PC GAMER PRESENTS

NEW & UPDATED

PC HARDWARE HANDBOOK

60 PAGES OF GUIDES

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FROM GRAPHICS OPTIONS TO PROTECTING YOUR TECH: ALL THE ADVICE YOU NEED

52 PAGES OF HARDWARE REVIEWS *INSIDE!*

BUILD THE BEST PC FOR YOUR BUDGET

Digital Edition

FUTURE

SEVENTH EDITION

REVIEWED CPUs | KEYBOARDS | GRAPHICS CARDS | MOTHERBOARDS | SSDs | MONITORS | EARBUDS | CASES

WELCOME TO

PC GAMER
PRESENTS

PC HARDWARE HANDBOOK

With the seemingly endless number of products to choose from, building and upgrading a PC can seem like a daunting task. That's why, on these pages, you'll find all the essential info you need to build and/or upgrade your own rig. Whether you're looking to switch out components to give yourself a performance boost ahead of the next slew of AAA games, or you're going to simply bite the bullet and put together a whole new rig, we've got the lowdown on the latest high-end kit, as well as budget and mid-range offerings that won't break the bank. If you're completely new to the idea of building a PC, we've included a jargon buster to teach you all of the terms used throughout this book, and by retailers or manufacturers. If you want to know the best products on the market today, we've got you covered with reviews and head to heads covering components and peripherals, as well as a buyer's guide for three different price ranges. From processors, motherboards and graphics cards to keyboards, gaming earbuds and OLED monitors, discover everything you need to create your dream machine.

FUTURE

PC GAMER PRESENTS

PC HARDWARE HANDBOOK

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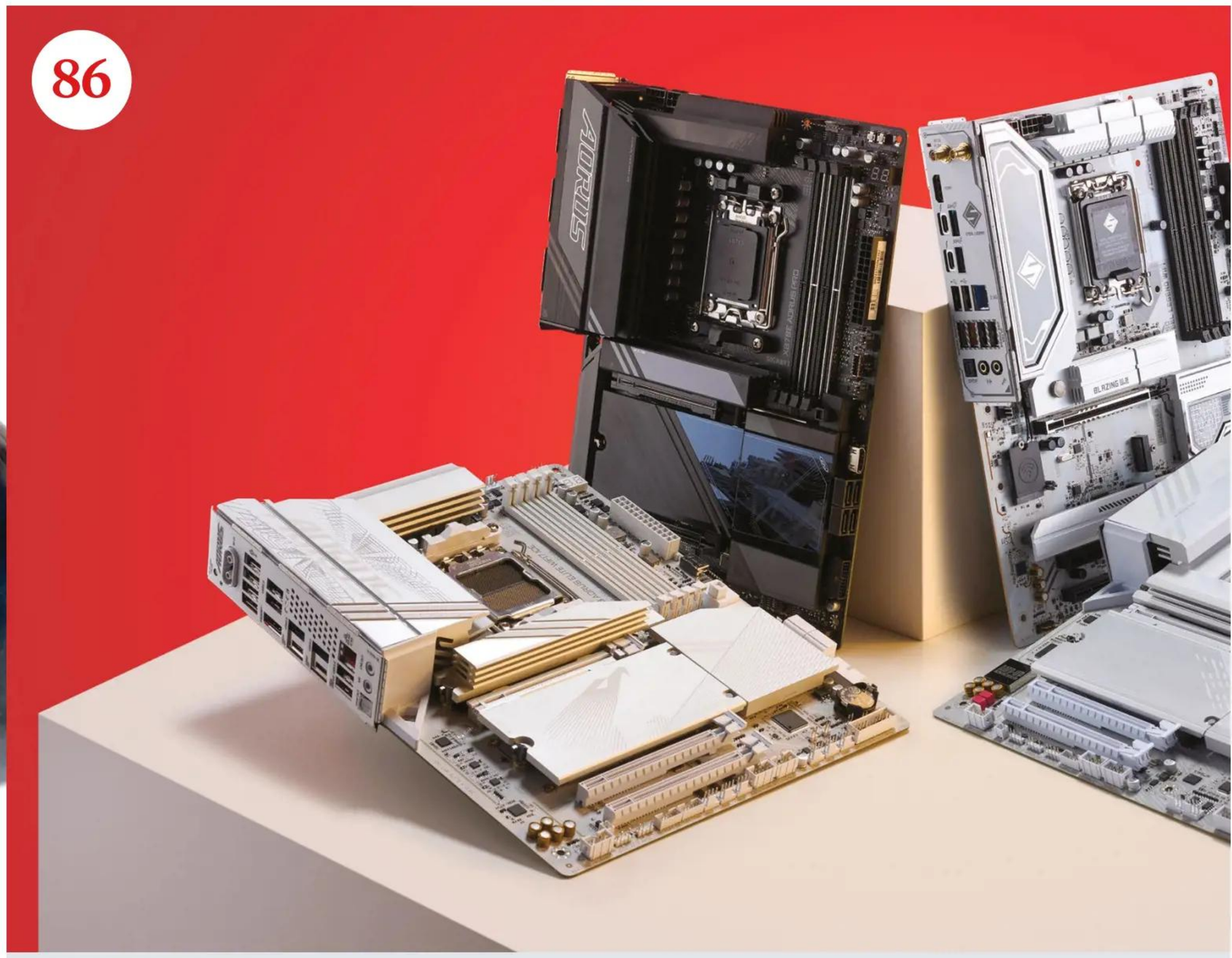

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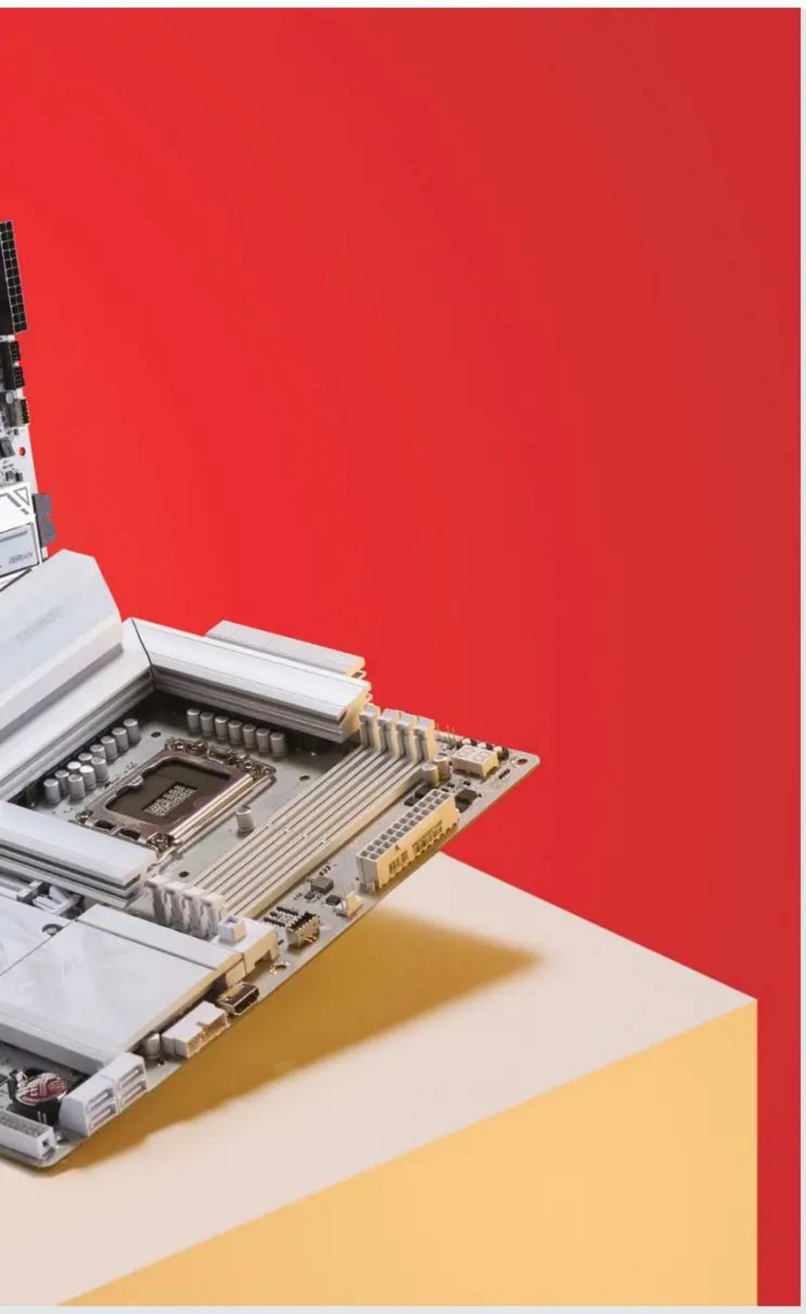

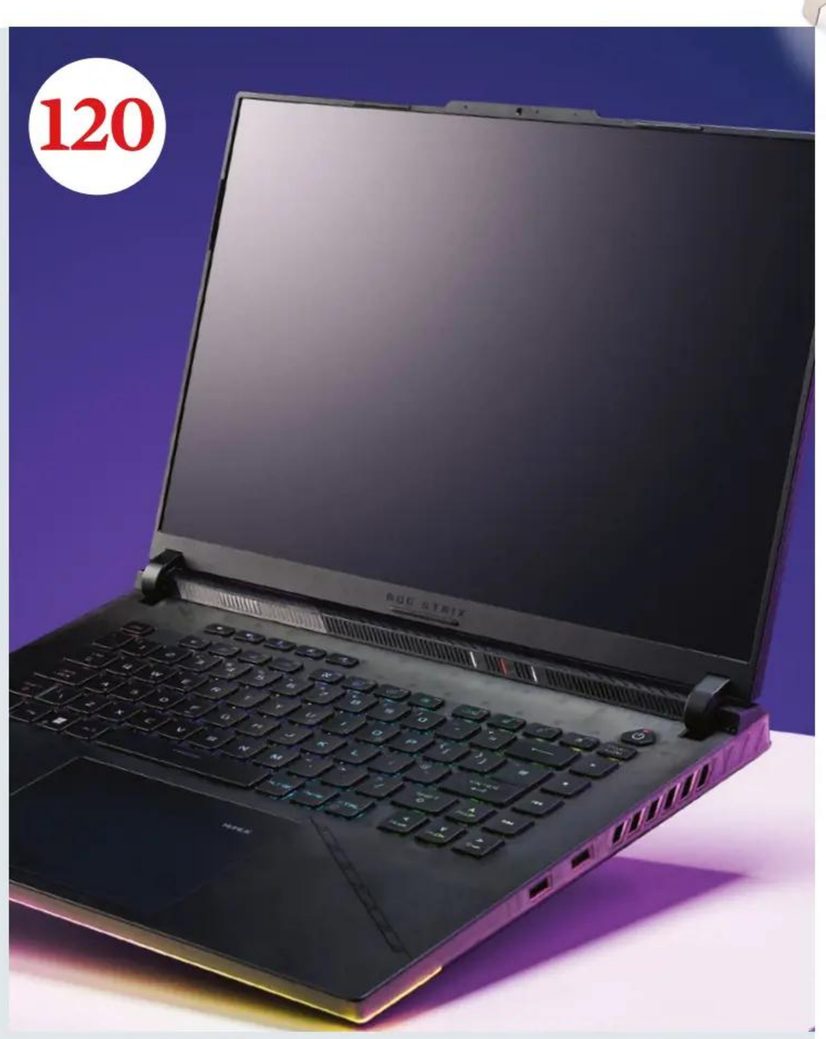

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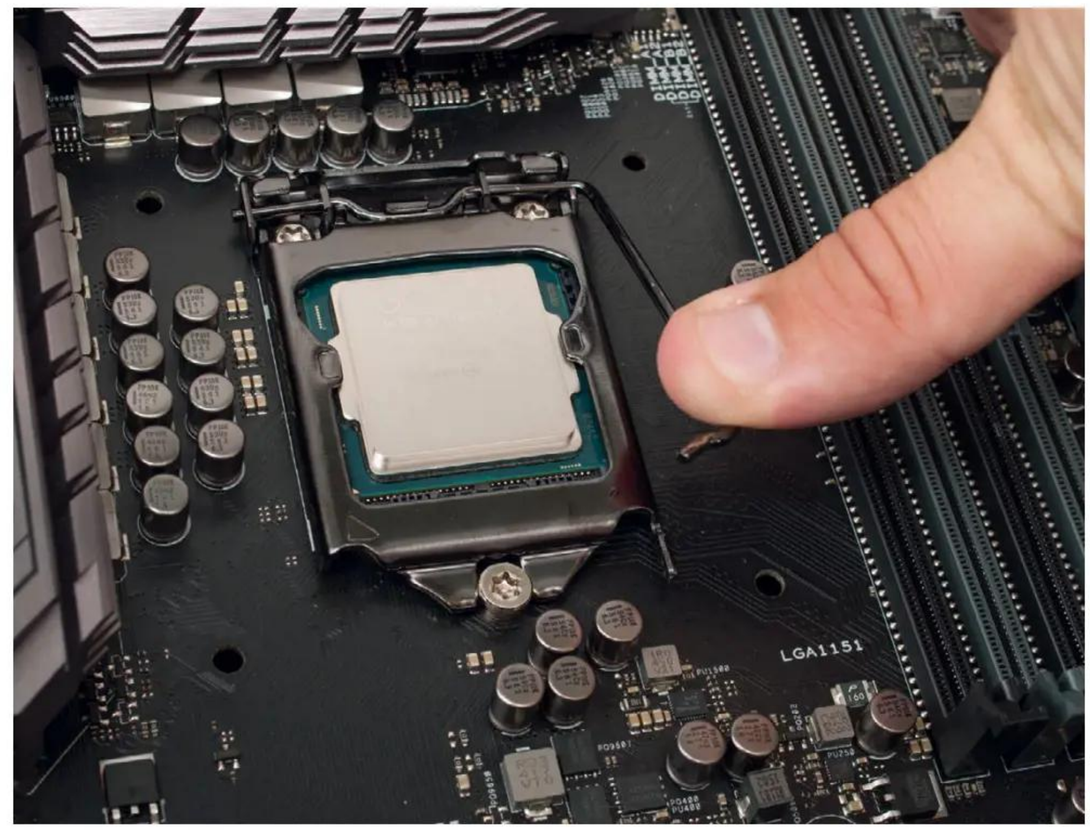
HERE'S WHAT YOU NEED TO BUILD YOUR OWN PC FROM SCRATCH



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JARGON BUSTER

James Norris explains and demystifies PC hardware terms

Whether you are lost in a labyrinthine tech support forum and nothing's making sense, or you just want to refresh your PC building and maintenance knowledge, I'm here to help with a glossary of the most common hardware terms and their straightforward explanations.

If you're looking for more back-to-basics help with both hardware and games, check out The Complete Guide to PC Gaming at **www.bit.ly/completepc**.

0-9

32-bit – When referencing computer architecture, the term 32-bit is used to denote the number of bits that can be processed simultaneously. Systems using 32-bit CPU and OS architectures generally have lower performance potential and RAM capacity when compared to their newer, 64-bit brethren. This term is also used to describe the colour range of a monitor that provides 32-bit per pixel of colour information, which means eight bits per channel for red, green and blue, along with an 8-bit transparency channel.

64-bit – Again referencing computer architecture, 64-bit is used to indicate the number of bits that can be processed at the same time, in this case twice as much as 32-bit, which provides processing and memory advantages for systems designed around this greater potential. Most modern computer systems use 64-bit architecture.

802.11 – Wi-Fi data standard specification family that runs on the 2.5GHz or 5GHz wireless bands.

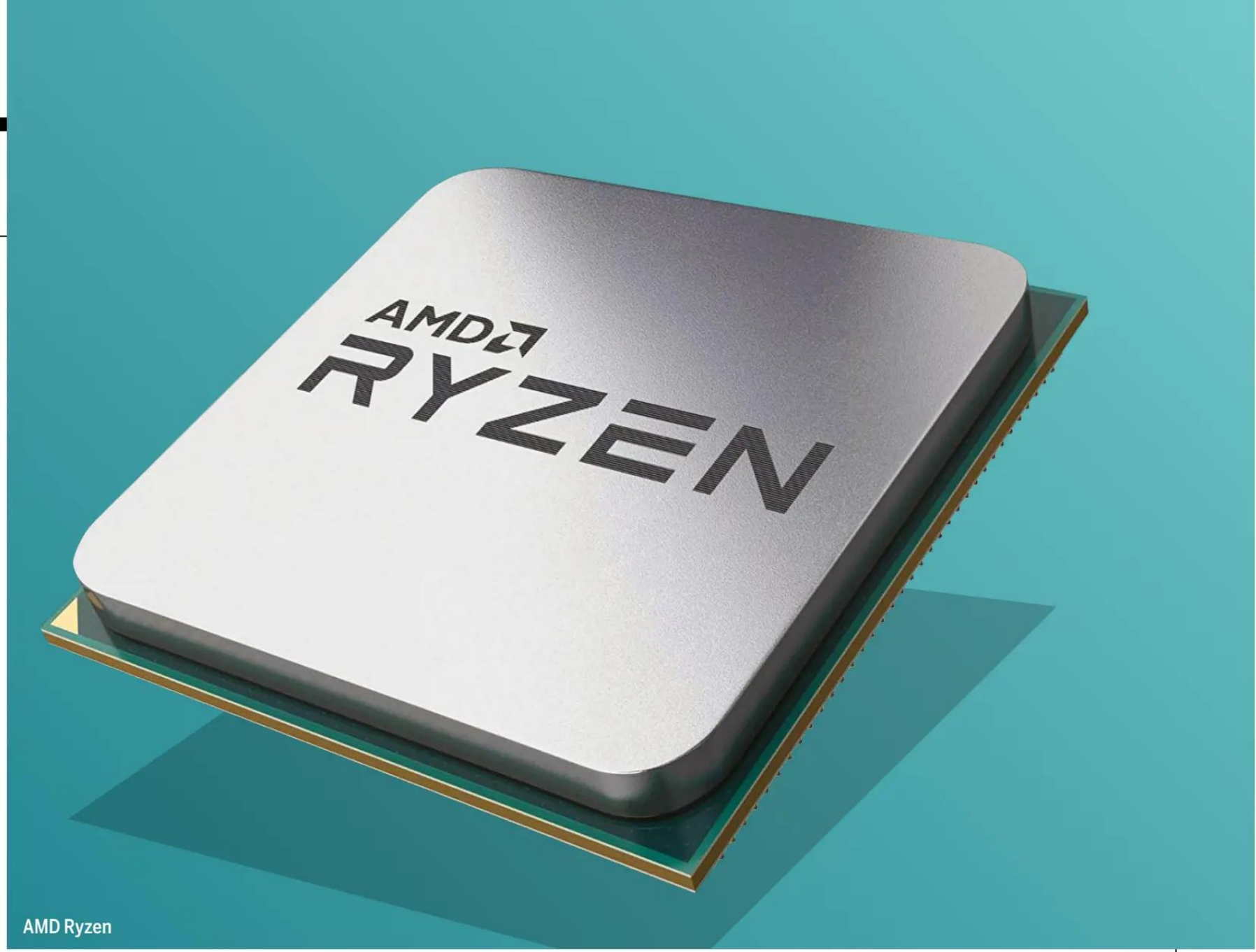
A

AMD Radeon – AMD's brand name for its series of graphics cards, DRAM modules, SSDs and supporting software. Usually refers to graphics cards or GPUs.

AMD Ryzen – AMD's competitor to Intel's Core series processors, now in their second generation. Ryzen processors, based on the Zen architecture, offer slightly lower single-core speeds than their Intel counterparts but offer more cores at similar or lower prices.

APU – Accelerated Processing Unit. AMD's definition for a CPU/GPU fusion designed for budget and midrange gaming-oriented systems

Aspect ratio – The size of a computer screen's width relative to its height. Back during the CRT era, this was normally 4:3, but with the advent of flat-screen displays, 16:9 has become the accepted standard. Other common aspect ratios include 21:9 for ultrawide monitors, and 16:10 for productivity-based work. Note that aspect ratio does not specify resolution or the actual size, just the proportions of the display.



AMD Ryzen

Acer – Acer Inc. is a computer hardware company, based in Taiwan, that's known for its Predator series of products and competitive pricing.

ASUS – ASUSTek Computer Inc., based in Taiwan, is a computer company specialising in high-performance, gamer-oriented hardware. ASUS owns the popular Republic of Gamers brand.

ATX – Advanced Technology eXtended. Midrange desktop PC size standard for motherboards and cases.

B

Bandwidth – Refers to the maximum rate of data transfer from one place to another, measured in bits per second. This applies to your internet connection, as well as your PC's hardware.

Blu-Ray

BenQ – A Taiwanese hardware manufacturer known for high-performance gaming monitors and a competitive pricing structure.

BIOS – Basic Input/Output System, also Firmware, also UEFI. The BIOS is the low-level operating system of a component such as a motherboard or graphics card, often made user-accessible via a set of option screens that are available for configuration when your computer boots up.

Blu-ray – The high-density optical disc format that replaced DVD.

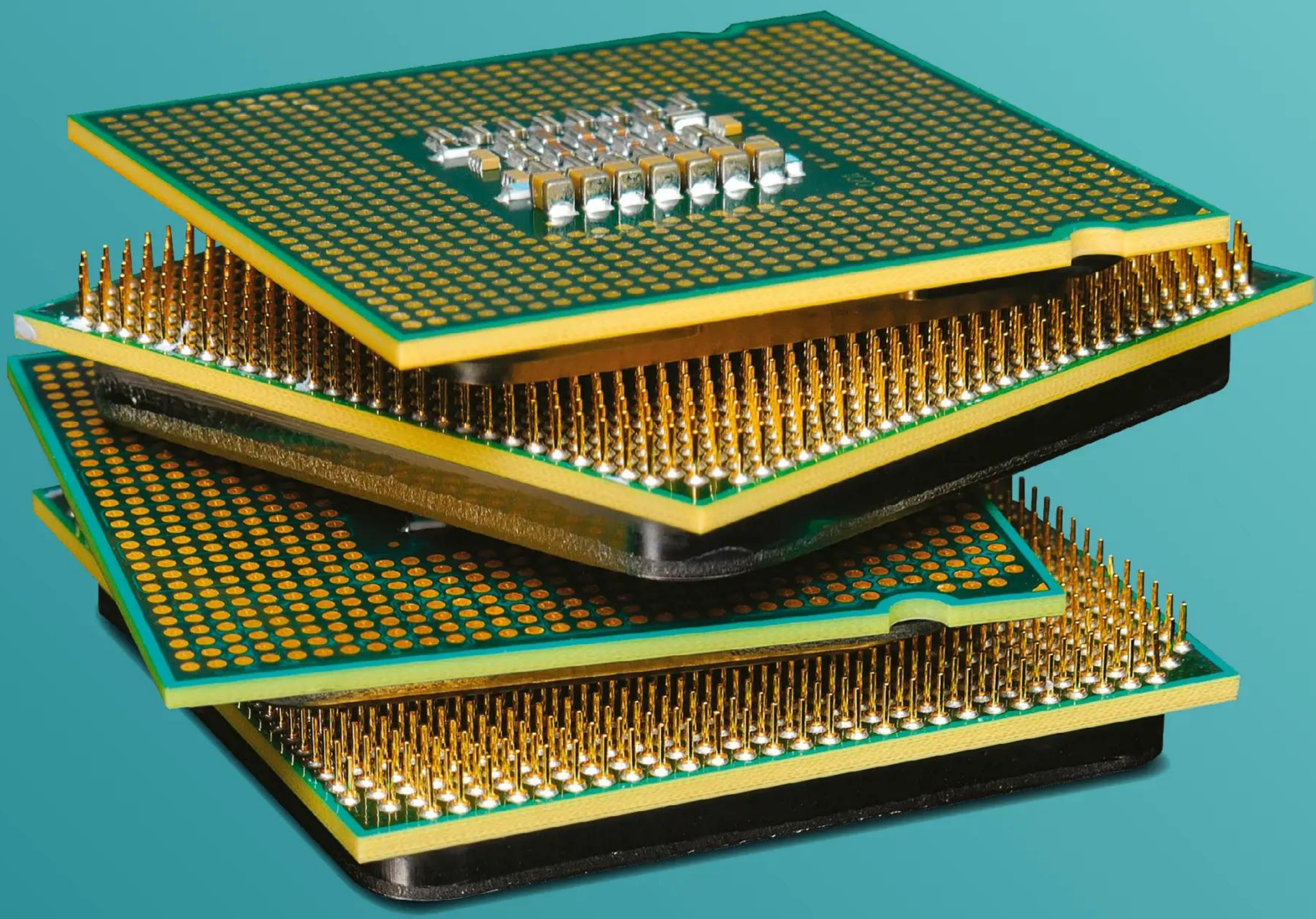
Bluetooth – A low-bandwidth wireless standard used for peripherals like mice, keyboards and speakers. Produces unacceptable lag for gaming on most systems, with RF-style wireless or corded devices preferred for high-performance situations.

Bus – In this context, a hardware bus is the architecture in a computer's subsystems that enables the various components to communicate with each other. This includes core areas such the system memory and extends to peripherals such as storage devices or expansion card slots, each of which have their own unique specifications.

C

Cable modem – The device used to provide an internet signal to your router from your ISP. Usually supplied by cable companies and ISPs to end users and often built into a small network router.

Cache – A small amount of very high-speed memory that's used to keep frequently accessed data handy for the CPU. A properly managed and sized cache has an outsized effect on system performance.



CPUs

Case – An enclosure that houses all the parts of a PC.
CD-R – Recordable Compact Disc.
Chipset – The series of integrated circuits that manages the functions of a motherboard.
Clock speed – The rate at which a computer performs calculation, usually measured in megahertz (MHz) or gigahertz (GHz).
Codec – Short for coder-decoder. A codec is software or hardware that encodes and decodes data streams.
Core – The computational centre of a processor, usually one of a group of up to six in a modern desktop CPU.
Corsair – Premium computer peripheral supplier based in Fremont, California and known for quality DRAM products, keyboards, water-cooling systems and high-fashion tower cases.
CPU – Central Processing Unit. The computation centre of a computer, comprised of one or more cores.
Crossover Ethernet Cable – A length of RJ-45 networking cable with a special wiring configuration that enables routers to be daisy chained together via a specially labelled or autosensing Ethernet port.

D

Das Keyboard – A boutique Austin, Texas-based hardware company that produces a range of well-received high-quality mechanical keyboards.
DHCP – Dynamic Host Configuration Protocol. An automatic IP addressing system used on modern TCP/IP networks and the internet that provides each computer with an IP address without requiring a manually entered or fixed-number identification scheme. Widely used by internet access hardware such as network routers.
DDR – Double Data Rate memory. Available in many speeds and sizes.
DisplayPort – DisplayPort is a high-performance digital video connector designed for speedy refresh rates and high resolutions.
DMA – Direct Memory Access. Refers to devices that can directly utilise system memory without draining processor resources.
DPI – Dots Per Inch. Used to determine printing and screen resolution.
Drive bay – A place inside a computer case provided to install a hard drive. Comes in 5.25-inch and 3.5-inch sizes.
DRAM – Dynamic RAM. DRAM refreshes constantly to hold data. It's slower than static RAM, but cheaper.
Driver – The specialised software that controls the low-level functions of hardware components, usually provided by the component manufacturer or occasionally by the OS vendor.

Case

E

E-ATX – Extended ATX. Extra-large ATX size used for deluxe motherboards and computer cases.

F

FAT – File Allocation Table. A family of robust but simple filing systems used by many OS implementations, such as MS-DOS, as well as standalone hardware such as printers or IP cameras. FAT files often have limitations on naming conventions and size.
Firewall – A software or hardware network barrier that protects users from outside attacks and surveillance.
Firmware – Low-level software built into a device's non-volatile memory (memory which retains data even if the power is switched off). It communicates with OS drivers and other hardware.

ITX

FLOPS – Floating Point Operations Per Second. A measure of computational performance that leans on complex floating-point operations. GPUs are particularly robust at performing these, outperforming even high-end CPUs by several orders of magnitude.
FreeSync – An AMD-created, but otherwise free and open, monitor variable sync standard, compatible with VESA's Adaptive Sync protocol. Essentially, rather than the monitor refreshing at a steady rate, its refresh rate changes with the framerate of the game you're playing. FreeSync 2 updates the standard to include lower minimum framerates, HDR, HDMI support and integrated colour space management.

G

Gigahertz – 1000MHz. A unit of internal clock speed used by CPUs and other components to specify device performance. Adjusting the clock speed higher provides better performance, although doing so can impact stability and power consumption.
G.Skill – A computer hardware manufacturer, based in Taiwan, that's best known for its top-shelf, high-speed DRAM products.
G-Sync – Similar to FreeSync, except proprietary. This is a monitor adaptive sync standard used by Nvidia to smooth framerate transitions and eliminate display tearing. Requires Nvidia graphics hardware and a G-Sync-capable monitor.

H

Hard Boot – Resetting a computer from a powered-off condition.
Hard disk drive (also mechanical hard drive) – These legacy storage devices utilise rotating magnetic disks to store data and generally feature lower costs and larger capacities than solid-state drives (SSDs). While mechanical hard disk systems are a mature and stable technology, SSDs have recently begun to supplant them. The faster the rotational speed of the disk, the better the performance and the higher the cost of the drive. 5400RPM disks are considered mainstream, while 7200RPM and 10000RPM speeds are reserved for high-performance drives.
HBM – High Bandwidth Memory. A type of stackable memory used in graphics cards that provides high performance in a small form factor.
Hyperthreading – A CPU technology that enables two threads to share a CPU core, doubling the thread capabilities of a processor. Especially useful for low-core-count laptops.

I

Intel Core i9 – Intel's newest consumer CPU. The Core i9 series takes over from the previous top-of-the-line i7 processors and introduces features formerly only found on enterprise-grade hardware, running from six to 18 cores and supporting hyperthreading. The i9-9900K, with eight cores running at a peak of 5GHz, is a gaming beast.
IP address – Internet Protocol address. The unique numeric address of a networked device, displayed as a series of numbers, for example 192.168.0.2 in the commonly used version four of the IP protocol. As demand for IP addresses has grown, version six of the IP protocol is being rolled out, which provides a much larger addressing space to cover the rapid growth of internet-connected devices.
IPS panel – In-Plane Switching. A type of advanced LCD display that offers superior colours and viewing angles.
ITX – Information Technology eXtended. Tiny desktop PC size standard used for tight spaces or boutique builds.

J

JEDEC – A colloquial term referring to the DRAM preconfigured memory setting profiles derived from the Joint Electron Device Engineering Council's specifications. Similar to XMP.

K

Kilohertz – 1000Hz; A unit of computing speed. Generally used to describe monitor refresh rates.
KVM switch – Short for Keyboard, Video, Mouse. A type of switchbox that enables multiple computers to be attached to a single keyboard, monitor, and mouse or other input device.

Hard disk drive

Jargon buster

L

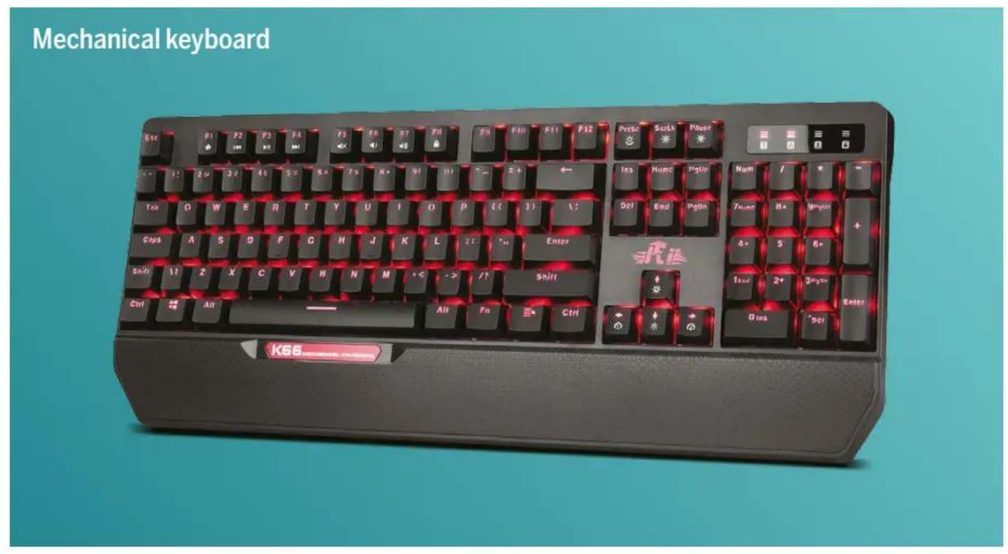
LAN/WLAN – Local Area Network / Wireless Local Area Network. A private local network of computers usually connected via Wi-Fi or Ethernet.
Logitech – A highly successful Swiss computer peripherals company specialising in mice, headsets, keyboards and computer speakers.

M

MAC address – A code built into every network-capable port that uniquely identifies each device connection. Usually takes the form of six pairs of hexadecimal digits separated by a comma or dash.
Mechanical keyboard – A type of keyboard that uses microswitches instead of the default rubber domes for actuation. They tend to provide a form of tactile and audio feedback that certain users find satisfying.
Megahertz – 1000KHz. A unit of computing speed. Generally used to specify speeds on memory as well as on older processors.
MLC – Multi Level Cell. Normally refers to a NAND memory implementation. Cheaper but less durable than SLC.
MSI – Micro-Star International, a Taiwanese corporation that makes just about any kind of computing hardware you can imagine.
Motherboard – The centrepiece of a PC system and the place where all the other components are installed.

N

NAND flash memory – The type of memory used in SSDs.
NZXT – An American hardware company known for cases and components, such as liquid coolers.
Nvidia GTX – In Nvidia's current nomenclature, GTX refers to consumer graphics cards based on its last-generation Pascal and previous Maxwell architectures. The Pascal-based Nvidia GTX 1080 and big brother 1080 Ti were the first Nvidia cards able to provide 4K gaming at reasonable framerates, while the 1070 is designed to cover gaming needs at 1080 and 1440 resolutions and high detail.
Nvidia RTX – Featuring the new Turing architecture, Nvidia's RTX series of graphics cards, including the RTX 2080 and higher-performance RTX 2080 Ti, are the current top shelf when it comes to performance in consumer graphics cards, both in real-world and potential numbers. With Turing, 50% higher efficiency per core, faster memory and dedicated ray tracing and AI hardware, as well as jumps of over 20 frames per second are possible in many games.


Mechanical keyboard

SSD

Motherboard

O

OLED – Organic Light Emitting Diode. An advanced screen technology that offers low power, high performance and amazing image quality. Increasingly found on smartphones, such as the iPhone XS and Samsung Galaxy S9, as well as on large screen TVs.
Overclocking – Pushing a component beyond its rated specifications to improve its performance.

P

PCB – Printed Circuit Board. The backboard on which components such as sockets and Voltage Regulator Modules (VRMs) are mounted.
PCIe (OR PCI-E) – Peripheral Component Interconnect Express. A high-speed slot design used in modern computers for add-in cards.
Pixel – A single element or dot on a computer screen.
PSU – Power Supply Unit. A box-like component with cables that provides a computer with power.

R

RAID – Redundant Array of Independent Disks. A set of drives configured in an array for improved performance and reliability.
RAM – Random Access Memory. The computational workspace of a computer

Ultrawide Display

system. It's volatile, meaning the data it stores is lost when the system is reset or turned off.
RAMDAC – Random Access Memory Digital to Analogue Converter. Converts image data into signals that can be displayed on a monitor.
Razer – Razer Inc. is a gaming hardware company with headquarters in San Francisco and Singapore. Razer's entire product catalogue is gaming oriented. Known especially for its gaming laptops.
RJ-11 – An old-style telephone connector that looks like a narrow Ethernet (RJ-45) connector. Also used for analogue modems.
Roccat – A German peripheral manufacturer that specialises in input devices such as mechanical keyboards and mice, as well as headphones.
ROM – Read-Only Memory. An area of protected memory that contains specialised instructions.
Router – A hub that manages wired and wireless connections to a network.

S

SATA – Serial ATA. A data transport protocol used for storage devices.
Screen burn – The afterimage left on certain types of displays, such as OLEDs, after displaying static images for extended periods of time. Can cause permanent hardware damage.
SLC – Single-Level Cell NAND memory. The quickest, priciest and most expensive NAND implementation.
SO-DIMM – The type of DDR memory module used in laptop systems. Uses a smaller form factor than standard memory sticks.
Solid state – Used to describe a device with no moving parts.
SSD – Solid-State Drive. A storage drive made of non-volatile memory cells instead of a moving magnetic platter. Much faster than hard disk drives.
SteelSeries – High-end Danish gaming peripheral manufacturer known for headsets, mice and mechanical keyboards.
Stream processors – Limited instruction processors used in GPUs to perform specialised functions. Used for high-performance applications.

T

TDP – Total Dissipated Power. The maximum wattage a part will allow before shutting down or throttling to avoid damage or overheating. Can be used as a rough indicator of in-generation performance or efficiency.
TN panel – Twisted Nematic panel. An older style of LCD display that offers low price and very high speed, but is also notable for washed-out colours and poor viewing angles.
Touchpad – A small flat pad that registers mouse-style pointer movement when you slide a fingertip across it. Used for laptops.

U

Ultrawide display – A computer monitor that sports a cinema-like 21:9 aspect ratio. Available in 2560x1080 and 3440x1440 resolutions.
UPS – Uninterruptable Power Supply. A battery-backup power source that enables a computer system to continue functioning in the case of a power outage or other problems.
USB – Universal Serial Bus. A small hot-swappable data connector that's capable of high performance when using the latest specifications.

V

VA panel – Vertical Alignment panel. A type of LCD display that delivers high contrast ratios, deeper black levels and more accurate colours. VA panels are ideal for gaming.

W

WAP – Wireless Access Point. The place you log into a wireless network.
Watt – A measure of electrical power.
Webcam – A usually USB-based PC camera that provides live video for use with conferences, game streaming and other media projects.
WPA2 – Wi-Fi Protected Access 2. The most robust security protocol currently provided for many Wi-Fi networks.

X

XMP – Extreme Memory Profile. An Intel-derived DRAM settings standard that provides several fail-safe memory configurations beyond the default setting, allowing easy configuration of high-speed memory modules.

RIPJAWS V
RIPJAWS V
SAMSUNG
Solid State Drive

HOW TO BUILD A PC

Building a PC is a huge part of the joy of PC gaming. No one starts off as an expert PC builder, though, and here James Davenport takes you through the entire process step-by-step

1 PREPARE THE CHASSIS

→ Let's build. First, take off both side panels on the case. You'll need access to both sides for inserting hardware, cable management, and general ease of access. It can get crowded, quick.

→ Move any cables inside of the case out of the way. We'll get to moving those around in a while.

2 MOTHERBOARD PREP

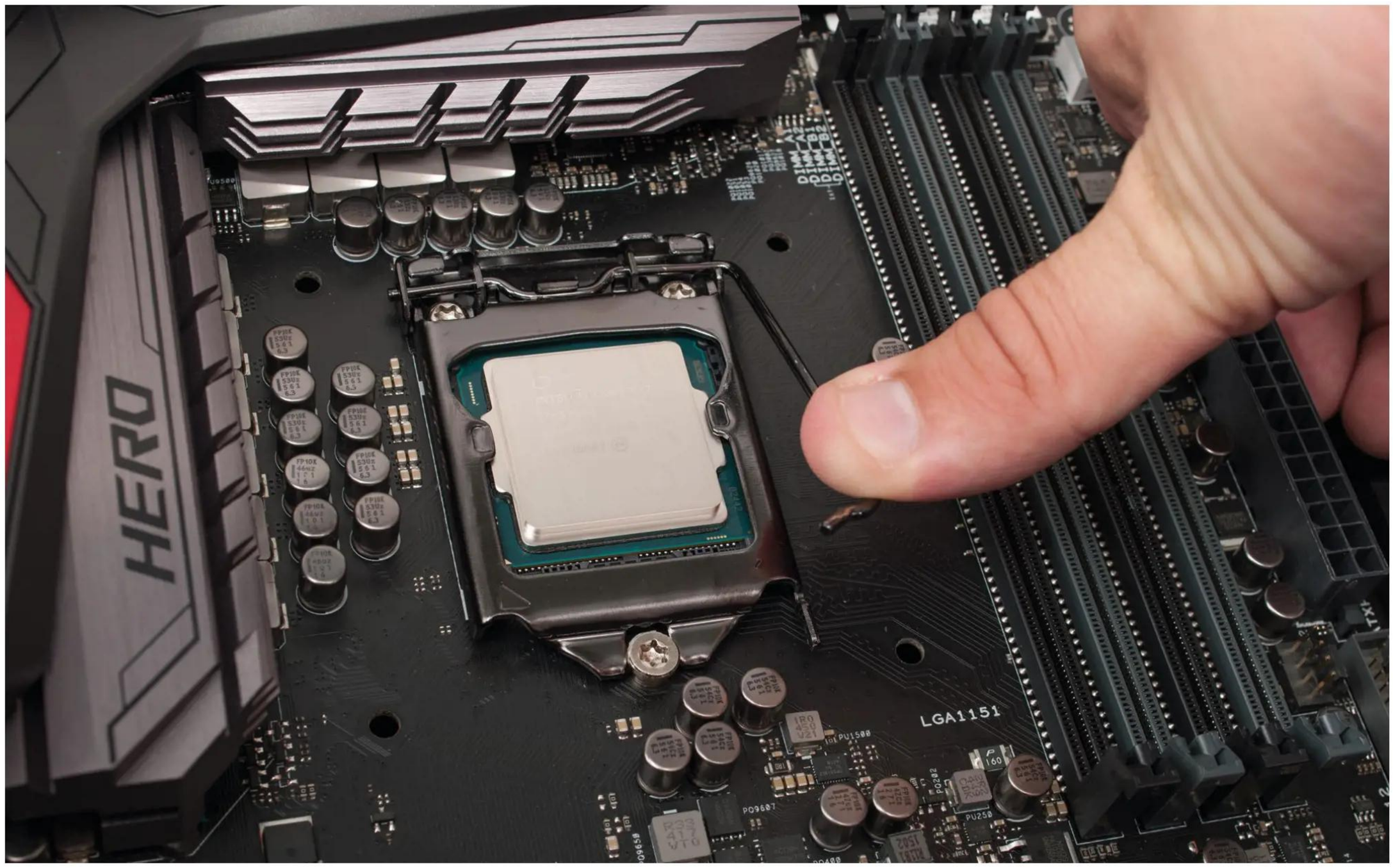
→ Your chassis should include motherboard standoff screws, as pictured (sometimes they're gold instead of black). These prevent your motherboard from making direct contact with the back of the chassis, which could short out the board. Reference the holes on your motherboard to see where the standoffs need to be, since this can vary. Screw them in tightly.

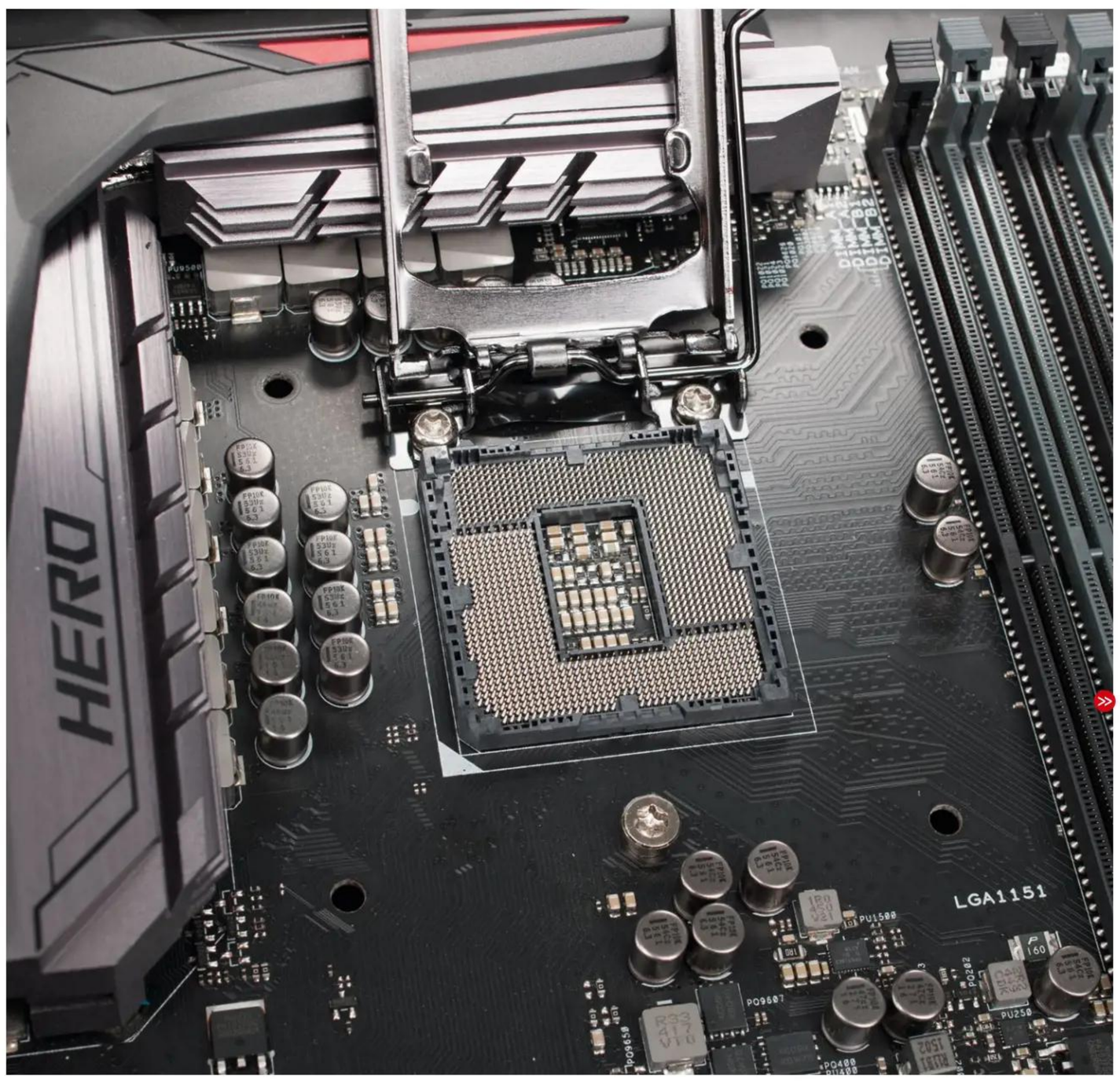
→ Take the I/O (input/output) shield and line it up with the frame from inside the case. Make sure you have it facing in the right direction before you pop it in. Again, make sure that you check your motherboard for reference. Push it in, making sure not to press too hard on the centre (but you might have to really press hard on those edges in order to make sure that it's in the right place). There should be a satisfying click from each side once it's aligned correctly and as it snaps into place. With this done, we can move onto the motherboard itself.

3 INSERT THE MOTHERBOARD

→ Once the chassis is prepped, it's time for you to insert the motherboard. This chassis has a convenient built-in standoff that centres the motherboard for you. However, not all cases will have one, so when you place it down – make sure that you do so gently – there may be some resistance up against the I/O shield. This is completely normal and nothing to worry about. Just make sure that no metal prongs accidentally get lodged into a USB port, otherwise it's game over! Once the motherboard is aligned with the standoffs, screw down the centre – don't tighten it yet – and then do the opposite corners. Screwing in opposite corners is a good rule of thumb for installing anything in a PC, as it lowers the risk of misaligning and potentially damaging your hardware. Tighten the screws bit by bit until the motherboard is firmly in place. Don't overdo it. If it isn't jostling around, it should be secure.

→ Once it's secure, tighten up the screws slowly and gently, working from opposite corners, to make sure that the motherboard stays seated correctly.





4

SEAT THE PROCESSOR

→ Good job. If you're reading this and not cursing or crying, you've successfully got a motherboard in a PC case. Next up we deal with the most important part of any PC: the CPU. Treat the CPU like an inexplicably living brain in a glass jar. Hold it at the edges and avoid touching the underside. Finger grease can mess with the heat diffusion, which is not good on one of the most expensive, vital, volatile PC components. To install it, lift the lever on the CPU socket on the motherboard, remove the plastic placeholder, and locate the golden arrow on your CPU. This, and the notches on your CPU, will let you know how to align the CPU above the slot. Make sure everything is matched up, then carefully lower the CPU straight down onto the socket. It should fit in effortlessly, so don't put extra pressure on it. CPUs are easily damaged.

→ Once the CPU is in place, lower the socket shield and secure it by pulling and locking the metal lever down. You'll feel resistance, and likely a few heart palpitations, but try not to worry too much, everything is (probably) okay.

5 PUT IN THE POWER SUPPLY

→ Now, for something much simpler... A PC isn't powered by magic, so a power supply (PSU) is necessary. Ours is a modular unit, meaning we can plug and pull cables as needed. Some PSUs have cables built into the unit, making cable management a hassle, so if you can, go modular. Installing is simple. Just make sure the PSU fan is either facing the chassis vent (or upwards if it works in with your airflow scheme) and then screw it in from outside the case.

6 READY THE RAM

→ With the PSU in, its time for another simple step: the memory. First, you'll need to locate the DIMM slots. Any DIMM-wit could do it! Sorry, that wasn't helpful. They're the four, thin, RAM-length slots next to the CPU. In order to take advantage of any dual-channel functionality, you'll need to install the RAM in alternating slots. Refer to your motherboard documents for details, but for us, the slots were labelled.

→ Placing the RAM is simple. Make sure the locks at the end of each slot are open, find the notch in your RAM, line it up with the notch in the slot, insert it, and push until the lock clicks and the RAM is securely in place. Don't be afraid to push down hard.

SOME PSUS HAVE CABLES BUILT INTO THE UNIT, MAKING CABLE MANAGEMENT A HASSLE, SO IF YOU CAN, GO MODULAR

7 INSTALL THE COOLER

→ This step will vary depending on what type of cooler is being installed, so be sure to refer to the manufacturer's instructions. If you're using a stock Intel cooler, installation is as simple as lining up the small fan and pressing down each corner until the legs snap into the motherboard.

