CUSTOM PC

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AMD Zen 3

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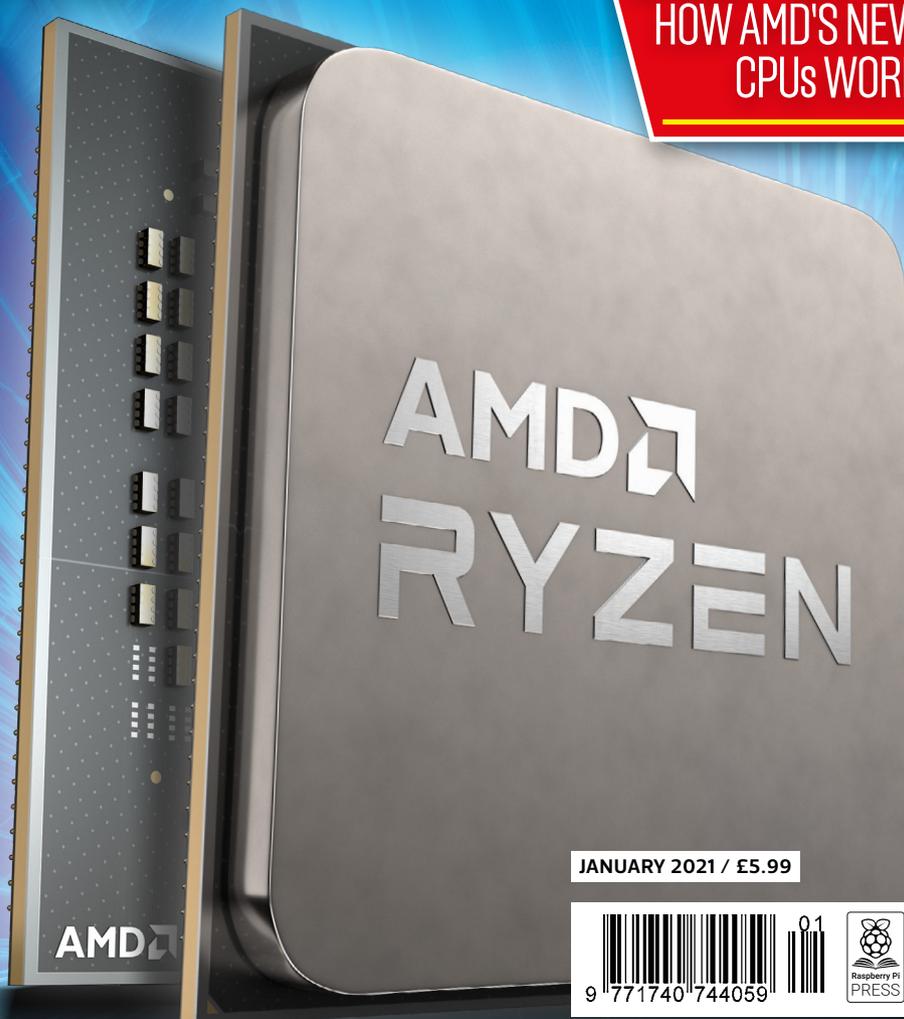
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Welcome

Custom PC Issue 208

/ FROM THE EDITOR

Intel's last stronghold falls

Well that just about wraps it up for Intel, doesn't it? At least when it comes to desktop PCs. With its move beyond 14nm fabrication beset by delay after delay, and following years of churning out the same quad-core LGA115x CPUs with minor tweaks year after year, Intel has been snared in AMD's circular brushstroke of doom, and seemingly can't escape.

Until now, despite its problems, Intel had a final stronghold in its defence against AMD's Ryzen army. Its CPUs' mighty single-threaded performance made them faster in most games than AMD chips, and they were faster in single-threaded desktop tasks such as image editing too. Of course, the CPU makes a miniscule difference to gaming performance compared with the GPU, but if you really wanted the fastest gaming performance possible, you needed to stump up the extra cash for an Intel CPU.

Meanwhile, AMD's Ryzen CPUs offered a better balance of all-round performance, thanks to their higher core counts than Intel's chips. That's all gone now. As you'll see on p16, Intel's final stronghold has fallen, with AMD's latest Zen 3 chips obliterating Intel's single-threaded benchmark scores in image editing and Cinebench.

The big deal for us is gaming though. Our regular game test for CPUs, Far Cry New Dawn, used to show a noticeable performance gap between Intel and AMD CPUs, but that gap no longer exists. AMD hasn't just caught up – it's now overtaken Intel here. If you want your Intel CPU to outperform a Zen 3 chip, you have to overclock it, and even then the performance difference is tiny.

As Richard Swinburne discusses on p8, AMD now knows it's in a strong position, and that it can even comfortably charge more for its CPUs. For the first time since the Athlon 64 vs Pentium 4 days, AMD can no longer be considered the underdog. **CPC**

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ISSUE 208

ISSUE 208 SUBSCRIBERS EDITION

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RICHARD SWINBURNE / VIEW FROM TAIWAN

ZEN PHILOSOPHY

AMD is now in a very strong position against Intel, and Richard Swinburne thinks even more options will turn up next year

In a shift from its usual summer cadence of CPU launches, AMD announced its latest Zen 3 CPUs in October, with in-store availability right now. AMD claimed – and let's not understate this – a massive 19 per cent gain in IPC, and therefore single-core performance leadership. AMD hasn't been able to make this claim since it introduced the Athlon 64 17 years ago. It's a true milestone.

AMD originally piled as many cores as possible into the first Ryzen chips to outmanoeuvre Intel, but we're not getting more cores with Zen 3 – the Ryzen 9 5950X maxes out at the same 16 cores as the 3950X. If you're a long-term CPC reader, back in issue 169, I noted that the trend of pumping up core counts would quickly run out of steam. Three years later, and it looks like this is the case, yet AMD has still managed to keep firing on all cylinders to make even this launch count.

AMD announced Zen 3 as the Ryzen 5000 series. Apart from three non-retail APUs, it skipped the whole 4000-series on desktop. This naming jump provides a clear cut between Zen 2 and Zen 3. Comparatively, the Ryzen 3000-series used Zen 2 on most desktop CPUs, but only Zen 1 on APUs, mobile CPUs or some crossover cases, such as all-in-one PCs.

Intel attempted to usurp the announcement with a pre-announcement of its forthcoming Rocket Lake platform, due in March 2021. Notably, Rocket Lake isn't yet another revision of Intel's Skylake architecture, but is instead based on the more exciting Tiger Lake architecture – already available in laptops – but backported from 10nm SuperFin to 14nm. It should be a considerable upgrade for Intel's desktop CPUs. At

> Make no mistake, AMD is ahead, so it's no longer the 'value' brand you knew beforehand

a minimum, it brings a long overdue architecture upgrade and PCI-E 4 support. A competitive market benefits all of us.

AMD is taking its six-month advantage and running with it. Unlike Zen 2, which launched with six CPUs, Zen 3 currently offers four, with single 6, 8, 12 and 16-core flavours. The equivalents of the Ryzen 5 3600 and Ryzen 7 3700X – popular CPUs from the Zen 2 generation – are notably absent, so the 3000 and 5000-series will likely co-exist in the market for the foreseeable future. The launch prices of the new Ryzen 5 5600X, Ryzen 7 5800X, Ryzen 9 5900X and 5950X are also higher than the equivalent Zen 2 models at launch.

Make no mistake, AMD is ahead, so it's no longer the 'value' brand you knew beforehand. If we simply draw a line between platform equivalents, such as using a Core i7-10700K with Z490 vs a Ryzen 7 5800X with B550, the Intel option is now cheaper. However, since the 3600 and 3700X Ryzen options remain available, AMD still has an equally affordable and popular option to offer; it's just not Zen 3. AMD has also committed to ensuring that current B550, A520, X570 motherboards, and even some X470 and B450 motherboards, will support Zen 3, so even if you buy a cheaper Zen 2 option now, you still get that upgrade option later. Intel doesn't have that track record with backwards compatibility.

It's my expectation that in March, AMD will retire its Zen 2 CPUs, and introduce the missing 5600 and 5700X options, and possibly cut prices slightly. Also, due to the improved design of Zen 3, there's even a chance we'll see a new 10-core CPU (maybe called the 5850X?) option as well. CPC

Richard has worked in tech for over a decade, as a UK journalist, on Asus' ROG team and now as an industry analyst based in Taiwan 🔵 @ricswi

TRACY KING / SCEPTICAL ANALYSIS

NOT ACTUAL GAME FOOTAGE

As the ASA clamps down on misleading casual game adverts,
Tracy King analyses the implications for the wider game industry

A t last, some action about a subject that's simultaneously trivial and also very important. The Advertising Standards Authority has banned a series of misleading adverts for the games Homescapes and Gardenscapes. These ads first came to my attention when they started featuring bizarre gruesome artwork and comedic horror gameplay footage, in which you had to stop a dismemberment or other impending terrible death of a cute sheep, sometimes via 'pull the pin' gameplay.

The ads were attention-grabbing, and they worked. Lots of people downloaded the games, and lots of people got rightly annoyed when they turned out to be bog-standard 'match three' games, not comedy horror pin-pulling puzzle games.

It seems trivial, because these are free, casual games, but the case raises an essential issue for all gamers – consumer rights. We have them, but when we try to use them, we're often not taken seriously because 'it's just games'. However, we're entitled to get what was advertised.

Gamers have had to put up with marketing shenanigans since the 1980s, when box art promised incredible or even sexy adventures that the 8-bit graphics couldn't possibly represent. To be fair, there were usually a few screenshots on the back of the box or cassette inlay card (yes, I'm that old) and we didn't have many other game options, so we gave it a free pass, even while crying disappointed tears into our Commodores.

But once gaming became seriously profitable, big marketing campaigns appeared, and pushed hard at the boundaries of acceptability. One of the most famous examples is 2001's Metal Gear Solid 2. The trailers and demo featured Snake, one of the gaming world's most beloved characters, and set expectations accordingly. Cue disappointment and outrage when the main character in the game turned out not to be Snake, but Raiden. Which would be fine if Konami hadn't strongly indicated otherwise.

The difficulty is that it sounds a bit whiny to complain that the game you bought doesn't star your problematic fave. However, it's a serious principle, even if that particular example isn't as egregious as No Man's Sky, which overpromised in its marketing material to a degree that broke the Internet.

Of course, gameplay is complex and fun is subjective. I'm not necessarily entitled to a refund if I simply didn't enjoy a game, and I'm definitely not entitled to complain that the game's advert looked more fun than the actual game, as long as the advert is representative of what the ASA calls 'core gameplay' (minigames, side quests and FMV don't count, so developers can't use them as the main thrust of a game advert). However, I'm entitled not to be misled.

In 2013 the Advertising Standards Authority 'informally resolved' a complaint about Aliens: Colonial Marines, in which SEGA agreed that the final game was different enough to the trailers to require a disclaimer on any future advertising, setting a precedent.

The Homescapes ads did indeed (briefly) show a disclaimer, 'not all images represent actual gameplay', but that wasn't enough and I'm glad to see the ASA take stronger action. As a former marketing professional, I know too well that as long as there's profit, many companies will attempt to get away with as manipulative a tactic as possible. When the ASA goes as far as banning an advert, it's also effectively banning the tactic. So yes, Homescapes is a trivial, free mobile game, but its players have done us all a massive service. **CPC**

> No Man's Sky overpromised in its marketing to a degree that broke the Internet

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Gamer and science enthusiast Tracy King dissects the evidence and statistics behind popular media stories surrounding tech and gaming @tkingdot

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Incoming

INTEL LAUNCHES 10-CORE CPU FOR £440

In a bid to nab some of AMD's limelight with the Zen 3 launch, Intel has released a new 10-core LGA1200 CPU at a cheaper price than the Core i9-10900K. The new Core i7-10850K offers ten Hyper-Threaded cores, and has a turbo boost frequency of up to 5.2GHz, with Turbo Max 3 peaking at 5.1GHz and a base clock of 3.6GHz.

In terms of specs, that means the base clock and turbo clock sit only 100MHz below that of the flagship Core i9-10900K, with a 200MHz on the Turbo Max 3 frequency, which currently costs £550 inc VAT from **scan.co.uk**, but the new Core i9-10850K only costs £440 inc VAT from the same retailer. As its 'K' suffix suggests, the new CPU also has an unlocked multiplier for overclocking.

As with the Core i9-10900K, though, the new CPU is still manufactured on Intel's aging 14nm process, and there's no PCI-E 4 support either. We've taken our first look at the Core i9-10850K in the CyberPower Infinity 910 RTX on p42.
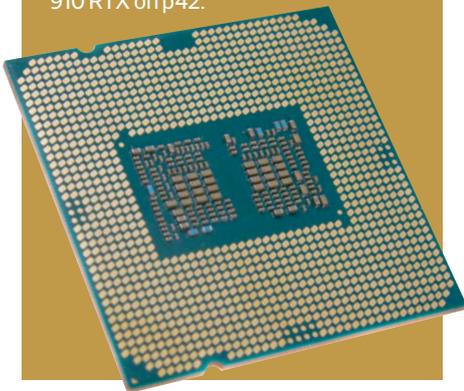
AMD ANNOUNCES RADEON RX 6000 GPUs

By the time you read this, AMD will have lifted the lid on some of the details of its new GPUs, which the company has started calling 'Big Navi'. Irritatingly, the big reveal was just after our print deadline for this issue, with no pre-briefing information available, so we don't know any of the finer details yet.

However, we do know that the new line-up will be called the Radeon RX 6000 series, and AMD showed off a demo of one of the new GPUs running Borderlands 3 smoothly at 4K after the initial Zen 3 reveal. AMD claims its new top-end GPU is capable of playing Borderlands 3 with Badass Quality at 61fps, Gears of War with Ultra Quality at 73fps and Call of Duty: Modern Warfare with Ultra Quality at 88fps (all at 4K).

We also know that the reference models will have new cooler designs, rather than the noisy blower coolers we saw on the first Navi GPUs last year. We're hoping to get our hands on some of the new GPUs in our next issue and see if they can compete with Nvidia's latest Ampere chips. Who knows, maybe there will actually be some stock of them too!

ARCTIC LAUNCHES RGB AIR COOLER

Cooling specialist ARCTIC has launched a hefty new air cooler for Intel and AMD CPUs, and it's equipped with A-RGB lighting. The new Freezer 50 has six large direct-contact heatpipes, which run through 104 aluminium heatsink fins. The whole setup is cooled by a pair of fans in a push-pull configuration, one of which is a 120mm model, while the other one is a 140mm spinner.

ARCTIC claims that this setup produces 'strong airflow without compromising on volume – even at maximum speed the Freezer 50 only reaches 0.4 Sone'. Meanwhile, the A-RGB lighting illuminates the ARCTIC logo and two strips on the top of the cooler, and hooks up to a 3-pin digital RGB connector. An optional A-RGB controller unit, complete with a remote control, is also available for users who don't have an RGB-equipped motherboard.

The ARCTIC Freezer 50 supports Intel's LGA2011, LGA2066, LGA1200 and LGA115x sockets, as well as AMD's Socket AM4, and there's also a separate Threadripper edition, denoted with a 'TR' suffix on the product name. The standard ARCTIC Freezer 50 is available to buy now from **scan.co.uk** for £60 inc VAT, or for £70 inc VAT with the optional lighting controller.

CORSAIR RELEASES CHERRY VIOLA KEYBOARD

Corsair has released a new mechanical gaming keyboard based on Cherry's Viola switches. According to Corsair, the new keyswitches have a 'self-cleaning V-Shape contact system and a two-stage, CrossLinear activation'. The result, says the company, 'is a smooth linear keypress and a satisfying fast reset ready to take on whatever your fingers can throw at it'.

The new keyswitches will be mounted in Corsair's K60 RGB Pro, which uses the firm's distinctive aluminium frame, an attractive brushed aluminium top and offers per-key RGB backlighting. Unlike the K70, however, the media controls are secondary functions of the F keys, and there's no volume roller wheel.

Corsair is also launching a non-RGB version with a single-colour LED backlight, but still uses the Viola switches. A Low Profile version, based on Cherry's MX Low Profile RGB Speed keyswitches, will be available too, as well as an SE version of the RGB Pro with double-shot keycaps and a magnetic detachable palm rest.

PHANTEKS UNVEILS £64 ECLIPSE P360A

Phanteks has released a new high-airflow E-ATX case, with a tempered glass side panel and RGB fans, which costs just £63 inc VAT. The new Eclipse P360A features a front panel made from fine mesh, with a pair of 120mm RGB fans behind it. You get two fans with the case out of the box, with mounts for a further three inside the chassis.

The P360A also caters for water cooling, with room for a 240/280mm radiator in the front, and another 240mm radiator in the roof. Meanwhile, CPU cooler clearance stands at up to 160mm, and there's room for a 400m graphics card, which can be vertically mounted with a separate bracket. The case is made from steel and has a tempered glass side panel. The Phanteks Eclipse P360A is available now from **overclockers.co.uk** in black and white versions.

Rumour control

WE PRESENT SOME OF THE LATEST UNCONFIRMED TECH GOSSIP. TAKE THESE STORIES WITH THE APPROPRIATE PINCH OF SALT

NVIDIA CANS 20GB RTX 3080 AND 16GB RTX 3070

While Nvidia's GeForce RTX 3080 currently comes with 10GB of memory, the tech rumour mill has been buzzing with rumours about a 20GB version that was planned to counteract AMD's forthcoming Big Navi GPUs at the end of the year, as well as a 16GB version of the RTX 3070 (which has 8GB as standard).

However, tech site **videocardz.com** claims to have spoken to two independent sources, who say these plans have been cancelled. The site also says a planned card called the GeForce RTX 3070 Ti, which upped the number of CUDA cores in the RTX 3070 from 5,888 to 6,144, has also been cancelled. According to one of the site's sources, a reason for the 20GB RTX 3080's cancellation could be yield issues with GDDR6X memory, although this doesn't explain the other cards being allegedly cancelled.

Letters

Please send us your feedback and correspondence to
letters@custompcmag.org.uk

Is my GPU obsolete?

Following on from a recent letter you published, asking about the best time to buy PC parts, I thought I'd ask a question that's been troubling me – what makes a PC part obsolete? This week I had a motherboard capacitor blow on a very serviceable rig with a Core i7-2600K and DDR3 RAM. As I can no longer easily buy an LGA1155 or DDR3 motherboard, I have some parts that are now obsolete. This is acceptable, as they've served me well for years.

A more concerning obsolescence comes from a graphics card I bought brand new, having done a fair amount of research, just under a year ago. When the GeForce RTX 2060 Super was released, many of the reviews said it was now pointless buying an RTX 2070, due to the 2060 Super very nearly matching the 2070 in all tests.

I managed to pick up a new GeForce RTX 2070 at this time for £50 *less* than the cheapest 2060 Super and thought I'd done well. The problem is that the 2070 never now gets compared with anything

The GeForce RTX 2070 is still a decent GPU, as long as you're not expecting to run ray tracing at high resolutions

When's the next issue out?

CUSTOMPC
Issue 209
On sale on Thursday, 3 December
DEC **03**

in graphics card reviews. The tables show the Super versions of all cards, but never the original Founders Edition RTX cards.

Have driver updates meant the Super versions are now much better than they were, and have they overtaken the original versions of the cards above them? No one uses the original wave of RTX cards in reviews anymore. The Google dictionary definition of obsolescence is 'the process of becoming obsolete or outdated and no longer used' – is the graphics card I bought a year ago now obsolete?

Other than the lack of original RTX cards featured in upcoming reviews of new GPUs, congratulations on keeping the magazine brilliant during the difficult months this year has brought, and I'd like to give a special shout-out to Tracy for her scientific, non-prejudiced articles that challenge the common beliefs of the media and tech world. Recent Covid-related conspiracy theories mean we all need more Tracys in our world.
CHRIS HOLLOWAY

Ben: I'm glad you're enjoying our magazine, Chris, and I agree that Tracy's column is a valuable asset in these times. Regarding non-Super cards not being featured in review graphs, this is down to the general

shortage of RTX review samples we've retained, rather than any statement on obsolescence.

Basically, we don't have a standard GeForce RTX 2070 in the Labs, and it's now difficult to get one for future tests, from either Nvidia or board partners, as this GPU isn't widely marketed any more. As you say, the RTX 2070 was (and still is) slightly quicker than the RTX 2060 Super, and you got a good deal on the price. We still recommend the RTX 2060 Super on our Elite list for an affordable RTX PC, and your RTX 2070 will be even better. As long as you're not running ray tracing at high resolutions, your card is definitely not obsolete yet.

Practical yokes

I feel like you could have done more with the flight controller Labs test in Issue 207. You could have included more niche products, such as the lovely VKB-Sim Gladiator and other flight controls.

A lot of people would be much happier with a Honeycomb yoke and throttle quadrant than a HOTAS Warthog, but that's my opinion.
CIAN ORMOND

Ed: We strive to cover a wide a range of products but, as you point out, niche products can be missed. We decided to stick to flight sticks rather than broader flight control interfaces for this test, as they have wider appeal for more than just terrestrial flight sims, such as Star Wars: Squadrons. The VKB–Sim Gladiator admittedly slipped under our radar, though, so we'd be keen to follow up with a review of that at a later date, and we may look at yokes separately too.

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Reviews

AMD RYZEN 7
5800X / **£410** inc VAT

SUPPLIER scan.co.uk

While Intel has offered better 8-core options for gaming than AMD over the past couple of years, the Ryzen 7 5800X is now looking to massively boost performance over its predecessors, especially when it comes to games.

With the Ryzen 7 5800X, we could be looking at a CPU that not only makes Intel's 8-core CPUs look redundant, but its 10-core Core i9-10900K as well.

Unlike most previous 8-core CPUs, the Ryzen 7 5800X doesn't come with a cooler in the box. In fact, most Ryzen 5000-series CPUs don't include a cooler, but if you're spending £400 on a CPU, we think it's fair to say you'll want a third-party cooler anyway.

Under the hood, there are still eight cores and 16 threads, and the core CPU dies are built on a 7nm manufacturing process. The memory controller and I/O die is the same as the one used in Zen 3 CPU too, but the Ryzen 7 5800X has a very different internal chiplet arrangement to the Ryzen 7 3800X.

The latter had two separate core complexes, with four cores apiece, and a split L3 cache. With the new chip, the CCX has a single 8-core unified design with its own 32MB L3 cache that's shared with all cores, reducing latency and improving inter-core communications. There's still 512KB of L2 cache per core, which is the reason why there's just 4MB here and 6MB with the 12-core Ryzen 9 5900X.

The thermal design power (TDP) still stands at the same 105W as the 5900X, though, and that might seem strange considering it only has eight cores. The reason is that those eight cores can ramp up to a much higher frequency. With the Ryzen 7 5800X, all cores together could top out at 4.5GHz with our launch BIOS, which goes to show that you can't tell a lot from the base frequency rating. However, all the Ryzen 9 5900X's cores could only hit 4.1GHz together. This is a huge all-core boost frequency, especially given that we only managed to manually overclock the Ryzen 9 5900X 100MHz higher than this frequency.

This extra clock speed headroom may mean that, in some moderately threaded tasks, the 8-core CPU is just as fast or faster than the 5900X, in spite of its 4-core, 8-thread deficit, or the fact that its peak single-core boost frequency is also 100MHz lower.

We don't have concrete UK pricing on Zen 3 CPUs at the time of going to press, but the 5800X is slated to set you back around £400 inc VAT, which is a little more than the price of the Core i7-10700K and around £100 more than the current Ryzen 7 3800X. This means it needs to deliver in terms of both gaming and content creation performance in order to justify its price, especially when Intel's Core i5-10600K costs a heck of a lot less money.

SPEC

Base frequency
3.8GHz

Max boost frequency
4.7GHz

Core
Zen 3

Manufacturing process
7nm

Number of cores
8 x physical (16 threads)

IGP
None

Simultaneous Multithreading
Yes

Cache
32MB L3, 4MB L2

Memory controller
Dual-channel DDR4, up to 3200MHz

Packaging
AMD Socket AM4

Thermal design power (TDP)
105W

Features
Precision Boost 2, Precision Boost Overdrive, FMA3, F16C, SHA, BMI / BMI1 + BMI2, AVX2, AVX, AES, SSE4a, SSE4, SSSE3, SSE3, SSE2, SSE
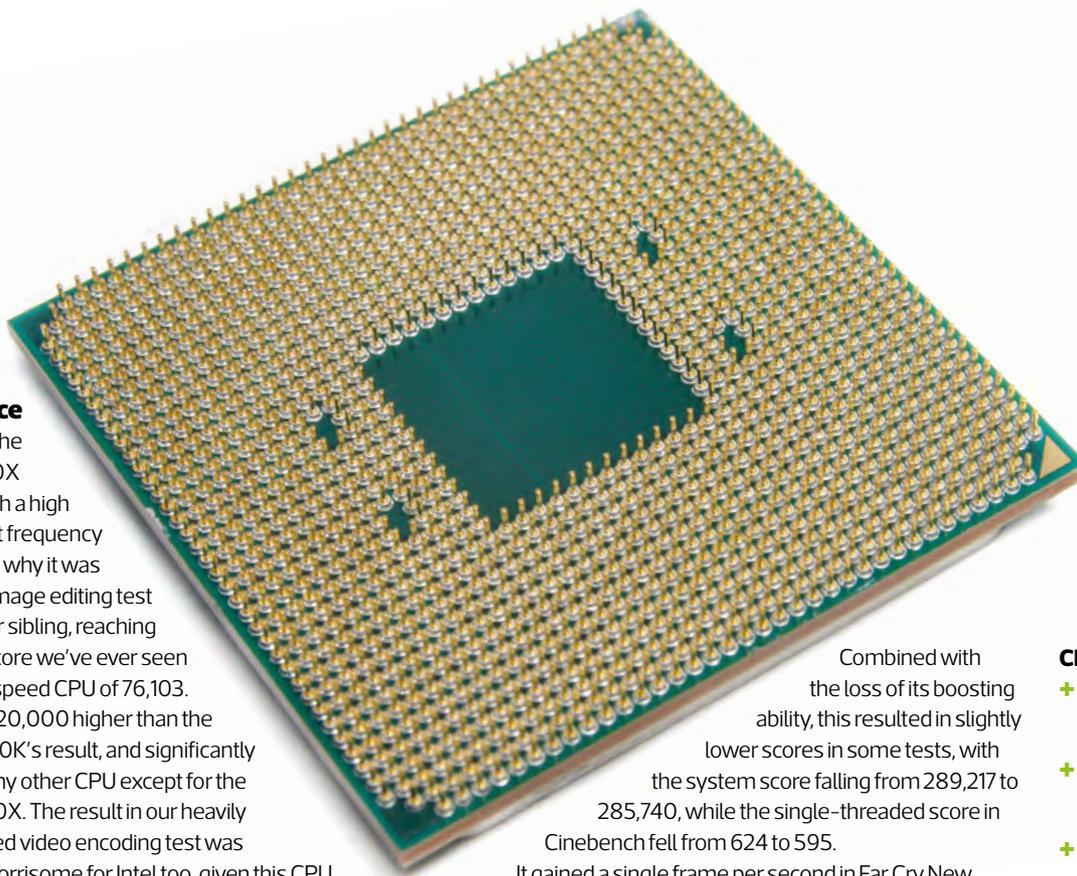
Performance

The fact that the Ryzen 7 5800X can reach such a high all-core boost frequency might explain why it was faster in our image editing test than its bigger sibling, reaching the highest score we've ever seen from a stock speed CPU of 76,103. That's nearly 20,000 higher than the Core i5-10600K's result, and significantly higher than any other CPU except for the Ryzen 9 5900X. The result in our heavily multi-threaded video encoding test was particularly worrisome for Intel too, given this CPU essentially matched the Core i9-10900K.

Incredibly. The 5800X came within reach of the Ryzen 9 3900X too, which has four more cores and eight more threads and is only one generation older. Only the Ryzen 9 5900X managed to beat it in our heavy multi-tasking test and again, the Ryzen 9 3900X was closest, but still 30,000 points short. Overall, in our RealBench tests, the Ryzen 7 5800X proved to be a match for Intel's Core i9-10900K, faster than the Ryzen 9 3900X in many tests and much faster than its predecessors too.

In Cinebench, the single-threaded score sat at 624, which was a little down on the Ryzen 9 5900X, but still over 90 points higher than the Core i9-10900K and miles faster than any older AMD CPUs. The multi-threaded score of 5,989 wasn't quite enough to see off the Core i9-10900K or Ryzen 9 3900X, but it was only 300 points away from the former and nearly 1,000 points higher than the Ryzen 7 3800X, which is a huge improvement.

And in that all-important gaming performance, the 5800X matched the Ryzen 9 5900X in Far Cry New Dawn, with a minimum 99th percentile of 104fps, which was faster than the Core i9-10900K and a massive 21fps higher than the Ryzen 7 3800X at 1080p. Metro Exodus saw it offer a slight advantage over its 12-core sibling, where it was just a hair's breadth behind the Core i9-10900K too.

We managed to achieve the same 4.6GHz all-core overclock on the Ryzen 7 5800X as we did with the Ryzen 9 5900X, but while the latter benefited massively from the extra multi-threaded grunt, the Ryzen 7 5800X could already reach 4.5GHz across all cores at stock speed.

Combined with the loss of its boosting ability, this resulted in slightly lower scores in some tests, with the system score falling from 289,217 to 285,740, while the single-threaded score in Cinebench fell from 624 to 595.

It gained a single frame per second in Far Cry New Dawn and Metro Exodus, but did see the Cinebench multi-threaded score rise from 5,989 to 6,125. Power consumption remained fairly static, though, with the load draw sitting at 268W at stock speed and 262W when overclocked – this is likely due to the fact that the stock speed voltages were higher, if only temporarily.

Conclusion

While overclocking proved slightly pointless, that's only because the Ryzen 7 5800X is able to achieve huge frequencies for a Ryzen CPU at stock speed. Its stock all-core boosting ability meant its multi-threaded performance came close to matching 10-core CPUs such as the Core i9-10900K and Ryzen 9 3900X in some tests. Meanwhile, its lightly threaded performance is exceptional, posting some of the highest stock speed results we've seen in a number of tests and outstripping Intel in Far Cry New Dawn.

The only real threat is likely to come from AMD's Ryzen 5 5600X, which could offer similar gaming performance and enough multi-threaded grunt to keep most people happy. However, as a happy medium between the latter and the Ryzen 9 5900X, the Ryzen 7 5800X is a fantastic CPU that's more than a match for any CPU Intel offers in the same price league.

ANTONY LEATHER

CHIPS

+ Nearly as fast as 10-core CPUs in content creation
+ Excellent all-round performance
+ Faster than Intel in Far Cry New Dawn

FRIES

− Intel faster in some games once overclocked
− Ryzen 5 5600X may offer better value
− Ryzen 9 5900X only costs £100 more

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VALUE
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AMD RYZEN 9 5900X / **£500** inc VAT

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SPEC

Base frequency
3.7GHz

Max boost frequency
4.8GHz

Core
Zen 3

Manufacturing process
7nm

Number of cores
12 x physical (24 threads)

IGP
None

Simultaneous Multithreading
Yes

Cache
64MB L3 cache, 6MB L2 cache

Memory controller
Dual-channel DDR4, up to 3200MHz

Packaging
AMD Socket AM4

Thermal design power (TDP)
105W

Features
Precision Boost 2, Precision Boost Overdrive, FMA3, F16C, SHA, BMI / BMI1 + BMI2, AVX2, AVX, AES, SSE4a, SSE4, SSSE3, SSE3, SSE2, SSE

In the early 2000s, we were revelling in the competition between Intel's Pentium 4 and AMD Athlon 64, which saw great leaps in performance and CPUs from the underdog that genuinely outperformed Intel's equivalents at nearly every turn. So far, Ryzen hasn't quite lived up to the same prowess. Gaming performance has been lacking in many titles that showed hints of being CPU-bound, making Intel CPUs better choices for pure gaming systems. Today, though, the Zen 3 architecture sees AMD catching up with Intel in most games, and the Ryzen 9 5900X is an absolute monster in content creation too.

Before we get to the numbers, though, let's talk about specifications. At first glance, not much appears to have changed with AMD's new 12-core, 24-thread CPU compared with the Ryzen 9 3900X, and the more recent Ryzen 9 3900XT. The peak boost frequency has risen from the latter's 4.7GHz to 4.8GHz, the L2 cache still stands at 6MB and the total L3 cache remains at 64MB. The CPU's chiplets are still made using a 7nm manufacturing process too.

However, that's not to say that there haven't been significant changes under the hood. AMD has introduced a unified core complex (CCX), where a single 32MB pool of L3 cache is shared between eight cores. This differs from Zen 2, where each CCX was split into two pieces, each with four cores, and with direct access to only half the L3 cache.

There have also been significant pipeline optimisations, which boost the number of instructions that can be processed per clock (IPC) compared with Zen 2, and latencies should be much lower, thanks to far less arduous core-to-core communications. You can read our full deep dive into Zen 3 on p78, but in short, the areas where previous Zen iterations were weakest are now a whole lot stronger and more efficient. Meanwhile, areas where Ryzen was already strong are faster still.

The 7nm manufacturing process has also been refined, enabling AMD to increase clock speeds, but with no additional power consumption. We saw the beginnings of this with the XT CPUs a few months ago, where the Ryzen 5 3600XT proved to be a great overclocker for a Ryzen chip.

The 105W TDP remains the same as its predecessor for this 12-core part, so there's no reason why any motherboard that could handle a Ryzen 9 3900X couldn't also handle the Ryzen 9 5900X. That's good news, because if you have a decent X470 motherboard, apart from lacking PCI-E 4 support, you'll see little benefit from opting for a newer motherboard, at least in performance terms. The downside is that you may have to wait until 2021 for a compatible BIOS.

At the time of going to press, there was no official UK pricing available for Ryzen 5000-series CPUs, but the Ryzen 9 5900X should retail for around £500, or a touch more. The Ryzen 5 5600X and Ryzen 9 5950X will land next month too, so we keenly await their arrival for review in our next issue. Anyway, while Zen 3 CPUs are pricier than their Zen 2

equivalents, the Ryzen 9 5900X is still likely to be cheaper than the Core i9-10900K. However, Intel has sneakily returned fire with the Core i9-10850K, which is essentially a cut-price version of its 10-core flagship for just £440 (featured in the CyberPower Infinity 910 RTX on p42).

Performance

Using our early BIOS, the Ryzen 9 5900X hit a peak boost frequency of 4.8GHz on a single core, and regularly topped out at 4.1GHz on all cores in multi-threaded tasks at stock speed. Overclocking proved fruitful too, with a vcore of 1.25V seeing us reach an all-core overclock of 4.6GHz.

That's far higher than you'll expect to see with Precision Boost Overdrive, and many lightly threaded tests may benefit here too. However, some lightly threaded tasks could drop in performance after overclocking, thanks to the stock speed boost being able to stretch to another 200MHz.

In our RealBench image editing test, which stresses single-threaded performance, the Ryzen 9 5900X added over 11,000 points to the result of the Ryzen 9 3900XT, and also beat the Core i9-10900K. It's not as quick as the Ryzen 7 5800X here, but it's still way ahead of any other CPU.

Those extra cores made it a monster in our heavily multithreaded video encoding test too, adding over 100,000

points to the score of the Ryzen 9 3900XT and nearly 200,000 points to the Core i9-10900K's performance, with similar gains once overclocked. Multi-tasking was a similarly easy win with a massive leap over both its predecessor and Intel's mainstream desktop flagship, with the new AMD CPU sitting at the top of the chart in the system score too.

By far the most impressive result, though, was the single-threaded test in Cinebench. A score of 631 here is huge and nearly 100 points higher than that of the Ryzen 9 3900XT and Core i9-10900K. The multi-threaded test wasn't bad either at 8,316, rising to just under 9,000 points once overclocked. These results were both over 1,000 points ahead of the Ryzen 9 3900XT and miles faster than the Core i9-10900K.

Far Cry New Dawn once again saw significant improvements over previous Ryzen CPUs, with the 5900X's 99th percentile frame rate of 103fps bettering every other CPU, as did the average frame rate of 136fps. The Core i9-10900K only gets the better of it when it's overclocked, but even then the overclocked AMD CPU is just a few frames per second behind. Metro Exodus saw the Intel CPU edge slightly ahead, with a 99th percentile of 43fps for the Core i9-10900K and 41fps for the Ryzen 9 5900X. These figures rose to 47fps and 43fps respectively after overclocking, with only small gains over AMD's Zen 2 CPUs in this game.

Conclusion

It's clear that AMD has some serious silicon engineering on its hands with Zen 3, and the fact that these significant gains can be seen in games as well as content creation mean that we simply can't recommend Intel CPUs at this price any longer. Even with our comparatively modest GeForce RTX 2070 Super test card, there were huge gains in Far Cry New Dawn at 1080p when moving from Zen 2 to Zen 3, which were enough to leapfrog the Core i9-10900K, and it will be the same in other games where Intel was once so dominant.

Content creation is now completely AMD's area too, with any heavily multi-threaded software seeing Intel run with its tail between its legs. Overclocking yields decent gains too, but whether you're up for some BIOS tinkering or not, the Ryzen 9 5900X is an absolute beast and the ideal £500 CPU for people who take gaming seriously, and also spend a lot of time dabbling in content creation. If you do less of the latter then the Ryzen 7 5800X is a better buy.

TWELVE

+ Superb multi-threaded performance

+ Mind-boggling single-threaded performance

+ Excellent frame rates

TWELVETY

– No cooler in the box

– Not compatible with 400-series motherboards until next year

– Ryzen 7 5800X offers better value

VERDICT

A devastatingly fast CPU in every respect – there's simply no point in buying an Intel Core i9-10900K now.

PERFORMANCE
49/50

FEATURES
13/15

VALUE
32/35

OVERALL SCORE
94%

AMD RYZEN 5000-SERIES BENCHMARK RESULTS

GIMP IMAGE EDITING

	Stock speed	Overclocked
AMD Ryzen 9 5900X	71,875	71,216
AMD Ryzen 7 5800X	76,103	74,486
AMD Ryzen 9 3900XT	60,254	60,316
AMD Ryzen 9 3900X	59,863	59,307
AMD Ryzen 7 3800XT	62,966	62,408
AMD Ryzen 7 3800X	63,850	60,339
Intel Core i9-10900K	62,790	67,907
Intel Core i5-10600K	58,088	64,387

HANDBRAKE H.264 VIDEO ENCODING

	Stock speed	Overclocked
AMD Ryzen 9 5900X	959,116	959,423
AMD Ryzen 7 5800X	726,017	719,524
AMD Ryzen 9 3900XT	803,216	848,828
AMD Ryzen 9 3900X	781,028	823,521
AMD Ryzen 7 3800XT	617,079	637,569
AMD Ryzen 7 3800X	614,233	612,914
Intel Core i9-10900K	730,663	755,102
Intel Core i5-10600K	448,350	492,725

HEAVY MULTI-TASKING

	Stock speed	Overclocked
AMD Ryzen 9 5900X	357,064	367,627
AMD Ryzen 7 5800X	330,807	324,507
AMD Ryzen 9 3900XT	303,849	302,927
AMD Ryzen 9 3900X	290,785	291,201
AMD Ryzen 7 3800XT	272,590	268,430
AMD Ryzen 7 3800X	259,899	260,800
Intel Core i9-10900K	295,870	311,048
Intel Core i5-10600K	216,577	231,885

SYSTEM SCORE

	Stock speed	Overclocked
AMD Ryzen 9 5900X	352,999	355,552
AMD Ryzen 7 5800X	289,217	285,740
AMD Ryzen 9 3900XT	339,812	351,000
AMD Ryzen 9 3900X	331,393	341,818
AMD Ryzen 7 3800XT	286,141	290,271
AMD Ryzen 7 3800X	282,970	281,988
Intel Core i9-10900K	319,985	331,496
Intel Core i5-10600K	228,408	245,067

Stock speed / Overclocked

CINEBENCH R20 MULTI-THREADED

	Stock speed	Overclocked
AMD Ryzen 9 5900X	8,316	8,994
AMD Ryzen 7 5800X	5,989	6,125
AMD Ryzen 9 3900XT	7,266	7,704
AMD Ryzen 9 3900X	7,100	7,586
AMD Ryzen 7 3800XT	5,109	5,313
AMD Ryzen 7 3800X	5,013	5,187
Intel Core i9-10900K	6,325	6,451
Intel Core i5-10600K	3,514	3,859

CINEBENCH R20 SINGLE-THREADED

	Stock speed	Overclocked
AMD Ryzen 9 5900X	631	593
AMD Ryzen 7 5800X	624	595
AMD Ryzen 9 3900X	516	497
AMD Ryzen 7 3800XT	537	511
AMD Ryzen 7 3800X	513	508
Intel Core i9-10900K	532	523
Intel Core i5-10600K	489	516

Stock speed / Overclocked

FAR CRY NEW DAWN
1,920 x 1,080, Ultra settings

	Stock speed 99th percentile	Stock speed avg	Overclocked 99th percentile	Overclocked avg
AMD Ryzen 9 5900X	103fps	136fps	105fps	138fps
AMD Ryzen 7 5800X	104fps	135fps	105fps	135fps
AMD Ryzen 9 3900XT	89fps	124fps	90fps	123fps
AMD Ryzen 9 3900X	85fps	122fps	89fps	122fps
AMD Ryzen 7 3800XT	88fps	123fps	89fps	123fps
AMD Ryzen 7 3800X	83fps	121fps	88fps	122fps
Intel Core i9-10900K	98fps	135fps	111fps	140fps
Intel Core i5-10600K	90fps	129fps	96fps	126fps

METRO EXODUS
1,920 x 1,080, Ultra settings, HairWorks off

	Stock speed 99th percentile	Stock speed avg	Overclocked 99th percentile	Overclocked avg
AMD Ryzen 9 5900X	41fps	77fps	43fps	78fps
AMD Ryzen 7 5800X	42fps	78fps	42fps	79fps
AMD Ryzen 9 3900XT	41fps	77fps	42fps	77fps
AMD Ryzen 9 3900X	41fps	77fps	40fps	78fps
AMD Ryzen 7 3800XT	40fps	78fps	40fps	77fps
AMD Ryzen 7 3800X	40fps	78fps	40fps	78fps
Intel Core i9-10900K	43fps	82fps	47fps	82fps
Intel Core i5-10600K	42fps	82fps	43fps	83fps

Stock speed 99th per centile / Stock speed avg
Overclocked 99th percentile / Overclocked avg

TOTAL SYSTEM POWER CONSUMPTION
Idle

	Stock speed	Overclocked
AMD Ryzen 9 5900X	102W	109W
AMD Ryzen 7 5800X	102W	104W
AMD Ryzen 9 3900XT	104W	113W
AMD Ryzen 9 3900X	99W	100W
AMD Ryzen 7 3800XT	118W	111W
AMD Ryzen 7 3800X	118W	120W
Intel Core i9-10900K	67W	99W
Intel Core i5-10600K	56W	88W

Lower is better

Load

	Stock speed	Overclocked
AMD Ryzen 9 5900X	269W	284W
AMD Ryzen 7 5800X	268W	262W
AMD Ryzen 9 3900XT	261W	272W
AMD Ryzen 9 3900X	241W	276W
AMD Ryzen 7 3800XT	237W	233W
AMD Ryzen 7 3800X	225W	227W
Intel Core i9-10900K	157W	240W
Intel Core i5-10600K	300W	349W

Lower is better

Stock speed / Overclocked

WHAT'S THE BEST MEMORY FOR AMD ZEN 3 CPUs?

