pentium TF, Pentium TG, Pentium TH, Pentium TI, Pentium TJ, Pentium TK, Pentium TL, Pentium TM, Pentium TN, Pentium TO, Pentium TP, Pentium TQ, Pentium TR, Pentium TS, Pentium TU, Pentium TV, Pentium TW, Pentium TX, Pentium TY, Pentium TZ, Pentium UA, Pentium UB, Pentium UC, Pentium UD, Pentium UE, Pentium UF, Pentium UG, Pentium UH, Pentium UI, Pentium UJ, Pentium UK, Pentium UL, Pentium UM, Pentium UN, Pentium UO, Pentium UP, Pentium UQ, Pentium UR, Pentium US, Pentium UT, Pentium UV, Pentium UW, Pentium UX, Pentium UY, Pentium UZ, Pentium VA, Pentium VB, Pentium VC, Pentium VD, Pentium VE, Pentium VF, Pentium VG, Pentium VH, Pentium VI, Pentium VJ, Pentium VK, Pentium VL, Pentium VM, Pentium VN, Pentium VO, Pentium VP, Pentium VQ, Pentium VR, Pentium VS, Pentium VT, Pentium VU, Pentium VV, Pentium VW, Pentium VX, Pentium VY, Pentium VZ, Pentium WA, Pentium WB, Pentium WC, Pentium WD, Pentium WE, Pentium WF, Pentium WG, Pentium WH, Pentium WI, Pentium WJ, Pentium WK, Pentium WL, Pentium WM, Pentium WN, Pentium WO, Pentium WP, Pentium WQ, Pentium WR, Pentium WS, Pentium WT, Pentium WU, Pentium WV, Pentium WX, Pentium WY, Pentium WZ, Pentium XA, Pentium XB, Pentium XC, Pentium XD, Pentium XE, Pentium XF, Pentium XG, Pentium XH, Pentium XI, Pentium XJ, Pentium XK, Pentium XL, Pentium XM, Pentium XN, Pentium XO, Pentium XP, Pentium XQ, Pentium XR, Pentium XS, Pentium XT, Pentium XU, Pentium XV, Pentium XW, Pentium XY, Pentium XZ, Pentium YA, Pentium YB, Pentium YC, Pentium YD, Pentium YE, Pentium YF, Pentium YG, Pentium YH, Pentium YI, Pentium YJ, Pentium YK, Pentium YL, Pentium YM, Pentium YN, Pentium YO, Pentium YP, Pentium YQ, Pentium YR, Pentium YS, Pentium YT, Pentium YU, Pentium YV, 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Pentium LR, Pentium LS, Pentium LT, Pentium LU, Pentium LV, Pentium LW, Pentium LX, Pentium LY, Pentium LZ, Pentium MA, Pentium MB, Pentium MC, Pentium MD, Pentium ME, Pentium MF, Pentium MG, Pentium MH, Pentium MI, Pentium MJ, Pentium MK, Pentium ML, Pentium MM, Pentium MN, Pentium MO, Pentium MP, Pentium MQ, Pentium MR, Pentium MS, Pentium MT, Pentium MU, Pentium MV, Pentium MW, Pentium MX, Pentium MY, Pentium MZ, Pentium NA, Pentium NB, Pentium NC, Pentium ND, Pentium NE, Pentium NF, Pentium NG, Pentium NH, Pentium NI, Pentium NJ, Pentium NK, Pentium NL, Pentium NM, Pentium NO, Pentium NP, Pentium NQ, Pentium NR, Pentium NS, Pentium NT, Pentium NU, Pentium NV, Pentium NW, Pentium NX, Pentium NY, Pentium NZ, Pentium OA, Pentium OB, Pentium OC, Pentium OD, Pentium OE, Pentium OF, Pentium OG, Pentium OH, Pentium OI, Pentium OJ, Pentium OK, Pentium OL, Pentium OM, Pentium ON, Pentium OP, Pentium OQ, Pentium OR, Pentium OS, Pentium OT, Pentium OU, Pentium OV, Pentium OW, Pentium OX, 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