→ Most coolers require some kind of backplate installation, which means you'll be coming from the underside of your motherboard. With an air cooler, you'll probably thread mounting screws through the top of the motherboard and attach them to the backplate with nuts. On the top side, directly over the CPU, goes the cooler itself. Make sure you align each corner around the CPU.

→ Plug the cooler's power cable into the motherboard. The manual should illustrate where the pins are in case they're not labelled on the motherboard itself. We plugged into CPU_FAN and W_PUMP.

8

INSTALL THE SSD

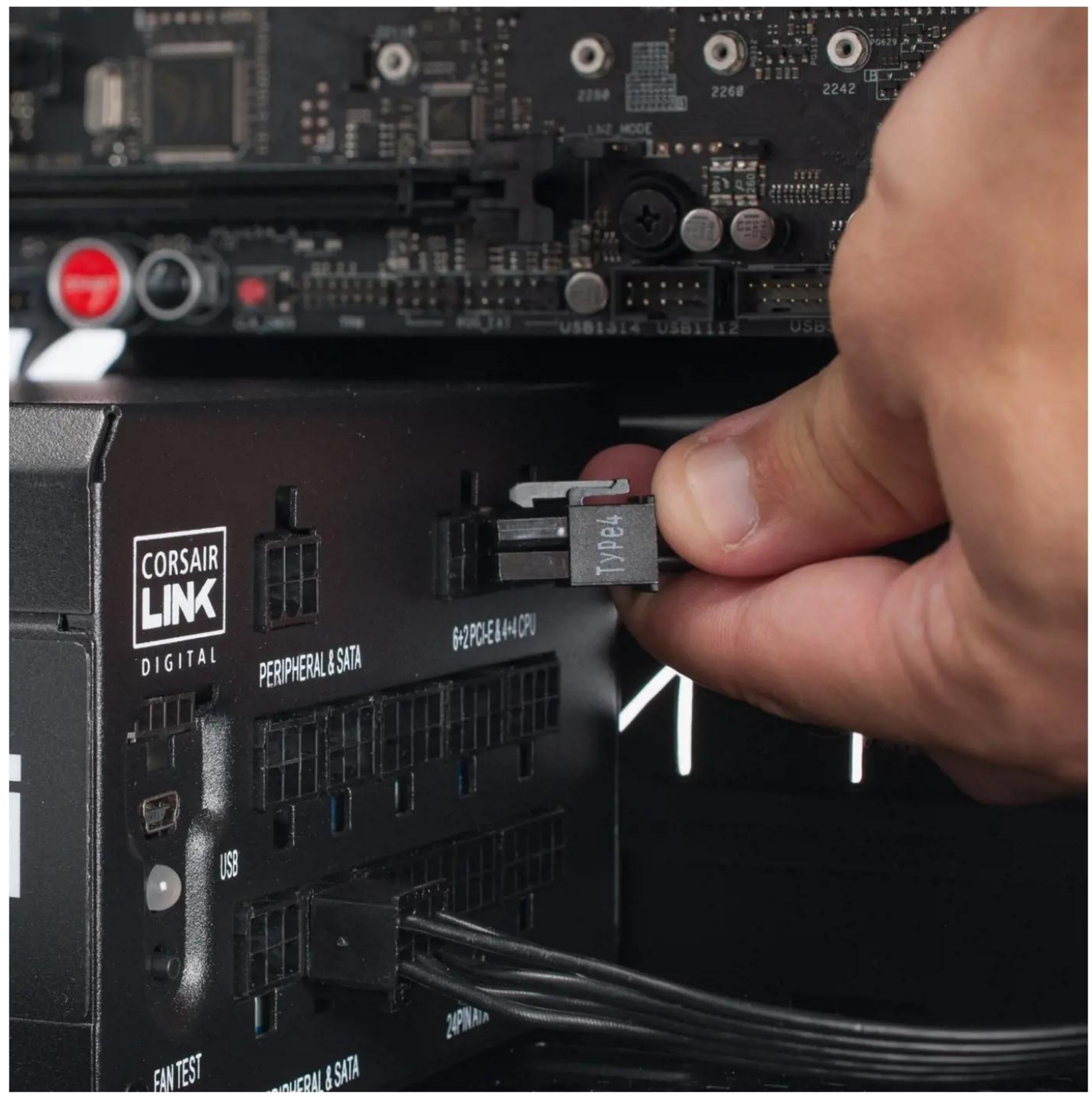
→ Of course, every PC needs non-volatile memory for storage, but nowadays, there's an allowance for plenty of variation. What you see on these pages is a simple build, so in this case we're just sticking with a single SSD.

→ Installing an SSD is easy in this Fractal Design Define R5 case. You'll find that most cases are built with SSDs in mind these days: just screw the drive into one of the provided SSD trays, and then screw the SSD plus tray into wherever the chassis allows. Now is a good time to start thinking about cable management, too.

→ The drive will need power and a way to interface with the other PC components. First, you'll need to plug the SATA data and power cables into the drive.

→ Be sure to arrange your cables with some kind of logic in mind that prevents them from trailing across the motherboard, if possible. Most cases let you snake cables through the base behind the mobo by using conveniently placed routing holes, but not all chassis are quite so lucky.

→ Next, the SATA data cable plugs into the motherboard. Some plugs have different speeds or interfaces, so check your motherboard manual for specifics about which to use. Lastly, the power cable goes to the PSU, as indicated either on the PSU itself or in the manual.



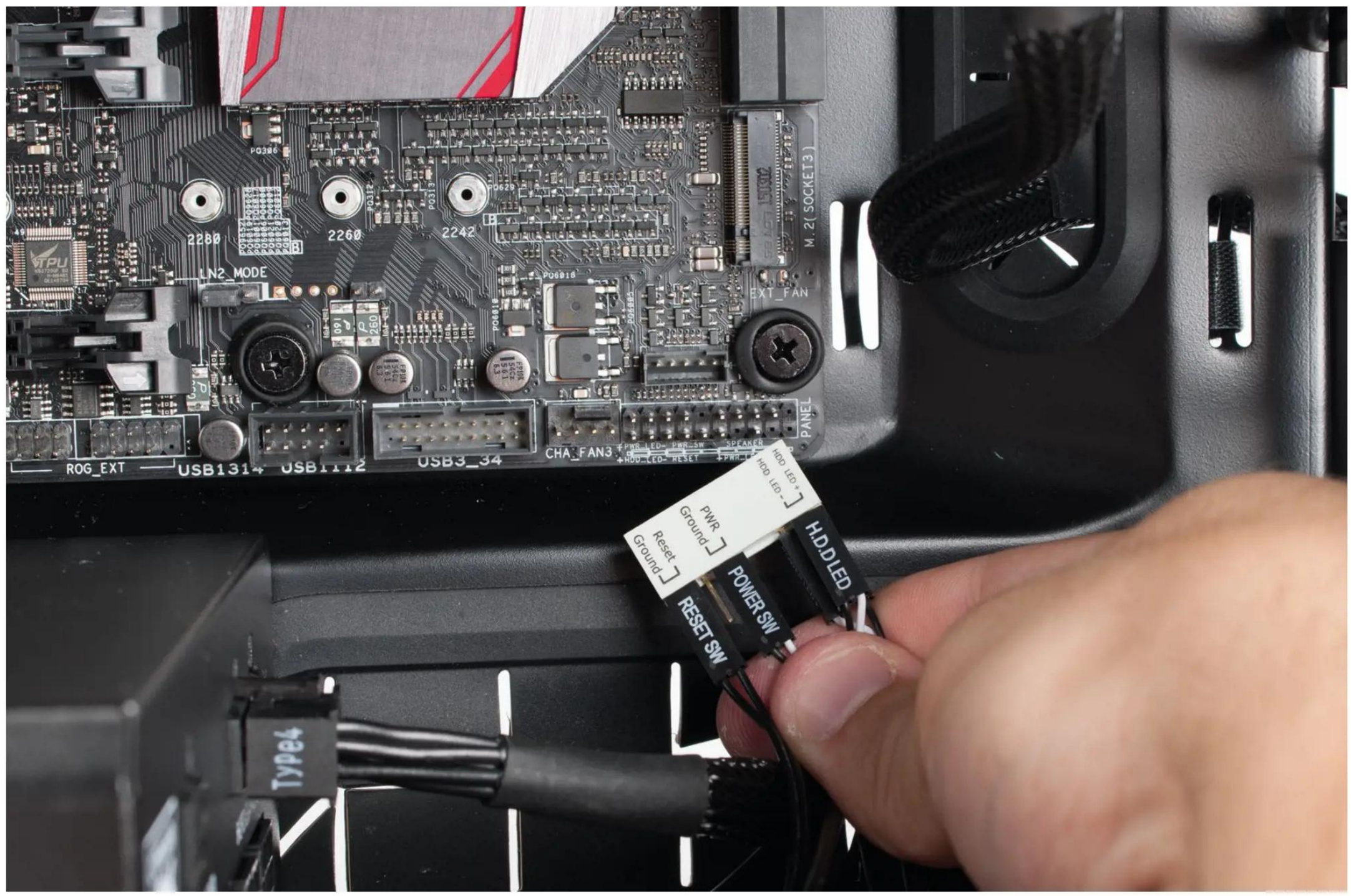
9

INSTALL THE GPU

→ It's time to seriously pump this PC up with the graphics card. Fortunately, installing this in your PC is extremely simple. First, remove the PCI-E slot shields near the rear of the case where your video card will lay. You'll find that most of today's graphics cards take up two slots.

→ Grab your graphics card, align it with the PCI-E slot, and press it down gently until you feel the card lock into place. Secure the graphics card by screwing it in with thumbscrews where the slot shields used to be.

→ Graphics cards need extra power to function, so find the power cables your GPU requires and plug them in (they're typically labelled PCI-E or VGA). Don't worry since PSU cables only fit where they're meant to, thanks to an elaborate set of square and hexagonal plug components. Of course, if your PSU is modular, make sure the cables are plugged into the unit as well.



10

PANEL CONNECTORS

→ In order to get the lights and switches on the front of your chassis to work, these tiny cables need to plug into your motherboard in very specific places. Refer to the motherboard manual and on-board labelling if necessary. There may be some front panel USB cables too, but those are much easier to deal with. Plug them in as indicated here.

→ A motherboard needs power too. Find the 24-pin power connector, orient it correctly, and push it into the motherboard until it's firmly connected. Standard ATX motherboards also require an additional power connection close to the CPU, usually four to six pins. Check for one, plug it in, and then make sure all power cables plug back into the PSU if it's modular.

→ There should be fan connectors in various locations on the motherboard. Find the ones that best suit your cable management and plug them in.

→ Wrap things up by doing any last minute cable management. It's not a bad idea to double check your connections and make sure all of your components are firmly seated, too.

11

AND THEN, A PC!

→ Be sure to take a step back and drink it all in. You've (probably) successfully expressed yourself via expensive hardware, sweat, tears and a healthy dose of love. This is the beginning of a new era for you, but it doesn't have to end here. Feel free to add components we didn't cover. If you're a fan of antiquated tech, then throw in a disc drive. Want to open up your PC to more peripherals? Add a bluetooth receiver. Not enough red LEDs in your life? Well, then light that sucker up. It's your PC, make it your way. The platform is open for a reason, after all.

TROUBLESHOOTING

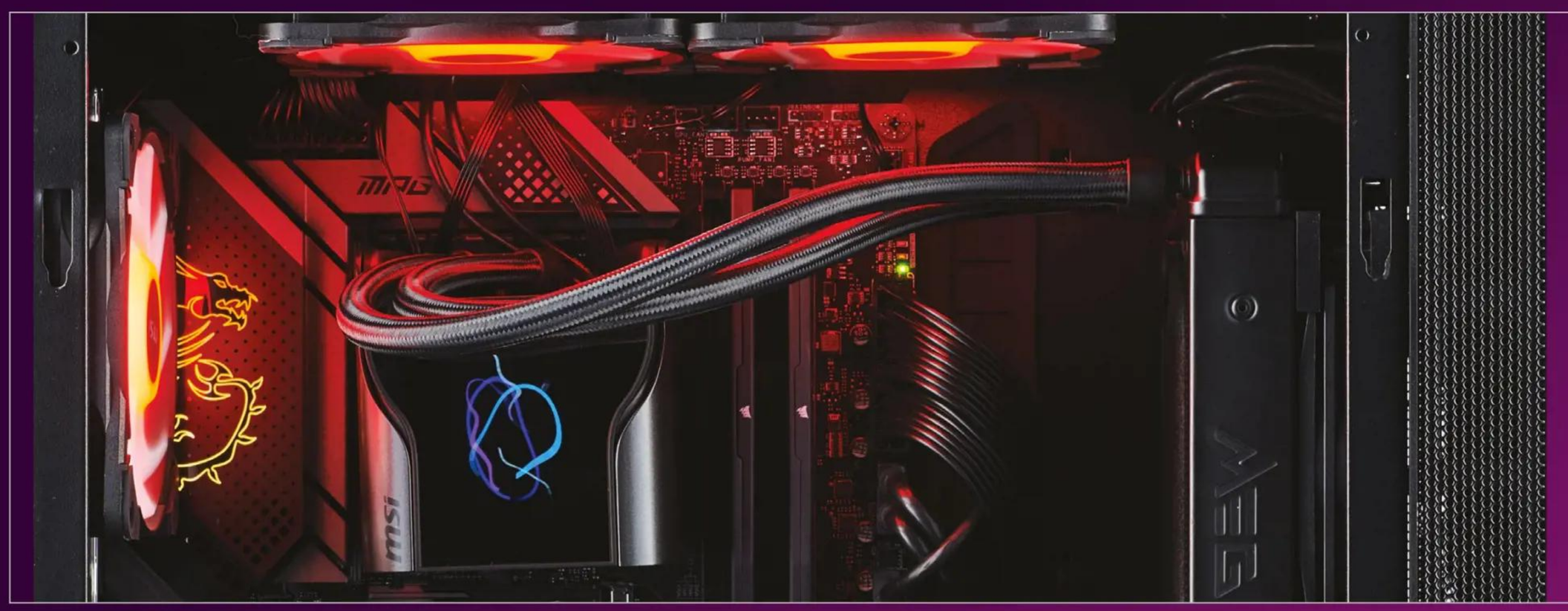
→ **No power? Try reseating connections between PSU and the motherboard.**

→ **Still nothing? Recheck the mobo's front panel cables.**

→ **If you're getting power, but no bootup, check the RAM. Maybe try the other set of DIMM slots.**

→ **Check your video cable – it should be connected to the graphics card, not to the motherboard.**

→ **If nothing else works, most manufacturers offer solid support.**



ONE-MANUFACTURER BUILD WITH MSI

Is using one manufacturer's components a good idea?

LENGTH OF TIME: **2–3 HOURS** LEVEL OF DIFFICULTY: **EASY**

THE CONCEPT

If you built your desktop PC, it's probably a hodgepodge of different manufacturer components all working in tandem. That's the beauty of PC building—if you want to mix things up for price or performance reasons, common standards mean you can. But every manufacturer seems to have its own lighting standards and management app, and some use different styling or colouring that can mess with a uniform look. But what if you want to build a computer, while still recreating the feel of a pre-built system. What would that look like?

Thanks to the good people at MSI, we can find out! During discussions about the company's 2022 components, including its first SSD drive, the Spatium M480, and the Sekira 100R case, we asked them: could we get everything into our labs at the same time and make a build out of it all? The company obliged, sending all the components we needed apart from the CPU and RAM, the only items they don't manufacture.

The resulting all-MSI build is at the cutting edge of current tech specs, thanks to its DDR5 and PCIe 4.0-compatible motherboard, and what's more, it's also pretty good value for money. Remember, adding the latest SSD and RAM to your build will increase its overall price, so if you already have some DDR4 RAM you want to use, go for the cheaper DDR4 model motherboard while you wait for DDR5 sticks to come down in price.

It's also worth noting that MSI provided its own keyboard, mouse, and monitor to complete the look, but we sadly didn't have space to include them. For now though, let's get on with the build!

THE INGREDIENTS

MSI sent some fantastic components for us to work with—we're not talking money-no-object stuff, but the type of components I'd choose if I was trying to spec out a value for money future-proofed system. Key to this is the motherboard, the MSI MPG Z690 EDGE WIFI ($310), which supports Intel's 12th generation processors, PCIe 4.0 SSDs, and DDR5 RAM. You can save $20-30 by opting for MSI's DDR4 version of the same board, which I'd recommend if you have existing RAM you can reuse, because DDR5 RAM is still just so ridiculously expensive right now.

Thankfully, PCIe 4.0 SSD drives aren't as much of a premium over their 3.0 equivalents, despite offering nearly double the speed. The MSI Spatium M480 PLAY 2TB ($330) is $100 more than a PCIe 3.0 equivalent like the Samsung 970 Evo Plus. MSI's drive seems custom-built to appeal to the PS5 market thanks to its giant heatsink, but this cooling will at least keep the storage cool during serious PC use. MSI provided a relatively low-end graphics card for this build, so if you have the budget, we'd recommend the 3060 or 3070 instead.

MSI's AIO cooler, the MEG CoreLiquid S280 is a dual-fan (2x 140mm) design. The MPG A1000G 1000W power supply is overkill, but gives plenty of overhead for future upgrades. A realistic power draw here is 480W, so we'd go for a 600W PSU.

For the CPU, Intel graciously offered an i9-12900K, which is total overkill when matched to the RTX 3050. For RAM, we found 32GB of Corsair's Vengeance DDR5-4800, again overkill for this system, but will definitely max out the performance of the chip.

INGREDIENTS

PART		STREET PRICE
Case	MSI MPG Sekira 100R	$120
Motherboard	MSI MPG Z690 EDGE WIFI DDR5	$320
CPU	Intel Core i9-12900K	$610
GPU	MSI GeForce RTX 3050 GAMING X 8G	$360
Memory	Corsair Vengeance 32GB (2 x 16GB) 4800MHz DDR5 C40	$285
PSU	MPG A1000G 1000W	$180
Storage	MSI Spatium M480 Play M.2 2280 PCIe 4.0 2TB	$330
CPU Cooler	MSI MEG CoreLiquid S280	$220
OS	Windows 11 Home 64-bit OEM	$32
Total		$2,438

msi
msi

One-manufacturer build with MSI

1

ENTER THE DRAGON

I start with MSI's dragon-emblazoned Sekira 100R Case —a full-size chassis that's compact and won't take up a lot of space. The case comes with four RGB fans pre-installed—three of which are in the front and one at the rear. There's also space for two more fans at the top, which I'll end up using later (see step 7). The case is easy to take apart—a top panel keeps both the glass panel on the left side and the metal panel on the right stay in place. The trickiest part is the cable management on the rear, as you need to keep cables flat to slide the panel back on. I bent a set of pins on the RGB controller as a result of our messiness.

2

FANNING THE FLAMES

The next step was to install the radiator before doing anything else with the case. The front of the case features a window, but only halfway down the cover, meaning you can only see half of the RGB fans. I decided to remove all of the RGB fans from the front and put two of them at the top later in the build. I installed the non-RGB fans that come with the cooler in the top part of the case front, as they'd be obscured by the metal part of the cover anyway. In hindsight, I should have made things easier and put the rad at the top of the case, but I still think that it is better at the front. MSI's radiator is dead easy to install as it's relatively small, although the large cooling block is a little cumbersome. I removed the large plastic cover over the display to make the build a little easier.

3

CENTRAL INTELLIGENCE

Next, it was time to start adding components to the motherboard while it was outside of the case. I started with Intel's chipset by unhooking the socket's arm, opening the latch, and simply dropping the chipset into place. It should sit comfortably on the motherboard with the writing on the chip facing up and not moving laterally once in place. The bracket requires a little force to hook it back under and hold the processor in place, but nothing to be afraid of. One challenge I faced was that MSI's cooler comes with an LGA1700 bracket for Intel chips but this wasn't included in the package—presumed missing after doing the rounds with other reviewers. No matter, I pilfered the bracket from Sam's NZXT H1 chassis and that worked fine. Make sure your cooler comes with the right brackets and order separately if needed.

4

SPATIUM STATION

MSI's Spatium M480 Play SSD isn't half chunky, coming as it does with a heatsink that makes it compatible with Sony's PS5 console. I removed the cover on the motherboard and had intended to reinstall the heatsink pre-installed on its cover. However, after opening the SSD drive's box, the first thing I saw was a warning against taking the heatsink off. I ignored this and began removing the screws on the drive holding it in place. It remained difficult to remove thanks to whatever adhesive MSI has used. "You win, MSI", I thought, and put the screws back in place and screwed the drive into the motherboard as is. One of the benefits of using all-MSI components is that everything matches, and looks pretty good to boot. Our photographer, Olly, who has an aversion to MSI's dragon logo, begs to differ, however.

5

RAISE THE ROOF

Before adding the graphics card to the newly-installed motherboard, I figured I'd use two of the three RGB fans left over and add them to the ceiling as exhausts. Should I have done this before installing the motherboard? Sure! But this is only my second Maximum PC build, so it's a lesson for next time. Besides, these fans are relatively small and the mounting screws are screwed in from the top of the case on the outside, so it wasn't fiddly. The lighting on these fans is controlled by a pre-installed unit on the rear of the case, which has a single RGB connector that goes to the JRAINBOW1 header on the motherboard. This unit controls lighting only, so you need to connect the fan leads directly to the motherboard. Thankfully, this mobo has plenty of SYS_FAN headers for the five fans inside this case, so no problem there.

6

GRAPHIC CONTENT

MSI's RTX 3050 Gaming X is fairly compact inside the case thanks to its twin-fan design. Before I install it, I need to remove two of the shields in the rear of the case. MSI's case design means that the screws holding these shields in place are covered by another metal shield, which has holes to get a screwdriver through. I found this fiddly and unscrewed the shield during installation. The RGB logo can be controlled by MSI's Mystic Light app. The graphics card also boasts a higher boost clock of 1845MHz over the standard 3050's 1777MHz boost clock for some minor performance gains. I also found the card relatively easy to buy, at the time of writing, indicating that it's of limited use to crypto miners or not profitable enough for scalpers. The only catch is that it's still $100 more than the RRP of the standard RTX 3050.

7

RAMPED UP

Completing the motherboard construction phase of the build is the RAM. As this is a DDR5-compatible motherboard, I brought out the big guns—two sticks of Corsair Vengeance 16GB 4800MHz performance DRAM, which Corsair had kindly provided previously. We tried other manufacturers to see what DDR5 they had, but found it difficult to get anything—perhaps a sign of the low demand for the faster standard given the inflated prices or continuing low stock levels. At $285, this kit is nearly double that of Corsair's DDR4 Vengeance kits such as the LPX or RGB Pro. This is an area where you can save money without a huge performance hit, especially if you have DDR4 sticks already. If that's the case, opt for the DDR4 model of this motherboard, which will save you some money while you wait for DDR5 prices to fall.

8

COMBINING THE TWO

With the motherboard now sporting all components except the graphics card, it's time to get it into the chassis. However, I couldn't find the nine short screws required, probably because some of these components had been used elsewhere. Thankfully, I have a magnetized drawer of spare screws for such emergencies and with the motherboard in, it was time to connect the CPU cooler. I applied an LGA1700 mount on the rear of the motherboard, where there is a hole in the case. I screwed the bracket around the four corners of the CPU, grabbed the cooling block, and used a screwdriver to tighten it into place. I made sure the tubes that connect the radiator to the block sat above the block itself, as it has an IPS display that shows the temperature, weather, and a host of other information.

9

WATT THE HECK

I've put it off for as long as possible, but it's now time to install the power supply and connect the power cables. To MSI's credit, this stage is pretty easy thanks to its compact size and the fact that it's fully modular. I tend to work from top to bottom when it comes to power, so I start with the CPU power cable at the top of the motherboard, then add in the motherboard power cable, the GPU power cable, and the SATA power cable used for the fan lighting. The Sekira 100R comes with 3.5-inch hard drive bays at the bottom of the case, next to the power supply. Because I'm not installing any mechanical drives in this build, I unscrew this bracket to make as much room as possible for the power cables. While I'm at it, I remove the 2.5-inch drive bracket that sits just below the motherboard to make things look cleaner through the window.

10

CONNECTING WITH NATURE

The next fiddly task is flipping the case on its side and connecting all of these power cables and header cables onto the motherboard. This isn't a massively roomy case, but it's still relatively easy to connect the cables where they need to go, and the all-black finish to the MSI components and cabling certainly appeals to the stealth fan in me. There is some RGB from the fans and the GPU when I turn it on, but I do like the uniform look of this all-MSI build. The most fiddly part of any build is connecting cables to the motherboard headers, and that's no different here—there are five fan power cables to connect all over the motherboard and I needed someone to hold a phone flashlight when connecting the various case headers such as reset and power button. I also added the plastic cover to the CPU cooler, which easily clips on with no screws.

11

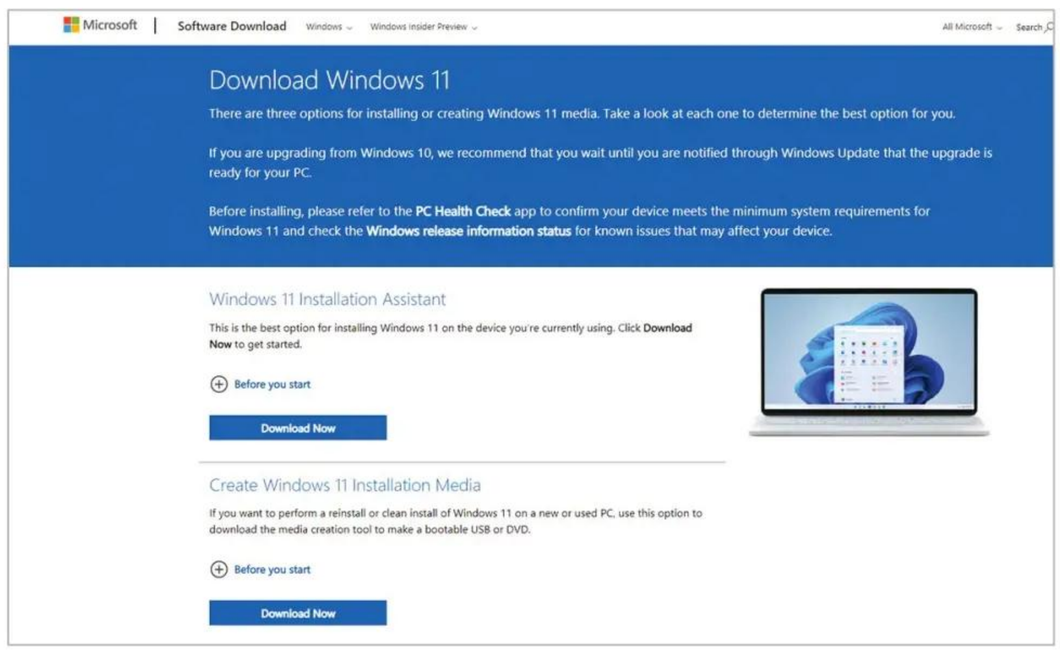
TIE ME UP! TIE ME DOWN!

Excited to get all of the case panels back on and the system powered up, I was halted in my tracks by my less-than-stellar cable management. To my credit, I had been feeding excess cabling through the case's velcro ties but, as a result, created thick bunches of cables that put pressure on the side panel, preventing it from locking into place. In the process, I also pulled on one of the RGB cables and damaged two pins of the controller, which I bent back into place. I then spent 15 minutes releasing some of the cabling out of the ties, running it up to the holes in the top of the case, then tucking excess power cables behind the PSU, where there was plenty of space. The result isn't the cleanest looking back-panel I've managed, but MSI's various cables were nice and long and it won't be visible.

12

WIN-D'OHS

After putting the case back together, I headed to the Microsoft site on my laptop to create a Windows 11 installation disk and waited for it to download. After an installation error, a different USB stick fixed the issue. Windows 11 was installed within an hour, and one hour later, I'd performed the latest Windows updates, installed Nvidia's graphics software, and downloaded MSI Center from the Microsoft Store. Having one app to control all the computer's functions, from lighting to temperatures and overclocking, makes a nice change from using a myriad of different software. It also makes it easy to keep the motherboard drivers and firmware up-to-date to maximize the system's performance. MSI apps won't win any design awards, but it's all there if you want to tinker.



1 MSI's CPU cooler comes with a 2.4-inch IPS display that can be configured to display information on the temperature, weather, images or video, and more.

2 We hope you're fans of the MSI dragon logo, as there are no less than four visible through the window of the case. We do like the uniformity though.

3 We like the restrained amount of RGB in the case, which just adds a splash of colour to an otherwise stealthy look.

4 This case comes with a removable 2.5-inch caddy below the motherboard, but we took it out to complete the clean aesthetic.

THE CONCLUSION

Creating an all-MSI build using its latest components was a fun and relatively trouble-free experience that resulted in a satisfyingly uniform look. The stealth black look on the major components helped the lighting on the fans, GPU, and heatsink block really pop, and I was particularly enamored with the relatively small footprint of the case itself.

Our benchmarks demonstrated a few interesting results as we opted to compare it to a couple of other recent Intel 12th generation builds. In both our April 2022 Intel 12th gen build and May 2022 Intel NUC build, we used the Gigabyte GeForce RTX 3050 Gaming OC card, which outperformed MSI's card by up to 20 percent in a couple of our tests, thanks to its higher core clock speed of 1822MHz compared to MSI's 1552MHz. At just $20 more, keep an eye out for Gigabyte's card if you're in the market for an RTX 3050.

On the positive side, MSI's Spatium drive lived up to its promised speeds, massively outperforming the PCIe 3.0 Samsung 980 drive in comparisons, and even outperforming the PCIe 4.0 WD_BLACK SN850 drive from last month's Intel NUC build, particularly on sequential write speeds. MSI's drive even keeps up with the best drives from our SSD group test in the previous issue, featuring the likes of XPG, Seagate, and Samsung.

The Cinebench score disparity was also eye-opening between the top-end i9-12900K in this build and the mid-range Intel Core i5-12400. The faster DDR5 RAM in this system may also have something to do with this, but given other benchmark tests, we suspect it's negligible. If you're doing a lot of CPU-heavy operations, it may be worth going for the more expensive i9 chip, or at least something in between. If you're a gamer though, it's clear that Intel's 12th gen Core i5 chip is more than enough when paired with the RTX 3050.

What are the benefits of going all-MSI on this build? Aside from a Windows 11 installation issue that required us to change USB flash drives, it was a simple build, but we'd expect that even if we had used different manufacturer's components. What we enjoyed most, though, was being able to use MSI's Dragon Center software in Windows to control every element of the system.

MSI also supplied us with a GK50 Low-Profile TKL Keyboard (reviewed in our March issue), a Clutch GM41 wireless mouse, MPG Artymis 273CQRX-QD monitor, and GV60 microphone—all of which could be managed from one single piece of software. On my personal PC, I run a Gigabyte motherboard, Logitech peripherals, and a Razer headset, and have so many different apps that I never bother changing the settings. It made me think about going single-manufacturer in my next personal build. See you next time!

BENCHMARKS COMPARISON

	ZERO-POINT	
3DMark: Fire Strike (Index)	14,995	14,757 (-1.6%)
CineBench R15 Multi-Thread (Index)	1,778	3,890 (118.8%)
CrystalDisk Q32T1 Sequential Read (MB/s)	3,557	7,106 (99.8%)
CrystalDisk Q32T1 Sequential Write (MB/s)	2,779	6,814 (145.2%)
Total War: Warhammer II (fps)	72	65 (-19.7%)
Rise of the Tomb Raider (fps)	113	107.55 (-4.8%)
Tom Clancy's Ghost Recon: Wildlands (fps)	57	49.62 (-13%)

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Our zero point is April 2022's Intel 12th Gen Cover Build, which featured an MSI MAG Z690 Tomahawk DDR4, Intel Core i5-12400, Gigabyte GeForce RTX 3050 Gaming OC 8GB, Corsair Vengeance 16GB DDR4-3200, and Samsung 980 1TB SSD. All game tests are performed at 1080p at the highest graphical profile.

RYZEN AGAIN The resurrection of AMD

Five years ago, AMD nearly went to the wall. Now, it has the edge on Intel and Nvidia, and billions in the bank. Jeremy Laird investigates its dramatic resurgence

Make a note of the date, 22nd February 2022. That was the day AMD's market capitalization—essentially, its overall value as a company—surpassed Intel's for the first time. It was nothing less than a spectacular reversal in fortunes for a company that had been on the very brink just a few years earlier. Forget wondering whether AMD can even survive, it is now an entirely legitimate question to ask whether AMD can overturn Intel's dominance of the PC. Truly, AMD has become the pretender to Intel's throne.

Of course, stock prices don't tell you everything about a company's real-world proportions. Intel still has a 75 percent market share for PC processors and generates massively more revenue and profit than AMD. But the notion of AMD as the usurper of Intel's position as the predominant purveyor of PC processors and platform technology is now more plausible than ever.

How, exactly, did AMD turn it around? Now that's a question. As we'll see, a little bit of luck didn't hurt. But as the saying goes, you make your own luck and there's absolutely no denying the heightened competence and consistency with which AMD has been led since Lisa Su took over the company in 2014.

All told, AMD's recovery from near oblivion makes for a fascinating story of corporate and technological rejuvenation.

IT IS NOW AN ENTIRELY LEGITIMATE QUESTION TO ASK WHETHER AMD CAN OVERTURN INTEL'S DOMINANCE OF THE PC

Left: AMD's Zen 3 architecture is keeping Intel's latest Alder Lake CPUs honest

Below: Due later this year, Zen 4 will pack 5nm technology and a massive 40 percent increase in single-core performance

UNDENIABLY INTIMATE. Often symbiotic. And occasionally parasitic. Such has been AMD's relationship over the decades with its greatest rival, Intel. Truly these are two companies with a shared destiny. The story of AMD begins way back in 1969. Inevitably, Intel looms large right from the beginning. AMD was founded by eight former employees of Fairchild Semiconductor and headed up by none other than Jerry Sanders, former marketing boss of Fairchild and the leading figure in AMD's early years. It was only 12 months earlier that Robert Noyce and Gordon Moore also left Fairchild to set up... you guessed it, Intel.

Both of the companies set out to make an impact in the nascent integrated circuits business, otherwise known as computer chips. But from the start, they took different paths. Intel went heavy on the R&D to create its own designs, while AMD opted for the quicker and less expensive route to market by being a so-called second source supplier of microchips designed by Fairchild and National Semiconductor.

Second sourcing is all about securing reliable component supply and not depending on just one company. You can read how AMD went from a second source supplier of IBM-compatible CPUs to sharing full access to Intel's all-important x86 instruction set in the boxout on page 37. But suffice to say, by the early 1980s, AMD was carving out a niche as the leading alternative to Intel in the PC processor market.

Intriguingly, AMD was much more competitive during this early period than the standard narrative of perennial underdog allows. The usual refrain around AMD's latter-day success with its current Zen-based CPUs involves the mighty K8 series, the architecture that underpinned the Athlon 64, as the only substantial example of AMD getting one over on its arch-nemesis. But the real story is much more complicated than that.

As early as 1984, AMD was manufacturing Intel's 286 processor as a second source supplier to IBM but achieving up to 20MHz clockspeeds whereas Intel's in-house chip topped out at 10MHz. The 386 era was something of a hiatus as AMD and Intel feuded over rights to the x86 ISA, but when AMD eventually managed to reverse engineer the Intel chip, just like the 286, AMD's take on 386 outclocked its Intel rival.

It wasn't until the Pentium era in the mid-1990s, however, that AMD attempted its own true in-house design, the ill-fated K5. Arguably AMD's first major failure, K5 arrived later than planned in 1996, missed its clockspeed targets, and generally couldn't compete with Intel's then protagonist, the Pentium Pro. AMD recovered with the K6 the following year and kept Intel honest right through until late 2003, often landing significant blows with chips like the K7, otherwise known as the first Athlon processor, but never quite knocking Chipzilla out. That brings us to a pivotal moment in AMD's history, the arrival of K8, the mighty Athlon 64.

Codenamed Clawhammer, the Athlon 64 was the first desktop CPU to deliver 64-bit instruction capability to the desktop. Not only that, but it also delivered outstanding per-clock performance at a time when Intel's Pentium 4 Netburst architecture was hitting a frequency wall. Once intended to scale all the way to 10GHz, Intel found clockspeed gains increasingly tough beyond 4GHz. The Athlon 64 wasn't just competitive, it absolutely trounced the Pentium 4.

K8 was killer in server systems, too, thanks to its advanced integrated memory controller and HyperTransport interlink, which made Intel's Front Side Bus and northbridge technology look every bit as antiquated as it was. K8 should have been the moment when AMD finally became Intel's equal. But, somehow, AMD let that advantage slip. As the years ticked by and K8 and its descendants aged, AMD's product execution got worse and worse. Not only did AMD fail to release a truly new core architecture for eight years following the original K8 but when it did make a major revision, taking K8 quad-core and calling it K10, AMD managed to add a serious flaw, known as the 'TLB bug'.

From there, the K8 line never truly recovered. By the late 2000s, something radical and new was required. That something turned out to be Bulldozer. Intended to be the once and future king of CPUs, Bulldozer instead became the villain of the AMD story, the architecture that nearly brought the company down. Released in late 2011, Bulldozer was by many measures the most advanced and forward-thinking PC processor AMD, or any other company for that matter, has

ever produced. It unceremoniously ditched conventional thinking around CPUs containing multiple almost entirely discrete CPU cores in favor of a much more complex and highly integrated architecture designed around modules.

Each module contained a pair of integer units and shared not only its instruction decode and retire hardware but also L1 and L2 cache along with a single floating-point unit. Unlike anything AMD and Intel had produced before, the thinking behind Bulldozer was to produce smaller, more efficient chips that would deliver exceptional multi-threaded performance for a given die area.

BULLDOZER ISSUES

Marketed as the AMD FX, part of the problem with Bulldozer was that it did not contain conventional cores that could easily be compared with Intel's CPU or even AMD's legacy designs. The first top-of-the-range FX 8150 chips were packed with four Bulldozer modules, but AMD chose to pitch them as eight-core CPUs. While a Bulldozer module was clearly more complex than an Intel CPU core, such were the extensive shared resources in each dual-integer module that single-core performance was disappointing despite running far higher 4.2GHz peak clockspeeds compared to its predecessor, and indeed, Intel's 3.8GHz Core i7-2600K competitor.

And when we say disappointing, we mean it. Not only was Bulldozer slightly slower than AMD's elderly and outgoing Phenom II K10-based CPUs when it came to single-core workloads, but Intel's 2600K was also roughly 50 percent faster. Compounding the single-core performance problem was the fact that the PC software ecosystem had yet to fully embrace the multi-threaded model, something that was particularly true of games, not least because the prevailing iteration of Microsoft's DirectX multimedia API had poor support for multi-core CPUs.

The upshot? Bulldozer had limited opportunity to do its multi-core thing. But even when it could, it was more a case of closing the gap to the merely quad-core 2600K than actually overtaking it. Bulldozer definitely did not perform like a full eight-core CPU and it was, by any sane measure, a failure. The consequence for AMD's business was catastrophic. In 2012, AMD lost over $1billion. By mid-2015, most industry observers were predicting AMD would go bankrupt. In total, it took five long years for AMD to return to profit.

The story of how AMD turned things around from the Bulldozer debacle obviously centers on Zen, the CPU architecture that saved the company. But there's plenty more to AMD's revival besides. Indeed, some aspects of AMD's recovery date back to long before Bulldozer appeared, let alone Zen. In 2008, AMD announced plans to spin off its in-house foundry, the part of the company that fabricated CPU dies, into a new, separate entity known as Global Foundries.

At the time, the move looked like a desperate measure to inject funds into an increasingly cash-starved business than a positive long-term strategy. However, the latter is exactly how things have now turned out. When AMD ditched its own fabs, Intel had long been the undisputed world leader in chip production. More recently, Intel's fabs have been in serious trouble. Its 10nm node has taken so long to come up, that Intel felt the need to rebrand it 'Intel 7' to make it look more competitive. Intel 10nm was at least five years late when it came fully on stream last year.

All the while, AMD has been a customer of TSMC, the Taiwanese foundry that now has a clear edge over everyone else when it comes to process technology. Such is TSMC's current technological advantage, Intel has made the humiliating move of announcing plans to farm out some of its own chip production to the Taiwanese outfit. Admittedly, TSMC's 7nm node is probably only comparable to Intel's 10nm node in terms of transistor density and efficiency. But AMD was able to start producing CPUs on the TSMC 7nm in mid-2019. It would take Intel another 2.5 years to launch its first 10nm desktop processor, the 12th Gen Alder Lake CPU.

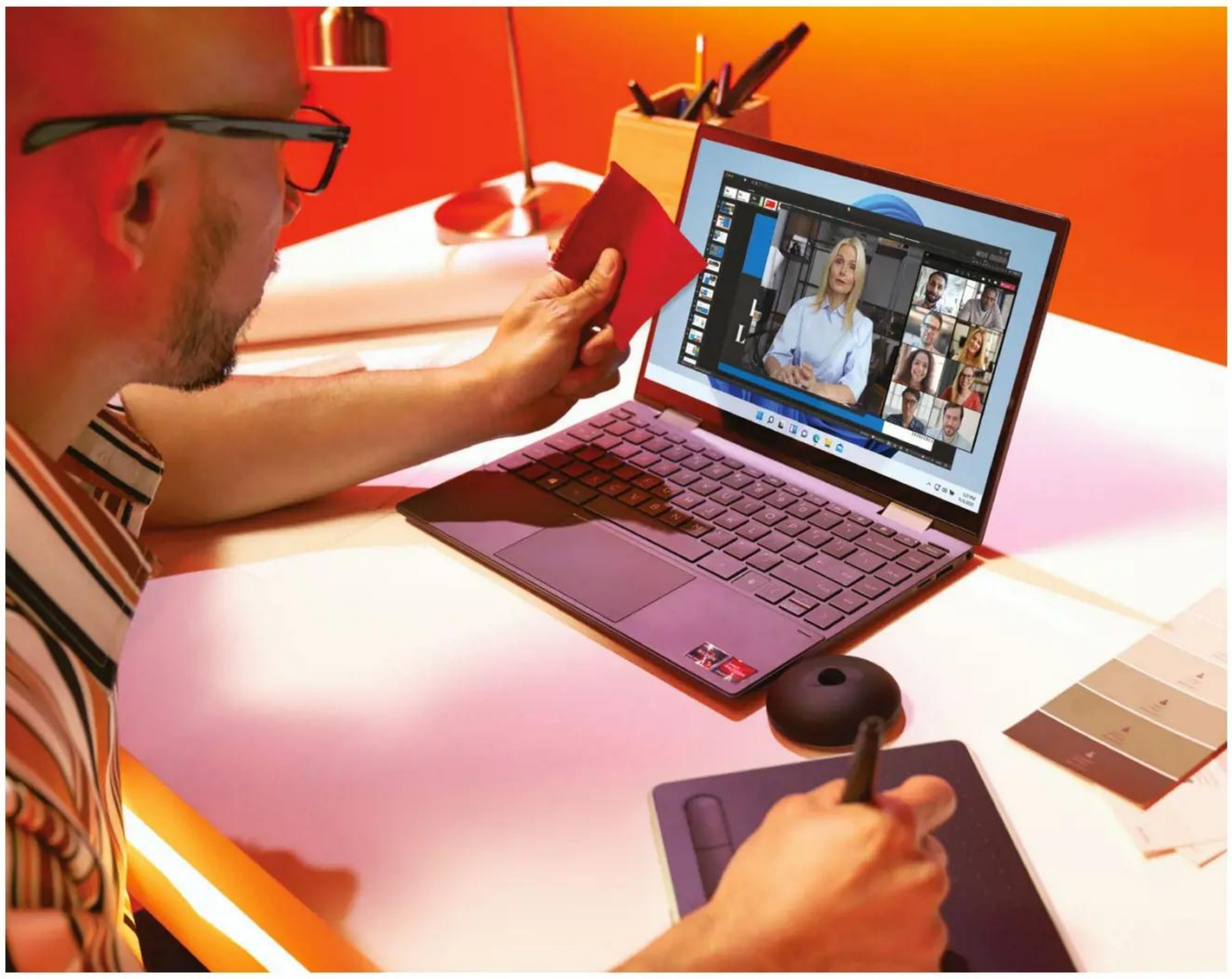
TSMC ADVANTAGE

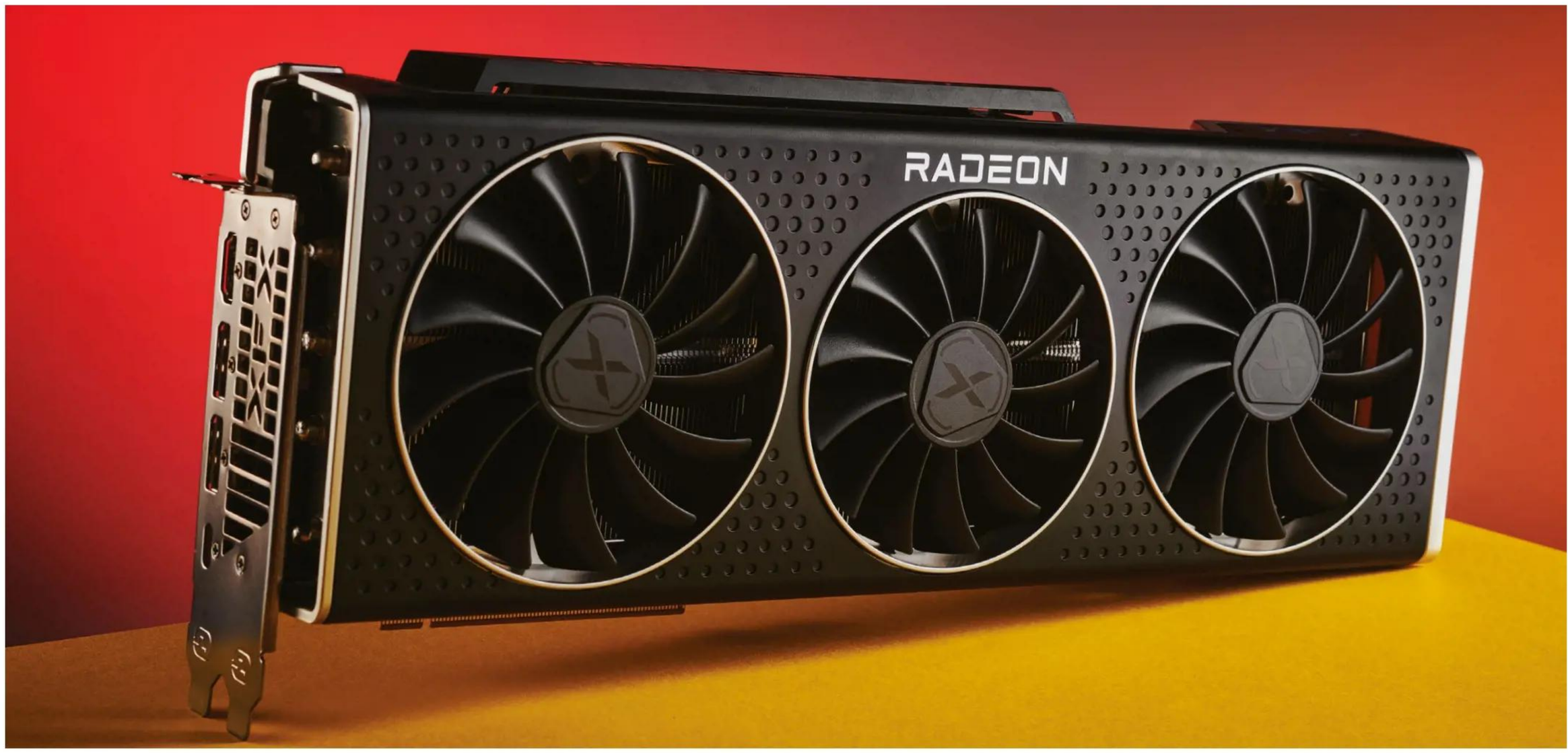
Making matters worse for Intel, TSMC has actually been producing chips on its even more advanced 5nm node since 2020 for other customers, most notably Apple. AMD is due to launch its first 5nm CPU later this year. We don't expect Intel to release TSMC's-produced CPUs until at least 2023 and it's likewise doubtful whether we'll see chips based on Intel 4, the direct competitor to TSMC 5nm, before the end of next year, either. In short, it turns out that selling off its fabs and partnering with TSMC has given AMD a huge advantage in terms of production technology. Maybe that was planned. Maybe it was luck. But it's been absolutely critical all the same.

Another part of the current recovery that actually began before the Bulldozer debacle involves graphics. Back in 2006, AMD snagged Canadian graphics outfit ATI. At the time, the deal looked dubious, not least because AMD paid a cool $5.6 billion in cash and shares for ATI, or around half of what AMD itself was worth at the time. Not only was the acquisition a real stretch financially, just 18 months later, AMD had written down nearly $3 billion of that investment in ATI, which was over half of its value gone. It looked like a complete disaster.

If those early ATI numbers were a fiscal car crash, the long-term strategy was actually sound. Acquiring ATI put AMD in the unique position of being able

Below: AMD's Ryzen mobile CPUs are even more competitive than its desktop chips





Above: AMD's RDNA 2 cards pack a punch, but RDNA 3 will be the next big leap forward when it arrives later this year

to offer both high-performance processors and cutting-edge graphics. Intel's graphics capabilities were limited at the time and even now it has yet to prove the new Arc project will amount to truly competitive GPUs. Meanwhile, not only has Nvidia lacked an x86 CPU product of any kind, it lacks the licensing required to even contemplate competing in that market.

As it happens, one of the most obvious direct benefits to AMD of that CPU-GPU nexus enabled by ATI involves not the PC, but consoles. Thanks to AMD's unique ability to offer its customers both processing and graphics, in 2013 not only the Microsoft Xbox One but also Sony's PlayStation 4 were launched with AMD power. Admittedly, per-unit revenues for AMD from consoles at the time were thought to be puny. However, with millions of consoles sold AMD was pulling in the vital cash that it needed. By the end of 2013, AMD actually turned a profit for a quarter or two, despite its core CPU business still shrinking at the time.