AMD's Infinity Fabric is still very much involved in die-to-die communications within Ryzen CPUs and, since it's tied to memory speed, it seemingly makes sense to opt for the fastest possible memory. AMD has also shifted its Infinity Fabric ratio up a gear with Zen 3. A 1:1 ratio now requires memory speeds of 4000MHz, instead of 3733MHz or 3800MHz with Zen 2 CPUs, depending on the motherboard.

However, any memory much faster than 3466MHz can be expensive. For example, a 4000MHz Corsair Vengeance RGB memory kit costs £150. By comparison, a 3466MHz version of the same kit can be bought for under £110. Is it worth paying the extra money? To find out, we've put three memory speeds to the test, using a pair of 8GB (16GB total) Corsair Vengeance RGB modules, to see which speed is best for a Zen 3 system.

Performance

Our GIMP image editing test has often been impacted quite heavily by memory speed, and the same was true here, with the score falling from 71,875 with 3466MHz memory to 66,801 with 3000MHz memory. However, the difference made by 3800MHz memory was within the margin of error, with the latter actually returning a slightly slower result.

Again, there was a noticeable improvement in our Handbrake encoding test when moving from 3000MHz to 3466MHz, with the score rising from 899,662 to 959,116. However, this only rose to 962,398 at 3800MHz with the same timings.

The multi-tasking test was a bit finicky, with tiny gains across the speed range, and a blip with the 3466MHz memory being oddly slower than with the 3000MHz memory over several runs, although we do often see weird performance quirks with new technology and beta firmware. Nevertheless, the overall system score tells the correct story, with 3466MHz being the sweet spot and 3800MHz only being worth the upgrade if you're not spending more than another £10-£15.

Cinebench once again saw a bigger leap in the multi-threaded test between 3000MHz and 3466MHz than between 3466MHz and 3800MHz. However, the single-threaded test saw a bigger gain when moving from 3466MHz to 3800MHz, although it was the only test to do so. Finally, Far Cry New Dawn didn't respond much to memory speed, with only one or two frames per second separating the best and worst results.

Conclusion

Despite a slight upshift in the 1:1 Infinity Fabric ratio, there's not much point in buying 3800MHz+ memory for a Zen 3 system. A 3466MHz or 3600MHz kit will be more than adequate. The only situation where you should be opt for faster memory is if the prices come down to a point where it makes sense to spend an extra £10 just to squeeze out every last drop of performance.

ANTONY LEATHER

BENCHMARK RESULTS
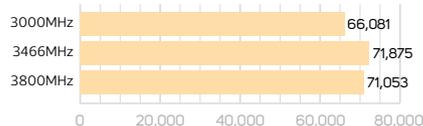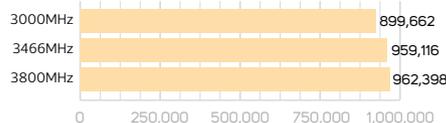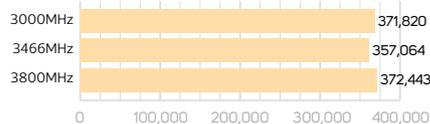
GIMP IMAGE EDITING

Speed	Score
3000MHz	66,081
3466MHz	71,875
3800MHz	71,053

HANDBRAKE H.264 VIDEO ENCODING

Speed	Score
3000MHz	899,662
3466MHz	959,116
3800MHz	962,398

HEAVY MULTI-TASKING

Speed	Score
3000MHz	371,820
3466MHz	357,064
3800MHz	372,443

SYSTEM SCORE

Speed	Score
3000MHz	340,376
3466MHz	352,999
3800MHz	354,959

CINEBENCH R20 MULTI-THREADED

Speed	Score
3000MHz	8,238
3466MHz	8,316
3800MHz	8,355

CINEBENCH R20 SINGLE-THREADED

Speed	Score
3000MHz	630
3466MHz	631
3800MHz	638

FAR CRY NEW DAWN
1,920 x 1,080, Ultra settings

Speed	99th percentile	Average
3000MHz	103fps	134fps
3466MHz	103fps	136fps
3800MHz	104fps	135fps

99th percentile / Average
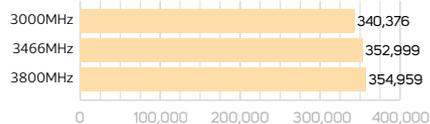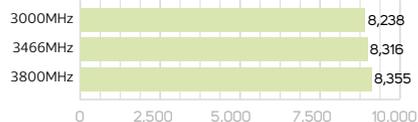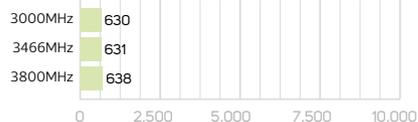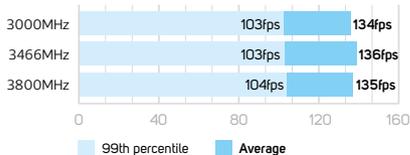
HOW TO OVERCLOCK AMD'S ZEN 3 CPUs
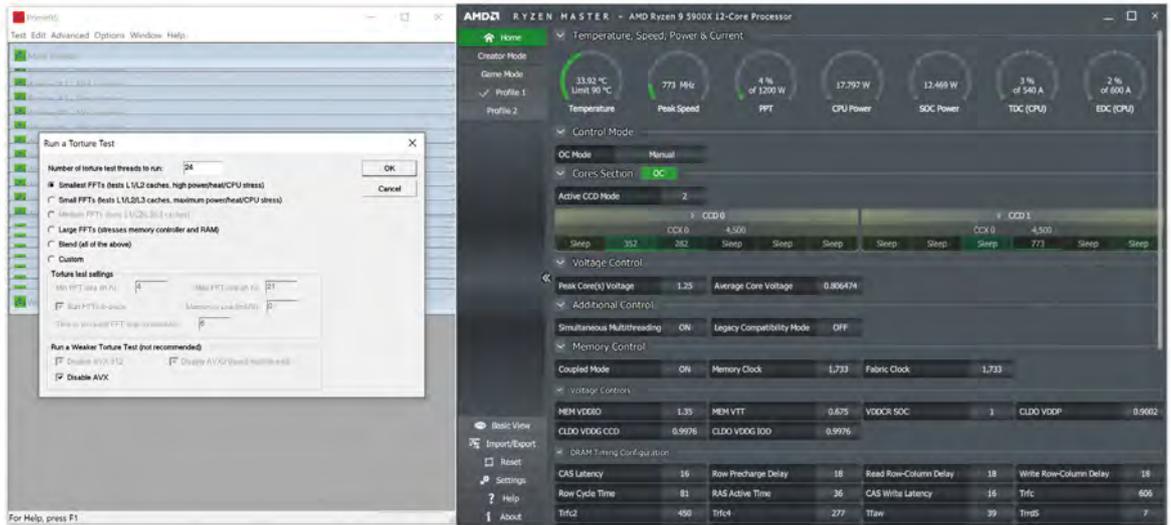
Start by gauging the power of your cooling setup with a Prime95 stress test

We found that an all-core frequency of 4.5GHz with a 1.25V vcore was a solid starting point

Not much has changed when it comes to overclocking Zen 3 CPUs compared with Zen 2 chips, and sadly it looks as though we'll have to wait a little longer for new techniques, such as per-core overclocking, which was rumoured to land with Zen 3. For now, it's all about pushing that manual all-core overclock as far as possible with safe voltages. You also need to weigh up whether this is worth it, or whether you might be better off running your CPU at stock speed or using AMD's Auto Overclocking.

This choice largely depends on your needs. Any manual overclock will prevent your CPU from hitting its peak boost speed on a single core (such as 4.8GHz on the Ryzen 9 5900X), and no cores will reach frequencies higher than the one set in your manual all-core overclock. However, in some situations, as we saw with the Ryzen 5 3600XT, AMD's 7nm CPUs are refined enough to occasionally allow manual overclocks that get pretty close to the peak single-core boost speed anyway.

This means you'll lose little real-world performance, as most software uses more than one or two threads now, and you'll likely gain a substantial amount of multi-threaded performance. We'll look at the benefits of Auto Overclocking at the end of this section, but for now, we'll focus on how to achieve the best manual overclock with your Zen 4 CPU.

Check your cooling

Before you start, check that your cooling is up to the task. Run the latest version of Prime95 (**mersenne.org**), and select the 'Smallest FFTs' test, while disabling any AVX options at the bottom. Also, download Ryzen Master from **amd.com** and click OK in Prime95 to run the test.

Using Ryzen Master, monitor the CPU temperature for ten minutes. If the final temperature is lower than 75°C, you can proceed with overclocking using the following steps. If not, you'll likely need a more potent CPU cooler.

An all-core overclock to 4.5GHz with a 1.25V vcore was fairly easy to achieve on our Ryzen 9 5900X with decent cooling, so we suggest starting there and seeing how high a frequency you can achieve with that voltage, before reducing it back.

In Ryzen Master, head to the Profile 1 tab on the left, and then select Manual on the upper tabs. Enable both CCDs by clicking on them, and hit the vertical grey button to the left of the CCD sections to mirror the speed you enter on one core to the rest of them.

Now enter a vcore of 1.25V in the Peak Core(s) Voltage section at the bottom. This is the maximum voltage you should use for a 24/7 overclock on a Zen 3 CPU, so ideally, you want to reduce this figure as much as possible later.

Ryzen Master doesn't allow overclocks to stick between reboots. As such, once we're done here, we'll need to head into the EFI to make our tweaks permanent, but this method for finding a stable overclock is much easier than using the EFI and constantly rebooting.

Finally, Ryzen Master includes a stability test, courtesy of the Apply and Test button. This lasts for around 30 seconds, but is enough to show if you have a stable overclock. If this test passes, go ahead and run Prime95 again with the same settings as before and monitor the temperature, making sure it stays below 85°C this time.

Now it's time to reduce the voltage to optimise your overclock. Reduce the voltage by two steps and run Prime95 again for five minutes, then repeat that process until you encounter stability issues. Once that happens, go back to Ryzen Master and increase the voltage by two steps. In the end, we found our CPU only needed 1.175V at 4.5GHz, which is perfectly safe for an everyday overclock and saw much lower temperatures than at 1.25V too.

Overclocking in the EFI

Once you've nailed down your stable overclock in Ryzen Master, it's time to head into the EFI to force your motherboard to set your overclock each time your PC boots. Shut down your PC, and hit the Del key when you see text on the screen as your PC boots – this should take you into your motherboard's EFI.

Locate the overclocking section, which on our Gigabyte motherboard was the Tweaker section, and then find the settings for the CPU clock ratio or multiplier, CPU vcore and memory. Input your chosen voltage and frequency (using a clock ratio of 45 for a 4.5GHz frequency, for example). While you're here, set the XMP memory profile to your memory's correct rated speed, which will make sure your memory is running at its rated frequency, voltage and timings.

Precision Boost Overdrive and Auto Overclocking

As we mentioned at the beginning, the trouble with manually overclocking Ryzen CPUs is that you lose the CPU's boosting features, meaning no cores will go faster than your manual overclock speed. For example, the Ryzen 9 5900X can reach a peak boost of 4.8GHz at stock speed, so overclocking it manually to 4.5GHz will see you lose 300MHz. This won't be across all cores, though, as that peak boost frequency only

applies to one or two cores, depending on your CPU. Manual overclocking has its benefits, but there's a balance, and a good compromise is using AMD's Precision Boost Overdrive and Auto Overclocking features in Ryzen Master. This will mainly affect boosting in multi-threaded tasks, and only if you have good enough cooling.

We found that setting the uplift to its maximum of 200MHz resulted in a decent all-core boost frequency in multi-threaded applications, where the CPU reached 4.3GHz instead of 4.1GHz. The CPU retained its lofty stock speed peak boost too, so you get the best of both worlds.

Auto Overclocking is easy to use too, and means you don't need to worry about setting voltages and multipliers yourself. To start, head into Ryzen Master and select Profile 1 under the left tabs. Then head into the Automatic Overclocking section and increase the Boost Override CPU to 200. Click Apply and run Prime95's smallfft test again, plus CPU-Z (**cpuid.com**) to see just how much of an uplift your CPU and cooling will allow.

ANTONY LEATHER

Input your settings to the EFI to make them permanent

AMD's Auto Overclocking feature saves you worrying about setting voltages and multipliers yourself
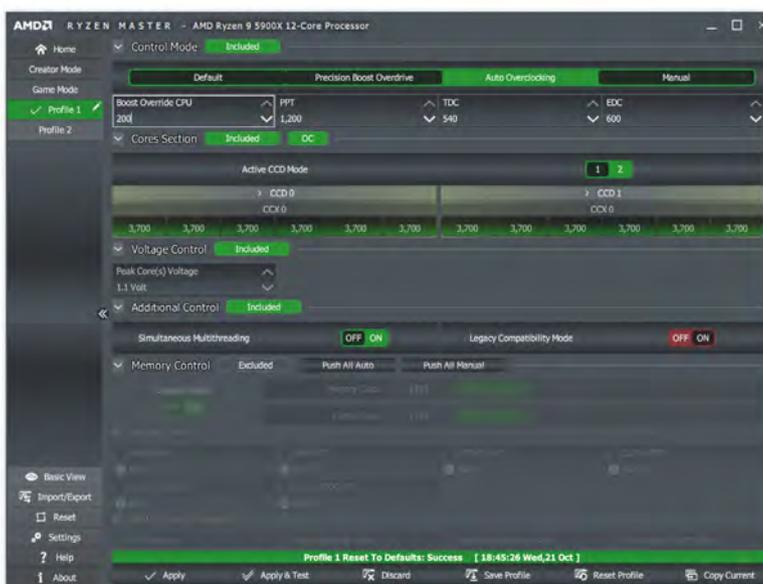
NVIDIA GEFORCE
RTX 3090 / **£1,399** inc VAT

SUPPLIER nvidia.com
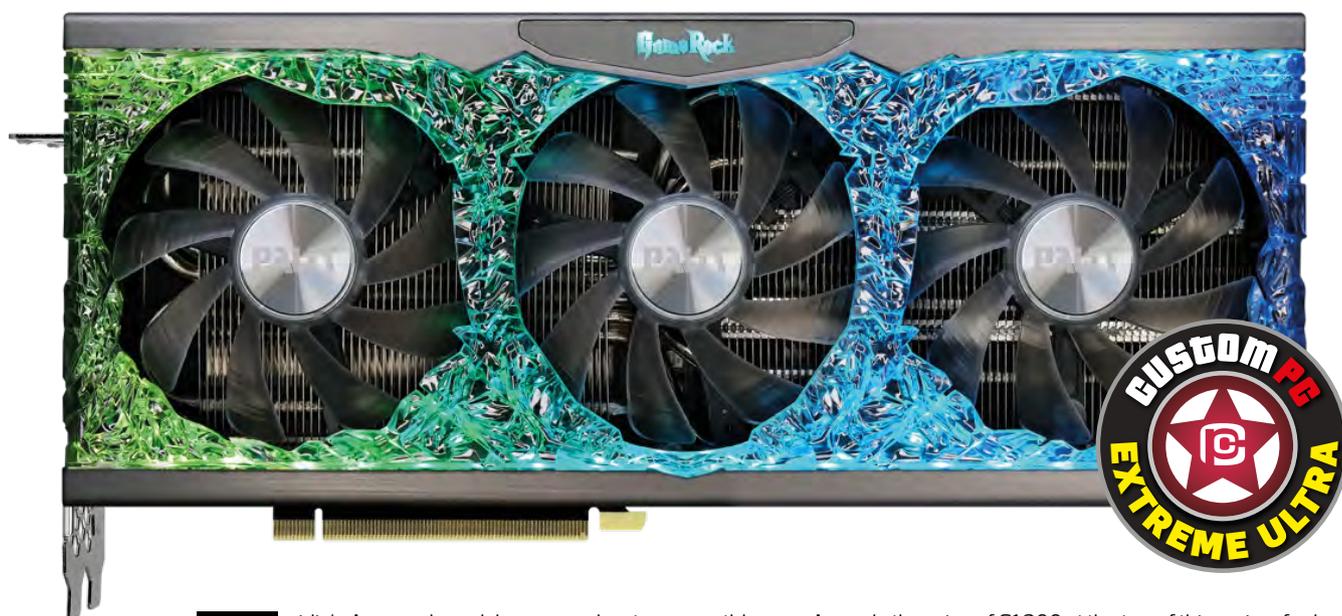
Nvidia's Ampere launch has gone about as smoothly as navigating a penny farthing through a quarry while wearing stilts. The RTX 3080 blew us away with its barnstorming benchmark results in Issue 207, but buying one now either involves optimistically adding your name to a pre-order waiting list, or handing thousands of pounds to a scalper on eBay. Stocks of both the RTX 3080 and the RTX 3090 are currently sold out everywhere.

As such, the price of £1,399 at the top of this review feels a bit like a token gesture. Our current advice is to just be patient, wait for the ridiculous stock situation to blow over and pick up a card at a normal price next year.

We're also well aware of reports about third-party Ampere cards crashing out of games to the Windows desktop, which some online commentators have put down to the capacitor configurations used on some cards. This isn't a problem we've been able to replicate on the samples we've tested, and Nvidia's latest (over 600MB!) driver seems to have solved a lot of the issues people were reporting. Either way, we'll be keeping an eye on the situation.

In the meantime, we've managed to get hold of a blinged-up Palit GameRock GeForce RTX 3090 card for testing. There's no UK pricing for this card yet, and even if there were, you wouldn't be able to buy it right now anyway. As such, we're going to review it at Nvidia's quoted price for the Founders Edition, on the basis that you should be able to pick up a card (or one that performs similarly) for around this price once the stock situation is sorted.

GEFORCE RTX GPU COMPARISON

	RTX 3090	RTX 3080	RTX 3070	RTX 2080 Ti	RTX 2080 SUPER	RTX 2070 SUPER
Price (inc VAT)	£1,399	£649	£469	£995	£618	£434
Manufacturing process	Samsung 8nm	Samsung 8nm	Samsung 8nm	TSMC 12nm	TSMC 12nm	TSMC 12nm
CUDA cores	10,496	8,704	5,888	4,352	3,702	2,560
RT cores	82 (2nd-gen)	68 (2nd-gen)	46 (2nd-gen)	68 (1st-gen)	48 (1st-gen)	40 (1st-gen)
Tensor cores	328 (3rd-gen)	272 (3rd-gen)	184 (3rd-gen)	544 (2nd-gen)	384 (2nd-gen)	320 (2nd-gen)
GPU base clock	1395MHz	1440MHz	1500MHz	1350MHz	1650MHz	1605MHz
GPU boost clock	1695MHz	1710MHz	1725MHz	1545MHz	1815MHz	1770MHz
Memory	24GB GDDR6X	10GB GDDR6X	8GB GDDR6	11GB GDDR6	8GB GDDR6	8GB GDDR6
Memory clock (effective)	19.5GHz	19GHz	14GHz	14GHz	15.5GHz	14GHz
Memory interface width	384-bit	320-bit	256-bit	352-bit	256-bit	256-bit
Memory bandwidth	936GB/sec	760GB/sec	448GB/sec	616GB/sec	496GB/sec	448GB/sec

Inside the GPU

The GeForce RTX 3090 is based on the same GA102 Ampere GPU as the RTX 3080. This 628mm^2 chip is built on an 8nm process and contains a whopping count of 28.3 billion transistors. Unlike the RTX 3080, however, the RTX 3090 doesn't have a disabled graphics processing cluster (GPC), so it has the full count of seven.

Even at this point, however, the chip isn't completely fully enabled – there are still two streaming multiprocessors (SMs) disabled on the RTX 3090, so it has 82 rather than the full count of 84. We suspect this limit was made in order to maximise yield rather than to wait for a completely enabled part later, as the performance difference would be minimal.

Either way, the RTX 3090 has a beefy spec list, with 10,496 CUDA cores, compared to 8,704 on the RTX 3080. It also has 82 2nd-gen RT cores for ray tracing, compared to 68 on the RTX 3080, and 328 3rd-gen Tensor cores for Nvidia's deep learning-based tech, such as DLSS anti-aliasing. Clock speeds are lower than those of the RTX 3080, but not by much, with a stock boost clock of 1695MHz, compared to 1710MHz on the RTX 3080.

Nvidia has also really gone to town on the RTX 3090's memory configuration. It has a whopping 24GB allocation of GDDR6X memory, running at an effective clock speed of 19.5GHz (compared to 19GHz on the RTX 3080), and it's attached to a fat 384-bit wide memory interface. The end result is a total memory bandwidth figure of 936GB/sec, edging close to 1TB/sec.

The cards

All the usual board partners have launched GeForce RTX 3090 cards, many of which are based on Nvidia's reference PCB, while others have their own designs. Nvidia also has its own Founders Edition card available (using the loosest possible definition of 'available') on its website, which is bigger than the RTX 3080 Founders Edition we reviewed last month, but has a similar design, with a big wedge cut out of the PCB to make way for an airflow system that goes right through the card.

The idea is that it works in conjunction with your case's airflow system, and we found that the RTX 3080 Founders Edition's cooler worked well with our graphics test rig last month. However, as Antony Leather points out on p98, it's not such a great design if you don't have a standard case airflow configuration, particularly with cramped mini-ITX cases.

Meanwhile, our Palit GameRock test card is an absolute monster. Palit says it takes up 2.7 slots, so while its I/O plate on the back only takes up two slots, it will block a third slot below it on your motherboard too. Unlike Nvidia's RTX 3080 Founders Edition, it has three 8-pin PCI-E power sockets on the top edge, rather than using the new compact 12-pin design. Unlike the RTX 3080, the RTX 3090 also has an SLI connector on the top edge, meaning you can pair up two of them for even faster gaming performance in games that support it.

This means you won't need any adaptors to get it running with an existing PSU, but you'll need plenty of power. Our test system drew 570W from the mains with the RTX 3090 running at full pelt – we'd recommend an 850W PSU for an RTX 3090 system to get the best balance of efficiency and headroom.

There will be two versions of this GameRock card – one that runs at stock speed (which is how we've tested it), and one that overclocks the GPU boost frequency by 150MHz to 1845MHz, although there's no memory overclock. The

AVAILABLE

+ Great 4K frame rates

+ Superb ray-tracing performance

+ Even faster than RTX 3080

UNAVAILABLE

− Hardly any stock

− Very expensive

− Not much faster than RTX 3080 at 1080p

− High power draw

big deal about this GameRock card, of course, is it's bling. Taking inspiration from the likes of G.Skill's Trident Royal memory, the front of the cooler is covered in faceted transparent plastic, creating a jewelled effect to show off the RGB lighting.

Opinion was divided on its appearance among the team (I think it looks like tasteless tat; Antony Leather thinks it looks gorgeously premium), but it certainly makes a big impression. The lighting also runs across the edge of the card, and there's a chunky backplate on the back. The lights are really bright and clear when they're all running too. Perhaps most importantly, though, the cooler works really well. The fans don't spin up when the card is idle, and while the noise is noticeable during games, it's a low rumble rather than an annoying trebly hiss, and it doesn't noisily oscillate up and down either.

Performance

As we expected, the GeForce RTX 3090 is indeed the fastest gaming GPU we've ever tested, although not always by as much as you'd expect. At 1,920 x 1,080, there was often very little difference between the RTX 3080 and 3090, and there sometimes wasn't much difference between the two at 2,560 x 1,440 either. However, you don't buy a £1,399 GPU to play games at 1080p, and the RTX 3090 noticeably pulls away from the RTX 3080 at 4K.

Its 159fps 99th percentile frame rate in Doom Eternal at 4K shows that you could happily partner the RTX 3090 with a 144Hz monitor for fast-paced first-person shooters – this also again shows that Ampere is geared towards increasing raw shader power as well as ray-tracing performance. Meanwhile, its 99th percentile result of 34fps in Metro Exodus at 4K without DLSS is also just about playable, as opposed to the RTX 3080's 28fps. Add DLSS, and this demanding game at Ultra settings (including ray tracing) runs at an average of 71fps, with a solid 99th percentile result of 47fps.

Likewise, the RTX 3090's 99th percentile result of 44fps in Shadow of the Tomb Raider with High ray-traced shadows and no DLSS is noticeably smoother than the 38fps from the RTX 3080. The results were similar in Battlefield V at 4K too. It's these very demanding tests at high resolutions that really benefit from the RTX 3090's power.

Conclusion

If you want to play the latest games at 4K with all the eye candy turned up then the GeForce RTX 3090 is the card you want. There's little point in buying it for gaming at lower resolutions – you may as well save yourself some money and buy the RTX 3080 instead for that – but if you have a healthy bank balance and a 4K monitor, this is the card to buy.

That said, while the RTX 3090 is faster than the 3080 at 4K, it isn't anywhere near twice the speed, and it costs twice as much. In terms of bang per buck, the RTX 3090 can't compete with its smaller sibling, but that's the price you have to pay if you want the very fastest GPU. If you can afford it, and you want to play games at 4K, it currently doesn't get any better than the RTX 3090, but most gamers will be better off saving some money and buying the RTX 3080 instead.

BEN HARDWIDGE

PERFORMANCE
40/40

FEATURES
20/20

VALUE
15/40

OVERALL SCORE
75%

VERDICT

Superb 4K gaming performance, but it's much more expensive than the RTX 3080 and not much faster at lower resolutions.

DOOM ETERNAL

1,920 x 1,080, Vulkan, Ultra Nightmare settings

GPU	99th percentile	Average
Nvidia GeForce RTX 3090	319fps	433fps
Nvidia GeForce RTX 3080 10GB FE	309fps	424fps
Nvidia GeForce RTX 2080 Ti FE	244fps	349fps
Nvidia GeForce RTX 2080 Super FE	216fps	327fps
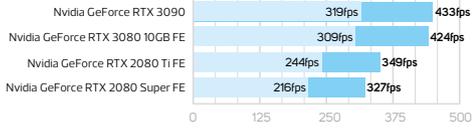
2,560 x 1,440, Vulkan, Ultra Nightmare settings

GPU	99th percentile	Average
Nvidia GeForce RTX 3090	271fps	388fps
Nvidia GeForce RTX 3080 10GB FE	252fps	362fps
Nvidia GeForce RTX 2080 Ti FE	172fps	270fps
Nvidia GeForce RTX 2080 Super FE	157fps	238fps
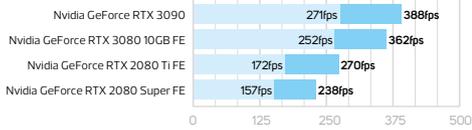
3,840 x 2,160, Vulkan, Ultra Nightmare settings

GPU	99th percentile	Average
Nvidia GeForce RTX 3090	159fps	236fps
Nvidia GeForce RTX 3080 10GB FE	135fps	212fps
Nvidia GeForce RTX 2080 Ti FE	95fps	147fps
Nvidia GeForce RTX 2080 Super FE	82fps	125fps

METRO EXODUS

1,920 x 1,080, Ultra settings, HairWorks off, Advanced PhysX off, Ultra RT

GPU	99th percentile	Average
Nvidia GeForce RTX 3090	63fps	112fps
Nvidia GeForce RTX 3080 10GB FE	59fps	107fps
Nvidia GeForce RTX 2080 Ti FE	49fps	85fps
Nvidia GeForce RTX 2080 Super FE	41fps	69fps

2,560 x 1,440, Ultra settings, HairWorks off, Advanced PhysX off, Ultra RT

GPU	99th percentile	Average
Nvidia GeForce RTX 3090	51fps	87fps
Nvidia GeForce RTX 3080 10GB FE	49fps	78fps
Nvidia GeForce RTX 2080 Ti FE	37fps	59fps
Nvidia GeForce RTX 2080 Super FE	30fps	47fps

2,560 x 1,440, Ultra settings, HairWorks off, Advanced PhysX off, Ultra RT, DLSS

GPU	99th percentile	Average
Nvidia GeForce RTX 3090	58fps	100fps
Nvidia GeForce RTX 3080 10GB FE	53fps	91fps
Nvidia GeForce RTX 2080 Ti FE	44fps	72fps
Nvidia GeForce RTX 2080 Super FE	37fps	60fps

3,840 x 2,160, Ultra settings, HairWorks off, Advanced PhysX off, Ultra RT

GPU	99th percentile	Average
Nvidia GeForce RTX 3090	34fps	49fps
Nvidia GeForce RTX 3080 10GB FE	28fps	42fps
Nvidia GeForce RTX 2080 Ti FE	21fps	31fps
Nvidia GeForce RTX 2080 Super FE	16fps	24fps

3,840 x 2,160, Ultra settings, HairWorks off, Advanced PhysX off, Ultra RT, DLSS

GPU	99th percentile	Average
Nvidia GeForce RTX 3090	47fps	71fps
Nvidia GeForce RTX 3080 10GB FE	43fps	64fps
Nvidia GeForce RTX 2080 Ti FE	33fps	49fps
Nvidia GeForce RTX 2080 Super FE	28fps	40fps

Legend: ▢ 99th percentile ▢ Average

TOTAL SYSTEM POWER CONSUMPTION

GPU	Idle	Load
Nvidia GeForce RTX 3090	77W	570W
Nvidia GeForce RTX 3080 10GB FE	57W	456W
Nvidia GeForce RTX 2080 Ti FE	60W	381W
Nvidia GeForce RTX 2080 Super FE	57W	368W

Legend: ▢ Idle ▢ Load

SHADOW OF THE TOMB RAIDER

1,920 x 1,080, Highest settings, High ray-traced shadows, TAA

GPU	99th percentile	Average
Nvidia GeForce RTX 3090	76fps	127fps
Nvidia GeForce RTX 3080 10GB FE	76fps	123fps
Nvidia GeForce RTX 2080 Ti FE	65fps	105fps
Nvidia GeForce RTX 2080 Super FE	61fps	93fps

2,560 x 1,440, Highest settings, High ray-traced shadows, TAA

GPU	99th percentile	Average
Nvidia GeForce RTX 3090	72fps	106fps
Nvidia GeForce RTX 3080 10GB FE	68fps	99fps
Nvidia GeForce RTX 2080 Ti FE	50fps	75fps
Nvidia GeForce RTX 2080 Super FE	42fps	63fps

2,560 x 1,440, Highest settings, High ray-traced shadows, DLSS

GPU	99th percentile	Average
Nvidia GeForce RTX 3090	73fps	116fps
Nvidia GeForce RTX 3080 10GB FE	73fps	111fps
Nvidia GeForce RTX 2080 Ti FE	56fps	89fps
Nvidia GeForce RTX 2080 Super FE	50fps	75fps

3,840 x 2,160, Highest settings, High ray-traced shadows, TAA

GPU	99th percentile	Average
Nvidia GeForce RTX 3090	44fps	63fps
Nvidia GeForce RTX 3080 10GB FE	38fps	54fps
Nvidia GeForce RTX 2080 Ti FE	27fps	40fps
Nvidia GeForce RTX 2080 Super FE	21fps	32fps

3,840 x 2,160, Highest settings, High ray-traced shadows, DLSS

GPU	99th percentile	Average
Nvidia GeForce RTX 3090	58fps	84fps
Nvidia GeForce RTX 3080 10GB FE	52fps	75fps
Nvidia GeForce RTX 2080 Ti FE	42fps	60fps
Nvidia GeForce RTX 2080 Super FE	34fps	49fps

BATTLEFIELD V

1,920 x 1,080, Ultra settings, DX12, High DXR, TAA

GPU	99th percentile	Average
Nvidia GeForce RTX 3090	100fps	129fps
Nvidia GeForce RTX 3080 10GB FE	100fps	125fps
Nvidia GeForce RTX 2080 Ti FE	84fps	100fps
Nvidia GeForce RTX 2080 Super FE	74fps	86fps

2,560 x 1,440, Ultra settings, DX12, High DXR, TAA

GPU	99th percentile	Average
Nvidia GeForce RTX 3090	83fps	98fps
Nvidia GeForce RTX 3080 10GB FE	75fps	91fps
Nvidia GeForce RTX 2080 Ti FE	58fps	71fps
Nvidia GeForce RTX 2080 Super FE	47fps	58fps

3,840 x 2,160, Ultra settings, DX12, High DXR, TAA

GPU	99th percentile	Average
Nvidia GeForce RTX 3090	44fps	57fps
Nvidia GeForce RTX 3080 10GB FE	35fps	50fps
Nvidia GeForce RTX 2080 Ti FE	27fps	37fps
Nvidia GeForce RTX 2080 Super FE	22fps	29fps

3,840 x 2,160, Ultra settings, DX12, High DXR, TAA

GPU	99th percentile	Average
Nvidia GeForce RTX 3090	44fps	63fps
Nvidia GeForce RTX 3080 10GB FE	38fps	54fps
Nvidia GeForce RTX 2080 Ti FE	27fps	40fps
Nvidia GeForce RTX 2080 Super FE	21fps	32fps

3,840 x 2,160, Ultra settings, DX12, High DXR, DLSS

GPU	99th percentile	Average
Nvidia GeForce RTX 3090	68fps	78fps
Nvidia GeForce RTX 3080 10GB FE	60fps	71fps
Nvidia GeForce RTX 2080 Ti FE	51fps	59fps
Nvidia GeForce RTX 2080 Super FE	41fps	48fps

Legend: ▢ 99th percentile ▢ Average

240MM AIO LIQUID CPU COOLER
CORSAIR H100I ELITE CAPELLIX

/ £150 inc VAT

SUPPLIER scan.co.uk

ELITE
+ Powerful software
+ Detailed fan, light and pump control
+ Excellent cooling

1337
− Noisy at full speed
− Expensive

Corsair's H100i Elite Capellix introduces the company's bright, vivid Capellix RGB LEDs into a CPU cooler for the first time, as well as tweaking performance compared to previous models. The pump speed has been increased by 200rpm at its peak, and the fan profile curves have been altered, providing a little extra oomph at the various presets. The fans still top out at a monstrous 2,400rpm, though, which will allow it to deal with more heat than the likes of the Antec Neptune 240, which can only reach 1,600rpm with its 120mm fans.

The ML120 RGB fans included with the H100i Elite Capellix are available separately, but not with the same lofty speed rating. However, the fans retail at nearly £90 for a triple pack, which does help this cooler justify its considerable price tag of £150.

Thankfully, the fans look fantastic and the lighting is more vivid and accurate than that on the Antec Neptune 240, although it costs nearly twice the price. You can also alter the lighting of all eight RGB LEDs on each fan, with the semi-transparent fans doing a great job of diffusing the light evenly.

The fans and pump are controlled according to the coolant temperature, which should mean they don't need to ramp up and down as often as a cooler based on CPU temperatures. As well as reaching lofty speeds, the fans can now make use of a zero-RPM mode too, where they shut off completely at coolant temperatures below 40°C.

You also get the usual Extreme, Balanced and Quiet profiles, which allow for quick tweaking for a quicker response from the fans and pump. You can add your own profile too, but all the presets eventually see the fans hit full speed. Corsair also includes an iCUE Commander Core hub, with six individual fan channels and Corsair 4-pin RGB ports, which you can use to control up to six RGB fans directly using a USB header and Corsair's iCUE software.

While you're still restricted by Corsair's ecosystem here, iCUE can at least control your motherboard's lighting and headers now, so you shouldn't have to stray into other manufacturers' software or ecosystems, even if you add your own lighting strips.

The pump only requires a single connector to hook up to the hub for speed and lighting control, which dramatically reduces the cable spaghetti around your CPU socket. The pump has an all-new lighting system too, again with Capellix RGB LEDs, which look supremely clear and vibrant, illuminating the logo, as well as the inner and outer rings on

SPEC

Compatibility
Intel: LGA1200, LGA115x, LGA2066, LGA2011; AMD: Socket AM4, AM3/+, AM2/+, FM2/+, FM1, TR4/X

Radiator size with fans (mm)
120 x 277 x 52 (W x D x H)

Fans
2 x 120mm

Stated noise
10dBA-37dBA

TEMPERATURE RESULTS (DELTA T)

AMD SOCKET AM4

Corsair H100i Elite Capellix (max)	45°C
Corsair H100i Elite Capellix (med)	52°C
Corsair H100i Elite Capellix (min)	58°C
Corsair H115i RGB Pro XT (max)	43°C
Antec Neptune 240	57°C
ARCTIC Liquid Freezer II 240	56°C

0   25   50   75   100
Lower is better

INTEL LGA1151

Corsair H100i Elite Capellix (max)	50°C
Corsair H100i Elite Capellix (med)	54°C
Corsair H100i Elite Capellix (min)	59°C
Corsair H115i RGB Pro XT (max)	46°C
Antec Neptune 240	54°C
ARCTIC Liquid Freezer II 240	53°C

0   25   50   75   100
Lower is better

LGA2066

Corsair H100i Elite Capellix (max)	50°C
Corsair H100i Elite Capellix (med)	54°C
Corsair H100i Elite Capellix (min)	59°C
Corsair H115i RGB Pro XT (max)	46°C
Antec Neptune 240	54°C

0   25   50   75   100
Lower is better

the default housing, with 21 individually controllable RGB LEDs. There are two pump tops included, with one allowing the inner logo and two outer rings to be illuminated, while another flips the lighting and has the logo and rings in black, but allows the lighting to spread over a much larger area.

You also get enough screws in the box to mount a second row of fans for a push/pull airflow setup, and mounting kits for all current and plenty of past sockets. Most configurations are fitted using thumbscrews, courtesy of the familiar CoolIT four-point mounting gear and pump brackets we've seen on previous Corsair coolers. The exception is Socket AM4, which makes use of the stock AMD mounting points.

There are only two points of pressure here rather than four, but it's extremely easy to install as a result. Installation on LGA115x and LGA1200 sockets requires a backplate, which makes it a little trickier, but installation is also simple on AMD and Intel's HEDT platforms thanks to their topside threaded mounting points.

Meanwhile, the compact radiator measures just 120mm wide and 277mm long, so it should fit into most dual or triple fan mounts. Plus, with a depth of just 27mm, it should squeeze into tight spaces too.

Performance

As expected with two monstrous fans at the helm, the H100i Elite Capellix performed excellently, managing similar results to the much larger Corsair H115i RGB Pro XT in all sockets, and knocking 10°C or more off the results of the ARCTIC Liquid Freezer II 240 and Antec Neptune 240 in our Socket AM4 system.
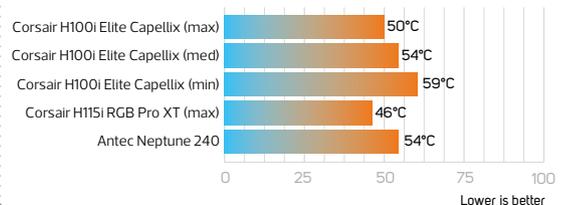
There was less than half that gap when dealing with our Core i5-9600K, where the delta T of 50°C was only a few degrees lower, but the gap widened a little when coping with our monstrous Core i9-9980XE. Here, the delta T of 52°C was 5°C cooler than the Antec cooler.

However, at full speed, the Corsair is extremely noisy and far louder than either Antec or ARCTIC coolers. Switching to the Balanced speed profile saw similar noise levels to those coolers, but it was only significantly cooler than them in our Socket AM4 system. In both Intel systems it was on par or slightly worse, while the Quiet profile saw much warmer temperatures on every socket.

Conclusion

Rather than a pure performance consideration, the Corsair H100i Elite Capellix has a multi-pronged approach to get you to reach for your wallet. Firstly, it looks fantastic, thanks to its clean design and superb RGB lighting. The latter stretches from the pump to the fans and is fully customisable, even including an optional pump top.

What's more, the fact that you can now control most motherboard RGB arrays, including their headers, from iCUE means that investing in Corsair's ecosystem makes more sense than it did a year ago. You can now synchronise colours and effects across all your hardware, including non-Corsair products. You also get the iCUE Commander Core hub, which means less cable clutter and a hassle-free way to add four other Corsair fans or RGB components to the mix, all tweakable in Corsair's iCUE software.

