

Haswell (microarchitecture)

This article is about the Intel microarchitecture. For other uses, see [Haswell](#).

Haswell is the codename for a processor microarchitecture developed by Intel as the “fourth-generation core” successor to the Ivy Bridge microarchitecture.^[1] Intel officially announced CPUs based on this microarchitecture on June 4, 2013 at Computex Taipei 2013,^[2] while a working Haswell chip was demonstrated at the 2011 Intel Developer Forum.^[3] With Haswell, which uses a 22 nm process,^[4] Intel also introduced low-power processors designed for convertible or “hybrid” ultrabooks, designated by the “Y” suffix.

Haswell CPUs are used in conjunction with the Intel 8 Series chipsets, Intel 9 Series chipsets, and Intel C220 series chipsets.

1 Design

The Haswell architecture is specifically designed^[5] to optimize the power savings and performance benefits from the move to FinFET (non-planar, “3D”) transistors on the improved 22 nm process node.^[6]

Haswell has been launched in three major forms:^[7]

- Desktop version (LGA 1150 socket and the new LGA 2011-v3 socket): *Haswell-DT*
- Mobile/Laptop version (PGA socket): *Haswell-MB*
- BGA version:
 - 47 W and 57 W TDP classes: *Haswell-H* (for “All-in-one” systems, Mini-ITX form factor motherboards, and other small footprint formats)
 - 13.5 W and 15 W TDP classes (MCP): *Haswell-ULT* (for Intel’s UltraBook platform)
 - 10 W TDP class (SoC): *Haswell-ULX* (for tablets and certain UltraBook-class implementations)

1.1 Notes

- ULT = *Ultra Low TDP*; ULX = *Ultra Low eXtreme TDP*

- Only certain quad-core variants and BGA R-series stock keeping units (SKUs) receive GT3e (Intel Iris Pro 5200) integrated graphics. All other models have GT3 (Intel HD 5000 or Intel Iris 5100), GT2 (Intel HD 4200, 4400, 4600, P4600 or P4700) or GT1 (Intel HD Graphics) integrated graphics.^[8] See also Intel HD and Iris Graphics for more details.
- Due to the low power requirements of tablet and UltraBook platforms, Haswell-ULT and Haswell-ULX are only available in dual-core configurations. All other versions come as dual- or quad-core variants.

1.2 Performance

Compared to Ivy Bridge:

- Approximately 8% faster vector processing^[9]
- Up to 5% faster single-threaded performance
- 6% faster multi-threaded performance
- Desktop variants of Haswell draw between 8% and 23% more power under load than Ivy Bridge.^{[9][10][11]}
- A 6% increase in sequential CPU performance (eight execution ports per core versus six)^[9]
- Up to 20% performance increase over the integrated HD4000 GPU (Haswell HD4600 vs Ivy Bridge’s built-in Intel HD4000)^[9]
- Total performance improvement on average is about 3%^[9]
- Around 15 °C hotter than Ivy Bridge, while clock frequencies of over 4.6 GHz are achievable^{[12][13][14][15][16][17]}

2 Technology

See also: Intel HD Graphics

2.1 Features carried over from Ivy Bridge

- 22 nm manufacturing process^[4]

- 3D tri-gate transistors^[18]
- Micro-operation cache (Uop Cache) capable of storing 1.5 K micro-operations (approximately 6 KB in size)^[19]
- 14- to 19-stage instruction pipeline, depending on the micro-operation cache hit or miss (an approach used in the even earlier Sandy Bridge microarchitecture)^[19]
- Mainstream variants are up to quad-core.^[20]
- Native support for dual-channel DDR3 memory,^[21] with up to 32 GB of RAM on LGA 1150 variants
- 64 KB (32 KB Instruction + 32 KB Data) L1 cache and 256 KB L2 cache per core^[22]
- A total of 16 PCI Express 3.0 lanes on LGA 1150 variants^[23]