Granted, AMD's losses continued to swell through 2014 and 2015. But the console deals provided a vital flow of money during its most precarious period. Those console design wins had other benefits besides the pure cashflow. First, those console APUs, which combined AMD's low-power Bobcat CPU cores with its GCN or Graphics Core Next graphics IP, proved that AMD could adapt and integrate both halves of its main businesses into a single-chip product with bespoke elements for customers. Owning the IP in both major consoles also meant that nearly every significant game was built primarily to run on AMD's GCN graphics architecture, including most triple-A PC games.

If those are the background stories, the most important elements of AMD's new dawn actually fell into place remarkably soon after the release of Bulldozer. As the late 2000s bled into the early 2010s and the Bulldozer era, AMD was running out of options with its existing product lines.

The foundries had been sold off, while opportunities from ATI's graphics IP had been maxed out on console and ATI's mobile graphics IP had been offloaded at arguably far too low a price to Qualcomm. Incidentally, the result of that particular fire sale was the Adreno graphics core found in so many smartphones today. Adreno is, of course, an intentional anagram of Radeon, ATI's, and then AMD's consumer graphics brand.

Whatever, there was nothing AMD could do but dig out of trouble the old-fashioned way, by building better products. But better products don't just appear. Living, breathing people make them. And that's precisely where two key figures enter the equation, Lisa Su and Jim Keller. You can read all about Lisa Su's contribution in the boxout on page 39. But the short version is that her leadership has been critical in AMD's renaissance. If AMD wouldn't have begun without Jerry Sanders, it wouldn't have survived without Lisa Su.

As for Jim Keller, without his contribution, AMD would have struggled to turn the corner, too. Keller, of course, had been at AMD before, most notably as the lead architect on the now mythical K8 or Athlon 64. Since his last posting at AMD, among myriad other things, Keller did a stint at a certain computer outfit known as Apple. Anyway, Apple is famously secretive about almost everything. But many industry observers credit Keller with key elements of Apple's A4 and A5 iPhone and iPad SoCs.

The A5 in particular laid the foundations for what has become Apple's utterly dominant position when it comes to smartphone performance and efficiency. Ironically, that technical advantage is now spilling over into full-function computers as Apple transitions its Mac systems to in-house silicon derived from that same line of iPhone and iPad chips.

So, while Keller certainly made a huge contribution to AMD's revival, it could be his work while he was with Apple that eventually poses the greatest challenge to AMD's current business model, especially if it eventually forces the PC industry to adopt ARM technology.

If that's a story for another day, what has mattered for AMD's revival is Keller's involvement with Zen, the CPU architecture that turned AMD's fortunes around. As Keller himself says, his primary contribution isn't typically the nuts and bolts of a chip's architecture, though we suspect he's pretty knowledgeable when it comes to those elements. Instead, Keller

has always emphasized his role in getting people working together effectively.

GROWING AUTHORITY

According to an interview with Keller last year, he took the job at AMD on the proviso that he would be given broad authority for developing what was to become AMD's savior, the Zen architecture. When he arrived as CPU president at AMD in 2012, he had 500 people under him. By the time he left in 2015, that number had swelled to 2,400. As Keller quipped, with that many people under his command, he was "hardly writing RTL (the low-level abstraction that allows chipmakers to lay out the very wiring of a CPU)".

Keller says he operated under the assumption that everything about Bulldozer was bad. He wanted a clean slate and any existing technology needed to prove itself worthy of inclusion in future products. But as critical as his role clearly was, he resists the idea that he was the 'father' of Zen. In fact, Zen was designed by hundreds of engineers including an SoC team split between Texas and India, a group in Colorado was responsible for the floating-point cache, another in Texas did the core execution front end, while the architecture's broad methodology team was spread across the world.

Still, Keller's influence on Zen is undeniable and it's likely that every iteration of Zen so far, including the latest Zen 3 architecture in today's Ryzen 5000 Series chips, was laid out in at least broad terms as part of the long-term roadmap developed under Keller's leadership. Everything that we have seen so far from Zen is a Keller-era chip. All of which just leaves the minor matter of what makes Zen tick? Why has it been such a smash hit CPU design?

Revealed in February 2016 but not actually available to buy in the form of the Ryzen 1000 series CPUs until a year later, Zen was a ground-up new architecture just as Keller desired. In some ways, it was a more traditional design than Bulldozer and its highly-integrated descendants. Zen returned to discrete cores, each with its own fetch, decode, execution, and retire, plus L1 and L2 cache memory.

PIPELINE DREAMS

In fact, the entire pipeline was redesigned with shorter, more responsive instruction pipelines for more performance per clock, thereby dumping Bulldozer's clockspeed-enabling deep pipeline design. The net result was over 50 percent improvement in performance per clock from each thread compared with Excavator, the final iteration of the Bulldozer line of CPU architectures, and something in the region of 80 percent better by that same measure over the original Bulldozer cores. Granted, it wasn't enough to beat Intel for single-threaded performance. But AMD was back in the game, quite literally given how important single-threaded performance is to gaming.

Just as important as radically improving per-core and per-clock performance with the original Zen architecture was the shift to multi-chip modules with Zen 2. Instead of producing the entire CPU on a single die, the Zen 2 processor package contains multiple so-called 'chiplets'. Zen 2's 'compute' die was built on TSMC's 7nm node and contained eight cores. That was paired with a central 'I/O' die manufactured on Global Foundries' cheaper 12nm node and connected via AMD's Infinity Fabric links.

The I/O die is a hub for all off-chip communications, housing the PCIe lanes for the processor, plus the memory controller and aforementioned Infinity Fabric links to further compute chiplets. Yep, that's right, further compute chiplets. In other words, with Zen 2 AMD could add another compute die and in an instant take the total core count up to 16, far more than Intel offered at the time for desktop customers.

That physical modularity would eventually allow AMD to introduce crazy core count chips for the high-end desktop market in the form of ThreadRipper CPUs, eventually topping out at fully with the 64 cores. However, Intel's hitherto monolithic designs do have some advantages. Chip-to-chip latency in an AMD chiplet design can create performance bottlenecks in certain scenarios.

But, crucially, Intel's monolithic approach makes it slow to respond. Where AMD can, in theory, simply insert another compute die full of cores into the CPU package, Intel must design, tape out and optimize a whole new chip if a core count increase is desired.

COMPREHENSIVE ROADMAP

The final part of the Zen puzzle is what you might call roadmap execution. AMD didn't just wheel out the original Zen architecture in the Ryzen 1000 series chips and then call it a day, something it was arguably guilty of with K8. Under Lisa Su's overall command, Keller and his team laid down a multi-year, multi-generation roadmap of architectures with planned improvements and upgrades. And more important than just about anything else, AMD

HOW DID AMD END UP WITH TOTAL ACCESS TO INTEL'S PRECIOUS X86 ISA?

In the early days of desktop computing, the market was flo with competing and indeed incompatible microarchitectures. But IBM was on a quest for broad software compatibility, a vision it rightly thought would accelerate the adoption of desktop PCs. So, when IBM selected Intel's 8086 architecture for its nascent PC, it also dictated a 'second source' supplier for the very same CPU. Enter AMD as that second source supplier, manufacturing direct copies of the Intel 8086 under license.

When Intel declined to extend that license to include the 386 successor to the 286 in the mid-1980s, AMD was forced to reverse engineer the chip. Intel sued, lost, and eventually agreed to a license that allowed AMD to build chips around Intel's x86 instruction set so long as it didn't directly copy the architecture of its CPUs. If that licensing arrangement inevitably involved money in Intel's direction, all that ended abruptly in November 2009. Thanks to Intel's adoption of AMD's 64-bit extension of the x86 ISA, the original creator of x86 was no longer in a position to demand royalties from AMD and a comprehensive, royalty-free, cross-license platform was agreed upon. AMD is free to use x86, Intel is free to use x86-64 and neither pays the other party a penny.

Below: AMD's 64-bit extensions to the x86 ISA have put the company on equal footing with Intel

then executed that roadmap flawlessly. No delays. No major bugs.

In 2019 came the first really big upgrade in the Ryzen 3000 series and Zen 2. Although a development of the original Zen architecture and cores, it still increased single-thread performance by a hefty 20 percent and also upped the headline core count to fully 16 cores for mainstream desktop processors, far above anything Intel was offering. Just a few years earlier, when AMD was stumbling and Intel was allowing the CPU market to stagnate, four cores were the most you could have in this same segment. AMD was radically shaking up the market.

Next, in 2020 came Zen 3 in the Ryzen 5000 series. In many ways, Zen 3 is the Zen architecture fully realized. At a high level, it looks a lot like Zen 2. You have the same chiplet architecture with 7nm compute dies, each with eight cores, plus that 12nm I/O chiplet.

But every segment of the core has been redesigned, with major changes including wider INT/FP dispatch, larger buffers and execution windows, better branch prediction, and more. In total, AMD claims a further uptick in single-thread performance for Zen 3 of 19 percent compared to Zen 2.

But arguably the most important revision was to the layout of the eight-core compute die. Previous Zen CPUs had been composed of core complexes or CCXs containing four cores. Within a CCX, each core has its own L1 and L2 cache, while L3 cache is shared across the four cores. Of course, Zen CPUs contain more than four cores. The problem came when a core in a separate CCX needed access to data stored in the L3 cache of another CCX. That created cache latency and therefore impacted performance.

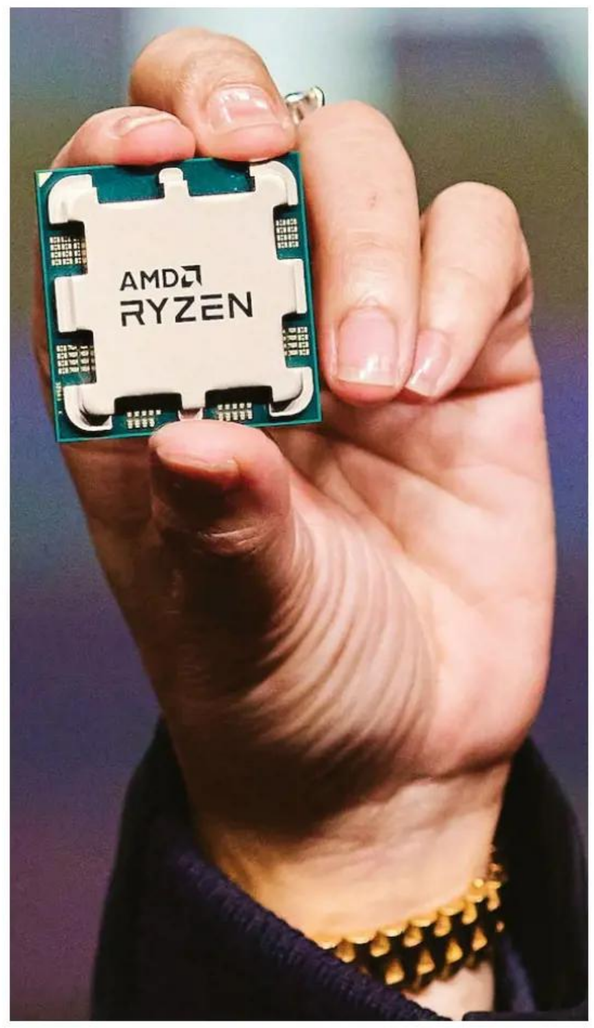
For Zen 3, the CCX size has been increased to eight cores. So, any Zen 3 chip with up to eight cores entirely avoids that occasionally debilitating CCX-to-CCX L3 cache latency. That's particularly important for applications like gaming that are acutely sensitive to cache performance. Workloads that more neatly lend themselves to parallelization, such as video encoding, aren't nearly as sensitive to cache latency. So, performance was already scaling very nicely with AMD's earlier quad-core CCX designs and indeed multi-chip CPU models.

Did we mention that as these desktop chips were rolling out, AMD was also making serious headway into the laptop market for the first time? If anything, AMD's Ryzen APUs have been even more competitive. Partly that has been down to superior process technology from TSMC that is even more critical for mobile chips than desktop processors.

That advantage arguably reached its zenith in 2020 when AMD launched the 7nm Renoir Ryzen 4000 APUs for laptops. Thanks to the inherent efficiency of the Zen architecture, plus the superiority of TSMC's 7nm node and the integration of AMD's Radeon graphics technology, all the while Intel was struggling to bring its 10nm node online, AMD found itself with a killer mobile offering to which Intel had absolutely no answer.

Renoir and its 2021 Cezanne successor are so much better than the Intel alternatives when it comes to both power consumption and performance, it allowed AMD to finally break into laptops in a big way. Mobile platforms have always been a tough nut to crack for AMD thanks to Intel's greater resources and ability to help PC makers integrate their chips into the thermal and physical constraints of a laptop. In the past, when AMD had managed to produce decent but not world-beating mobile CPUs, they made almost no impact on the market. But Renoir was so good that the biggest players in the PC market including Dell, HP, Lenovo, and Asus could no longer afford to ignore AMD. They had to build Ryzen into their laptops.

Right: AMD's CEO shows off its upcoming Intel killer, the Zen 4-based Ryzen 7000 CPU



Below: AMD's chiplet technology has enabled ThreadRipper CPUs with crazy core counts

FULL SPEED AHEAD

As if all that wasn't impressive enough, check out AMD's forward roadmap. Later this year, Zen 4 and the Ryzen 7000 series of CPUs is due. Not only will Zen 4 move to TSMC's more advanced 5nm node for the compute chiplets and 6nm for i/O, but it will also bring another big step in single-thread, per-clock performance of around 25 percent. Factor in higher clockspeeds, in part thanks to that 5nm node, and per-core performance will be up by a massive 40 percent.

At launch, we're not expecting more than 16 cores. But a 24-core mainstream desktop Zen 4 product is possible, while Zen 4 ThreadRipper Pro CPUs with a staggering 128 cores are expected.

Further out than Zen 4, things inevitably get more speculative, at least from an outsider's perspective. Zen 5 is surely a done deal from a design perspective, but little is publicly known about its core

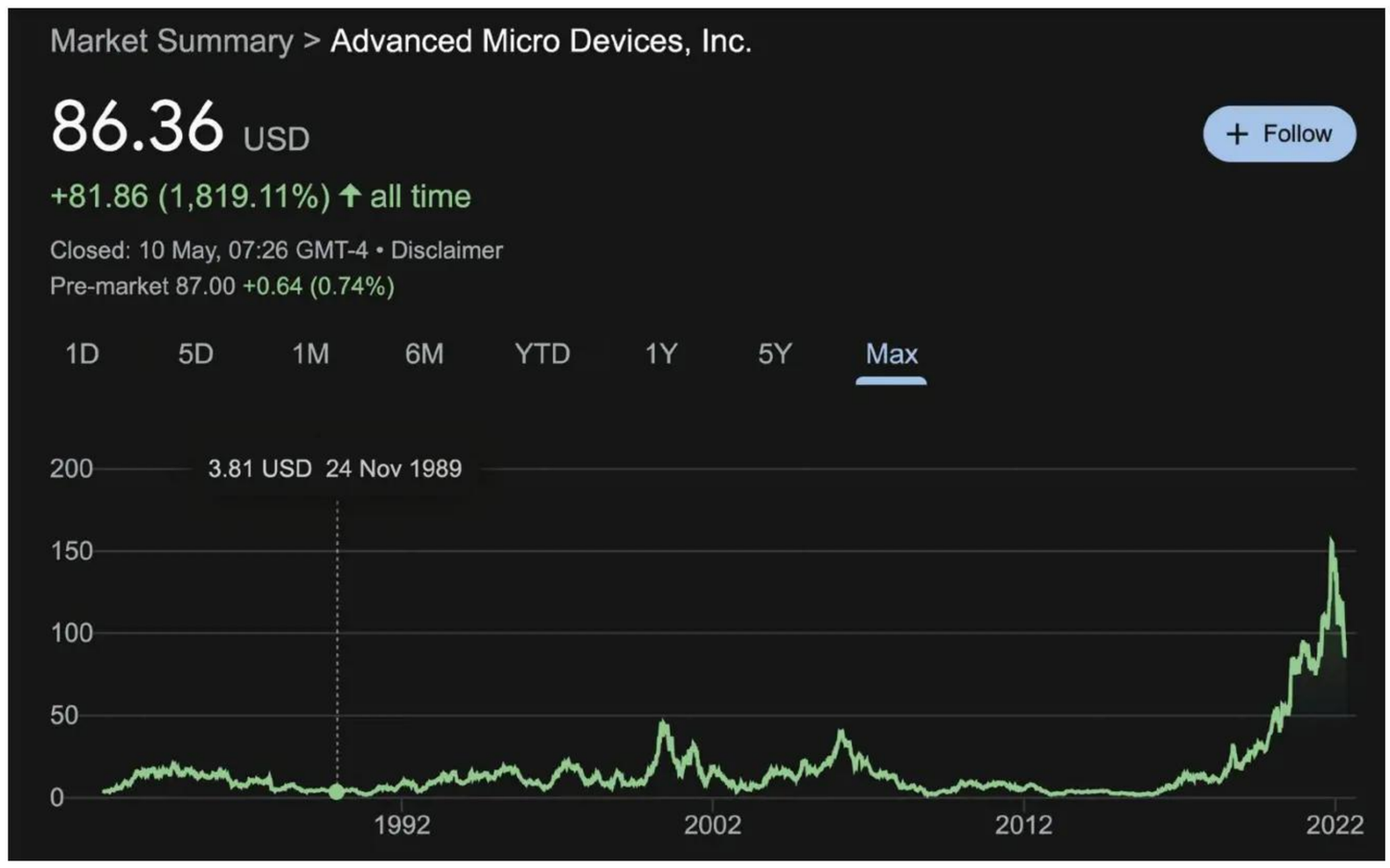
architecture or features. But if there's something about AMD's plans we'd most like an inside take on, it's any alternatives AMD may be working on to replace ye olde x86 instruction set.

How so? Apple's M1 chips in its latest Mac computers have comprehensively proven that ARM CPUs can compete on not just efficiency, but pure performance. Now more than ever, ARM looks plausible as a replacement architecture for x86 in the PC. Back when Jim Keller was running AMD's CPU business, there were indeed plans to hedge for that precise scenario with a modular CPU platform known as Skybridge that supported both ARM and x86 cores. The ARM version of Skybridge was codenamed K12 and originally due in 2016, but never actually appeared.

Last year, AMD's CFO Devinder Kumar said the company was "ready to go" with ARM CPUs if that's what the market required. For now, there are no announced ARM-based CPUs in AMD's roadmap. But we suspect Keller's work on K12 will position AMD well should the need arise. After all, it was that effort under Keller's leadership at Apple that laid the foundations for the all-conquering Apple M1 family of SoCs. If ARM does turn out to be critical in future, it also won't hurt AMD's chances that its rival Nvidia's attempts to acquire ARM itself have now failed.

If a transition to ARM for AMD and indeed the PC as a whole is a rather speculative notion, what we can say for sure is that AMD's prospects look better now than at any time in its history. Its current CPU products are as good as or better than Intel's by almost every relevant metric. And its graphics business is nearly as competitive as Nvidia's.

What's more, AMD's roadmaps for both CPU and graphics could well deliver it a clear performance and technological advantage over both of its key rivals by the end of this year. The best CPU and the best graphics chips from one company. The king of the PC? It's looking extremely likely that, by the end of 2022, it will be AMD.



Above: AAMD's stock price has fallen from its peak, but is still 2,000 percent up from when Lisa Su joined in 2014

JUST HOW BAD DID IT GET FOR AMD?

It's well known that AMD struggled in the mid-2010s. But just how bad did the cash crisis get? As the 2000s came to a close, AMD's business was turning sour. Profits of $360 million in 2010 and $491 million in 2011 flipped into a monumental loss of $1.18 billion in 2012.

In 2013, the bleeding subsided somewhat with a loss of $83 million, only for the losses to balloon once again to $403 million in 2014, $660 million in 2015, and $497 million in 2016. That's a total of $2.8 billion leaving the building over the course of six years. As for how close AMD came to folding, its cash balance of $1.9 billion at the end of 2011 had shrunk to just $716 million by mid-2016.

Clearly, that could not continue, which is why many industry analysts were predicting AMD would be bankrupt by 2020. Happily, that never happened and, by the end of 2017, AMD had begun to turn the ship with a small but symbolically important profit of $43 million. In 2018, AMD had stopped the rot, returning $337 million. A steady, if unspectacular, result of $341 followed in 2019.

But it was 2020 that proved AMD had truly entered a new era of high profitability, clocking up $2.49 billion of net income. The following year was even better at $3.62 billion, with 2022 looking set to be even stronger, with a $786 million profit in the first quarter, up a massive 42 percent on the same period in 2021.

If AMD carries on like that, it will breach the $5 billion profit barrier in 2022. And memories of the comapny's flirtation with bankruptcy just a few years ago will have been erased.

BUILD A $999 GAMING PC

How close can we get to that 1K sweet spot, and what kind of PC does it get you? Zak Storey finds out...

One of the most common questions we get asked by folks is how much they should be spending on their next rig. It's a tricky one to answer. The value of the dollar changes depending on the total available budget for a system, but there's also a secondary factor you need to consider, and that's one of price to performance. Once you get past a certain price point, the amount of performance you get for the money you spend inevitably begins to drop – in some cases, rather dramatically.

Take AMD's Threadripper 2970WX, for example. At stock, it scores a fairly heady 4,407 points in Cinebench R15. Compare that to a Ryzen 5 2600's 1,274 points, and that's a 246 percent increase in performance. However, each dollar you put into the 2970WX effectively gains you 3.39 points, against the 2600's 6.71 points per dollar, which is an increase in value of near enough 98 percent.

So, this is our 'sweet spot' build. The rig of choice for those trying to get the most bang for their buck today. It's not the most value-oriented system out there, nor does it cater toward the high end, but if you're trying to make every single dollar count, this is a really good place to start.

INGREDIENTS

PART		PRICE
CPU	AMD Ryzen 5 2600	$160
GPU	XFX Radeon RX 590 8GB Fatboy OC+	$280
Mobo	MSI B450M Mortar	$95
Memory	16GB (2x 8GB) HyperX Predator @ 3,200MT/s	$157
SSD	480GB Adata SU630 2.5-inch	$58
Cooler	Stock (AMD Wraith Stealth)	$0
PSU	500W Cooler Master MasterWatt Lite	$50
Case	Thermaltake Level 20 VT	$99
OS	Windows 10 Home (64-bit)	$100
Total		**$999**

PRICES CORRECT AT TIME OF PRINTING.

PROCESSOR

AMD RYZEN 5 2600 $160

What AMD has done to the CPU market is nothing short of incredible. The value proposition Ryzen represents is staggering, and nowhere is this more apparent than with the Ryzen 5 2600. Six cores and 12 threads for $160 is simply amazing. Couple that with it being the best value-for-money processor in our testing, plus the fact it's unlocked for some serious overclocking, and you're quickly on to a winner.

In-game performance has increased by leaps and bounds since first-generation Ryzen as well. This is mostly down to memory latency improvements and added game support for the new architecture.

GRAPHICS CARD

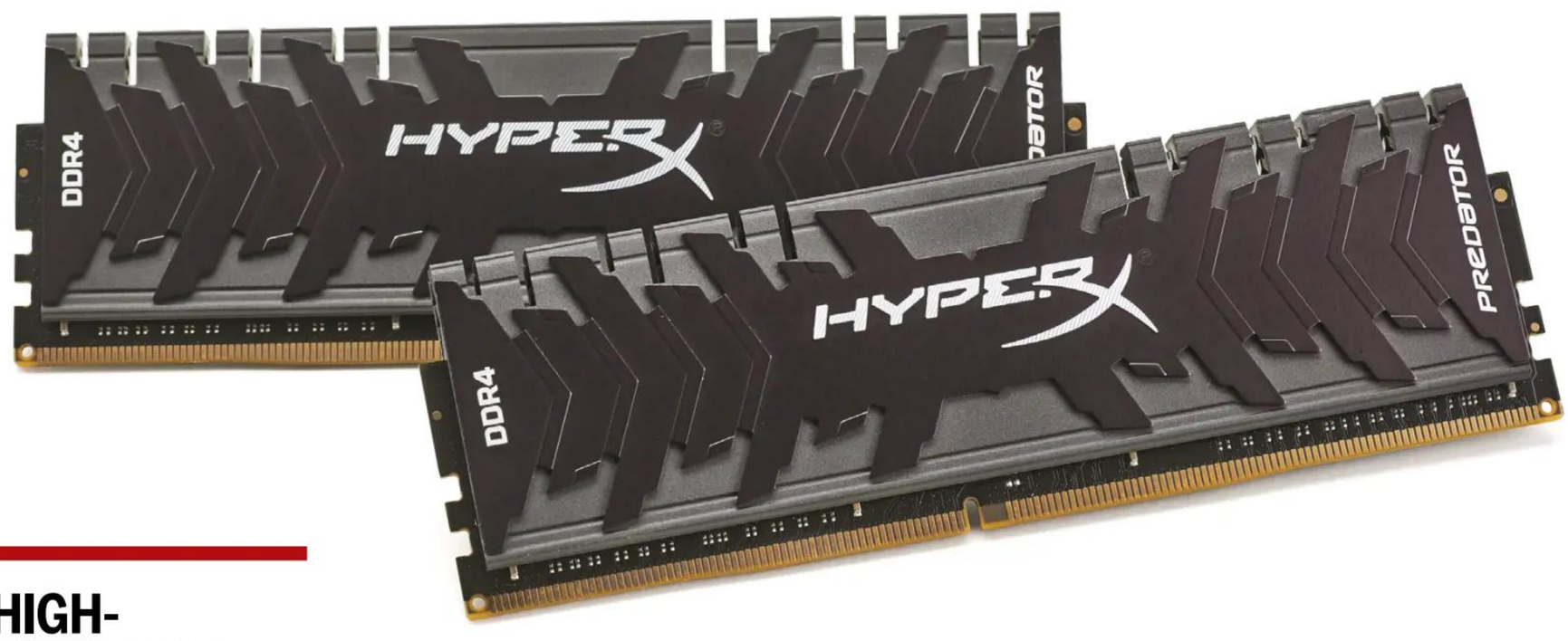
XFX RADEON RX 590 8GB FATBOY OC+ $280

We may have given the RX 590 a hard time over the previous few issues, but that's only because it's a refresh of a refresh, and like a disappointed parent, we just want AMD to do better. If you're building a brand new rig, however, it's hard to argue with Team Red's pricing on this GPU. In fact, it's the best bang-for-the-buck GPU we've found. XFX's iteration, the Radeon RX 590 8GB Fatboy, is a clean-looking piece of hardware. Perhaps a bit garish, with its faux carbon fibre and bright red fan stickers, but of the two 590 options we have (this and the baby blue monstrosity from Sapphire), this is our preferred choice.

MEMORY

16GB (2X 8GB) HYPERX PREDATOR @ 3,200MT/S $157

Ryzen thrives on high-frequency memory, and for now, the sweet spot seems to be the 3,200MT/s mark. Although, admittedly, this isn't quite the cheapest kit out there, we feel that 16GB – at least for now – is the perfect amount for any 1080p and 1440p gaming machines. It's also enough for any multitude of programs, enabling you to run Chrome tabs, Discord, and a game all at the same time, without too much trouble. It's also ideal for non-3D Photoshop work, and to get your head into the world of Premiere Pro, too – although After Effects would, of course, benefit from more memory.



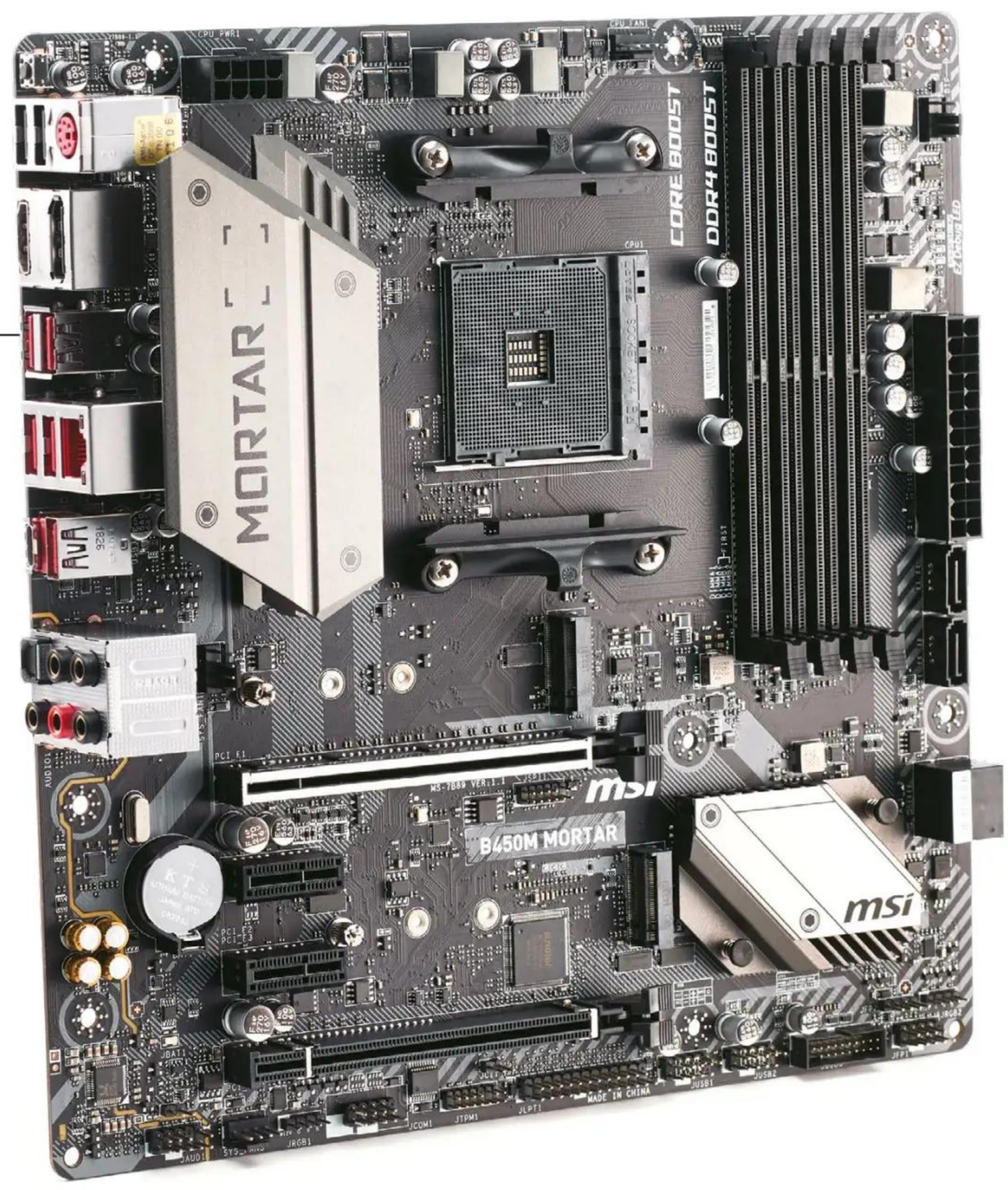
RYZEN THRIVES ON HIGH-FREQUENCY MEMORY, AND FOR NOW THE SWEET SPOT SEEMS TO BE THE 3,200MT/S MARK

MOTHERBOARD

MSI B450M MORTAR $95

Spending hard cash on motherboards when you're on a budget is almost always a challenging thing to convince yourself to do. A lot of the time, to hit that $100 mark, you're left with a sour taste in your mouth, because most mobos look ugly and sparse. There's little in the way of personality at that price.

MSI's B450M Mortar is a fine example of a manufacturer bucking that trend. From the stylised heatsinks to the reinforced PCIe bracket and plethora of connectivity options, it's a nice all-rounder to pair with our case and Ryzen 5 processor. On top of that, MSI has the second-best BIOS UI we've encountered to date, and for $95, that's not to be sniffed at.



SOLID STATE DRIVE

480GB ADATA SU630 2.5-INCH SSD $58

For this build, we've decided to go with a single solid-state drive to power everything: Adata's SU630 480GB SSD. It represents a huge value proposition right now, as it comes in at just $58. Yeah, you're going to have to be a little sparing with your apps and media, but overall it's hard to pass up the opportunity, even if the performance mostly comes from the SLC cache buried within it.

In an ideal world, we'd recommend you go with something like an 860 Evo 250GB instead, then pull an HDD from an older machine for everything else, if you're on a budget. But if you absolutely must have a sizeable and affordable SSD, the SU630 is the way to go.

POWER SUPPLY

500W COOLER MASTER MASTERWATT LITE $50

From the wall, our system should be drawing around 315W when under maximum load. So, this time around, we've gone with a named-brand, non-modular 500W power supply, which gives us around 37 percent headroom for any future upgrades, and plenty of leeway if we want to overclock our Ryzen 5 2600. It's always advisable to stick with a branded PSU, because if it dies, and takes your system with it, you'll need a decent warranty to rely on to recoup your losses – something you might not get with cheaper, lesser-known brands.

COOLER

AMD WRAITH STEALTH $0

Nothing says value quite like 'free', does it? Or rather, 'included', because this cooler comes with the Ryzen 5 2600 and is part of the overall cost. AMD's Wraith Stealth is a nicely designed, low-profile air-cooled heatsink for your Ryzen 5 2600, and it packs more than enough thermal performance to help alleviate the heat output of your six-core processor.

You can now buy a few different variants of this from after-market sellers, and for our build, we've gone for the Spire model of the Stealth (because we really wanted that red LED ring, OK?), but generally they all perform exceptionally well straight out of the box, and even come with thermal paste pre-applied.

IT'S ALWAYS ADVISABLE TO STICK WITH A BRANDED PSU, BECAUSE IF IT DIES, AND TAKES YOUR SYSTEM WITH IT, YOU'LL NEED A DECENT WARRANTY

CASE

THERMALTAKE LEVEL 20 VT MICROATX $99

Last but not least, we've gone for something of an unorthodox chassis for this system. Thermaltake's Level 20 VT reminds us a lot of the BitFenix Prodigy. Its horizontal motherboard mounting system, the massive 200mm front intake fan, and the huge amount of modularity embedded within it make it a prime candidate for our microATX ambitions.

Its looks are certainly open to interpretation, that's for sure, but on the whole, it's not too bad. There's plenty of glass here to enjoy, and although it's a funky case to build in, there are some creature comforts to keep things in check.

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PC GAMER

SMASHING THROUGH A THERMALTAKE CHASSIS

LENGTH OF TIME: **1–2 HOURS** LEVEL OF DIFFICULTY: **MEDIUM**

Originally, this build was based on a $799 budget, and although that's certainly possible, it didn't meet that perfect price-to-performance ratio we wanted to achieve, so after a hell of a lot of tweaking and nagging, we managed to bump that figure up to $999.

Actually, it came to a bit more than that initially, with the final price tag above our target, but checking prices just before going to press saw it slip back down to our initial goal. Spot on it in fact. You can probably build for less anyway, especially if you already have some form of Windows license, and if you're upgrading or migrating a system, simply entering the key upon installation, or logging in to your account and authorising the edition of Windows, will happily authenticate the system, and give you full access to all of those Windows features we love. So, the total hardware cost is just $899.

We could have saved a bit of cash here and there, particularly with the storage, but on the whole, we're pretty happy with how the whole thing turned out. It'll be pretty nifty at 1080p gaming, and our processor of choice, the Ryzen 5 2600, is actually the best value processor we've seen to date.

DECISIONS, DECISIONS

From the outset, we knew that we wanted to roll with a Ryzen 5 2600, and either a Vega 56 (surprisingly affordable nowadays) or an RX 590. Reason being that both cards represent a pretty strong value proposition these days, and as we hadn't had a good look at Vega 56 for some time, we thought it might have been worth a second try.

After much debate, we finally settled on the RX 590, because it pulled us below our budget, and still provided us with solid frame rates at 1080p. 16GB of RAM seemed like a sensible decision, too – 8GB setups seem to have gone the way of the dodo, and with ever expansive Chrome footprints and a myriad other apps sucking up memory nowadays, having more capacity should make the world of difference. Pairing that capacity with a high frequency should also help keep our Ryzen sample running at full tilt.

The last things we had to consider were the case and the SSD. We would have liked to have featured Fractal Design's Meshify C Compact for this build, but couldn't get it in time, unfortunately, so we chose the Thermaltake Level 20 VT instead. Although visually striking, it is a bit of an anomaly, thanks to its layout. If we were to redo this build, either Fractal's Meshify C Compact or our favourite mATX case from NZXT (the H400i) would be our preferred choice.

1

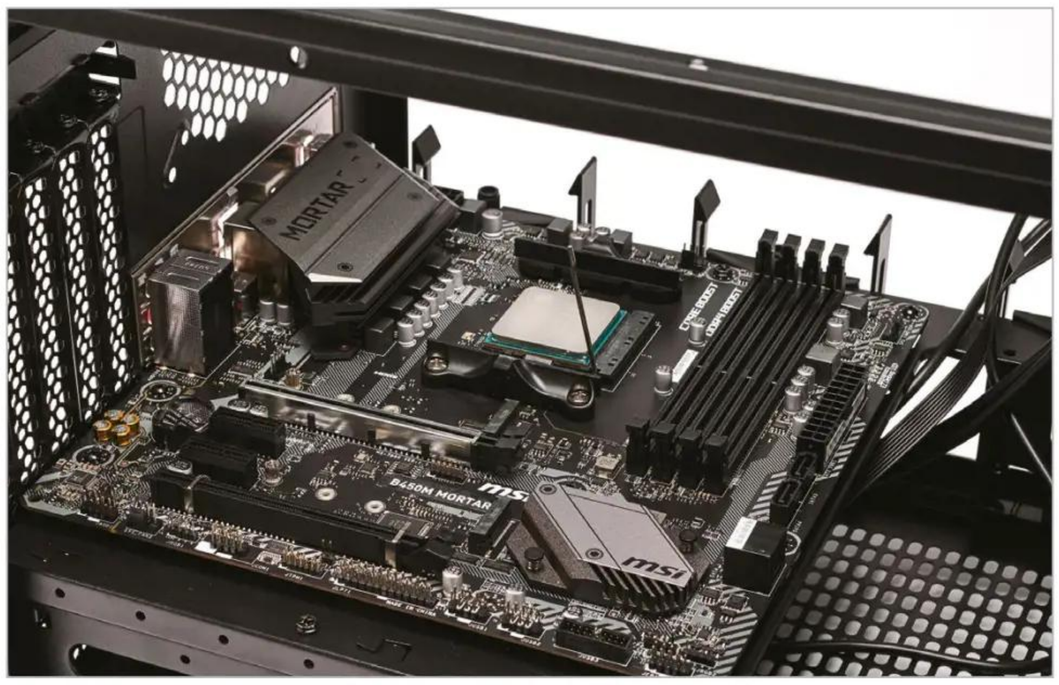
CHASSIS STRIP-DOWN

The first thing we do with any case is strip it down as far as possible. That means removing as many panels as we can, along with any internal mounting hardware that we don't need, and making sure the fans are in the right position, too. We've left the front 200mm fan in this build, simply because we have nothing to replace it with. Always keep your tempered glass panels safe, ideally wedged between the sheets of polystyrene in your case box, if possible. It's also handy to have a magnetic bowl or tub around for you to put all your screws in, so you don't lose them. As a final preparation, make sure you're working in a static-free, safe environment (don't worry about a static strap; just earth yourself every now and then on something big and metal), and you're good to go.

2

MOBO INSTALL

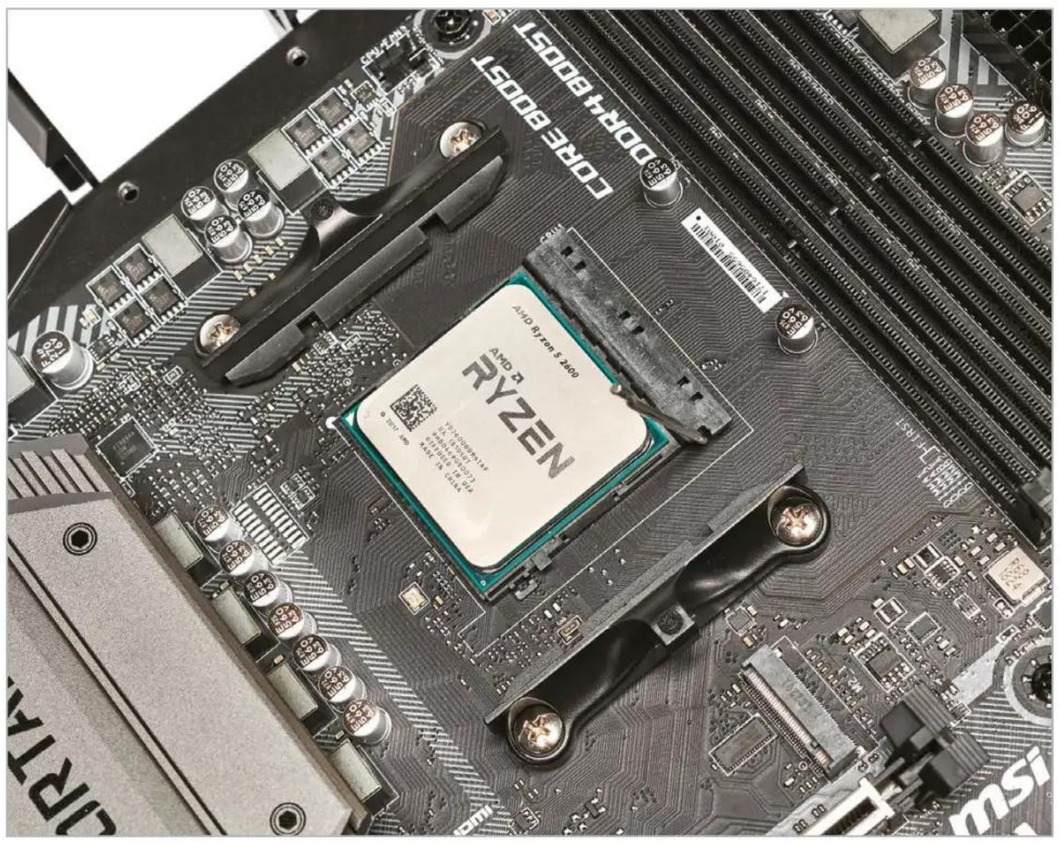
Because our build is relatively straightforward, and the cooling isn't exceptionally complex to fit, it's OK to install your motherboard first here. Grab your rear I/O shield and fit that first, pressing it in from the inside, making sure to orient the ports and cutouts correctly. Then slide your motherboard into position, over the motherboard stand-offs, and secure down with the correct screws. If you have a more advanced cooling solution, we advise holding off on this step, unless the CPU cutout is substantial, and first install the mounting hardware for your cooler, before installing the motherboard into the chassis.



3

RYZEN READY

Installing Ryzen processors is genuinely one of the least daunting parts of building a PC nowadays. Especially in contrast to Intel's LGA setup, where if you bend even one pin out of alignment, it could mean the death of your mobo. In Ryzen's case, lift the retention arm up, locate the gold triangles on the corners of your processor and the CPU socket, line them up, gently slot the CPU in, then secure the retention arm back down again. Simple.



4

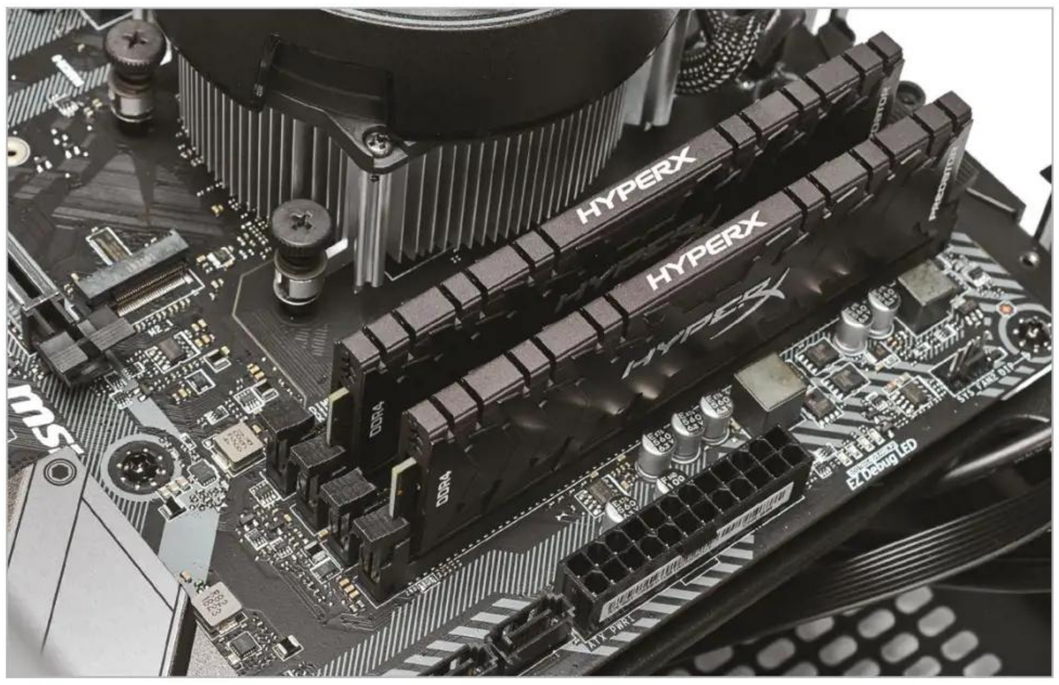
COOLER CRAFTSMANSHIP

Now you're ready to chill your processor. If you're installing an aftermarket cooler, you should follow the instructions in the manual. With our Wraith Stealth, however, it's a little more straightforward. You need to unscrew both of the mounting brackets AMD includes as standard, to the north and south of the processor. Then, with the backplate still in place (preferably held up by your hand), gently place your new Wraith on top, and secure the screws down, a little bit at a time, in a diagonal or star shape pattern. Screw in the top-left one, then the bottom-right, then top-right, then bottom-left, until it's secure. If it's a second-hand cooler, an aftermarket heatsink, or one you've used before, remember to make sure you place some thermal paste on the processor before you install the cooler. Oh, and don't forget to connect your fan cable to the CPU fan header.

5

MAKING MEMORIES

Installing your DDR4 is a fairly simple process. Make sure you line up the notch on the bottom of each memory stick with the notch on the DIMM slot, lift the retention clips up on each end, then slowly place each stick straight down, until it clicks into place and the clips latch back down. Typically, you have to make sure you use the colour-coded slots to ensure you're getting your dual-channel operation; however, some motherboards might prioritise one pair of slots over the others. Check the manual or, in our case with the Mortar, the motherboard itself, because it tells you which two channels it wants you to plug memory into first.



6

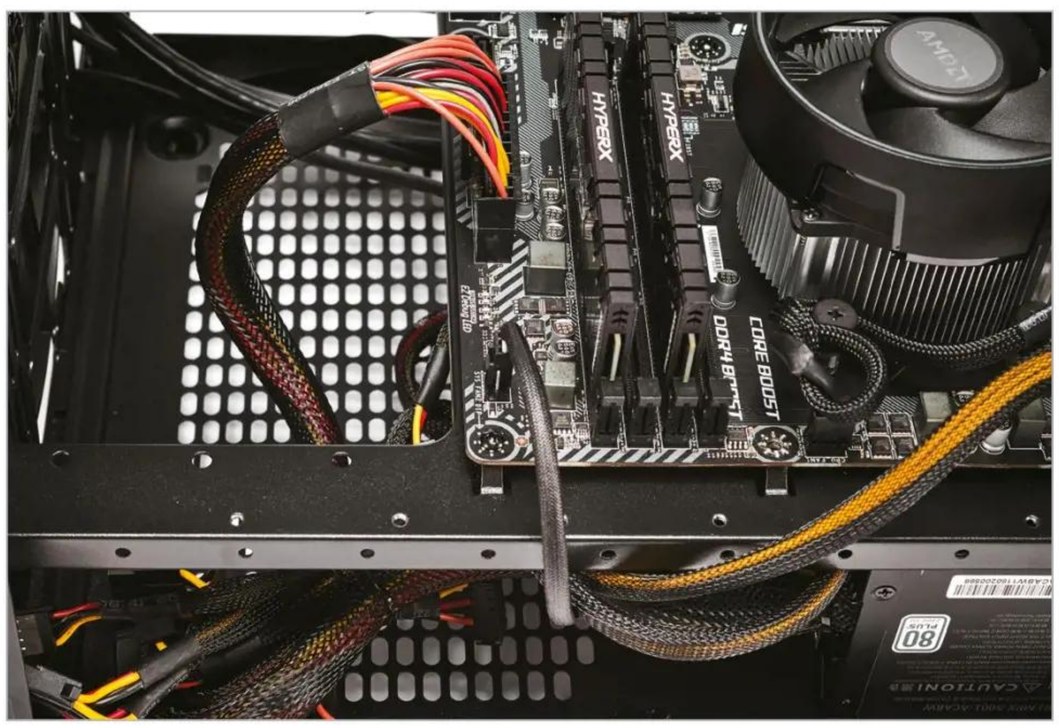
BIZARRE POWER INSTALLATIONS

It took us a while to get to grips with how you actually install this power supply. Most cases allow you to install your PSU either from the rear of the case or the side. With the Level 20, however, this isn't possible. To get your power supply installed, you have to remove the two thumb screws located at the bottom of the floor panel, then lift the entire chassis frame out of its base. Then, with the frame out (and hardware still attached), you can either place the PSU in the bottom plate and drop the frame back down, or secure it to the frame before securing the frame to the base once more. It's a little unintuitive, but not too challenging. Also, remember to make sure your fan is facing downward, because there's nowhere for the power supply to draw air in from directly upward.

7

CABLE MAGIC

Next, you're going to want to start plugging in your cables where you can, and try to sort out that tangled mess. Begin by pre-routing your cables where you want them to go: the 24-pin, the PCIe power pin, and the eight-pin CPU power. Keep an eye on any Molex or SATA devices you want to install, then go ahead and do your best to fold up and secure the rest of the cables with cable ties. This helps keep them out of the way, and improves airflow, too. We've also plugged our front fan into an onboard system fan header, and rerouted our front I/O cables to the other side of the case, to allow better access to the front panel headers on the motherboard.