Then you have the performance, and while at similar noise levels its cooling power isn't much better than cheaper coolers, such as the ARCTIC Liquid Freezer II 240 and Antec Neptune 240, the Corsair can switch into a higher gear and drop temperatures further when required. It's pricey, but if you only have space for a 240mm liquid cooler and you need as much cooling power, RGB lighting and software control as you can get, this is the cooler for you.

ANTONY LEATHER

VERDICT

An excellent, flexible 240mm liquid cooler that's dripping with features, although it can get noisy and it's not cheap.

LGA115x	
COOLING	
38/40	
FEATURES	
18/20	
DESIGN	
15/20	
VALUE	
15/20	
FITTING	
Easy	

OVERALL SCORE

86%

AM4	LGA2066
COOLING	**COOLING**
37/40	**38**/40
FEATURES	**FEATURES**
18/20	**18**/20
DESIGN	**DESIGN**
15/20	**15**/20
VALUE	**VALUE**
15/20	**15**/20
FITTING	**FITTING**
Easy	**Easy**

OVERALL SCORE | **OVERALL SCORE**

85% | **86**%

38IN GAMING MONITOR

LG ULTRAGEAR 38GN950 / **£1,500** inc VAT

SUPPLIER scan.co.uk

LEADING LIGHT

+ Fantastic overall image quality

+ Excellent gaming performance

+ Big screen size and resolution

+ Passable HDR

LEAD LINED

− HDR still not great

− No stand rotation or speakers

− Very expensive

SPEC

Screen size
38in

Resolution
3,840 x 1,600

Panel technology
IPS

Maximum refresh rate
144Hz (160Hz overclocked)

Stated response time
1ms

Stated contrast
1,000:1

Adaptive sync
FreeSync and G-Sync

Display inputs
1 x DisplayPort 1.2, 2 x HDMI 1.4

Audio
No speakers, headphone out

Stand adjustment
Height, tilt

Extras
100 x 100mm VESA mount, 2-port USB 3 hub

LG's UltraGear 38GN950 is a 38in mammoth of a screen that not only offers a bump in screen size over your typical 34in ultrawide display, but an increase in resolution too. Instead of the 3,440 x 1,440 pixels typical of such screens, here you get 3,840 x 1,600.

It has some serious gaming credentials too. Like the recently reviewed LG UltraGear 34GL850 (see Issue 206), it boasts a 160Hz maximum refresh rate when overclocked (144Hz default), marking an improvement over the 100Hz (120Hz when overclocked) previous-generation ultrawide IPS screens.

Along with this, it has a claimed 1ms response time, although this is a bit of a far-fetched claim. Such a rapid response is only achieved in a handful of colour transitions (response times vary depending on which colour a pixel is changing to and from), and with the monitor set to its 'Faster' overdrive setting, which produces a mass of terrible-looking inverse colour ghosting.

Nonetheless, even with the overdrive dropped down a notch, this panel offers a significant upgrade in overall gaming performance over older 4ms ultrawide screens, and outstrips even other competing modern 1ms ultrawide models. Adding further to its gaming credentials is official FreeSync Premium Pro and G-Sync compatibility, and sure enough, the overall gaming experience here is very impressive, with no tearing artefacts and smooth motion. Again, if you already own a 34in 100Hz ultrawide monitor, this screen offers a noticeable upgrade.

Also included is support for the HDR 600 standard. This stipulates that a display can produce a peak brightness of 600 nits, includes a degree of local backlight dimming, has true 10-bit colour processing and can produce a peak black level brightness of 0.1nits while another portion of the screen is at maximum brightness.

Sure enough, the 38GN950 passes all these criteria, with us measuring a peak brightness of 760 nits and peak black level of 0.11 nits in HDR mode (for a total contrast of 6,909:1). We also detected eight backlight zones, and can confirm that the display can produce the colour fidelity required for HDR.

That's good in theory but, ultimately, eight backlight zones is nowhere near enough to prevent the whole backlight needing to be at the same brightness for any given frame, essentially dropping the contrast to its native level. You certainly get an impressive level of eye-searing dazzle when called upon from frame to frame, but you almost never get the simultaneous brightness and darkness that's the real hallmark of great HDR.

Otherwise, out-of-the-box image quality is superb, with a 6,487K colour temperature, 979:1 contrast ratio, 2.22 gamma recording and a 0.23 delta E measurement. You also get a very good sRGB mode, with adjustable brightness for desktop work and image editing. The on-screen display is also excellent (although it lacks an FPS indicator option) and connection options are adequate. However, while the stand's height and tilt are adjustable, it lacks rotation and you don't get any speakers.

Conclusion

A massive screen size, a high resolution, fantastic out-of-the-box image quality, class-leading gaming performance and better than most HDR makes this a stunning screen. There are a few slip-ups, such as the lack of rotation in the stand and no speakers, but they're minor grumbles. Instead, the big question mark here is the price. At £1,500, this is a hugely expensive panel, especially when you can pick up 34in panels with similar gaming performance for under £500. If you want a massive, high-resolution HDR gaming panel, though, and you have the money, the LG is a great buy.

EDWARD CHESTER

IMAGE QUALITY
28/30

GAMING
28/30

FEATURES
16/20

VALUE
10/20

OVERALL SCORE
82%

VERDICT

A class-leading behemoth of a gaming monitor, but it has an eye-watering price.

ACER NITRO VG271UP / **£299** inc VAT

SUPPLIER overclockers.co.uk

Acer's Nitro VG271UP is a 2,560 x 1,440 IPS panel with a 144Hz refresh rate, along with FreeSync and Nvidia G-Sync compatibility, plus a 1ms response time. The resolution is high enough to make games look crisp without taxing mid-range GPUs, and the IPS technology should deliver solid image quality.

Acer's panel looks the part. The base uses slim, angular struts with blue accents and the stand is finished in the same metallic shade. It has slim bezels too, so this display can be easily used in a multi-monitor setup. Meanwhile, the on-screen display (OSD) menu system is easy to navigate, and the joystick and trio of buttons at the rear are sturdy and well signposted.

There are no USB ports, though, and you don't get a headphone holder or any cable management. The panel has 25 degrees of tilt and VESA 100mm support, but that's it for adjustment. Build quality is average too – the display wobbles too much on its stand and the plastic rear is weak.

Thankfully, the Acer has decent core image quality. Out of the box, its delta E of 1.9 is great and its colour temperature of 6,501K is tremendously accurate. The Acer's display rendered 99.9 per cent of the sRGB gamut with 134.9 per cent volume, which is another top-notch result. These results mean the Acer delivers accurate, nuanced colour. Its contrast level of 1,070:1 is decent too, and the default brightness level of 257cd/m² is fine for everyday use – if a little underwhelming compared with other screens.

Ramping the panel up to its maximum brightness of 354cd/m² saw those results maintained, and dropping down to 150cd/m² saw no major change. The Acer also has a decent

sRGB mode – the delta E of 0.63 is fantastic, although its brightness of 137cd/m² is a bit dim.

Uniformity is average though – the brightness dipped by 18 per cent in the left-hand corners and there was backlight bleed at the top of the display. The Acer's 84.7 per cent AdobeRGB coverage level isn't quite good enough for serious work either, and the panel only supports 10-bit colour at 120Hz or below – head beyond that and you're restricted to 8-bit colour. The Acer also supports the DisplayHDR 400 standard, and its peak brightness of 475cd/m² exceeds its requirements, but there simply isn't the contrast or depth of colour here to deliver a meaningful improvement in HDR media.

Gaming performance is solid though. While we did see some minor motion blur in testing, the Nitro performed reasonably well here. It's certainly fast and smooth enough to handle fast-paced shooters to a good standard, and its active sync support ensures there's no tearing. That said, the latest high-speed TN displays will provide a snappier feel if you're serious about competition, and you could even get a 240Hz 1080p TN panel at this price.

Conclusion

The Acer Nitro VG271UP looks good, and it offers great colours, decent contrast and a fast refresh rate ability, alongside a decent resolution and active sync support. However, it suffers when it comes to features and adjustability, and the stand is a bit wobbly. If you don't need a USB hub, and you're not bothered about having a flexible stand, though, the Acer does offer a good balance of solid image quality and decent gaming performance for a reasonable price.

MIKE JENNINGS

SPEC

Screen size
27in

Resolution
2,540 x 1,440

Panel technology
IPS

Maximum refresh rate
144Hz

Stated response time
1ms

Stated contrast
1,000:1

Active sync
FreeSync and G-Sync compatible

Display inputs
1 x DisplayPort 1.4, 2 x HDMI 2

Audio
2 x 2W speakers, headphone out

Stand adjustment
Tilt

Extras
100 x 100mm VESA mount

NITROUS

+ Decent core image quality
+ Bold, attractive design
+ Good sRGB mode

NOXIOUS

− Minimal adjustment
− Mediocre build quality
− Not great with HDR

IMAGE QUALITY
33/40

FEATURES
20/30

VALUE
23/30

OVERALL SCORE
76%

VERDICT

Solid image quality and decent gaming performance, but it does miss out on a few features.

ROCCAT ELO 7.1 AIR / **£90** inc VAT

SUPPLIER game.co.uk

ELECTRIC LIGHT ORCHESTRA

+ Light and comfortable

+ Flat and balanced sound

+ Great value

ONE MAN BAND

– Awkwardly placed volume control

– Ringing headband

Roccat's new ELO 7.1 Air gives you a proper wireless gaming headset for just £90 inc VAT. That modest pricing is reflected in the design, which sports a plain all-black finish and simple shape. However, you still get RGB lighting in the form of the backlit Roccat lettering on the right earcup and the Roccat logo on the other (the lighting can be dimmed via software). Build quality is also solid, with no signs of weak spots and a generally solid feel throughout.

The springy metal headband provides the clamping force for the headset, but in one of the more bizarre design oversights we've encountered in some time, the headband rings like a bell if it's knocked. This sound is then transmitted through the headset to its microphone. You'll need to hit it quite often and hard to disrupt your gaming session or video chat, but it was an occasional distraction in our testing.

The headband uses a self-adjusting system, where the floating padded strap stretches internally as it comes into contact with your head, raising and lowering the band accordingly. It worked well for us, but the lack of strict adjustability reduces the range of head sizes that can be accommodated.

The earcups are on the smaller side, but are well contoured to avoid squashing your ears. The padding is also sufficiently deep, and includes a section of softer foam where the arms of glasses would pass through them, making the headset more comfortable for glasses wearers.

Meanwhile, the microphone is a basic detachable, bendable affair that plugs into the left earcup. Its sound quality is nothing special, but it's adequate for gaming sessions. More impressive is the built-in microphone monitoring, with a dial for adjusting the monitoring level next to the volume wheel on the left earcup. It's a shame these dials are both small though – it's a little tricky to locate them both and too easy to knock one rather than the other.

Also in this cluster of controls is a mic-mute button, a tiny power button and a USB Type-C charging port. Battery life appeared to largely live up to Roccat's impressive 24-hour claims in our testing.

Sound quality is impressive, not because of outstanding levels of detail, but thanks to the headset offering a reasonably flat sound profile. Bass is on the beefy side, but it's not massively overdone, and the high end isn't cranked up to the overly shrill levels of some gaming headsets either. We found this headset lent itself well to music and video watching as well as gaming.

If you do want sound that will give you a gaming advantage, you can turn on the Superhuman Hearing setting in Roccat's Swarm software, which boosts those frequencies often associated with in-game sounds, such as footsteps. It works surprisingly well, allowing you to pick out enemies more easily, even if it does make the whole soundscape sound rather strange. The excellent virtual surround sound can also be switched on and off via software, although sadly there isn't a button on the headset for quickly making the switch.

Conclusion

The Roccat ELO 7.1 Air has impressed us. Its compact and simple design looks the part, it sounds good, it has a few extra features such as the microphone mix dial, and the combination of decent battery life and a USB Type-C charging port makes it easy to keep the headset going. The ringing headband and limited adjustability aren't ideal, but the modest price of this wireless headset makes it an easy recommendation.

EDWARD CHESTER

SPEC

Audio config
Stereo and virtual 7.1 surround

Frequency range
20-20,000Hz

Stated battery life
24 hours

Connection
2.4GHz wireless

Weight
345g

VERDICT

Adequate all-round performance and a few extra features make this a great-value wireless headset.

DESIGN/COMFORT
15/20

FEATURES
15/20

SOUND QUALITY
31/40

VALUE
19/20

OVERALL SCORE
80%

CHILLBLAST AERO RGB / **£40** inc VAT

SUPPLIER chillblast.com

Chillblast has been producing custom-made PCs and laptops for years, and has often picked up **Custom PC** awards. However, the company has now turned its hand to producing a gaming mouse, in the shape of the Chillblast Aero RGB. This ultra-lightweight mouse weighs in at an impressively low 72g. To attain this lightness, the body is covered in hexagonal holes that, rather neatly, reveal a backlit Chillblast logo glowing inside.

The perforations extend to the back edge of the left and right buttons, as well as the underside of the mouse, but aren't present where your fingers make contact with the front of the buttons, nor the sides of the mouse. This makes for a more familiar feel than the perforated sides of a mouse such as the Finalmouse Ultralight, although it's less grippy. That's a shame, as the finish of the whole mouse is a plain matt plastic, which can be slippery if your hands are dry – a rougher or rubberised finish would aid grip.

Looking at the overall design, it's hard not to see the strong resemblance to the Glorious PC Gaming Race Model O, with its identical symmetrical design, perforation layout and similar finish. Regardless, we like the design, with its desktop-hugging strip of RGB lighting, illuminated scroll wheel and otherwise all-black livery.

The symmetrical shape is on the low side, so it mainly suits fingertip grip, but it can also work for palm grip, although we found the back too slippery for claw grip. The sides have a slightly convex profile, which leaves a relatively small central raised patch onto which your thumb and fingers can grip. It works, but we find the slightly flatter sides of the Logitech G Pro Wireless more comfortable.

Meanwhile, the cable has a modern lightweight style, where a wide braided tube loosely covers a much thinner, more flexible cable inside it. This makes for a less robust cable than your typical connection lead, but it's also more pliable, and it doesn't push back against you and disturb your aim.

You get left, right, middle/scroll and side buttons, along with a tiny DPI button on the top. On the underside there's also a polling rate button. All the other settings are changed via Chillblast's surprisingly slick software. You can set up to six DPI settings, change the lighting effects and program the buttons. The scroll wheel and Chillblast logo lighting correspond with the DPI setting you've chosen, so they can't show effects, but you can change the colour for each DPI setting.

Tracking performance is as good as we've come to expect from modern mice. It uses a PixArt PAW3327DB sensor, which is a tried and tested optical sensor with a maximum DPI of 6,200, and it can maintain tracking at up to 30G acceleration and 220 inches per second.

Meanwhile, the left and right buttons have Huano switches rated for 10 million clicks. They feel great, but the side buttons have a lot of extra travel after the switch has triggered, making for a spongey feel.

Conclusion

For a first try at an own-brand mouse, the Chillblast Aero RGB is mightily impressive. It looks smart – that RGB strip around the base is perhaps our favourite implementation of RGB lighting on a mouse, plus it has good overall performance, easy-to-use software and a very attractive price. The shape could be more comfortable, and the finish can be slippery, but this is a great lightweight mouse for just £40 inc VAT.

EDWARD CHESTER

SPEC

Weight
72g

Dimensions (mm)
67 x 128 x 38 (W x D x H)

Sensor
PixArt PAW3327DB

Buttons
6 (left, right, scroll wheel, back, forward, DPI)

Cable
1.8m, braided

Extras
RGB lighting

CHILLBLAST

+ Good performance
+ Attractive lighting
+ Very light
+ Keenly priced

CHILLBLAINS

− Slightly slippery finish
− Side buttons are a little spongey
− Overly rounded sides

DESIGN
17/20

FEATURES
15/20

PERFORMANCE
24/30

VALUE
25/30

OVERALL SCORE
81%

VERDICT
Great lighting, decent software and a solid lightweight design for just £40, although it's not perfect.

GAMING KEYBOARD
CORSAIR K100
/ £230 inc VAT

SUPPLIER overclockers.co.uk

OPTIMUS PRIME
+ Fast and sensitive key action
+ Loads of features
+ Superb build quality
+ Great RGB lighting

CLIFFJUMPER
− Very expensive
− No USB 3
− Some flimsy buttons

The K100 is Corsair's new flagship keyboard, so it has a huge price alongside a truckload of features. The most exciting addition can be found beneath the double-shot PBT keycaps – Corsair's first opto-mechanical switches.

The Corsair OPX switches balance mechanical-style keys with laser actuation. The OPX keys have a 45g actuation force, a 1mm actuation point and 3.2mm of travel alongside n-key rollover and anti-ghosting. The keys are lightning-fast and extremely sensitive – they hardly need to be pushed for a keypress to register, and the button movement is light, linear and shallow.

Their sensitivity impresses, but they're not for everyone, particularly if you want tactile feedback, but there's another option, as the K100 is also available with Cherry MX Speed Silver switches that have a 1.2mm actuation point. Comparatively, the rival Razer Huntsman Elite has a 1.5mm actuation point and 3.5mm travel distance – alongside a modest tactile bump. Beyond that, conventional mechanical switches that aren't designed for speed will have taller, heavier and more tactile typing actions, and many gamers will prefer that more robust experience.

Also, bear in mind that the different between an opto-mechanical switch and a mechanical switch is relatively minor. Most people will notice the difference in terms of feel, but only the keenest players will gain a significant advantage.

The rest of the K100's specification is suitably high-end. On the inside, there's a new multi-core Arm processor that enables the K100 to handle complex, 20-layer lighting effects and store up to 200 profiles. It also allows this keyboard to use a 4kHz polling rate, although the K100 is set to 1kHz by default and this is fine for virtually every user. Corsair's excellent iCUE app controls this keyboard's options, and it's both intuitive and powerful.

Meanwhile, the top-left portion of the keyboard houses a textured wheel that can offer eight new functions, including skipping music tracks, switching apps, scrolling and

altering the brightness of the lighting. The centre of the wheel is a button that switches its purpose, and RGB LEDs indicate which mode is active. The wheel is flanked by profile-switching and Game buttons, and it worked well during our tests.

The features elsewhere are plentiful. Each button has an individual RGB LED, and those lights are joined by a 44-zone strip of customisable lighting around the K100's edges. There are six macro keys that can also be used with Elgato streaming decks, and in the top-right corner there's a volume roller and media keys. Corsair also includes ten replacement keys – six for MOBA gaming, four for FPS gaming – and there's a comfortable magnetic wrist rest. The entire unit is sturdy too, although it's hardly small – the K100 weighs 1.2kg and is 470mm wide.

There are no big issues here – just tiny quibbles. The K100 has USB pass-through, but it's only USB 2, and at this price we'd expect USB 3. The media keys and the buttons on either side of the wheel are a tad flimsy as well. The rival Razer Huntsman Elite costs £185 and has similarly speedy keys, but it doesn't have the K100's more complex computational abilities, and it has fewer RGB LED zones, no function wheel and no macro keys.

Conclusion
The K100 is a superb keyboard. The laser-powered switches are fast, smooth and light, and it's packed with features – from the task-switching wheel to the plentiful RGB LEDs. Not everyone will enjoy the Corsair's airy, linear keys, though, and the price is stratospheric, so only shell out if you're going to use every feature.

MIKE JENNINGS

SPEC

Connection
Wired, USB

Cable
1.8m braided

Material
Plastic, aluminium

Switch type
Corsair OPX or CherryMX Speed Silver

Backlighting
RGB

Extras
Detachable wrist rest, media keys, function wheel

DESIGN
39/40

FEATURES
34/35

VALUE
15/25

OVERALL SCORE
88%

VERDICT
Top-tier design and features alongside delicate, fast keys, but it's very expensive and the typing action won't suit everyone.

GAMING LAPTOP
ASUS TUF A15 / £999 inc VAT

SUPPLIER currys.co.uk

Asus' TUF A15 is a rare gaming laptop that comes in at under £1,000, but still sports a Ryzen 7 4800H CPU. The lower price doesn't mean a dull design either. The A15's lid is coated with a vibrant electric blue finish, there's a large TUF logo and the corners have military-style accents. At the rear there are large air vents, and opening the lid reveals brushed metal going in different directions.

Meanwhile, the weight of 2.3kg and the 24mm-thick body are fine, if not spectacular, making this a realistic machine to take to LAN events. Build quality is middling though – the A15 will withstand trips outside, but there's a fair bit of the movement in the base, so you'll want a padded bag for it.

All the I/O basics are covered. On the left edge, you'll find two full-sized USB 3.2 Gen 1 ports and a Type-C connection that supports DisplayPort, alongside an HDMI output, a Gigabit Ethernet socket and an audio jack. On the right, there's a USB 2 port. The base panel can also be removed, and on the inside, the A15 serves up SSD access, two memory slots and a spare M.2 connector.

There's no card reader, though, and the mediocre webcam has no Windows Hello integration. Pricier machines will include these features, alongside faster USB ports and more memory than the 8GB of single-channel memory included in the Asus. On the plus side, it's good to see a 512GB Kingston NVMe SSD as standard, but there's no hard drive. There's dual-band Wi-Fi too, but it's 802.11ac rather than Wi-Fi 6.

The key components are the aforementioned AMD Ryzen 7 4800H CPU, which has eight SMT-enabled cores and a turbo speed of 4.2GHz. There's a half-decent GPU in the form of the GeForce GTX 1660 Ti too – it's a modest Turing-based GPU with 6GB of memory, 1,536 stream processors and no ray-tracing hardware or Tensor cores, but it's still much better than integrated graphics for gaming.

The chiclet keyboard has a generous 2mm of travel, and the layout is good – there's a numberpad, separate cursor keys and an extended spacebar. The lengthy travel distance delivers a decent experience – these buttons are quiet, consistent, comfortable and reasonably quick for typing. You'll only need to look elsewhere if you're hunting for a shorter, snappier feel. The only downside to the keyboard is the RGB lighting, which only has a single zone. The trackpad is also reasonable, although the buttons are a little soft.

Performance
The GTX 1660 Ti's 36fps minimum in Shadow of the Tomb Raider at Highest settings is playable, but the GPU didn't have enough memory to run Doom Eternal at Ultra Nightmare settings. We dropped down to Ultra settings and the A15

SPEC

CPU
2.9GHz AMD Ryzen 7 4800H

Memory
8GB 3200MHz DDR4

Graphics
Nvidia GeForce GTX 1660 Ti 6GB

Screen
15.6in 1,920 x 1,080 IPS 144Hz

Storage
512GB Kingston OM8PCP3512F-AB M.2 SSD

Networking
Dual-band 802.11ac Wi-Fi, Gigabit Ethernet, Bluetooth 5

Weight
2.3kg

Ports
2 x USB 3.2 Gen 1, 1 x USB 3.2 Gen 1 Type-C, 1 x USB 2, 1 x audio, 1 x HDMI
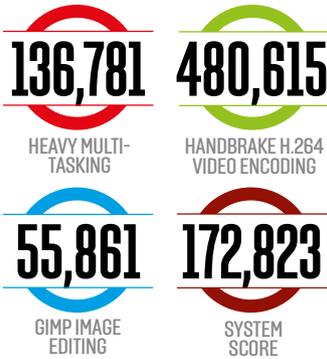
Dimensions (mm)
360 x 256 x 24 (W x D x H)

Operating system
Windows 10 Home 64-bit

Warranty
One year parts and labour return to base

136,781
HEAVY MULTI-TASKING

480,615
HANDBRAKE H.264 VIDEO ENCODING

55,861
GIMP IMAGE EDITING

172,823
SYSTEM SCORE

DOOM ETERNAL
1,920 x 1,080, Vulkan, Ultra settings

| Asus TUF A15 | 57fps | 107fps |

0 30 60 90 120

METRO EXODUS
1,920 x 1,080, Ultra, HairWorks off, Advanced PhysX off

| Asus TUF A15 | 22fps | 42fps |

0 30 60 90 120

SHADOW OF THE TOMB RAIDER
1,920 x 1,080, Highest settings, TAA

| Asus TUF A15 | 36fps | 60fps |

0 30 60 90 120

99th percentile ■ Average
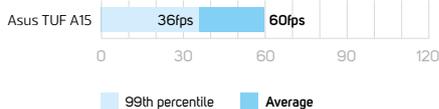
recorded a decent 99th percentile minimum of 57fps. The laptop didn't handle Metro Exodus smoothly, although it stuttered to a 99th percentile of 22fps and only hit 32fps at Medium settings.

Those scores are hindered by the A15's single-channel memory. We installed 16GB of dual-channel 2666MHz DDR4 memory and its Shadow of the Tomb Raider 99th percentile score jumped by 12fps, for example. Bear in mind that we ran all our tests without ray tracing enabled, as there are no RT cores in this GPU.

The GTX 1660 Ti may handle mainstream games at playable frame rates if you're prepared to drop the settings, especially with dual-channel memory, but the RTX 2060 lurks over its shoulder. If you're willing to accept a weaker Core i5 CPU then you can find that GPU in £999 machines. You'll need to spend £1,099 to get it alongside a Core i7 CPU and a little more to pair the RTX 2060 with the AMD Ryzen 7 4800H.

Thankfully, the Asus' AMD processor is excellent, although it was also affected by the single-channel memory. Its Handbrake video encoding score jumped from 480,615 to 545,132 once we'd improved the memory, and the multi-tasking test saw a small gain too. The A15's overall result of 172,823 rose to 190,975 with dual-channel memory.

Positively, the Ryzen chip is always faster than Intel's Core i7-10750H, and it's fine for gaming, everyday computing and

multi-tasking. We'd always recommend dual-channel memory, though, especially if you want to use your machine for content creation.

The 1080p IPS display has the resolution to deliver crisp gameplay, and it has a fast 144Hz refresh rate too, making undemanding esports titles look smooth and responsive. The quality is middling though. The contrast ratio of 1,390:1 delivers good depth, but the delta E of 5.19 is poor and the colour temperature of 7,280K results in a slight tinge of blue. The panel also only displayed 54.5 per cent of the sRGB colour gamut. Ultimately, this display looks washed out – it's acceptable for gaming, but no titles will look their best.

Meanwhile, the speakers have good volume and mid-range punch but a tinny top end and a lack of clarity when audio gets busier. Not surprisingly, battery life is poor as well. The Asus lasted for six and a half hours when working but only just over an hour when gaming. The A15 is a decent thermal performer though. It's cool inside and out, and the noise levels are fine – the fan output is modest and easy to mask.

Conclusion

The A15 has enough graphical ability to handle single-player games and esports titles at reasonable settings without ray tracing, and its AMD CPU is superb. It also has that bold blue design, a decent keyboard and a low price. That tight budget does mean a disappointing screen and mediocre connection options, though, as well as single-channel memory. It's possible to install dual-channel memory, but it's an added cost that could alternatively take you into RTX 2060 territory. The A15 is a solid enough laptop for the price, but it would be better balanced for budget gaming with a lesser CPU, an RTX GPU and dual-channel memory.

MIKE JENNINGS

VERDICT

A reasonable laptop for the money, but its screen isn't great and its memory configuration hinders performance.

TOUGH
+ Relatively cheap
+ Excellent CPU
+ Capable mid-range gaming pace
+ Good keyboard

ROUGH
– Single-channel memory
– Underwhelming screen
– Average connection options
– No ray tracing

PERFORMANCE
16/25

DESIGN
16/25

HARDWARE
15/25

VALUE
20/25

OVERALL SCORE
67%

RECOIL III PRO

15.6" Matte Full HD Screen
Intel® Core™ i7-9750H
16GB Corsair 2400MHz
6GB GeForce GTX 1660 Ti
1TB SEAGATE 7mm SATA HDD (7,200)
Genuine Windows 10 Home

This spec from
£1,189.99

PULSAR ELITE

PCS WRAITH RGB
Intel® Core™ i5-9400F
ASUS® PRIME Z390-P
8GB Corsair VENGEANCE 2400MHz
6GB GEFORCE GTX 1660
Genuine Windows 10 Home

This spec from
£849.99

PROTEUS MASTER

15.6" Matte Full HD IPS Screen
Intel® Core™ i7-9750H
8GB Corsair 2133MHz
6GB GeForce GTX 1660 Ti
1TB SEAGATE 7mm SATA HDD (5,400)
Genuine Windows 10 Home

This spec from
£1,199.99

PULSAR ULTRA

CORSAIR OBSIDIAN 500D RGB
Intel® Core™ i9-9900K
Gigabyte Z390 AORUS Master
32GB Corsair VENGEANCE 3000MHz
11GB GEFORCE RTX 2080 Ti
Genuine Windows 10 Home

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£2,849.99

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GAMING LAPTOP
LENOVO LEGION 7i

/ **£2,199** inc VAT

SUPPLIER laptopsdirect.co.uk

Lenovo's Legion 7i is a pricey powerhouse that balances Lenovo's hard-nosed design with serious gaming power. Its GeForce RTX 2080 Super Max-Q GPU balances 3,072 stream processors and 8GB of memory with modest base and boost speeds of 735MHz and 1080MHz. Meanwhile, its Core i7-10750H CPU has six Hyper-Threaded cores, and there's 16GB of dual-channel DDR4 memory clocked to a rapid frequency of 3200MHz.

Storage is handled by a 1TB Samsung PM981 NVMe SSD that delivers superb read and write speeds of 3,506MB/sec and 3,015MB/sec, and you get Wi-Fi 6 and a Gigabit Ethernet connection too.

Meanwhile, the exterior sports a curious blend of business-like subtlety and gaming touches. The body is made from gunmetal aluminium that looks like it could have come straight from a workstation – the speaker grilles and power button are subtle, and there are no extraneous angles. That's counteracted by RGB LEDs around the base, with lights emerging from the air vents, more lighting on the keyboard and an illuminated logo. Even the right-hand USB port has RGB LEDs.

That port is a USB 3.2 Gen 1 socket with a maximum speed of 5GB/sec, and there are also two USB 3.2 Gen 2 ports with double the bandwidth. The connection options are rounded out by a USB 3.1 Gen 2 Type-C port that supports Thunderbolt and DisplayPort, along with an HDMI output and a 720p webcam with a privacy shutter. The only notable omissions are card and fingerprint readers, which may prove irritating if you want to use this laptop for work.

It's all wrapped in a body that weighs 2.1kg and measures 20mm thick, which is impressively svelte considering the specification. Build quality is reasonable too – the Lenovo is sturdy enough to withstand being lugged around the house and to LAN events. The only downside is the area beneath the keyboard, which flexes a little too much.

The keyboard's typing action is consistent, firm and fast, though, and its RGB LEDs can be customised using Corsair's iCUE system. It's fine for gaming too, although the buttons only have a modest 1.3mm of travel. The trackpad is accurate as well, and its buttons are fast, but it's also positioned so far on the left that it conflicts with the WASD keys.

Our review model of the Legion uses the part number 81YU001SUK and is one of the more expensive models. The only pricier option costs £2,899 and upgrades you to a Core i9-10980HK CPU, 32GB of memory and a 240Hz display. There's also a £1,999 machine that pairs the Core i7 CPU with an RTX 2070 Super Max-Q, and more affordable options balance a good range of lower-spec Intel CPUs and Nvidia GPUs.

Performance
The RTX 2080 Super Max-Q played Shadow of the Tomb Raider with ray tracing at a smooth minimum of 50fps and zipped through Doom Eternal at 133fps. It could only manage 29fps in our tough Metro Exodus benchmark at Ultra settings, but activating DLSS improved that score to 31fps – drop the settings below Ultra and it will be playable. It's great gaming performance for a slim mobile machine at the screen's native 1,920 x 1,080 resolution.

The CPU's overall result of 195,446 is superb, showing that this machine has enough power to tackle content creation and work tasks, as well as gaming. There are two ways to get more CPU power, and neither is ideal: opt for a pricier Core i9 CPU, or choose an AMD Ryzen 7 or 9 chip, which aren't yet available in laptops with the RTX 2080 Super.

SPEC

CPU
2.6GHz Intel Core i7-10750H

Motherboard
16GB 3200MHz DDR4

Graphics
Nvidia GeForce RTX 2080 Super Max-Q 8GB

Screen
15.6in 1,920 x 1,080 IPS 144Hz G-Sync

Storage
1TB Samsung PM981 M.2 SSD

Networking
Dual-band 802.11ax Wi-Fi, Gigabit Ethernet, Bluetooth 5

Weight
2.1kg

Ports
2 x USB 3.2 Gen 2, 1 x USB 3.2 Gen 1, 1 x USB 3.2 Gen 2 Type-C/Thunderbolt 3/DisplayPort, 1 x audio, 1 x HDMI

Dimensions (mm)
360 x 255 x 20 (W x D x H)

Operating system
Windows 10 Home 64-bit

Warranty
One year parts and labour return to base

AUGUSTUS

+ Consistently fast
+ Not too large, heavy or loud
+ Smooth, high-quality screen
+ Relatively affordable

NERO

− No card or fingerprint reader
− Occasional build quality issues
− Poor battery life

Surprisingly, noise levels are never bad either. Fan noise is present during gaming, but it's moderate and consistent. A bit of warm air escapes from the side vents and the base panel becomes hotter, but it's never uncomfortable. On the inside, the GPU's peak delta T of 41°C is fine.

During gaming tests, the processor throttled to 3.3GHz, and dropped to 2.8GHz during a full-system stress test after hitting a peak delta T of 73°C, but the throttled speed didn't hinder gaming. It's unlikely that you'll run the chip at 100 per cent for prolonged periods anyway, even when working. Happily, there were no throttling issues during CPU-based benchmarks.

Meanwhile, the display has a 144Hz refresh rate and Nvidia G-Sync support, so it's set up for smooth, fast gaming. The contrast ratio of 1,083:1 is enough to prove punchy without going overboard, and the delta E of 3.75 shows reasonable colour reproduction. Uniformity levels are impressive, with the brightness only deviating by 4 per cent, and the Lenovo's display rendered virtually 100 per cent of the sRGB and Adobe RGB gamuts. The only issue is the cool colour temperature of 7,604K. It doesn't hamper gaming, but it's too wayward for some colour-sensitive workloads.

The display is paired with great speakers, with huge volume and well-balanced audio. The bass could be stronger, but that's a minor complaint, and these speakers are better than those on most gaming laptops.

Don't expect much from the battery though. It lasted for just over two hours in a work test, and only one hour and

DOOM ETERNAL
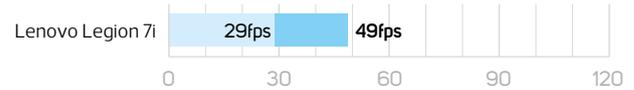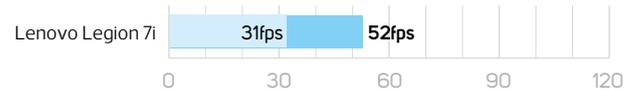1,920 x 1,080, Vulkan, Ultra settings

Lenovo Legion 7i — 133fps / 189fps (scale 0–240)

METRO EXODUS
1,920 x 1,080, Ultra, HairWorks off, Advanced PhysX off, Ultra RTX

Lenovo Legion 7i — 29fps / 49fps (scale 0–120)

1,920 x 1,080, Ultra, HairWorks off, Advanced PhysX off, Ultra RTX, DLSS

Lenovo Legion 7i — 31fps / 52fps (scale 0–120)

SHADOW OF THE TOMB RAIDER
1,920 x 1,080, Highest settings, High ray-traced shadows, TAA

Lenovo Legion 7i — 50fps / 82fps (scale 0–120)

▫ 99th percentile   ▪ Average
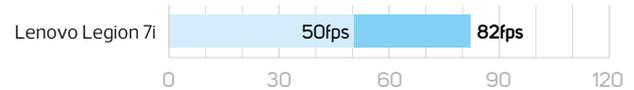
57,798 — GIMP IMAGE EDITING
506,720 — HANDBRAKE H.264 VIDEO ENCODING
195,291 — HEAVY MULTI-TASKING
195,446 — SYSTEM SCORE

22 minutes in gaming. Halving the brightness added ten minutes to that result. In short, don't expect to get much done unless you're plugged into the mains.

Conclusion

Lenovo's Legion 7i may look staid, but delve into this laptop and you'll find loads to like. Its components are reliably fast, it has decent build quality, a comfortable keyboard and reasonable thermal performance, as well as a fast screen that's easily good enough for gaming. It's even relatively affordable compared with similarly specified rivals. Its battery life and colour temperature could be better, and the base has a bit of flex in it, but the Legion is otherwise one of the best RTX 2080 Super laptops around.

MIKE JENNINGS

VERDICT

Lenovo's Legion serves up great performance, screen quality and ergonomics at a reasonable price. It's a winner for high-end portable gaming power.

PERFORMANCE **22**/25
DESIGN **21**/25
HARDWARE **23**/25
VALUE **20**/25

OVERALL SCORE **86**%

INTEL Z490 GAMING PC

CYBERPOWER INFINITY 910 RTX / **£2,099** inc VAT

SUPPLIER cyberpowersystem.co.uk

CyberPower's Infinity 910 RTX CyberPower packs in an awful lot of hardware considering its £2,099 price, including an RTX 3080 graphics card. The card inside this machine is an MSI Ventus 3X 10G OC model, with three beefy fans, a subtle industrial design and a boost clock that's been improved from 1710MHz to 1740MHz. More importantly, it's based on Nvidia's new Ampere architecture, with 8,704 CUDA cores and 10GB of GDDR6X memory.

Meanwhile, the Core i9-10850K processor is the new cut-price 10-core CPU in Intel's Comet Lake Core i9 range, but the specification remains impressive. It has ten Hyper-Threaded cores, a base speed of 3.6GHz and a turbo peak of 5.1GHz that rises to 5.2GHz with TVB.

Those speeds are only 100MHz behind Intel's Core i9-10900K. CyberPower has paired this high-end chip with 16GB of 3200MHz memory, a 500GB WD Black SN750 NVMe SSD and a 2TB hard disk, and it's all powered by a Corsair RM850x PSU, which has an 80 Plus Gold certification and a modular design.

It's all plugged into an MSI MPG Z490 Gaming Carbon WiFi motherboard, which has two M.2 connectors with heatsinks, a pair of spare DDR4 slots, and free 16x and 1x PCI-E 3 slots.

Connection options are good too, with 2.5Gbps Ethernet, dual-band Wi-Fi 6 and Bluetooth 5.1, alongside four USB 3.2 Gen 2 connectors and a faster USB 3.2 Gen 2x2 Type-C port. It's also good to see a decent ALC1220 audio codec, and ample on-board fan and USB connectors. The only key missing features are PCI-E 4 support, and any on-board buttons and displays.

SPEC

CPU
3.6GHz Intel Core i9-10850K

Motherboard
MSI MPG Z490 Gaming Carbon WiFi

Memory
16GB Corsair Vengeance LPX Black 3200MHz DDR4

Graphics
MSI GeForce RTX 3080 Ventus 3X 10G OC

Storage
500GB WD Black SN750 M.2 SSD, 2TB Seagate Barracuda hard drive

Networking
2.5Gbps Ethernet, dual-band 802.11ax Wi-Fi, Bluetooth 5.1

Case
NZXT H511

Cooling
CPU: Cooler Master MasterLiquid Lite 240 with 2 x 120mm fans; GPU: 2 x 90mm fans; roof: 1 x 120mm fan; rear: 1 x 120mm fan

PSU
Corsair RM850x 850W

Ports
Front: 1 x USB 3.2 Gen 2, 1 x USB 3.2 Gen 1, 1 x audio; rear: 4 x USB 3.2 Gen 2, 1 x USB 3.2 Gen 2x2 Type-C, 2 x USB 2, 1 x PS/2, 1 x optical S/PDIF, 5 x audio

Operating system
Microsoft Windows 10 Home 64-bit

Warranty
Two years parts and labour, plus third year labour only. First six months collect and return, then return to base

All this gear is housed in an NZXT H511 chassis, which is a modified version of the common H510, although disappointingly, it lacks a USB Type-C port. Elsewhere, build quality is solid and it looks smart, with a sleek front panel, clean lines and a tempered glass side panel. The 210mm width and 460mm height make it relatively compact too.

In the front of the case, you'll find a Cooler Master MasterLiquid Lite radiator with two 120mm fans, while two more 120mm fans function as roof and rear-mounted exhausts. All four fans have customisable lighting, and they're programmed to rotate through a swathe of bright colours alongside two case-mounted strips of RGB LEDs.

CyberPower has kept the cabling tidy around the front, even if the NZXT's modest size means the insides are a little cramped. Around the rear, the build remains neat thanks to fastidious cabling, and there's space for one spare 3.5in drive and two 2.5in drives. There's also a control box with space for three more synchronised fans.

CyberPower's machine is covered by a three year labour warranty with two years of parts coverage, which is good, although you only get six months of collect and return service. As a point of comparison, this PC is £300 cheaper than last month's Scan 3XS Vengeance XTi iCUE, which had a stock-speed RTX 3080 alongside a 12-core AMD Ryzen 9 3900X and a motherboard with slightly poorer connection options. Scan's system justified its higher price with the extra multi-threaded CPU power, its PCI-E 4 SSD and a better warranty, but the CyberPower offers a decent saving if gaming performance is your priority.

BUZZ LIGHTYEAR

+ Superb gaming speed
+ Neat and compact chassis
+ Solid component choices

BUZZ KILLER

− AMD Zen 3 CPUs now better than Intel
− A little too noisy
− Mediocre SSD

60,302
GIMP IMAGE EDITING

754,057
HANDBRAKE H.264 VIDEO ENCODING

293,940
HEAVY MULTI-TASKING

286,013
SYSTEM SCORE

Performance

When running our test games at 4K, the CyberPower's 99th percentile minimum was an astounding 132fps in Doom Eternal, and it can handle ray-traced games at this setting if you enable DLSS too – even our hardcore Metro Exodus test on Ultra settings didn't drop below 41fps. If you play games at 2,560 x 1,440 then you'll have no trouble turning on all the eye candy, even without DLSS.