2.2 New features

- Wider core: fourth arithmetic logic unit (ALU), third address generation unit (AGU),^{[24][25][26]} second branch execution unit, deeper buffers, higher cache bandwidth, improved front-end and memory controller, higher load/store bandwidth.
- New instructions^[27] (HNI, includes Advanced Vector Extensions 2 (AVX2), gather, BMI1, BMI2, ABM and FMA3 support).^[28]
- The instruction decode queue, which holds instructions after they have been decoded, is no longer statically partitioned between the two threads that each core can service.^[19]
- New sockets and chipsets:
 - LGA 1150 for desktops, and rPGA947 and BGA1364 for the mobile market.^[29]
 - Z97 (performance) and H97 (mainstream) chipsets for the Haswell Refresh and Broadwell, in Q2 2014.^[30]
 - LGA 2011-v3 with X99 chipset for the enthusiast-class desktop platform *Haswell-E*.^[31]
- Intel Transactional Synchronization Extensions (TSX) for the Haswell-EX variant. In August 2014 Intel announced that a bug exists in the TSX implementation on the current *steppings* of Haswell, Haswell-E, Haswell-EP and early Broadwell CPUs, which resulted in disabling the TSX feature on affected CPUs via a microcode update.^{[32][33][34][35]}
- Hardware graphics support for Direct3D 11.1 and OpenGL 4.3.^{[36][37][38]} Intel 10.18.14.4578 driver is the last planned driver release on Windows 7/8.1.^[39]
- DDR4 for the enthusiast and enterprise/server segments^[40] and for the Enthusiast-Class Desktop Platform Haswell-E^[41]
- Variable Base clock (BCLK)^[42] like LGA 2011.^[43]
- Four versions of the integrated GPU: GT1, GT2, GT3 and GT3e, where GT3 version has 40 execution units (EUs). Haswell's predecessor, Ivy Bridge, has a maximum of 16 EUs. GT3e version with 40 EUs and on-package 128 MB of embedded DRAM (eDRAM), called *Crystalwell*, is available only in mobile H-SKUs and desktop (BGA-only) R-SKUs. Effectively, this eDRAM is a Level 4 cache; it is shared dynamically between the on-die GPU and CPU, and serving as a victim cache to the CPU's Level 3 cache.^{[44][45][46][47][48]}
- Optional support for Thunderbolt technology and Thunderbolt 2.0^{[49][50]}
- Fully integrated voltage regulator (FIVR), thereby moving some of the components from motherboard onto the CPU.^{[51][52][53]}
- New advanced power-saving system; due to Haswell's new low-power C6 and C7 sleep states, not all power supply units (PSUs) are suitable for computers with Haswell CPUs.^{[54][55]}
- 37, 47, 57 W thermal design power (TDP) mobile processors.^[20]
- 35, 45, 65, 84, 88, 95 and 130–140 W (high-end, Haswell-E) TDP desktop processors.^[20]
- 15 W or 11.5W TDP processors for the Ultrabook platform (multi-chip package like *Westmere*)^[56] leading to reduced heat, which results in thinner as well as lighter Ultrabooks, but the performance level is slightly lower than the 17 W version.^[57]
- Shrink of the Platform Controller Hub (PCH), from 65 nm to 32 nm.^[58]

2.3 Server processors features

- Haswell-EP variant, released in September 2014, with up to 18 cores and marketed as the Xeon E5-1600 v3 and Xeon E5-2600 v3 series.^[61]
- Haswell-EX variant is expected to be released in 2015, with 18 cores and functioning TSX.^{[34][62]}
- A new cache design.
- Up to 35 MB total unified cache (last level cache, LLC) for Haswell-EP^[63] and up to 40 MB for Haswell-EX.

- LGA 2011-v3 socket replaces LGA 2011 for the Haswell EP; the new socket has the same number of pins, but it is keyed differently due to electrical incompatibility.^{[64][65][66]}
- The already launched Xeon E3 v3 Haswells will get a refresh in spring 2014,^[67] together with a refreshed Intel C220 series PCH chipset.^[68]
- TDP up to 160 W for Haswell-EP.^[69]
- Haswell-EP models with ten and more cores support *cluster on die* (COD) operation mode,^[70] allowing CPU's multiple columns of cores and last level cache (LLC) slices to be logically divided into what is presented as two non-uniform memory access (NUMA) CPUs to the operating system. By keeping data and instructions local to the "partition" of CPU which is processing them, therefore decreasing the LLC access latency, COD brings performance improvements to NUMA-aware operating systems and applications.^[71]

2.4 Haswell Refresh

Around the middle of 2014, Intel released a refresh of Haswell, simply titled *Haswell Refresh*. When compared to the original Haswell CPUs lineup, Haswell Refresh CPUs offer a modest increase in clock frequencies, usually of 100 MHz.^[72] Haswell Refresh CPUs are supported by Intel's 9 Series chipsets (Z97 and H97, codenamed *Wildcat Point*), while motherboards with 8 Series chipsets (codenamed *Lynx Point*) usually require a BIOS update to support Haswell Refresh CPUs.^[73]