8

GRAPHICAL TOMFOOLERY

Now it's time to get your GPU in. To do this, remove the two screws holding down the rear PCIe covers, and lift them out of the case. Then you need to carefully line up your graphics card with the uppermost slot on your motherboard ours is reinforced with steel, and bright silver, (in contrast to the other slot, which is black). Then line up the GPU with the rear I/O and the PCIe slot, and firmly push the GPU into place. Once that's done, you can take that PCIe cable you routed earlier and plug it into the PCIe power at the top. We've actually tucked our cable down into the GPU itself, because the shroud extends further than the PCB of the card.

9

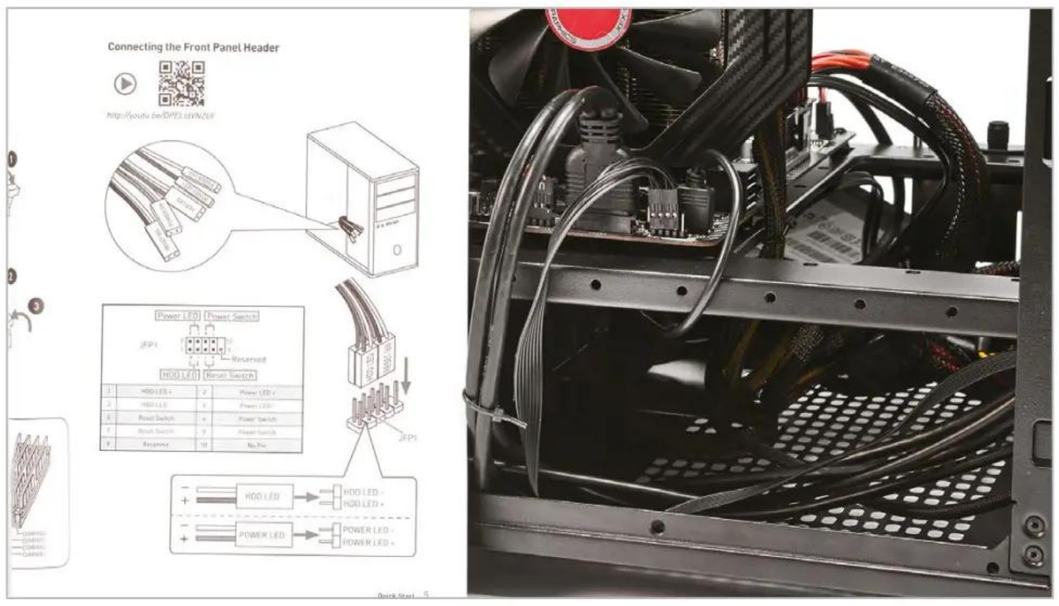
SSD MOUNTS?

Now, you may be thinking: Those look like SSD mounts to the left and right. And the answer should just be: Yep, they are. However, they suck. Seriously suck. The only way you can install an SSD is with the label facing away from you, and even if you decide to do that, you can't have the ports facing down – what you're left with is an SSD in a caddy, with a label facing backward, and the ports on top. Yup. Design oversight, thy name is Thermaltake. We're actually using them as a form of cable management here, trapping the CPU cable down against the PSU, and then keeping the SSD loose in the chassis. Because it's not a spinning disk, our SU630 doesn't mind which way you orient it, so tucking it out the way underneath the motherboard tray is a solid bet. We could have fitted it in one of the 3.5-inch hard drive caddies underneath the GPU, but that would mess with our cable management bundle, and as airflow is only provided by that 200mm fan, the more we have of that, the better.

10

IS THAT A MANUAL?

Yes, it is. MSI is one of a handful of manufacturers that drive you up the wall when it comes to front panel connectors. Most manufacturers – Gigabyte, Asus, EVGA – include written instructions on the motherboard as to where each pin needs to be installed. MSI doesn't. JFP1 signifies where the front panel headers are, but unless you've got a keen memory, or work with MSI motherboards every day, you're going to have no choice but to dig out the motherboard manual so you can plug each connector into its required slot. Remember, for HDD and power LEDs to operate correctly, the + and – need to be correctly oriented on the pins. We've also installed the USB 3.0 header, USB 2.0 header, and the front panel HD audio connector while doing this bit of the build.



11

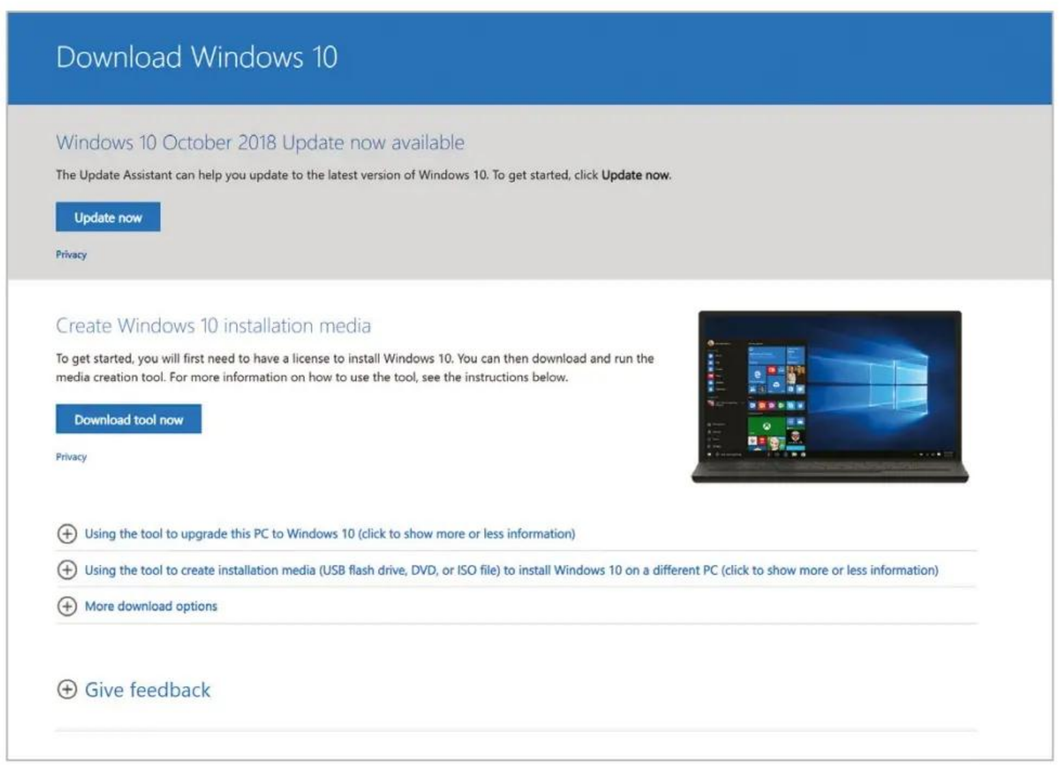
PANEL TIME

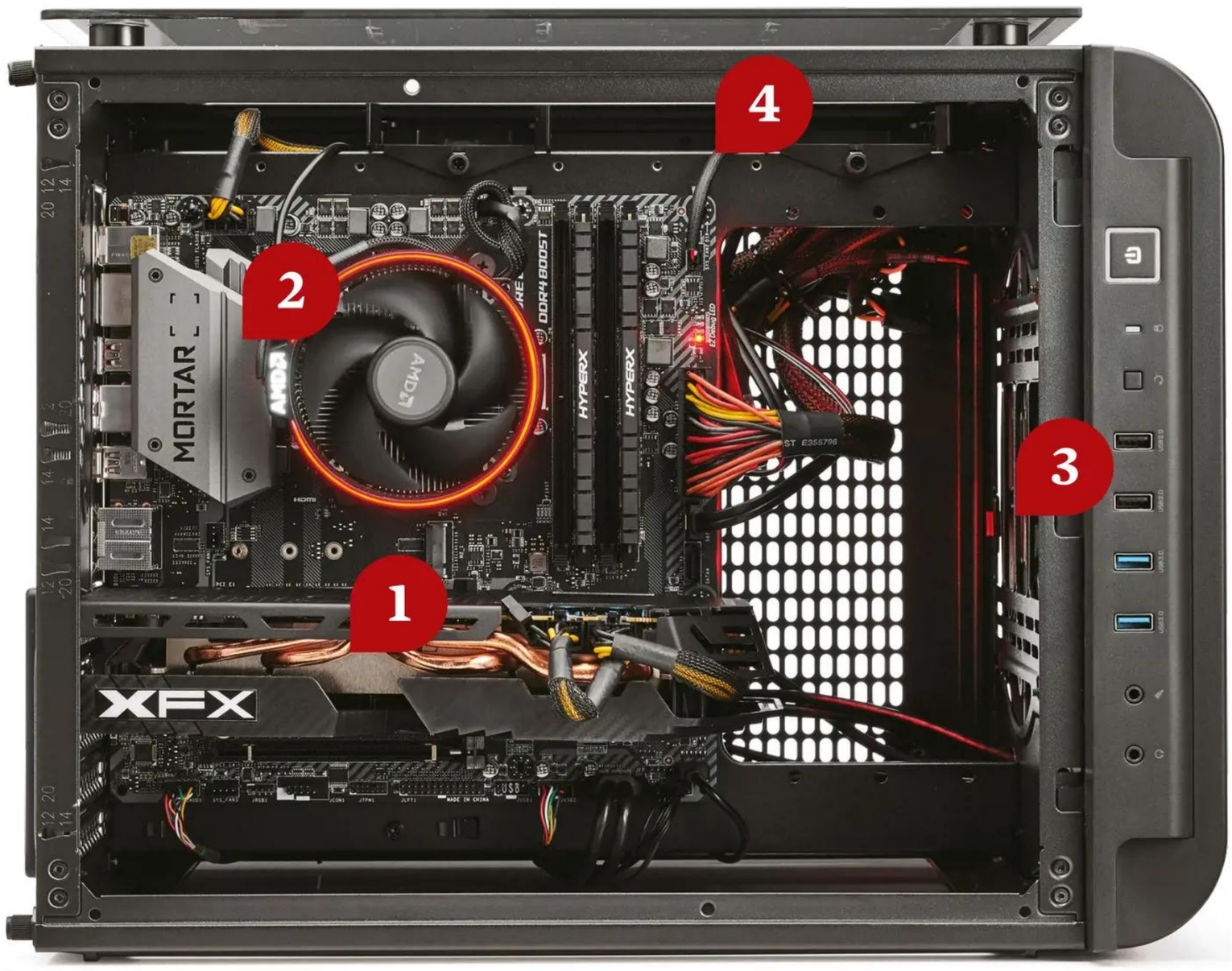
Once that's done, it's time to fit all the panels back on the chassis. First, though, plug your system into the wall, power on the PSU, and hit that power button up top. If it boots, you can switch it off again, and begin re-assembling your case. Remember to make sure there are no fingerprints on the underside of each panel as you secure it back down, especially when you're working with tempered glass. The last thing you want is to finish fitting all those shiny new panels, then have to take them off again to get at the smudges. Once you've reached this step, voila – you're done. The building part of this rig is all wrapped up, so now we can move on to software.

12

WINDOWS INSTALL

Last but not least, you need to crack out a Windows install USB. To do that, on a separate Windows 10 PC, head to **http://bit.ly/Win10MediaKit**, click the big 'Download tool now' button, then double-click the EXE file that downloads. You need an 8GB USB stick installed beforehand, but this runs you through the USB boot tool creation wizard. Once done, you need to plug the USB stick into your new machine, power it on, then mash the Delete key to get into the BIOS, change the boot order, so your USB is first, hit F10, save, exit, then go through the install process.





1 A top-down look this time around, but you can see why this style of design often leads to a mess when it comes to interior cable management. It's difficult to route things when the mobo is flat.

2 We've gone with AMD's Wraith Spire on our build, because we wanted to add a little pizzazz to the affair.

3 We've removed the radiator brackets at the top of the chassis to help us maintain a clean top-down aesthetic.

4 A good upgrade for this would be to drop in a 250GB Samsung 960 Evo M.2 drive here, for some OS grunt.

CASE STUDY

Our $999 build is complete, and what a journey it's been. The Thermaltake Level 20 VT was not the chassis we wanted to use – it's interesting, don't get us wrong, but it's not what we'd call a conventional case to work in. Alas, print deadlines stop for no man, and we had little choice but to forsake our delayed Fractal case and instead opt for the glass confines of this giant cube.

Was it a challenge? Yes and no. Less challenging, more confusing. Once all the glass panes were removed, the first issue was the roof bars in the top. These aren't screwed down; rather, there's a thin slice of metal securing each bar in place that you have to bend up to get the bar out. Then there was the power supply installation. There's no obvious or easy way to install a PSU into this chassis. You can't do it sideways, you can't do it from the rear. As mentioned, we had to unsecure the base, lift up the remainder of the chassis, then drop the PSU into place, before carefully repositioning the chassis back down, and securing it and the power supply. It's a clumsy solution, but it works.

Then there's the SSD caddies. What a nightmare. Only one set of mounting screw locations, which forces your label the other way around, and no way to make the connectors face the bottom. We'd also have liked to see an easier way of mounting those traditional 3.5-inch hard drives, preferably from the rear, in a more hot-swappable manner. The notion of hot-swap hard drives may be pushing up daisies right now, but reaching around inside to pull the sleds out feels unintuitive.

Other than those pesky case chassis conundrums, though, the overall spec of this rig – 16GB of RAM, an RX 590, a fairly sizable HDD, and a six-core, 12-thread processor – is incredibly sound and gives it some serious grunt for any task you throw its way.

That 16GB of DDR4 @ 3,200, paired with our Ryzen 5 2600, makes it a true pro at any and all multithreaded tasks you throw its way, and as more games are leaning toward a 'more threads the better' standpoint, it won't let you down in the future there, either. The RX 590 is also an incredibly cost-effective card for 1080p. Yeah, we weren't happy with it at launch, but that doesn't stop it from being a solid card at this resolution, beating even the GTX 1060 when it comes to value for performance.

The weakness of this rig lies with the SSD, however. Unfortunately, Adata's QLC-based SU630 is incredibly underwhelming. From the lackluster cache to the poor long-term sequential performance, coupled with some serious doubts about endurance, it simply doesn't make sense as a drive. The fact that you can now pick up a 500GB Samsung 860 Evo for only a bit more cash (current price is $78) means that there's just not enough to convince us of QLC's value right now.

BENCHMARKS

	ZERO-POINT	
Cinebench R15 Multi-Thread	1,152	1,242 (8%)
CrystalDisk QD32 Sequential Read (MB/s)	3,400	558 (-84%)
CrystalDisk QD32 Sequential Write (MB/s)	1,720	521 (-70%)
Rise of the Tomb Raider (fps)	60	70 (17%)
Total War: Warhammer II (fps)	46	47 (2%)
Tom Clancy's Ghost Recon: Wildlands (Avg fps)	39	42 (8%)
3DMark: Fire Strike (Index)	11,101	13,441 (21%)

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Our zero-point consists of an AMD Ryzen 5 1600, 16GB of Crucial Ballistix Sport LT @ 2,666, an EVGA GeForce GTX 1060 3GB, and a 250GB Samsung 960 Evo M.2 PCIe SSD. All tests were performed at 1080p at the highest graphical profile.

The motherboard is the foundation of every PC but how well do you know this complicated component? *Darien Graham-Smith* explores all its main features

THE MOTHERBOARD MAP

1 CHIPSET

The chipset is a collection of controller chips that manage the flow of data between the CPU and other components. It might be hidden under a heatsink, as in the image opposite, but it's present on every board. Different chipsets support different processors: Intel's 13th generation Core processors can only be used in a board that uses one of the company's 600-series or 700-series chipsets, while AMD's Ryzen 7000-series CPUs need an AMD B650 or X670 chipset.

The chipset doesn't just determine what CPU you can use. It also dictates other technical features of the motherboard, such as whether it works with DDR4 memory or requires more expensive DDR5 modules, and how many PCI-Express lanes and USB connectors it has. You don't have to research the technical details of the chipset before buying a PC, though – you can just check the features of the board itself.

2 CPU SOCKET

Intel's 12th and 13th-generation desktop processors use the LGA1700 socket format. The letters stand for 'land grid array', meaning the socket contains 1,700 tiny pins, which press against a grid of flat contact points on the base of the processor. Installing the CPU in a socket like this is a simple case of dropping the chip into the housing and locking it in place with a latch.

For AMD's Ryzen 7000-series processors, the socket AM5 connector is an almost identical LGA design, with 1,718 pins. Older Ryzen CPUs use PGA (pin grid array) sockets, where the motherboard mount has thousands of tiny holes and the pins stick out of the underside of the chip. The two designs are electronically identical but PGA is more fiddly and it's easier to bend or break the pins.

3 RAM SLOTS

Some motherboards use DDR4 RAM, while others require the newer, faster, and more expensive DDR5 modules. These technologies aren't cross-compatible, and a little plastic key that sticks up near the centre of the slot ensures that you can't accidentally plug in a module of the wrong type.

You'll often see memory slots in coloured pairs. This is for dual-channel configurations: if you put two identical DIMMs into matching slots, the motherboard can boost performance by accessing them in parallel. Dual-channel memory is optional, however – you can put any DIMM of any size into any slot. You can also mix modules with different speed ratings, although they will all uniformly operate at whatever frequency is set in the BIOS.

4 CPU POWER CONNECTOR

Most CPUs draw less than 20W when sitting idle, but their demands can instantly rocket when you fire up a heavyweight workload. Ryzen 7000 processors can demand up to 230W with all cores active, while the Intel 19-13900K goes as high as 250W.

To ensure that the CPU gets all the power it needs, the motherboard provides one or two dedicated 12V power sockets, fed directly from the main power supply. A single eight-pin power connector can deliver up to 288W, so you don't normally need to connect a second socket unless you're planning to overclock. There's no harm in doing so, though – the CPU won't draw more power than it needs.

5 MOTHERBOARD POWER CONNECTOR

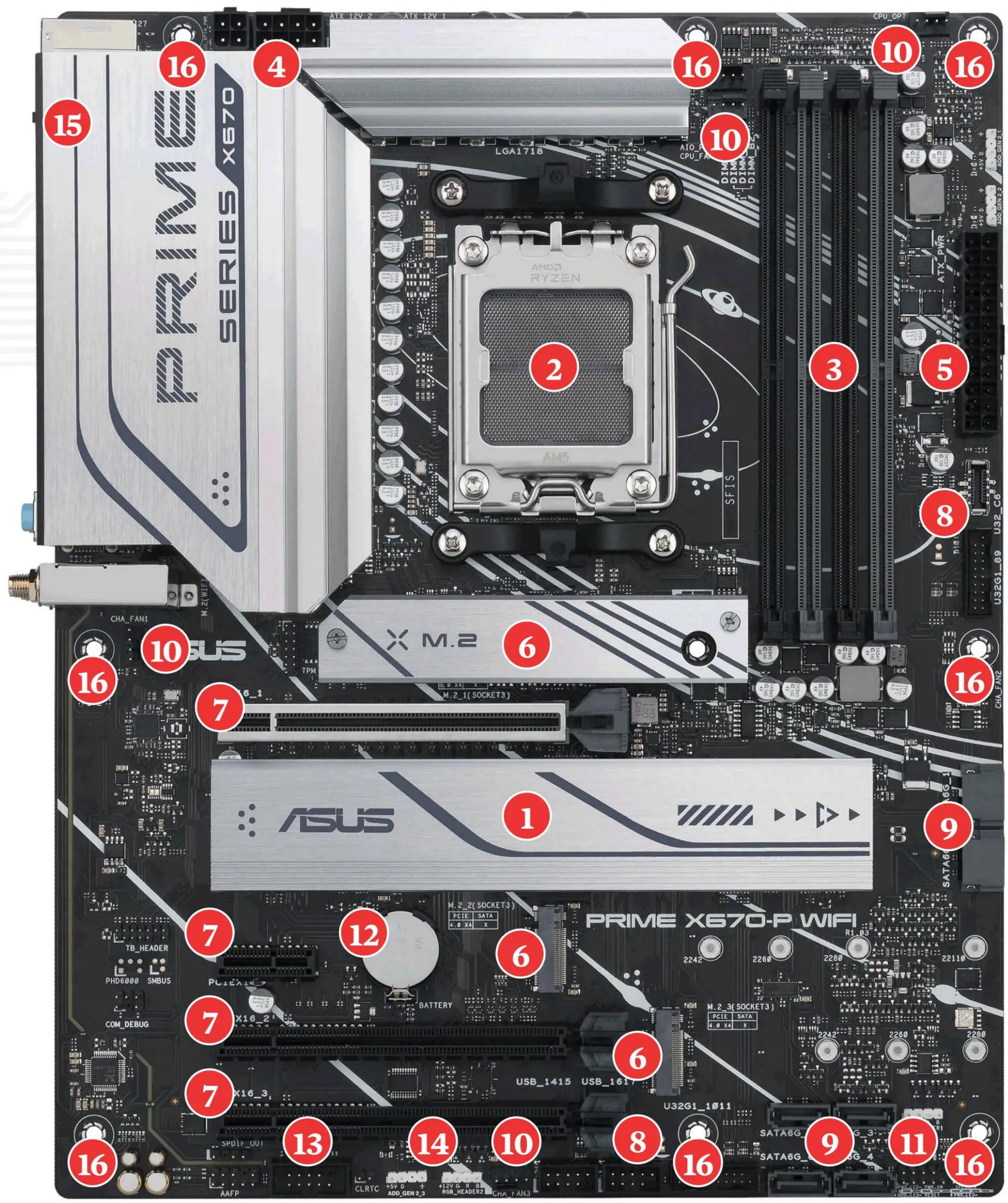
The standard power plug on an ATX power supply has 24 pins, which deliver multiple power feeds at 3.3V, 5V, and 12V, to drive various components integrated into the motherboard. Some of the pin housings are square while others have angled sides, so it's impossible to plug the power connector in the wrong way round. There is also a plastic clip that holds it in place once it's correctly inserted.

The power plug is sometimes split into two, with the last four pins detached from the rest – this is to enable compatibility with older motherboards that use a 20-pin socket. A plastic lip lets you connect the two sections into a standard 24-pin plug and holds both parts in place once the plug is fully inserted.

6 M.2 SLOT

Any modern motherboard will offer at least one SSD slot in the 22mm M.2 format. For example, the Asus Prime X670-P WiFi in our image has three slots, with a heatsink over the first. It's questionable how necessary that is, however: an overheating SSD can lead to errors and crashes, but any drive that needs a heatsink to work reliably should come with one attached.

M.2 supports both the NVMe and SATA standards, but you'll rarely see a SATA drive in this format because NVMe is far faster. Just how much faster depends on the PCI Express version used by your slot and your drive – if the motherboard and SSD both support PCI-E 5, you could see transfer rates as high as 13GB per second. But that's for the future. For now, PCI-E 4's bandwidth of around 8GB per second is plenty, and Gen4



SSDs (as they're often called) can't saturate it.

To the side of the M.2 slots, you'll see a row of screw holes, which can be used to fit drives of various standard lengths. In practice, most M.2 drives use the 2280 format (22mm wide x 80mm long) and are secured with a single screw 80mm away from the slot.

7 PCI-E SLOTS

PCI Express slots come in three different standard sizes – x1 (25mm), x4 (39mm), and x16 (89mm). You can actually install a card of any size in any slot: an x1 card will work in an x4 or x16 slot, and many boards have open-ended connectors that let you plug an x16 card into a shorter slot. This is likely to limit the card's performance, however. As the name implies, an x4 slot has only a quarter of the bandwidth of x16.

As with M.2 slots, the actual speed of each slot depends on the PCI-E generation. The latest PCI-E 5.0 standard is twice as fast as 4.0, with the ability to transfer 64GB/sec over a full-sized x16 slot. AMD's upcoming Radeon RX 7900-series GPUs are set to be the

first cards that can take full advantage of that enormous speed.

8 USB HEADER

In addition to the USB sockets on the rear panel (see sidebar opposite), most PC cases have a few additional sockets at the front or side. For these to work, they need to be connected to USB headers on the motherboard.

These come in various designs, to suit different types of USB ports: a basic USB 2 port uses a nine-pin connector, while a USB 3.2 port requires a specific 20-pin plug. Each header can drive two external USB ports – if your board has any spare headers, you can make use of them by investing in a cheap backplate that adds extra USB sockets to the rear of the case.

9 SATA CONNECTORS

M.2 SSDs are fast but SATA drives are much better value for bulk data storage. It's also an easy technology to get along with since all SATA ports use the same connectors and run at the same speed (6Gbits/sec). Some boards offer two sets of ports pointing in different directions, but this is just to suit different case layouts. If you want more SATA ports than your board offers, you can add more via a PCI-E card.

On high-end boards, there may be a specific group of SATA ports that can work together as a RAID array, configured via the BIOS. In the absence of this feature, you can use Windows' Storage Spaces feature to create a pooled virtual drive from any set of disks, or fit a dedicated SATA RAID controller card.

10 FAN CONNECTORS

Somewhere near the CPU socket, you'll find a header for plugging in the CPU fan. This isn't optional: if the processor overheats, the whole system will run slowly or crash. However, it's up to you whether you make use of the other fan headers dotted about the board. Outside of enthusiast builds, case fans are unlikely to make a noticeable difference to performance or stability.

Many boards offer a mix of three- and four-pin fan headers. You can plug any fan into any header, but using a four-pin fan with a four-pin header allows you to manage the fan's speed from the BIOS or a companion app. Typically, you might set your fans to run slowly and quietly most of the time, then automatically speed up if the motherboard temperature exceeds a certain threshold.

11 FRONT PANEL CONNECTOR

The front panel connector looks like a regular header, with 15 bare pins sticking up from the motherboard. However, it doesn't connect to a single cable, but to a collection of little two- and three-pin plugs that dangle inside the PC case. These plugs make the power button, reset button, power LED and hard disk LED work, as well as the loudspeaker that beeps when you power on or reset the system. There's no standard layout for front panel connectors, so if you're assembling a PC, you may need to refer to the manual to work out which plug goes where. Occasionally, the details may be printed directly on the board, as in our example image.

12 BATTERY

A few decades ago, motherboards used to feature a small cache of battery-powered memory, so that BIOS settings would be remembered even when the computer was unplugged from the mains. Today's boards use flash memory, so the battery is no longer needed for that purpose, but most motherboards still include a CR2032 battery, just so they can keep track of the date and time when there's no power. Since most desktop PCs are kept permanently plugged in, this battery can easily last for more than five years, but if your desktop remains in service long enough, the battery will eventually need replacing.

13 COM HEADER

The RS-232 serial interface is a relic of the dial-up era: with a maximum speed of 115Kbits/sec, it's about 0.0006 percent as fast as a modern USB connection. Unsurprisingly, it has been a long time since we've seen a motherboard with an old-fashioned nine-pin serial socket on the rear panel.

Yet serial connections do still have a role to play in certain industrial and scientific settings, controlling custom machinery that might have been designed 40 years ago. The COM header lets you attach a backplate with a serial connector so that the latest boards can be integrated into legacy workflows.

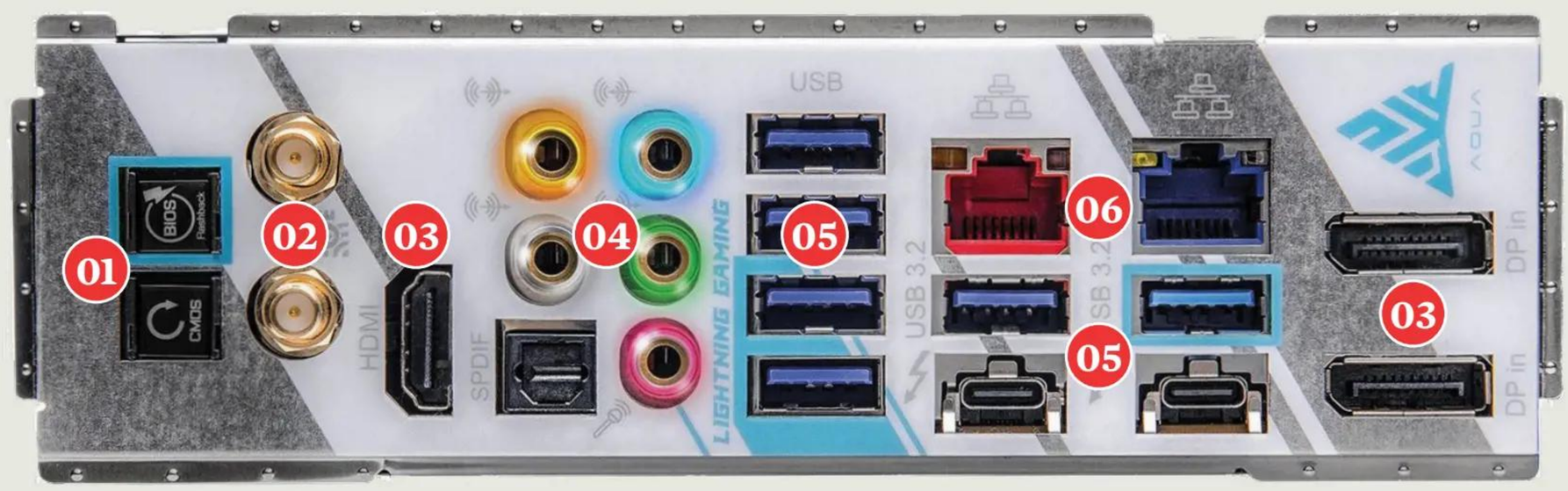
14 RGB HEADER

While there's no universal standard for RGB lighting and accessories, many motherboards offer connectors that can power LEDs, and let you control their colour patterns via the BIOS or a dedicated app. Be warned, though: three-pin ARGB connectors put out 5V on the first pin, while the older four-pin RGB standard supplies 12V, so don't push a three-pin plug onto a four-pin header.

WHAT ABOUT LAPTOPS?

Inside every laptop, there's a motherboard that does the same basic job as a desktop board. However, laptops are more minimally designed, with a focus on minimising weight, size, and power consumption. Unscrew the casing from your laptop and it's unlikely you'll find any internal headers or expansion slots – the memory is often soldered in place. You'll see fewer chips, too, as CPU manufacturers seek to maximise efficiency by building multiple components into one physical package. Alongside the CPU cores, a mobile processor might contain memory, storage, and networking controllers, so there's no need for a separate chipset – it's all bundled into one system-on-a-chip. An example of SoC design is the Apple Silicon architecture, used for the company's M1 and M2 processors. These not only combine CPU and chipset functions, but they also have all the system RAM built into the chip. This makes memory upgrades impossible but allows the CPU to access data at extremely high rates. Meanwhile, the motherboard becomes much less important.

Laptops focus on minimalism



THE REAR PANEL

EVERY MOTHERBOARD OFFERS A VARIETY OF CONNECTORS AND PORTS AT THE REAR. HOWEVER, IT'S RARE THAT ANY TWO BOARDS OFFER THE SAME SELECTION OF SOCKETS, SO IT'S WORTH INVESTIGATING WHAT'S THERE

01. BIOS buttons
If you like to tinker with your BIOS, you could accidentally get into a situation where the computer can't start up. Enthusiast boards often offer handy buttons that reset your system to default settings or recover a backed-up configuration. Without these, the only way to undo a configuration error might be to open up the PC and press a button on the motherboard – or set a jumper.

02. Wireless antenna connectors
If your board has built-in Wi-Fi, the backplate should include two screw-in antenna connectors. A small aerial unit is normally included in the box, and this will work fine for the average home. If you want the very best reception, you can replace this with any antenna assembly that uses the standard 3.5mm TS-9 connector.

03. Video Connectors
If you're using a PCI-E graphics card then you can normally ignore these – the card will have its own ports. However, for integrated CPU graphics, you'll want an HDMI or DisplayPort output socket. It's possible to run video over a USB Type-C connector, but that's unusual in desktop boards. Older DVI or VGA connectors can also be useful for projectors or other legacy displays.

04. Audio jacks
Most motherboards have built-in audio hardware – the number of sockets at the back determines whether you're limited to basic stereo or whether you can take advantage of 5.1 or 7.1 surround sound. An S/PDIF connector lets you connect your PC to an AV receiver or other digital-compatible destination, for the best possible sound quality.

05. USB ports
There's a confusing range of USB standards currently in use. Many boards offer a mixture of ports rated at 5Gbits/sec and 10Gbits/sec, while some go up to 20Gbits/sec. Different speeds are sometimes indicated by differently coloured ports, but there's no consistency to this. You'll likely see a mix of Type-A and Type-C sockets too, but this isn't a big deal – with a cheap converter plug or cable you can connect any USB device to any socket.

06. Network ports
Most motherboards offer one Gigabit Ethernet port; some have two, which can be aggregated to create a 2Gbits/sec link. Native multi-Gigabit Ethernet is also becoming common: the ASRock Z690 Aqua (pictured) has one 2.5GbE connector and one 10GbE port. If your board doesn't have the connector you want, you can buy a USB 2.5GbE or 5GbE adapter quite cheaply. 10GbE can be added via a PCI-E card.

07. Legacy ports (not pictured)
Other connectors you might see include a nine-pin serial port (see above), a round six-pin PS/2 connector for a keyboard or mouse, a 25-pin parallel port for old printers, and a flat eSATA connector – from the days when SATA was the fastest way to connect an external drive. If you don't recognise these connectors, you don't need them. They won't do any harm, but they do take up space that could be used for more modern connectors.

15 LED READOUT

Some motherboards have an LED screen that shows a series of cryptic numbers while the PC is starting up and running. Decoded, these numbers tell you what the BIOS is doing at any given moment – or what error it has encountered. For example, if the computer won't start, the code might indicate whether the problem happened while initialising the CPU, memory, graphics card, or SSD. This might be useful information to an enthusiast system builder, but the latest UEFI BIOS systems can often provide useful messages on the screen in plain English.

16 SCREW HOLES

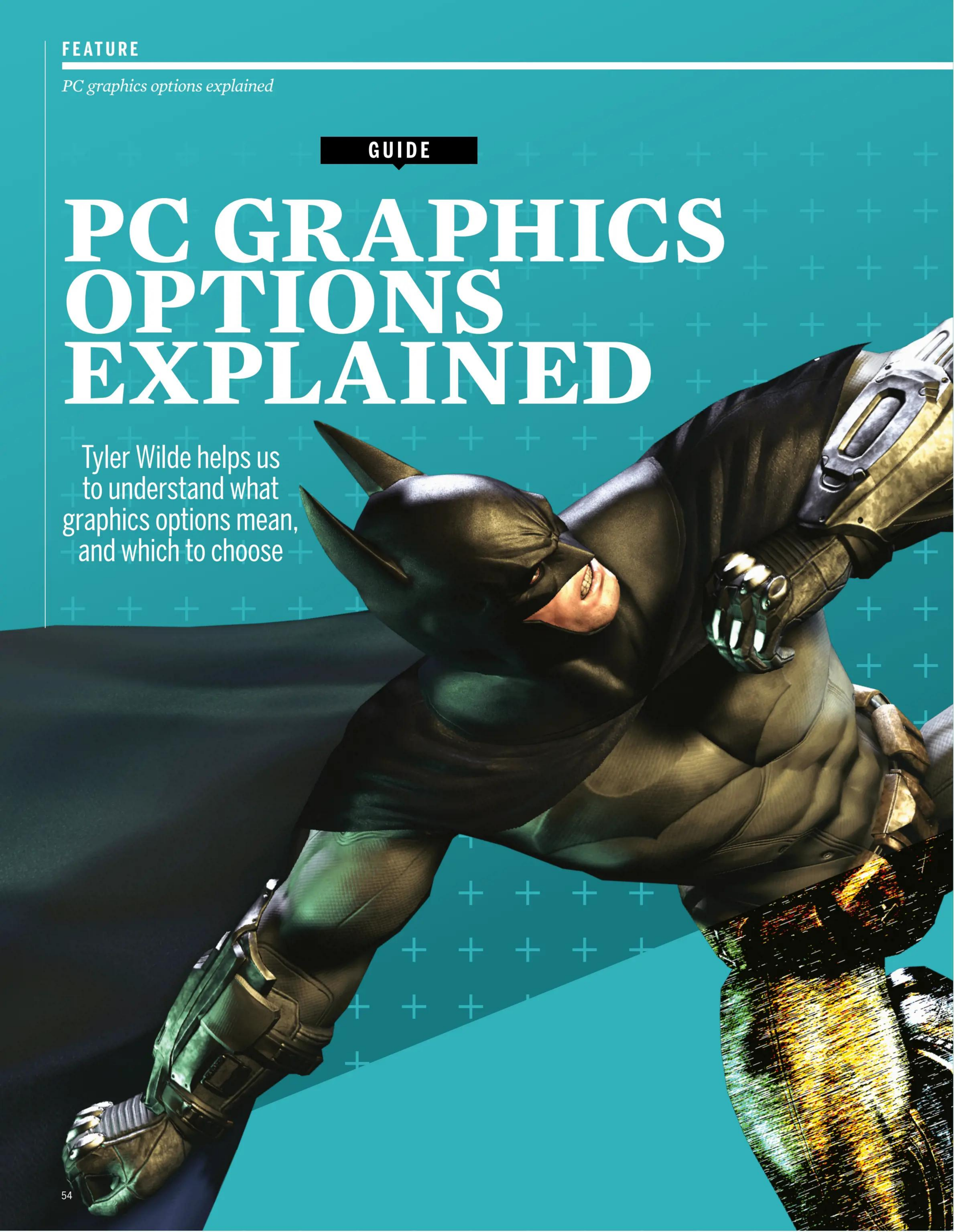
The screw holes in a motherboard aren't exactly hi-tech, but they're still important: they determine which cases the board can be installed in. The ATX format, originated by Intel in 1995, defines a size of 305 x 244mm, with nine screw holes in specific locations around the edge and one near the middle.

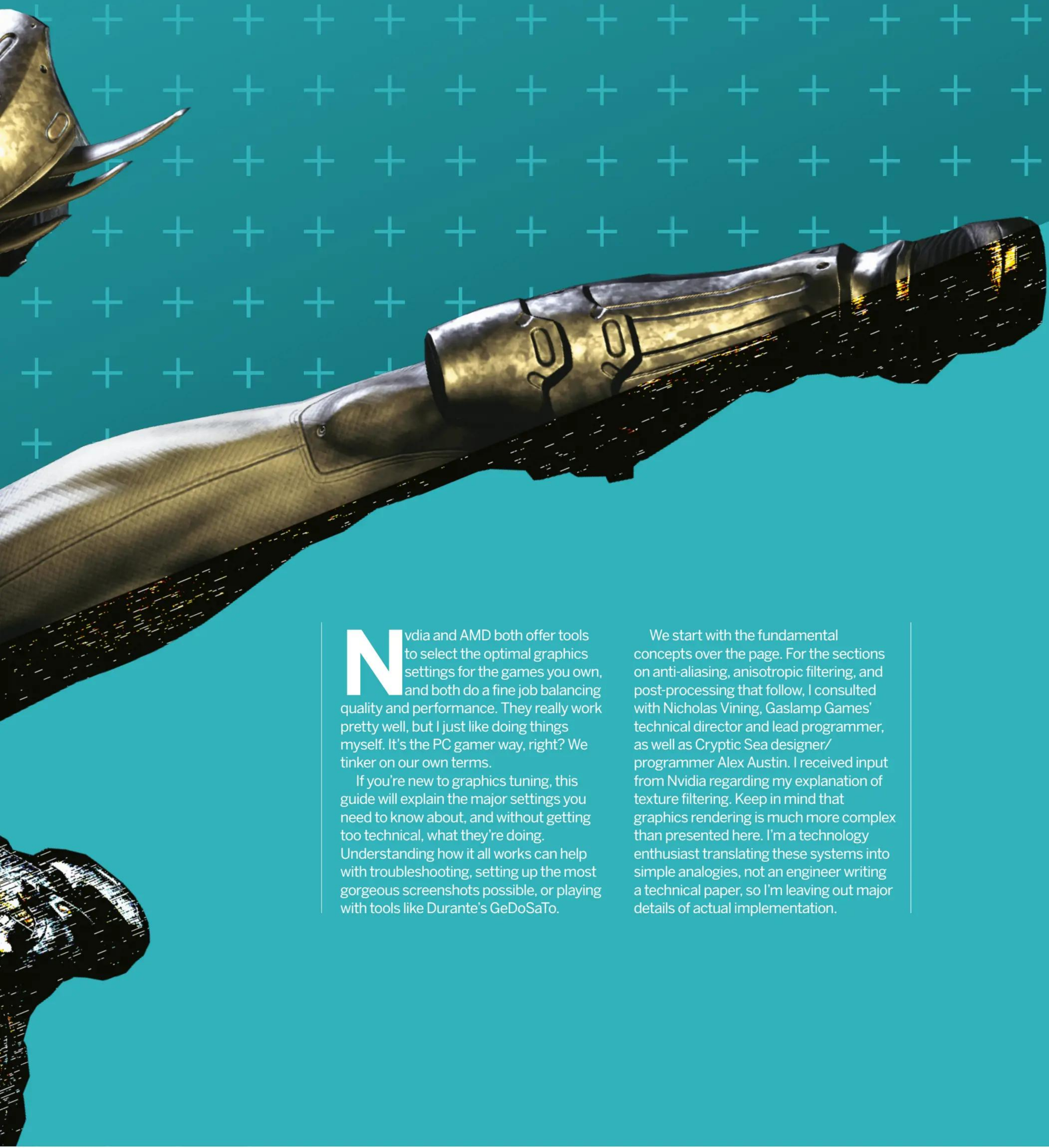
Most ATX cases can take a microATX board (244x244mm). If the case doesn't have microATX fittings, seven of the nine hole locations are the same, which is enough to hold the board in place securely. If you are building a PC using a different format, such as FlexATX (229x191mm) or mini-ITX (170x170mm), check the case mountings are a match for the board.

GUIDE

PC GRAPHICS OPTIONS EXPLAINED

Tyler Wilde helps us to understand what graphics options mean, and which to choose





Nvdia and AMD both offer tools to select the optimal graphics settings for the games you own, and both do a fine job balancing quality and performance. They really work pretty well, but I just like doing things myself. It's the PC gamer way, right? We tinker on our own terms.

If you're new to graphics tuning, this guide will explain the major settings you need to know about, and without getting too technical, what they're doing. Understanding how it all works can help with troubleshooting, setting up the most gorgeous screenshots possible, or playing with tools like Durante's GeDoSaTo.

We start with the fundamental concepts over the page. For the sections on anti-aliasing, anisotropic filtering, and post-processing that follow, I consulted with Nicholas Vining, Gaslamp Games' technical director and lead programmer, as well as Cryptic Sea designer/programmer Alex Austin. I received input from Nvidia regarding my explanation of texture filtering. Keep in mind that graphics rendering is much more complex than presented here. I'm a technology enthusiast translating these systems into simple analogies, not an engineer writing a technical paper, so I'm leaving out major details of actual implementation.

THE BASICS

RESOLUTION AND FPS

A pixel is the most basic unit of a digital image – a tiny dot of colour – and resolution is the number of pixel columns and pixel rows in an image or on your display. The most common display resolutions are: 1280x720 (720p), 1920x1080 (1080p), 2560x1440 (1440p), and 3840 x 2160 (4K or 'ultra-HD'). Those are 16x9 resolutions – if you have a display with a 16x10 aspect ratio, they're slightly different: 1920×1200, 2560x1600, and so on, while ultrawide displays can be 2560x1080, 3440x1440, etc.

FRAMES PER SECOND

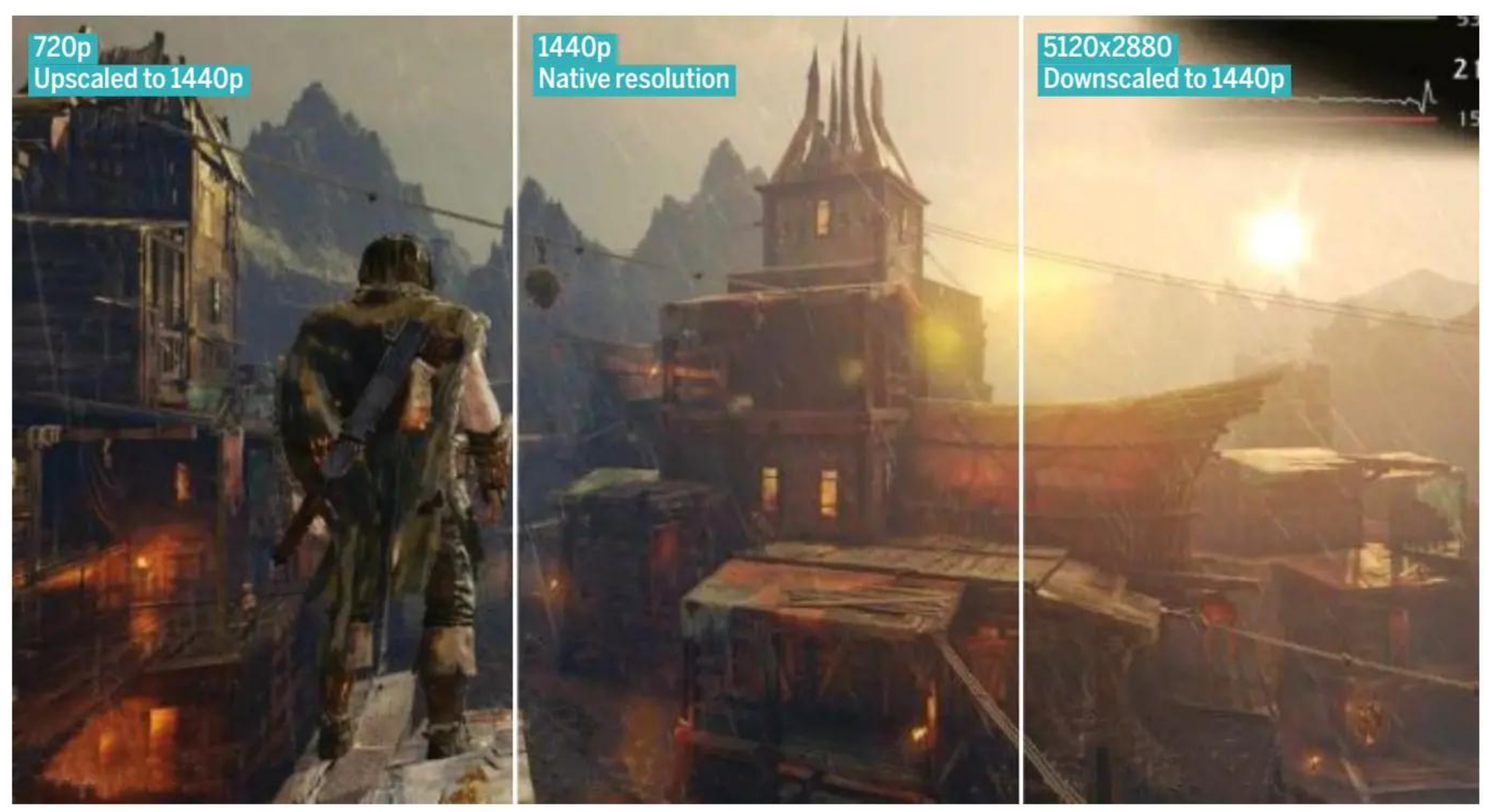
If you think of a game as a series of animation cells – still images representing single moments in time – the FPS is the number of images generated each second. It's not the same as the refresh rate, which is the number of times your display updates per second, and is measured in hertz (Hz). 1 Hz is one cycle per second, so the two measurements are easy to compare: a 60 Hz monitor updates 60 times per second, and a game running at 60 FPS should feed it new frames at the same rate.

The more work you make your graphics card do to render bigger, prettier frames, the lower your FPS will be. If the framerate is too low, frames will be repeated and it will become uncomfortable to view – an ugly, stuttering world. Competitive players seek out high framerates in an effort to reduce input lag, but at the expense of screen tearing (see right), while high-resolution early adopters may be satisfied with lower framerates at 1440p or 4K.

PSCALING AND DOWNSAMPLING

Some games offer a 'rendering resolution' setting. This setting lets you keep the display resolution the same (your display's native 1080p or 1440p, for instance) while adjusting the resolution the game is being rendered at (but not the UI). If the rendering resolution is lower than your display resolution, it will be upscaled to fit your display resolution – and, as expected, look like garbage, because the image is being blown up.

If you render the game at a higher resolution than your display resolution, which is an option in Shadow of Mordor, the image will be downsampled (or 'downscaled') and will look much better at a high cost to performance.



VERTICAL SYNC AND SCREEN TEARING

When a display's refresh cycle is out of sync with the game's rendering cycle, the screen can refresh during a swap between finished frames. The effect is a 'break' called screen tearing, where we're seeing portions of two or more frames at the same time. It is also our number one enemy after low framerate.

One solution to screen tearing is vertical sync (vsync). It's usually an option in the graphics settings, and it prevents the game from messing with the display until it completes its refresh cycle, so that the frame swap doesn't occur in the middle of the display updating its pixels. It's not a perfect solution as, unfortunately, vsync causes its own problems, one being that it contributes to input lag when the game is running at a higher framerate than the display's refresh rate.

ADAPTIVE VERTICAL SYNCHRONIZATION

The other big problem with vsync happens when the framerate drops below the refresh rate. If the framerate exceeds the refresh rate, vsync locks it to the refresh rate: 60FPS on a 60Hz display. That's fine, but if the framerate drops below the refresh rate, vsync forces it to jump to another synchronized value: 30 FPS, for instance. If the framerate fluctuates above and below the refresh rate often, it causes stuttering. We'd much rather allow the framerate to sit at 59 than punch it down to 30.

G-SYNC AND FREESYNC

New technology is starting to solve this big mess. The problems stem from one thing: displays have a fixed refresh rate. But if the display's refresh rate could change with the framerate, we could eliminate screen tearing and eliminate the stuttering and input lag problems of vsync at the same time. Of course, you need a compatible video card and display for this to work, and there are two technologies that do that: Nvidia has branded its technology G-sync, while AMD's efforts are called Project FreeSync. Initially, Nvidia cards only supported G-sync monitors, but GeForce cards will now work with some FreeSync monitors.

PERFORMANCE

Because it determines the number of pixels your GPU needs to render, resolution has the greatest effect on performance. This is why console games which run at 1080p often upscale from a lower rendering resolution – that way, they can handle fancy graphics effects while maintaining a smooth framerate. I benchmarked the Shadow of Mordor resolutions to the left (all settings on maximum) on the Large Pixel Collider with two of its four GTX Titans active, to show how much resolution affects performance.