The Intel CPU and overclocked GPU help the CyberPower outpace last month's Scan PC in most games. However, the performance of AMD's latest Zen 3 silicon (see p16) means AMD can properly compete on this front now too, although the new Core i9-10850K is still competitive at this price.

Meanwhile, the new Intel CPU's image editing score of 60,302 is marginally better than that of the Ryzen 9 3900X used in Scan's machine, but behind the results from AMD's new Ryzen 9 5900X (see p18). The CyberPower was also 64,000 points behind the Scan in our heavily multi-threaded Handbrake video-encoding benchmark, which is no surprise given the Scan's two extra CPU cores.

Meanwhile, the SSD's read and write speeds of 2,327MB/sec and 1,006MB/sec are miles behind the pace delivered by the PCI-E 4 drives deployed on AMD platforms, although you rarely see these peak speeds outside of large-scale file transfers.
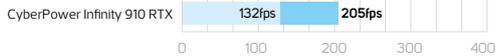
Finally, CyberPower's machine is an average thermal performer. There are no issues with the CPU and GPU delta Ts of 45°C and 53°C, but it's not particularly quiet. Whether it's idle or playing games, you can hear the noise made by this system.

Conclusion

The GeForce RTX 3080 is fantastic, and the CyberPower has a good motherboard, solid components and a compact, neat chassis. Intel may have lost its single-threaded performance lead to Zen 3, and the Ryzen 9 3900X and 5900X have two more cores for multi-threading performance too. However, the Core i9-10850K is still a cracking CPU for a gaming PC such as this one. If gaming is your top priority, then the CyberPower is a great system for the money.

MIKE JENNINGS

VERDICT
The RTX 3080 offers dazzling speeds, and this keenly priced PC is capable elsewhere too.

PERFORMANCE
24/25

DESIGN
22/25

HARDWARE
23/25

VALUE
22/25

OVERALL SCORE
91%

Custom kit

Phil Hartup checks out the latest gadgets, gizmos and geek toys

SUBSONIC ADVANCED HEADSET STAND / **£18.76** inc VAT

SUPPLIER amazon.co.uk

The aptly named Subsonic advanced headset stand is, as you would expect, a headset stand for when you want to go below the speed of sound. What happens when you take this stand above 768mph is anybody's guess. When stationary on a desk, however, the Subsonic turns out to be quite clever. Its first role is as a headset stand, and it does this perfectly adequately, as you would expect, but it also has a couple of additional roles.

The Subsonic acts as a two-port USB 2 hub, with the ports located at 90 degrees from each other. You wouldn't want use it for storage devices given the low speed, but it's ideal for headsets, gamepads, keyboards and so on.

It also acts as a mouse bungee, with a cable grabber through the middle to keep your mouse unencumbered by any desktop clutter. The Subsonic has RBG lighting as well, offering an array of selectable colours so it can fit in with an unaddressed illuminated setup. It's a surprisingly efficient, if slightly ostentatious, solution to desktop tidiness issues.

Subpar ●●●●○ **Subsonic**

LAMICALL GOOSENECK PHONE HOLDER / **£14.44** inc VAT

SUPPLIER amazon.co.uk

A phone holder equipped with a very long, sauropod-like neck, the Lamicall is designed to give you a grippy device to hold your phone. At the base of the device is a plastic clamp with cushioned grippers to avoid damaging the surface to which you attach it. At the head is the claw for your smartphone, or potentially any similar lightweight device you can cram into its jaws.

The claw has rubberised grips, and manages to be simple and convenient to use, so you can pop a device in and out of it easily. It's also substantial enough that a smartphone or similar device, once properly placed, isn't going to fall out. The claw rotates, but that's the limit of the articulation – most of it has to come from the neck. Scaled up to this size, the gooseneck becomes rather ungainly and awkward, but once it's in place it does effectively keep your phone gripped in front of you.

Goosed ●●●○○ **Gooseneck**

SADES MECHANICAL HALF GAMING KEYBOARD / **£21.59** inc VAT

SUPPLIER amazon.co.uk

The Sades is a keyboard for people who know they're only going to use the left half of their keyboard's keys for their game of choice. You get a mechanical keyboard that covers as far across as QWERT, with the numbers 1–6 and F1–F5, as well as Escape and tilde. You even get half a wrist rest with it. The Sades itself is solid and has the sort of satisfying click you'd expect from a mechanical gaming keyboard, and the wrist rest is also surprisingly comfortable, lending the unit a chunky, toy-like quality, but in a good way.

The shape of the Sades means it benefits from being placed to the left of a regular keyboard, opposite to where a mouse would sit on the right, which is a more comfortable setup than playing with a main keyboard in a typing position. The Sades is also illuminated, with different-coloured lights in the rows from top to bottom. You better like this colour scheme, as it's the only one you get, without even the option to switch off the lights. The Sades does a good job, though, even if it looks a little haphazard.

Half measure ●●●○○ **Half-Life**

NURALOOP EARPHONES / **£199** inc VAT

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SUPPLIER nuraphone.com

The NuraLoops are paired Bluetooth 5 earphones that take advantage of the same ear-profiling system that appeared in the Nuraphones headphones. This technology involves the earphones testing your ears using an array of sounds during the setup procedure, which then creates a profile that tailors the output to your ears. What happens between the profile and the sound output is rather opaque, but the net result is extraordinarily high sound quality.

Controls are simple and can be remapped. By default, you double-tap the right earphone to pause or play, and double-tap the left one for noise cancelling. The earphones also respond to touch as if they were dials – you can adjust volume level on the right, and noise cancelling on the left. The noise cancelling is particularly impressive – even if you're not listening to anything, it can shut out most of the outside world, but not so much that you won't hear nearby cars and so on.

The controlling app provides options for automatic power control, so the earphones detect if they're in use or have been removed, but there's also a manual mode with an additional timer if you want more direct control. Meanwhile, charging comes courtesy of a magnetised USB connector that hooks onto the cable between the earphones, and you can also use this connection to hook up a 3.5mm headphone jack if the batteries are low. The batteries themselves are good for up to 16 hours and charge fast.

All this, and the NuraLoop handles voice calls well too. The device is supplied with four different-sized earpieces, and it will even tell you if it isn't fitted properly. This almost disconcerting level of attention to detail is evident with the NuraLoop as a whole and the result is outstanding.

Feedback loop ●●●●● **NuraLoop**

RUNNINGSNAIL MULTI-PURPOSE CRANK RADIO / **£19.90** inc VAT

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SUPPLIER amazon.co.uk

The RunningSnail is a curious amalgamation of an old-school portable FM/AM radio, an LED torch and a 1,000mAh power pack with a small solar panel and a crank-powered generator. The old-school credentials of the radio are evidenced by the lack of a headphone connector and matching dials for tuning and volume (the latter doubles as an on/off switch). You can get a decent-quality signal and sound with some fiddling, but it can be finicky.

The heart of the RunningSnail is the battery and the crank system that powers it, and this can be used to charge other devices, or it can be recharged via micro-USB.

The 1,000mAh capacity is fine for the radio and torch, but a typical smartphone will quickly slurp that up and still have room for much more.

A light on the front indicates when the RunningSnail is being charged, either by USB or the crank, but there's no indication of how much charge is in there. That's fine for the radio or the torch – if it runs out you can wind the handle until it works again, but you can't hook it up to your phone and crank the handle continuously to watch movies indefinitely. It's a handy gizmo to have around for emergencies and power cuts, but that's about it.

Hopping slug ●●●○○ **Running snail**

Seen something worthy of appearing in Custom Kit? Send your suggestions to ✉ phil.hartup@gmail.com

Speed demons

Antony Leather checks out the latest PCI-E 4 NVMe M.2 SSDs to see which super-fast drives are worth your cash

How we test

As PCI-E 4 motherboards become more commonplace, and with Nvidia's RTX IO tech allowing a graphics card to bypass the CPU and load game data directly from an SSD into VRAM, the value of upgrading to a PCI-E 4 SSD is becoming more tangible. However, they're still a premium and relatively rare option.

We've used an AMD Ryzen 5 3600XT, along with an MSI MEG X570 Unify motherboard, to test the PCI-E 4 SSDs this month, although all signs point to Intel's current Z490 motherboards being able to support these SSDs with its future Rocket Lake CPUs too. For now, though, you'll need a motherboard with either AMD's X570 or B550 chipset.

We've put each SSD through its paces in both CrystalDiskMark and AS-SSD to assess sequential and random performance in a range of tests, as well as stress-testing each SSD to see how toasty it gets under peak loads – it's important to assess the performance of heatsinks or whether they need them at all.

As many of this month's SSDs are identical under the hood, and all use the same capacity and retail for very similar prices, we've stuck to the usual scoring regime of performance, features and value, since features are where many battles are won. The value is a weighted calculation based on a combination of the performance, features and price, with the final score being the total of all three scores.

Contents

1TB CORSAIR FORCE MP600 / **£172** inc VAT

With quite a long history of making SSDs, Corsair at least has some brand awareness when it comes to pitching its Force MP600 drive, which is otherwise identical to some of the other drives on test. The 1TB model we've reviewed here costs £172 inc VAT, which is within spitting distance of the other two SSDs based on a Phison E16 controller and TLC NAND this month. So as we've said in those reviews, your choice here really comes down to price, features and any other factor outside of performance, where the three will perform very similarly.

The Force MP600 looks attractive and much more like it means business than the Sabrent SSD, and that large black heatsink helped to chill it to a peak temperature of 66°C too. This means it's a much better option if your motherboard lacks its own M.2 heatsinks, or you prefer to use your SSD's heatsink, perhaps to highlight the fact that you have a super-fast PCI-E 4 SSD behind a tempered glass window. However, the Corsair's heatsink is quite large too, reaching 1cm up from the SSD's PCB, which may interfere with other devices plugged into your motherboard.

JEDI
+ Attractive heatsink
+ Much faster than PCI-E 3 M.2 SSDs
+ Good warranty

DARK SIDE
− Not everyone needs a heatsink
− Slightly pricier than competition
− Software feels dated

SPEC

Full capacity 1TB

Formatted capacity 931GB

Heatsink Yes

NAND TLC

Controller Phison E16

Endurance 1,800 TBW

Warranty Five years

Once formatted, our sample had a capacity of 931GB, with the rest of the storage space allocated to overprovisioning, but Corsair's software can alter this amount to gain back a little more capacity.

The software is reasonable, but feels quite dated, especially compared with Corsair's iCUE lighting and cooling software. The software enables you to see the SSD's temperature, and also clone your old storage drive to your new SSD, but it's not quite as feature-rich as the copy of Acronis True Image included with the Sabrent Rocket NVMe 4.0.

You get the same warranty, though, which includes a guarantee for 1,800 written terabytes – enough to fill the drive nearly 2,000 times, with the warranty stretching to five years too. Like other SSDs based on Phison controllers, the capacity options include 500GB and 2TB options as well, should a 1TB model not offer enough space for all those storage-eating games, or if you want to save yourself some money.

In terms of performance, the Corsair Force MP600 was a little behind the other two SSDs based on Phison controllers on test when it comes to sequential read speed, hitting 4,837MB/sec compared to the usual figures of around 5,000MB/sec, but in most other tests, it was faster than the other two drives, or on par with them, generally sitting within the margin of error for the software.

It also posted the best 4K random read speed in CrystalDiskMark of 1,570MB/sec, even beating Samsung's mighty 980 Pro – only the Sabrent Rocket NVMe 4.0 managed to produce faster 4K random write speeds.

Meanwhile, AS-SSD saw sequential speeds that were much closer to the competition – in real-world use, none of these speed differences will be noticeable.

Conclusion
If aesthetics are important, the Corsair Force MP600 goes a long way to justifying the extra few pounds you'll need to spend over the Sabrent Rocket NVMe 4.0. Its snazzy heatsink looks the part, and it does a good job of cooling the SSD under heavy load conditions too. However, bear in mind that most PCI-E 4-equipped motherboards already include at least one half-decent M.2 heatsink, and the Sabrent also has the bonus of a full copy of Acronis True Image.

That said, while the Corsair's software looks a bit dated, it does at least offer a drive cloning option, unlike the Gigabyte Aorus NVMe Gen4 SSD. The Sabrent might offer a better deal overall, but the performance of all three Phison-based drives is very similar – if you want a PCI-E 4 SSD with a heatsink then the Corsair is the one to buy.

VERDICT
A slightly premium SSD with a great-looking and effective heatsink.

PERFORMANCE 43/50

FEATURES 19/20

VALUE 27/30

OVERALL SCORE **89**%

1TB GIGABYTE AORUS NVME GEN4 SSD / **£169** inc VAT

SUPPLIER scan.co.uk

I f you like your M.2 SSD to have some heft to it, then the Gigabyte Aorus NVMe Gen4 SSD is for you. The massive slab of copper strapped to the PCB means you'll definitely want to make sure it's well secured to your motherboard, but you'll also need your system's colour scheme to accept it, as it has a habit of sticking out.

Like the other two M.2 PCI-E 4 SSDs based on Phison controllers on test this month, the Aorus NVMe Gen4 SSD retails for around £170 inc VAT. That means there are just a few pounds separating it from the prices of the Sabrent Rocket NVMe 4.0 and Corsair's Force MP600.

Like the Corsair Force MP600, the Gigabyte's heatsink is removable, should you wish to use your motherboard's own heatsink, and it's a little shorter than the one on the Corsair SSD too, so it's less likely to clash with other components on your motherboard.

The software included with the Gigabyte is very basic, though, offering just the drive status and a secure erase function, but no drive cloning feature or separate software for the task. This means that the Corsair and Sabrent options offer more convenience if you're planning to clone your existing drive, unless you have the option of using software you already own.

In terms of core specs, the Phison E16 controller sits at the heart of the SSD, along with 1TB of TLC NAND memory. This capacity

stretches to 931GB once the drive is formatted, with the rest of the storage space used for overprovisioning.

However, again, there's no option in the software to adjust the overprovisioning, as you can with the other drives on test. Thankfully, Gigabyte includes the same five year warranty as you get from Sabrent or Corsair, plus an identical 1,800 terabytes written (TBW) endurance rating, which is significantly higher than that of Samsung's 980 Pro.

Firing up the SSD and running our thermal stress test saw the heatsink keep the SSD below a peak of 66°C, which is far better than the heatsink-less Sabrent and Samsung SSDs.

This heatsink will help to keep temperatures in check in tight spaces, especially if there's little local airflow where you install the SSD on your motherboard.

In terms of performance, the Gigabyte generated similar test results to the other two SSDs based on Phison controllers this month, with a sequential read speed in CrystalDiskMark of 5,002MB/sec and a read speed of 4,258MB/sec.

The 4K 32-queue, 4-thread test saw read and write speeds of 1,570MB/sec and 1,289MB/sec respectively, which are both similar to Corsair and Sabrent's efforts, as are the 4K random read and write figures in AS-SSD of 76MB/sec and 193MB/sec.

Only the Samsung 980 Pro managed faster speeds, with its sequential read speed of 6,804 and write speed of 4,934 dwarfing those of every other SSD on test by sizeable margins, including those of the Aorus NVMe Gen4 SSD, but for a much higher price.

SPEC

Full capacity	1TB
Formatted capacity	931GB
Heatsink	Yes
NAND	TLC
Controller	Phison E16
Endurance	1,800 TBW
Warranty	Five years

COPPER

+ Competitive performance
+ Large, effective heatsink
+ Reasonable price

PLASTIC

− Poor software suite
− Divisive heatsink colour

Conclusion

The basic software suite is all that separates the Gigabyte Aorus NVMe Gen4 SSD from an award, as it otherwise performs almost identically to Corsair and Sabrent's offerings this month, using the same NAND memory and controller. The heatsink works well at keeping the SSD cool too, although it's likely your PCI-E 4 motherboard will have its own heatsink too.

The copper finish also pegs the SSD into a certain aesthetic that some may find doesn't suit their system. However, if you're not picky about looks, and you don't have a need to clone your existing drive, the Gigabyte is still a speedy SSD.

VERDICT

A fast SSD with a compact, hefty heatsink, although its software suite is poor compared with the competition.

PERFORMANCE	FEATURES	OVERALL SCORE
43/50	18/20	**88**%
VALUE 27/30		

1TB SABRENT ROCKET NVME 4.0 / **£165** inc VAT

With so few PCI-E 4 SSDs on the market at the moment, and even fewer controllers to differentiate them, the Sabrent Rocket NVMe 4.0 has its work cut out if it wants to differentiate itself from the Corsair Force MP600 and Gigabyte Aorus NVMe Gen4 SSD.

All three of these drives are based on the same Phison PS5016-E16 controller, as well as Kioxia TLC NAND memory. What's more, all three of these competing drives sport the same capacity options, with our sample offering 1TB of total storage space, with a formatted capacity of 931GB – the rest of the storage space is used for overprovisioning. The Sabrent also offers the same 1,800TBW endurance rating and five year warranty as the Corsair and Gigabyte drives.

At first glance, the Sabrent Rocket NVMe 4.0 might appear to lose ground to the other two SSDs with its lack of a sporty heatsink. As a result, during our thermal stress test, the Sabrent's peak temperature hit 82°C, while the Corsair MP600, for example, reached just 66°C in the same test. However, there's also a sliver of copper on top of the SSD beneath the

label to spread the heat, allowing you to easily use your motherboard's heatsink instead.

As a result, we can't be too harsh here, as most PCI-E 4 motherboards offer at least one M.2 port with a heatsink. For an extra £50, you can obtain the same SSD with a large heatpipe-equipped heatsink, but we'd sooner spend less money and find another means of cooling it.

Meanwhile, Sabrent's software is very similar to that of Corsair, with basic controls over firmware updates and overprovisioning, as well as temperature monitoring. It also looks less dated than Corsair's supplied software. What's more, while the Corsair's software can clone SSDs, as a bonus, you get a full copy of Acronis True Image with the Sabrent Rocket NVMe 4.0. This is a more powerful and flexible tool when it comes to drive imaging; given that the two SSDs cost around the same amount of money, if you're not fussed by the Corsair's heatsink, the Sabrent Rocket NVMe 4.0 just edges ahead in terms of value.

As for performance, the Sabrent's test results were not surprisingly almost identical to those of the other three SSDs based on Phison controllers on test this month. That said, the Corsair lost a little ground to the Sabrent in a couple of tests, which resulted in the latter gaining a small advantage, with peak sequential read and write speeds of 5,002MB/sec and 4,258MB/sec.

Interestingly, there were very few areas where the more expensive Samsung 980 Pro was significantly ahead. The only notable

area was raw sequential read speed, which was close to 1,802MB/sec faster, while its sequential write speed was 676MB/sec faster. These tests don't represent most people's real world though – you'll be hard-pushed to tell the difference for the most part.

Conclusion

While the performance of the Sabrent Rocket might be similar to that of the other drives based on Phison controllers this month, and you don't get a fancy heatsink with it either, the Sabrent offers superb value. Not only is it keenly priced, but you also get a copy of Acronis True Image, and most PCI-E 4 motherboards come with M.2 heatsinks anyway.

However, the three SSDs are identical under the hood, so it's really down to how much you want to spend and whether you need a heatsink. In other areas, such as performance and warranty, there's nothing between the three drives, but the Sabrent Rocket NVMe 4.0 just about offers the best value for money.

ROCKET SHIP
+ Reasonable price
+ Fast sequential transfers
+ Good software

ROCKET SALAD
− No heatsink
− Can get toasty without extra cooling
− Competition looks better

SPEC
Full capacity 1TB

Formatted capacity 931GB

Heatsink Yes, slimline

NAND TLC

Controller Phison E16

Endurance 1,800 TBW

Warranty Five years

VERDICT
A great software bundle just about pips the competition to the post, but the Sabrent performs similarly to the competition.

PERFORMANCE	FEATURES
44/50	19/20

VALUE
29/30

OVERALL SCORE
92%

1TB SAMSUNG 980 PRO / **£216** inc VAT

W ith the Samsung 980 Pro, we finally get on to an SSD with some different silicon under the hood, and it's also much more expensive than other SSDs on test this month. That's mainly because Samsung is boasting some serious performance figures for the 980 Pro, with a claimed 7,000MB/sec read speed. If this stands up to testing, it would be 2,000MB/sec faster than the competition, basically enabling you to dish out an additional 2GB/sec when transferring files from the SSD over a PCI-E 4 interface.

Unlike most other PCI-E 4 SSDs that use the Phison E16 controller, the 980 Pro uses Samsung's own Elpis controller, along with 3D TLC NAND memory. Our 1TB model also has a 114GB single-level cell (SLC) cache. This means that if the drive filled to full capacity, there will be a marked drop-off in performance as the SSD starts writing directly to the tri-level cell (TLC) NAND. However, it's unlikely you'll see that happen, even if you deal with lots of large files regularly.

Compared with Samsung's fantastic PCI-E 3 970 Pro drives, the 980 Pro uses TLC rather than multi-level cell (MLC) NAND, which is cheaper, but slower and less durable in terms of write endurance. As a result, the terabytes written (TBW) rating has fallen from 1,200TB to just 600TB, although the overall warranty still stands at five years. Unless you absolutely hammer the drive and write over 2TB of data to the drive each week, you won't get near that limit. Even so, that endurance rating is much lower than that of the other drives on test this month.

Like previous Samsung M.2 SSDs, the 980 Pro lacks a fully fledged heatsink, and instead has a thin sliver of copper sitting on the underside of the SSD. During our thermal stress test, the drive reached a peak temperature of 81°C, which is undeniably toasty, but bear in mind that most PCI-E 4 motherboards are equipped with heatsinks that will help to rein in those temperature spikes.

Unlike the Phison-based drives, the Samsung also has a wider range of capacities available, with models ranging across 250GB, 500GB, 1TB and (soon) 2TB capacities. They're not cheap though – our 1TB sample demands a hefty price of £216 inc VAT, which is around £50 more than the Sabrent Rocket NVMe 4.0 (see p51).

The 980 Pro also comes with Samsung's Magician software, which has a more modern appearance than the other manufacturers' software packages we tested this month. It allows you to see drive information, run performance benchmarks, adjust overprovisioning and carry out performance optimisation, as well as view the drive's health and how much data has been written to it. Samsung offers free separate data migration software as well.

Amazingly, Samsung's performance claims largely held up. The sequential speeds in CrystalDiskMark were phenomenal, with a read speed of 6,800MB/sec, which is nearly 2GB/sec faster than the competition and a massive boon if you regularly shunt big files around. The write speed of just under 5GB/sec was rapid too, being a good 700MB/sec quicker than the competition.

However, 4K random performance was average at best, and the Samsung certainly didn't have an advantage over the other SSDs in this Labs in most of the other tests. The other notable exceptions were our AS-SSD IOPS tests, where the Samsung pulled in front of the other drives, but not by such a huge margin.

Conclusion

The Samsung 980 Pro is undoubtedly the fastest consumer M.2 SSD out there right now, with blistering sequential performance, especially when reading. However, the lack of any other eyebrow-raising numbers to justify the price tag means that, unless you must have the fastest SSD, the cheaper Phison-based drives offer far better value and are also still extremely fast. **CPC**

SPEC

Full capacity 1TB

Formatted capacity 931GB

Heatsink Yes, slimline

NAND TLC

Controller Samsung Elpis

Endurance 600TBW

Warranty Five years

SAMSUNG

+ Blistering sequential performance
+ Excellent software
+ Fast IOPS performance

SAMSTUNG

− Very expensive
− Low endurance rating
− No topside heatsink

VERDICT

Ridiculously fast, but only in sequential tests, and you pay a hefty price for it.

PERFORMANCE 48/50
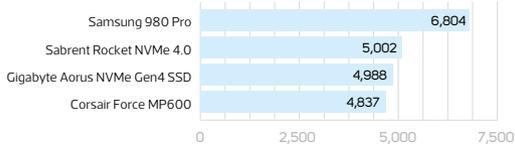
FEATURES 17/20

VALUE 23/30

OVERALL SCORE 88%

PCI-E 4 NVME SSD LABS RESULTS

CRYSTALDISKMARK SEQUENTIAL 1M Q8 READ (MB/SEC)

Samsung 980 Pro	6,804
Sabrent Rocket NVMe 4.0	5,002
Gigabyte Aorus NVMe Gen4 SSD	4,988
Corsair Force MP600	4,837

AS-SSD SEQUENTIAL READ (MB/SEC)

Samsung 980 Pro	5,423
Sabrent Rocket NVMe 4.0	4,201
Gigabyte Aorus NVMe Gen4 SSD	4,187
Corsair Force MP600	4,185
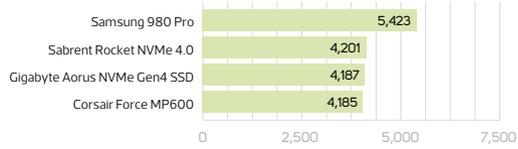
CRYSTALDISKMARK SEQUENTIAL 1M Q8 WRITE (MB/SEC)

Samsung 980 Pro	4,934
Corsair Force MP600	4,283
Gigabyte Aorus NVMe Gen4 SSD	4,279
Sabrent Rocket NVMe 4.0	4,258
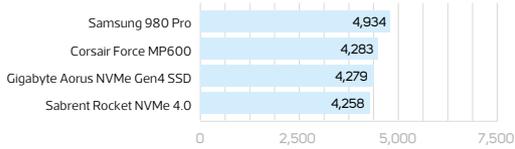
AS-SSD SEQUENTIAL WRITE (MB/SEC)

Gigabyte Aorus NVMe Gen4 SSD	4,000
Samsung 980 Pro	3,967
Corsair Force MP600	3,904
Sabrent Rocket NVMe 4.0	3,848
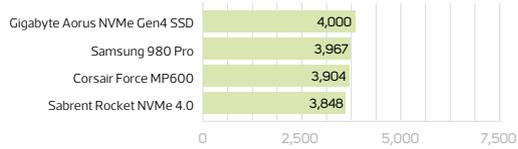
CRYSTALDISKMARK RANDOM 4K Q32 T4 READ (MB/SEC)

Gigabyte Aorus NVMe Gen4 SSD	1,570
Sabrent Rocket NVMe 4.0	1,565
Corsair Force MP600	1,498
Samsung 980 Pro	1,486
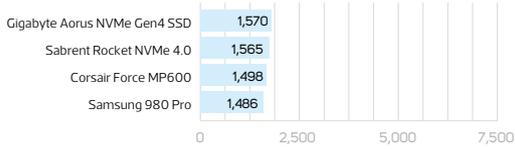
AS-SSD 4K RANDOM READ (MB/SEC)

Samsung 980 Pro	79
Sabrent Rocket NVMe 4.0	76
Corsair Force MP600	75
Gigabyte Aorus NVMe Gen4 SSD	69
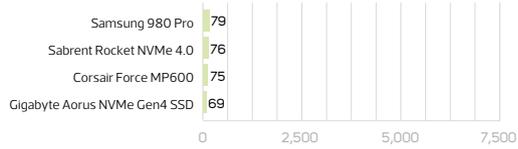
CRYSTALDISKMARK RANDOM 4K Q32 T4 WRITE (MB/SEC)

Sabrent Rocket NVMe 4.0	1,336
Corsair Force MP600	1,315
Gigabyte Aorus NVMe Gen4 SSD	1,289
Samsung 980 Pro	1,274
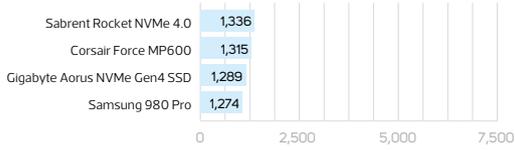
AS-SSD 4K RANDOM WRITE (MB/SEC)

Sabrent Rocket NVMe 4.0	193
Corsair Force MP600	192
Samsung 980 Pro	183
Gigabyte Aorus NVMe Gen4 SSD	170
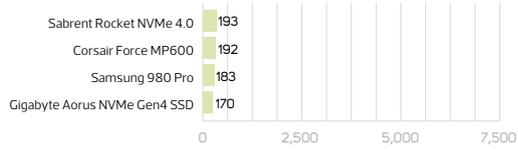
AS-SSD 4K 64-THREAD READ (IOPS)

Samsung 980 Pro	570,040
Sabrent Rocket NVMe 4.0	489,498
Corsair Force MP600	485,794
Gigabyte Aorus NVMe Gen4 SSD	477,587
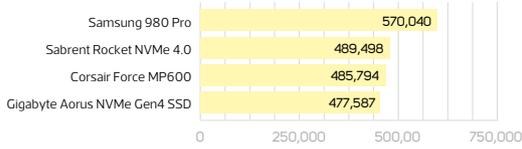
AS-SSD 4K 64-THREAD WRITE (IOPS)
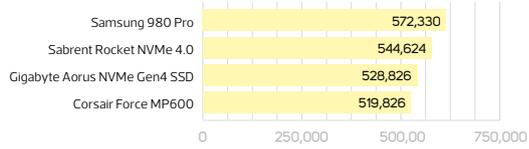
Samsung 980 Pro	572,330
Sabrent Rocket NVMe 4.0	544,624
Gigabyte Aorus NVMe Gen4 SSD	528,826
Corsair Force MP600	519,826

LABS TEST

Wireless mechanical keyboards

Want the freedom of wireless without compromising on typing quality? **Edward Chester** checks out the burgeoning market for wireless mechanical keyboards

How we test

Mechanical keyboards are still considered the ultimate typing and gaming tool by many, but by and large they don't offer the freedom of movement and lack of desk-cluttering cables of a wireless connection. However, a handful of new models are starting to offer the best of both worlds.

There were a couple of key factors to test with these wireless models. The first is to ensure that the wireless signal is sufficiently quick and reliable so as to not interrupt gaming or slow down typing. We tested alongside a wireless mouse (Logitech G Pro wireless) and wireless headset (Roccat ELO 7.1 Air) to provide as much of a challenge as possible. And, to cut a potentially long story short, we found that none of the keyboards on test (nor indeed the other peripherals we were using) suffered any issues with signal integrity or lag.

Some of the boards also only offered a Bluetooth connection, rather than a dedicated wireless connection with an included dongle. Here, we performed the tests with the same setup and again found no issues. With this established, we mainly concentrated on testing whether or not each keyboard offered an overall good typing and gaming experience. Were the keys stable and responsive? Did any gaming modes or extra keys prove useful?

We also assessed the overall portability and versatility of the design. Wireless keyboards are useful for clearing cable clutter, but could also be worth considering for a multi-monitor/system setup, gaming on the sofa or taking your system out on the road, so we took all these scenarios into account.

Battery life and the battery system itself are also factors. Some keyboards have non-replaceable rechargeable batteries and corresponding cable connections, whereas some use replaceable AA batteries that aren't rechargeable via a USB connection, and in some cases, lack any wired connection.

Finally, we accounted for design, build quality and the totting up of any extra features, which we compared against the price. These wireless mechanical keyboards come at quite a premium compared with both wired mechanical keyboards and non-mechanical wireless boards, so value plays a crucial part in our verdicts.

Contents

KEYCHRON K2 VERSION 2 / **£84** inc VAT

The Keychron K2 has the notable accolade of being the most funded keyboard on Kickstarter, raising over a million US dollars for its wireless, Mac-ready spin on the mechanical keyboard. Sporting a compact, frame-filling TKL layout and retro-chic design, you can certainly see why it attracted attention.

Starting with that design, you can clearly see the Keychron's retro influences. It may not be the most original aesthetic but we have to confess that we think it looks great to our tastes. It certainly helps that Keychron has gone for a compact layout, where the keys entirely fill the base of the board, as you'll often see with 60 per cent boards such as the Royal Kludge RK61 (see p61). There's no sign of the unbalanced-looking open spaces you'll see on traditional TKL layouts, such as the Logitech G915, making the design pleasing to the eye.

Build quality is okay, although as you'd expect for its surprisingly modest price, we're not talking the level of boutique, high-end keyboards we showcased in our custom keyboard feature (see Issue 203). The frame is all plastic, and while it's certainly sturdy, you don't get the real heft of boards built around thick slabs of metal. The keycaps are a bit cheap-feeling and don't use doubleshot legends either – as with the Royal Kludge Sk61, this is a snazzily designed but relatively budget keyboard.

The downside to the compact TKL layout, of course, is that you miss out on some of the creature comforts of traditional layouts. If you're used to being able to quickly move between the cursor keys and the Home/End/Del cluster, it's a little frustrating that all these keys are rearranged. The right Shift key and Ctrl keys are bunched up as well, although we found this less of a problem.

The Keychron uses standard Gateron (Cherry MX clone) switch varieties, and these proved reliable in action. You also get a selection of Mac and Windows keycaps (swap Alt for Command and so on), and on the side is a sliding switch for changing between the two layouts electronically.

Alongside this is another switch for changing the keyboard between Bluetooth and wired modes. Sadly, the keyboard doesn't include a low-latency dedicated 2.4GHz wireless connection, so in theory, it's not as good for gaming where you want the absolute most reliable, fastest response. However, unlike with gaming mice, we didn't find the Bluetooth connection to be any hindrance when gaming, although you will of course need a Bluetooth adaptor, which isn't a given on many PCs.

A USB Type-C port is also found on the left edge, and it's used for connecting directly to a PC and charging the non-removable battery. The side-mounted socket is an oddity for a typical PC setup, but Keychron does include a cable with a 90-degree angled plug, so at least the cable still projects backwards.

Keychron claims up to 240 hours of battery life with the backlight off, or 15 hours actively typing with the backlight on. Realistically, we found this translates to charging every two or three days if used regularly – a step up from the Razer but well behind the Logitech G915.

Conclusion

Bucking the trend for vapourware that has accompanied many Kickstarter projects, the Keychron K2 offers a stylish retro design and good all-round performance. The lack of a 2.4GHz wireless connection will be a limitation for some, but otherwise this is a decent, if relatively budget-feeling, wireless keyboard for a surprisingly good price.

SPEC

Dimensions (mm) 313 x 123 x 41 (W x D x H)

Weight 900g

Format TKL (85 keys)

Connections Bluetooth, USB

Switch type Gateron Blue, Brown and Red

Backlighting White or RGB

Extras Mac and Windows keycaps

KEY WORKER

+ Stylish retro design
+ Good all-round performance
+ Interchangeable Mac and Windows keys
+ Good value

CHRONIC PAIN

− No 2.4GHz wireless
− USB socket is on side
− Slightly underwhelming build quality

VERDICT

Proving that zeitgeist-chasing design and crowdfunding doesn't always result in disappointment, the Keychron is a capable and good-value keyboard.

DESIGN	FEATURES
20/25	20/25

PERFORMANCE	VALUE
20/25	22/25

OVERALL SCORE 82%

LOGITECH G613 / **£100** inc VAT

Logitech G613's is an odd beast. While the company's newest wireless effort, the G915 (see p59), leans fully into the idea of slimness and portability that you might expect from a wireless device, the G613 is comparatively very chunky.

The main culprit is the non-removable plastic wrist rest that's integrated into the whole build of the keyboard. Add the fact that the G613 has a full-sized keyboard design, including a numpad and even a column of extra gaming keys down the left edge, and you end up with a huge footprint.

The keyboard's heavy too, weighing in at 1.46kg, and it uses full-height keys as well. The end result is a keyboard that you won't want to be moving around, although the incorporated wrist rest does actually make typing on your lap more comfortable than keyboards without a wrist rest, or a removable one that may move around and end up becoming detached.

Conversely, the low profile and hard plastic of the wrist rest mean there are more comfortable wrist rest designs available. It's not great when you compare it with the thicker, padded wrist rest of the likes of the Razer BlackWidow V3 Pro (see p60), for example.

For all its bulk, the G613 isn't actually all that stiff, with the keyboard flexing noticeably

SPEC

Dimensions (mm) 478 x 216 x 33 (W x D x H)

Weight 1.46kg

Format Full size (105 + 6 gaming keys)

Connections 2.4GHz Lightspeed wireless, Bluetooth

Switch type Logitech Romer-G

Backlighting None

Extras Six multimedia buttons, six gaming keys, USB receiver

when twisted from either end and when pressed in the middle. It's not enough flex to make for an annoying bouncy typing experience, but it's a little disappointing given the heft of this keyboard.

Then again, this is a cheap typing tool for a wireless model, so some cost cutting is to be expected. Another cost saving is that you miss out on backlighting, which further dents the appeal of this keyboard for use on the sofa as well as your desk.

All those negatives out the way, the core experience of this keyboard – wrist rest aside – is great. That full-sized layout means there are no compromises in terms of general typing, data entry (numpad) and gaming (G keys). In fact, although Logitech's Romer-G tactile switches feel a little stiffer and spongier than typical Cherry MX Brown tactile switches, we really enjoyed the overall typing experience on this keyboard.

The keyboard can be connected to your PC either via Bluetooth, or with Logitech's high-speed LightSpeed 2.4GHz wireless mode, using the included tiny adaptor. The latter can be stored in the battery compartment, alongside the two AA batteries that Logitech says can last up to 18 months. There's no way to physically plug the keyboard into your PC though.

Other features include a standard set of rather horrible-feeling, but functional, multimedia keys. There's also a gaming mode switch that will disable the Windows keys, and any other keys you specify via Logitech's software.

It's a little disappointing that the keyboard otherwise offers next to no programmability

LIGHT SPEED
+ Wireless convenience
+ Decent typing experience
+ Clean, simple design

LIGHT ENTERTAINMENT
– Poor multimedia switches
– Wobbly keys
– Fixed wrist rest

though. You can assign commands to the gaming keys on the left hand edge, but that's it – the rest of the keyboard is fixed.

Conclusion

The Logitech G613 offers an interesting combination of features and ideas. On the one hand, it has a good mechanical keyboard feel with the convenience of a wireless connection, and all the essentials you'd expect from a full-sized keyboard for a very reasonable price. However, its design is a bit dumpy, it lacks backlighting and its size means it's not very portable. Its fixed wrist rest isn't very comfortable and means you don't have the option of adding a third-party wrist rest either. If it lost its weird fixed wrist rest, the G612 would be an easier recommendation.

VERDICT

An odd choice of a fixed wrist rest lets down this otherwise capable and good-value keyboard.

DESIGN	FEATURES	OVERALL SCORE
13/25	20/25	**75%**
PERFORMANCE	VALUE	
22/25	20/25	
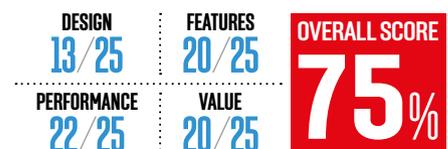
LOGITECH G915 TKL / **£199** inc VAT

Sitting firmly in the 'reassuringly expensive' category, the G915 is a very pricey keyboard, with the full-sized version costing a whopping £210 and this compact tenkeyless (TKL) version without a numpad still setting you back £200. Wireless mechanical keyboards do tend to be pricey – as the even more expensive Razer Black Widow V3 Pro shows – but it's a whopping fee for a TKL model.

It's good, then, that the G915 largely looks and feels the part. Its top is wrapped in a fetching and firm sheet of brushed aluminium, which is shown off particularly well in the silver and white version, although it still looks very attractive on the black version too. It's sturdy as well, despite the main body of this low-profile keyboard measuring just 9mm thick.

It's also surprisingly heavy, weighing in at 819g. Combine the weight with the curved, thin design of the G915's sides, as well as its slightly front-heavy balance, and it's surprisingly tricky to pick up. Hooking your hands underneath the sides, tipping it vertically and gripping it between the palms of your hands seems to be the easiest method.

TENKEYLESS

+ Neat low-profile compact design

+ Great gaming and typing experience

+ Smart backlight

HOPELESS

− Very expensive

− Poor-quality multimedia buttons

− Inaccessible battery

SPEC

Dimensions (mm) 368 x 150 x 22 (W x D x H)

Weight 810g

Format TKL (88 keys)

Connections 2.4GHz Lightspeed wireless, Bluetooth, micro-USB

Switch type Logitech GL low profile

Backlighting RGB

Extras Four multimedia buttons, USB receiver, volume wheel

It's otherwise a great piece of design, although the premium appearance is let down a bit by the rather toy-like round multimedia buttons, asymmetrically placed Lightspeed logo and the whole top section looking a little too much like an afterthought (it looks better on the full-sized version). That said, the knurled metal volume wheel is pleasingly tactile.

The round buttons are also terrible quality. They're just squishy rubber caps, with presumably rubber dome-style switches underneath, which provide a thoroughly mushy, unsatisfying response. We also suspect the rubber won't survive as much abuse as harder plastic buttons.

Around the back of the keyboard is its power switch and micro-USB charging port, while the underside is home to feet for raising the back of the keyboard, with two levels available. There's also a stowage area for the wireless adaptor but, unlike some models, the battery isn't accessible. Logitech claims 40 hours (30 for the full-sized version) of battery life of active use at 100 per cent backlight brightness (it will last longer when in standby) and a full recharge in three hours. We used the keyboard regularly (although not exclusively) for a working week and it never dropped below the 15 per cent battery level that will trigger its indicator light.

The G915 uses Logitech's own low-profile GL mechanical switches, with the usual clicky, tactile and linear key actions available. These aren't compatible with MX-style keycaps with a cross mount, unlike the other three non-

Logitech keyboards on test. The included keycaps look and feel great, though, as do the switches. Quite a firm action is required on the tactile model we tested, but we found it to be an excellent typing and gaming tool. The RGB backlighting looks very smart too, thanks in part to the clean and clear font used on the keycaps.

Conclusion

There's no two ways about it, the G915 isn't as good as you'd expect for its high price. Those mushy rubber multimedia keys are pretty unforgiveable on a keyboard that costs nearly £200. That applies doubly for this TKL version, which should offer a greater saving over its full-sized siblings than just £10. All that said, we simply loved using this keyboard's low-profile mechanical switches and the tactile response offered here is great. The design is also smart, and this TKL version offers a truly compact, portable design that you'd expect from a wireless keyboard.