The CPUs codenamed *Devil's Canyon*, covering the i5 and i7 K-series SKUs, employ a new and improved thermal interface material (TIM) called next-generation polymer thermal interface material (NGPTIM). This improved TIM reduces the CPU's operating temperatures and improves the overclocking potential, as something that had been problematic since the introduction of Ivy Bridge.^[74] Other changes for the Devil's Canyon CPUs include a TDP increase to 88 W, additional decoupling capacitors to help smooth out the outputs from the fully integrated voltage regulator (FIVR), and support for the VT-d that was previously limited to non-K-series SKUs.^[75] TSX was another feature brought over from the non-K-series SKUs, until August 2014 when a microcode update disabled TSX due to a bug that was discovered in its implementation.^{[34][35]}

3 List of Haswell processors

3.1 Desktop processors

- All models support: *MMX*, *SSE*, *SSE2*, *SSE3*, *SSSE3*, *SSE4.1*, *SSE4.2*, *F16C*, *Enhanced Intel SpeedStep*



Intel Haswell i7-4771 CPU, sitting atop its original packaging that contains an OEM fan-cooled heatsink

Technology (EIST), Intel 64, XD bit (an NX bit implementation), Intel VT-x, and Smart Cache.

- Core i3, i5 and i7 support *AVX*, *AVX2*, *BMI1*, *BMI2*, *FMA3*, and *AES-NI*.^[76]
- Core i3 and i7, as well as the Core i5-4570T and i5-4570TE, support *hyper-threading* (HT).^[76]
- Core i5 and i7 support *Turbo Boost 2.0*.^[76]
- Although it was initially supported on selected models, since August 2014 desktop variants no longer support *TSX* due to a bug that was discovered in its implementation; as a workaround, a microcode update disabled the TSX feature.^{[32][34][35][76]}
- SKUs below 45xx as well as R-series and K-series SKUs do not support *Trusted Execution Technology* or *vPro*.^[76]
- *Intel VT-d*, which is Intel's *IOMMU*, is supported on all i5 and i7 "non-K" SKUs and on most, but not all, i5 and i7 "K" SKUs. Two "K" SKUs without VT-d support are the i5-4670K and i7-4770K.^{[76][77][78]} Support for VT-d requires the chipset and motherboard to also support VT-d.
- Models i5-4690K and i7-4790K, codenamed Devil's Canyon, have a better internal *thermal grease* to help heat escape and an improved internal *voltage regulator* ("FIVR"), to help deliver clean power in extreme situations like overclocking.

- Transistors: 1.4 billion^{[79][80]}

- Die size: 177 mm²^[79]

- Intel HD and Iris Graphics in following variants:

- R-series desktop processors feature Intel Iris Pro 5200 graphics (GT3e).^[81]

- All other currently known i3, i5 and i7 desktop processors include Intel HD 4600 graphics (GT2).^[82]
- The exceptions are processors 41xxx, which include HD 4400 graphics (GT2).
- Celeron and Pentium processors contain Intel HD Graphics (GT1).
- Pentium G3258, also known as the *Pentium Anniversary Edition*, has an unlocked multiplier and is highly overclockable. Its release marks 20 years of “Pentium” as a brand.^[83]

The following table lists available desktop processors.

^a Some of these configurations could be disabled by the chipset. For example, H-series chipsets disable all PCIe 3.0 lane configurations except 1×16.

^b This feature also requires a chipset that supports VT-d like the Q87 chipset or the X99 chipset.

^c This is called *20th Anniversary Edition* and has an unlocked multiplier.

SKU suffixes to denote:

- K – unlocked (adjustable CPU multiplier up to 63x)
- S – performance-optimized lifestyle (low power with 65 W TDP)
- T – power-optimized lifestyle (ultra low power with 35–45 W TDP)
- R – BGA packaging / High-performance GPU (currently Iris Pro 5200 (GT3e))
- X – extreme performance (adjustable CPU ratio with no ratio limit)

3.2 Server processors



Intel Xeon E3-1241 v3 CPU, on top of its original packaging with an OEM fan-cooled heatsink