***Shadow of Mordor* resolution benchmarks**
(2x Nvidia GTX Titan SLI)

	Avg. FPS	Max FPS	Min FPS
1980x720 (1/2 resolution)	102	338	30
2560x1440 (native resolution)	51	189	23
5120x2880 (2x resolution)	16	26	10

ANTI-ALIASING

If you draw a diagonal line with square pixels, their hard edges create a jagged 'staircase' effect. This ugliness (among other artefacts) is called aliasing. If resolutions were much higher, it wouldn't be a problem, but until display technology advances, we have to compensate with anti-aliasing.

There are many techniques for anti-aliasing, but supersampling (SSAA) is useful to explain the process. It works by rendering frames at a higher resolution than the display resolution, then squeezing them back down to size. On the previous page, you can see the anti-aliasing effect of downsampling SoM from 5120x2880 to 1440p.

Consider a pixel on a tile roof. It's orange, and next to it is a pixel representing a cloudy sky, which is light and blueish. Next to each other, they create a hard, jagged transition from roof to sky. But if you render the scene at four times the resolution, that one orange roof pixel becomes four pixels. Some of those pixels are sky-coloured and some are roof-coloured. If we take the average of all four values, we get something in between. Do that to the whole scene and the transitions become softer.

That's the gist, at least, and while it looks very good, supersampling is computationally expensive.

MULTISAMPLING (MSAA)

More efficient than supersampling, but still demanding. This is the standard, baseline option in older games

COVERAGE SAMPLING (CSAA)

Nvidia's more efficient version of MSAA.

CUSTOM-FILTER (CFAA)

AMD's more efficient version of MSAA.

FAST APPROXIMATE (FXAA)

Rather than analysing the 3D models (ie MSAA, which looks at pixels on the edges of polygons), FXAA is a post-processing filter, meaning it applies to the whole scene after it has been rendered, and it's very efficient. It also catches edges inside textures that MSAA misses. This is the default in many modern games because it has very little overhead.

MORPHOLOGICAL (MLAA)

Available with AMD cards, MLAA also skips the rendering stage and processes the frame, seeking out aliasing and smoothing it. As Nicholas Vining explains, "Morphological anti-aliasing looks at the morphology of the jaggies on the edges. For each set of jaggies, it computes a way of removing the aliasing which is pleasing to the eye. It does this by breaking down edges and jaggies into little sets of morphological operators, like Tetris blocks, and then uses a special type of blending for each Tetris block."

ENHANCED SUBPIXEL MORPHOLOGICAL (SMAA)

Another post-processing method, described as combining MLAA with MSAA and SSAA strategies. You can apply it with SweetFX, and many modern games natively support this.

TEMPORAL (TAA OR TXAA)

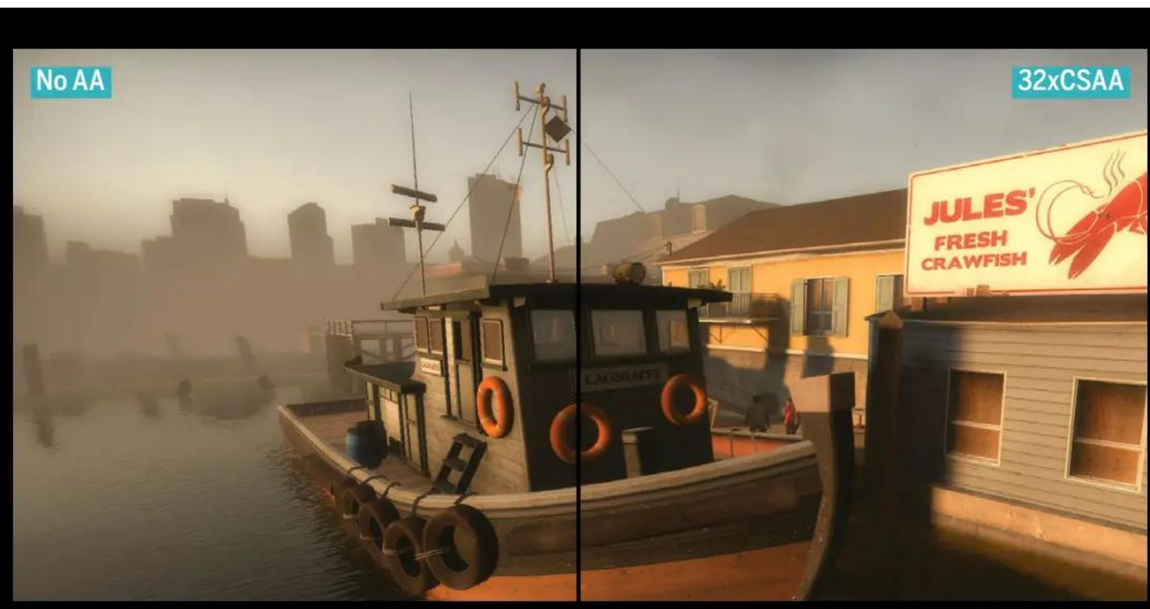
TXAA was initially supported on Nvidia's Kepler and later GPUs, but more general forms of temporal anti-aliasing are now available and are typically just labelled TAA. TAA compares the previous frame with the current frame to look for edges and help remove jaggies. This is done through a variety of filters and can help reduce the 'crawling' motion on edges, which looks a bit like marching ants. It cannot, however, remove actual ants from inside your display. If that happens, you should probably just throw that display out.

MULTI-FRAME (MFAA)

Introduced with Nvidia's Maxwell GPUs. Whereas MSAA samples in set patterns, Multi-Frame allows for programmable sample patterns.

DEEP LEARNING SUPER-SAMPLING (DLSS)

Nvidia's latest, available on certain games using new GeForce RTX cards. According to Nvidia, "DLSS leverages a deep neural network to extract multidimensional features of the rendered scene and intelligently combine details from multiple frames to construct a high-quality final image. DLSS uses fewer input samples than traditional techniques such as TAA, while avoiding the algorithmic difficulties such techniques face with transparency and other elements." In other words, it's better and more efficient at doing the things Temporal AA does, or at least it's supposed to look better once it has been properly trained for a specific game.



WHAT DO THE NUMBERS MEAN?

Anti-aliasing settings almost always include a series of values: 2x, 4x, 8x, and so on. The numbers refer to the number of colour samples being taken, and in general, the higher the number, the more accurate (and computationally expensive) the anti-aliasing will be.

Then there's the special case of the 'Q'. CSAA attempts to achieve a quality better than or equal to MSAA with fewer colour samples, so 8xCSAA actually only takes four colour samples. The other four are coverage samples. 8QxCSAA, however, bumps the number of colour samples back up to eight for increased accuracy. You'll rarely encounter CSAA these days, so let's call that a fun fact.

WHICH AA SHOULD I USE?

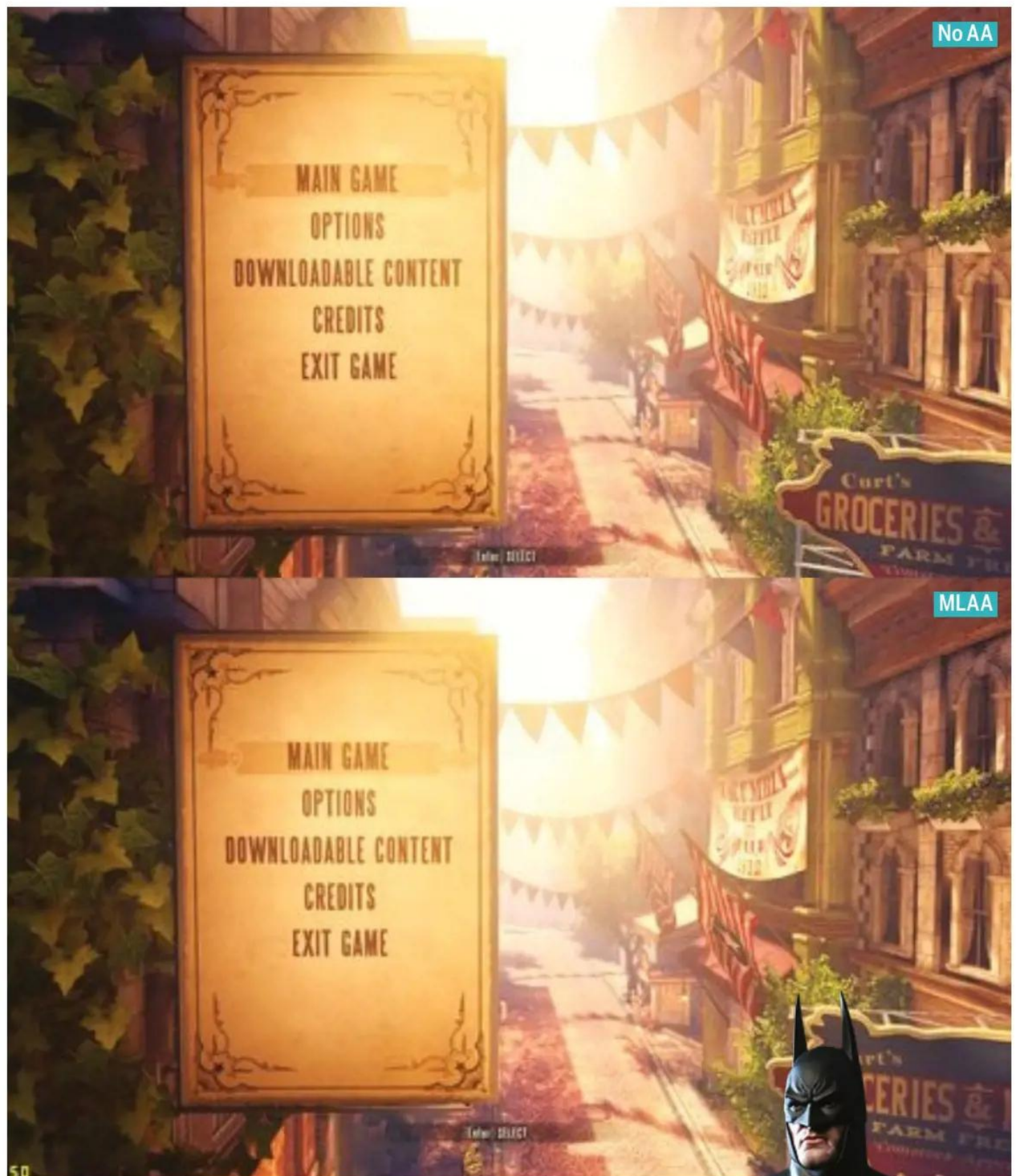
It depends on your GPU, your preference, and what kind of performance you're after. If framerate is an issue, however, the choice is usually obvious – FXAA is very efficient. If you've got an RTX card, and the game you're playing supports it, give DLSS a try – you paid for it, and it's top of the line. In older games, you'll probably have to do a bit of testing to get the combination of look and performance you want. If you have the hardware to do it, you can also try supersampling instead of using the built-in options, which usually works. Overriding settings in other ways, however, isn't a sure thing.

OVERRIDING ANTI-ALIASING SETTINGS

Theoretically, in-game graphics options shouldn't matter. You can just open up the Nvidia or AMD control panel and override their settings. Unfortunately, that's not really the case. While you can set overrides for any game, I've had little success getting them to work. "Very often when overrides don't work it's due to deferred rendering," says Vining, "which just breaks a lot of common anti-aliasing techniques." Alex Austin also notes that some of his techniques don't work with override settings. So, it's just a matter of testing. Turn off all AA in the in-game options, set the override in your control panel, and hop back in: it should be apparent whether or not it took effect.

I've found that AMD's MLAA works the most when enabled in the control panel. It's important to note, however, that it's a post-processing filter and applies to everything in the scene. That means it can take care of hard edges within textures, which can be good, but comes with the side-effect that it may also go after desirable edges, such as in text. Notice how it slightly smooths the text in the BioShock Infinite menu, and even goes so far as to smooth my FRAPS FPS overlay.

Supersampling using Nvidia's DSR or AMD's Virtual Super Resolution, however, is more reliable. In the AMD settings, you simply have to turn Virtual Super Resolution on in the Display tab. If you have an Nvidia card, head to the 'Manage 3D settings' section of the Nvidia Control Panel, where you can select DSR factors up to 4x. Do one of those things, and in your games' options you should be able to select resolutions higher than your display resolution. Do so, and the game will run at the selected resolution and be downsampled to your display resolution – very taxing, but the end result looks nice.



PERFORMANCE

I used Batman: Arkham City's benchmarking tool to test a few older anti-aliasing methods: MSAA, FXAA, and TXAA. The results show, as expected, that FXAA is the least resource intensive, while MSAA and TXAA cause a significant drop in average framerate over no anti-aliasing.

Some more modern games don't give you much of a choice. Battlefield 5, for example, offers me two TAA quality options. Assassin's Creed Odyssey offers low, medium, high, and adaptive options.

***Batman: Arkham City* AA benchmarks**
(2x Nvidia GTX Titan SLI)

	Avg. FPS	Max FPS	Min FPS
No AA	161	224	57
MSAA 8x	84	166	44
FXAA (high)	154	204	60
TXAA (high)	98	118	67

TEXTURE FILTERING

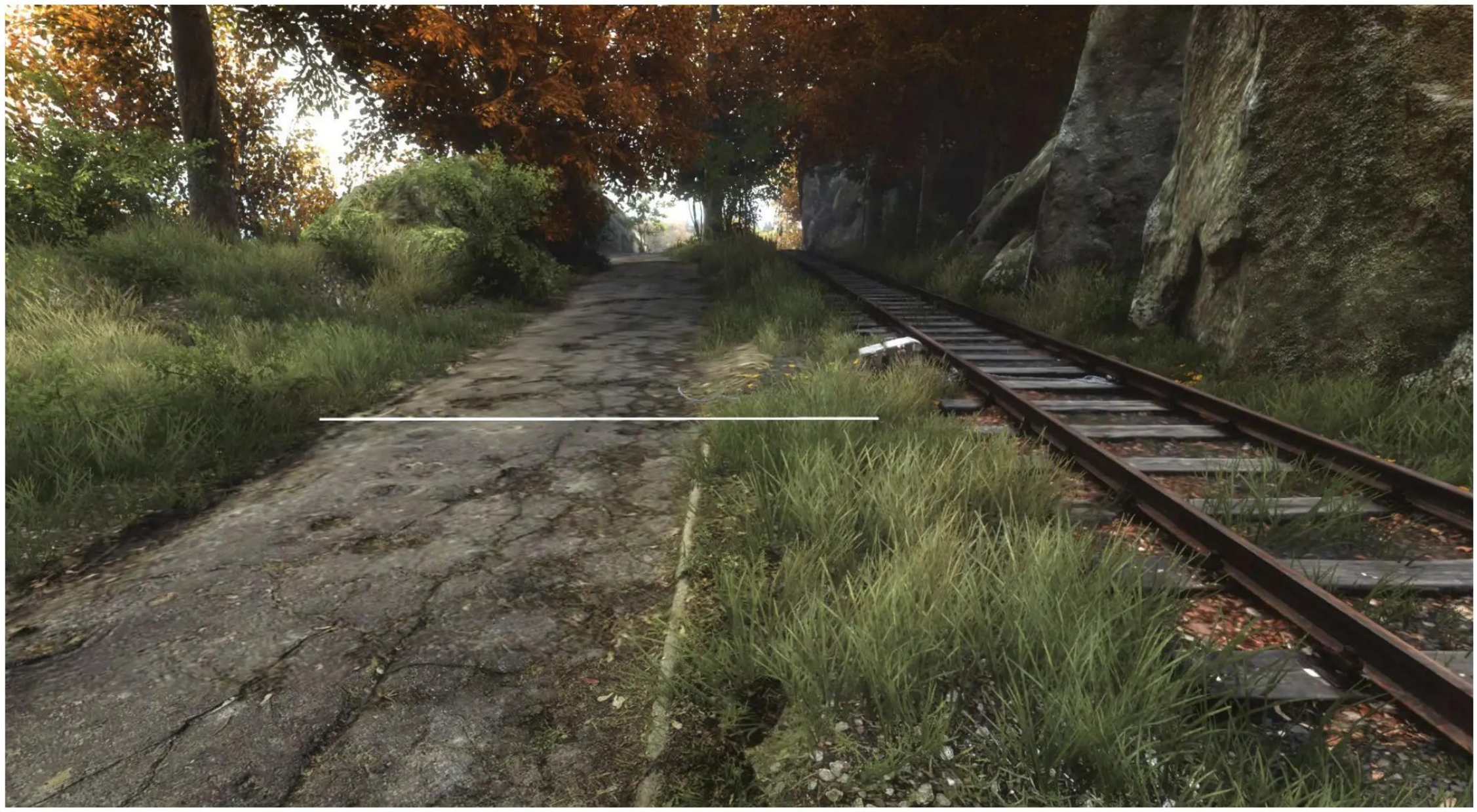
BILINEAR AND TRILINEAR FILTERING

WE DON'T WANT TO SEE WHERE ONE MIPMAP ENDS AND ANOTHER BEGINS

Texture filtering deals with how a texture – a 2D image (and other data) – is displayed on a 3D model. A pixel on a 3D model won't correspond directly to one pixel on its texture (called a 'texel' for clarity), because you can view the model at any distance and angle. So, when we want to know the colour of a pixel, we find the point on the texture it corresponds to, take samples from nearby texels, and average them. The simplest method of this is bilinear filtering, and that's all it does: when a pixel falls between texels, it samples the four nearest texels to find its colour.

Introduce mipmapping, and you have a new problem. Say the ground you're standing on is made of cracked concrete. If you look straight down, you're seeing a big, detailed concrete texture. But when you look way off into the distance, where this road recedes toward the horizon, it wouldn't make sense to sample from a high-resolution texture when we're only seeing a few pixels of road. To improve performance (and prevent aliasing, Austin notes) without losing much or any quality, the game uses a lower-resolution texture – called a mipmap – for distant objects.

When looking down this concrete road, we don't want to see where one mipmap ends and another begins, because there would be a clear jump in quality. Bilinear filtering doesn't interpolate between mipmaps, so the jump is visible. This is solved with trilinear filtering, which smooths the transition between mipmaps by taking samples from both.



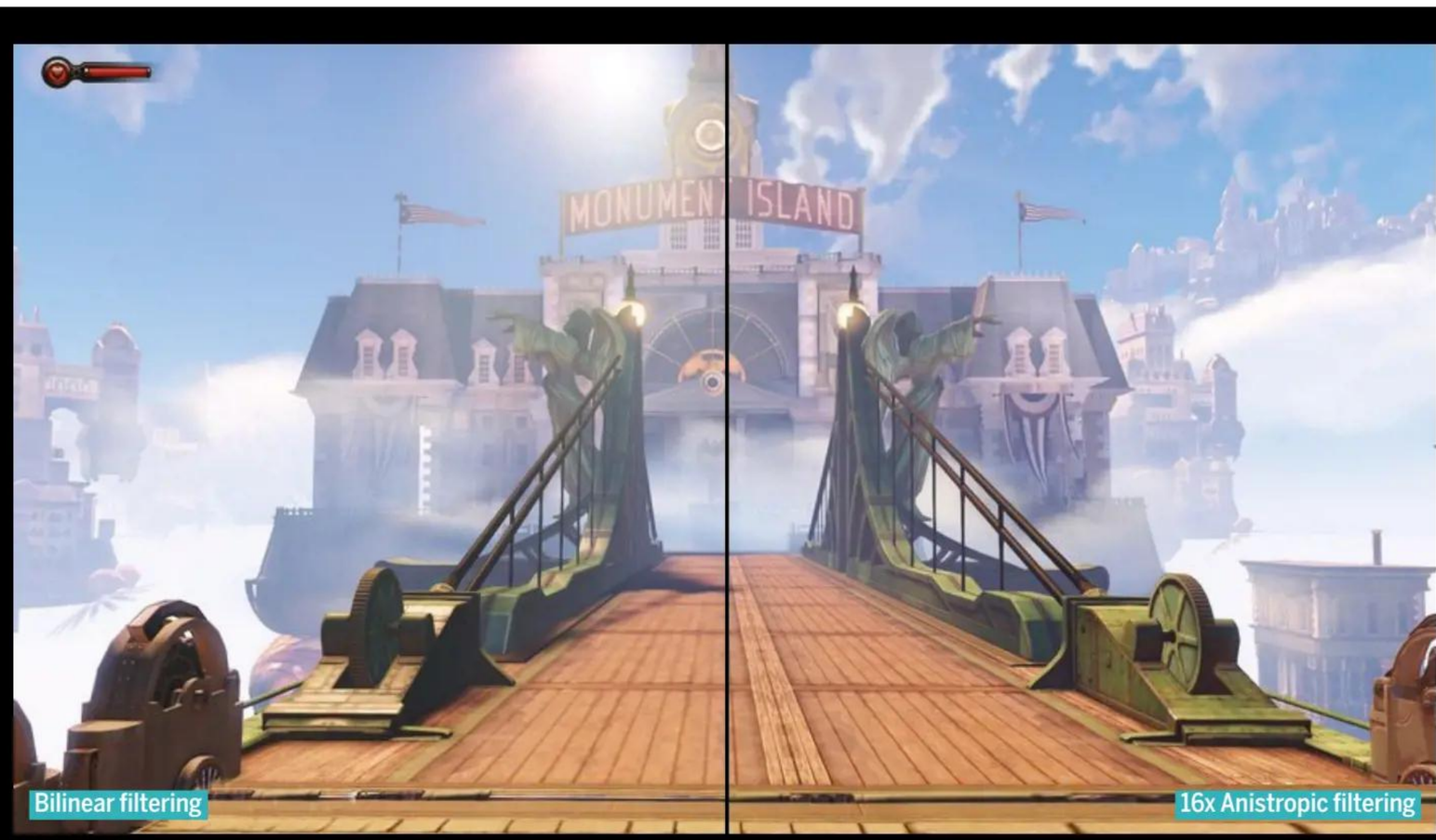
ANISOTROPIC FILTERING

Trilinear filtering helps, but the ground still looks all blurry. This is why we use anisotropic filtering, which improves texture quality at oblique angles. To understand why, visualise a square window – a pixel of a 3D model – with a brick wall directly behind it as our texture.

Light is shining through the window, creating a square shape on the wall. That's our sample area for this pixel, and it's equal in all directions. With bilinear and trilinear filtering, this is how textures are always sampled. If the model is also directly in front of us, perpendicular to our view, that's fine, but what if it's tilted away from us?

If we're still sampling a square, we're doing it wrong, and everything looks blurry. Imagine now that the brick wall texture has tilted away from the window. The beam of light transforms into a long, skinny trapezoid covering much more vertical space on the texture than horizontal. That's the area we should be sampling for this pixel, and in the form of a rough analogy, this is what anisotropic filtering takes into account. It scales the mipmaps in one direction (like how we tilted our wall) according to the angle we're viewing the 3D object.

This is a difficult concept to grasp, and we have to admit that our analogy does little to explain the actual implementation of it.



PERFORMANCE

Anisotropic filtering it's not nearly as much of a hit as anti-aliasing, which is why it rarely appears in menus these days – it's just on, no matter what. Using the BioShock Infinite benchmarking tool, I only saw average FPS drop by six between bilinear filtering and 16x anisotropic filtering. That's not much of a difference considering the huge quality increase. High texture quality is pointless with poor filtering.

WHAT DO THE NUMBERS MEAN?

Anisotropic filtering isn't common in modern settings menus anymore, but where it does appear, it generally comes in 2x, 4x, 8x, and 16x flavours. Nvidia describes these sample rates as referring to the steepness of the angle the filtering will be applied to, "AF can function with anisotropy levels between 1 (no scaling) and 16, defining the maximum degree which a mipmap can be scaled by, but AF is offered to the user in powers of two: 2x, 4x, 8x, and 16x. The difference between these settings is the maximum angle that AF will filter the texture by. For example: 4x will filter textures at angles twice as steep as 2x, but will still apply standard 2x filtering to textures within the 2x range to optimise performance. There are diminishing returns with the use of higher AF settings because the angles at which they are applied become rarer."

QUALITY SETTINGS & POST-PROCESSING

BioShock Infinite texture quality benchmarks
(2x Nvidia GTX Titan SLI)

	Avg. FPS	Max FPS	Min FPS
Very low	103	295	30
Normal	101	180	20
Ultra	92	178	15

QUALITY SETTINGS

What quality settings actually do will vary depending on what game you're playing. In general, they raise and lower the complexity of the game's assets and effects, but going from 'low' to 'high' can change a bunch of variables. Increasing the shadow quality, for instance, might increase the shadow resolution, enable soft shadows as well as hard shadows, increase the distance at which shadows are visible, and so on. It can have a significant effect on performance.

Texture quality, which lowers and raises the resolution of textures, tends to affect performance and visual quality a lot. We benchmarked BioShock Infinite with all settings set to high, changing only the texture quality, to get a sense of how expensive it is. That's an average FPS jump of 11 between 'very low' and 'ultra.' Not too bad, but the amount of slow-down will vary system-to-system. There's no quick method for determining the best quality settings for your system – it's a case where they just need to be tested, and we recommend starting with Nvidia or AMD's suggestions, then raising the quality on textures, lighting, and shadows and finally checking out your framerate.

AMBIENT OCCLUSION

Ambient lighting exposes every object in a scene to a uniform light – think of a sunny day, where even in the shadows, a certain amount of light is scattered about. It's paired with directional light to create depth, but on its own it looks flat.

Ambient occlusion attempts to improve the effect by determining which parts of the scene shouldn't be exposed to as much ambient lighting as others. It doesn't cast hard shadows like a directional light source, rather, it darkens interiors and crevices, adding soft shading. Screen space ambient occlusion (SSAO) is an approximation of ambient occlusion used in real-time rendering, and has become commonplace in games in the past few years – it was first used in Crysis.

Sometimes, it looks really dumb, like everything has a dark 'anti-glow' around it. Other times, it's effective in adding depth to a scene. All major engines support it, and its success will vary depending on the game and implementation.

Improvements on SSAO include HBAO+ and HDAO.

HIGH DYNAMIC RANGE RENDERING (HDRR)

High dynamic range was all the rage in photography a few years ago. The range it refers to is the range of luminosity in an image – that is, how dark and bright it can be. The goal is for the darkest areas to be as detailed as the brightest areas. A low-dynamic-range image may show lots of detail in the light part of a room, but lose it all in the shadows, or vice versa. In the past, the range of dark to light in games was limited to 8 bits (only 256 values), but as of DirectX 10 128-bit HDRR is possible. HDR is still limited by the contrast ratio of displays, though. There's no standard method for measuring this, but LED displays generally advertise a contrast ratio of 1000:1.

DEPTH OF FIELD (DOF)

In photography, depth of field refers to the distance between the closest and furthest points which appear in focus. If I'm taking a portrait with a small DOF, for instance, my subject's face might be sharp while the back of her hair begins to blur, and everything behind her is very blurred. In a high DOF photo, on the other hand, her nose might be as sharp as the buildings behind her.

In games, DOF generally just refers to the effect of blurring things in the background. Like motion blur, it pretends our 'eyes' in the game are cameras, and creates a film-like quality. It can also affect performance significantly depending on how it's implemented. On the LPC, the difference was negligible, but on the more modest PC at my desk (Core i7 @ 3.47 GHz, 12GB RAM, Radeon HD 5970) my average framerate in BioShock Infinite dropped by 21 when going from regular depth of field to Infinite's DX11 'Diffusion Depth of Field.'

MOTION BLUR

Motion blur is pretty self-explanatory: it's a post-processing filter which simulates the film effect caused when motion occurs while a frame is being captured. Many gamers I've seen in forums or spoken to prefer to turn it off. Not only because it affects performance, but because it just isn't desirable. I've seen motion blur used effectively in some racing games, but I'm also in the camp that usually turns it off. It doesn't add enough for me to bother with any performance decrease.

BLOOM

The famously overused bloom effect attempts to simulate the way bright light can appear to spill over edges, a visual cue that makes light sources seem brighter than they are (your display can only get so bright). It can work, but too often it's applied with a thick brush, making distant oil lamps look like nuclear detonations. Most games offer the option to turn it off. The screenshot above is from Syndicate, which probably includes the most hilarious overuse of the effect.

CONCLUSION

How these settings affect visual quality will vary from game to game, and how they affect performance will vary from system to system. These benchmarks are anecdotal, but they can give us an idea of which processes are generally more taxing than others. Whenever a graphics intensive game releases, especially if it's on a new engine or uses new tech, you can bet we're working on a performance and settings guide for PCGamer.com.

PROTECT YOUR TECH

Having your laptop, tablet or phone stolen is depressingly common. As Mike Bedford explains here, there's a lot you can do to keep your IT equipment safe

AT A GLANCE

HOW TO FIND WHAT YOU'RE LOOKING FOR

• Anti-theft products, **p66**
Anti-theft products range from devices to provide physical security, through alarms that will let you know if your equipment is tampered with, to products to mark your gear uniquely and indelibly. We look at the pros and cons of each, and identify some suitable products.

• Behavioural changes, **p67**
Even if you don't want to buy any anti-theft products – although we certainly suggest you do – you could probably make your kit a lot more secure just by altering the way you behave. It's all too easy to let your guard down, so here are some common-sense precautions.

• DIY solutions, **p68**
Creating your own anti-theft products could provide you with extra functionality while being an interesting exercise and perhaps providing a cost saving. We recommend a couple of DIY solutions: a software-only laptop alarm, and a proximity tag with app.

We have good news and bad news. The good news is that the crime rate has been falling in the UK, from a peak in 1995. Similar trends apply in many other countries. The bad news is that, despite a reduction in household burglary, property theft overall – and theft from the person in particular – has remained high or risen over the same period, with computer-related equipment being targeted. Mobile phones are particularly sought after, but we're guessing most would-be thieves wouldn't turn their nose up at a top-of-the-range laptop or tablet either.

It's a depressing irony, then, that although convenience while you're out and about is the whole reason for using portable electronic devices, once your equipment is taken out of the home or office it becomes much more likely to attract the attention of criminals. What's more, the consequences could be serious. Certainly, the cost of replacement of the hardware has to be considered – and even if it's insured, you won't necessarily be fully reimbursed for the loss – but this is just a start. The possibility of theft makes data backup even more important on a laptop or tablet than it is on a desktop but, unless you use a cloud backup or an external disk kept separately from the laptop, your data will only be secured once you get back home. Potentially, therefore, you stand to lose a day or more of work and information which – in the case of notes made at a meeting, for example – might be difficult to replace.

We also have to consider the fact that sensitive data could fall into the wrong hands. Finally, getting a replacement for a stolen item, setting it up, re-installing all your software and restoring your data will take some time. Unless you have a spare, therefore, you could be without a laptop or tablet for quite a few days and this could have a serious impact on your productivity.

It's common to believe that these problems always happen to someone else and are probably due to carelessness. However, one in 10 laptops is stolen during its lifetime and half a million people in the UK had a phone stolen in 2016. If these statistics have convinced you that this is a subject that can affect us all, do read on because, as you'll see, a small change in your behaviour and a modest investment in anti-theft products could make your equipment a whole lot more secure. We're going to be looking mainly about prevention of laptop theft here but some of the products, and most of our advice, applies equally to tablets, smartphones, cameras or just about any other electronic equipment you might want to use on the move.

GET THE RIGHT PRODUCT

Just as there are several ways of protecting your home or car from theft, the same applies to your laptop. The choice is even more diverse, however, so a bit of guidance is called for. Anti-theft products that are suitable for high-tech gear fall into three main categories.

First are products that make it physically difficult for a thief to get away with your gear – we can think of these as the equivalent of the lock on a door. Second are those devices which will draw attention to a thief should they attempt to steal your equipment; this is the equivalent of a household burglar alarm. And third are products for marking your kit to improve the likelihood of it being returned if it is stolen while, at the same time, making it less attractive to a would-be thief. Again, very similar products are available for household items. Here we'll look at each category in turn, examining their pros and cons and highlighting some actual products. First we need to make an important point, though: no single type of product is better than the others and each offers benefits in certain circumstances. So, just as it's common to have locks on your house doors and a burglar alarm, it would be wise to consider protecting your portable gear with at least two, if not all three, types of products.

PHYSICAL ANTI-THEFT KIT

Most laptops have a so-called Kensington lock slot which is used to secure it using a security cable from Kensington (**www.kensington.com**) or other manufacturers. The cable is wrapped around some immovable object such as the legs of a desk, then the end is threaded through a loop in the cable before being inserted into the Kensington slot. The laptop is now secured against casual theft, although it won't deter a thief equipped with a pair of bolt cutters or who is prepared to damage the laptop to release the security cable. The laptop can be removed by its rightful owner using either a key or a combination lock, depending on the specific product. Prices vary significantly, from as little as £3 to over £35.

Tablets rarely, if ever, have Kensington lock slots and smartphones are never equipped in this way. Realistically, it's probably easier to just make sure that phones are always kept in a secure place, and any adaptor would be quite intrusive on such small devices. Nevertheless, if you're willing to accept a bulge on the back cover, cable anchors that glue onto the back of smartphones are available from various sources and these can also be used on tablets. However, a better solution for tablets is the Blade Universal Lock Slot Adaptor provided by Maclocks (**www.maclocks.co.uk**). This is a low-profile hinged bracket that can be attached to the base of tablets using high-strength adhesive, which allows a security cable to be attached, and that folds away when not in use. It costs from £38.

ALARMS

The first type of alarm we'll look at, the Lock Alarm Mini (www.lockalarm.com) at £25, serves a dual purpose in also providing physical protection. Like security cables, this product also incorporates a steel wire that is fitted to any type of product that has some sort of loop through which it could be threaded. For a laptop, you also need an adaptor which allows it to be fitted into a Kensington lock slot. The wire is much thinner than Kensington-type security cables but it probably won't succumb to small wire-cutters and, in addition, its small diameter allows it to be retracted into the body of the unit when not in use. Where it differs from a plain security cable is that a 100dB alarm will sound if the cable is cut. A movement sensor can also be activated.

The next type of alarm, and one that is becoming increasingly popular, is the proximity alarm. These generally take the form of a Bluetooth-enabled tag that is attached to the equipment being protected and is paired with a smartphone. There are lots on the market, each with slightly different features, and although this isn't a comparative review, we will indicate what to look for and approximately how much you can expect to pay. First, it's important to recognise that the tags tend to be in the region of 35mm across and cannot easily be attached to a laptop. They're frequently shown hanging from keyrings but they could readily be attached to a laptop case or hidden in one of its pockets. To truly be called a proximity alarm, an audible alarm should sound if the phone and the tag are separated by more than some preset distance. Not all tags offer this useful feature, perhaps because it's tricky to gauge distance from Bluetooth signal strength.

What they do all offer, however, is a means of manually triggering an alarm on the tag from the paired phone if the tag is still within Bluetooth range – up to several tens of metres, depending on the device and whether there are walls between the tag and the phone. This helps you to track down the tag and might cause a thief to abandon it if it truly has been stolen. Many also have a crowd-finding facility which, even without people's active participation, employs the user community to help find a device if it's out of Bluetooth range. In reality, this isn't going to be much use unless you're in a densely populated area and you've chosen one of the most popular brands.

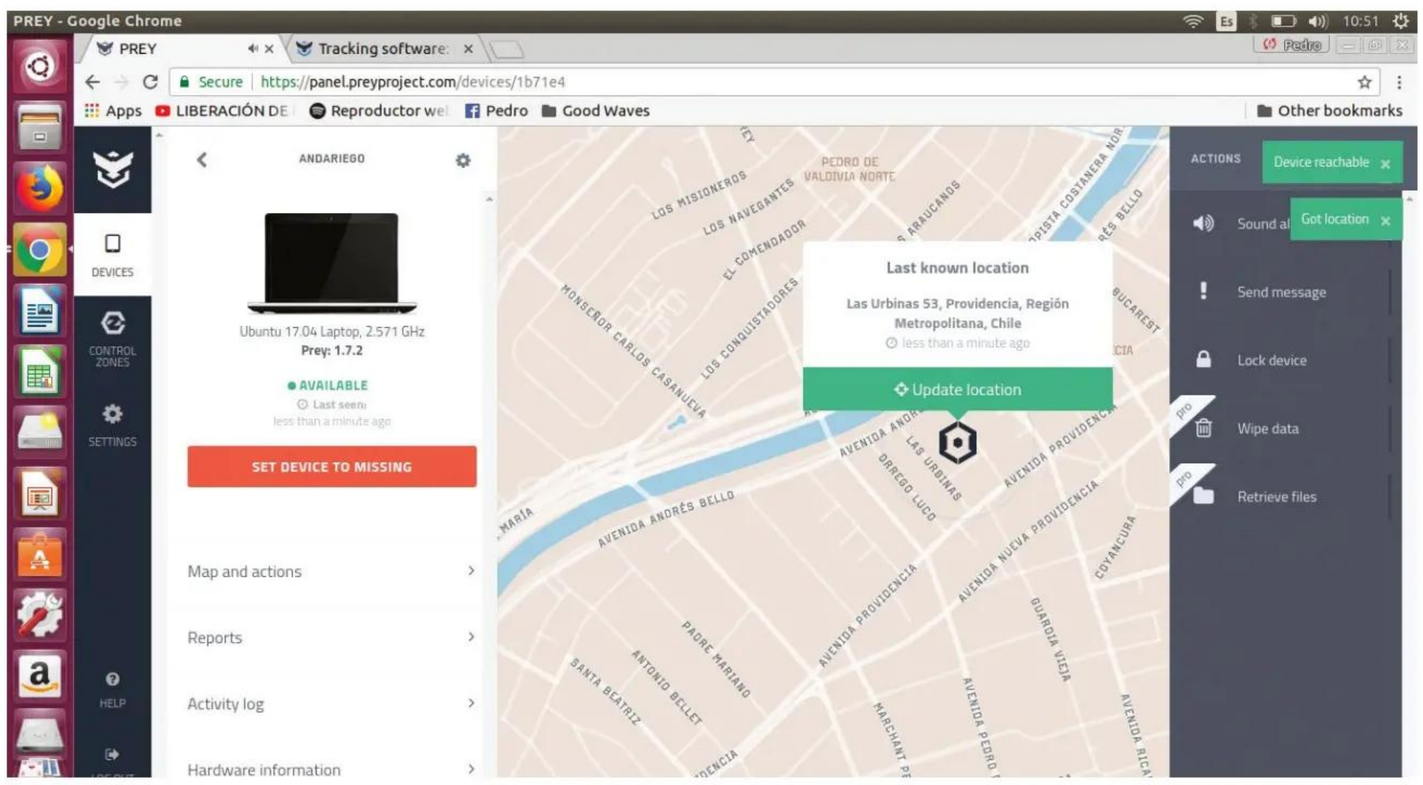
These products are equally effective against accidental loss as against theft, and to help you here, most associated apps will allow you to see, on a map, where your tag was last detected. Tags cost from about £20, but some have batteries that cannot be recharged or replaced so you have to buy a new tag – often at a reduced price, fortunately – after the year or so it takes for the battery to run down. The product family that is probably the market leader is Tile (www.thetileapp.com) although, as yet, it doesn't feature a true proximity alarm. The PebbleBee Honey (www.pebblebee.com) is one that does offer a proximity alarm, also known as geofence, functionality.

MOST LAPTOPS HAVE A SO-CALLED KENSINGTON LOCK SLOT THAT IS USED TO SECURE THEM WITH A CABLE

QUICK GUIDE

PREY: TRACKING SOFTWARE

Prey doesn't stop your mobile device being stolen, but makes it more likely you'll be able to get it back if it's taken from you. It takes the form of software that you install that runs in the background. If your device is stolen, you report it as stolen on the Prey website and, from then on, whenever it's switched on you'll receive reports containing an IP address and a location based on nearby Wi-Fi signals. If the device has a camera you'll get photos of whoever's using it, and receive screenshots – which might be useful as they could show, for example, the culprit's Facebook page. Armed with this, you could approach the police, who might be able to recover your device. The Pro version allows you to remotely delete files. Prey is open source and the standard version is free. It is available for most operating systems from www.preyproject.com.



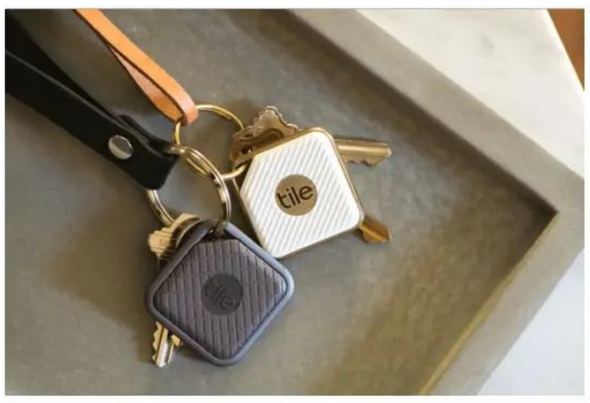
Below: Prey provides you with reports, including information about the location of missing devices

The other main type of alarm that's relevant to laptops is the purely software version. These are really only effective against opportunistic theft and will sound if, for example, the mains power supply or a mouse is unplugged from an unattended laptop. Unfortunately, pretty much all of these alarms only work on Windows and, while a few free packages are still available for download, most commercial products have been discontinued. However, for those proficient in coding, a DIY solution could be a possibility.

MARKING PRODUCTS

Products for marking equipment serve two quite distinct purposes. First, they improve the likelihood of your equipment being returned to you if it's stolen and subsequently recovered by the police. Second, because possession of marked equipment could be discriminating, it makes your laptop or other equipment a much less attractive target to a potential thief. Two categories of product achieve these two important functions.

The first category allows you to mark a product in a way that is highly visible and difficult to remove. One type comprises stencils, prepared with either your address or a unique serial number, that are supplied with an applicator and special ink. The ink etches into the surface of your laptop or other equipment, thereby making its removal almost impossible. The other main type involves specially prepared tamper-resistant labels, again showing your address or an ID, which are supplied with an adhesive for attaching them to your equipment. Again, removal is



Top: SmartWater is almost impossible to remove and uniquely identifies the owner Above: Tags from Tile use Bluetooth to help you track down missing devices

difficult and, at best, will leave tell-tale signs. When a serial number is used as opposed to an address, this product is sold with registration to a database – accessible by the police – that associates the owner with the equipment. The advantage this offers is that equipment can be re-registered if you sell it. Retainagroup (www.retainagroup.com) offers this type of product in the UK, and STOP (www.stoptheft.com) offers it in the US.

At first sight, the second category of products – those that mark your products invisibly – seems a strange concept. Some companies sell invisible ink pens that you'd use to write your postcode or ZIP code on your equipment, which becomes visible if you shine an ultraviolet light on it. We don't recommend this solution since it offers no deterrent value and is also potentially removable with a solvent if the thief discovers the marking. Where things get more interesting is when we consider those products such as SmartWater, which is an invisible ink, prepared with a formulation unique to each customer, that you apply to the equipment and is almost impossible to remove completely. It can be detected with an ultraviolet light, leading the police to forward recovered equipment to SmartWater for analysis to reveal the registered owner.

It's provided with warning labels that you can attach to marked equipment, thereby providing that all-important deterrent value. SmartWater is sold in the UK; prices range from £25-35 for products in the Home Security range and these can be purchased from https://shop.smartwater.com. In the US, up to ten items can be protected for as little as $5 per month – see https://shop.smartwatercsi.com.

BEHAVIOURAL CHANGES

Physical protection, alarms and marking products are important anti-theft measures and should be seriously considered by anyone who regularly takes valuable equipment outside the home or office. However, your behaviour is also important and changes here could prove to be equally as effective in preventing loss.

Our first piece of advice is to not advertise the fact that you're carrying valuable equipment when you're not using it. When you're walking down the street, keep small items such as phones in your pocket or handbag rather than in your hand, where they can be easily seen and could readily be snatched from your grasp. Needless to say, this isn't feasible with larger items such as tablets and laptops. However, it's not necessary to carry them in a conventional laptop case, which does little to disguise the expensive equipment it contains. A police Crime Prevention Officer we spoke to said that he always carries his laptop in a scruffy supermarket bag because nobody would guess it contained anything more valuable than a few cans of beans.

If you want something a bit smarter, or that provides more protection from knocks, you could consider a backpack. You could use an ordinary backpack of the sort you might take on a hike, but a special laptop backpack might be more appropriate, because they're designed to hold a laptop of a particular size and have plenty of compartments for accessories and documents. You can easily pay over £100 for such a backpack, but we recommend opting for a much cheaper one so it's not as conspicuous. These are widely available from several suppliers. With laptop backpacks now fairly common, their stealth value is not as great as it once was, but a thief will still find it

STENCILS, PREPARED WITH EITHER YOUR ADDRESS OR A UNIQUE SERIAL NUMBER, ARE SUPPLIED WITH AN APPLICATOR AND SPECIAL INK

PRODUCTS

Anti-theftdevicetypes to consider

1 LOCTOTE FLAKSACK SPORT

It's difficult to provide physical protection for individual small items, as you can easily do with a laptop. However, the LocTote FlakSack Sport (http://loctote.com, £75) keeps several small pieces of equipment secure. It takes the form of a slash-resistant bag with a nylon and steel locking strap and combination lock with which you can attach it to an immovable object.

2 LOCK ALARM MINI

The Lock Alarm Mini (www.lockalarm.com, £25) offers both physical protection and an alarm. The physical protection is provided by a strong steel cable to secure your laptop or other kit. This is difficult to cut with hand tools and, if a thief does try to cut through it, an alarm will sound.

3 SMARTWATER

SmartWater provides the benefits of both visible and invisible marking. Warning labels act as a deterrent, while the invisible paint is very difficult to remove and the smallest trace is enough to identify you as the owner. You can mark up to 50 items for £35 from https://shop.smartwater.com.

harder to take a backpack from your back than a case from your hand.

Next, think about the situation when you're using your equipment, most notably your laptop, in a public place such as an airport lounge, railway station, coffee shop or university library. It would be rare for a laptop to be stolen while you're actually using it, although you should be careful about leaving a phone in view. After all, it only takes a momentary lapse in your attention for someone to walk off with any such small items. The main risk to your laptop, however, is if you need to take a break, perhaps to buy a coffee. It's important to recognise that your insurance company might not reimburse you if leave your laptop unattended – and if it belongs to your employer, you might find yourself having to answer some very difficult questions from your boss.

Of course, the safest piece of advice that we can give is to never leave your laptop unattended, even if you only intend to be away for a very short time. That's not always possible though, even if you just need a short trip to the loo, and in any case you might not want to appear neurotic (Looking neurotic is better than losing your laptop, but we have to be realistic). This being the case, how about carrying out a risk assessment to come up with your own set of rules?

You might decide, for example, that you will never leave your laptop unattended in an airport, on a train, or in a coffee shop or bar (and that really is the only sensible option in these places). If you're in the university library, you might decide that you'd be prepared to ask someone to watch it for you, as long as you're not going to be away for more than two minutes. This is also an instance in which you might decide to use a software alarm, bearing in mind that it'll only provide a minimal degree of protection.

IT'S IMPORTANT TO RECOGNISE THAT YOUR INSURANCE COMPANY MIGHT NOT REIMBURSE YOU IF YOU LEAVE YOUR LAPTOP UNATTENDED

DIY SOLUTIONS

If you're a developer as opposed to a user, you might want to consider creating your own anti-theft utilities and devices. We've already seen that software-only laptop alarms are few and far between and most of those that do exist only operate under Windows. Still, there's some benefit in having an extra layer of protection, even if it's not 100 per cent effective. So how about writing your own alarm? Since this will cost you nothing at all except your time, it's worth considering.

The advantage in writing your own alarm is that you can decide exactly how you'd like it to operate. Be prepared to be innovative. Some features, such as sounding if the power supply is unplugged, are surely essential, but there are other useful things you might choose to add. For example, you might find that certain patterns of Wi-Fi signal strength are indicative of the laptop being moved, as opposed to someone just walking between it and the access point. If so, this might provide a means of detecting theft of your laptop, even if it wasn't connected to mains power.

An alternative is to detect motion directly. While nearly all smartphones contain the accelerometers that would permit this, they are not nearly as ubiquitous in laptops. Some products, most notably Lenovo ThinkPads, have accelerometers as part of the Hard Drive Active Protection System (HDAPS) which parks the disk drive heads to prevent damage to platter if the laptop is dropped. Another example are convertible laptop/tablets that often include an accelerometer so that screen rotation can be detected. Finally, don't forget that an alarm could be disabled just by turning off the laptop or closing its lid, so do be sure to disable both the power and the lid switch whenever the alarm is active.

Another DIY project you might want to attempt is a proximity alarm based on a small single board computer with an associated Android or iOS app. The Particle Photon (www.particle.io) would be a contender due to its small size and, while it isn't much cheaper than an

QUICK GUIDE

ENCRYPT SENSITIVE DATA

Losing a laptop could deny you access to important data, at least until you can access a backup, but if sensitive data falls into the wrong hands it could be even more costly. An obvious precaution is not to store sensitive information on your portable devices unless you really need to access it when you're away from home. If it is necessary to store that data when you are on the move, though, it would be wise to encrypt it. Choosing an ideal solution is a major topic in its own right.

Below Security cables, like this one from Kensington, are ideal for deterring casual laptop theft

Visibly marking your gear provides a deterrent to potential thieves

QUICK GUIDE

INSURANCE

Insurance is important for valuable equipment but do make sure your equipment is adequately covered. Details differ between countries, insurance companies and policies, but there are two things you should check: Does your household policy provide adequate cover for equipment that you take out of the house? And is equipment covered if you use it for business? If the cover provided by your general policy doesn't meet your needs, look for dedicated insurance for your tech gear.

THE ADVANTAGE IN WRITING YOUR OWN ALARM IS THAT YOU CAN DECIDE EXACTLY HOW YOU'D LIKE IT TO OPERATE

off-the-shelf Bluetooth tag, it does offer some benefits. First and foremost is the fact that you can add whatever features you want, rather than being constrained by what's on offer in commercial products. In fact this additional functionality needn't be restricted to theft prevention. These tiny SBCs are often targeted at Internet of Things applications, so you could use it to experiment with real-world monitoring too.