VERDICT

A few too many flaws to justify its high asking price, but the typing action is superb.

DESIGN	FEATURES	OVERALL SCORE
22/25	20/25	**76**%
PERFORMANCE	VALUE	
22/25	12/25	
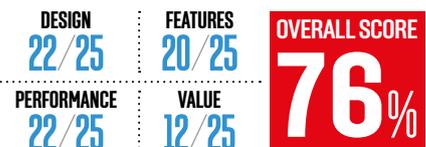
RAZER BLACKWIDOW
V3 PRO / **£230** inc VAT

SUPPLIER razer.com

Razer's new flagship keyboard adds a HyperSpeed wireless connection to its updated BlackWidow keyboard design, for a typing and gaming experience that should be world-beating. Unlike the Logitech G915, it's a full-height chunky keyboard and there isn't a TKL variant, at least for the moment

Once again, Razer has waltzed away with the prize for the best-looking product in its class. It's not just the choice of an all-black livery, the smart font or the metal top to the keyboard's chassis. It's not even the simple fact that Razer has a funky-looking logo that, unlike so many other logos, often adds to the design rather than diminishing it. It's all these factors combined, along with a general sense of proportion and just the right finishing touch.

Build quality feels good too. The keyboard is weighty and solid, although it isn't as stiff as you might expect – the G915 twists less. However, the stabilisation on the long keys – mainly the spacebar – is very poor, making for surprisingly wobbly keys.

On the plus side, you get double-shot ABS keycaps – that's where two injections of different coloured plastic are used to form the legends, rather than the legends being screen-printed on the keys. This means the legends won't wear out quickly. The volume and multimedia keys feel far more robust and precise than on the Logitech models too.

One slight slip-up, which we've noticed before on doubleshot keycaps, is a lack of clarity in some finer lettering. The likes of Del and End have little dark patches where the light doesn't shine through as evenly, making them a little hard to read. The thin (but otherwise attractive) font Razer has chosen probably doesn't help here either.

One of the big selling points is the use of Razer's aforementioned low-latency, high-speed wireless connection, HyperSpeed. This requires the included dongle that can be stowed in a panel on the underside of the keyboard. Bluetooth is also available as a connection option, and you can connect and charge the BlackWidow via a USB Type-C port on the back.

The battery isn't accessible, but Razer claims up to 192 hours of battery life. However, that's with the backlighting turned off – battery life plummets with the lighting enabled. At 100 per cent brightness in constant use, it drops dead in 13 hours, and although it will generally last most of a week with more typical use at lower brightness (and with the lights turning off in standby), it's still markedly lower than the G915's 30-40 hours with lighting.

Thankfully, despite this review sample – and all currently available versions – using a US layout, the typing experience is excellent.

Razer's switches feel fantastic, and respond as quickly and reliably as you'd expect, although the clicky switches are particularly loud. You miss out on any dedicated gaming keys, as you find on the Logitech G613, as well.

Meanwhile, the included wrist rest is reasonably thick and has a pleasant squishy padded surface, although it oddly doesn't actually attach to the front of the keyboard. It will stay put on a flat surface but it isn't ideal for more mobile use.

Conclusion

The BlackWidow V3 Pro is an excellent mechanical keyboard that will satisfy serious typists and gamers alike. It looks fantastic, feels well made and has all the key features you'll need. Razer's software for programming the lighting and buttons is excellent too. However, poor battery life, iffy backlighting on some keys and a high price will dent its appeal.

SPIDEY SENSE

+ Smart design
+ Mostly good build quality
+ Comfortable wrist rest

PETER TINGLE

− Narrow key font
− Free-floating wrist rest
− Expensive

SPEC

Dimensions (mm) 450 x 15 x 43 (W x D x H)

Weight 1.15kg

Format Full size (105 keys)

Connections 2.4GHz HyperSpeed wireless, Bluetooth, USB Type-C

Switch type Razer mechanical (clicky, linear or tactile)

Backlighting RGB

Extras Four multimedia buttons, USB receiver, volume wheel

VERDICT

A fantastic keyboard for typists and gamers alike, although it demands a serious price and requires regular charging if you use the lighting.

DESIGN	FEATURES	OVERALL SCORE
24/25	21/25	**79%**
PERFORMANCE	VALUE	
21/25	13/25	
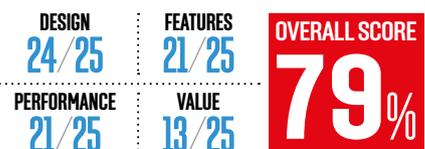
ROYAL KLUDGE
RK61 / **£50** inc VAT

SUPPLIER amazon.co.uk

With possibly the strangest company name we've ever encountered, the RK61 by Royal Kludge appears every bit the cheap knockoff to be avoided like the plague. However, with thousands of units sold, plenty of positive reviews and a list price of just £50, Royal Kludge's design is clearly onto a winner.

Sure enough, design is one area this keyboard gets very right. Accepting the fact that white keyboards will end up looking obviously grotty once used for a while, fresh out of the box, the all-white look with light blue backlighting is really swish. There's also a black variant with orange backlighting and RGB variants. It certainly helps that the RK61 sports a 60 per cent layout, which is where you not only lose the numpad, but also the F keys and separate cursor and Home/End key cluster. The result is a tightly filled-to-the-edges tiny keyboard.

We recently looked at the KB Paradise V60 (see Issue 203) and found its 60 per cent layout too restrictive. However, Royal Kludge has made a couple of tweaks that greatly elevate the experience. For a start, the Fn key that's used to trigger the secondary functions that replicate missing keys is situated in the bottom-right corner, rather than further into

the keyboard, as on the KB Paradise V60. This makes it much easier and more intuitive to find with your little finger.

The other tweak is that the cursor keys, which initially appear to be secondary functions of the right Alt/Ctrl, right-click menu and question mark keys are in fact the primary functions. We find cursor keys simply too useful to be confined to a secondary function, so it made a huge difference. Exactly which layout will suit you best will depend on how you mostly use your keyboard, but we found this setup suited our needs better than the V60.

The main downside here is that the layout is technically a US one, with a small Enter key and no £ sign on the 3 key. However, the keyboard still functioned as a UK layout by default and we found we got used to it surprisingly quickly.

The Royal Kludge uses an unspecified Cherry MX switch clone, with blue clicky, brown tactile and red linear variants available (although only blue and brown seem to be available in the UK). Some reports say they're Kailh switches but it seems like the exact brand of switch used can vary. Regardless, we found the blue variant in our review model to feel excellent. What's more, the stabilisation for the longer keys – particularly the spacebar – put the Razer board to shame.

The other big downside with this keyboard is a lack of a dedicated 2.4GHz wireless connection. Your only connection options are Bluetooth or USB Type-C. The battery isn't great either. With the backlight on, it's only rated to last ten hours, although the manufacturer claims it will last 360 hours on standby. For a keyboard that you might keep plugged in

SPEC

Dimensions (mm) 291 x 101 x 41 (W x D x H)

Weight 570g

Format Full size (105 keys)

Connections Bluetooth, USB Type-C

Switch type Unspecified Cherry MX clone

Backlighting Blue (orange and RGB variants available)

Extras None

ROYAL
+ Smart compact design
+ Clever key layout
+ Great typing experience
+ Very cheap

KLUDGE
− Still too compact for some
− No 2.4GHz wireless connection
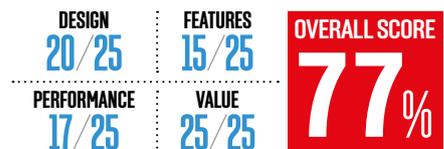− US layout only
− Poor battery life

most of the time and only occasionally take wirelessly, it's plenty but that short battery life would become irksome if you used the keyboard wirelessly all day every day, and wanted to use the backlight.

Conclusion
The Royal Kludge is a fantastic little compact keyboard that belies its budget price. It looks great, the typing experience is excellent (US layout aside), it feels well put together, and it's genuinely small and light enough to fit in a backpack. The battery life isn't great, and there's no 2.4GHz wireless connection, but it works well for Bluetooth and wired use, and it's a steal for just £50. **CPC**

VERDICT
An incredibly low price makes the Royal Kludge's few quirks easy to swallow.

DESIGN	FEATURES	OVERALL SCORE
20/25	15/25	**77%**
PERFORMANCE	VALUE	
17/25	25/25	

How we test

MOTHERBOARDS

TEST PROCESSORS
> **Intel LGA1200** Intel Core i9-10900K
> **Intel LGA2066** Intel Core i9-7900X
> **AMD AM4** AMD Ryzen 9 3900X
> **AMD TRX4** AMD Threadripper 3970X

Our test gear comprises a GeForce RTX 2070 Super Founders Edition and a 2TB Samsung 970 Pro SSD (or a PCI-E 4 1TB Corsair MP600 SSD on X570 and TRX40 boards). We also use Corsair Vengeance RGB 3466MHz DDR4 RAM – a 16GB dual-channel kit for mainstream systems, and a 32GB quad-channel kit for HEDT systems. All CPUs are cooled by a Corsair Hydro-X water-cooling loop, with two XR5 240mm radiators, an XD3 RGB reservoir and an XC7 RGB waterblock.

We test with our RealBench suite and Far Cry New Dawn on Windows 10 Home 64-bit. We also test the board's M.2 ports, and record the noise level and dynamic range of integrated audio using RightMark Audio Analyzer. Where possible, CPUs are overclocked and benchmarked again.

PROCESSORS

TEST MOTHERBOARDS
> **Intel LGA1200** MSI MEG Z490 Ace
> **Intel LGA2066** MSI MEG X299 Creation
> **AMD AM4** Gigabyte X570 Aorus Master
> **AMD AM4 (APU)** MSI X470 Gaming Pro Carbon
> **AMD TRX4** Asus ROG Zenith II Extreme
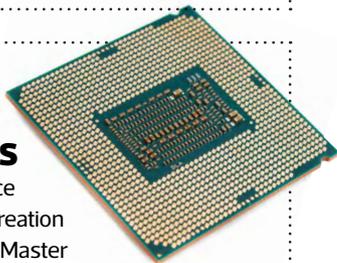
Our CPU test setup comprises a GeForce RTX 2070 Super Founders Edition (or an APU's integrated GPU), a 2TB Samsung 970 Pro SSD, and Corsair Vengeance RGB 3466MHz DDR4 memory – a 16GB dual-channel kit for mainstream systems, and a 32GB quad-channel kit for HEDT systems. A Corsair Hydro-X water-cooling loop, with two XR5 240mm radiators, an XD3 RGB reservoir and an XC7 RGB waterblock is also used.

We use Windows 10 Home 64-bit, and test with our RealBench suite, as well as Cinebench for 3D rendering and Adobe Premiere Pro for video export times. Far Cry New Dawn and Metro Exodus test gaming performance. Finally, we record the total power draw of the test PC. We run all tests at stock speed and at the highest stable overclocked frequency.

MONITORS

We test image quality with an X-Rite iDisplay Pro colorimeter and DisplayCal software to check for colour accuracy, contrast and gamma, while assessing more subjective details such as pixel density and viewing angles by eye. For gaming, we test a monitor's responsiveness subjectively and then also use Blur Buster's excellent ghosting UFO test to check the sharpness of the display in high-speed motion.

CPU COOLERS

We measure the CPU temperature with CoreTemp, and subtract the ambient air temperature to give a delta T result, enabling us to test in a lab that isn't temperature controlled. We load the CPU with Prime95's smallfft test and take the reading after ten minutes.

TEST KIT
Fractal Design Meshify C case, 3000MHz Corsair Vengeance LPX memory, 256GB Crucial MX100 SSD, be quiet! System Power 9 500W PSU, Windows 10 64-bit.

INTEL LGA1151
Intel Core i5-9600K CPU overclocked to 4.8GHz with 1.2V vcore, Asus ROG Strix Z370-E Gaming motherboard.

INTEL LGA2066
Intel Core i9-7900X overclocked to 4.2GHz with 1.15V vcore, MSI X299M Gaming Pro Carbon AC motherboard.

AMD AM4
AMD Ryzen 7 1700 overclocked to 3.9GHz with 1.425V vcore, MSI X470 Gaming Pro Carbon AC motherboard.

AMD TRX4
AMD Threadripper 3960X overclocked to 4.2GHz with 1.265V vcore, 32GB of 3466MHz Corsair Vengeance RGB memory, Samsung 960 Pro SSD, Corsair RM850i PSU, ASRock TRX40 Taichi motherboard.

GRAPHICS CARDS

We mainly evaluate graphics cards on the performance they offer for the price. However, we also consider the efficacy and noise of the cooler, as well as the GPU's support for new gaming features, such as ray tracing.

Every graphics card is tested in the same PC, so the results are directly comparable. Each test is run three times, and we report the average of those results.

We test graphics cards at 1,920 x 1,080, 2,560 x 1,440 and 3,840 x 2,160, although we omit the latter resolution on cheaper cards that can't produce playable frame rates at this setting.

TEST KIT
Intel Core i7-8700K overclocked to 4.7GHz on all cores, 16GB Corsair Vengeance LED 3000MHz DDR4 memory, Gigabyte Z370 Aorus motherboard, Cooler Master MasterLiquid 240 CPU cooler, Corsair HX750 PSU, Cooler Master MasterCase H500M case, Windows 10 Home 64-bit.

GAME TESTS
Metro Exodus Tested at Ultra settings with Ultra ray tracing, but with Advanced PhysX and HairWorks disabled. We run the game's built-in benchmark, and report the 99th percentile and average frame rates.

Battlefield V Tested in DirectX 12 at Ultra settings on every card. If a GPU also supports real-time ray tracing, we then test it with DXR enabled on High settings with TAA, and also with DLSS if it's supported. We run through a one-minute custom benchmark in the 'Under No Flag' War Story, recording the 99th percentile and average frame rates with FrameView.

Shadow of the Tomb Raider Tested at the Highest settings preset with High ray-traced shadows enabled. We test with TAA, and also with DLSS if it's supported. We run the built-in benchmark and record the 99th percentile and average frame rates with OCAT.

Doom Eternal Tested at Ultra Nightmare settings, with resolution scaling disabled. We run a custom benchmark in the opening level of the campaign, and record the 99th percentile and average frame rates with FrameView.

POWER CONSUMPTION
We run Metro Exodus at Ultra settings with Ultra ray tracing at 2,560 x 1,440. We measure the power consumption of our whole graphics test rig at the mains during the test, and record the peak power draw. This result is for the whole system, not the graphics card alone.

CUSTOM PC AWARDS

EXTREME ULTRA
Some products are gloriously over the top. They don't always offer amazing value, but they're outstanding if you have money to spend.

PREMIUM GRADE
Premium Grade products are utterly desirable, offering a superb balance of performance and features without an over-the-top price.

PROFESSIONAL
These products might not be appropriate for a gaming rig, but they'll do an ace job at workstation tasks.

APPROVED
Approved products do a great job for the money; they're the canny purchase for a great PC setup.

CUSTOM KIT
For those gadgets and gizmos that really impress us, or that we can't live without, there's the Custom Kit award.

CUSTOM PC REALBENCH

Our own benchmark suite, co-developed with Asus, is designed to gauge a PC's performance in several key areas, using open source software.

GIMP IMAGE EDITING
We use GIMP to open and edit large images, heavily stressing one CPU core to gauge single-threaded performance. This test responds well to increases in CPU clock speed.

HANDBRAKE H.264 VIDEO ENCODING
Our heavily multi-threaded Handbrake H.264 video encoding test takes full advantage of many CPU cores, pushing them to 100 per cent load.

LUXMARK OPENCL
This LuxRender-based test shows a GPU's compute performance. As this is a niche area, the result from this test has just a quarter of the weighting of the other tests in the final system score.

HEAVY MULTI-TASKING
This test plays a full-screen 1080p video, while running a Handbrake H.264 video encode in the background.

Core component bundles

The fundamental specifications we recommend for various types of PC. Just add your preferred case and power supply, and double-check there's room in your case for your chosen components, especially the GPU cooler and graphics card. We've largely stopped reviewing power supplies, as the 80 Plus certification scheme has now effectively eliminated unstable PSUs. Instead, we've recommended the wattage and minimum 80 Plus certification you should consider for each component bundle. You can then choose whether you want a PSU with modular or captive cables.

Budget system with integrated graphics

Quad-core CPU, basic gaming

*Needs a micro-ATX or ATX case.
We recommend a 350W 80 Plus power supply.*

COMPONENT	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
CPU	AMD Ryzen 5 3400G	scan.co.uk	#194 p20	£130
CPU COOLER	AMD Wraith air cooler included with CPU	N/A	#194 p20	£0
GRAPHICS CARD	AMD Radeon RX Vega 11 integrated into CPU	N/A	#194 p20	£0
MEMORY	16GB (2 x8 GB) Corsair Vengeance LPX Pro 3200MHz (CMK16GX4M2Z3200C16)	scan.co.uk	#204 p74	£65
MOTHERBOARD	Asus TUF B450M-Plus Gaming (micro-ATX)	awd-it.co.uk	#204 p74	£79
STORAGE	500GB WD Blue SN550 (M.2 NVMe)	scan.co.uk	#204 p24	£62

Total £336

Budget gaming system

Quad-core CPU, 1080p gaming

Needs a micro-ATX or ATX case. We recommend a 450W 80 Plus power supply. See Issue 204, p74 for an example build guide.

COMPONENT	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
CPU	AMD Ryzen 3 3300X	ebuyer.com	#203 p28	£120
CPU COOLER	ARCTIC Freezer 7 X	scan.co.uk	#202 p20	£18
GRAPHICS CARD	PowerColor Radeon RX 5600 XT	ebuyer.com	#204 p74	£255
MEMORY	16GB (2 x8GB) Corsair Vengeance LPX Pro 3200MHz (CMK16GX4M2Z 3200C16)	scan.co.uk	#204 p74	£65
MOTHERBOARD	Asus TUF B450M-Plus Gaming (micro-ATX)	awd-it.co.uk	#204 p74	£79
STORAGE	500GB WD Blue SN550 (M.2 NVMe)	scan.co.uk	#204 p24	£62

Total £599

UPGRADES				
SWAP GRAPHICS CARD	Nvidia GeForce RTX 2060 (1080p gaming with ray tracing and some 2,560 x 1,440 gaming)	scan.co.uk	#199 p50	£288
SWAP STORAGE	1TB WD Blue SN550 (M.2 NVMe)	scan.co.uk	#204 p24	£108

Entry-level RTX gaming system

6-core CPU, 2,560 x 1,440 gaming, real-time ray tracing at 1080p

Needs a micro-ATX or ATX case. We recommend a 550W 80 Plus Bronze power supply. See Issue 201, p76 for an example build guide.

COMPONENT	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
CPU	AMD Ryzen 5 3600	scan.co.uk	#195 p16	£190
CPU COOLER	Antec Neptune 240	scan.co.uk	#204 p16	£75
GRAPHICS CARD	Zotac GeForce RTX 2060 Super Mini	scan.co.uk	#199 p53	£360
MEMORY	16GB (2 x 8GB) Corsair Vengeance RGB Pro 3466MHz (CMW16GX4 M2C3466C16)	scan.co.uk	#201 p76	£121
MOTHERBOARD	MSI MAG B550M Mortar (micro-ATX)	ebuyer.com	#204 p42	£130
STORAGE	500GB WD Blue SN550 (M.2 NVMe)	scan.co.uk	#204 p24	£62

Total £938

UPGRADES

SWAP GRAPHICS CARD	Nvidia GeForce RTX 2070 Super*	scan.co.uk	#193 p16	£420
ADD SECONDARY STORAGE	Western Digital Blue 4TB	overclockers.co.uk	#166 p54	£95
SWAP STORAGE	1TB WD Blue SN550 (M.2 NVMe)	scan.co.uk	#204 p24	£108

***We recommend waiting until the launch of the GeForce RTX 3070 and AMD's new GPUs before making a GPU purchase in this price league.**

Mid-range gaming system

8-core CPU, 2,560 x 1,440 and some 4K gaming with real-time ray tracing

Needs an ATX case with room for a 240mm all-in-one liquid cooler. We recommend a 750W 80 Plus Bronze power supply.

COMPONENT	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
CPU	AMD Ryzen 7 5800X	scan.co.uk	#208 p16	£410
CPU COOLER	Antec Neptune 240	scan.co.uk	#204 p16	£75
GRAPHICS CARD	Nvidia GeForce RTX 3080 Founders Edition	nvidia.com	#207 p16	£649
MEMORY	16GB (2 x 8GB) ADATA XPG Spectrix D60G 3600MHz (AX4U3600 38G17-DT60)	amazon.co.uk	#199 p57	£116
MOTHERBOARD	Asus ROG Strix X570-E Gaming (ATX)*	overclockers.co.uk	#193 p44	£290
STORAGE	1TB Sabrent Rocket NVMe 4.0	amazon.co.uk	#208 p51	£165

Total £1,705

UPGRADES

ADD SECONDARY STORAGE	Western Digital Blue 4TB	overclockers.co.uk	#166 p54	£95
SWAP CPU COOLER	Corsair H100i RGB Platinum (240mm AIO liquid cooler)	scan.co.uk	#185 p82	£125

***This motherboard will require a BIOS update in order to recognise the new CPU.**

Core component bundles cont ...

4K gaming system

12-core CPU, 4K gaming with real-time ray-tracing abilities

Needs an E-ATX case with room for a 240mm all-in-one liquid cooler. We recommend an 850W 80 Plus Gold power supply.

COMPONENT	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
CPU	AMD Ryzen 9 5900X	scan.co.uk	#208 p18	£500
CPU COOLER	Corsair H100i RGB Platinum (240mm AIO liquid cooler)	scan.co.uk	#175 p20	£125
GRAPHICS CARD	Nvidia GeForce RTX 3090	nvidia.com	#208 p24	£1,399
MEMORY	16GB (2 x 8GB) ADATA XPG Spectrix D60G 3600MHz (AX4U3600 38G17-DT60)	amazon.co.uk	#199 p57	£129
MOTHERBOARD	MSI Prestige X570 Creation (E-ATX)*	overclockers.co.uk	#193 p48	£440
STORAGE	1TB Samsung 980 Pro	ebuyer.com	#208 p52	£216

Total £2,796

UPGRADES

ADD SECONDARY STORAGE	4TB Western Digital Blue	overclockers.co.uk	#166 p54	£95
SWAP CPU	AMD Ryzen 9 3950X (16 cores)	scan.co.uk	#197 p24	£690

*This motherboard will require a BIOS update in order to recognise the new CPU.

Heavy multi-threading workstation

Serious multi-threaded power, 1080p gaming

Needs an E-ATX case with room for a 280mm all-in-one liquid cooler. We recommend a 750W 80 Plus Gold power supply.

COMPONENT	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
CPU	AMD Threadripper 3960X	scan.co.uk	#197 p18	£1,240
CPU COOLER	NZXT Kraken X63 (280mm AIO liquid cooler)	overclockers.co.uk	#207 p47	£135
GRAPHICS CARD	Nvidia GeForce GTX 1660 Super	ebuyer.com	#199 p46	£205
MEMORY	32GB (4 x 8GB) Corsair Dominator Platinum RGB 3600MHz	scan.co.uk	#197 p20	£273
MOTHERBOARD	ASRock TRX40 Taichi (E-ATX)	overclockers.co.uk	#198 p44	£470
STORAGE	1TB Sabrent Rocket NVMe 4.0	amazon.co.uk	#208 p51	£165

Total £2,488

UPGRADES

SWAP GRAPHICS CARD	Nvidia GeForce RTX 3080 Founders Edition (2,560 x 1,440 and some some 4K gaming with real-time ray tracing)	nvidia.com	#207 p16	£649
SWAP CPU	AMD Threadripper 3970X (32 cores – massive multi-threaded power)	scan.co.uk	#197 p19	£1,800
ADD SECONDARY STORAGE	4TB Western Digital Blue	cclonline.com	#166 p50	£95

Mini PCs

Our favourite components for building a micro-ATX or mini-ITX PC. Always double-check how much room is available in your chosen case before buying your components. Some mini-ITX cases don't have room for large all-in-one liquid coolers, for example, or tall heatsinks. You'll also need to check that there's room for your chosen graphics card. We've also recommended a small PSU and a low-profile CPU cooler, if your chosen case requires them.

Mini-ITX

Motherboards

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
Intel Z490 (LGA1200)	Asus ROG Strix Z490-I Gaming	scan.co.uk	#206 p40	£280
AMD B550 (AM4 budget)	Asus ROG Strix B550-I Gaming	overclockers.co.uk	#206 p44	£210
AMD X570 (AM4 mid-range)	Asus ROG Strix X570-I Gaming	overclockers.co.uk	#198 p20	£290

Cases

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
ALL-PURPOSE	Cooler Master MasterBox NR200P	overclockers.co.uk	#206 p18	£90
MID-RANGE	Phanteks Enthoo Evolv Shift Air	overclockers.co.uk	#195 p49	£95
PREMIUM	NZXT H1	scan.co.uk	#201 p24	£299

CPU coolers

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
LOW-PROFILE	Noctua NH-D9L	amazon.co.uk	#143 p17	£45

Micro-ATX

Motherboards

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
AMD X399 (TR4)	ASRock X399M Taichi	scan.co.uk	#179 p28	£330
AMD B550 (AM4)	MSI MAG B550M Mortar	ebuyer.com	#204 p42	£130

Cases

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
BUDGET	Fractal Design Focus G Mini	scan.co.uk	#180 p46	£47
MID-RANGE	Fractal Design Define Mini C	scan.co.uk	#161 p26	£70

ATX cases

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
BUDGET	Phanteks Eclipse P300 Glass	overclockers.co.uk	#176 p28	£55
BUDGET QUIET	be quiet! Pure Base 500	scan.co.uk	#196 p24	£70
SUB-£100	be quiet! Pure Base 500DX	overclockers.co.uk	#202 p39	£99
COMPACT	Fractal Design Define 7 Compact	scan.co.uk	#203 p32	£100
MID-RANGE	Phanteks Eclipse P600S	overclockers.co.uk	#202 p44	£128
SUB-£150	Fractal Design Define 7	overclockers.co.uk	#204 p18	£140
PREMIUM	Phanteks Enthoo Evolv X	overclockers.co.uk	#187 p24	£200

Networking

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
ROUTER (WI-FI 6)	TP-Link Archer AX6000	overclockers.co.uk	#196 p57	£280
MESH ROUTER (WI-FI 6)	Asus AiMesh AX6100	amazon.co.uk	#196 p54	£399
WI-FI ADAPTOR	TP-Link Archer TX3000E	overclockers.co.uk	#196 p58	£50
SINGLE-BAY NAS BOX	Synology DS118	box.co.uk	#174 p34	£155
DUAL-BAY NAS BOX	Synology DS220j	box.co.uk	#200 p22	£155
DUAL-BAY MEDIA NAS BOX	Synology DS218play	box.co.uk	#174 p34	£214

Monitors

F – FREESYNC, G – G-SYNC, W – ULTRAWIDE

Up to 24in

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
24IN, 144Hz, TN, 1,920 x 1,080, F, G	AOC G2590FX	scan.co.uk	#190 p53	£178
24IN, 144Hz, VA, 1,920 x 1,080, F	AOC C24G1	cclonline.com	#191 p28	£185
24IN, 165Hz, TN, 2,560 x 1,440, G	AOC AGON AG241QG	cclonline.com	#169 p55	£465

Over 28in

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
31.5IN, 60Hz, VA, 4K, F	iiyama ProLite XB3288UHSU	scan.co.uk	#205 p43	£350
34IN, 144Hz, IPS, 3,440 x 1,440, W, F	iiyama G-Master GB3461WQSU	cclonline.com	#206 p53	£399
34IN, 144Hz, IPS, 3,440 x 1,440, W, F, G	LG UltraGear 34GN850	overclockers.co.uk	#206 p55	£970
38IN, 144Hz, IPS, 3,840 x 1,600, W, F, G, HDR	LG UltraGear 38GN950	scan.co.uk	#208 p30	£1,500
35IN, 200Hz, VA, 3,440 x 1,440, W, G, HDR	Asus ROG Swift PG35VQ	scan.co.uk	#198 p58	£2,499
43IN, 120Hz, VA, 4K, F, G	Asus ROG Strix XG438Q	amazon.co.uk	#205 p39	£1,015

Up to 28in

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
27IN, 144Hz, IPS, 1,920 x 1,080, F, G	AOC 27G2U	scan.co.uk	#201 p53	£230
27IN, 165Hz, VA, 2,560 x 1,440, F	MSI Optix MAG272CQR	box.co.uk	#201 p28	£390
27IN, 240Hz, IPS, 1,920 X 1,080, F, G	Acer Nitro XV273	alza.co.uk	#204 p25	£378
27IN, 144Hz, IPS, 2,560 x 1,440, F, G	Asus TUF Gaming VG27AQ	overclockers.co.uk	#201 p54	£440
27IN, 165Hz, IPS, 2,560 x 1,440, F, G	Gigabyte Aorus FI27Q	overclockers.co.uk	#201 p55	£475
27IN, 240Hz, TN, 2,560 x 1,440, F, G	AOC AG273QZ	overclockers.co.uk	#202 p27	£580

Non-gaming

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
27IN, 60Hz, IPS, 4K	AOC U2790PQU	amazon.co.uk	#194 p30	£336

Peripherals and audio

Gaming keyboards
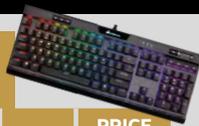
CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
MEMBRANE	Corsair K55 RGB	amazon.co.uk	#201 p45	£49
BUDGET TKL MECHANICAL	HyperX Alloy FPS Pro	amazon.co.uk	#201 p46	£70
WIRELESS TKL MECHANICAL	Keychron K2 Version 2	keyboardco.com	#208 p57	£84
MECHANICAL	Corsair K68 RGB	overclockers.co.uk	#181 p53	£120
MECHANICAL MMO	Corsair K95 RGB Platinum	overclockers.co.uk	#164 p26	£180
PREMIUM MECHANICAL	Corsair K70 Mk.2 Low Profile	scan.co.uk	#193 p56	£160
PREMIUM TKL MECHANICAL	Asus ROG Strix Scope TKL Deluxe	scan.co.uk	#202 p24	£140
LUXURY MECHANICAL	Razer Hunstman Elite	box.co.uk	#193 p59	£185
LUXURY WIRELESS MECHANICAL	Razer BlackWidow V3 Pro	razer.com	#208 p60	£230

Gaming mice

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
BUDGET GAMING	Corsair M55 RGB Pro	amazon.co.uk	#200 p24	£37
FIRST-PERSON SHOOTER	SteelSeries Rival 600	box.co.uk	#184 p59	£74
MMO	Razer Naga Trinity	scan.co.uk	#186 p52	£90
WIRELESS	Corsair Dark Core RGB Pro	amazon.co.uk	#202 p25	£90
AMBIDEXTROUS	Razer Lancehead Tournament Edition	amazon.co.uk	#177 p53	£75
ULTRA LIGHTWEIGHT	Glorious PC Gaming Race Model O	overclockers.co.uk	#195 p58	£53

Peripherals and audio cont ...

Game controllers

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
RACING WHEEL	Logitech G29 Driving Force	argos.co.uk	#202 p50	£270
PREMIUM RACING WHEEL	Fanatec CSL Elite PS4 Starter Kit	fanatec.com	#202 p49	~£506
GAMEPAD	Microsoft Xbox One Wireless Controller	argos.co.uk	#191 p56	£50
BUDGET FLIGHT STICK	Logitech Extreme 3D Pro Joystick	currys.co.uk	#207 p52	£34
FLIGHT STICK	Thrustmaster T.1600M FCS HOTAS	thrustmaster.com	#207 p56	£140

Gaming headsets

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
STEREO	Sennheiser GSP 300	amazon.co.uk	#194 p56	£90
SURROUND	Asus ROG Centurion	overclockers.co.uk	#163 p49	£200
WIRELESS	Corsair Virtuoso RGB Wireless	ebuyer.com	#204 p50	£154

Speakers

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
STEREO	Edifier R1280DB	amazon.co.uk	#192 p57	£120

Non-gaming keyboards

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
WIRELESS MULTI-DEVICE	Logitech K780	ebuyer.com	#203 p58	£74
TKL MECHANICAL	Majestouch Convertible 2 Tenkeyless	keyboardco.com	#203 p55	£140

PCs and laptops

Pre-built PC systems

CATEGORY	NAME	CPU	GPU	SUPPLIER	ISSUE	PRICE (inc VAT)
ENTRY-LEVEL RTX GAMING	PC Specialist Magma R2	AMD Ryzen 5 3600XT stock speed	Nvidia GeForce RTX 2060 Super	pcspecialist.co.uk	#205 p30	£1,330
8-CORE GAMING	Wired2Fire Predator	AMD Ryzen 7 3700X stock speed	Nvidia GeForce RTX 2060 Super	wired2fire.co.uk	#196 p40	£1,411
GEFORCE RTX 3080 GAMING	CyberPower Infinity 910 RTX	Intel Core i9-10850K stock speed	Nvidia GeForce RTX 3080	cyberpowersystem.co.uk	#208 p42	£2,099
PREMIUM MINI-ITX	Corsair One i160	Intel Core i9-9900K stock speed	Nvidia GeForce RTX 2080 Ti	corsair.com	#190 p32	£3,250
WATER-COOLED 16-CORE GAMING	CyberPower Hyper Liquid Ultra 9 RTX	AMD Ryzen 9 3950X stock speed	Nvidia GeForce RTX 3090	cyberpowersystem.co.uk	#203 p38	£4,145
DREAM PC	Scan 3XS Barracuda	Intel Core i9-10980XE OC to 4.3GHz	Nvidia GeForce RTX 3090	scan.co.uk	#145 p58	£13,768

Laptops

CATEGORY	NAME	CPU	GPU	SCREEN	SUPPLIER	ISSUE	PRICE (inc VAT)
THIN AND LIGHT GAMING	Asus ROG Zephyrus G14 GA401IV	AMD Ryzen 9 4900HS stock speed	Nvidia GeForce RTX 2060 Max-Q	14in 2,450 x 1,440 IPS 60Hz	overclockers.co.uk	#202 p28	£1,800
GAMING	Chillblast Phantom 17	Intel Core i7-10875H stock speed	Nvidia GeForce RTX 2070	17.3in 1,920 x 1,080 IPS 144Hz	chillblast.com	#197 p53	£1,660
HIGH-PERFORMANCE GAMING	Lenovo Legion 7i	Intel Core i7-10750H stock speed	Nvidia GeForce RTX 2080 Super Max-Q	15.6in 1,920 x 1,080 IPS 144Hz G-Sync	laptopsdirect.co.uk	#208 p40	£2,199

Games

RICK LANE / INVERSE LOOK

RAY OF LIGHT

Real-time ray tracing is an amazing technology wasted in the pursuit of realism in fast-paced games, argues Rick Lane

The launch of Nvidia's RTX 3000-series GPUs has been met with huge excitement among PC enthusiasts, but many people have still yet to be convinced by the benefits of real-time ray tracing for the money – the top five GPUs in the current Steam hardware survey all have no ray-tracing features, for example. This isn't a fault of the technology itself – the ability to fully simulate real-time lighting, shadows and reflections is genuinely astonishing.

The issue, for me at least, is more to do with how ray tracing has been marketed, and how it's used in many of the games that feature it. Since the launch of the RTX 2000-series, ray tracing has been touted as another major step forwards in the push towards graphical realism. Finally, players will experience realistic lighting of environments as the virtual sun tracks across the virtual sky, and accurate simulation of reflections on different surfaces, from glass to polished wood.

The problem with this narrative is that, over the past ten years, computer graphics tech has become extremely good at faking many of the effects generated by real-time ray tracing. If you look at two side-by-side screenshots of Call of Duty: Modern Warfare – one with ray tracing on and one with ray tracing switched off – the differences are relatively minor. Meanwhile, in play, the imagery comes so thick and fast that your brain doesn't have time to acknowledge any noticeable improvements provided by ray tracing.

This is because Call of Duty's environments are intensely authored, so many of the 'dynamic' effects that ray tracing might offer have already been individually created in the game world by the game's environment artists. This is the case for most games that strive to be visually realistic.

This isn't to say that ray tracing is useless, however. Curiously, ray tracing has its most significant effect on games that have a more abstract or stylised look. Remedy's Control, for example, offers a fantastic showcase of real-time ray-traced reflections. The game's hyper-brutalist architecture – all burnished concrete, marble floors and glass-lined offices – means light is constantly bouncing off one reflective surface to another, lending the game a stunning and highly distinctive look, an ever-shifting hall of mirrors.

> Control offers a fantastic showcase of real-time ray-traced reflections

Perhaps the greatest advocate for ray tracing is, of all games, Minecraft. Obviously, introducing ray-traced lighting and reflections to its blocky, low-polygon world makes a huge visual difference by default. But more to the point, the game's vast, randomly generated world offers infinite opportunities for dynamically generated interplay between lights, shadows and reflections. When you have multiple lights shining through differently coloured glass and then bouncing off crystalline water, the power of ray tracing really becomes clear.

This is the fundamental irony of ray tracing. While it's touted as the next step in realistic graphics, the tech is at its most effective when used to create surreal environments. For ray tracing to flourish in games, we need to start thinking of it less as a technology, and more as a stylistic tool that can be used not just for embellishment but also for creating entirely new visual experiences. **CPC**

Rick Lane is Custom PC's games editor @Rick_Lane

Serious Sam 4 / **£30.99** inc VAT

DEVELOPER Croteam / **PUBLISHER** Devolver Digital

Serious Sam 4 makes itself difficult to dislike. When you're mowing down Kleer skeletons with twin assault rifles after blowing up Vesuvius, while on a mission to find the Holy Grail, it feels churlish to note that the engine is the same one used to run Serious Sam 3 nine years ago, or that the character animations are stiffer than a drill sergeant's underpants, and that the whole experience feels a bit sloppy and lacking in finesse.

Despite appearances, though, quite has a lot has changed in Serious Sam 4. The game switches out the familiar deserts and temples of Egypt for the rolling countryside and picturesque villages of Italy and France. The game still has a penchant for very flat expanses and repetitive-looking ruins, but on the whole, environments are more diverse. There's even one mission set in a fairly accurate recreation of the walled city of Carcassonne.

Encounters have been considerably diversified too, thanks mainly to a large influx of new enemies. Alongside Biomechanoids and Beheaded Kamikazes are several new types of low-level grunt, including giant walking pustules

that explode spectacularly when killed, and a four-armed wizard-lizard thing that throws fireballs at you. Also, while most of the game still involves furiously backpedalling away from hordes of foes, the game mixes up the action with giant mech sequences and an amusing detour in a combine harvester.

Sam's skill set has expanded considerably as well. Most notably, he can now dual-wield any weapon in the game (yes, including miniguns), which adds considerable variety to figuring out the most efficient way of killing enemies. Alongside his many weapons, he also has access to some powerful gadgets, ranging from automatic combat drones to mini-nukes and even portable black holes.

The whole game also has a knockabout sense of fun, aping the 'badass FPS protagonist' in a way that's fun without being mean-spirited. Your motley crew of companions embark on one-liner competitions while mowing down enemies. When Sam is asked about his favourite author, he replies 'Philip K. Dick' to which another character exclaims 'Wait, Sam reads BOOKS?!'

It's clearly a game made with love, but it's also undeniably rough around the edges. Visually it's way behind the times, with character models in particular looking extremely dated. The game's problems don't end there either. It's also overlong, with levels unnecessarily padded out with side-missions, and encounters that simply go on for too long. There are only so many Kleer skeletons you can kill before you start to get bored.

If Serious Sam 4 was a meal, it would be spaghetti bolognese. It looks a mess and you've probably been given too much of it, but it's also full of delicious red stuff and is generally a joy to eat.

RICK LANE

SERIOUS SAM
+ Fantastic combat
+ More diverse environments
+ More weapons and gadgets

CASUAL CARL
− Slapdash presentation
− Overlong

/ VERDICT
Fire bullets by the bucketload in this enjoyable, if rather roughshod, FPS sequel.

OVERALL SCORE

75%

Crusader Kings III / **£41.99** inc VAT

DEVELOPER Paradox Interactive / **PUBLISHER** Paradox Interactive

Although Crusader Kings III has the appearance and general mechanics of a typical grand strategy, in play it's more a blend of Game of Thrones and The Sims. It isn't simply about trying to conquer territory and govern your kingdom. It's about trying to do both those jobs while your maniac brother is plotting to murder you, while your hot-tempered heir is determined to get himself killed in battle, and your nymphomaniac queen is squeezing out bastards like a human Pez dispenser. It's an enormous, entirely dynamic human soap opera, and it's utterly brilliant.

It lets you assume control of almost any medieval dynasty at virtually any time during that period. You could play as Charlemagne or Alfred the Great in the early 800s AD, or Harold Godwinson or William the Conqueror in the year 1066. You could be the King of Scotland, the Holy Roman Emperor or even the Pope. Alternatively, you could fill the moccasins of some minor noble anywhere from Iceland to the farthest reaches of the Muslim Empire.

Whichever role you choose to play in this game's absurdly detailed medieval world, your goal is almost whatever you want. You could try to conquer the lands of local dukes and earls, or focus on domestic affairs, building up towns and managing your finances. You could scheme to assassinate neighbouring rulers, your spouse or your child. You could do nothing, and simply watch the game's cogs turn like a dynamically generated TV drama.

This is the essence of Crusader Kings. As a sequel, Crusader Kings III's main goal is to make that drama easier to enjoy. Paradox's grand strategy games are notoriously complex, but Crusader Kings III tries hard to meet you halfway with that complexity.

An extensive tutorial themed around an Irish Petty King gives you a crash course in the game's basic systems, while the completely reworked UI is designed to make the game's many bells and whistles clearer. This doesn't mean CK III is easy to comprehend, however. The simple nature of medieval social structures – the nested titles, labyrinthine family trees and many overlaps between realms and domains – makes it a challenging game to parse before you starting grappling with its mechanics.