Intel Xeon E5-1650 v3 CPU; its retail box contains no OEM heatsink

- All models support: *MMX, SSE, SSE2, SSE3, SSSE3, SSE4.1, SSE4.2, AVX (Advanced Vector Extensions), AVX2, FMA3, F16C, BMI (Bit Manipulation Instructions 1)+BMI2, Enhanced Intel SpeedStep Technology (EIST), Intel 64, XD bit (an NX bit implementation), TXT, Intel vPro, Intel VT-x, Intel VT-d, hyper-threading (except E3-1220 v3 and E3-1225 v3), Turbo Boost 2.0, AES-NI, and Smart Cache.*
- Haswell-EX models (E7-48xx/88xx v3) support *TSX*, while for Haswell-E, Haswell-WS (E3-12xx v3) and Haswell-EP (E5-16xx/26xx v3) models it was disabled via a microcode update in August 2014, due to a bug that was discovered in the TSX implementation.^{[34][35]}
- Transistors: 5.56 billion^[88]
- Die size: 661 mm²^[88]

The first digit of the model number designates the largest supported multi-socket configuration; thus, E5-26xx v3 models support up to dual-socket configurations, while the E7-48xx v3 and E7-88xx v3 models support up to quad- and eight-socket configurations, respectively. Also, E5-16xx/26xx v3 and E7-48xx/88xx v3 models have no integrated GPU.

Lists of launched server processors are below, split between Haswell E3-12xx v3, E5-16xx/26xx v3 and E7-48xx/88xx v3 models.

SKU suffixes to denote:

- L – low power

3.3 Mobile processors

- All models support: *MMX, SSE, SSE2, SSE3, SSSE3, SSE4.1, SSE4.2, F16C, Enhanced Intel SpeedStep Technology (EIST), Intel VT-x, Intel 64, XD bit (an NX bit implementation), and Smart Cache.*
- Core i3, i5 and i7 support *AVX, AVX2, BMI1, BMI2, FMA3, and hyper-threading (HT).*
- Core i3, i5 and i7 except the Core i3-4000M support *AES-NI*.^[93]

- Core i5 and i7 except the Core i5-4410E, i5-4402EC, i7-4700EC, and i7-4702EC support *Turbo Boost 2.0*.
- Platform Controller Hub (PCH) integrated into the CPU package, slightly reducing the amount of space used on motherboards.^[94]
- Transistors: 1.3 billion^[95]
- Die size: 181 mm²^[95]

The following table lists available mobile processors.

1. When a cooler or quieter mode of operation is desired, this mode specifies a lower TDP and lower guaranteed frequency versus the nominal mode.^{[96]:71–72}
2. This is the processor's rated frequency and TDP.^{[96]:71–72}
3. When extra cooling is available, this mode specifies a higher TDP and higher guaranteed frequency versus the nominal mode.^{[96]:71–72}

SKU suffixes to denote:

- M – mobile processor (Socket G3)
- Q – quad-core
- U – ultra-low power (BGA1168 packaging)
- X – “extreme”
- Y – extreme low-power (BGA1168 packaging)
- E / H – BGA1364 packaging

4 See also

- LGA 1150: Original Haswell chipsets
- List of Intel chipsets
- List of Intel CPU microarchitectures

5 Notes

- [1] Implemented as eDRAM and serving primarily to increase the performance of integrated GPU, while being shared with the CPU.
- [2] Maximum QPI speed depends on the CPU model.
- [3] Unconfirmed details may differ from surrounding models

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- [96] “4th Generation Intel Core processor based on Mobile M-Processor and H-Processor Lines Datasheet, Volume 1 of 2” (PDF). *Intel.com*. December 2013. Retrieved 2013-12-22. Configurable TDP (cTDP) and Low-Power Mode (LPM) form a design vector where the processor behavior and package TDP are dynamically adjusted to a desired system performance and power envelope. [...] With cTDP, the processor is now capable of altering the maximum sustained power with an alternate guaranteed frequency. Configurable TDP allows operation in situations where extra cooling is available or situations where a cooler and quieter mode of operation is desired.
- [97] “The technical details behind Intel’s 7 Watt Ivy Bridge CPUs”. *Arstechnica.com*. 2013-01-14. Retrieved 2013-12-22. If the CPU needs to work hard for an extended period of time and the laptop gets warmer, it will slowly ramp down its speed until it’s operating at its stated TDP. [...] There are two OEM-configurable “power level” states that define how quick the CPU can be in these situations: PL2 tells the processor how much power it’s allowed to use when it needs a short burst of speed, and PL1 defines how quickly the processor can run under sustained load. [...] This is at the heart of what Intel is doing with the Y-series processors: their maximum TDP has been lowered four watts, from 17 to 13. Intel is also validating them for use at two lower PL1 values: 10 watts and 7 watts. This is where the marketing we discussed earlier comes in—rather than keeping these values under the covers as it has so far been content to do, Intel has taken that lowest value, put it on its product pages, and called it SDP.
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7 External links

- “Intel Haswell Architecture Disclosure: Live Blog”. *AnandTech*. September 11, 2012.
- “4th Generation of Core Microarchitecture: Intel Haswell”. *X-bit labs*. September 12, 2012.