On the downside, many of the smaller SBCs – the Particle Photon included – have Wi-Fi rather than Bluetooth. For a tag that has to operate on internal batteries for perhaps a year or more, this would be a serious disadvantage as Wi-Fi is much more power-hungry than Bluetooth. If you're going to run your tag from an external battery and are prepared to recharge it periodically, however, this is no longer a disadvantage, and has the extra benefit of a greater range.

Another platform that's designed specifically as a tag, is the open source RuuviTag (https://tag.ruuvi.com). This takes the form of a compact circular board powered from an onboard button cell, housed in a round waterproof case, fitted with various sensors including an accelerometer, and including Bluetooth. It costs €69 excluding VAT for three units (that works out to roughly £76 including 24% EU VAT at the time of going to press).

It is likely that you will never find a solution that allows you to keep your laptop completely secure 100% of the time – of course, accidents can and often do happen – but you can do your best to minimise the risk of theft.

Right: It's much harder to steal a laptop if you carry it in a backpack

HOW TO

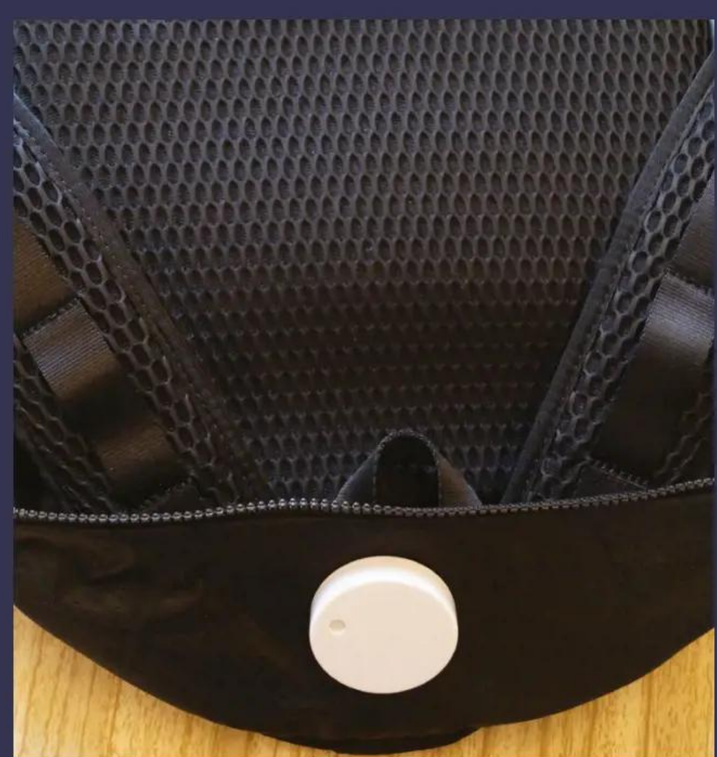
MAKE A DIY BACKPACK TRACKER WITH RUUVITAG

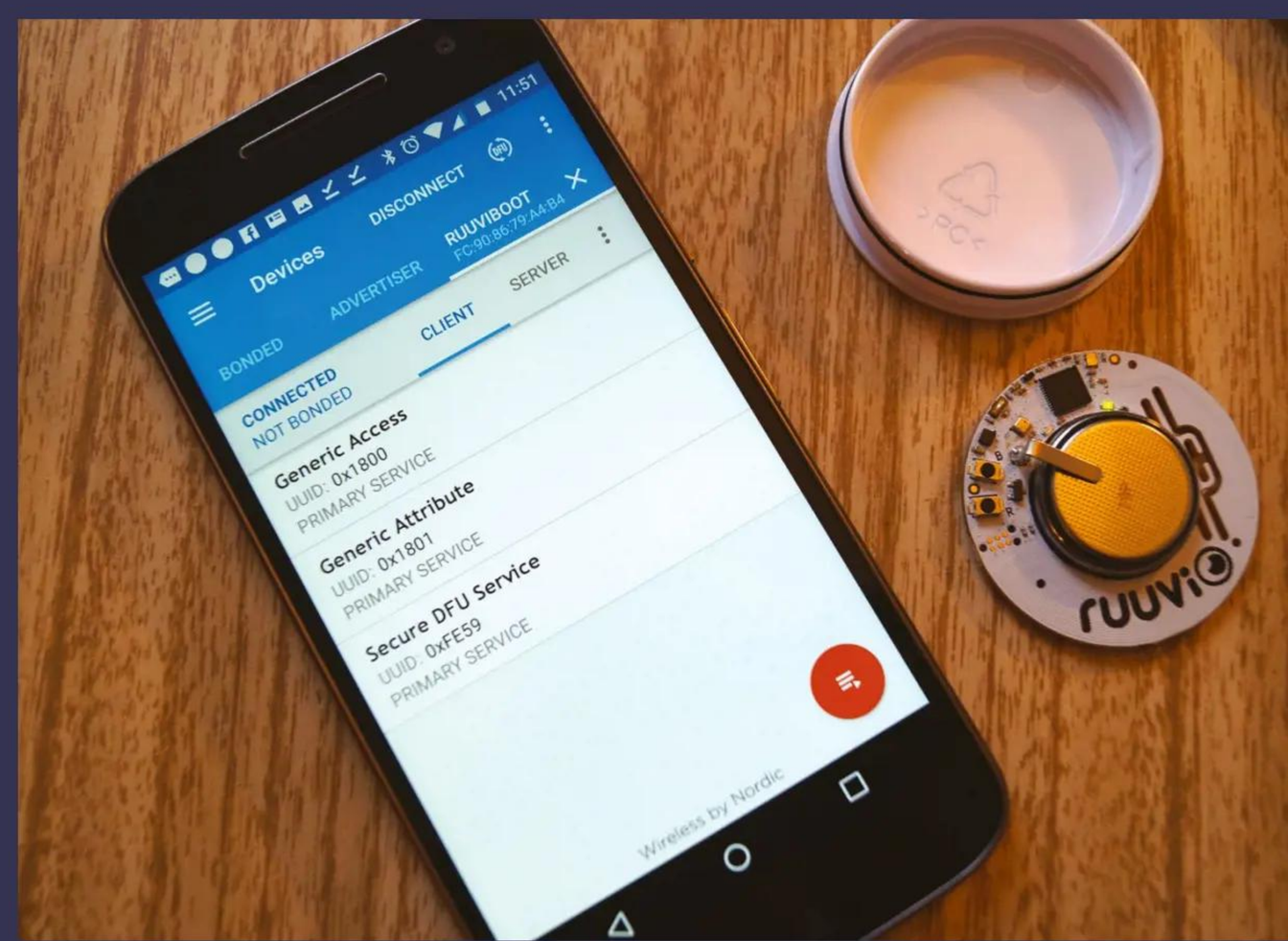
1 BACKPACK BEACON

This project is a simple way to make your own tracking device that you can tuck away in your backpack. Essentially, what you are doing is turning the RuuviTag into a proximity beacon and for this we're using Eddystone, the open beacon format from Google. Make sure you're running the latest version of Eddystone by flashing the firmware. The RuuviTag is set up for Over the Air (OTA) updating, so it's easy to flash. You'll need a phone: we used the Moto G4 Android smartphone for the job, so we needed to download nRF Connect (**http://bit.ly/nRFConnect**) from the Play Store.

2 ENTER THE BOOTLOADER

Now you need to head on over to **https://lab.ruuvi.com/dfu** on your phone, scroll to the 'Ruuvi Firmware' link and download it. To flash RuuviTag, we first need to enter its bootloader, so prise it open and pop it out of its enclosure using the attached metal clip. On the RuuviTag, you'll notice two tiny buttons. Press the one marked R while keeping B pressed to enter the bootloader. If you're successful you'll get a red light. Next, open nRF Connect and swipe down to refresh. 'Ruuviboot' should pop up as a found device so press 'Connect'. At this point the light on the board will turn green.





3 PREPARE TO FLASH

In the top right-hand corner of the app's GUI there's a tiny DFU icon which you now need to tap. This enables you to select the file type you want to use. The default 'Distribution package (ZIP)' is correct, so Click 'OK' and select the Ruuvi Firmware. This will start the upload to your RuvviTag. (Note: It's confusing but the firmware file is actually called weather_station_1.0.1.zip.) Once complete, it will display 'Application has been sent' and disconnect from Ruuviboot. Now you've got to configure your tag as a beacon.

4 GET EDDY READY

Head back to **https://lab.ruuvi.com/dfu/** and download the second link called 'Eddystone'. Go back to Step 3 and follow the same process, but choose eddystone_dfu_1.0.0.zip to upload.

5 CONFIGURE YOUR BEACON

Now to the configuration proper. First, download nRF Beacon for Eddystone (http://bit.ly/nRFBeaconforEddy), but this time press B to get a red light and enter config mode. Launch the nRF Beacon for Eddystone, click the 'Update' tab, click the RuvviTag Device from available devices and you'll connect. This will bring up an 'Unlock Beacon' box that needs a 16 byte default unlock code. This will be: 0x00112233445566778899aabbccddeeff. Configure the beacon by typing a dummy address into 'Slot 0', such as **https://my-backpack**. The transmission interval needs to be set to 300 milliseconds, so edit 'Adv. interval'. The recommended transmission power is -4 decibel-milliwatts (dBm), so alter that in the 'Radio Tx Power' option. Now click 'Disconnect'. You're all set!

6 TEST YOUR BACKPACK BEACON

We stuck the tag inside a backpack, at the top. This shouldn't affect the signal too much, but you could put it on the outside – the RuuviTag is waterproof. To track your tag, you can use any beacon scanner. We've just used Beacon Toy (**http://bit.ly/BeaconToy**). Open the side menu and click on 'Beacons around me' and your Ruuvitag will pop up. The tag has a range of 50 metres (150 feet), but you'll get a distance from your backpack in metres to track it.

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GROUP TEST

GAMING CPUs

If you're looking to upgrade your gaming PC's processor, there's a stack of new models to choose from. But which is best for you?

By Nick Evanson

The last year has been one of change for AMD and Intel, with both rolling out new ranges of desktop CPUs. The former launched the Ryzen 9000-series in August, using its Zen 5 architecture, which is an overhaul of Zen 4 for more speed. Intel released the Core Ultra 200S lineup in October, based on Arrow Lake, its first multi- tile chip for desktop PCs.

The old Core names are now gone, along with Hyper-Threading and support for DDR4. In their place is a big reduction in power. Let's go!

Ryzen 5 9600X

AMD **£270**

Little Zen

1 It's the cheapest of all the new processors from AMD and Intel, but don't let the price deceive you. The Ryzen 5 9600X might just be all the gaming CPU you need.

Compared to the last-gen Ryzen 5 7600X, the new model sips at power in games, making it very easy to cool and ideal for use in compact and small form factor builds. Some motherboards let you increase the power limit, but the Zen 5 chip doesn't run much better with more power. While six cores might seem like a small amount, it's more than enough for most games and you can overclock it, if you want a bit more poke. It's only when you turn to content creation and heavy multithreaded tasks that the little Ryzen struggles against the competition.

The only major thing that stands in the way of picking the Ryzen 5 9600X is that the last-gen Ryzen 5 7600X is still being made and it's a lot cheaper than the new model. This is true for all Zen 5 chips, though, and their prices will fall in time.

PC GAMER VERDICT

- → Solid gaming performance
- → Easy to cool
- → Zen 4 is cheaper

SPECS CORES: 6 / **THREADS:** 12 / **BASE CLOCK:** 3.9 GHZ / **BOOST CLOCK:** 5.4 GHZ / **L3 CACHE:** 32 MB / **TDP:** 65 W / **SOCKET:** AM5

Ryzen 7 9700X

AMD **£340**

Everyone's Zen

2 If you want an AMD processor that's great at gaming and handling all kinds of productivity tasks, without ruining your wallet, then the Ryzen 7 9700X is a great choice and is one of the best all-round CPUs I've tested.

While not much faster than its predecessor, the Ryzen 7 7700X, it uses way less power in games and content creation. That makes the chip easier to keep cool but it also means your PC is cheaper to run and quieter to use.

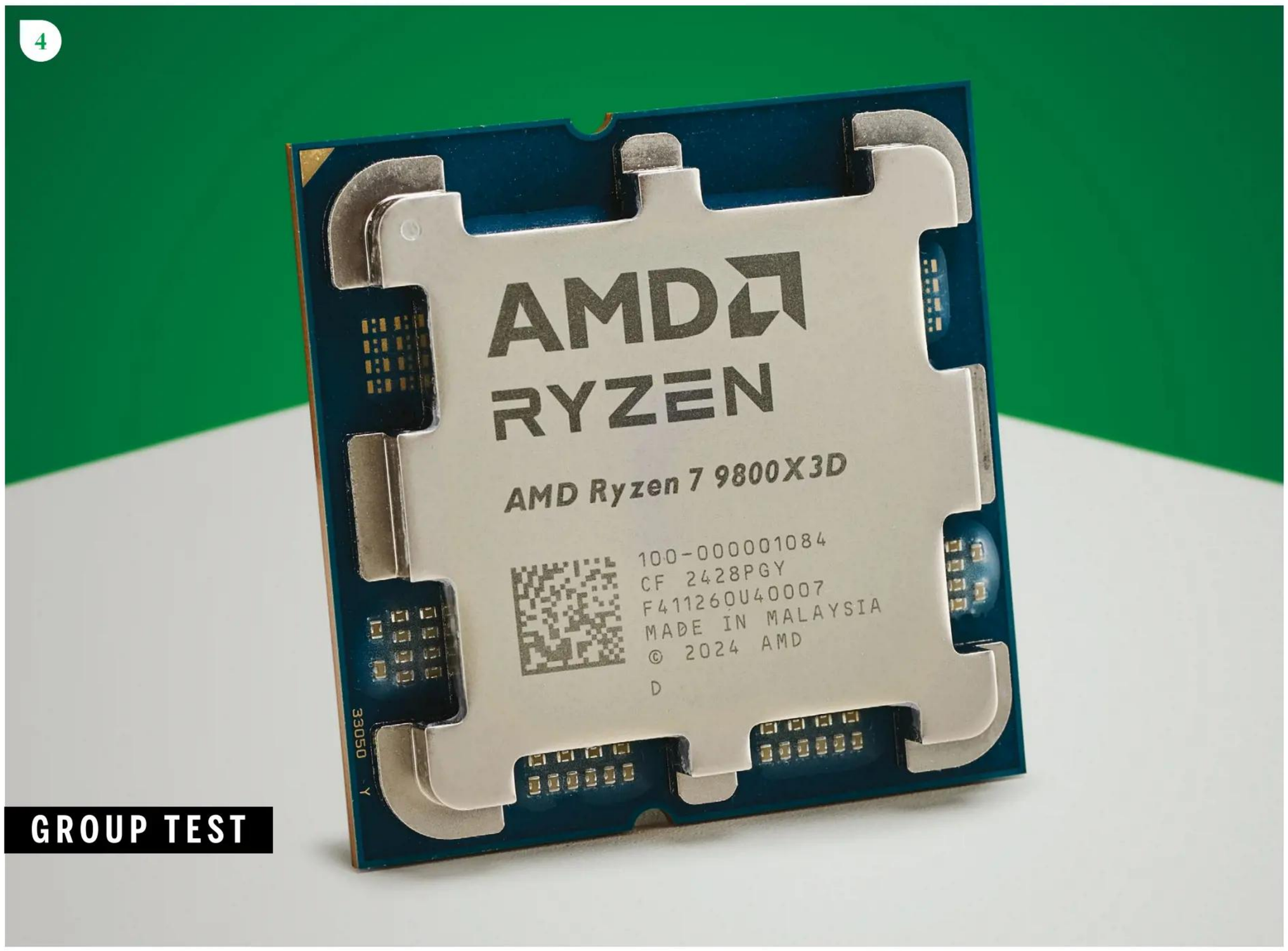
You'd expect a jack-of-all-trades chip to be weak at something but that's not the case here, with support for 16 threads and a high 5.5 GHz boost clock. You can give it more power with some AM5 socket motherboards but like its Ryzen 5 sibling, it won't run noticeably better.

The only problem the Ryzen 7 9700X faces is that the last-gen 7700X can be had for a lot less money and it's not that much slower in games. But if heat and noise are your bugbears, as they are for me, then Zen 5 is the way to go.

PC GAMER VERDICT

- → Good all-round performance
- → Sips power in all tasks
- → Zen 4 is better value

SPECS CORES: 8 / **THREADS:** 16 / **BASE CLOCK:** 3.8 GHZ / **BOOST CLOCK:** 5.5 GHZ / **L3 CACHE:** 32 MB / **TDP:** 65 W / **SOCKET:** AM5



Ryzen 9 9950X

AMD **£610**

All Core Zen

3 When it comes to blasting through content creation workloads, such as 3D rendering or video editing, the Ryzen 9 9950X is pretty hard to beat thanks to its 32 threads and high clock speeds.

The big Zen 5 chip is no slouch in games, too, though it can be a little picky about what settings you use and which drivers you have installed. As with all AMD Ryzen processors that have more than eight cores, a fresh installation of Windows is a must to ensure everything is correctly set up, in terms of software support.

That 170 W power limit might seem daunting but paired with a decent AIO liquid cooler, it'll run cool and quiet all day long. It can use quite a bit of energy when idle, though it depends on what motherboard you use.

You pay a pretty penny for all those cores and threads, and the high price is difficult to swallow when last-gen Ryzen 9 processors are much cheaper and not especially that much slower in comparison.

PC GAMER VERDICT

- → Ace multithreaded performance
- → Runs very cool
- → Expensive

SPECS CORES: 16 / **THREADS:** 32 / **BASE CLOCK:** 4.3 GHZ / **BOOST CLOCK:** 5.7 GHZ / **L3 CACHE:** 64 MB / **TDP:** 170 W / **SOCKET:** AM5

Ryzen 7 9800X3D

AMD **£450**

Gaming Zen

4 If all you care about is having the best possible performance in games, then there's only one CPU worth choosing and it's the Ryzen 7 9800X3D. It's by far the best gaming CPU I've seen. The gaming crown used to be worn by the last-gen Ryzen 7 7800X3D but AMD has reworked its 3D V-Cache technology to now sit underneath the chiplet housing all of the cores and cache. The result is a CPU that runs faster and cooler, and that extra L3 cache really helps with power efficiency. Not every game will benefit from the presence of the 3D V-Cache and you ideally need a powerful graphics card to take full advantage of the performance gains. But if you want a gaming CPU to last for many years to come, it's the one to pick. The Ryzen 7 7800X3D and 9800X3D are both super popular with PC gamers and stocks of both chips disappear quickly. If you can find the previous gen model for a decent price, then you'll still be getting a very fast gaming chip.

PC GAMER VERDICT

- → Eye-popping fps
- → Super efficient
- → 7800X3D is still around

SPECS CORES: 16 / **THREADS:** 32 / **BASE CLOCK:** 4.7 GHZ / **BOOST CLOCK:** 5.2 GHZ / **L3 CACHE:** 96 MB / **TDP:** 120 W / **SOCKET:** AM5

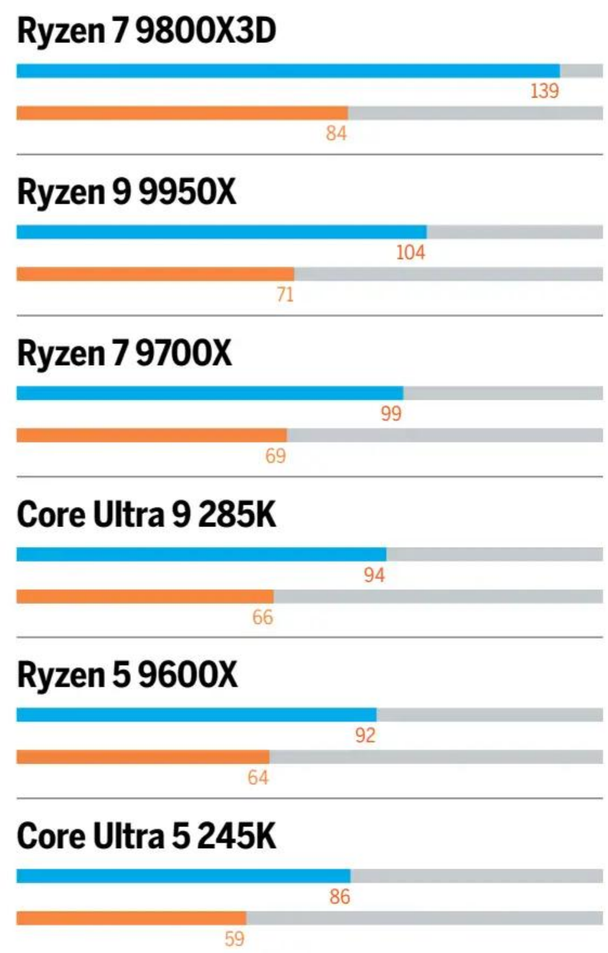
GROUP TEST

NEW CORE ULTRA 200S CHIPS USE WAY LESS POWER THAN PREVIOUS INTEL CPUS

BENCHMARKS

Baldur's Gate III
1080p, Ultra quality, RTX 4070

Average fps (higher is better) / 1% Low fps (higher is better)



Core Ultra 5 245K

INTEL **£279**

Baby Arrow

5 Intel changed so many things for its Arrow Lake design that it's hard to convey it all in a few words, but the key takeaway is that the new Core Ultra 200S chips use way less power than its previous CPUs, especially in games. The downside to this is that they're just not as good at gaming as the older processors, such as the Core i5 14600K. It's not a big performance gap but you don't expect a new CPU to be slower than those it's replacing.

Another important change in the chip architecture is the removal of Hyper-Threading from the P-cores, where each core could handle two threads. To make up for this, Intel seriously improved its E-cores and in content creation, 14 Arrow Lake threads are just as good as 20 Raptor Lake threads.

The Ultra 5 245K's performance isn't consistent but as it's completely new, it might get better with software updates over time. If you take the gamble and buy one, at least you won't need a massive cooler to shift its heat.

PC GAMER VERDICT

- → Low power
- → Handy for content creation
- → Slower than competition

SPECS CORES: 6P+8E / **THREADS:** 14 / **BASE CLOCK:** 4.2 GHZ (P-CORE) / **BOOST CLOCK:** 5.2 GHZ (P-CORE) / **L3 CACHE:** 26 MB / **TDP:** 125 W / **SOCKET:** LGA1851

Core Ultra 9 285K

INTEL **£549**

Grown-up Arrow

6 Intel's Core Ultra 9 285K, a fully enabled Arrow Lake chip, shares the same drawbacks as the cut-down 245K. Its performance is inconsistent and in games, it's readily beaten by older and cheaper processors. For a flagship model, that hardly seems like an incentive to buy one. However, those 24 threads are good in content creation workloads, though it does depend on the application. The Ryzen 9 9950X is better overall and while more expensive, there are more AM5 motherboards around compared to the number of LGA1851 boards for Arrow Lake. At least Intel has reigned in its historical hunger for energy and the 285K uses almost half the amount of power as the Core i9 14900K does in games. You're not getting cutting-edge performance but you are getting a cooler and quieter PC. Unlike AMD's Zen 5 chips, Intel's new processors do comfortably fully support ultra-fast RAM, such as DDR5-8000, but the gains are generally small and not worth paying extra for.

PC GAMER VERDICT

- → Low power
- → Slower than competition
- → Not the best value

SPECS CORES: 8P+16E / **THREADS:** 24 / **BASE CLOCK:** 3.7 GHZ (P-CORE) / **BOOST CLOCK:** 5.7 GHZ (P-CORE) / **L3 CACHE:** 40 MB / **TDP:** 25 W / **SOCKET:** LGA1851

GROUP TEST

MAINSTREAM GRAPHICS CARDS

These entry-level and mid-range graphics cards are where the bulk of PC gamers spend their cash, but which are worth the money?

By Jacob Ridley

The most popular graphics card of a generation is rarely the best-performing. Instead it's the one the most people can reasonably afford. The most popular cards, according to Steam's monthly hardware survey, are the RTX 3060, GTX 1650, and GTX 1060. Unsurprising, but what's somewhat more shocking is you have to look pretty far down the list to find any high-end GPUs noted at all.

Nvidia and AMD sell higher volumes across the lower rungs of the GPU market. The so-called 'mainstream' cards. What constitutes a mainstream graphics card is a constantly shifting definition and not easily defined by price alone. In the early days of PC gaming, £399 was kingly money to spend on an add-in card, whereas nowadays that's barely more than budget. Blame inflation, and try not to think about it too much.

There are heaps of options available to the budding PC gamer with a reasonable amount to spend. At every conceivable budget between £250 and £600, there are multiple cards competing for your attention. That's why I've grabbed one of each arguably mainstream card today – some more entry-level, some more mid-range – to help you decide on the best value for your rig.

THERE ARE HEAPS OF OPTIONS AVAILABLE TO THE BUDDING PC GAMER

Mainstream Graphics Cards

Radeon RX 7800 XT

AMD **£479**

Bang for your buck

1 Look through the latest graphics card releases and you'll find few really stand out for value for money. The RX 7800 XT is one of the good ones, however. It delivers frame rates loosely level with the RX 6800 XT and RTX 3080 for significantly less cash.

The RX 7800 XT is a modern Radeon card in a couple of ways. For starters it's constructed of chiplets, 5nm and 6nm chips, and is one of the first few graphics cards to ever do so. It also is built with AMD's latest RDNA 3 architecture for top shader performance, and comes with 16GB of memory to ensure you're unlikely to run out while gaming. This card truly delivers excellent frame rates versus the RTX 4070 it's ostensibly quite a lot cheaper than. For purely rasterised performance, this is the card to go for, especially now that AMD offers a suite of upscaling and frame generation technologies. AMD's card does fall flat, however, once ray tracing is enabled, and there's no denying Nvidia has the better software tech right now.

PC GAMER VERDICT

- Beefy VRAM
- Often matches RTX 4070
- Poor ray tracing performance

SPECS ARCHITECTURE: RDNA 3 / **TRANSISTORS:** 28.1B / **VRAM:** 16GB GDDR6 / **MEMORY SPEED:** 19.5 GBPS / **MEMORY BUS:** 256-BIT / **TBP:** 263W

GeForce RTX 4070

NVIDIA **£579**

Power-savvy pick

2 Delivering a tantalising mix of RTX 3080-grade performance and high efficiency, the RTX 4070 is one of the more well-balanced GPUs of its generation. Even in the face of AMD's cheaper option, the RTX 4070 is an attractive proposition, though that's in some part thanks to the RTX 40-series' secret sauce. The 4nm GPU humming away at the centre of the RTX 4070 maintains solid frame rates for 1440p. You can push it to 4K and expect decent results at times, too, which is surprising from a card that demands 200W. Though it loses points for only having 12GB of GDDR6X memory – we'd like more for the money.

The RTX 4070 does score bonus points for DLSS and frame generation support, courtesy of the Ada Lovelace architecture. These features can help take the edge off rendering a game like *Alan Wake 2*, which is one of the finer examples of what Nvidia's 40-series generation can do. The RTX 4070 also trumps AMD's alternative when it comes to ray tracing.

PC GAMER VERDICT

- Excellent efficiency
- RTX 40-series features
- Not quite cheap enough

SPECS ARCHITECTURE: ADA LOVELACE / **TRANSISTORS:** 35.8B / **VRAM:** 12GB GDDR6X / **MEMORY SPEED:** 21 GBPS / **MEMORY BUS:** 192-BIT / **TBP:** 200W

GROUP TEST

GeForce RTX 4060 Ti

NVIDIA **£389**

Surface level

3 Considering how the RTX 3060 Ti was my favourite graphics card of the RTX 30-series generation, you'd expect me to be similarly pumped for its replacement. Alas, the RTX 4060 Ti isn't quite the diamond in the rough the RTX 3060 Ti once was.

The RTX 4060 Ti actually offers fewer CUDA cores than an RTX 3060 Ti. Moreover, it has fewer RT cores, Tensor cores, and ROPs. It even has half the memory bus width. For those reductions, it is surprisingly the faster card in our benchmarks. But how is that possible? That's achieved through a larger L2 cache, at 32MB to 4MB, and running the GPU nearly 1GHz faster. From framerates alone you can make the case for the RTX 4060 Ti as a mid-range GPU worth sticking inside a gaming PC. It's far from sluggish. My issue is that it doesn't look like much of a generational improvement over the RTX 30-series, and the more you pry into its silicon the more apparent that becomes. At least it's the same price – a small silver lining?

PC GAMER VERDICT

- Faster than a 3060 Ti
- Just don't look at the specs
- 160W TGP

SPECS ARCHITECTURE: ADA LOVELACE / **TRANSISTORS:** 22.9B / **VRAM:** 8GB GDDR6 / **MEMORY SPEED:** 18 GBPS / **MEMORY BUS:** 128-BIT / **TBP:** 160W

GeForce RTX 4060

NVIDIA **£289**

In disguise

4 Aimed squarely at the 1080p gaming crowd, the RTX 4060 is the cheapest way to score an RTX 40-series graphics card on desktop. It's also the cheapest way to score frame generation and DLSS 3.

This card is compact, low-power, and generally quicker than an RTX 3060. At 115W, it's massively more efficient than the 170W card it ostensibly replaces, too. So it's a major upgrade? Not so fast. The RTX 4060 comes with just 8GB of GDDR6 memory, a reduction on the maximum 12GB configuration on the RTX 3060. Also a smaller memory bus, and fewer CUDA cores, RT cores, and Tensor cores. It does partially make up for those deficiencies with a healthy cache and clock boost, but nevertheless feels like less card.

The RTX 4060 benefits from a lower price tag than the RTX 3060 at launch, which helps to partially mitigate the reductions seen across key specs. Though there's no shaking the feeling it looks more like an RTX 4050 in ways rather than an RTX 4060.

PC GAMER VERDICT

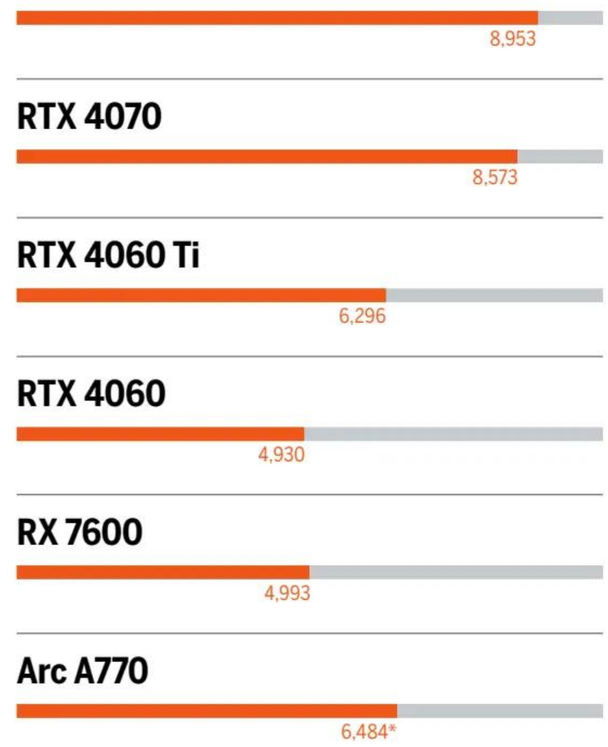
- Faster than a 3060
- Barely over 100W
- Unimpressive silicon

SPECS ARCHITECTURE: ADA LOVELACE / **TRANSISTORS:** 22.9B / **VRAM:** 8GB GDDR6 / **MEMORY SPEED:** 17 GBPS / **MEMORY BUS:** 128-BIT / **TBP:** 115W

THIS INTEL CARD REPRESENTS THE HIGH-END OF THE ALCHEMIST ARC LINEUP

BENCHMARKS

3DMark Time Spy Extreme performance graph ('GPU Index score' values)



*Intel Arc GPUs tend to skew higher in 3DMark synthetic benchmarks compared to in-game performance.

Radeon RX 7600

AMD **£260**

Affordable, unexciting

5 There's not a great deal of competition at the very budget end of the graphics card market. At the tail-end of the last generation, you had AMD, Nvidia, and Intel all battling it out with fairly reasonably priced cards, but nowadays it's only really AMD offering anything new under the £299 mark. It's a good thing AMD does offer the RX 7600 at this sort of budget-friendly price tag, otherwise we'd be in a really sticky situation. The bad news is that AMD's RX 7600 isn't an entirely exciting GPU. It's a resolutely 1080p graphics card with 8GB of GDDR6 memory, and it doesn't make waves in benchmarking. Perhaps I'm being too mean about this little card. It's compact, runs modern games just fine, and offers a modern architecture at a price where Nvidia doesn't bother to tread. For that, it's certainly got its place in the market. Though it'd have been great to see something really set the budget GPU world on fire – the RX 7600 doesn't do that, at least not at the price it's selling for today.

PC GAMER VERDICT

- → Reliable performance
- → Relatively high power
- → Quite boring

SPECS ARCHITECTURE: RDNA 3 / **TRANSISTORS:** 13.3B / **VRAM:** 8GB GDDR6 / **MEMORY SPEED:** 18 GBPS / **MEMORY BUS:** 128-BIT / **TBP:** 165W

Arc A770

INTEL **£340**

Still truckin'

6 Intel is still around in the budget graphics card game with the same first-generation product it released back in late 2022. There's no sign of Battlemage, the second-generation Arc GPUs, though we're expecting some movement early next year.

This Intel card represents the high-end of the Alchemist Arc lineup. As such, it's practically beefy in some regards next to the other cheaper cards in this test. The 16GB of memory is matched only by the RX 7800 XT, and the 256-bit memory bus and 225W TBP both speak to a high performing card. Unfortunately, that's not always the case, as driver issues are still a common enough occurrence on Arc despite Intel pumping out improvements. The good news is that Intel hasn't been afraid to drop the price of the A770 in light of fresh competition. Often under MSRP, this card should only be considered with a discount. Though word of warning: if you want to play older games or you can't enable resizable BAR, look elsewhere.

PC GAMER VERDICT

- → Overkill, in ways
- → Regular driver updates
- → Regular driver issues

SPECS ARCHITECTURE: ALCHEMIST / **TRANSISTORS:** 21.7B / **VRAM:** 16GB GDDR6 / **MEMORY SPEED:** 16 GBPS / **MEMORY BUS:** 256-BIT / **TBP:** 225W

Motherboards

Motherboards aren't super exciting. They're not the component that we see posted on social media alongside the words, "I can't believe I got one!!!" Nope, a motherboard is just a slab of PCB and some copper wires.

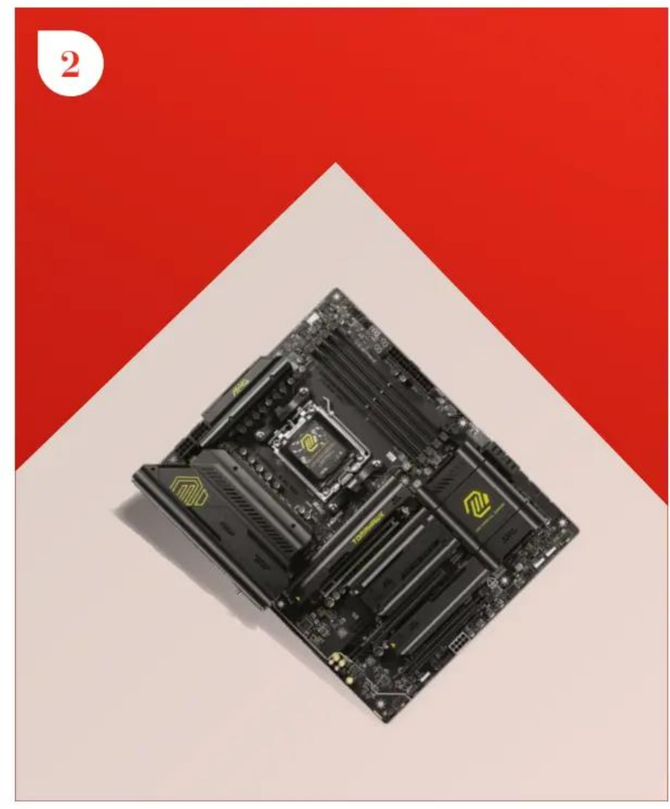
A slab of PCB that connects up your CPU and RAM and ensures both are fed with clean power to run at their best. That is the difference between a high-speed or sluggish SSD. That decides whether you have enough USB ports, fast Wi-Fi, or Bluetooth. That ensures your audio sounds crystal clear. You can see where I'm going with this: a motherboard is pretty important, actually.

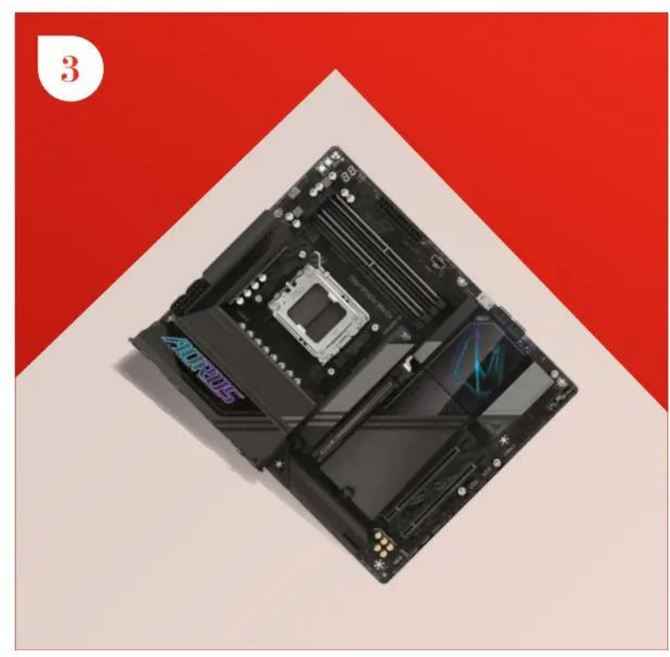
With the arrival of two new generations of CPU from both AMD and Intel at the tail-end of 2024, we've been flooded with motherboards to test for the latest chips. We're focusing on just the high-end chipsets here. For AMD's 9000-series, that means the X870/E chipset. For Intel's Core Ultra 200S-series, Z890.

GROUP TEST

MOTHERBOARDS

An often overlooked component, these clever boards take the hassle out of building a gaming PC. *By Jacob Ridley*





Z890 Steel Legend WiFi

ASROCK **£254**

Tastefully lit

1 Intel's Arrow Lake chips are a tough sell, though if you've somehow ended up with one, I've got just the motherboard for you. This Steel Legend offers up a rare white and grey colourway, which looks supremely good in a matching case, though the RGB lightstrip that runs from edge to edge beneath the bottom M.2. slot is a standout feature in any situation. Enough about the looks. I was most impressed with the Steel Legend when I peeled off the top SSD heatsink with the integrated latch. It's such a simple solution, it makes you wonder why anyone ever bothered with screws in the first place. There are four M.2 slots, too, including one rated for PCIe 5.0, which might actually be useful in 2025 as cheaper PCIe 5.0 drives are to be expected.

The Steel Legend doesn't let up with a large number of ports on the rear IO, including twin Thunderbolt 4 ports, and Wi-Fi 7 support. Altogether, it's a snug fit for Intel CPUs and a solid core for an Arrow Lake machine.

PC GAMER VERDICT

- → RGB looks great
- → Easy SSD access
- → Reasonable price

SPECS SIZE: ATX / **SOCKET:** LGA1851 / **REAR USB/THUNDERBOLT PORTS:** 10 / **M.2 SLOTS:** 4 / **WI-FI:** 7 / **VRM:** 18+1+1+1+1

MAG X870 Tomahawk WiFi

MSI **£280**

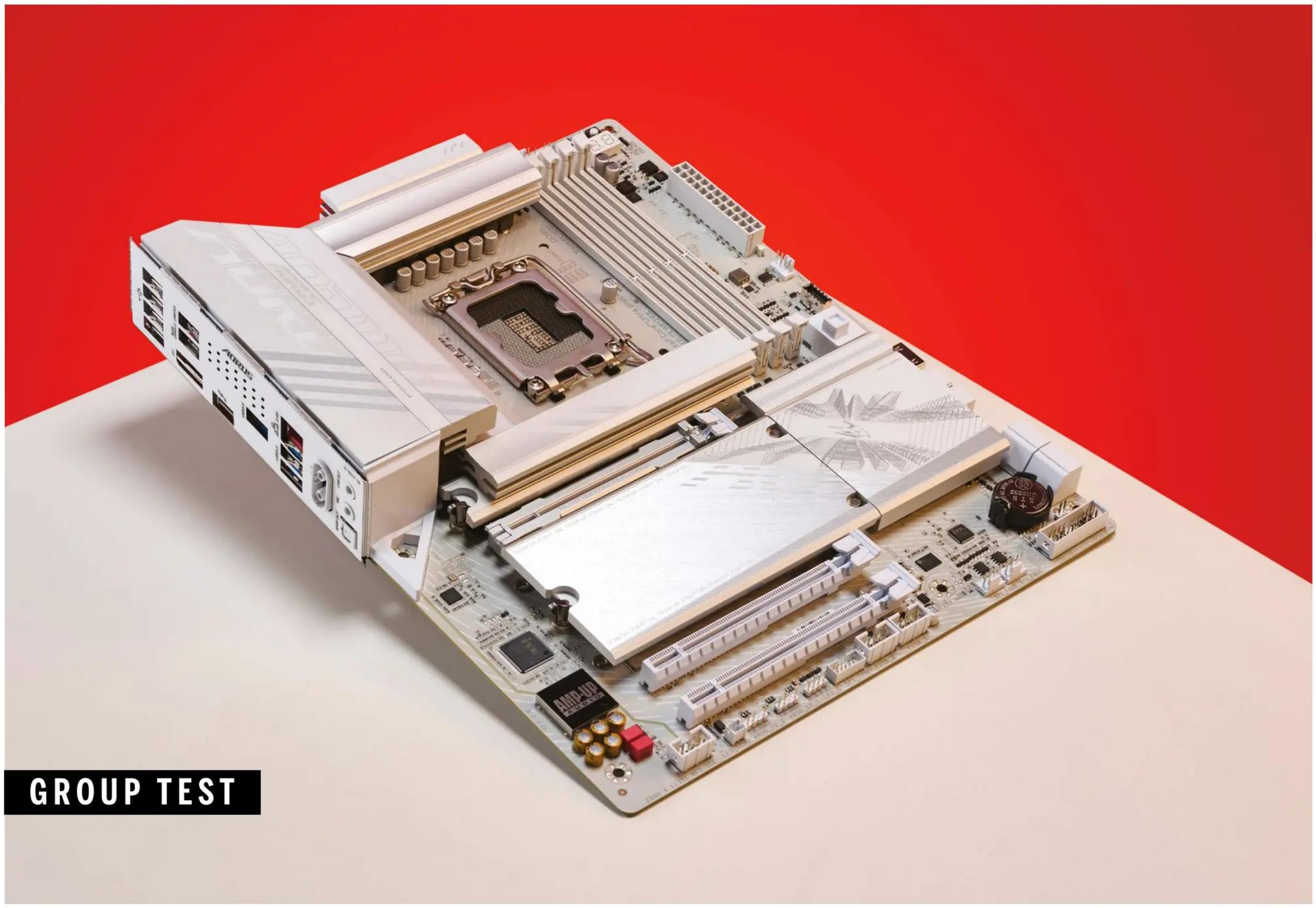
Best of the bunch

2 You can easily go overboard with a motherboard. A smarter move is to find one that offers many of the genuinely useful high-end features without the colossal price tag. That's why we like this MSI MAG X870 Tomahawk – it's convenient, high-end, and doesn't cost a fortune. For starters, the build quality is fantastic here. There's a wealth of plating across the board and adequate cooling for both VRM and SSD. Both the SSD and GPU are a breeze to access, too, thanks to quick release mechanisms. It feels as much a high-end motherboard as we'd like it to be, considering it still costs a good chunk of change. One of the main factors in deciding whether to buy any motherboard is how many USB ports and M.2. slots it has. Luckily for MSI, this Tomahawk has plenty of both. There are two USB4 ports, for the most bandwidth hungry stuff, and ten more of various speeds for everything else. The four M.2 slots are icing on the cake. Yep, this motherboard offers everything you need for a AMD-powered gaming PC.

PC GAMER VERDICT

- → Tons of ports
- → Good thermals
- → Easy to set-up

SPECS SIZE: ATX / **SOCKET:** AM5 / **REAR USB/THUNDERBOLT PORTS:** 12 / **M.2 SLOTS:** 4 / **WI-FI:** 7 / **VRM:** 14+2+1



X870E Aorus Pro

GIGABYTE **£330**

PCIe 5.0 galore

3 PCIe 5.0 SSDs deliver much higher maximum bandwidth versus more common PCIe 4.0 drives. In the realm of 10,00-12,000 MB/s. The problem is that's only really good on paper, or rare occurrences when you're transferring files between two PCIe 5.0 drives. In other key metrics, such as random 4K IOPS, the humble PCIe 4.0 drive works nearly as well, and for a whole lot less money/heat.

Why does any of this matter for the Aorus Pro? Well, what this capable motherboard offers is a way to tap into the benefits of PCIe 5.0 with three high-speed M.2 slots to choose from. With at least two occupied, you can benefit from those higher sequential speeds. However, if you use the second of third NVMe slots, you will have to halve the first PCIe slot, from x16 to x8, which might see you lose a small amount of performance.

So, is it worth it? The Aorus Pro is very well equipped and I do appreciate its clean aesthetic, but I struggle to justify the multitude of PCIe 5.0 slots, especially when others offer competitive packages for less.

PC GAMER VERDICT

- → 3x PCIe 5.0 NVMe slots
- → Gorgeous
- → Do you need all that?

SPECS SIZE: ATX / **SOCKET:** AM5 / **REAR USB/THUNDERBOLT PORTS:** 11 / **M.2 SLOTS:** 4 / **WI-FI:** 7 / **VRM:** 16+2+2

Z890 Aorus Elite WiFi 7 Ice

GIGABYTE **£280**

Blue steel

4 Here we are, then. The more sensible Gigabyte option, though this one is intended for Intel's Core Ultra processors rather than AMD's chips. We have this motherboard's almost identical AM5 twin right over the page in this group test, which means we have both major manufacturers covered on the same board for comparison.

This motherboard's special feature is looking drop dead gorgeous, obviously. The subtle lighting is one thing, but combine this silver and white motherboard with a white chassis and you're going to be the envy of the town. Thankfully, this motherboard isn't just stylish, it has substance too.

The VRM is not quite the same as the Pro model, but it's solid. It also lacks the many PCIe 5.0 NVMe SSD slots found on the Pro model, but I'm fine with that too. The Elite still offers four NVMe slots, one of which is rated to PCIe 5.0 speeds, which will suffice. Though I am a little disappointed in the selection of USB ports on the rear: only one Type-C, in 2025? Even if it's Thunderbolt, I want more.