Crusader Kings III has one strict rule and one vague goal. The rule is that your dynasty leader must have an heir. That's because your heir takes over your faction when your current leader dies, so dying without one means the game is over. There are several ways to acquire an heir, but the main one is marriage plus the biological results of said marriage.

Your vague goal, meanwhile, is to give your heir the best start in life. There are many ways to do this, starting from the genes up. As with previous entries in the series, each character is defined from a huge list of personal traits. These include physical traits, such as beauty, strength

KING KONG

+ Brilliant dynamic storytelling

+ More refined and accessible than CK II

+ Great new military and intrigue systems

KING RALPH

– Still a steep learning curve

or feebleness; mental and emotional traits, such as intelligence, temperance, lustfulness and various kinds of madness; and lifestyle traits, from architect to torturer.

In Crusader Kings III, some traits are also congenital, which means they can be passed down to your children. So if you want, you can try to genetically engineer the perfect ruler by marrying subsequent leaders to appropriate spouses. Alternatively, you could deliberately spawn a monster that would make Caligula look stable.

Rulers are also more defined by these traits than previously. A dynasty leader who acts against his personality incurs stress, and too much stress can kill them. This encourages you to play in character rather than winging your way through your murdering monarch's reign because you don't want to get your hands dirty. Dynasty heirs also choose a lifestyle at the outset of their rule, focusing on one of several vocations, such as martial prowess, scholarship or intrigue. As they grow older, they gain experience in this lifestyle, unlocking new abilities.

All of this, alongside the visual improvements to character models, is designed to make Crusader Kings' medieval cast more vivid and personable, and it succeeds. At the same time, CK III refines and deepens several core systems. If you like to rule through fire and sword, you'll be pleased to know that Crusader Kings III makes managing armies easier. Rallying your domain's levies is now done automatically – you just have to choose the rally point and raise your levies.

There's also more nuance to warfare. Rulers can bolster their armies by recruiting personal forces, and the types of unit you recruit have different effects (siege engines make sieges resolve faster, for example). Add the fact that terrain affects attack and defence bonuses, and CK III's wars no longer solely come down to strength in numbers.

The real strength of previous Crusader Kings games, however, was not in their warfare but their political intrigue, and that remains the same here. Alongside the ability to create schemes that range from trying to impress someone to trying to murder them, CK III introduces a new mechanic system known as hooks. Hooks can be attained in various ways, such as doing favours for people, or blackmailing them with information gained by your Spymaster.

Depending on the type of hook, they can be used to get a character to join your faction, renegotiating a feudal contract with a vassal, or forcing someone to become an agent in your murder scheme. It palpably communicates that Machiavellian approach to politics, using people as pawns in increasingly elaborate political schemes.

The result is one of the best storytelling engines in gaming – it's up there with the likes of Dwarf Fortress for its dynamic narrative potential. That said, while it's a vast and incredibly rich game in its own right, Crusader Kings III still doesn't have the same level of depth as the previous game if you own all the expansions. However, the new systems and, more importantly, the third game's refinements more than make up for that.

RICK LANE

/ VERDICT

The best gaming soap opera, Crusader Kings III is a great strategy game and a phenomenal example of dynamic storytelling.

OVERALL SCORE

93%

MAFIA: DEFINITIVE EDITION / **£34.99** inc VAT

DEVELOPER Hangar 13 / **PUBLISHER** 2K Games

BADABING

+ Superb visual makeover
+ Improved driving and gunfights
+ More authentic script

BADABOOM

− Combat still fairly basic
− Some iffy changes to characterisation

/ VERDICT

Mafia: Definitive Edition is a slick and dependable wise guy, although not quite imaginative enough to be a Don.

OVERALL SCORE

78%

Mafia: Definitive Edition goes further than most video game remakes. Not only does it completely rebuild the game in a new engine, but it also rewrites the script and recasts the actors for the main roles.

Players assume the role of Tommy, a taxi driver by in the fictional US city of Lost Heaven. Struggling to get by in the Great Depression, a chance encounter with two local mobsters sees Tommy fall in with the local Salieri crime family. Tommy's star rises quickly while his moral centre collapses, and he soon goes from collecting protection money and beating up rival gangsters to being involved with bank robbing and even political assassinations.

True to the original game's structure, Mafia plays like a GTA game with the side-missions removed. Although a purely linear story, it makes good use of its large, open city, which has been meticulously recreated with lots of added period detail. Missions are heavily story driven, with lavish, cinema-quality cutscenes bookending a mix of driving between locations and tense, spectacular gunfights.

All three elements have been reworked for the remake. Car handling has been adjusted to make driving the 1930s vehicles easier, although they still feel believably bulky. The infamously difficult race mission early in the game is now actually enjoyable, rather than a vehicular nightmare that could potentially prevent you from seeing the rest of the game. The smattering of car chases are fantastic fun, with the remake adding a ramming ability and 'escape points', where driving through roadworks or other obstacles hinders whoever's chasing you.

Gunplay, meanwhile, has been modernised, introducing a cover-system and shifting the camera to an over-the-shoulder perspective. There's little original about the combat, but the satisfying weapons and creative scenarios make up for the systemic mundanity. Highlights include a tense battle for survival at a countryside farm during a thunderstorm, and a ferocious gunfight through a bordello that spills onto Lost Heaven's rooftops.

Mafia's main attraction was always the story, and that's no different here. The sweeping tale of organised crime is familiar, but rich in detail and entertainingly paced. There is one issue with the remake's rewrite, however, which is that the three main characters – Tommy, Paulie and Sam – are less distinctive personalities. In the original game, Tommy is disarmingly likeable, which stands in stark contrast to his terrible crimes. In the remake, he's a more typical wise guy, and as a result, the story about the seductive nature of the Mafia loses some of its power.

Character quibbles aside, Mafia: Definitive Edition is a polished and meticulous remake. It isn't quite an offer you can't refuse, but it doesn't deserve to sleep with the fishes.

RICK LANE

TONY HAWK'S PRO SKATER 1+2 / **£44.99** inc VAT

DEVELOPER Vicarious Visions / **PUBLISHER** Activision

Activision may have milked the Tony Hawk cash cow until it died of dehydration, but the original game and its sequel remain stone cold classics, and this meticulous remaster of them demonstrates why. The giant, jittery polygons of the early games have been replaced with all the technological mod cons of Unreal Engine 4, and the imaginative levels and skate parks have been recreated with high-resolution textures, benefiting from dynamic lighting and shader effects such as water and glass reflections.

Meanwhile, character models are based on new body scans of the original skaters, complete with new animations for tricks and bails. It looks fantastic, but crucially, not *too* fantastic. It doesn't go overboard with effects or lighting, instead prioritising performance and image clarity, so you aren't distracted from the core focus of pulling off wicked combos of skateboarding tricks. It still looks and feels like a Tony Hawk game.

The remake is largely faithful to how the original games played too. The core structure remains the same, with small but open levels that each require you to complete around ten different tasks. These range from general objectives, such as attaining high scores and collecting the letters of the word 'skate', to level-specific tasks such as collecting five textbooks or destroying five police cars.

Completing enough of these tasks will unlock the next level. This light and loose structure might seem simplistic by today's standards, but with many modern titles being massively overwrought, it's refreshing to play a game that lets its creative side breathe, and doesn't try to cling to your attention like a leech.

The trick system has also been carefully recreated, letting you perform the full range of flips, grabs and grinds (a gamepad is recommended). That said, there are some important changes. The remake adds manuals from Tony Hawk's 2 to Tony Hawk's 1, and introduces reverts to both games. These are basically connecting tricks that, when combined, allow you to build up much bigger combos.

Including manuals and reverts as standard is the right decision, allowing for greater creativity in combos, and more competitive multiplayer action in modes such as the fantastic HORSE. This is a score-attack version of hangman where players take turns pulling off tricks, with the round's loser gaining a letter of the word HORSE (or another chosen word).

The only real issue is that the price is a little steep. Even with two games, this remake is unlikely to last more than a few evenings, so a price around £30 would be more appropriate. However, this doesn't take away from the quality of the remaster; like the man to whose name it's attached, it can still skate with the best of them 20 years later.

RICK LANE

HALF PIPE
+ Looks great
+ Plays great
+ Is great

HALF BAKED
− A bit short
− High price

/ VERDICT
Tony Hawk grinds smoothly into the modern era with this carefully designed remake.

OVERALL SCORE

85%

REALITY CHECK

It's not impossible. **Rick Lane** used to bullseye womp rats in his T-16 back home

REVIEW

STAR WARS: SQUADRONS

/ £30.99 inc VAT

DEVELOPER EA Motive / **PUBLISHER** EA

N ot only is Star Wars: Squadrons the best Star Wars game in over a decade, but it's also one of the most thrilling VR experiences currently available. If you've ever wanted to physically sit in the cockpit of an X-Wing, or get up close and personal with a Star Destroyer, then Star Wars: Squadrons is the closest you're going to get without some serious innovations in space travel.

Squadrons isn't a VR exclusive game. Instead, it's a standard experience with VR support. Moreover, it's an excellent game with or without a VR headset, although we'd find it hard to go back to playing it on a conventional monitor after experiencing it in VR.

Specifically, Squadrons is a space dogfighter that harks back to the LucasArts classics X-Wing and TIE Fighter, only designed with the kind of budget normally reserved for making actual Star Wars films. If you played either of those LucasArts games, you'll be instantly familiar with the base mechanics of Squadrons. Play primarily revolves around battling enemy ships in free space, rolling and weaving through the inky void as you attempt to keep enemies in your sights while simultaneously avoiding landing in their sights.

A key mechanic brought over from the LucasArts games is power shifting. At any given moment, you can divert your ship's power to prioritise engines, lasers or (if your ship has them) shields. Using these abilities is crucial to getting the edge in a fight – prioritising engines to chase down foes, switching to lasers, so they fire longer and recharge faster, then diverting to shields when an enemy gets you in their sights to minimise the damage.

Squadrons both looks and sounds fantastic. The game's environment artists have excelled themselves in ensuring missions are visually diverse. You'll be fighting inside nebulae, through asteroid fields and above the surface of vast gas giant planets. The many ship models are also lovingly recreated. Flying close to the rugged surfaces of a Star Destroyer or a Rebel Cruiser is particularly satisfying. Plus, of course, the game's audio benefits from Star Wars' now iconic sound library, from the screams of passing TIE fighters to the squidgy blasts of an X-Wing's laser cannons.

Squadrons offers its dogfighting spectacle in both single and multiplayer variants. Both are excellent, but it's the single-player one that brings the biggest surprises, offering a fully fledged, two-pronged campaign that sees you play as pilots from both rebel and imperial camps. Featuring 16 lengthy and beautifully crafted missions, ranging from hunting rebel refugees through an inhabited
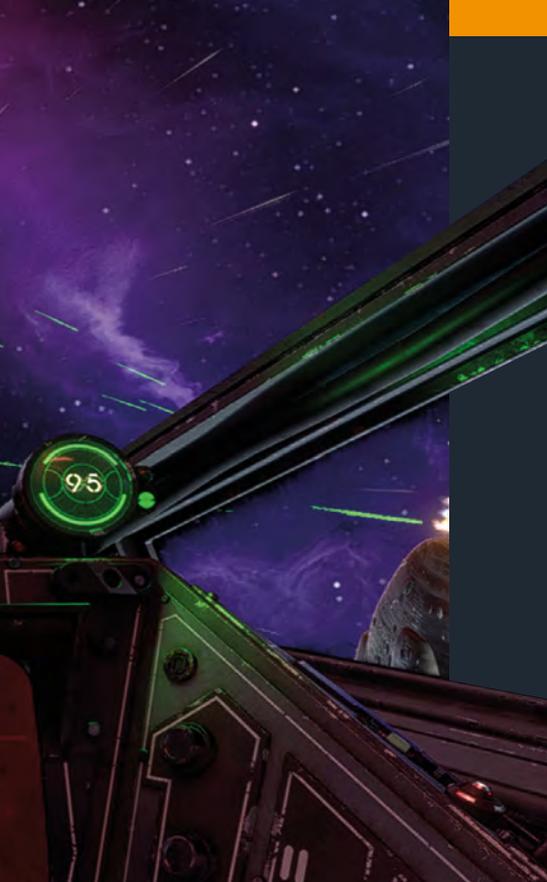
asteroid, to hijacking a Star Destroyer with Wedge Antilles, it's superbly thought out and also brilliantly written. The chatter of your AI squad mates is particularly excellent, lending a strong sense of character and camaraderie to individual missions.

It's a fantastic game when played on a conventional monitor, but VR enhances all its good aspects further. Squadrons is easily the most absorbing VR experience since Half-Life Alyx. The first X-Wing mission is genuinely breathtaking when played in VR. It starts with you seated in the X-Wing's cockpit in deep space. All the buttons and dials are physically there in front of you. Your virtual left arm rests against the cockpit wall at an angle, with your fist gripping the throttle. If you straighten your back and raise your chin, you can see the nose of the X-Wing poking into space around 5m in front of you.

Then the game takes you on a fly-through of an assembled rebel fleet. Weaving through these giant ships and gaining an intimate sense of their sheer size is completely absorbing, and Squadrons has barely got started then. When you're barrelling along the underside of a Star Destroyer, green laser bolts juddering your whole ship as they bounce off your shields, it feels like VR was made specifically for this game.

The benefits VR offers to Squadrons aren't purely aesthetic either. In some ways, it makes the ships easier to fly. The X-Wing's open canopy means you can track enemy ships with your eyes, watching them through the sides and the roof of the canopy as you bank around to chase them. Flying TIE fighters is trickier, as the front-facing window forces you to rely more on instrumentation, but you can lean forwards to peek around the edges of the window, which is neat.

As a slight aside, playing Squadrons was a surprisingly comfortable VR experience. Combat flight sims tend to be the most intense VR games. All the rolling around is liable to make you sicker than riding a rollercoaster with norovirus, but Squadrons uses various techniques to minimise VR sickness, such as narrowing your field of view when you turn.

The experience wasn't entirely nausea-free for us, but it was never unbearable, and

it's easily playable for multi-hour stints before a break is required.

As a VR experience, Squadrons excels. As a VR game, however, it could be better. Primarily, there's no support for touch controllers, meaning you need to use either your keyboard and mouse, a gamepad or a flight stick to play. Keyboard and mouse controls are particularly challenging to use while blind to your real-world surroundings.

More to the point, the lack of support for motion control means there's no ability to physically interact with cockpits and ship interiors. Admittedly, such a feature would likely make controlling ships too unwieldy for the fast-paced action, but it still seems like a missed opportunity.

Squadrons is also a better VR experience on dedicated headsets, such as the Rift or Index, than on the Quest with Link. The latter results in frame rate issues and tracking hitches, as well as an issue where the rendering can't keep up with your head's movement, resulting in black squares appearing in the periphery of your vision.

It's unfortunate that Squadrons doesn't go all in on VR support, as it has the potential to be the best VR game ever made. Nonetheless, this is a fantastic Star Wars experience, and even with its limitations, the VR mode is incredible. Make no mistake, the Force is strong with this one. **CPC**

A NEW HOPE

+ Brilliant space dogfighting
+ Captivating campaign
+ Truly astonishing VR experience

PHANTOM MENACE

− No support for touch controls
− No motion control
− Issues on Oculus Quest with Link

VERDICT

The best Star Wars game in years, and the best VR experience since Half-Life: Alyx, Squadrons is a long-awaited Star Wars triumph for EA.
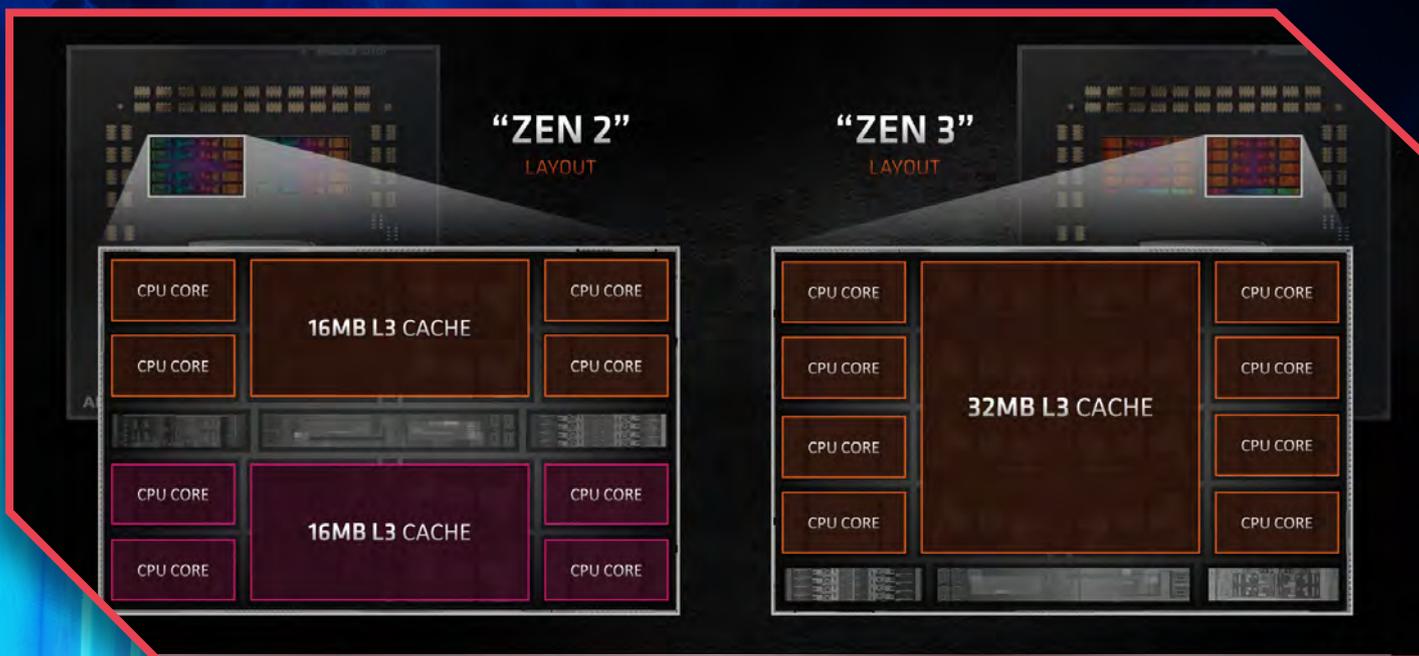
OVERALL SCORE

88%

Zen 3

IN

DEPTH

**EDWARD CHESTER EXPLORES THE ARCHITECTURAL
CHANGES AT THE HEART OF AMD'S LATEST PROCESSORS**

"ZEN 2" LAYOUT

"ZEN 3" LAYOUT

CPU CORE · CPU CORE · 16MB L3 CACHE · CPU CORE · CPU CORE
CPU CORE · CPU CORE · 16MB L3 CACHE · CPU CORE · CPU CORE

CPU CORE · CPU CORE · CPU CORE · CPU CORE · 32MB L3 CACHE · CPU CORE · CPU CORE · CPU CORE · CPU CORE
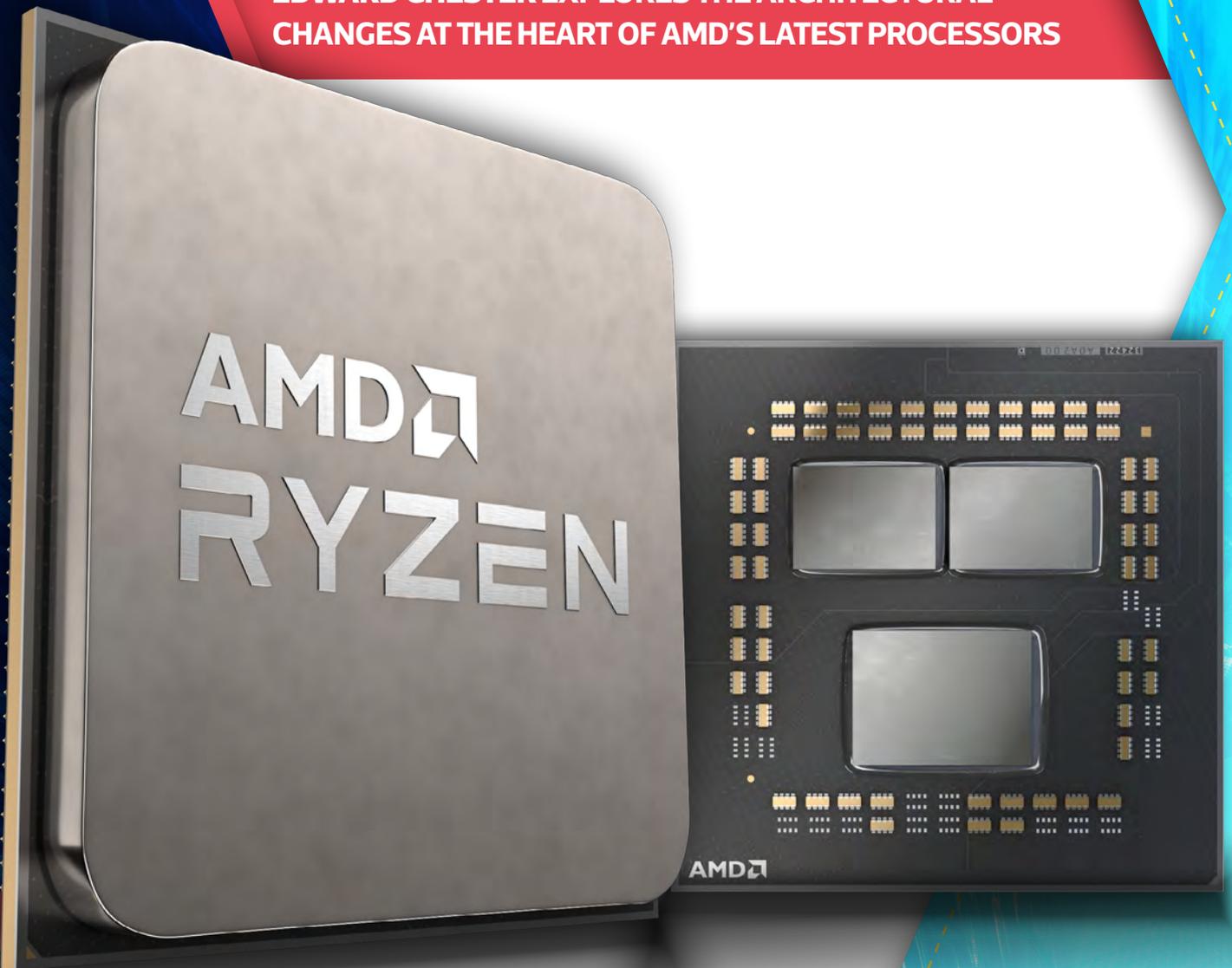
Zen 3 combines the separate 4-core CCX of Zen 2 into a single 8-core arrangement

All eight cores on a CCD are now configured as a single 8-core CCX with a single massive shared 32MB pool of L3 cache

AMD's new Zen 3 architecture is finally here and it brings a host of improvements with it. Together, these tweaks provide a claimed headline figure of a 19 per cent improvement in instructions per clock (IPC), as well as ever so slightly faster clock speeds than Zen 2.

However, with this new design being built on the same 7nm process as Zen 2, this marks what looks like a return to the tick/tock design process that was a staple particularly of Intel CPU designs of the past. With this schedule, in one year the architecture largely stays the same but the manufacturing process shrinks, and the next year, the same manufacturing process is used but the design changes.

Zen 3, then, is the proverbial tock of this cycle, with AMD bringing extensive, if often incremental, changes to the core design of its Zen microarchitecture. As a result, AMD has finally brought its CPUs into true performance parity with Intel when it comes to that most coveted of crowns – gaming. In this feature, we'll explore the intricate details of just what those changes entail, and how these changes cumulatively combine to provide one of the biggest leaps in instructions per clock we've seen from a CPU in some time.

Chiplet champion

With Zen 2, AMD introduced a cunning new approach to CPU design by separating off a host of ancillary CPU functions, such as the memory controller, I/O Hub and Infinity Fabric hub into a separate chip, which is called the cIOD.

The main data-crunching cores were then formed in clusters of eight cores on separate dies called core chiplet designs (CCDs). Multiples of these CCDs could then be combined with a cIOD to form every model from modest 6-core Ryzen chips to the 16-core Ryzen 9 3950X. Add more chiplets, and you could even get up to the 64 cores in AMD's range-topping Threadripper 3990X.

This chiplet-based design philosophy enabled AMD to dramatically reduce the manufacturing costs per die, compared with trying to print the whole design on one die. It also allowed for an approach that we now see with Zen 3, which is relatively easy upgrade paths.

For Zen 3, AMD has taken its existing cIOD chips – that were already built on Global Foundries' older 12/14nm process – and just added the new core designs of Zen 3 that have been built on TSMC's 7nm process. This means the new CPUs can, in theory, drop into existing AM4 motherboards with little fuss. In practice, though, firmware updates will be needed for existing AMD 500-series motherboards, and while support will come to AMD 400-series boards, the first beta releases aren't expected until January 2021.

AMD hasn't revealed what further overall package designs we'll see using the Zen 3 core design, but it's a safe bet that we'll see the same quad-die Threadripper and eight-die EPYC designs. Some sort of variant using the same core design but with a fully integrated GPU, akin to the 2400G and 3400G, also seems likely.

Cores, combine!

While the fundamental principle of chiplet design hasn't changed with Zen 3, AMD has changed the typical configuration of the CCDs. Let's start by looking at a Zen 2 Ryzen

"ZEN 3" OVERVIEW

2 THREADS PER CORE (SMT)

STATE-OF-THE-ART BRANCH PREDICTOR

CACHES
- I-cache 32k, 8-way
- Op-cache, 4K Instructions
- D-cache 32k, 8-way
- L2 cache 512k, 8-way

DECODE
- 4 instructions / cycle from decode or 8 ops from Op-cache
- 6 ops / cycle dispatched to Integer or Floating Point

EXECUTION CAPABILITIES
- 4 integer units
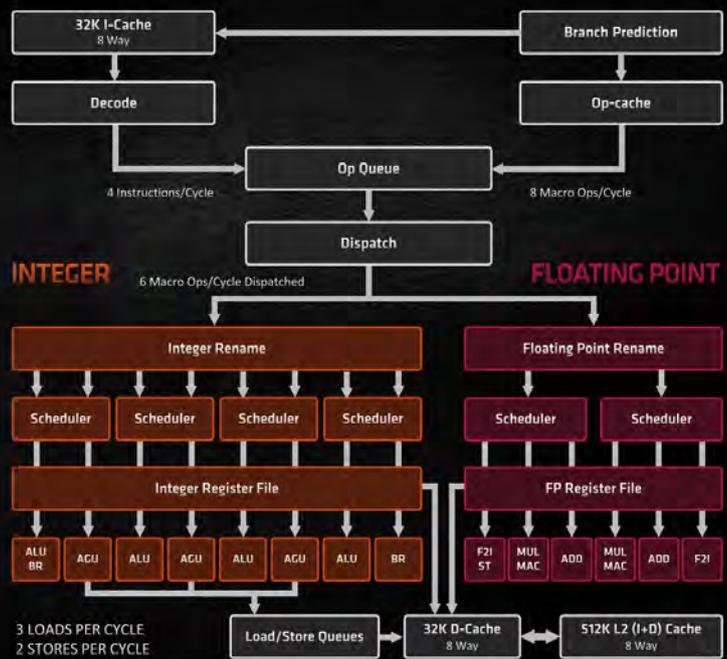- Dedicated branch and store data units
- 3 address generations per cycle

3 MEMORY OPS PER CYCLE
- Max 2 can be stores

TLBs
- L1 64 entries I & D, all page sizes
- L2 512 I, 2K D, everything but 1G

TWO 256-BIT FP MULTIPLY ACCUMULATE / CYCLE

CCD – while it presents as a physical chip with eight cores, internally, those eight cores are split into two banks of four cores called a core complex (CCX). This CCX shares a big 16MB of L3 cache that allows each of the four cores to relatively quickly share data.

With this old design, any data sharing between CCXs required stepping down to the comparatively slow Infinity Fabric connection, which was known to introduce performance issues in a variety of situations. This was problematic enough that it prompted AMD to work with Microsoft to provide a Windows update, which ensured that related threads were opened on neighbouring cores on a CCX before using another one, greatly improving performance across the board.

For Zen 3, then, AMD has scrapped this on-die separation and now all eight cores on a CCD are configured as a single 8-core CCX with a massive shared 32MB pool of L3 cache. This new configuration still doesn't make up for slower data transfer between physical CCDs, but the idea is that for most applications where speed of data sharing was a concern – such as gaming – the larger 8-core design is much more likely to capture the vast majority of shared-data situations.

Specifically, because this bottleneck was mainly a concern for situations where a largely single-threaded application, such as most games, might have a few other ancillary threads running, having 'only' four cores could mean that some of those ancillary threads were offloaded to another CCX, introducing delays. With eight cores per CCX, this likelihood is greatly diminished.

As well as reducing the likelihood that data will need to be transferred over Infinity Fabric between cores, the larger CCX design and doubled L3 cache also simply provides a larger single pool of data for all the cores. As a result, not only can data move more quickly, but there's also a greater chance that the data any given core may need will be on hand and not require a full memory call, effectively reducing memory latency.

While the move to a single, larger CCD might at first seem to reduce the effectiveness of the whole chiplet approach – after all, isn't the point to have many smaller dies and not fewer larger ones? – remember that the physical size and configuration of the CPUs won't be changing.

AMD's previous CCDs were still monolithic dies containing eight cores, it's just that

When it guesses a branch incorrectly, the new design can get its new prediction stream going much faster

internally they were configured with separate CCXs. The new arrangement just brings them together internally. It was only on APUs with integrated graphics (such as the Ryzen 5 3400G) that a single CCX was actually used, but even then it was integrated into a single die along with the graphics and cIOD functions.

Although Zen introduces a much larger L3 cache than Zen 2, and shares it across twice as many cores, delving a little deeper into the cache hierarchy reveals that this is largely the only change to the cache setup. As with Zen 2, Zen 3's L3 cache is populated only by victims from L2 (a cache victim is any cache block that has been ejected from higher level caches – the data is kept in a lower level cache in case it's needed later) and is configured in a 16-way associative manner.

As we move from the cross-core L3 cache and into each individual core, each one gets the same 512KB L2 instruction and data cache as Zen 2, and above that, again the L1 instruction and data caches remain at 32KB. The L1 and L2 caches also retain their 8-way associative structure.

In general, the higher the associativity of a cache, the greater the likelihood the required data is in the cache (a cache hit), but any individual cache lookups will be slower. Finding the balance between hit rate and per-lookup speed is a crucial part of processor cache design, and it's why we see the L3 cache use a higher associativity than the L2 cache.

The overview

As we move a further step inwards from the CCX, we get to the Zen 3 core itself and it's here that you'll find most of the changes responsible for the headline 19 per cent IPC improvement. However, as AMD has been at pains to point out, the improvement doesn't come from just one area, but from multiple little tweaks throughout the core design.

AMD hasn't broken down the percentage change of each contributing factor in terms of its performance uplift, but it has detailed those contributing factors. Cache prefetching, execution engine, branch prediction, micro-op cache, front end design and load/store design have all been changed, and it's the interplay of all these factors that has resulted in such an impressive improvement in IPC.

The most obvious overarching theme can be summed up by the company's own design goal: 'lower latencies and larger structures to extract instruction level parallelism for feeding the execution engines'. In other words, by improving the way data is fed into the execution engine – the actual number crunching parts – more performance can be extracted, and that's a process that starts at the front end of the CPU.

The front end

The front end of a CPU core's pipeline is the part that's responsible for fetching operations that are then executed by the back end of the pipeline, here called the execution engine.

Larger operations are broken down by the front end into micro operations (micro-ops), which can be executed by the components of the execution engine. Front-end design is hugely important to modern CPU design, because a great deal of a processor's performance comes from managing the flow of these micro-ops to the execution engine.

One of the key roles of the front end is also predicting what might happen next for any

FETCH/DECODE

"ZEN 3" DESIGN GOAL: FASTER FETCH, ESPECIALLY FOR BRANCHY AND LARGE FOOTPRINT CODE

IMPROVED BRANCH PREDICTION
- TAGE branch predictor
- Redistributed BTBs for better prediction latency
  - L1 BTB: 1024 entries
  - L2 BTB: 6.5K entries
- Larger 1.5K indirect target array (ITA)
- Lower mispredict latency
- No "bubble" on most predictions

OPTIMIZED 32KB, 8-WAY L1I CACHE
- Improved prefetching
- Improved utilization

STREAMLINED OP-CACHE
- Faster sequencing of Op-cache fetches
- Finer-grained switching of Op-cache / I-cache pipes

Branch Prediction · Instruction Cache · Instruction Byte Queue · Pick · Decode · Op-cache · 4 Instructions · 8 Macro Ops · Micro-Op Queue · Stack Engine · Memory Dependence Detection · Microcode ROM · Dispatch · 6 Macro Ops Dispatch
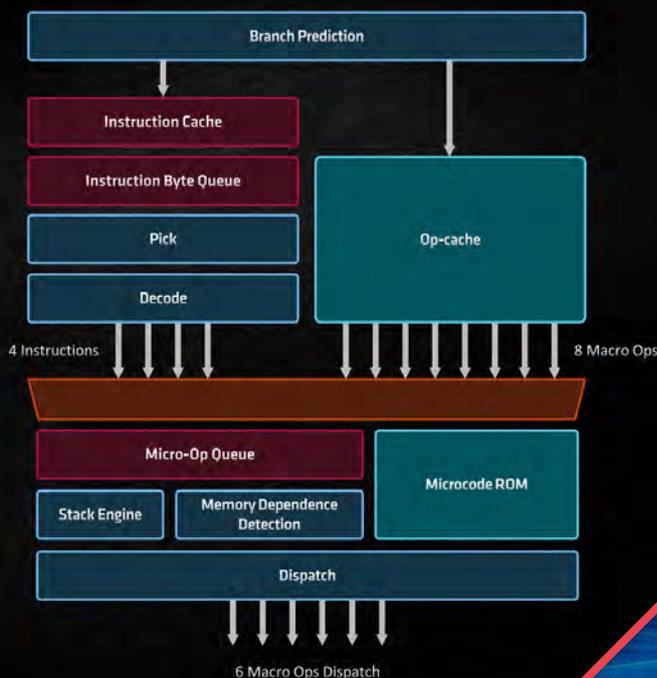
given thread's instructions. Specifically, the most obvious and intuitive reason for wanting to predict what might happen next is when a program branches. That's when you have a statement in your code such as an IF, THEN or ELSE clause.

The program can only proceed once the decision has been made whether to follow the IF option or the ELSE option. However, you can get ahead of the game by already having the hardware ready for both options – once the decision arrives, you can move on to the correct branch straightaway.

This branch prediction has seen a marked improvement with Zen 3. For a start, the main prediction engine, the tagged geometric (TAGE) branch predictor, has been sped up, while the branch target buffer (BTB) arrangement has been tweaked for lower latency. The L1 BTB has doubled in size from 512 entries (which in turn was a doubling from 256 with Zen 1) to 1,024 entries.

However, proving the point that all such performance improvements result from a balance of factors, the L2 BTB cache has actually dropped in size slightly from 7K entries to 6.5K. Essentially, the emphasis has been put on increasing the likelihood of a hit on the faster L1 buffer before hitting the slower, larger L2 buffer.

Similarly, the indirect target array – used to store predictions for situations with a choice of more than two branches – has increased from 1K on Zen 2 to 1.5K on Zen 3 (Zen 1 had just 512 entries).

Also crucial is the fact that the branch predictor pipeline has been shortened, so that when it does guess the branch incorrectly, the new design can get its new prediction stream going much faster. AMD claims this setup leads to 'no bubble' on most predictions, which is a term used to refer to a situation where a hang in the data stream – such as an incorrect prediction – causes the whole pipeline to be stalled or delayed, like an air bubble in a cooling loop.

The shorter, faster pipeline with Zen 3 should ensure that any stalls are filtered out much more quickly, reducing any potential delays and getting the data to the execution engine more quickly. Further improvements come from improved prefetching of instructions from the L2 cache to the L1 instruction (L1I) cache, as well as improving utilisation within the L1I cache.

Another key consideration for a front end is efficiently managing the stream of instructions that are being fed into the micro-op queue (the waiting area for micro-ops before being passed to the execution engine), from both the decode engine and the op-cache. Zen 3 can more quickly sequence micro-ops from both sources to minimise the number of stalls from a lack of micro-ops.

We've scheduled your execution

The next step in eking out more performance from the Zen design is in improving the overall performance of the execution engine. This comes in two main parts – one for performing integer (whole number) calculations and one for floating point (numbers with a decimal point) calculations. Both these main sections have seen upgrades since Zen 2.

Starting with the integer side of the equation, nearly every aspect of the circuit has been slightly upgraded. The operation

On the integer side of the equation, nearly every aspect of the circuit has been slightly upgraded

A wider 10-issue integer execution engine improves the number of instructions per cycle

INT EXECUTION

"ZEN 3" DESIGN GOAL: LOWER LATENCIES AND LARGER STRUCTURES TO EXTRACT ILP FOR FEEDING THE EXECUTION ENGINES

- 96 entry integer scheduler, up from 92
  - 4x 24-entry ALU/AGU schedulers
- 192 entry physical register file (up from 180)
- 10 issue per cycle, up from 7
  - 4 ALUs, 3 AGUs, 1 dedicated branch, 2 St-data
- 256 entry ROB, up from 224

6 macro ops per cycle dispatch

Integer Rename

Scheduler 3 | Scheduler 2 | Scheduler 1 | Scheduler 0

Integer Register File

ALU3 | BRU1 | ALU2 | AGU2 | ALU1 | AGU1 | ALU0 BRU0 | AGU0

3X 64-bit loads
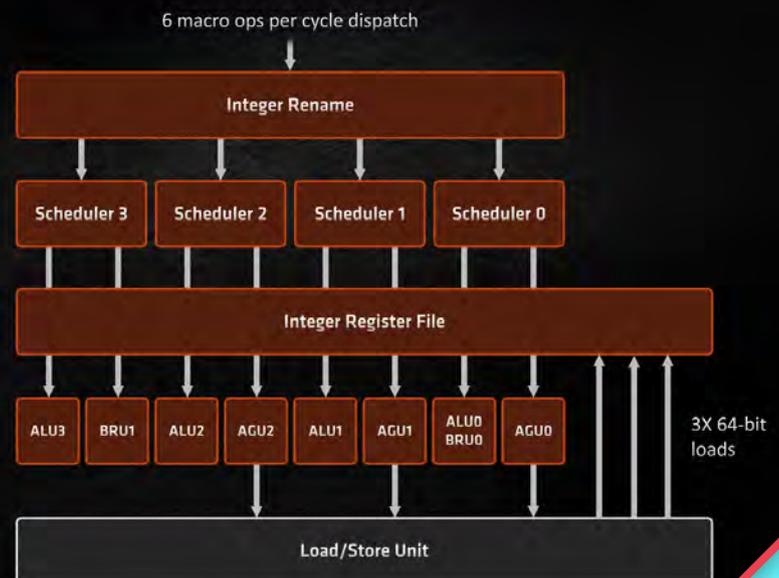
Load/Store Unit

FP EXECUTION

"ZEN 3" DESIGN GOAL: LOWER LATENCIES AND LARGER STRUCTURES TO EXTRACT ILP FOR FEEDING THE EXECUTION ENGINES

- Faster 4-cycle FMAC
- Increased Dispatch Bandwidth
- Separate F2I/Store Units
- Larger Scheduler

Micro-Op Dispatch

Floating Point Scheduler

256-bit Load Store ← 256-bit loads

256-bit Floating Point Register File

Forwarding Muxes

STORE F2I | MUL0 MAC0 | ADD0 | MUL1 MAC1 | ADD1 | F2I
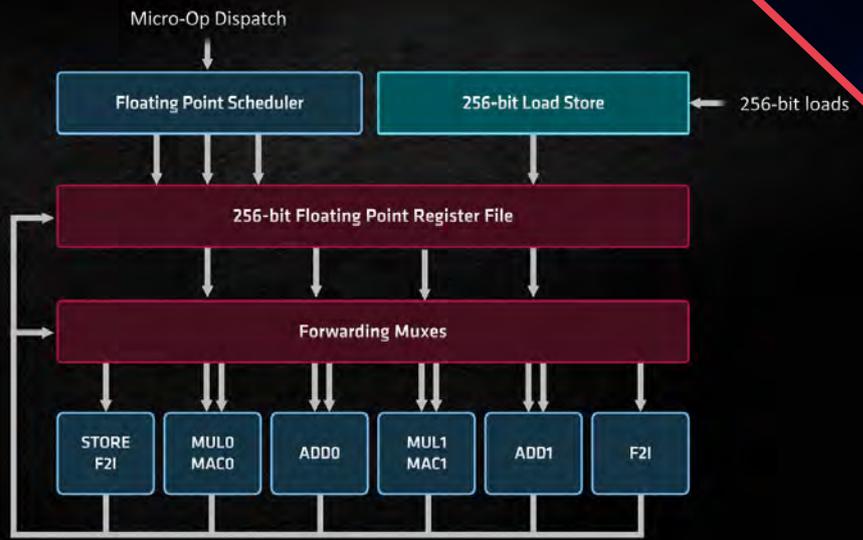
The floating point section can now dispatch six micro-ops per cycle, up from four in Zen 2
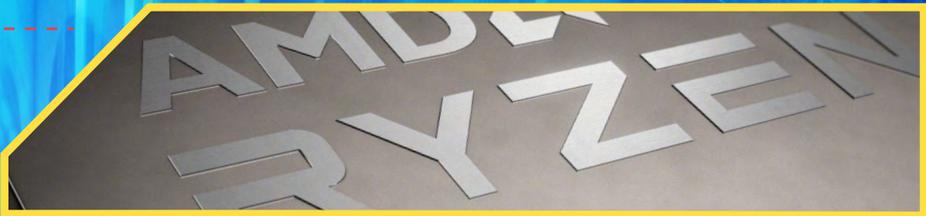
scheduler now deals with 96 entries, up from 92 previously, while the physical register file has gone from 180 up to 192 entries and the re-order buffer (ROB) has increased from 224 to 256. All these improvements are the sort of incremental bumps you might expect with a slight tweak to a CPU architecture, although none would seem to tally with a 19 per cent performance improvement in IPC.