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8.1 Text

- **Haswell (microarchitecture)** *Source:* [https://en.wikipedia.org/wiki/Haswell_\(microarchitecture\)?oldid=779798088](https://en.wikipedia.org/wiki/Haswell_(microarchitecture)?oldid=779798088) *Contributors:* Nealmcb, Ixfd64, Mearling, Ronz, Med, Conti, Ehn, Thue, Bevo, Ancheta Wis, Axeman, Lethe, Alexander.stohr, Rchandra, Phongn, Uzume, Ary29, DmitryKo, Thorwald, FT2, Bender235, Guy Harris, Yamla, Axl, Ronark, SidP, Gwking, GregorB, Xsecret~enwiki, Vossanova, Calebrw, Bubba73, Jeff02, Nicapicella, Dadu~enwiki, RussBot, WritersCramp, Cwllq, Ondenc, Loonquawl, Anetode, Voidxor, Garion96, SmackBot, Colinstu, Reedy, Timeshifter, Chuhangjin, Edmundgreen, Chris the speller, QTCaptain, Thumperward, Frap, Alphathon, Dillona, Martijn Hoekstra, A5b, JzG, Wislam, Davidlark, Joffeloff, Hvn0413, Jankratochvil, Nicoli nicolovich, MFago, Raysonho, Jesse Viviano, Vatech09, Safalra, Cydebot, W.F.Galway, Thijs!bot, Louis Waweru, James086, Uruiamme, Hexeon, Wideofox, Carewolf, Cyclonius, Arch dude, Magioladitis, C0d1f1ed, NoErr, FarbrorJoakim, KohanX, VolkovBot, Echrei, David.bar, John2213, BwDraco, Razvan NEAGOE, Wingedsubmariner, Haseo9999, Webmeischda~enwiki, Minimac93, Artem-S-Tashkinov, ParallelWolverine, Oldag07, Sakkura, SilverbackNet, Johan nl, Alik Kirillovich, Aducci, Wikievil666, Plastikspork, Area256, Niceguyedc, Gu1dry, BlueLikeYou, Mewtu, XLinkBot, Timoka10, Dsimic, Addbot, Razr Nation, Ramu50, Jchap1590, Birdmanyen, Jasper Deng, Compaq999, Skilltim, Matthew Anthony Smith, BeardWand, Yobot, Thomasxstewart, AnomieBOT, Götz, DarkLight748, Citation bot, Jeremonkey, Phistuck, Xqbot, UnknownMathematician, Friederbluemle, Thehelpfulbot, CHR15x94, FrescoBot, Lonaowna, Thegreymouser, Ballyweg, HRoestBot, Tanweer Morshed, Tom.Reding, Tcnuk, JoonaZZ, Diblidabliduu, Crackwitz, Ale And Quail, Cmpxchg8b, Tonyhallmailbox, Visite fortuitement prolongée, MoreNet, מִיכָאֵל טַינְטַס, Tyntas, XJDHDR, RjwilmsiBot, Borandi, EmausBot, Banks1990, Dewritech, ZéroBot, AbigwikiFan, ArachanoxReal, H3llBot, SporkBot, Xxxxxls2, Zee991, Azul120, Mark Martinec, Unibrow1994, ClueBot NG, Wikinium, BroderickAU, Rockycrab, VanishedUser sdu8asdasd, Jyro117, Helpful Pixie Bot, Electriccatfish2, Terryrusso, BG19bot, Satusguy, Meustrus, Trevayne08, Longerbiggestronger, Strz4life, SS1901, BattyBot, DrEVILish, Chrkv, Joey2250, Øx, DualSignal, Rviktork, Teamkillervt, Btwarren, Democrab, RMCD bot, Wario-Man, Dbussanich, JS987654, Wcrlewis, CentrallyProcessed, Tyream, DigitalSteel, Kostal.david8, Comp.arch, Erikjac, Daethz, Someone not using his real name, Oranjelo100, Jianhui67, Paper9oll, ScotXW, Dark Mistress, LMY441900, Monkbot, Chessfan4, ChamithN, IruDog, Akinwiki, StePAhi, Veswild, Vimacs, Feminist, HuangHe THATIC, IBugOne, Bender the Bot, Laurdecl and Anonymous: 431

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