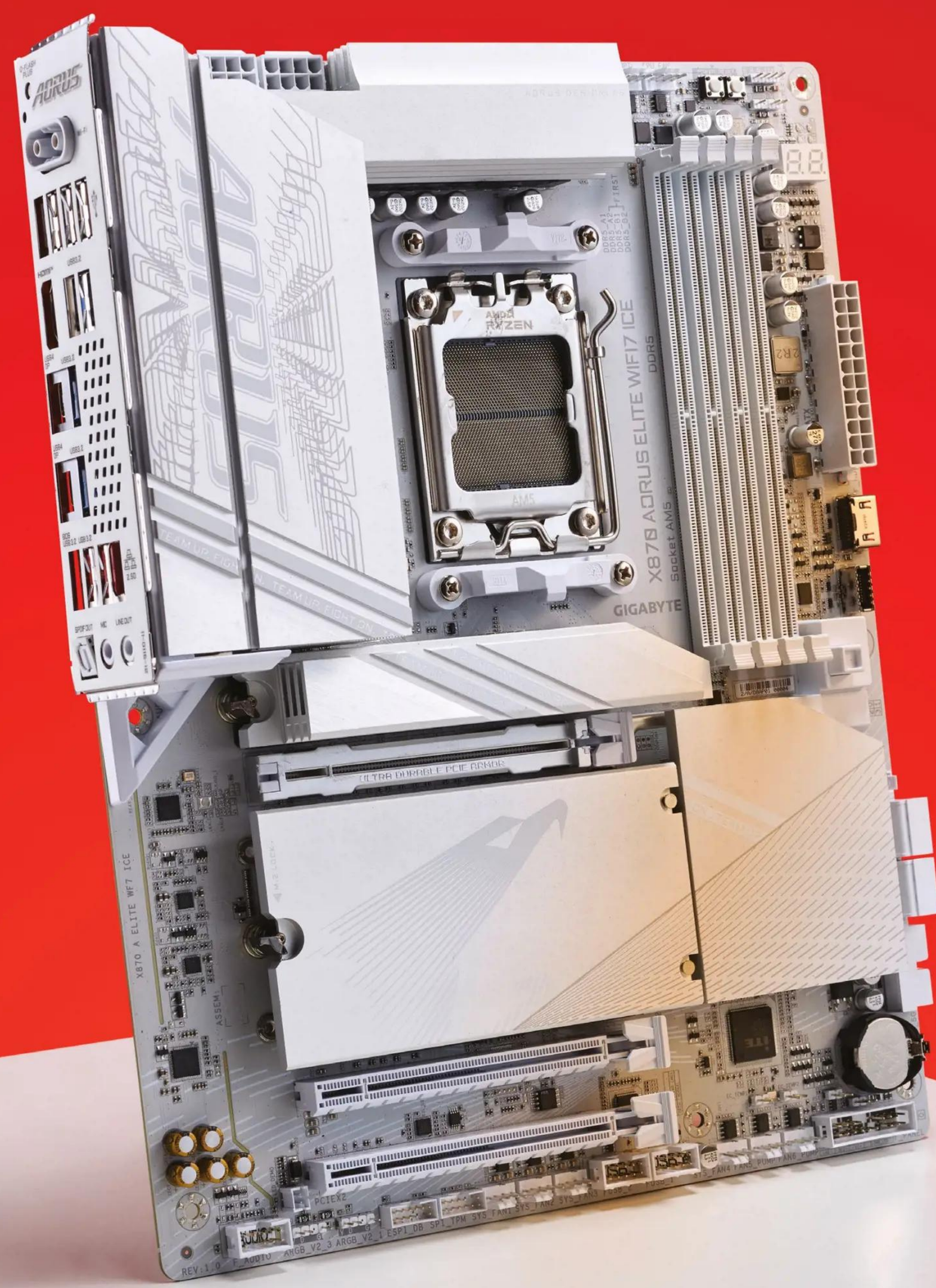
PC GAMER VERDICT

- → Looks great
- → Smart spec
- → Only one USB Type-C on the rear

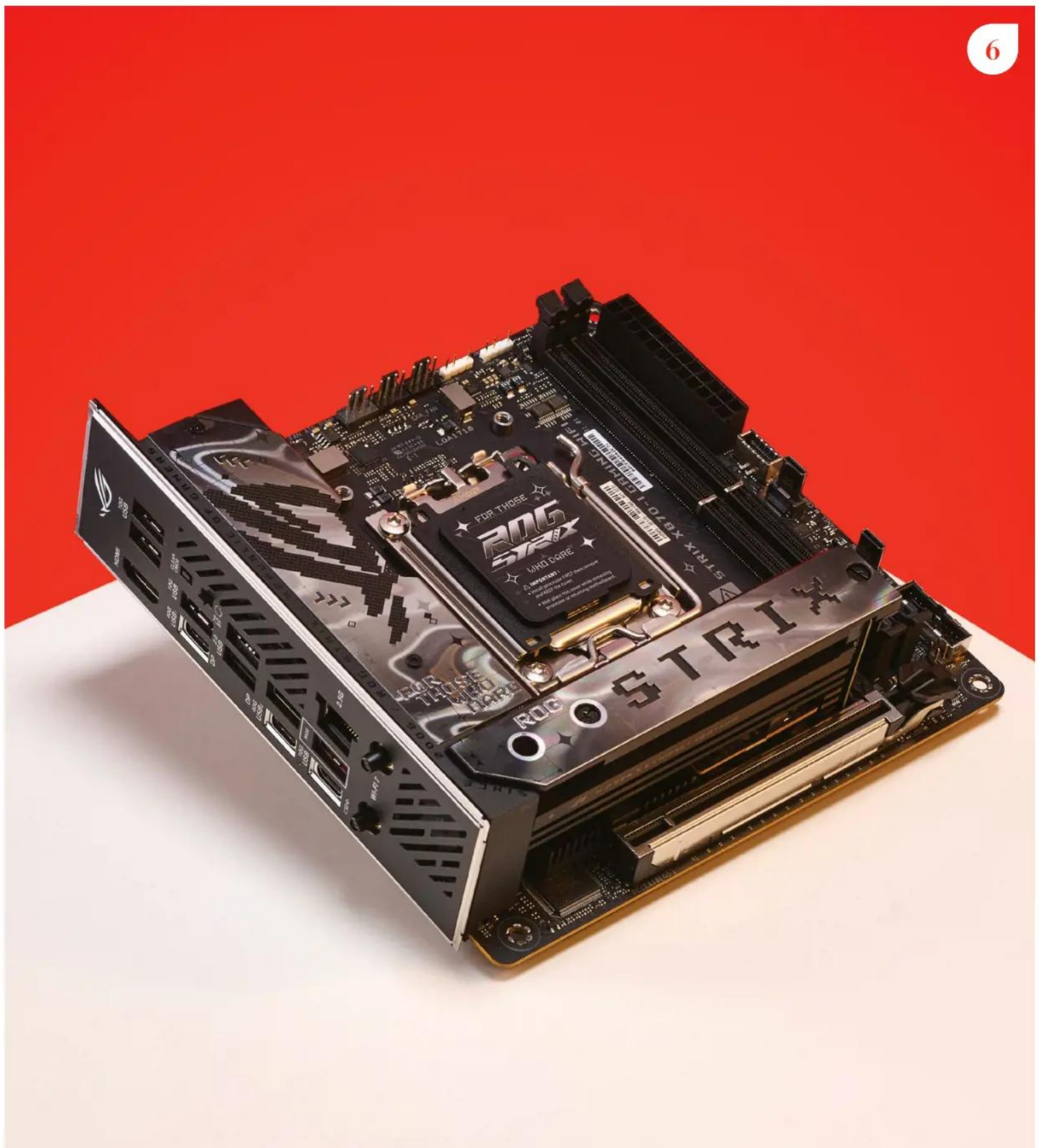
SPECS SIZE: ATX / **SOCKET:** LGA1851 / **REAR USB/THUNDERBOLT PORTS:** 10 / **M.2 SLOTS:** 4 / **WI-FI:** 7 / **VRM:** 16+1+2

GROUP TEST

5



GIGABYTE CAN OFFER THREE PCIE 5.0 NVME SSD SLOTS ON THE AMD VERSION



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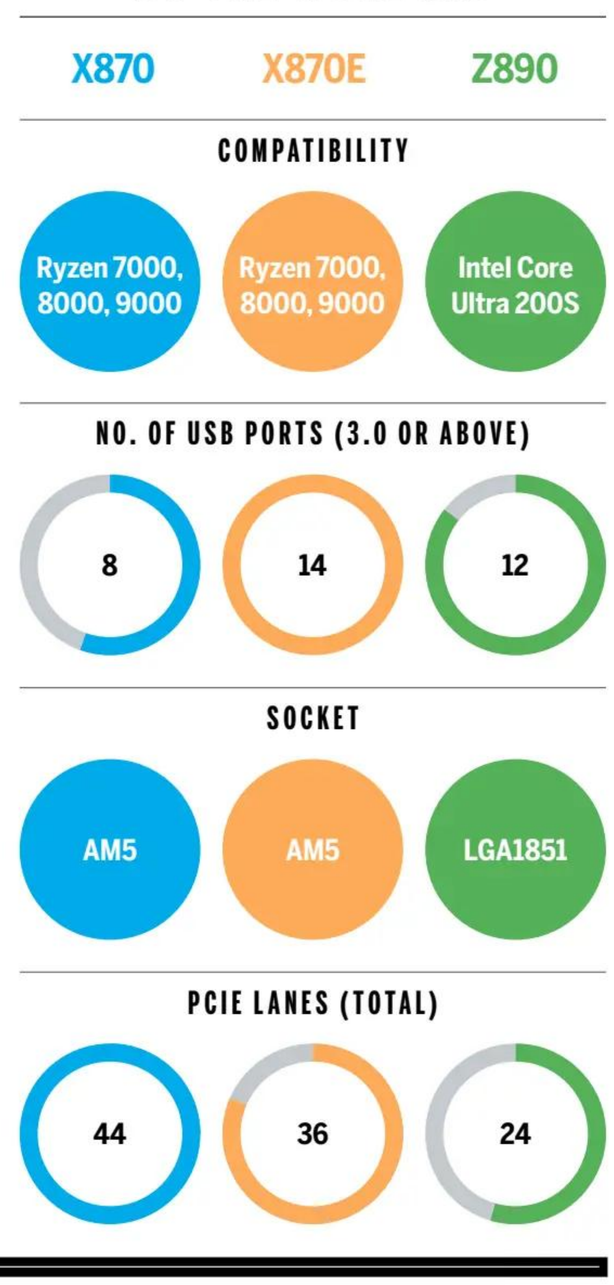


X870 Aorus Elite WiFi 7 Ice

GIGABYTE **£277**

Same same, but different

5 The Gigabyte X870 Aorus Elite WiFi 7 Ice isn't a carbon copy of the Intel version except made for AMD Ryzen chips. They don't even look the same. What's more, while history would traditionally see the Intel version weirdly better than the AMD version just because, this is the other way around. The AMD version rocks. Thanks to the X870 chipset, Gigabyte can offer three PCIe 5.0 NVMe SSD slots on the AMD version of this board. That makes Intel's single slot look rather pedestrian. Sure, I still don't think you need three PCIe 5.0 slots, but unlike the X870E Aorus Pro this motherboard doesn't charge you for it. Once again, you have to decide between having an x16 or x8 PCIe slot or the extra SSDs, but that's your call. There are other key differentiators. The VRM on the AMD version is a 16+2+2 configuration, much like the Aorus Pro, and it has 12 USB ports on the rear IO. Two of which are USB Type-C, which was one of my main complaints with the Intel version. So, if you needed any further convincing to go AMD this time around, here it is.

PC GAMER VERDICT

- Not identical to the Intel version
- Better, actually
- 3x PCIe 5.0 slots

SPECS SIZE: ATX / **SOCKET:** AM5 / **REAR USB/THUNDERBOLT PORTS:** 12 / **M.2 SLOTS:** 4 / **WI-FI:** 7 / **VRM:** 16+2+2

ROG Strix X870-I Gaming WiFi

ASUS **£420**

So sweet

6 One look at this Mini-ITX motherboard and I was sold. I don't always love the ROG style on a motherboard, but this? This I like. With limited space, Asus has crafted a masterpiece of traces and capacitors, matched only by this motherboard's similarly mega price tag. My appreciation only goes skin-deep but there's more to this compact board than meets the eye. It's tiny, which makes the fact there are two NVMe slots stacked atop of one another even more impressive. The IO has a small fan to keep the mass of stuffed squeezed shoulder to shoulder cool, though it's not noticeably loud like some of its stature. It also comes with more USB ports than you'd expect. A handful of expansion options help this Mini-ITX compete with the big boys. There's the small expansion board that plugs in to the two USB Type-C ports, and there's the Hive that sits externally and adds a pair of USB ports, among other functions. Though I have to mention this board's size means it lacks in some ways, which is a tough pill to swallow when you're paying a massive price.

PC GAMER VERDICT

- Adorable
- Amazing
- A-expensive

SPECS SIZE: MINI-ITX / **SOCKET:** AM5 / **REAR USB/THUNDERBOLT PORTS:** 10 / **M.2 SLOTS:** 2 / **WI-FI:** 7 / **VRM:** 10+2+1

Asus ROG Maximus Z790 Hero

This is a great board for Intel Core i7 or i9 performance enthusiasts.

Asus ROG Maximus Z790 Hero

A premium motherboard for premium Intel builders

Asus has built its Maximus range of motherboards to offer all of the features enthusiasts demand, such as the ability to safely overclock, plus no shortage of expansion slots and ports to expand as you go. In this regard, the ROG Maximus Z790 Hero has everything the most demanding of PC users will want, including compatibility with the latest PCIe 5.0 and DDR5 hardware. Only the ROG Maximus Z790 Extreme betters it in Asus's Z790 range, with more I/O ports, a 10Gb LAN connection, and a better VRM setup for overclockers who want to push their hardware to the absolute limits.

Visually, this motherboard is pretty understated – it's a black ATX-sized board with a mirrored plate over the I/O shroud that lights up with the ROG logo. Though it's still clearly a gaming-focused board, it doesn't go overboard on the RGB. The mobo supports Intel's 12th and 13th-generation Alder Lake and Raptor Lake processors and has four DDR5 slots with support for up 128GB per stick, clocked up to 7800MT/s. It also has two PCIe 5.0 x16 slots, one PCIe 4.0 x16 slot, and five M.2 slots, although only one of the latter is PCIe 5.0 compatible.

If you plan on buying one of these faster drives when they become available, you'll need to install an included expansion card, which will take up one of the board's two PCIe 5.0 slots. Or you can run two GPUs in tandem using Nvidia SLI and AMD CrossFire, not that anyone does this any more. Networking is impressive, with one 2.5G LAN port and a Wi-Fi 6E adaptor in the box, while there are ten USB-A ports, two Thunderbolt 4 ports, and one USB-C 3.2 Gen 2 connector on the back panel, which will be more than enough for even the most demanding of PC users.

TASTY TECH SPECS

If you're the sort of PC builder who enjoys having the latest and greatest tech, then you may have been salivating at those tech specs. This mobo is catered to PC builders looking to make the most of Intel's newest processors. We paired the board with the Intel Core i9-13900K processor, MSI GeForce RTX 4090 Gaming X Trio, and Corsair Vengeance 32 GB DDR5-5200 RAM. The only thing we couldn't do to max out the board's performance was use a PCIe 5.0 SSD, as there weren't any available at the time of reviewing.

Asus's BIOS is one of the easiest to navigate out of all mobo manufacturers, and users should update to the latest firmware. Head to the 'EzMode' and enable XMP settings on the RAM, and they will be good to go without the need for more tinkering. Those who want to push things further are well catered for in the BIOS's Advanced mode, where they can gently nudge the i9-13900K's 24 cores past stock values. Asus's teamed power stage design also allows the circuits to remain cool while providing power efficiently to the CPU, RAM, and other components. While most users won't need more performance from Intel's latest powerhouse chips, Asus's interface allows you to push its recent i7 and i9 releases safely and intuitively. For i3 and i5 chips though, this will probably be overkill.

If you don't need the latest tech, it's also worth looking at the much cheaper Asus Z790 DDR4 board. Out of the box, there isn't much difference between performance in games using the cheaper DDR4 board and the more expensive DDR5 model. If you already own a Z690 board, it may be worth hanging on to it and putting your money towards the latest Intel chip and Nvidia/AMD graphics processor. For the serious gamer or creative type with a shiny new i9-13900K chip to house, this is the best motherboard you can get without spending silly money.
– Guy Cocker

VERDICT 8

Asus ROG Maximus Z790 Hero

+ HEROIC Loads of I/O; PCIe 5.0 storage; ready to safely overclock Intel's latest CPUs.

– SHAMBOLIC Expensive; no 10Gb LAN port; PCIe 5.0 storage requires included expansion card.

£690, www.asus.com

BENCHMARKS

	ZERO-POINT	
Cinebench R23 Single	2,001	2,247 (12.3%)
Cinebench R23 Multi (Index)	27,016	35,457 (31.2%)
CrystalDisk QD32 Sequential Read (MB/s)	7,082	7,057 (-0.5%)
CrystalDisk QD32 Sequential Write (MB/s)	5,300	5,303 (0%)

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Z690 system consists of our Build It machine from the October 2022 issue (page 16), consisting of an NZXT N7 Z690 ATX mobo, Intel Core i9-12900K CPU, PNY XLR8 Gaming REV RGB 32GB (2 x 16GB) 3200MHz DDR4 RAM and PNY XLR8 XS3140 PCIe 4.0 NVMe 1TB SSD. The Asus ROG Maximus Z790 Hero build featured Intel Core i9-13900K CPU, Corsair Vengeance 32 GB DDR5-5200 RAM, and PNY XLR8 XS3140 PCIe 4.0 NVMe 1TB SSD. XMP was enabled on motherboard BIOS but no other overclocking performed.

SPECIFICATIONS

Size	ATX
CPU	Intel 12th & 13th Gen
Socket	LGA 1700
RAM	4x DDR5 (up to DDR5-7800+), 128GB limit
Chipset	Intel Z790
Expansion	2x PCIe 5.0 x16 (x16 or dual x8), PCIe 4.0 x16
Storage	6x SATA (6Gbps), 3x M.2 2242/2260/2280 (PCIe 4.0 x4, SATA), ROG Hyper M.2 expansion card (M.2 2242/2260/2280 (PCIe 5.0, SATA), ROG Hyper M.2 expansion card (M.2 2242/2260/2280 (PCIe 4.0, SATA)
Ports	BIOS FlashBack Button, Clear CMOS button, 2.5G LAN, Asus Wi-Fi, 2x Thunderbolt 4, 6x USB-A 3.2 Gen 2, 4x USB-A 3.2 Gen 1, USB-C 3.2 Gen 2, HDMI, Optical S/PDIF out, 5x Gold-plated audio jack
Audio	Realtek ALC4082
GPU feature support	Nvidia SLII, AMD Crossfire

GROUP TEST

POWER SUPPLIES

Watt's the best power supply for PC gaming? We've got you covered.

By Jacob Ridley

The best power supplies are so much more than a dull power brick. They're highly efficient electrical components, many able to deliver power in excess of 1,000W with little variance in voltage. That's the lifeblood of your PC, and if you think of all the drives and processors that require a steady stream of power, your PSU has its work cut out for it.

Being such an important component, we tend to look past the bargain basement PSUs. It's very rare that one has been built to a high standard as we need it to be. That's not to say we haven't considered some budget options, they just might cost you a small amount more than another seemingly competitive unit. You get what you pay for, however, and when it comes to your PSU a bit more cash can make for a much more reliable unit.

1

AX1600i

CORSAIR **£480**

The PSU of choice for enthusiast gamers

1 The AX1600i is the worthy successor of the legendary AX1500i. Both units are made by Flextronics, using cutting-edge technology, while offering the best performance that money can buy today.

The Corsair AX1600i is the first desktop PSU to use totem-pole PFC converter technology, which even several years after its release very few PSUs utilise. In short, the AX1600i can offer up to 99% efficiency, compared to the 96% efficiency levels that the most advanced conventional APFC converters can deliver. Besides being highly efficient, the AX1600i offers outstanding load regulation, excellent transient response, long hold-up time, and excellent ripple suppression. It also retains quiet operation, thanks to the relaxed fan profile.

You will pay a lot to get your hands on a Corsair AX1600i, but there is nothing else able to meet this PSU eye-to-eye when it comes to overall performance.

PC GAMER VERDICT

- Top performance in all areas
- High build quality
- Silent operation

SPECS MANUFACTURER (OEM): FLEXTRONICS / **MAX. DC OUTPUT:** 1600W / **EFFICIENCY:** 80 PLUS TITANIUM, CYBENETICS TITANIUM / **NOISE:** CYBENETICS A (20-25 DB[A]) / **COOLING:** 140MM FLUID DYNAMIC BEARING FAN / **MODULARITY:** YES (FULLY) / **WARRANTY:** 10 YEARS

RM750X (2021)

CORSAIR **£110**

The best mid-capacity PSU

2 The newest version of the Corsair RM750x unit, introduced in 2021, managed to improve an already outstanding product. Corsair's RMx line is among the best in the PSU market, combining high performance and reasonable prices, and the RM750x is clear proof of this. The competition is tough, but Corsair's R&D manager, Jon Gerow, and his team of engineers manage to create products that set the bar higher and higher.

The build quality is amazing in this CWT platform, which is only available to Corsair. The caps on both primary and secondary sides are Japanese and the FETs, along with the magnetic levitation fan, won't have a problem outliving the ten-year warranty.

The fan upgrade is a highly welcome feature, too. It boosts reliability, even under harsh conditions where most other fans would have issues in the long run. The cooling fan is the crucial part of every PSU, so it is important to use the best fan possible.

PC GAMER VERDICT

- Magnetic Bearing Fan
- High build quality
- Ten-year warranty

SPECS MANUFACTURER (OEM): CHANNEL WELL TECHNOLOGY / **MAX. DC OUTPUT:** 750W / **EFFICIENCY:** 80 PLUS GOLD, CYBENETICS GOLD / **NOISE:** CYBENETICS A- (25-30 DB[A]) / **COOLING:** 140MM MAGNETIC LEVITATION FAN / **MODULARITY:** YES (FULLY) / **WARRANTY:** 10 YEARS

GROUP TEST

HAS A CYBENETICS 'A' NOISE RATING, PROVING IT IS QUIET

Pure Power 11 FM 550W

BE QUIET! **£70**

The best low-capacity PSU

3 Be quiet! has developed a unique platform alongside OEM partner Channel Well Technology for its Pure Power 11 FM line, and the results are fantastic. The Pure Power 11 FM with 550W capacity is our top choice for this wattage category, and it is ideal for not demanding systems where users require a quality PSU under $100.

The PSU is 80 PLUS Gold and Cybenetics Gold certified in efficiency and has a Cybenetics 'A' noise rating, proving it is quiet. The dimensions are standard, with 160mm depth, and the cooling fan uses a rifle bearing for increased reliability. The five-year warranty is half than what the competition provides. Still, you cannot call it short.

The Pure Power 11 FM 550 showed in testing that it has no problem facing intense competition from Corsair, Seasonic, EVGA, Cooler Master and others. Perhaps its best competition is the Seasonic Focus Plus Platinum 550W, but this is still the outright winner.

PC GAMER VERDICT

- High performance
- Silent operation
- Only a five-year warranty

SPECS MANUFACTURER (OEM): CHANNEL WELL TECHNOLOGY / **MAX. DC OUTPUT:** 550W / **EFFICIENCY:** 80 PLUS GOLD, CYBENETICS GOLD / **NOISE:** CYBENETICS A (20-25 DB[A]) / **COOLING:** 120MM RIFLE BEARING FAN / **MODULARITY:** YES (FULLY) / **WARRANTY:** 5 YEARS

Pylon 450

XPG **£65**

A trustworthy budget PSU

4 This XPG is our favourite for such low wattage nowadays, covering just the bare essentials in terms of PC performance, as Corsair decided to withdraw the popular CX450 model. That used a modern but expensive platform, making it hard to keep its price low. From the moment the CX450 is out of the equation, the road is open for the Pylon 450 to shine.

From 2022, XPG upgraded the warranty on all Pylon models to five years to keep up with the competition. Given the fluid dynamic bearing fan and the reliable platform, the warranty upgrade makes sense. The compromise that had to be made to keep the cost down was the use of an outdated platform.

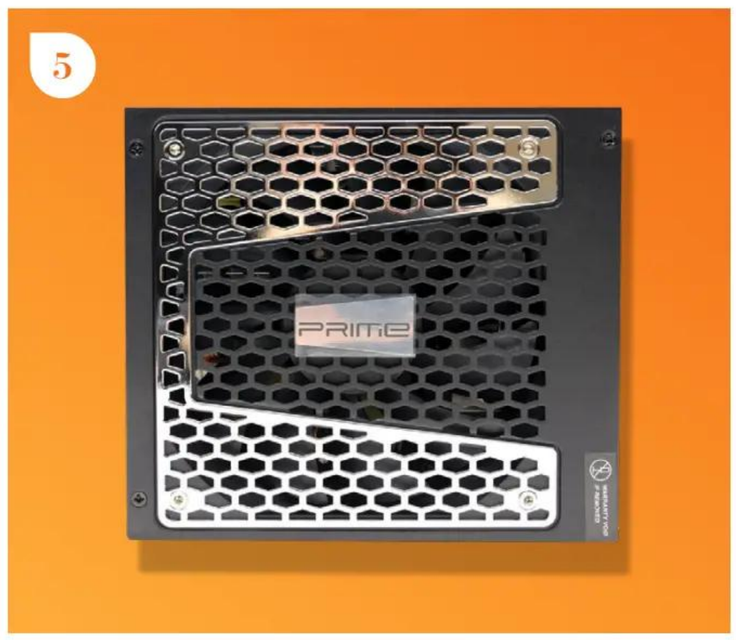
The non-modular cable design won't please most users, but modular cables would notably affect the final price, so they had to go to. Given the not-so-high number of cables in this PSU, the non-modular design isn't the worst. Thankfully, the five-year warranty is the cherry on top.

PC GAMER VERDICT

- Fluid dynamic bearing fan
- Five-year warranty
- Non-modular

SPECS MANUFACTURER (OEM): CHANNEL WELL TECHNOLOGY / **MAX. DC OUTPUT:** 450W / **EFFICIENCY:** 80 PLUS BRONZE, CYBENETICS BRONZE / **NOISE:** CYBENETICS A- RATING (25-30DB[A]) / **COOLING:** 120MM FLUID DYNAMIC BEARING FAN / **MODULARITY:** NO / **WARRANTY:** 5 YEARS

4



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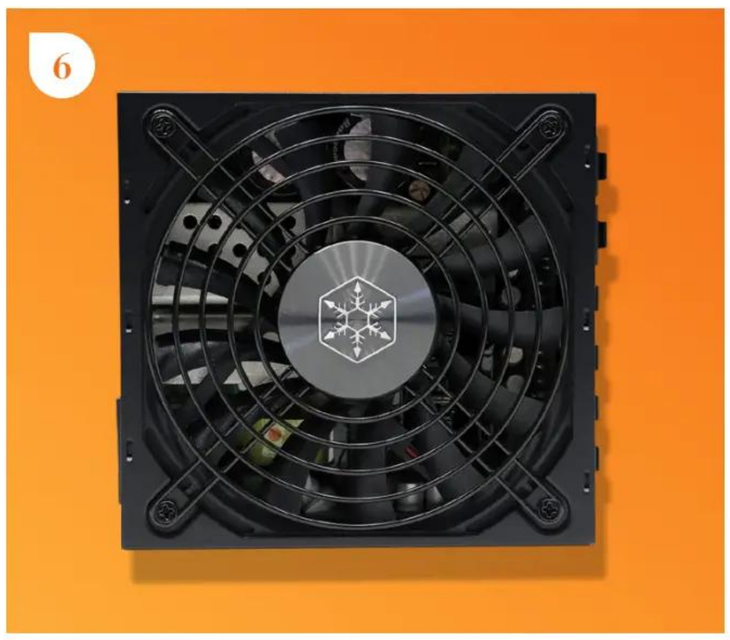


6

HOW WE TEST

Each PSU that we recommend has been tested rigorously by our friends and PSU experts over at Cybenetics, to ensure it's up to the standard we're after. A tremendous amount of testing goes into each PSU review, including the use of oscilloscopes, power analysers, infrared cameras and load testing devices. Since these are tests specifically designed for gaming PC power supplies, we're also double checking these PSUs run cool and quiet.

You might see a whole lot more of Cybenetics' own efficiency and noise certifications in coming years, as both have been officially acknowledged in the latest PSU standard published by Intel. If you want more information on the PSUs outlined in this issue, head to pcgamer.com to check out a full review for each model.

TX-1000

SEASONIC **£260**

The best 1000W PSU right now

5

The Seasonic TX-1000 has top-notch build quality. Besides great soldering work, it also uses Japanese caps everywhere, including many polymer caps besides electrolytic ones and a fluid dynamic bearing fan. Seasonic engineers did their best to offer sky-high efficiency under all load regions and silent operation, at the same time, along with increased reliability.

Performance-wise, this PSU belongs to the top league since it achieves tight load regulation on all rails, it has terrific ripple suppression without using the annoying in-line caps, and its hold-up time is sky-high. On top of that, the 5VSB rail's efficiency is high, and at light loads, the PSU achieves some of the highest efficiency readings we have seen.

Seasonic's Prime platform still holds the performance crown years after its development. Plus, when a manufacturer is confident enough to provide a platform with a 12-year warranty, you know that this is a bullet-proof product.

PC GAMER VERDICT

- High performance
- High-quality components
- 12-year warranty

SPECS MANUFACTURER (OEM): SEASONIC / **MAX. DC OUTPUT:** 1000W / **EFFICIENCY:** 80 PLUS TITANIUM, CYBENETICS TITANIUM / **NOISE:** CYBENETICS A+ (15-20 DB[A]) / **COOLING:** 135MM FLUID DYNAMIC BEARING FAN / **MODULARITY:** YES (FULLY) / **WARRANTY:** 12 YEARS

SX1000

SILVERSTONE **£195**

Incredible power in a tiny package

6

The SilverStone SX1000 is the strongest small factor unit we have tested so far, and it has enough connectors to support a strong gaming system even in a tight space. It even appears way stronger than its specs list appears, since we pushed it close to 1500W without issue.

SilverStone has equipped this PSU with two EPS and six PCIe connectors to ensure it can deliver its full power without any problems. Moreover, all cables are modular, making the PSU's installation a breeze. Because of the small PCB, the temperatures at the internals can go high, so a double ball-bearing fan is used, which can handle hot conditions without any problems.

Since everything small and powerful is usually expensive, especially in the IT world, the SX1000 will empty your wallet. That said, PSUs are inexpensive given the vital role that they have in every system, so a 250-300 dollar power supply doesn't look that expensive.

PC GAMER VERDICT

- Extremely high power-density
- High build quality
- Efficient

SPECS MANUFACTURER (OEM): ENHANCE ELECTRONICS / **MAX. DC OUTPUT:** 1000W / **EFFICIENCY:** 80 PLUS PLATINUM, CYBENETICS PLATINUM / **NOISE:** CYBENETICS STANDARD+ (35-40 DB[A]) / **COOLING:** 120MM DOUBLE BALL BEARING FAN / **MODULARITY:** YES (FULLY) / **WARRANTY:** 5 YEARS

The humble controller is easily overlooked by a PC gamer. We're too distracted by our light-up keyboards and ultralight mice. But it's a good time to start paying attention to. There are a range of new technologies vying to change controllers forever, and the expectation of what's good is changing constantly.

Take the Hall effect, for example. This is popular among gaming keyboards but has become one of the most requested features for controllers over the past couple of years – a request that many manufacturers are keen to meet. Then, when you think the dust has settled, along come TMR sticks that claim to be even better.

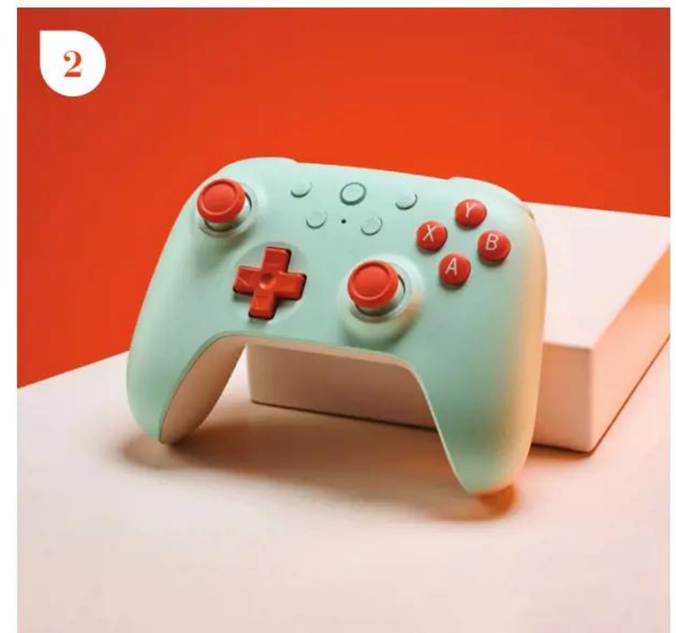
The best things about the controller market, however, are the prices. Unlike gaming keyboards and mice, the controller market is ruled by two mass-produced beasts from Microsoft and Sony. Third-party manufacturers are in a constant battle to bring down prices to meet them and win over potential customers that often prefer to stick to what they know. But as you'll see from our testing, you can get a whole lot more for your money.

GROUP TEST

CONTROLLERS

It's a fiercely competitive market out there for controllers, and it's only just getting started

By Jacob Ridley



V3 Pro

WOLVERINE £200

Better than ever

1 Razer has been trying to grab a slice of the premium controller market for years. You can't blame it for trying – Microsoft has had the market locked down with the illustrious Elite. Yet even the Xbox creator might be beaten at its own game by this pad.

The V3 Pro is off to a good start for the inclusion of Hall effect sticks. These promise a drift-free existence for the duration of their usage. That really matters when you're looking to spend triple-digits on a controller – which you absolutely will be with the V3 Pro. This controller may be expensive but it has a tank-like build and wonderfully clicky switches to justify the cost. The face switches give this controller a tactile edge that speaks to my nerdy soul. They are a little loud for late-night gaming – you're sure to annoy anyone in close proximity. Click, clack, click, clack. The V3 Pro goes one further with Mouse Click rear paddles and triggers. Yep, even the triggers are clicky if you want them to be. Though that's why this controller speaks to the pros, and to us mere mortals too.

PC GAMER VERDICT

- Hall effect
- Comfortable
- Snappy switches

SPECS WEIGHT: 281 G / **CONNECTIVITY:** XBOX WIRELESS, BLUETOOTH, USB TYPE-C / **STICK TYPE:** HALL EFFECT

Ultimate 2C Wireless

8BITDO £25

Budget hero

2 Budget takes on a new meaning with the 8BitDo Ultimate 2C. It feels nothing like the cheap pads of the past and much more like a premium model, and yet still it's more affordable than the Xbox Core Wireless Controller. Since when did budget controllers come with cream of the crop Hall effect sticks? They do now. The Ultimate 2C has two of them in a non-symmetrical layout, ergo the Xbox way, and even the triggers are Hall effect for maximum magnetic action. These all feel great to use, too, and we'd even rate the face buttons better than the Xbox Core controller's. There are two extra shoulder bumpers too.

The overall feel of the 8BitDo is more plasticky than Microsoft's main pad. The D-pad is a little less luxurious, too, though it's really not far off to be honest. As PC users, we also benefit from 8BitDo's standard 2.4 GHz connection over a dongle and Bluetooth as a backup, which means no extra dongles to take up space or whittle down your bank account. Good stuff.

PC GAMER VERDICT

- Hall effect
- Wireless
- Extra buttons

SPECS WEIGHT: 200 G / **CONNECTIVITY:** 2.4 GHZ, BLUETOOTH, USB TYPE-C / **STICK TYPE:** HALL EFFECT

Atom

CKRD **£15**

Adorable

3 The CKRD isn't going to replace your keyboard and mouse in most games. It's a bit too niche for that. Though it is a cleverly compact throwback to a time when controllers didn't have analogue sticks and double denim was more acceptable to wear in public. With just a D-pad, four shoulder buttons, and your usual array of face buttons, you are limited to what you can play with the CKRD Atom. Though to judge it on this alone would be a mistake. After all, it's cute. Its deceivingly tiny form factor means it's portable in such a way that it wouldn't be too weird to carry around in a bag with you at all times. You could store it in your jeans pocket, or perhaps your jeans jacket pocket.

It connects over Bluetooth, which is a higher latency connection than dedicated wireless, though the battery lasts a good ten hours or so. A USB Type-C cable comes to the rescue for truly lighting-fast play, and there's no faff setting this controller up either. More of a gaming accessory than a serious controller, we still had a blast playing 2D platformers on this.

PC GAMER VERDICT

- → Cute
- → Wireless
- → Good battery

SPECS WEIGHT: 90 G / **CONNECTIVITY:** BLUETOOTH, USB TYPE-C / **STICK TYPE:** NO STICKS

Envision Pro

SCUF **£180**

Missing out

4 The Scuf Envision Pro is a lovely controller but in desperate need of a version two. Let's start with the positives, namely a wonderful build quality with an almost soft-touch finish. It oozes quality, figuratively, so far it's been entirely ooze-free in testing. It's also wildly customisable thanks to a heap of shortcut buttons running beneath the analogue sticks. Though you will need iCUE to get the most out of it.

The requirement for some form of iCUE integration is a bit of frustration. I'm all up for my controller having lots of programmable bells and whistles, but when I first got this controller it wasn't possible to even use it without iCUE installed on my PC. You can set it up to function with your preferences baked into the hardware, though you still have to run through iCUE for the initial set-up.

Then there's the lack of Hall effect. Hall effect isn't everything, but on a controller that costs this much and is a modern design it feels like a big miss. Look at the 8BitDo: Hall effect for a fraction of the price of the Scuf. The Scuf is far superior in many ways.

PC GAMER VERDICT

- → Great feel
- → Lots of customisation
- → No Hall effect

SPECS WEIGHT: 241 - 285 G / **CONNECTIVITY:** 2.4 GHZ, USB TYPE-C / **STICK TYPE:** POTENTIOMETER

GROUP TEST

A FANTASTIC CONTROLLER FOR THE MONEY

MAGNETIC STICKS EXPLAINED

Analogue sticks traditionally use something called a potentiometer to measure how far a stick moves around in use. These potentiometers are cheap, efficient, and pretty accurate, until they're not. That's the big downside: they eventually wear out, leading to malfunctioning known commonly as stick drift. That's where magnets come to save the day.

Hall effect sticks have fewer parts touching one another, which extends their lifespan. They're much less prone to issues such as stick drift, as it's possible to finely tune their dead zone for optimal performance without leaving large margins in case something should go wrong.

Then there's TMR (tunnel magnetoresistance): a newer technology for controllers that claims both the benefits of Hall effect and lower power demands. It's also said to be more consistent. Though it still has a way to go before it's used widely.

Core Wireless Controller

XBOX **£50**

Standard bearer

5 The Xbox Core Wireless Controller is the best thing about an Xbox in 2024. I'm joking... mostly. It's a fantastic controller for the money, helped along by Microsoft's might and the economies of scale. How can some ma and pa controller company compete? The Xbox pad has a subtly textured finish, responsive sticks, excellent triggers, and it works a treat on PC out of the box. It uses AA batteries, which some won't like, but if you buy a pack of rechargeable batteries you can save on waste in a couple of ways: the batteries last longer and the controller won't need completely replacing when the batteries are dead for good. The biggest downside is the specialised Xbox Wireless dongle. It's like any other 2.4 GHz connection dongle, except Microsoft makes you pay extra for it rather than bundling it in the box. It's much better to play over 2.4 GHz for the lowest latency, though you can always opt for Bluetooth if you want to save the cash. Though if you're planning on that, why not just buy a better budget pad from the get-go?

PC GAMER VERDICT

- Great value
- Solid build
- Extra dongle required

SPECS WEIGHT: 280 G / **CONNECTIVITY:** 2.4 GHZ (WITH DONGLE), USB TYPE-C / **STICK TYPE:** POTENTIOMETER

Cyclone 2

GAMESIR **£56**

All the stuff

6 The Gamesir Cyclone 2 comes with TMR sticks. That stands for tunnel magnetoresistance. Much like traditional Hall effect sticks they harness the power of magnets for a more reliable function, no stick drift and a longer life. Though it's also said that TMR is more efficient and consistent than Hall effect. All of which is good news for a controller biz looking for the Next Big Thing.

Though the GameSir isn't just a TMR controller. It also has Hall effect triggers – it's a bit of a hybrid. That means it's supremely snappy and customisable, with a switch on the rear to adjust the triggers into 'hair trigger' mode.

The Cyclone 2 is just so gosh darned affordable that it makes you wonder about controllers that have half the features for the same money. It even has a charging stand. Admittedly, the Gamesir has some cheaper-looking materials to it, but that's somewhat excusable with the entire package taken into account. By any rate, I think we'll see more TMR controllers headed our way in the future.

PC GAMER VERDICT

- TMR sticks
- Gyro
- Rear buttons

SPECS WEIGHT: 299 G / **CONNECTIVITY:** 2.4 GHZ, BLUETOOTH, USB TYPE-C / **STICK TYPE:** TMR

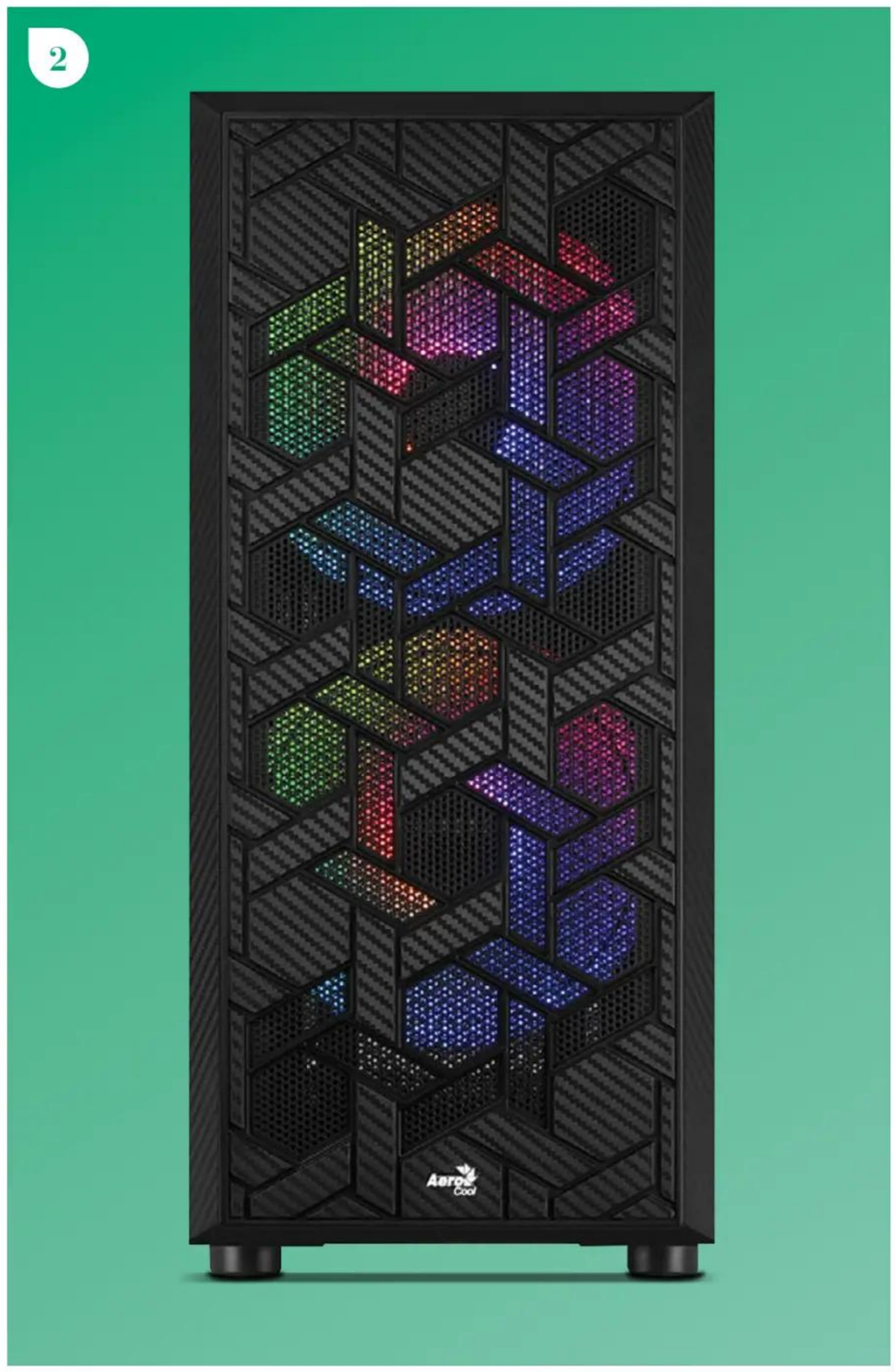
GROUP TEST

BUDGET CASES

Play it smart by saving money on your chassis and spending it on bigger and better components. *By Jacob Ridley*

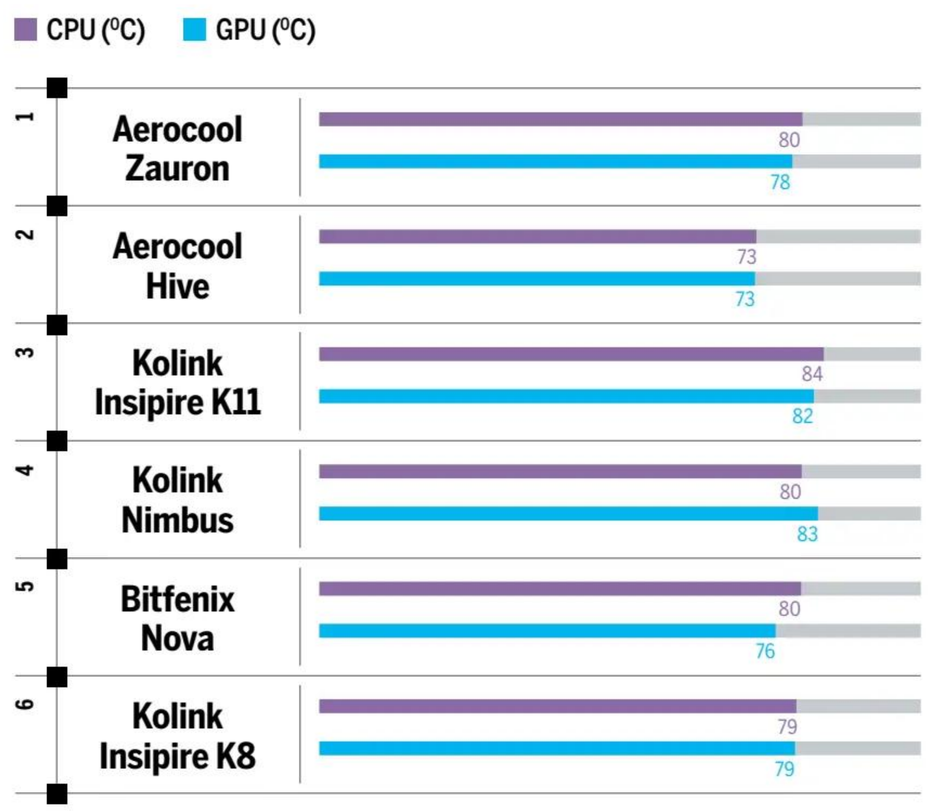
There's no denying the importance of a quality PC case in ensuring top performance out of your PC's parts. Your choice of case can mean the difference between optimal airflow and a weak breeze that could barely cool a capacitor. It can decide whether you have space for SSDs or have to stick one to the back of your motherboard tray with tack. It may even be the difference between a pain-free PC building experience and needing a plaster.

1



GO WITH THE FLOW

The main ingredient for an impressive PC case is airflow, but you'd be surprised by just how many case designs don't get this quite right. Ideally, we want our case to draw in cool air from a handful of high flow intake fans at the front, over our PC's components, then out the exhaust. Cheap cases, however, don't always come with the ideal number of fans for this optimal setup, so it's extra important to find one that is smartly designed to work with limited cooling potential. To test the thermal properties of these six cheap cases, I built a PC into each of them, then I ran a handful of benchmarks to put the CPU and GPU under day-to-day stress, and collated the average results into this graph.



Zauron

AEROCOOL **£32**

The budget case champ

1 The Aerocool Zauron is quite simply the most impressive budget case. Not only because it delivers what any PC gamer on a budget would need of it, but because it also does it on a shoestring budget. The Zauron is the cheapest case of the lot.

The layout of this case is exactly what is best for a case of this price tag and size, offering plenty of ventilation and space for an optimal fan setup. The PSU is fitted neatly away under a shroud and there's room for multiple fans or radiators in the front and top. On the side is a real tempered glass side panel, which is surprising on a case that asks so little. There's just one fan included, which is a bit of a knock to the Zauron because it's a single molex-powered fan with a fixed RPM. Yet average temperatures for both CPU and GPU are decent despite this. So while it may still have some of those cheap case flaws, much like the others, I can't argue with this case for the small sum of money demanded for it.

PC GAMER VERDICT

- → One of the cheapest cases we tested
- → Simple design and effective layout
- → Nice looking finish

SPECS SIZE: MID-TOWER / **2.5-INCH BAYS:** 4 MAX / **3.5-INCH BAYS:** 2 MAX / **MAX GPU LENGTH:** 325MM / **MAX FAN SUPPORT:** 6 X 120MM / **RGB LIGHTING:** FAN ONLY / **SIDE PANEL:** YES, GLASS / **FRONT PANEL:** POWER, RESET, AUDIO, 2 X USB 3.0

Hive

AEROCOOL **£50**

Keep it cool

2 The Aerocool Hive sits at the very edge of what I'd deem cheap enough for consideration. It just sneaks in there in this configuration, which comes with three fans in total, including two 140mm fans. There are also cheaper variants for less cash, so you have options here.

The Hive is absolutely a front-runner. It brings a smart and flexible layout, one not dissimilar to the Zauron, yet the inclusion of some fairly sizeable fans at a decent price helps make for an impressively cool case. These three fans are powered by individual SATA connections, so you have to bear with the set RPMs on offer. However, since the two front fans are 140mm in size they don't have to run as fast to deliver good cooling potential. The Hive posted the lowest temperatures on average, and while it isn't quite a match for the Zauron in price it is notably better for it. If you were planning to pick up the Zauron and a extra fan to go with it right away, you might want to consider the Hive instead.

PC GAMER VERDICT

- → The best cooling out of the box
- → Great layout
- → Looks good

SPECS SIZE: MID-TOWER / **2.5-INCH BAYS:** 3 MAX / **3.5-INCH BAYS:** 2 MAX / **MAX GPU LENGTH:** 317MM / **MAX FAN SUPPORT:** 8 X 120MM / **RGB LIGHTING:** FANS ONLY / **SIDE PANEL:** YES, GLASS / **FRONT PANEL:** POWER, RESET, AUDIO, 2 X USB 3.0, 1 X USB 2.0

GROUP TEST

Inspire K11

KOLINK **£40**

Look, a proper fan

3 The Kolink Inspire K11 is a picture of a modern mid-tower PC case, and I have to say I'm actually rather surprised by the general level of quality manufacturing with this case. It's very well put together, and while there are still a few signs of its budget roots, the case does well to mitigate those with a few smart decisions.

This is the only cheap case I tested that comes with a PWM fan able to be plugged directly into the motherboard. That means full control and fan curves. The included Umbra aRGB 120mm fan is installed in the rear of the case, which does leave you without a front intake fan for optimal airflow, but does light up all the colours of the rainbow.

Though it's worth noting that out of the box that single fan doesn't deliver particularly impressive thermal performance. That said, the Inspire K11 is pretty flexible, and if it wasn't for the fact that other cheap cases deliver a little more out of the box, this would be one of the best.

PC GAMER VERDICT

- → Proper PCIe slot covers
- → Surprisingly snazzy layout
- → No US availability

SPECS SIZE: MID-TOWER / **2.5-INCH BAYS:** 4 MAX / **3.5-INCH BAYS:** 2 MAX / **MAX GPU LENGTH:** 315MM / **MAX FAN SUPPORT:** 8 X 120MM / **RGB LIGHTING:** FAN AND FRONT / **SIDE PANEL:** YES, GLASS / **FRONT PANEL:** POWER, RESET, AUDIO, 1 X USB 3.0, 2 X USB 2.0

Nimbus

KOLINK **£47**

Styling on a budget

4 Kolink's Nimbus is relatively flashy case considering its bargainous intention. With an RGB LED strip surrounding the front fan vent and a tempered glass side panel, it has all the makings of a more pricey case.

The Nimbus features a solid layout that should be familiar to most PC gamers, and one that's tried and tested. It's also one of the Nimbus' best features because of the number of possible mounting points for cooling. Only a single fan comes pre-installed in the rear of the case, however, and doesn't do a stellar job. The RGB cable on the Nimbus couldn't reach the correct header on the NZXT N7 motherboard I used for testing, either, which means I had to control this via the front panel rather than my motherboard.

The Kolink has all the makings of a flexible PC case for a wide range of uses, and it does look great. However, it is let down by a few weak points, and I'd suggest you pick up a second fan.