Even less obvious a candidate for the big change is the cluster of four arithmetic logic units (ALUs) and three address generation units (AGUs), which are at the heart of the integer execution engine. Those are the same number of ALUs and AGUs found in Zen 2, with Zen 3 seemingly 'only' adding a dedicated branch unit for offsetting certain branching operations.

Crucially, though, one each of the ALU and AGU can perform a store operation in parallel with their regular arithmetic and address generation operations, increasing the overall number of operations that can simultaneously be performed per cycle from seven to ten. What's more, the ALUs and AGUs are

now paired up to share a scheduler – as opposed to having independent schedulers in Zen 2. This helps to ensure that all four ALUs are always kept busy, while still keeping other operations going in parallel.

Floating point
As for the floating point side of the design, the big upgrade with Zen 3 is the ability to dispatch six micro-ops per cycle, up from four in Zen 2, providing much greater overall bandwidth. This increased capacity is then reflected in the main operation units, where we see newly added, dedicated floating point-to-integer move (F2I) and store operation units.

These operations were previously handled inside the main multiplication (MUL) and addition (ADD) units. This move essentially frees up the MUL and ADD units, so they can perform more of those core calculations per cycle, rather than being tied up with housekeeping operations.

Another key change is the fused multiply-accumulate unit (FMAC), which is responsible for performing the specific task of adding one

number to the product of two other numbers (for example, 2 + 3 x 4), and has had its speed increased. It now takes four cycles to perform the operation, down from five before.

The final tweak is a larger scheduler that allows for more floating point instructions to be in flight at any given time. This increased capacity makes for higher utilisation of the floating point units, as a larger pool of instructions means there's a lower chance that the scheduler will be left waiting for some other operation to complete before an instruction is ready to go.

For instance, an instruction might be waiting for the load components to load in all the required operands. With more instructions from which to choose, the scheduler isn't starving the floating point units of instructions while it waits for those operands to arrive.

Loading and storing
The final main piece of the puzzle for the new Zen 3 core design is the loading and storing section. This is the section responsible for, as its name suggests, loading in data from

LOAD/STORE

"ZEN 3" DESIGN GOAL: LARGER STRUCTURES AND BETTER PREFETCHING TO EXTRACT ILP FOR FEEDING WIDER EXECUTION

- 64 entry store queue, up from 48
- 2K entry L2 DTLB
- 32KB, 8-way L1 data cache
  - 3x memory ops per cycle
  - Max 3 loads per cycle (max 2 if 256b)
  - Max 2 stores per cycle (max 1 if 256b)
- Faster copy of short strings
- Improved prefetching across page boundaries
- Better prediction of store-to-load forward dependencies
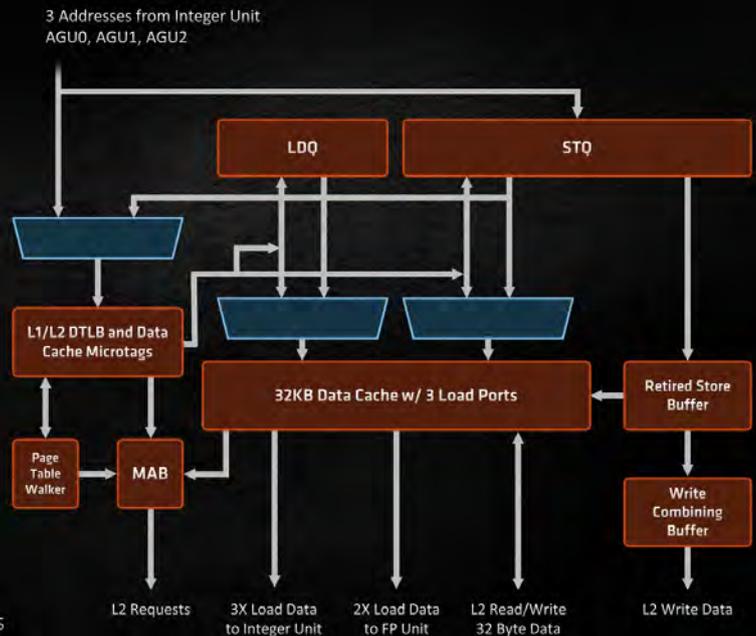
memory and sending it back out to memory (or caches) for storage. It interacts with the AGUs from the integer execution engine, with those address instructions being fed to the load/store queue. It also interacts with the integer and floating point register files that link directly to the 32K data cache and onto the 512K L2 cache.

With Zen 3, the overall load store unit bandwidth has increased, thanks to the ability to perform three load operations and two store operations per cycle. This appears to be a switch around from the configuration in Zen 2, which had one AGU that was only able to perform store operations, so it could do two loads and three store operations per cycle. However, AMD hasn't clarified exactly how the configuration has changed, only highlighting the core ability of Zen 3 to now perform those three loads and two stores per cycle, making for an apparently more flexible load/store configuration.

Meanwhile, if you're dealing in 256-bit floating point operations, Zen 3 retains the same two loads and one store per cycle ability as Zen 2. Prior to Zen 2, the Zen architecture required two cycles to perform a 256-bit calculation, which put a major dent in its

performance for certain complex calculations. Zen 2 then brought support for single-cycle 256-bit calculations, along with the load/store capacity to support it, and evidently AMD hasn't deemed performance requirements to have moved on to a point where even more 256-bit performance is required.

Store load prediction has also improved, helping to ensure that data is quickly accessible, even for more random workloads where data requirements aren't always predictable. Tying into this is the increase in translation lookaside buffer (TLB) walkers from two to six.

A TLB is used to store the recent translations of virtual memory to physical memory addresses. When an address is present in the TLB, it's considered a TLB hit and all is well. However, when it's not in the TLB, the search proceeds to the page table, in a process called a page walk. By having more page walkers, the system can deal with TLB misses quicker.

The store queue has also increased in size significantly from 48 entries to 64, again reinforcing this idea of keeping all processes constantly fed from larger stores of data. Elsewhere, the headline numbers don't

> **AMD is, of course, working on the follow-up to Zen 3, which is expected to arrive around this time next year**

CACHE COMPARISON

RESOURCE	ZEN	ZEN 2	ZEN 3
Load queue entries	72	72	72
Store queue entries	44	48	64
Micro-op cache	2KB	4KB	4KB
L1 instruction cache	64KB	32KB	32KB
L1 data cache	32KB	32KB	32KB
L2 cache	512KB	512KB	512KB
L3 cache per core	2MB	4MB	4MB
L2 translation lookaside buffer size	1.2KB	2KB	2KB
L2 translation lookaside buffer latency	8	6	6
L2 latency (cycles)	12	12	12
L3 latency (cycles)	35	39	46

CORE COMPARISON

RESOURCE	ZEN	ZEN 2	ZEN 3
Issue width	10	11	16
Integer register entries	168	180	192
Integer scheduler entries	84	92	96
Floating point register entries	160	160	160
Re-order buffer entries	192	224	32KB
FADD, FMUL, FMA	3, 4, 5	3, 3, 5	3, 3, 4
Floating point width	128	256	256
L1 branch target buffer entries	256	512	1,024
L2 branch target buffer entries	4,000	7,000	6,500
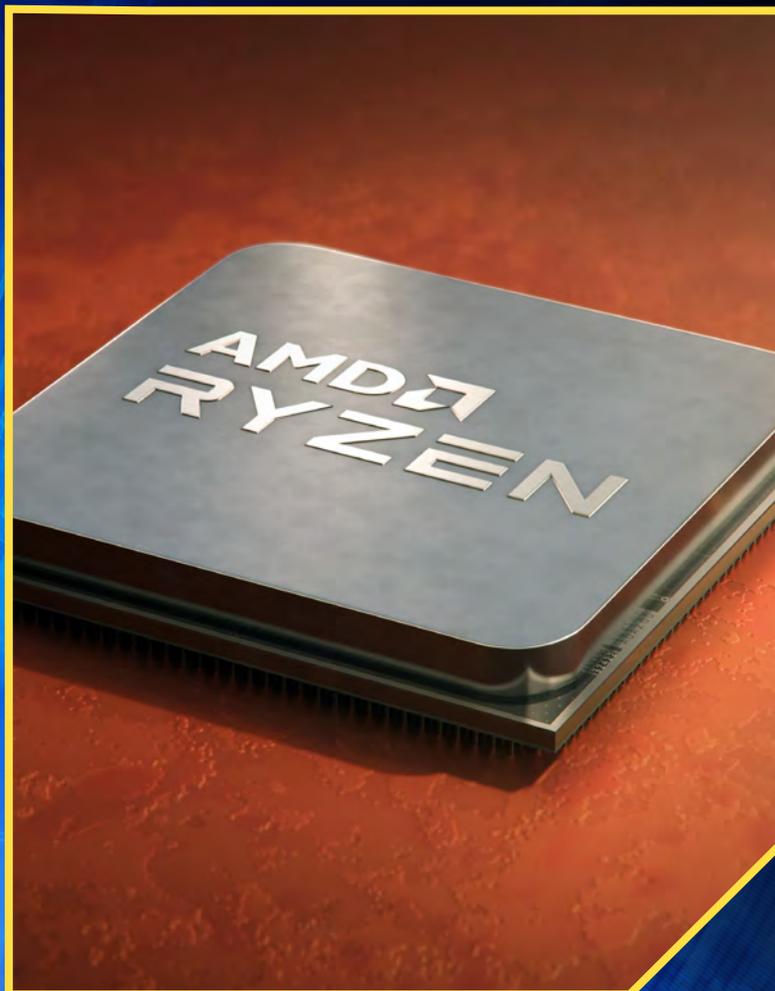
appear to have changed a great deal, with the data TLB remaining at 2K entries and the overall data cache remaining at 32KB, with an 8-way associativity.

Another crucial change is the improved prefetching of data across page boundaries. This taps into the larger L3 cache of the new design, ensuring that the CPU takes full advantage of the relatively huge shared data store, by seeking out any data it might be holding well in advance of it being needed higher up the cache structure.

The final notable tweak is better prediction of store-to-load forwarding dependencies. Store-to-load forwarding is used to prevent a load instruction occurring from the same address that a store instruction is about to change.

Without tracking such activities, the load instruction would read the old data before the new data was written by the store instruction.

With Zen 3, AMD has managed to improve its detection of those dependencies and forward them earlier in the pipeline, reducing the latency of such operations.

Security features and ISA expansion
Outside of the changes to the core performance of Zen 3, AMD has also added some more security features and instruction set architecture (ISA) compatibility.

On the security side, Zen 3 now supports shadow stack for protection against return-oriented programming (ROP) attacks.

Such attacks exploit the call stack of a program – often used to keep track of its subroutines – gaining control of the control flow and allowing for machine code instructions to be performed.

A shadow stack does as its name implies, shadowing the call stack. When a function completes, the return address of the call stack and shadow stack are

compared and, if they differ, the intrusion is detected.

On the instruction set side, Zen 3 now also supports memory protection keys (MPK) and includes AVX2 support for VAES/VPCLMULQD instructions.

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The future
AMD is, of course, already working on the follow-up to Zen 3, which is scheduled to arrive around this time next year. AMD says the core dies are on track to be built on TSMC's 5nm process, which will likely bring lower power usage and heat, and potentially higher clock speeds. However, tellingly, in AMD's chart highlighting the performance uplift of its last three Zen generations, there's a hint at a smaller increase for Zen 4.

With AMD now having largely caught up to Intel on this front, it's only to be expected that it might face some of the same problems further pushing performance. CPC

Integer scaling explained

MARK SIMPSON EXAMINES WHAT HAPPENS WHEN YOUR PC NEEDS TO RENDER BELOW YOUR SCREEN'S NATIVE RESOLUTION, AND HOW INTEGER SCALING CAN MAKE IT PIXEL-PERFECT

Ever since the death of the analogue CRT and the introduction of digital displays, there's always been the potential to drive a digital display at its non-native resolution.

Because a digital display's pixel grid is fixed and can't change depending on the input signal, unlike the more analogue system of phosphors excited on a CRT by its electron gun, it's always showing you those fixed pixels no matter what. On a modern digital display, it's common to just always render at the same resolution as your display, be that your operating system's desktop environment or a game, which takes away any question about scaling. Easy.

Any inability for your system to do that will always add scaling to the display back into the equation, and there are two broad underlying reasons why in most cases. The first one is performance. The GPU may not be able to render your game at the native resolution of your display at a high enough frame rate for you to enjoy it, demanding a lower-resolution, scaled-up render.

The second one is because the hardware or software doing the rendering simply can't output at your display's native resolution in the first place. An example is an emulator for an older system that supports resolutions well below your display, because higher resolutions weren't available at the time. In both cases, you need to take output images that aren't the same resolution as your display and make them fit to your display.

Maintaining performance and image quality

There are essentially infinite ways to scale an image from one resolution to another, up or down, but any desirable and practical methods have two key properties: performance and image quality. You need to be able to scale the image efficiently and quickly, whether it's performed in software or hardware, and it ideally has to look good at the end. A scaler without performance quickly becomes useless for real-time uses such as games, and one without a particular level of image quality will quickly be rejected as ugly, especially if it affects the spirit of the original content.

When thinking about scaling up the output of old systems, the scaler needs to remember that they were originally connected to low-resolution analogue CRTs.

The image on those monitors had a particular look about them, and if you take it away, you remove some of the nostalgia hit you'll get when playing those old systems via software emulation, or via a physical scaler that lets you display the original analogue output on your digital monitor.

Depending on the CRT technology in play, you could easily see individual RGB phosphor patterns and the phosphor masks, and if you were lucky enough to have a Sony Trinitron monitor, you could see the tiny tungsten phosphor grille support wires. Those visual aspects of the display technology of CRTs are now burned into the brains of people old enough to have experienced them almost as much as the content of the games played.

High-density modern displays

Outside of the case for upscaling old games, there's another class of scaling problem that's worth considering, which is drawing a desktop on a high-density display that packs in a serious amount of pixels per inch (ppi). These HiDPI displays put a huge amount of pixels in front of you, to the point where your visual system finds it hard to distinguish between pixels at sensible viewing distances.

AMD's integer scaling, demonstrated in Warcraft II: Tides of Darkness

Integer Scaling **OFF**   Integer Scaling **ON**
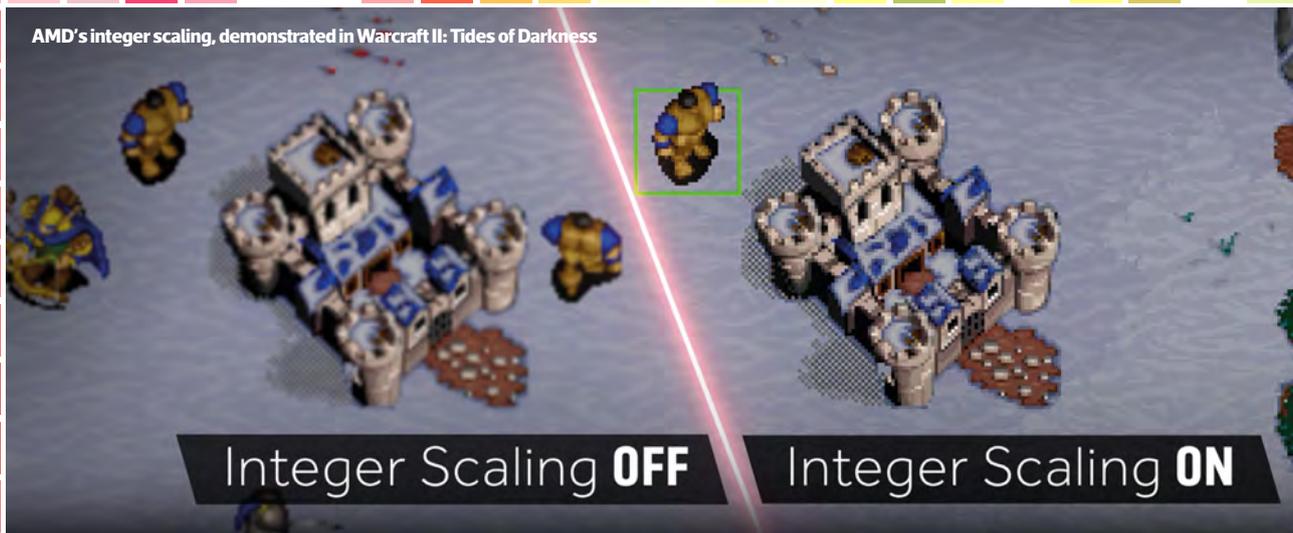
Historically, operating systems had their user interfaces (UI) designed for displays and printing systems with 72 pixels per inch (ppi), so if you ask them to render UI elements at the native resolution of a HiDPI display then they'll appear too small. It's easy to imagine why. I'm currently using a 27in 4K display with a pixel density of 163ppi, so an object that's 163 pixels wide will appear to be roughly an inch wide on the screen. That same 163-pixel wide object on an 82dpi display will appear roughly 2in wide. Density matters, so an operating system needs to treat the UI differently on HiDPI displays.

That means your operating system needs to offer a method of rendering your desktop UI in a scaled way on HiDPI displays, so it looks right. Some operating systems do an almost flawless job at it, particularly macOS. To be fair to Windows specifically, though, it's a very hard problem to solve on an operating system that must run legacy software

designed from the days when HiDPI display technology hadn't even been invented yet.

Now we know why scaling in general is necessary and non-trivial, let's circle back to upscaling older gaming content designed for much lower-resolution displays. GPU vendors can use built-in hardware on their modern products, which can help to solve the problem in a new way that has great performance and preserves as much of the image quality of the original content as possible, addressing the two key pillars of any scaling system. It's called integer scaling, so let's dive in and see how it works.

Integer scaling explained

The best way to understand integer scaling is to first think about some of the other ways you could potentially scale up an image to a higher resolution. Imagine you have to map one input pixel to more than one output pixel – you need a mathematical way

Games look very different on CRT monitors than on today's digital displays

of transforming that single input pixel into those multiple outputs.

Let's consider the simplest case: mapping a simple 4 x 4-pixel source image up to an 8 x 8-pixel target image. The source and target have the same aspect ratio, which is an important property for any scaler to consider, and the upscaled ratio is 2:1, resulting in four times as many pixels (2x more in both the horizontal and vertical dimensions) – 16 pixels in the source becomes 64 pixels in the target.

For the alternating pattern of pixels in the 4 x 4 source image, there are many ways you could take that source data and transform it into the 8 x 8 target. You could have a scaler

> ## Historically, user interfaces were designed for displays and printing systems with 72 pixels per inch

HiDPI density example
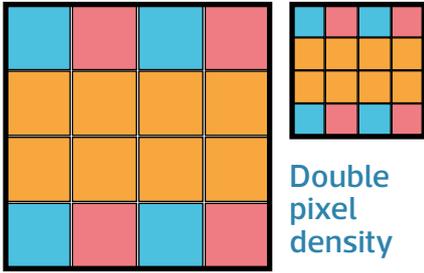
Double pixel density

Original pixel density

An object on a display with double the assumed pixel density ends up being much smaller

that says for each white pixel in the source image you want to have four pink pixels, and for each black pixel in the image you want to have four yellow pixels. Clearly, that's going to give you an 8 x 8 image that's upscaled from the 4 x 4 in a particular way, but not in a way that gives you a high-quality resulting image that preserves the look of the original. We can definitely do better.

Better upscaling filters

So, what about a method that takes an average of the colour of the 2 x 2 block of pixels near the source one, in order to generate more for an upscaled target? This is also known as a bilinear filter. That sounds good, since we need more pixels in the upscaled target, and while that approach will get you a more accurate representation than our white-to-pink and black-to-yellow swap from earlier, it's still not going to work with high-contrast imagery.

For example, think of the average colour between white and black: grey, and imagine that averaging effect carried out over the whole image as it was upscaled, smearing the wrong colour over the image anywhere that it finds high contrast, which is what tends to happen between the edges of objects. Imagine Mario and Yoshi smeared into the flatter backgrounds of Super Mario World. Again, we can do better.

The obvious path from that kind of idea is an increasingly wide filter, which takes a look at a larger area around the source pixel to find information to blend together for the new target pixels. Take a step past that and you get a filter that's content-aware. We mentioned the high-contrast edges that do badly with the averaging bilinear filter

Upscaling examples
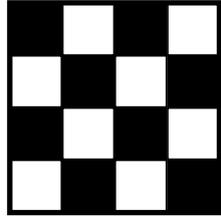
4 x 4 alternating black and white pixels

2x upscale to 8 x 8 gets right size but wrong colours

2x integer scaling is more pixelated but looks fine!
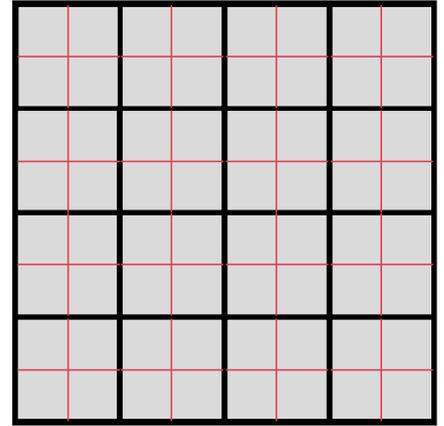
Bilinear upscale gets more correct colours but blurs high-contrast content

earlier, so maybe our new upscaling filter can adopt a different method when it encounters regions of pixels that are clearly distinct from one another in their colour, and therefore have high contrast. Both those approaches can provide higher image quality than the simpler bilinear filter, but only for certain kinds of content.

Bespoke filtering for particular content

That leads us to thinking about creating bespoke filters, which are tailored to the kind of content being upscaled. Earlier, we talked about preserving the look and feel of older games designed for much older, lower-resolution analogue display technologies, such as CRTs. Knowing that those games

have particular visual properties, and what they are, we can improve our filtering to make it more authentic.

So, knowing that we've got that pixelated, blocky look in every part of older games, how do we preserve it, rather than smear it all over the screen, with our earlier attempts at filtering the source image?

The current best answer is almost so obvious that you might initially wonder why it hasn't been the solution all along: for every input pixel that you sample, you just copy its colour wholesale to every target pixel. There's no average blending, no looking further outside the pixel at its neighbours to try to do better, no contrast or other content-aware approach. Just a plain old copy of the original colour into the upscaled region

– nothing more, nothing less. That's integer scaling and it's honestly that simple.

For every input pixel you want to upscale, you produce an integer multiple of new ones that are exactly the same in the upscaled image. So 2x integer scaling produces four new pixels in a 2 x 2 block for each input pixel, 3x integer scaling produces nine new pixels in a 3 x 3 block for each one, and so on.

There's no fractional arithmetic or fancy filtering – you just copy the pixel blocks. There has to be a catch though, right? There's a couple, sadly, and the aspect ratio of the original content, which we mentioned earlier in this feature, is the first one.

What's the catch?
In the modern era, we've moved to a much wider format display than the old days. Back then, standard-definition TV was usually broadcast in 4:3, 3:2 (particularly the analogue NTSC spec used in the USA) or 5:4 (our competing PAL format) aspect ratios.

There's a bit more to it than that too, because old analogue signals would hide information in the lines at the top that weren't meant to be displayed, giving rise to the concept of overscan, an issue that still haunts digital TVs to this day. In general,

though, we had fairly narrow formats back then, and old gaming systems would target displays in that format.

These days the most common digital display format by absolute miles is 1080p at a 16:9 aspect ratio, which is maintained by both 4K and 8K displays too. In the fringes of the modern gaming world, you'll find displays with even wider aspect ratios that head towards the cinematic 2.35:1 or higher. The problem that besets a cinematic presentation on a 16:9 TV or display at home is the same one that affects integer scaling as a technique, even though we've identified that it's a great upscaler for older more pixelated content: black bars.

Imagine a game system designed for PAL TVs that outputs 720 x 576 (5:4), and you want to integer-upscale it to your 16:9 or 4K display. Your 4K display is much wider, so stretching it out to fit is one technique, but that's not what integer scaling does, so you need bars on either side of the original-format image that's centred on your new display.

The same approach applies to old PC display formats, which were usually 4:3, with resolutions such as 640 x 480, or 800 x 600. Integer scaling up to a wider-format

display is possible, but the scaling options are limited, meaning 640 x 480 can be 2x integer-scaled up to 1,280 x 960 on a 1080p display, or 2,560 x 1,920 on a 4K display, with black bars on either side.

Knowing about the black bars problem, and knowing that integer scaling means you can only scale in whole numbers, you can see that some source resolutions just can't be integer-scaled to today's wider-format displays because the maths doesn't work out.

Take a resolution of 800 x 600, for example. You physically can't integer-scale that up to a 1080p display, since that's 1,920 x 1,080 pixels, while you could 2x scale in the horizontal direction, since that's only 1,600 pixels; 2x in the vertical doesn't fit because you'd need 1,200 pixels, more than the 1,080 available on your 1080p display. In these situations, which are more common than you might initially think on a 1080p 16:9 display, you're out of luck.

Integer scaling really only shines on higher-resolution modern formats, such as 4K and above, since you need that target pixel space to do the job in many cases. That's the second catch to which we alluded earlier, and it's the reason why, if it's so obvious that integer scaling is the right kind of scaling for certain kinds of content, it hasn't really shown up until recently.
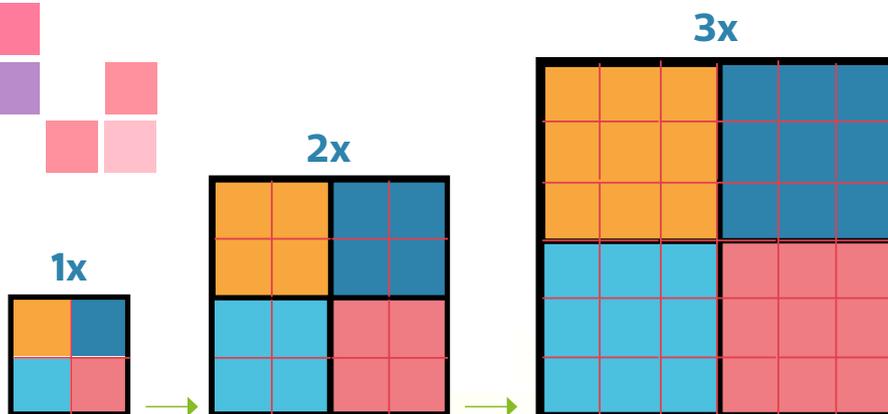
Integer scaling in hardware
There are ways to force your setup into integer scaling, though, ensuring pixel precision without blurring and smearing. Let's start by taking a short dive into the ways in which hardware might implement support for integer scaling. Intel, Nvidia and AMD have all leaned on existing hardware in their GPUs in order to accelerate it, and there are many different approaches.

Probably the easiest way to do it is via the display controllers that live on the GPU. Their sole job is taking a frame buffer the GPU has generated, which represents a frame of rendering in your game, or one that the operating system has generated while drawing itself, and turning it into signals to pump over the wire to your display.
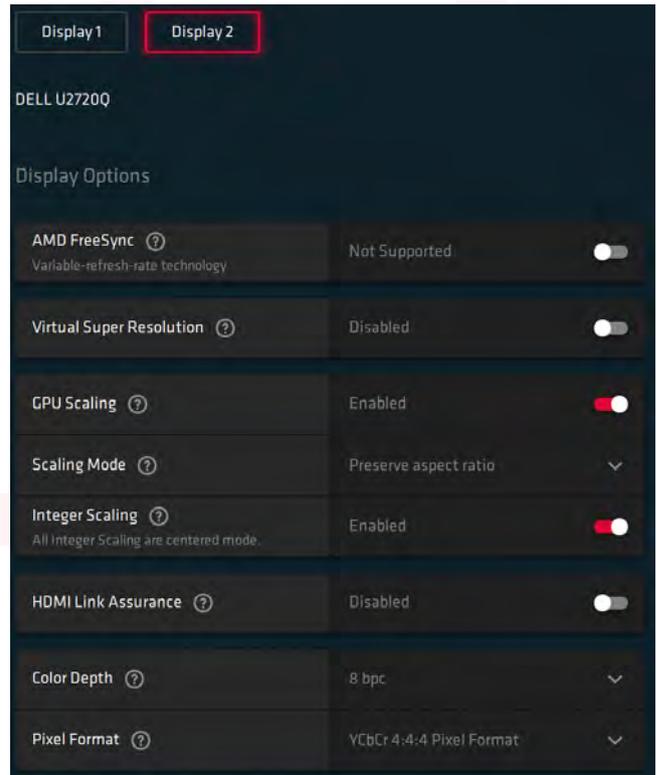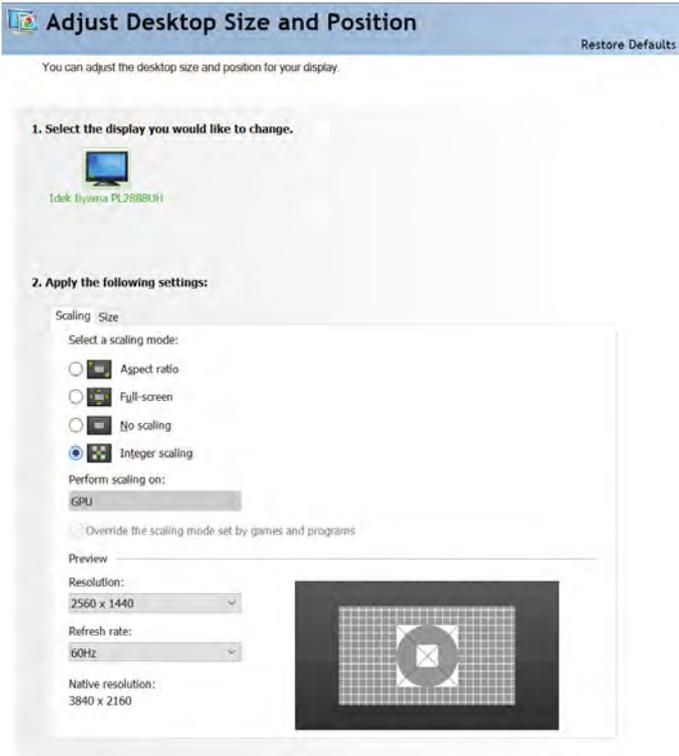
Display controllers tend to have scaling engines built into them to handle upscaling, because it's always potentially a task that a GPU might need to perform. Modern display controllers are usually specialised

Integer upscaling examples

1x **2x** **3x**

Integer scaling examples

Integer scaling simply copies the pixels, without the need for any filtering

You can force Nvidia GPUs to use integer scaling in the GeForce Control Panel

AMD's hardware has been capable of integer scaling since the first Graphics Core Next GPUs

for the general upscaling and filtering we mentioned earlier – the kinds that are good for some purposes, but not others.

If a GPU maker is lucky, it's a small matter of programming that display controller to just duplicate the incoming pixels into the square, integer-scaled regions as they go out over the wire. That's great if your display hardware supports it. Intel takes this approach when possible, for example.

Asking the shader core instead

The fallback is just asking the GPU's shader core to do it. In this case, the shader core draws the pixels anyway at the start, so it's not too much of a job. It basically does this behind the application's back as it draws at a lower resolution, and can then copy the output pixels to a larger scaled target image in the way we need for integer scaling to work correctly.

This method also requires no modification of the application or game drawing the source images.

AMD does it this way, which lets the company support the feature on a huge range of GPUs, stretching all the way back to the original GCN products introduced in

> **Integer scaling can breathe some fresh life into older content on your modern system**

2012. AMD even supports this technique on Windows 7 as well as Windows 10, compared with Nvidia and Intel, which only support it on Windows 10.

Meanwhile, Nvidia limits shader core integer scaling support to Turing-family GPUs and later, and Intel limits it solely to 10th-generation Core products. AMD's implementation also enables you to set integer scaling on a game-by-game basis, letting you limit using it with just the games that need it, unlike Nvidia and Intel. Intel's technique in particular isn't great because it applies to everything being rendered, not just the game.

Performance impact?
What performance impact?!

There's a minimal performance impact from this approach, because more memory bandwidth is consumed, and there's a bit

more shader processing that needs to happen, but on a modern GPU integer, scaling is effectively free for all intents and purposes.

The source resolution is low, so the extra work required is minimal enough to not matter most of the time, and target frame rates can likely always be met. We tested it out with some older PC game titles on an AMD Radeon RX 5700 XT under Windows 10 and noticed no real measurable performance hit.

If you own a high-resolution display and an OS and GPU combination that's modern and permissive enough, integer scaling can breathe some fresh life into some older content on your modern system, as well as enabling you to play modern games at lower resolutions on a high-resolution screen without

Default Intel scaling

Nearest neighbour with integer scaling

Nearest neighbour, with no integer scaling
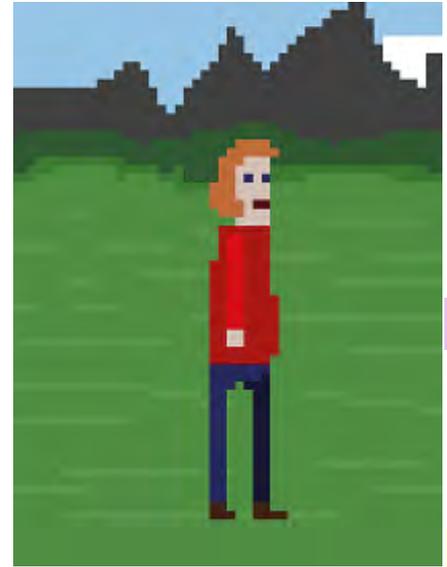
These images from indie game McPixel show Intel's nearest neighbour and integer scaling techniques in action

them looking blurry – great if you have a 4K screen for work, but only a low-powered GPU for gaming.

Limitations and the future

There's also scope for combining integer scaling with other techniques. Intel recognises the limitations of integer scaling

in its implementation, for example, and lets you combine it with 'nearest neighbour' upscaling after the integer scaling has done its work and, in some cases, where integer scaling can't work at all, as we discussed before, replacing it entirely.

Conceptually, 'nearest neighbour' upscaling and sampling overlays the target

pixel grid on top of the source one and, for every pixel that doesn't perfectly map to a source one, or an integer-scaled source one, it just picks the nearest one to the sampling point. You lose some of the perfect crispness you get with integer scaling, but you support more source resolutions.

Some emulators also use techniques that not only upscale but also change the presentation of the content, so it looks like it's running on a CRT, complete with scanline gaps, content-aware softening and luminance control to mimic the look of CRT phosphors. In addition, there are bespoke upscalers that are further tuned to the underlying content, and treat it differently while filtering to enhance and preserve the original look as much as possible.

Those techniques are usually implemented on the GPU using shader programs to let them be flexible and programmable, so there's no real scope for them being baked into silicon, but it's possible for GPU vendors to lift some of that innovation into the driver to make it available to game content outside of emulation. This could include older PC content that runs on modern PCs, but was just designed for the CRT era and much lower resolutions. Maybe that will happen in the years to come. **CPC**

Nvidia has enabled support for integer scaling on its Turing and Ampere GPUs
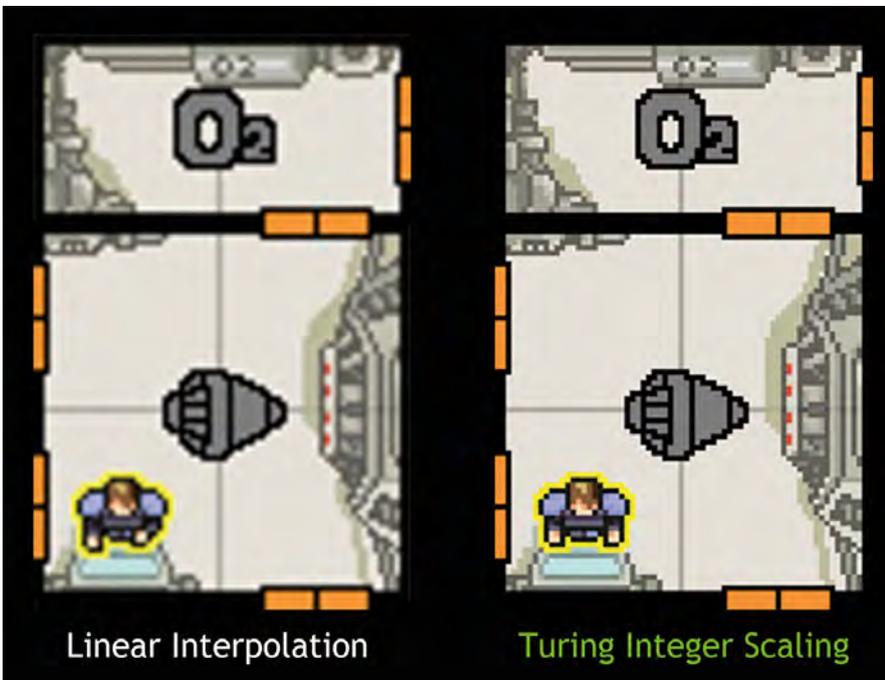
Linear Interpolation

Turing Integer Scaling

GARETH HALFACREE'S

Hobby tech

The latest tips, tricks and news in the world of computer hobbyism, from Raspberry Pi, Arduino, and Android to retro computing

REVIEW
MicroPython

MicroPython is available for a range of different microcontrollers, including the ESP32 inside this M5Stick-C

The launch of the Arduino platform is generally credited with making hobbyist-friendly embedded programming a thing, in no small part thanks to its Processing-based Wiring library, which sits over the top of the C/C++ programming language and makes it easier to handle the microcontroller and its peripherals.

Today, though, C and its variants aren't the most popular languages for learners – Python has long since supplanted them, offering a system that sits between the classic

MicroPython launched with dedicated 'PyBoard' hardware, such as this STM32-based D-series

Beginners' All Purpose Symbolic Instruction Code (BASIC) of the 1980s' finest home computers and lower-level languages, yet is used in professional environments too, offering a route to a career – that's not the case with BASIC.

Seeing a need to combine the world of Python and Arduino, physicist and software developer Damien George took to Kickstarter in 2013 to fund the development of MicroPython. As the name implies, MicroPython is a Python implementation designed for microcontrollers, and since its launch, it has only grown in popularity. MicroPython started with dedicated hardware, the STM32-based PyBoard development board. Since then, it's been ported to a range of devices, both officially and unofficially

– and even forked, with US-based hobbyist and education electronics specialist Adafruit launching its own MicroPython variant dubbed CircuitPython.

Today, MicroPython runs on the PyBoard family boards, which are based on the STM32, Texas Instruments CC3200, Espressif's ESP8266 and ESP32 modules, Microchip's PIC microcontrollers, Nordic Semi's NRF family, bare Arm processors, and even chips based on the free and open-source RISC-V instruction set architecture.

The way it runs on these devices differs from Arduino's approach too. With an Arduino, the user writes a program in the Arduino IDE

on a traditional desktop or laptop. When the program is finished, it's then compiled and flashed onto the microcontroller for execution.

With MicroPython, the development environment exists on the microcontroller itself. You can connect a MicroPython-running microcontroller to a USB port and open a serial connection to be greeted with the REPL – the read-eval-print loop, Python's interactive shell. Type commands line by line, and they'll be interpreted and executed directly on the device in real time.

That's not to say you can't write MicroPython programs the traditional way, of course. Using an integrated development environment (IDE) such as Thonny, you can write multi-line and even multi-file programs that can be saved locally and compiled just as with Arduino. Alternatively, they can be saved directly on the microcontroller in source-code form, ready to be loaded again on any PC to which the microcontroller is connected.

Autodesk limits free Fusion 360 features

Autodesk has placed new limits on non-paying users of its Fusion 360 CAD platform, including the removal of probing, tool orientation, multi-axis milling, public download and cloud rendering options. In a move designed to shift personal users to paying accounts, but that may instead see them jump ship to free and open source alternatives such as **freecadweb.org,** the new limits also see users unable to export files from the platform in the vendor-neutral DWG format. More information can be found at **autodesk.com/products/fusion-360/personal**

Writing a program in MicroPython will be immediately familiar to anyone who has experience with Python in general. It uses the same syntax, and the same system of indentation to nest code blocks together in loops, functions and so on. There are even MicroPython equivalents for the most common Python libraries, handling all sorts of applications, from network connectivity to timing and random number generation.

The machine library is MicroPython's key feature though. Designed using the same principles as Arduino's Wiring, the machine library abstracts the complexities of dealing with the microcontroller and its peripherals away from the user. Turning on a pin is as simple as configuring the pin as an output, then writing

```
pin.value(1)
```

If you only care about toggling it from its current state, use

```
pin.toggle()
```

The exact features available to the MicroPython user depend heavily on the microcontroller in use. Some smaller microcontrollers lack the memory for all possible libraries, while others may lack key peripherals.

Porting a program from one controller to another, then, isn't necessarily as simple

as copying and pasting the program code. However, it also shouldn't be much harder, at least between microcontrollers of roughly equivalent specification.

For those already invested in the Arduino ecosystem, there's no real need to pick up MicroPython – and that's doubly true for anyone keeping up with Arduino's work on cloud infrastructure, designed to make developing projects for the Internet of Things as simple as possible. With its name recognition, massive ecosystem and considerable head start, Arduino will still likely be most beginners' first port of call.