PC GAMER VERDICT

- → Glass side panel
- → No US availability
- → Second fan is recommended

SPECS SIZE: MID-TOWER / **2.5-INCH BAYS:** 4 MAX / **3.5-INCH BAYS:** 2 MAX / **MAX GPU LENGTH:** 315MM / **MAX FAN SUPPORT:** 6 X 120MM / **RGB LIGHTING:** FRONT / **SIDE PANEL:** YES, GLASS / **FRONT PANEL:** POWER, RESET, AUDIO, 1 X USB 3.0, 2 X USB 2.0

Nova

BITFENIX **£43**

Storage galore and nothing more

5 With two 120mm fans, heaps of storage bays, and a glass side panel, the Bitfenix Nova is shooting above its weight class. It even manages to squeeze in support for disc drive, for the people still rocking one of those. For its large storage capacity, the Bitfenix Nova offers a slightly less than optimal layout. A top-to-bottom storage cage takes up most of the front of the case, leaving zero room for a liquid cooler and potentially blocking off airflow, at least with a couple of hard drives installed. That said, with only an NVMe SSD installed, the CPU and GPU run at okay temperatures. The case also rattles something fierce for all the drive bays.

The Bitfenix Nova is a case with a lot of room for storage expansion, and in that sense there are no others I've tested that are a match for it. However, it's a little bland to look at, and the ill-fitting nature of the drive bays, and the position of them, does make me wonder how practical this case will be once it's filled up.

PC GAMER VERDICT

- → Glass side panel
- → Lots of expansion options
- → Paint job doesn't match

SPECS SIZE: MID-TOWER / **2.5-INCH BAYS:** 3 MAX / **3.5-INCH BAYS:** 4 MAX / **MAX GPU LENGTH:** 280MM / **MAX FAN SUPPORT:** 3 X 120MM / **RGB LIGHTING:** NONE (WHITE LED FAN) / **SIDE PANEL:** YES, GLASS / **FRONT PANEL:** POWER, RESET, AUDIO, 2 X USB 3.0

Inspire K8

KOLINK **£40**

Interesting but underwhelming

6 The Kolink K8 is a straightforward PC case. It's a fairly nondescript box with space for your precious PC components, plenty of ventilation, and room for expansion. It has some flair with a snazzy RGB strip down the front of the case, matching the cuboid pattern on its front, and the cut-out on top is a little more exciting than most.

You can build a PC inside the Inspire K8 without hitting any pain points, at the very least. There is only a single SATA-powered 120mm RGB fan pre-installed in this machine, though being so well ventilated it does do a fairly good job of keeping temperatures down. It could be mightily improved with another fan or two. I did run into a bigger issue with this case, however. Since there's no CPU cable cutout in the motherboard tray, I had to run that right the way across my build. The Kolink isn't terrible, it's just simply not a match for other cases I've tested in terms of value or features.

PC GAMER VERDICT

- → Best looking RGB on a cheap case
- → Actual glass side panel
- → A little pricey

SPECS SIZE: MID-TOWER / **2.5-INCH BAYS:** 4 MAX / **3.5-INCH BAYS:** 2 MAX / **MAX GPU LENGTH:** 300MM / **MAX FAN SUPPORT:** 6 X 120MM / **RGB LIGHTING:** FAN, FRONT / **SIDE PANEL:** YES, GLASS / **FRONT PANEL:** POWER, RESET, AUDIO, 2 X USB 3.0, 1 X USB 2.0

GROUP TEST

OLED GAMING MONITORS

OLED technology has arrived on the desktop at last

By Jeremy Laird

It's been an awfully long time coming. But rejoice, for the OLED revolution has finally made the leap from smartphones and TVs to the PC. You can now choose from a critical mass of gaming-optimised monitors all powered by the latest OLED tech.

From full 4K resolution and ultrawide aspect ratios to 240Hz refresh and sub-1m response times, OLED panels certainly tick a lot of boxes. You can even get an OLED monitor with a flexible screen. But is the technology truly ready for the demands of the PC?

Should you be worried about burn-in and image retention on an OLED PC monitor, for instance? What about peak brightness? Does OLED tech still have a problem lighting up the whole panel?

And if OLED is indeed up to proper PC duty, which of the brave new generation of purpose-built gaming panels should you pick? Time to find out.

Mobiuz EX480UZ

BENQ **£1,600**

Bigger isn't always a whole lot better

1 For now, all OLED gaming monitors are derived from HDTV tech. That's why you can only get the full 4K resolution from really large panels like the 48-inch BenQ Mobiuz EX480UZ.

Honestly, it's too big for a multipurpose desktop monitor. The ergonomics don't work and the pixels are fat and ugly. As something that doubles as a PC gaming monitor and maybe also a console screen, this BenQ only begins to make sense thanks to its combination of both DisplayPort 1.4 and HDMI 2.1 connectivity.

But even so, the LG-sourced OLED panel lacks punch next to any premium LCD monitor. It just doesn't work as well as the Samsung QD-OLED competition in a PC context. The HDR performance is decent in darker game scenes, but the more of the panel you light up, the less punch it has.

In the end, features like the bundled IR remote and better integrated speakers than usual for a PC monitor aren't enough to offset the fact that you can get a similarly-specced 120Hz 4K OLED TV for way less money.

PC GAMER VERDICT

- → The real 4K deal
- → Nice feature set
- → Limited full-screen brightness

SPECS SIZE: 48-INCH / **PANEL TYPE:** LG WOLED / **RESOLUTION:** 3840 X 2160 / **REFRESH:** 120HZ

Xeneon Flex 45WQHD240

CORSAIR **£2,100**

Corsair's flexible panel tech comes at a painful price

2 You'd better *really* like the Corsair Xeneon Flex 45WQHD240's bendy OLED panel tech, because it's hard to see what else justifies the price tag.

This Corsair 45-inch OLED monitor runs the same 3440 x 1440 native res as the 34-inch ultrawide competition. The net result is much bigger pixels on such a big panel. That's suboptimal on the Windows desktop, though less of an issue actually in game.

However, what certainly will bother you when you fire up, say, *Cyberpunk 2077* running with full HDR reheat enabled, is the Flex's weedy full screen brightness. It's very disappointing. It doesn't really even sizzle as much as you'd hope in darker game scenes with smaller light sources.

OK, the pixel response is outrageously fast and the 240Hz refresh makes for very low latency. But for almost any money, let alone this lofty price point, the panel simply lacks drama and fizz. So, it's nice to have the option of bending the Xeneon Flex or leaving it flat. But $2,000 worth of nice? That'll be a big, fat no.

PC GAMER VERDICT

- → Flexible panel tech
- → Very fast
- → Disappointing panel brightness

SPECS SIZE: 45-INCH / **PANEL TYPE:** LG WOLED / **RESOLUTION:** 3440 X 1440 / **REFRESH:** 240HZ

GROUP TEST

4

AW3423DW

ALIENWARE **£1,099**

The first and still one of the best OLED monitors

3 This is it, the daddy, the first true OLED gaming monitor. We were pretty blown away by the Alienware AW3423DW when we first saw it over a year ago, and not a lot has changed. This is still a stunning monitor.

It runs Samsung's QD-OLED tech, so full-screen brightness is no problem. More to the point, the HDR performance is pretty epic, with one proviso. A matte anti-glare coating slightly undermines the OLED panel's perfect black levels, which is a pity. Still, we also love the 34-inch ultrawide aspect ratio, it's just so immersive compared to a plain old 16:9 panel. Then there's the epic response you get with all OLED monitors and the low latency thanks to a 175Hz refresh.

OK, there are monitors with higher refresh. But that's quick enough for most needs short of pro esports. No, our main objection is the painful pricing, which is partly a factor of full Nvidia G-Sync Ultimate support, which costs plenty but doesn't actually add all that much.

PC GAMER VERDICT

- Gorgeous ultrawide OLED panel
- No brightness issues
- Too pricey versus the competition

SPECS SIZE: 34-INCH / **PANEL TYPE:** SAMSUNG QD-OLED / **RESOLUTION:** 3440 X 1440 / **REFRESH:** 175HZ

AW3423DWF

ALIENWARE **£929**

This is as good as OLED gaming currently gets

4 Add a single letter, save £200. That's the Alienware AW3423DWF for you, cheaper sibling to the full-spec Alienware AW3423DW. But what are you giving up?

Actually, almost nothing, just the mostly pointless Nvidia G-Sync module and 10Hz of refresh rate. That's a downtuning of the spec to 165Hz that we suspect is mostly symbolic. Whatever, what you do keep is the fabulous Samsung QD-OLED 34-inch ultrawide panel in all its HDR glory.

Goodness, it's gorgeous. What's more, it actually looks better in this cheaper Alienware 'F' model thanks to a glossy coating. That really brings out those black levels at the same time as letting that quantum-dot brightness do its thing.

Overall, there are few compromises, especially compared to alternatives with brightness-challenged LG panels, and loads to like, from incredible pixel speed to fantastic HDR punch. Overall, it's just what we've been hoping for from OLED tech and, for now at least, probably the best OLED gaming monitor on the market.

PC GAMER VERDICT

- Epic ultrawide OLED experience
- Punchy full-screen brightness
- Cheaper than the G-Sync version

SPECS SIZE: 34-INCH / **PANEL TYPE:** SAMSUNG QD-OLED / **RESOLUTION:** 3440 X 1440 / **REFRESH:** 165HZ

PHILIPS HAS DITCHED THE NVIDIA G-SYNC MODULE AND SWAPPED IN A USB-C PORT WITH POWER DELIVERY

GO FOR THE BURN

Burn-in is the biggest worry when it comes to OLED technology. It happens because the red, green and blue subpixels in OLED panels wear out at slightly different rates.

Of course, you won't care about the specifics if you find a ghostly shadow of the Windows taskbar etched into the bottom of your pricey OLED panel. You'll just wonder where the money went.

For now, there's no definitive verdict. Only two companies make the actual panels that go into OLED monitors: LG and Samsung. And there are some indications that LG's WOLED tech is slightly more burn-in resistant than Samsung's QD-OLED.

If you're particularly worried, then, go for a monitor with an LG panel. But all the options here are covered by a burn-in guarantee for a few years. So, there's no immediate cause for concern.

Evnia 34M2C8600

PHILIPS **£1,150**

Philips has gone glossy and it makes all the difference

5 OLED monitors are surely synonymous with cutting edge technology. Right now, it's the ultimate screen tech, right? Probably. But it's a surprisingly old-school feature that most impressed us about the Philips Evnia 34M2C8600. Yup, it's the glossy screen coating. And it makes all the difference compared to the matte coating on the Alienware AW3423DW.

Admittedly, Alienware has since added the AW3423DWF to its lineup, which is also glossy. But it was Philips that first proved how it maximises the contrast and black levels. That glossy coating really lets OLED panel tech sing. Elsewhere, you get a full 175Hz refresh and zippy pixel response, all wrapped up in an essentially identical 34-inch ultrawide package. But Philips has ditched the Nvidia G-Sync module and swapped in a USB-C port with power delivery.

The latter arguably isn't hugely relevant for gaming. So we'd opt for the cheaper 'F'-spec Alienware. But this Philips Evnia is still a super-sweet screen.

PC GAMER VERDICT

- OLED screen tech done right
- Glossy coating makes a difference
- Expensive

SPECS SIZE: 34-INCH / **PANEL TYPE:** SAMSUNG QD-OLED / **RESOLUTION:** 3440 X 1440 / **REFRESH:** 175HZ

Xeneon 27QHD240

CORSAIR **£949**

Corsair's 1440p OLED panel lacks pizazz

6 A thousand quid or very likely thereabouts is an awful lot for a 27-inch 1440p monitor. But such are the extremes of OLED tech, you can actually have a 48-inch 4K model from Gigabyte for less.

Of course, this Corsair monitor gets newer LG OLED panel tech. That does help a little with full-screen brightness. But the 27QHD240 still lacks punch. For sure, it's well behind screens with Samsung's QD-OLED tech for brightness, never mind an LCD monitor with a turbocharged mini-LED backlight. Still, the black levels are impeccable and the combination of 240Hz refresh and that signature OLED pixel speed makes for an outrageously pacey monitor. Speaking of which, the modest 2,560 x 1,440 res does at least mean that it's much easier to achieve those ultra-high frame rates than with a full 4K monitor.

It's just at this price point, 27 inches just doesn't feel terribly impressive. It's a good monitor, this Corsair Xeneon. We just want something a bit more dramatic for this much money.

PC GAMER VERDICT

- Super speedy pixels
- 240Hz refresh
- Lacks just a little punch

SPECS SIZE: 27-INCH / **PANEL TYPE:** LG WOLED / **RESOLUTION:** 2560 X 1440 / **REFRESH:** 240HZ

GROUP TEST

ERGONOMIC KEYBOARDS

If you're looking for day-long typing comfort, there's an ideal ergonomic keyboard that's just right for you.

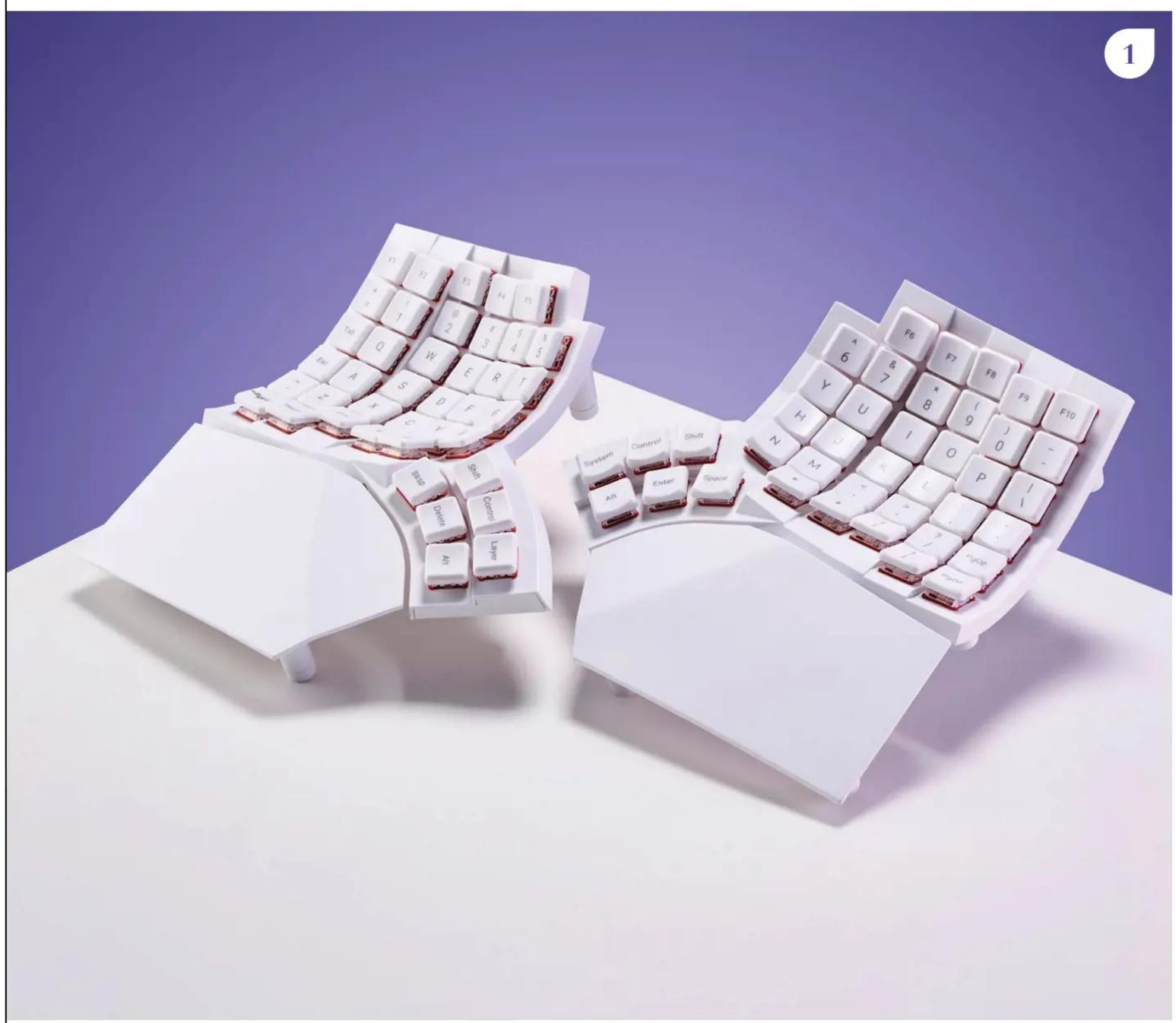
By Nick Evanson

Standard keyboards just aren't great for your body. The key layout makes your fingers constantly stretch and splay, and forces your wrists to rotate inward. Your hands sit close together, so your shoulders don't get much chance to relax.

A quality ergonomic keyboard counters all of this and the best ones are designed to relieve the stresses you get from typing and gaming all day long. Picking the right one is no easy task and there's no such thing as a perfect choice, as everyone's needs are different.

What suits one person could well be an annoyance to someone else. There are some important things to watch out for, though, so avoid paying for a label and look for the right features. Here are six ergo keyboards to whet your appetite and help you decide whether it's time to take the plunge.

Ergonomic Keyboards



Glove80

MOERGO **£320**

Extreme ergo

1 It's the most outrageous-looking and expensive keyboard here, but the Glove80 is peerless when it comes to comfort and features. It's also the most complex and hardest to adapt to, thanks to the bowl-shaped layout. If you can remap your brain to it all, then you'll wonder just why you put up with a traditional keyboard for so long. Your hands, wrists, and shoulders will thank you on a daily basis. Every key can be reconfigured via software and the uniform keycaps mean you can move them all about, as you see fit. The same is true for tenting and tilting, as many of the legs can be raised via a fiddly nut-and-bolt arrangement to get the perfect angle. The Glove80 demands commitment, not least because of the price tag. Everything about it has comfort at the heart of its design and that makes it very different from everything else you'll lay your hands on. It's the least gaming-friendly keyboard here, due to the thumb islands, but it's by far the most ergonomic.

PC GAMER VERDICT

- → Sublime comfort
- → Ultra portable
- → Very expensive

SPECS SWITCHES: MECHANICAL, THREE CHOICES OF KAILH CHOC / **KEYS:** 80 / **CONNECTIVITY:** WIRELESS OR WIRED, USB TYPE-C / **SPLIT:** FULLY SEPARATE / **TENTING:** CONTINUOUS / **TILTING:** CONTINUOUS

Moonlander

ZSA **£290**

Starship ergo

2 The highest levels of ergonomic comfort can be found with columnar keyboards, especially those that have thumb islands. This is where commonly used keys, such as Shift and Enter, are activated by your thumbs, reducing the amount of lateral movement your fingers need to go through.

ZSA's Moonlander is a stylish and feature-rich example of such a keyboard. Every key switch is hot-swappable and can be quickly remapped via software, and tenting is achieved through rotating metal legs and the islands. There's no tilting as such, but once tented the keyboard does provide a small amount of positive tilt. Adapting to the layout is tough and it could take you a long time to get used to it. Those thumb islands also make gaming quite fiddly, forcing you to remap keys in most games, but with fewer keys on each island, it's not as awkward as on the Glove80. The Moonlander is very expensive but you're getting one of the most comfortable and low-stress keyboards money can buy.

PC GAMER VERDICT

- → Really comfortable
- → Space-age looks
- → High price

SPECS SWITCHES: MECHANICAL, CHERRY MX OR KAILH / **KEYS:** 72 / **CONNECTIVITY:** WIRED, USB TYPE-C / **SPLIT:** FULLY SEPARATE / **TENTING:** CONTINUOUS / **TILTING:** NONE

THE MECHANICAL SWITCHES OFFER LOTS OF FEEDBACK

GROUP TEST

Freestyle Edge

KINESIS GAMING **£230**

Everyone's ergo

3 If you want a great keyboard that offers superb ergonomics, for all day typing, and still be great for gaming, then look no further. The fully split arrangement is permanently wired together but there's more than enough cable length to get things just right for you.

Despite all the features, the Freestyle Edge is compact and sleek, with detachable wrist pads. Though it lacks a number pad, it has plenty of keys, eight of which can be easily programmed for macros, across multiple profiles.

Out of the box, there's no support for tenting and tilting, but an optional lift kit gives you three levels of tenting and a fixed but small amount of positive tilt. Given how expensive the keyboard is, the fact that you have to pay out even more just to get some tenting is a bit cheeky.

It's a serious amount of money for a keyboard, but equipped with the lift kit, the Freestyle Edge is a perfect blend of ergonomic and gaming features. It's a bar from which to judge the rest.

PC GAMER VERDICT

- → Great all-rounder
- → Ideal for small hands
- → Tenting is an extra cost

SPECS SWITCHES: MECHANICAL, 4 CHOICES OF CHERRY MX / **KEYS:** 95 / **CONNECTIVITY:** WIRED, USB TYPE-A / **SPLIT:** FULL SEPARATE / **TENTING:** NONE, OPTIONAL KIT / **TILTING:** NONE, OPTIONAL KIT

C959 ErgoTKL

CLOUD NINE **£200**

Gamers' ergo

4 The C959 ErgoTKL is big, bold, and very ergonomic, provided your hands are the right size. The separate keyboard halves are connected via a proprietary cable that's long enough to suit most arrangements. And while the amount of tenting is fixed, the angle is a good all-round position. The mechanical switches offer lots of feedback and you can have as much click as you like, depending on which set you choose to purchase. There are four keys to program macros for and there's a handy control wheel for media and other functions, though its backlight is permanently on and very bright.

Tilting is restricted to negative values to cater for standing desk users, but the keyboard has a natural positive tilt due to the shape of the chassis. The overall ergonomics of the C959 are very good and if you're the right size for it, you can easily type all day and game all night. But you're going to have to pay a pretty penny for all that comfort.

PC GAMER VERDICT

- → Day-long comfort
- → Great for big hands
- → Constant wheel light

SPECS SWITCHES: MECHANICAL, THREE CHOICES OF KAILH / **KEYS:** 89 / **CONNECTIVITY:** WIRED, USB TYPE-A / **SPLIT:** FULLY SEPARATE / **TENTING:** FIXED 7 DEG / **TILTING:** -4 OR -7 DEG

5
logi
SWOOPING CURVES
ARE MORE THAN JUST
A NICE AESTHETIC

ERGO FEATURES THAT MATTER THE MOST

Tenting
Your wrists naturally rotate outward when resting your hands on a keyboard. Raising the middle so it forms a tent shape ensures your wrists are as relaxed as possible.

Split
Normal keyboards force your shoulders to rotate inward. Separating the keys lets them sit naturally. Fully split keyboards, where you can position the halves anywhere you like, are the most flexible of all.

Tilting
Your wrists should ideally rest flat, with respect to your forearms. Depending on how you're sitting and standing, you may want to tilt the keyboard.

Columnar
Standard layouts cause your fingers to splay while typing. A columnar arrangement has the keys in columns, meaning your fingers only need to move back and forth, easing the stress on them.

Ergo K860

LOGITECH **£110**

Office-based ergo

5 Logitech's premier ergonomic keyboard is the classic K860 and it's probably the ideal starting point, if you're considering how best to start supporting your body's needs. The keys are permanently split, though the separation could do with being a tad wider if you have broad shoulders. The level of tenting is greater than that of the Wave Keys and should suit most people, being around seven degrees or so. Swooping curves are more than just a nice aesthetic: they make the keyboard very comfortable to use. There's no option to apply a positive tilt, only two stages of a negative angle. Great for standing, but less so for sitting. Fortunately, the typing experience is very pleasant and although the key feedback is muted, it's enough to enjoy a spot of gaming.

However, the high wrist rest might limit just how long that session is, especially if you tend to sit quite low in relation to the keyboard. Office work is where the K860 truly excels.

PC GAMER VERDICT

- → Good ergonomics
- → Super quiet in use
- → Not much feedback

SPECS SWITCHES: MEMBRANE / **KEYS:** 110 / **CONNECTIVITY:** WIRELESS / **SPLIT:** FIXED / **TENTING:** FIXED / **TILTING:** -4 OR -7 DEG

Wave Keys

LOGITECH **£70**

Entry-level ergo

6 Most ergonomic keyboards are pretty expensive but not Logitech's Wave Keys, though it's not exactly a budget-level product. While the design won't be to everyone's taste, there's a full set of keys here and three wireless connection profiles, letting you use it on multiple devices. With only a modicum of tenting, your wrists are given the slightest of relief and for most users, it's not enough to be really effective. The key layout isn't split in any way and while the compact format is handy if you're short on desk space, it won't do your shoulders any favours over long periods. What may really put you off your office work and gaming is the serious lack of key feedback. It's great for being silent, but the rubbery feeling never lets you know if you're pressing too hard or too lightly. At least the wrist rest is comfortable and supportive. It's not too pricey and could be worth a look if you just want to dabble a toe, or more rather a finger, into the ocean of ergonomics.

PC GAMER VERDICT

- → Compact and cute-ish
- → Awful key feedback
- → Not all that much ergo

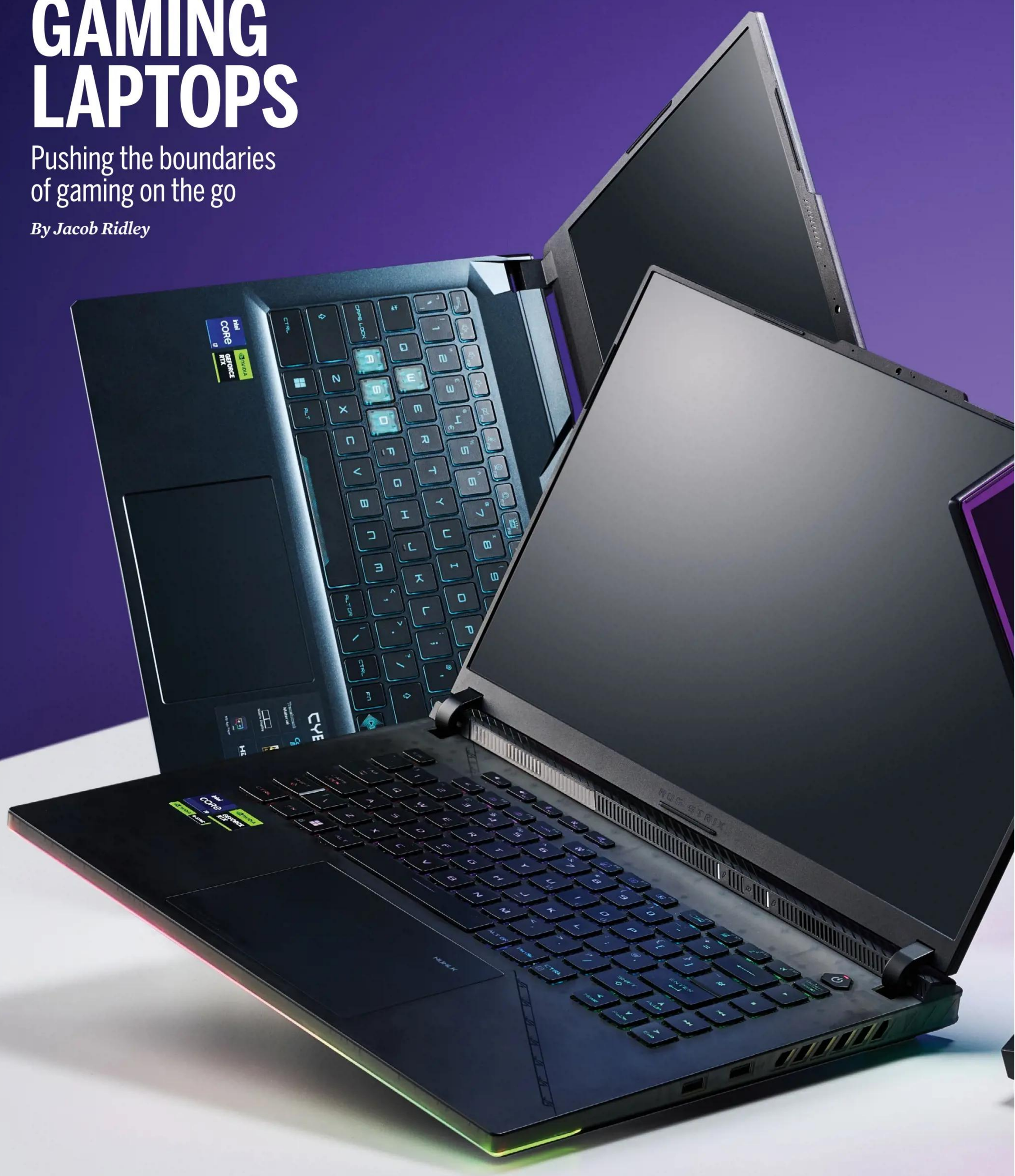
SPECS SWITCHES: MEMBRANE / **KEYS:** 100 / **CONNECTIVITY:** WIRELESS / **SPLIT:** NONE / **TENTING:** FIXED / **TILTING:** +4 DEG

GROUP TEST

GAMING LAPTOPS

Pushing the boundaries of gaming on the go

By Jacob Ridley



A new generation of GPUs has arrived and with them a new generation of gaming laptops. Some new designs, some a refresh of what came before. We've had heaps of RTX 40-series laptops in the PC Gamer labs for a spin round our benchmarking suite to give them a run for their money. There are also new AMD 7000-series GPUs for laptops announced, but, alas, no gaming laptops made it across our desks with one installed in time for this test.

Legion Pro 7i

LENOVO **£2,800**

Simply the best

1 This Lenovo Legion laptop is outstanding. Where other laptops try to squeeze in absurdly powerful RTX 4090 GPUs into a slim chassis with miserly results, Lenovo has opted for the much more sensible RTX 4080 here. But don't let that put you off. This laptop's excellent chassis will see it often outperform even those constrained RTX 4090 models at times. The Legion comes with a 1600p IPS screen rated to run at up to 240Hz. That's a tough target for most GPUs to hit, but the 150W RTX 4080 here manages to satiate that screen's refresh rate in many competitive games and deliver upwards of 100fps in more demanding titles.

That's down to the RTX 4080's Ada Lovelace silicon, and helped along by DLSS Frame Generation in supported games, but it's also down to a clever pick of CPU in the Legion with the Intel Core i9 13900HX. Stick that all together with 32GB of DDR5 RAM and a 1TB PCIe 4.0 SSD inside a grown-up chassis and the Lenovo stands out as the best gaming laptop right now.

PC GAMER VERDICT

- → RTX 4080 at its best
- → Excellent CPU
- → Smart chassis

SPECS CPU: INTEL CORE I9 13900HX / **GPU:** NVIDIA RTX 4080 (150W) / **RAM:** 32GB DDR5-5600 / **STORAGE:** 1TB NVME SSD / **SCREEN:** 16-INCH, 1600P, 240HZ

G5 KF

GIGABYTE **£1,200**

The affordable option

2 The latest generation of gaming laptops has made me rethink what an affordable machine is. Gone are the days of a chunky chassis with a no-frills feature set, and in their place you have a laptop like this Gigabyte G5. The G5 is cleverly designed for gaming without breaking the bank. The RTX 4060 at its core still benefits from Ada exclusive features like DLSS 3 and Frame Generation but importantly it's far from the lofty price tag of an RTX 4090. It's a great fit for the G5's 1080p, 144Hz screen, especially as Gigabyte is allowing the 75W RTX 4060 to ramp up to a respectable 2,100MHz. Though what I appreciate most about the G5 is just how easy it is to get under the hood and install a secondary M.2 SSD. There are a few screws to dispatch but then you can simply pop-off the rear panel and access the spare M.2 slot and RAM, if needed. I'd recommend the upgrade to a larger SSD as a priority, too, the included 512GB SSD is this laptop's weakest link. That and it's pretty loud.

PC GAMER VERDICT

- → High 1080p frames
- → Easy to upgrade storage
- → Loud

SPECS CPU: INTEL CORE I5 12500H / **GPU:** NVIDIA RTX 4060 (75W) / **RAM:** 16GB DDR4 3200 / **STORAGE:** 512GB NVME SSD / **SCREEN:** 15.6-INCH, 1080P, 144HZ

A HULKING BEHEMOTH THAT CAN ONLY BE DESCRIBED AS A DESKTOP REPLACEMENT

GROUP TEST

4

Blade 16

RAZER **£4,400**

Wowee pricey

3 The Razer Blade 16 is a gaming laptop we all understandably crave. It's stunning, well-provisioned, and hewn out of a chunk of shiny metal. It's decisively drool-worthy, but if you're looking for any sort of value proposition then look elsewhere.

Let's start with the great bits. Even inside its slender chassis, the Blade 16 packs an RTX 4090 capable of matching desktop machinery for framerates. We're talking about high framerate 4K gaming in a machine that looks like a MacBook from the dark side. Genuinely incredible. But, surprisingly, it's the 24-core CPU that really ramps up under load, hitting a thermal ceiling quicker than you can say 'Razer toaster'.

And the promise of a native UHD+ screen that can moonlight as a faster FHD+ screen doesn't live up to expectations, and it's a bit too much of a hassle to make it a reasonable ask of gamers on-the-go.

All in, the Blade 16 is a beast of epic proportions, but it's tough to recommend this high-end spec at the price asked for it.

PC GAMER VERDICT

- As premium as it gets
- Desktop-grade performance
- Frightening price

SPECS CPU: INTEL CORE I9 13950HX / **GPU:** NVIDIA RTX 4090 (175W) / **RAM:** 32GB DDR5-5600 / **STORAGE:** 1TB + 1TB NVME SSD / **SCREEN:** 16-INCH, DUAL-MODE, 120/240HZ

Titan GT77 HX

MSI **£5,300**

Performance, at what cost

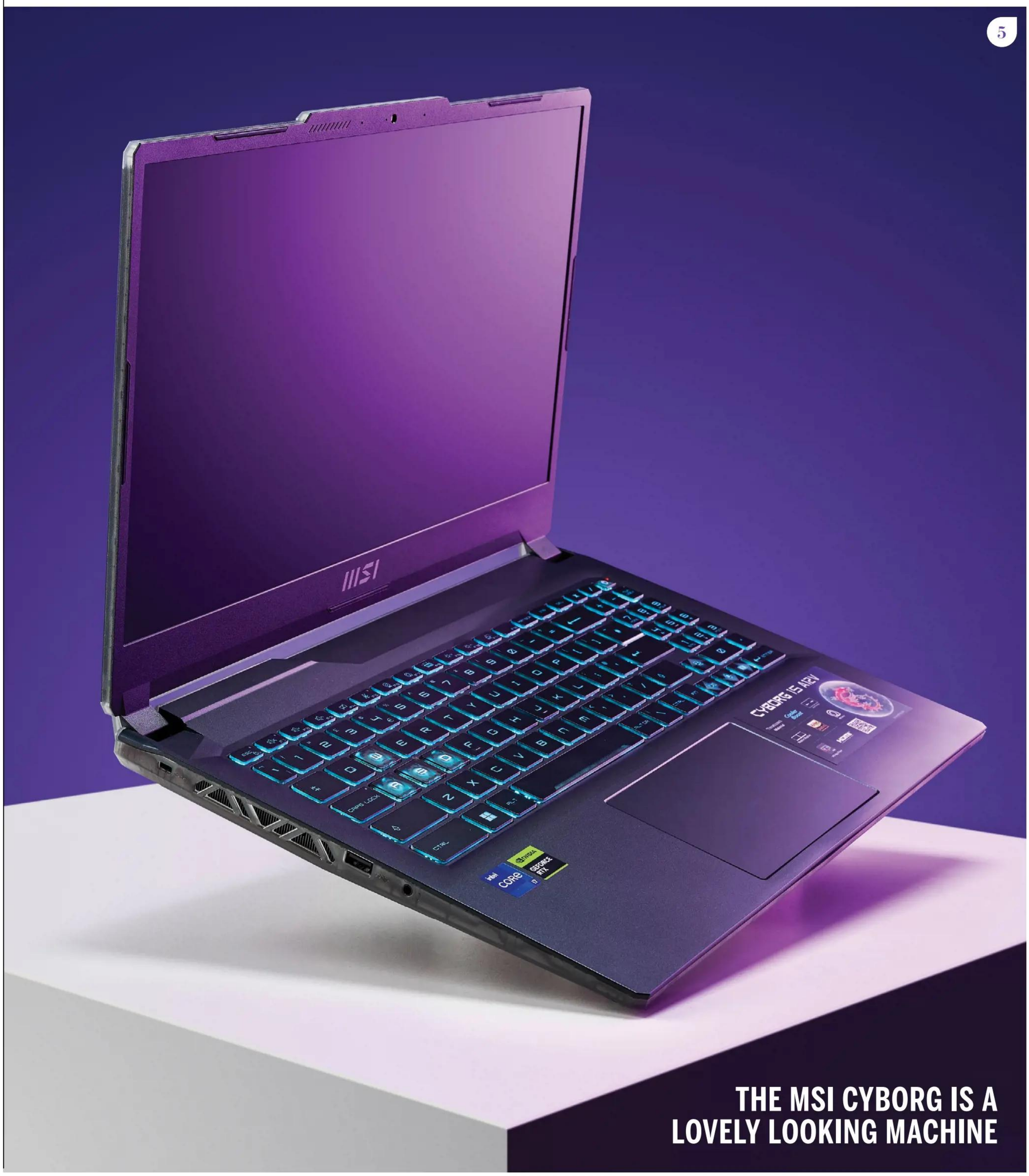
4 If you want the highest framerate out of a gaming laptop, the Titan GT77 will give you that. If you care about literally anything else – be it noise, power, price, or style – the Titan is not the laptop for you. Not even close.

The Titan is a hulking behemoth that can only be described as a desktop replacement. It's portable, but you wouldn't want to carry it around with you day-to-day. But it's sort of to be expected of a laptop that incorporates an RTX 4090 running at 175W alongside a Core i9 13950HX CPU. It comes with 64GB of DDR5 and 4TB of storage space, which conveys the sort of machine the Titan is. It's extreme. And while it's the quickest laptop we've tested, you're paying more than even Razer's RTX 4090-laden Blade 16. Out pricing Razer is quite a feat. Then there's the fact it's absurdly loud. MSI has put all the top parts into the Titan but there's been little more thought paid to the holistic laptop experience. It's just not much fun to use, really.

PC GAMER VERDICT

- Top performance
- Roars under load
- Ludicrous price

SPECS CPU: INTEL CORE I9 13950HX / **GPU:** NVIDIA RTX 4090 (175W) / **RAM:** 64GB DDR5-4000 / **STORAGE:** 4TB NVME SSD / **SCREEN:** 17.3-INCH, 4K, 144HZ

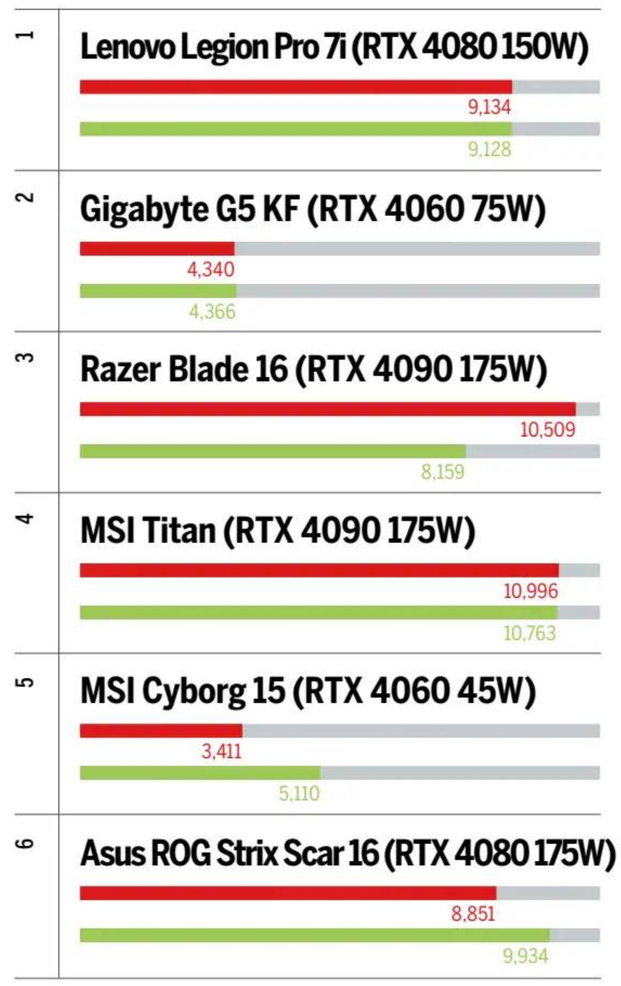


THE MSI CYBORG IS A LOVELY LOOKING MACHINE

BENCHMARKS

3DMark Time Spy Extreme

GPU index
CPU index



Cyborg 15

MSI **£1,099**

Sacrifices too much

5 The MSI Cyborg is a lovely looking machine. When I pulled it out of the box I had hoped its impressive specs list would see it rise to the top of the charts, too. But after some time using the Cyborg it's gone down in my estimations. This laptop does a lot to keep temperatures and noise in check – too much, in fact. The RTX 4060 within the Cyborg 15 runs at 45W, which is 30W lower than the Gigabyte G5's GPU. Because of that, the Cyborg falls majorly behind in terms of overall gaming performance across the board. And that's despite having a better processor at its core in the Core i7-12650H and running in its maximum performance mode.

The one upside of its low power operation is that it runs very quietly under load, but it's not like you can't turn down the G5 if noise matters that much to you. Plus the Cyborg only offers a single M.2 slot, which means upgrading the SSD would require copying the drive already in there somehow and then removing it from the machine entirely.

PC GAMER VERDICT

- → Quiet while gaming
- → Held back while gaming
- → No secondary M.2 slot

SPECS CPU: INTEL CORE I7 12650H / **GPU:** NVIDIA RTX 4060 (45W) / **RAM:** 16GB DDR5-4800 / **STORAGE:** 512GB NVME SSD / **SCREEN:** 15.6-INCH, 1080P, 144HZ

ROG Strix Scar 16

ASUS **£3,300**

No holding back

6 The ROG Strix Scar 16 is a gorgeous machine. The RGB strip across the front and back gradates through the translucent edge plastic giving it an ethereal look in the dark. And it's powerful too.

The numbers that the Intel Core i9-13980HX churns out in rendering benchmarks are tasty, with single-core performance that beats the Lenovo Legion Pro 7i's i9-13900HX by a good hundred points. In gaming, the RTX 4080 doesn't hold back with 175W to throw at today's top games, often hitting frame rates up to more confined RTX 4090-powered laptops.

All that power in a 16-inch laptop comes at a price, though. The CPU and GPU hit 105°C and 83°C respectively under load and there are some concerning noises coming from under the hood when you boot up a game. And while Nvidia's Optimus tech helps with in-game performance, switching between programs isn't as seamless as I'd like. It's been a little unresponsive actually and crashed just from me trying to open PCMark 10.

PC GAMER VERDICT

- → Funky design
- → Great gaming performance
- → Runs kinda hot

SPECS CPU: INTEL CORE I9 13980HX / **GPU:** NVIDIA GEFORCE RTX 4080 / **RAM:** 16GB DDR5-4800 / **STORAGE:** 1TB + 1TB NVME SS / **SCREEN:** 16-INCH, 1600P, 240HZ

BUYER'S GUIDE

Build the best PC for your budget

KEY

Budget build

PC gaming is for everyone. Pick these parts if you want to build a new, well-rounded PC for a good price.

Mid-range build

You want to run every new game at 1080p 60fps. This recommended build will see you through.

Advanced build

You're looking for the best PC on the market and superior components. But you still want to spend smart.

BUDGET BUILD

Enjoy 1080p gaming without breaking the bank

TOTAL £1,015

MOTHERBOARD

B660M Pro RS
ASRock **£112**
This is as cheap as we want to go while still offering room for expansion and upgrades down the line.

PROCESSOR

Core i5 13400F
Intel **£150**
With ten cores, six of them the Performance kind, this Raptor Lake Core i5 is fantastic value and a great all-rounder.

GRAPHICS CARD

Radeon RX 7600
AMD **£250**
AMD delivers what we need for 1080p gaming at a solid price. AMD claims it'll do over 350fps in *Rocket League*, which is a lot.

COOLER

Laminar RM1 (included with CPU)
Intel **Free**
There's room for an upgrade here, but on a budget the included CPU cooler will work just fine.

MEMORY

T-Force Vulkan Z 16GB
Teamgroup **£36**
8 GB of RAM is simply not enough these days, but 16 GB of speedy DDR4 is much more like it.

POWER SUPPLY

RM650 80 Plus
Corsair **£80**
A great power supply is a must, and Corsair builds some reliable workhorses. This one's a good balance of price and power.

SSD

SN770 1 TB
Western Digital **£60**
It's time to ditch SATA and go for an NVMe drive, even for a budget PC. You'll appreciate the extra speed and fast boot times.

CASE

Zauron
Aerocool **£32**
This Aerocool will let your components breathe and has space for further expansion and cooling.

DISPLAY

Mobiuz EX240
BenQ **£150**
This BenQ is proof you can buy a genuinely excellent 24in 1080p gaming monitor for not a huge sum of cash nowadays.

KEYBOARD

KM250 RGB
G.Skill **£55**
It's actually mind blowing what you can pick up for this little cash: a hot-swappable USB mechanical board that looks lovely.

MOUSE

G305 Lightspeed
Logitech **£30**
Even on a budget you can still grab a fantastic, ultra-rapid wireless squeaker like this one here.

HEADSET

HS55 Stereo
Corsair **£50**
Corsair's budget wired cans are comfy and have a surprisingly excellent microphone for the money.

MOUSE PAD

MM100
Corsair **£10**
A simple black rectangle that can make a world of difference over no-name models, and it's almost as cheap, too.

MID-RANGE BUILD

Our recommended build for playing the latest games

TOTAL £1,608

MOTHERBOARD

TUF Gaming B650-E
Asus **£170**
A reliable motherboard with plenty of frills, including Wi-Fi 6E, 2.5Gb Ethernet, PCIe 5.0 for the SSD and USB-C on the back.

PROCESSOR

Ryzen 7 7700X
AMD **£285**
For the longevity offered by the AM5 socket, we're going for AMD's excellent eight-core Ryzen 7.

GRAPHICS CARD

RX 7700 XT
AMD **£400**
If you can spare the extra cash, the RX 7800 XT is a tantalising upgrade. Nevertheless, we'll opt for AMD's cheaper card here.

COOLER

Peerless Assassin 120 SE
Thermaltake **£35**
It's a big beast, but it brings cooling performance to the table that's undeniably impressive.

MEMORY

Viper Venom DDR5-5600 16 GB
Patriot **£59**
It might not have fancy RGB lighting, but this Patriot RAM certainly has the speed you need for less.

POWER SUPPLY

Pure Power 12 M 750W
Be Quiet! **£104**
This larger Be Quiet! PSU offers a stable platform with PCIe 5.0 connectivity. At 750W, there's room for a GPU upgrade too.

SSD

NM790 1TB
Lexar **£70**
The Lexar proves you can, sometimes, have it all: blazing speeds, cool operation and a great price.

CASE

H7
NZXT **£100**
It's very clever of NZXT to design such an easy PC case to build into, and make it look so gorgeous too.

DISPLAY

PXC277 Advanced
Pixio **£210**
The price of this Pixio, considering the 1440p resolution and 165 Hz refresh rate, is quite something.

KEYBOARD

KM250 RGB
GO.Skill **£55**
You could spend more for a full-size gaming keyboard, but this G.Skill will certainly suffice for most gamers.

MOUSE

DeathAdder V2
Razer **£40**
This Razer mouse is a superb companion for competitive gaming without breaking the bank.

HEADSET

Cloud Alpha
HyperX **£60**
We're still not over the awesome audio quality and excellent comfort of the HyperX Cloud Alpha.

MOUSE PAD

G440
Logitech **£20**
This low-friction hard-top mouse pad with minimal branding offers the smoothest of glides for a reasonable price.

ADVANCED BUILD

Go above and beyond with a PC powerful enough to end worlds

TOTAL £6,221

MOTHERBOARD

MEG X670E Ace

MSI **£700**

There are cheaper X670 boards than this, but we're going extreme and this is one of the most fully featured around.

PROCESSOR

Ryzen 7 9800X3D

AMD **£450**

The upcoming Zen 5 top-end X3D models will have more cores, but for gaming this is the bee's knees.

GRAPHICS CARD

GeForce RTX 5090

Nvidia **£2,000**

The RTX 5090 is the new king of GPUs, offering some tasty DLSS 4 extras – if you can find one, that is.

COOLER

Galahad II Trinity 360

Lian Li **£150**

Lian Li's Galahad is all about pure liquid cooling performance and it delivers this flawlessly.

MEMORY

Trident Z5 RGB (2x16GB)

G.Skill **£115**

This is a new memory standard for a new era of memory speed. DDR5 is blisteringly and fantastically quick.

POWER SUPPLY

Prime TX-1000

Seasonic **£340**

An ATX 3.0 PSU would also be good here, but we've tested this Seasonic and know it's worthy of such a build.

BOOT DRIVE

NM790 4 TB

Lexar **£250**

With 4TB of storage, it's going to take one seriously big Steam library to get anywhere close to filling this drive up.

MOUSE PAD

Firefly V2 Pro

Razer **£100**

Do you need an RGB mouse mat? If it makes you feel any better it's excellent for flick shots.

CASE

5000D

Corsair **£139**

We swear this stylish mid-tower is bigger on the inside. It's the PC equivalent of the TARDIS.

DISPLAY

ROG Swift OLED PG32UCDM

Asus **£1,349**

You could be much more sensible on your screen than this. For this build, however, we only want the best.

KEYBOARD

ROG Strix Scope II 96 Wireless

Asus **£190**

We're keyboard snobs, and we can say with confidence that this full-sized Asus board is about as good as it gets.

MOUSE

DeathAdder V3 Pro

Razer **£118**

This is the best gaming mouse in our opinion, made better by an incredibly lightweight frame.

HEADSET

Maxwell

Audeze **£320**

Planar magnetic drivers make this headset pure heaven for audio fans. And everyone else, to be honest.

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Keep your PC safe

Make sure you're protecting your IT equipment in the best way possible with this expert advice

52 *pages* *OF IN-DEPTH REVIEWS FEATURING THE BEST PC KIT*

Group tests

It's head-to-head time in the battle of the builds as we test CPUs, motherboards, graphics cards and more

Buyer's guide

Discover all the hardware you need to supercharge your PC, whatever your budget

Accessories

Screens

CPUs

Power Supplies