For anyone just starting, or looking to branch out from Arduino, it's a different story. MicroPython is quick and easy to pick up, especially for anyone who has followed tutorials for stock Python.

The interactive REPL is particularly attractive for newcomers – simply type an instruction such as

```
print("Hello, world!")
```

and you'll see the result as soon as you hit the Enter key - a level of immediacy that will help to grab the interest of younger programmers.

MicroPython is available to download for a variety of microcontroller boards from **micropython.org**; those with boards not on the list should look to their vendors for an unofficial port, or try Adafruit's CircuitPython port at **circuitpython.org**

Adafruit forked MicroPython into its own education-focused variant, CircuitPython

REVIEW
SunFounder RasPad 3

At the moment of its inception, the Raspberry Pi single-board computer was designed for education. Sure, the initial batch – incorrectly predicted to maybe sell a couple of thousand units at the most – was built for hackers and hobbyists. However, the Raspberry Pi Foundation's stated aim is to get low-cost hackable computing into the hands of as many students as possible.
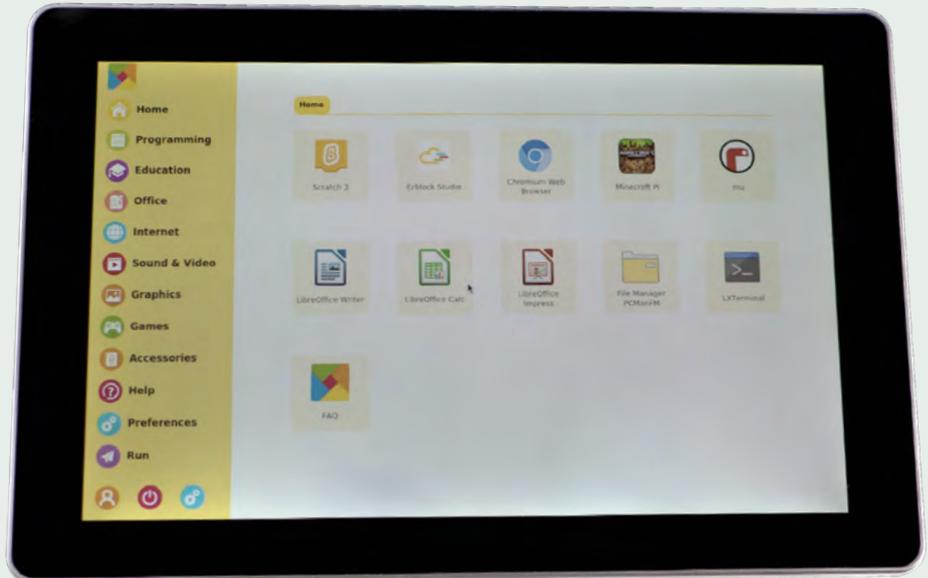
On its own, though, a Raspberry Pi single-board computer doesn't do very much when you get it out of the box. You need a monitor and a keyboard for it at the very least, and a mouse wouldn't go amiss either.

SunFounder sees this lack of a screen and input devices as a drawback, and in February 2018, launched a crowdfunding campaign for its answer: RasPad. It was a complete kit containing all the parts needed to turn a Raspberry Pi 3 into an all-in-one, battery-powered tablet computer.

Feedback from the initial RasPad production run brought an upgraded variant dubbed the RasPad 2, and now SunFounder has closed funding on a third iteration – not surprisingly called the RasPad 3.

Like its predecessors, the RasPad 3 is designed to turn a Raspberry Pi into a fully functional standalone tablet. Compatibility is limited this time to just the latest Raspberry

Pi 4 Model B, which is installed internally and connected via a series of short cables to a daughterboard, which drives the tablet hardware itself.

The front of the tablet hosts a 10.1in IPS capacitive-touch display panel with scratch-resistant glass covering, with a sadly disappointing 1,280 x 800 resolution. The two-part tablet body, meanwhile, is wholly plastic, held together by five screws fitted using the handily bundled screwdriver.

Inside the casing is the Raspberry Pi, which you need to supply yourself, the daughterboard, a battery, two small speakers and a small intake fan for cooling.

Outside, the daughterboard provides three USB 3 ports sharing a single USB 3 lane back to the Raspberry Pi, a Gigabit Ethernet port, a 3.5mm audio jack and a DC socket for the bundled 15V 2A power supply.

A smaller breakout board, equipped with a clever PCB shaped like a microSD card, provides external microSD card access, battery

The wedge shape and hefty near-1kg weight make the RasPad 3 an awkward tablet

The third RasPad kit is a clever design, let down by poor-quality parts and a handful of design flaws

status LEDs, and buttons for power, volume control and brightness.

In theory, then, the RasPad ticks a lot of boxes. In practice, though, it doesn't live up to expectations. Assembly is relatively straightforward, although a failure to line up the ports properly makes fitting the cables harder than necessary, and downloading the customised SunFounder operating system then burning it to a microSD card is painless.

It's at the first boot when problems begin. The display on our review unit was dim even at its maximum brightness and suffered extreme backlight bleed – an issue SunFounder claims will be resolved through more stringent quality control checks on the finished units.

**The larger battery is welcome, but it fails to get close to its claimed five-hour runtime**

Precursor handheld aims to simplify RISC-V work

Sutajio Kosagi, best known for the open-hardware Novena laptop and all-in-one desktop design (reviewed in Issue 146), is preparing to launch a crowdfunding campaign for a handheld RISC-V development device, called Precursor. 'Precursor was built for everyday use but compromises nothing as a development platform,' the company claims.

'Powered by an FPGA-hosted, soft-core System-on-Chip (SoC), it gives developers the freedom to customize nearly every aspect of the platform.' The handheld includes a physical keyboard, key security functions and a 100MHz VexRISC-V core running on an XC7S50-1L FPGA. More information on the device is available online at **crowdsupply.com/sutajio-kosagi/ precursor**

A clever PCB and ribbon cable arrangement provides external microSD access

You just need to supply a Raspberry Pi – there's even a screwdriver in the box
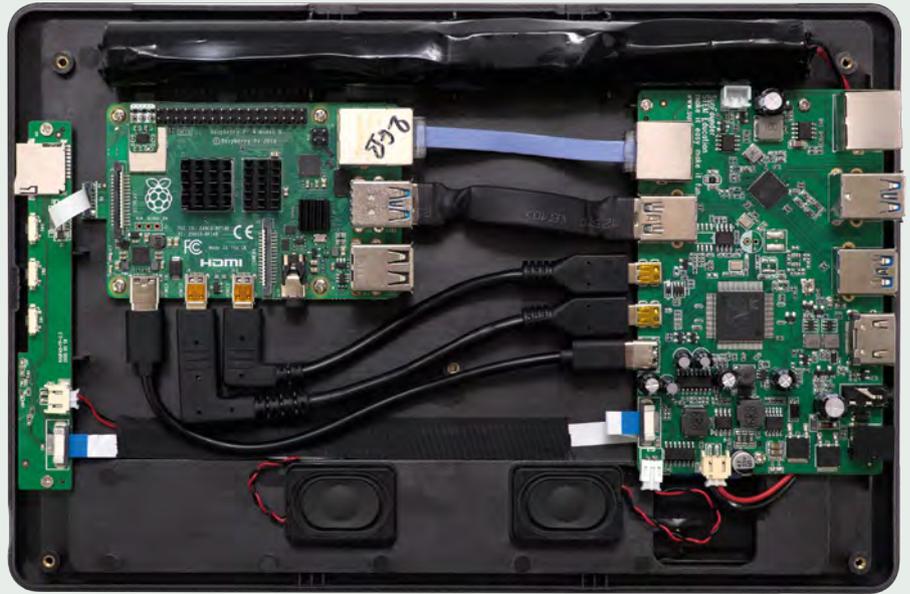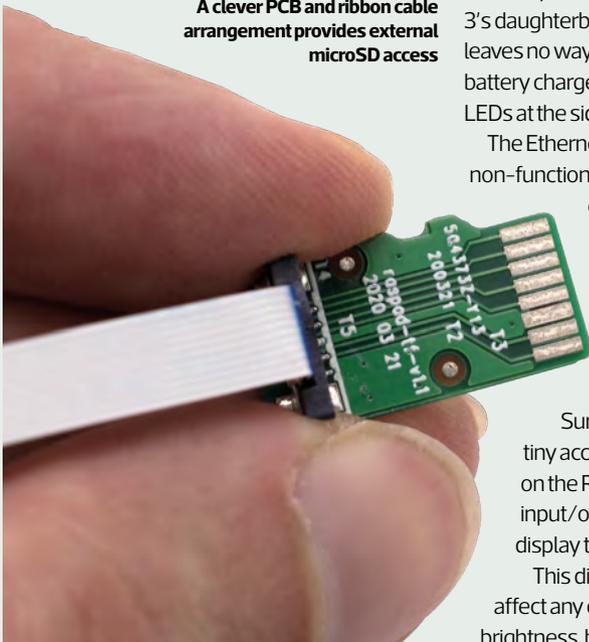
The RasPad 3's touch-screen is responsive, at least, although choosing a location in the mandatory startup wizard takes an unnecessary amount of scrolling due to a lack of scroll handles.

It also fails to set the regulatory domain for the radio, leaving Wi-Fi disabled until you set it manually via the Raspberry Pi Configuration Tool. The software in general also feels buggy and unfinished, and it originally shipped with a glaring security hole, which has thankfully now been resolved.

It's the hardware that disappoints the most though. Perhaps the biggest flaw is a lack of two-way communication between the RasPad 3's daughterboard and the Raspberry Pi, which leaves no way for you to monitor the device's battery charge beyond looking at the three LEDs at the side.

The Ethernet port on our sample was also non-functional, which SunFounder claims is a one-off failure of quality control – although, we note, at least one other contemporaneous review reported the same issue.

A more minor complaint is the lack of automatic rotation on the tablet. SunFounder cleverly includes a tiny accelerometer shim, which installs on the Raspberry Pi's general-purpose input/output (GPIO) header, allowing the display to rotate with the tablet.

This display rotation doesn't, however, affect any of the overlay messages for brightness, battery and contrast generated by

the daughterboard, which remain stubbornly fixed in their orientation, looking messy.

Meanwhile, battery life was a big complaint against the original RasPad, and while SunFounder has fitted a significantly larger battery to the RasPad 3 this time, it hasn't done much to help the situation. The company claims a five-hour runtime, but has since confirmed via email that this time is only achieved when the device is fully idle.

During a simple standard-definition video playback test, we measured a runtime of just two hours and 21 minutes, after which the RasPad hard-powered off without shutting down the Raspberry Pi.

There's also a noisy fan, which testing showed was wholly necessary to prevent the device from overheating.

Meanwhile, the tablet's thick wedge shape, and its weight (which is near to 1kg) make it only comfortable to use on a table – you won't want to use it while you're holding it in your hands.

In addition, access to the GPIO header is only made possible by continually taking the tablet apart, which enables you to add and remove a ribbon cable. It all adds up to the RasPad 3 being a great idea in theory, but with a sadly flawed execution.

The SunFounder RasPad 3 has now been successfully crowdfunded for a price of $129 US ex tax (around £100 ex VAT) per unit on **kickstarter.com**, and general orders will open up soon on **raspad.com**

REVIEW
The Games That Weren't

There's no shortage of stories about computer and video game development that end with the launch of a bestseller, but there aren't many stories about games never even making it to market, having been cancelled for one reason or another during development. The Games That Weren't is a collection of stories covering exactly this latter topic, collated from the website of the same name by Frank Gasking.

Published by Bitmap Books, the book has a similar concept to Phil Atkinson's Delete, (reviewed in Issue 166), but where Delete focuses purely on hardware, Gasking's attention is drawn to games. That's not to say the book exclusively covers games: Despite its name, The Games That Weren't includes a handful of gaming-related hardware devices, such as the Commodore 65 and Konix Multisystem. However, they're only given a two-page spread and line art illustration; it's clear they exist as garnish, rather than the meat of the book.

At 643 pages, The Games That Weren't is undeniably chunky. Split into decades, with the 1970s cut short by starting at 1975 and the 2010s ending in 2015, the book offers a look at the cancellations of a variety of games across almost every platform. Some were cancelled in their entirety, while others were only cancelled in the form of ports for particular systems.

Every game discussed in the book has an intro page, including information about the publisher, platform and reason for cancellation. There's also a simple check box telling you whether it's possible to play the game through the efforts of archivists and emulators.

What follows, though, depends on the game. Some games have only a single paragraph of information and a single screenshot; others are treated to ten or more pages with multiple screenshots, scans of archival material and so on. Some material is presented as a straight question and answer session with the developers and publishers involved; other material attempts to weave a central narrative.

Sadly, it's a target that doesn't always hit. The book's content is fascinating, but often difficult to read and could definitely have used more time under the watchful eye of editors and proofreaders. Run-on sentences and misplaced commas are plentiful, and there are typographical issues too: the book

A book filled with what could have been, The Games That Weren't is a collection of cancellation

incorrectly refers to the Konix Multisystem by the codename Flair One, despite the same sentence correctly identifying the company behind it as Flare Technology.

The further you read into the book, the more obvious it becomes that it's a collection of web clippings rather than a book. This is particularly clear in the woolly nature of citations – often information is presented as 'some sources say', 'it's thought', or 'it's believed', with no indication of the actual source, nor any attempt to back up the supposition with hard fact.

Gasking's choice of focus games is also strange. The cancelled ports of Last Ninja, for example, get multiple pages despite its successful launch on other platforms. Black Isle Studio's cancelled Fallout 3, by contrast, gets just three paragraphs and one screenshot, and there's no mention of Fallout Online.

Text aside, the book's production values are definitely up to Bitmap Books' high standards. Bonus points must be given for hiring an artist to recreate missing or poor-quality imagery too, although early 8-bit systems such as the ZX Spectrum are given a bit of a rose-tinted approach that masks their all too common graphical shortcomings. The Games That Weren't is available from **bitmapbooks.co.uk** for £29.99 (VAT exempt). **CPC**

Hardware isn't a focus, but a few key devices are given two-page spreads with line-art illustrations

Gareth Halfacree is a keen computer hobbyist, journalist, and author. His work can be found at **freelance.halfacree.co.uk** 🐦 @ghalfacree

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AOC C27G2ZU

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WORTH £300

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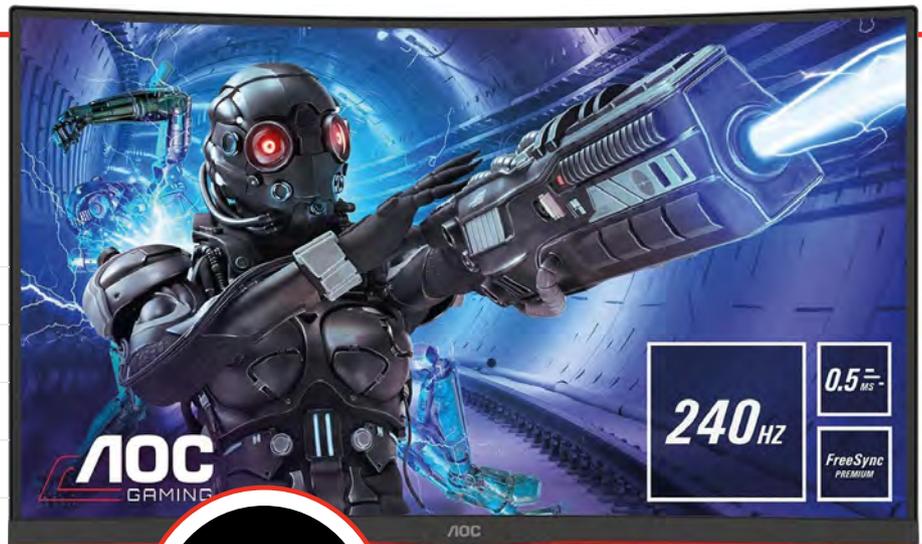
detail brought sharply into focus and every movement shown with crystal clarity, you can feel your reactions become at one with the action and elevate your game.

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Not all cases like the GeForce RTX 3080 Founders Edition

Nvidia's new RTX 3080 GPU is undoubtedly an amazing piece of gaming silicon. It's much faster than the RTX 2080 Ti and getting on for twice as quick as the RTX 2080 in many games, making it exactly what enthusiasts wanted in terms of an upgrade, especially as it costs the same price

The RTX 3080 Founders Edition is compact for the power on offer, but its flow-through fan design can pose problems in some cases

as the RTX 2080 a year ago. It can handle most games at 4K at maximum settings, and the Founders Edition looks pretty snazzy too.

There are some issues with the Founders Edition flavour of the RTX 3080, though, and they can impact a range of systems, especially smaller ones. The first issue is the flow-through design of one of its cooling fans. It's designed to blast air out the top of the card, thanks to the short PCB, aiming hot air towards the top of your case.

Of course, that's great in a standard tower design with an air cooler, case fans or an all-in-one liquid cooler's radiator in the right area to help get rid of the heat. However, there's plenty of situations where that won't be the case.

Mounting your graphics card vertically will see this hot air blasted

straight at your motherboard, potentially heating up M.2 SSDs and motherboard chipsets, especially during long gaming sessions. This setup can also mess with the airflow inside your case, with the warm air sitting in the middle of your case, rather than being directed at your CPU cooler or roof fans. Many graphics cards already allow air to spill out similarly, of course, but not to the same extent as the RTX 3080 Founders Edition in a single direction.

There's a far more worrying issue, though, which is in cases that plant the graphics card up against panels such as motherboard trays. This is common in mini-ITX cases, where PCI-E riser cables are used to locate the graphics card behind the motherboard, often in a separate chamber. They're obviously not designed for a flow-through fan

design, and some cases could see thermals skyrocket as a result, prompting your GPU to throttle as it overheats.

I investigated this issue on my YouTube channel recently and used

NZXT's otherwise superb H1 mini-ITX as a test subject. The result was just as I'd feared – the GPU temperature peaked at nearly 90°C, with the motherboard tray sitting within a few millimetres of the flow-through fan and massively obstructing its airflow. The side panel heated up to well over 50°C too, radiating heat throughout the case.

Some comments from H1 owners said I should have modded the case to add small fans to cool down the case, but this won't help much if the GPU fan is all but blocked.

The situation might be improved by cutting a hole in the offending panel, which would at least allow the graphics card to get rid of the heat. Additional fans might then make

more of a difference and keep the situation in check.

However, in cases where the graphics card is mounted in a way that blocks its flow-through fan, the best solution that avoids significant modding is water-cooling it.

That's not really possible in the H1, as the RTX 3080 is quite a toasty customer – you'd need at least a 140mm radiator to cool it and at least that again to deal with your CPU.

Other cases are obviously far more water cooling-friendly, so if you're thinking of investing in the RTX 3080 Founders Edition, or a partner card with a similar cooling arrangement, think carefully about the case you'll be using and seriously consider water-cooling your card too.

Liquid metal paste fixed my laptop

When I headed to CES in Las Vegas in January, which seems like a heck of a long time ago and was the last time I left the UK, I had a bit of a frustrating flight.

My little Dell Latitude 2-in-1 laptop decided to flake out more than usual and made my Avengers movie marathon less enjoyable than I'd planned. I picked it up a couple of years ago, primarily for travelling as it can morph into a half-decent tablet too, but the occasional blue screen of death (BSOD) meant I never completely trusted it.

Annoyingly, every 15 minutes or so I'd get a pesky BSOD. It seemed to be driver related, but once I got to the USA, I spent a jetlag-filled hour reinstalling Windows, updating the BIOS and using the latest drivers, only to see another BSOD again an hour later while watching Captain America doing what he does best.

While I haven't been travelling, the laptop has been gathering dust until I used it in this month's How to guide (see p100). I'd never thought to check the CPU temperature as a possible

reason for the instability, but when it approached 100°C immediately in the stress test, and wasn't far off even after a minute or two of playing a movie, I realised I'd found the likely cause of my problems.

Thankfully, removing the old thermal paste, cleaning the heatsinks and applying liquid metal paste, saw the temperature tumble by nearly 20°C.

I watched an entire two-hour movie with no BSODs, and my laptop is now basically fixed. If your laptop is running a little hot or noisy, or it has stability issues, it's definitely worth following our guide and trying some liquid metal thermal paste. There's a chance the old thermal paste has have gone off, and applying some high-performance paste could give it a new lease of life. **CPC**
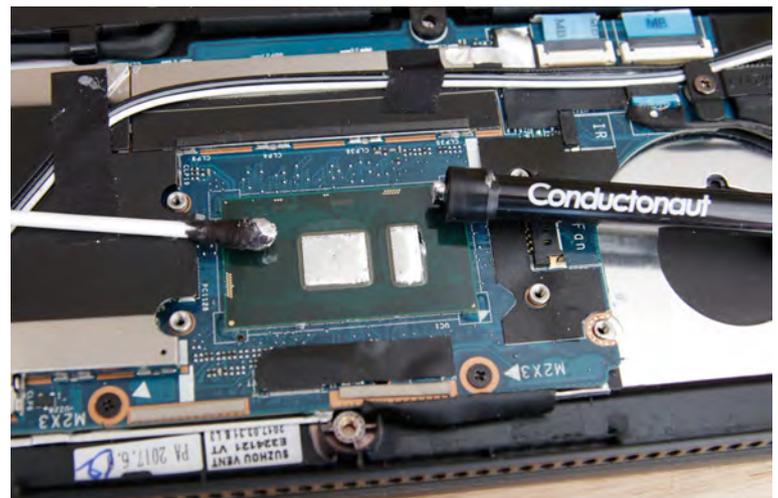
Liquid metal paste should be applied with care, but it can yield significant thermal improvements

Antony Leather is Custom PC's modding editor 🐦 @antonyleather

How to
Boost GPU cooling

Antony Leather shows you how to replace your graphics card's thermal paste and lower your GPU temperatures

TOTAL PROJECT TIME / 2 HOURS

C omponent manufacturers often don't use the best thermal paste with their graphics cards, at least not a paste that's on par with the best available to PC enthusiasts. Liquid metal pastes, and end even high-end ceramic pastes, are often better than the standard material placed between your GPU die and its heatsink. The paste can also dry out over time, resulting in climbing temperatures.

Whether your graphics card is old or new, it can be worth replacing the standard paste with a new material to ensure you're getting the best cooling possible. In this guide, we'll show you how to dismantle your graphics card and apply new paste safely, removing any thermal bottlenecks.

TOOLS YOU'LL NEED

Micro screwdriver set
Most hardware stores

Isopropyl alcohol or TIM cleaner
amazon.co.uk

Nail varnish
Most supermarkets

Metal polish
Most hardware stores

Microfibre cloth
Most hardware stores

Thermal paste
overclockers.co.uk

Air duster
Most hardware stores

Hairdryer
amazon.co.uk
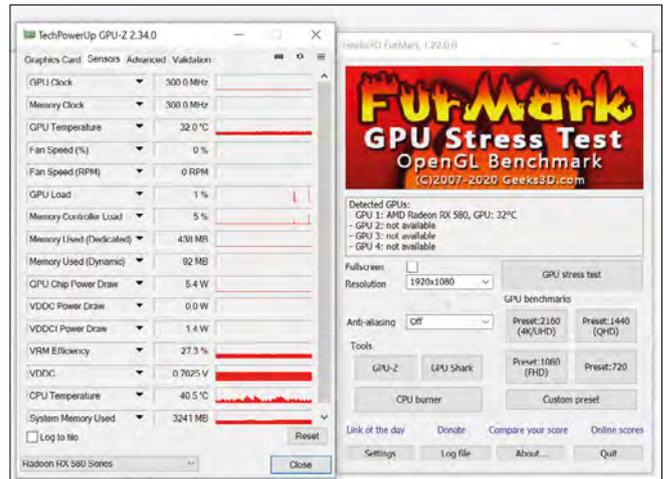
1 / CHECK CURRENT TEMPERATURES
Check your GPU temperature prior to dismantling your graphics card, so you can compare the fruits of your efforts. Start by downloading FurMark (**geeks3d.com**) and GPU-Z (**techpowerup.com**) and run both of them – start the FurMark benchmark and record the GPU temperature after five minutes.
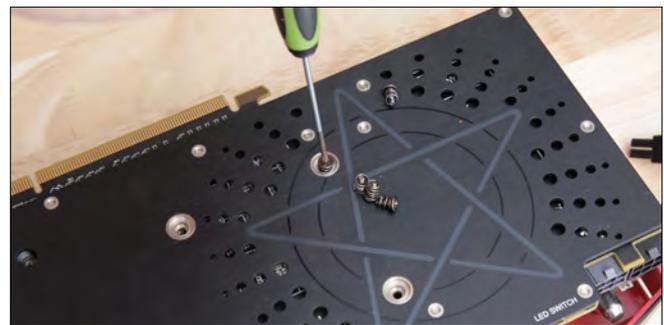
2 / REMOVE SCREWS
Locate the screws on the rear of your graphics card, which will enable you to detach the heatsink. Remove these screws and remember where each one went, taking a photo to remind you if necessary.

3 / REMOVE BACKPLATE
If there's a backplate, it will usually lift off first, revealing more screws beneath. However, each card is different, so continue removing screws until you feel the heatsink become loose.
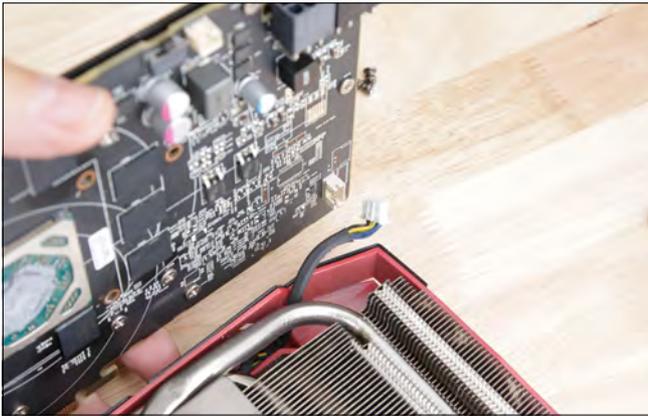
4 / LIFT AWAY HEATSINK

Once the screws are removed, gently lift away the heatsink and cooler section a little, checking for any cables that may be plugged into the PCB. If it won't lift off, try using a hairdryer on a high setting for 20 seconds to warm the thermal paste.

5 / DETACH CABLES

Modern graphics cards can have several cables attaching the cooler and PCB, providing power for the fans and lighting. Detach these cables gently, and then remove the cooler and heatsink section completely. Leave any thermal pads in place and take care not to damage them.
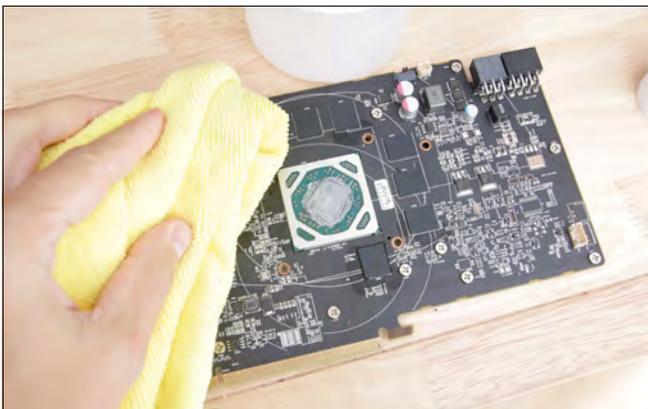
6 / CLEAN THE GPU DIE

The thermal paste is usually quite dry and easy to remove. Use isopropyl alcohol or thermal paste cleaner, along with a microfibre cloth, to remove any residue.

7 / CLEAN THE HEATSINKS

As with our laptop guide this month (see p102), you also want to clean the heatsink. If your graphics card is old, the surface may be oxidised or stained. If so, use Autosol metal polish to buff it to a shine before cleaning it thoroughly, again with isopropyl alcohol or thermal paste cleaner.

8 / APPLY NAIL VARNISH

If you're using liquid metal paste, it's important to insulate any exposed metal components that could be shorted out by the paste. Use nail varnish sparingly to cover an area 10mm away from the areas that require thermal paste. You can skip this step if you're using a standard ceramic paste.

9 / APPLY THERMAL PASTE

Go ahead and apply your chosen thermal paste. You only need a tiny amount the size of a grain of rice, applied lengthways along the die. If you're using a liquid metal paste, refer to our guide on p104. Our efforts using liquid metal paste resulted in a 9°C drop under load from 68°C to 59°C.

How to
Replace your laptop's thermal paste

A new application of thermal paste can help your laptop to run both cooler and quieter. **Antony Leather** shows you how it's done

TOTAL PROJECT TIME / 2 HOURS

In this issue of **Custom PC**, our 'How to' guides are dedicated to removing the stock thermal paste from your chips, and replacing it with a new application of high–performance paste. In this guide, we'll show you how to replace the thermal paste in your laptop, on both your CPU and GPU.

Doing so can shave several degrees off your laptop's CPU and GPU temperatures, especially if the original thermal paste has been sitting there for a while. This new layer of paste could improve cooling, which in turn could result in your components boosting to higher frequencies, as well as your fans running quieter.

TOOLS YOU'LL NEED

Micro screwdriver set
Most hardware stores

Isopropyl alcohol or TIM cleaner
amazon.co.uk

Nail varnish
Most supermarkets

Metal polish
Most hardware stores

Microfibre cloth
Most hardware stores

Thermal paste
overclockers.co.uk

Air duster
Most hardware stores

Hairdryer
amazon.co.uk

1 / CHOOSE PASTE
You have a choice between standard thermal paste and high–performance liquid metal paste. The latter may shave a couple of degrees more off temperatures, but the downside is that it's conductive, so you'll need to take extra steps to prevent it from shorting out components.
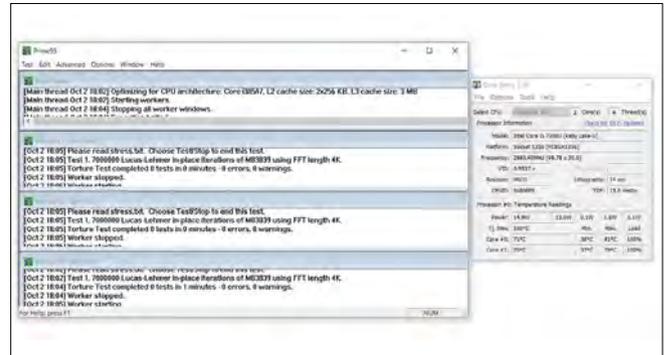
2 / CHECK CURRENT TEMPERATURES
Grab CoreTemp (**alcpu.com**) and Prime95 (**mersenne.org**), and run the latter's smallfft test with AVX disabled. If your laptop has a discrete GPU, run FurMark (**geeks3d.com**) and GPU–Z (**techpowerup.com**). Record your laptop's CPU and GPU temperatures under load for comparison later.

3 / REMOVE LAPTOP CASING
Most laptops have an underside casing that can be removed by removing a few screws, while some may also require some additional prising with a credit card. YouTube can sometimes show you handy ways of finding out how to do this with your model, and it's handy to know for upgrades too.
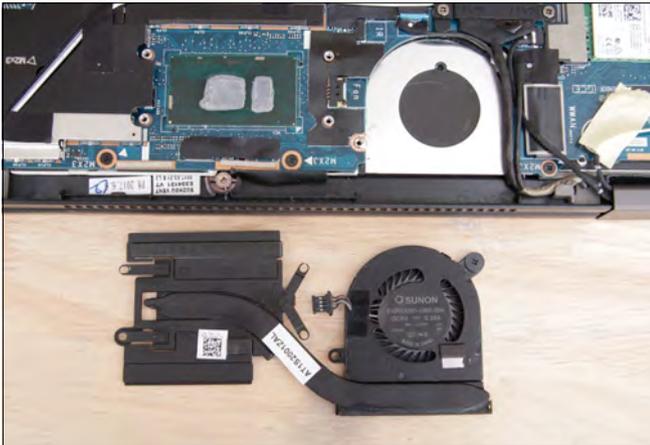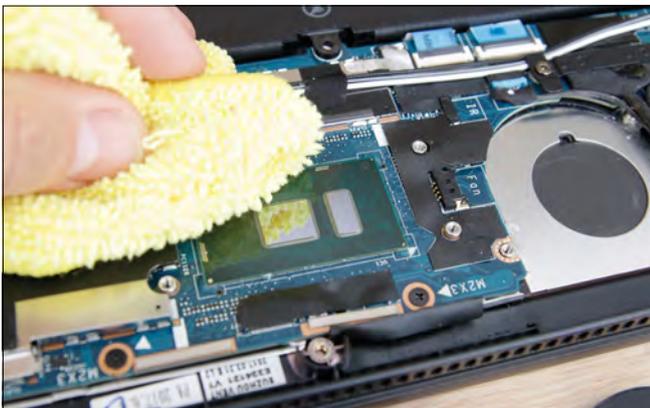
4 / REMOVE HEATSINKS

Locate the CPU and GPU heatsinks and detach them by removing their screws or clips. Place the screws back into their sockets once you're done for safekeeping. Now is a good chance to clear out any dust too, so use an air duster to blast away the dirt.
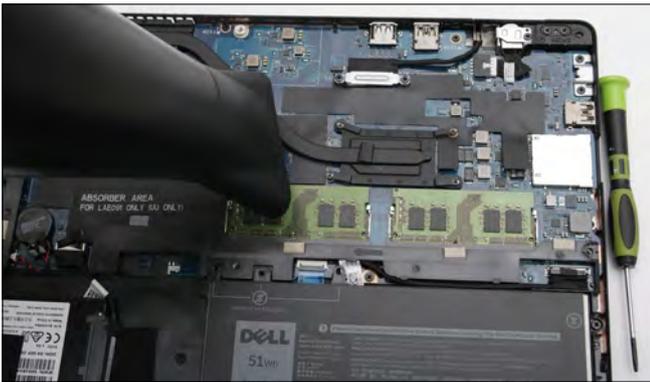
5 / USE HAIRDRYER

Thermal paste can sometimes act like glue and prevent you from removing the heatsinks. If you have any trouble removing them, try blowing a hairdryer at them for around 20 seconds on full heat to loosen it up.

6 / CLEAN THE DIES

Use isopropyl alcohol or thermal paste cleaner to remove the old thermal paste from the CPU and GPU dies with a microfibre cloth.

7 / CLEAN THE HEATSINKS

Use isopropyl alcohol or thermal paste cleaner to remove the old thermal paste from the heatsinks with a microfibre cloth. The heatsinks can become stained or oxidised over time as well, so use Autosol metal polish after removing thermal paste to clean them to a shine, then use isopropyl alcohol again to remove all residue.

8 / APPLY NAIL VARNISH

If you intend to use liquid metal paste, you'll need to add nail varnish around the CPU and GPU dies to prevent any metal components from being shorted should the paste run. Apply the varnish lightly over the area and allow it to dry for an hour.

9 / APPLY THERMAL PASTE

Apply liquid metal paste following the steps on p104, or apply standard paste by applying a small blob, around the size of a grain of rice, to each chip. You can then replace the heatsinks and reassemble your laptop. Our laptop's CPU temperature by fell a massive 16˚C after applying new liquid metal paste.

How to
Apply liquid metal thermal paste

Antony Leather shows you how to form the best possible thermal transfer between your CPU and your cooler

TOTAL PROJECT TIME / 30 MINUTES

If you want to ensure that the interface between your components' hotspots and their heatsinks is as effective as possible, then using liquid metal thermal paste, rather than standard ceramic paste, is the way to go. This eerily shiny liquid might look a bit like it's come straight out of Terminator 2, but thankfully, it won't morph into Robert Patrick and gun you down.

Liquid metal paste offers the best thermal properties you'll find in any thermal interface material, and it's the weapon of choice for people who delid their processors as well. In this guide we'll show you how to apply it to a CPU, but you can use the same procedure to boost your graphics card or laptop cooling by following our other guides this month too.

TOOLS YOU'LL NEED

Thermal Grizzly Conductonaut
overclockers.co.uk

Microfibre cloth
Most hardware stores

Thermal paste cleaner or isopropyl alcohol
amazon.co.uk

1 / CLEAN THE SURFACES
Thermal Grizzly Conductonaut includes wipes to clean your chip's die, heatspreader and heatsink, but you can also use isopropyl alcohol or thermal paste cleaner with a microfibre cloth. Cleaning ensures the best contact between the paste and surfaces, especially as the paste is expensive and you only get a few applications in the tube.

2 / APPLY THE PASTE
You need a blob the size of a grain of rice on CPUs, so start with this small amount and add a little more if necessary. Beware that the paste can stain your CPU's heatspreader and can be tricky to remove. You not only need to apply paste to the CPU, but also to your heatsink or waterblock.

3 / WORK IT INTO THE SURFACES
Using the applicators provided with the Thermal Grizzly Conductonaut, work the paste into the surfaces. Gradually, the paste will start to stick, giving the surface a mirror-like sheen.

Folding@home

Join our folding team and help medical research

ACTIVE USER MILESTONES

USERNAME	POINTS MILESTONE
Slavcho	3,000,000,000
tarka_dahl	900,000,000
kcanti	800,000,000
Bloo_Toon	300,000,000
Little_Willie	300,000,000
Dark_AvEnGer	200,000,000
BurnedFastfood	100,000,000
dis80786	80,000,000
fatchef	80,000,000
Chaplain-Brawl	80,000,000
TechnoStuck	80,000,000
Origami_Tsuki	80,000,000
Jon_Simmo	70,000,000
mort6dav3	70,000,000
phys1csb0y	70,000,000
meandmymouth	60,000,000
40138	60,000,000
gKitchen	60,000,000
Bedders	50,000,000
Serpentine	40,000,000
GreenPig	40,000,000
jvbrugger	40,000,000
Liaw_Jun_Xian	30,000,000
paul_warden	30,000,000
CheeZee73	20,000,000
bytemarq	20,000,000
Will_Walton	20,000,000
knobtasticus	20,000,000
Smauri	20,000,000
TokerRizla	10,000,000
Maleor	10,000,000
Chebob	9,000,000
GJBriggs	8,000,000
TheRepublicofKirkup	8,000,000

USERNAME	POINTS MILESTONE
Mikloid	7,000,000
markdiss	6,000,000
TheLimey	5,000,000
G4zm4n	4,000,000
Pausanias828	4,000,000
sparrowm7	4,000,000
PendragonOrion	4,000,000
jettison_theory	3,000,000
Trotski	1,000,000
RedGamerDanger	1,000,000
Drystan14	1,000,000
MDT	900,000
Cole	900,000
yonedafolding	800,000
Wenna	500,000
Wim_Dirks	300,000
mjgray87	300,000
PatWI	200,000
asp8410	100,000
PennnineLad	100,000
hamki	100,000
Joe	80,000
LincolnEss	80,000
Bloo_Town	70,000

WHAT IS FOLDING?

Folding@home uses the spare CPU and GPU cycles for medical research, with a current focus on COVID-19. You can get the client from **foldingathome.org/start-folding** and our team's ID is 35947. Once you pass a significant milestone, you'll get your name in the mag – we'll print all the milestones we can fit on the page. You can discuss folding with us and other readers online at the bit-tech forums (**custompc.co.uk/FoldingForum**).

TOP 20 PRODUCERS

RANK	USERNAME	DAILY POINTS AVERAGE	OVERALL SCORE
1	DocJonz	14,798,082	12,861,312,837
2	Dave_Goodchild	14,027,897	1,552,327,020
3	tarka_dahl	8,079,589	914,077,812
4	Desertbaker	8,035,724	2,768,766,677
5	Slavcho	6,614,506	3,147,093,178
6	Lordsoth	6,397,609	4,603,753,900
7	BurnedFastfood	3,300,813	257,741,091
8	rjcman	2,148,207	273,851,650
9	sonic_vortex	1,481,698	562,923,359
10	PC_Rich	1,136,439	6,291,445,077
11	Allan_Smith	1,134,363	760,983,870
12	Little_Willie	1,122,211	309,197,795
13	gKitchen	1,103,795	67,508,235
14	Simlec	1,099,295	228,945,346
15	Dickie	1,004,728	1,140,805,481
16	Chaplain-Brawl	977,458	82,635,369
17	Will_Walton	780,980	27,415,234
18	KevinWright	774,599	1,233,987,490
19	kcanti	732,718	803,918,503
20	meandmymouth	604,402	67,971,397

TOP 15 OVERALL

RANK	USERNAME	POINTS	WORK UNITS
1	DocJonz	12,861,312,837	327,821
2	PC_Rich	6,291,445,077	163,481
3	Shirty	5,123,598,623	38,984
4	Nelio	4,638,586,520	523,610
5	Lordsoth	4,603,753,900	175,474
6	HHComputers	3,544,050,839	85,007
7	Slavcho	3,147,093,178	68,843
8	Desertbaker	2,768,766,677	61,578
9	piers_newbold	2,703,256,197	107,638
10	Scorpuk	2,544,545,152	57,727
11	clanseven	2,223,720,446	33,156
12	Unicorn	1,753,462,654	57,079
13	daxchaos	1,637,104,710	41,302
14	Dave_Goodchild	1,552,327,020	145,836
15	Laguna2012	1,527,029,380	51,930

Retro tech

16-BIT SWANSONG

K.G. Orphanides takes a technical look at Intel's last
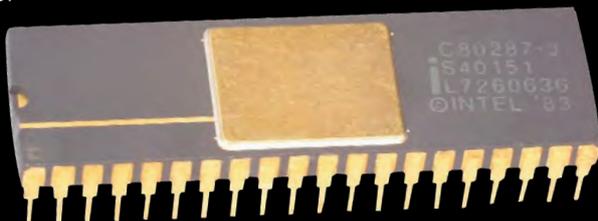16-bit x86 CPU, the 80286

We're now so used to tiny transistors that the 7nm process used to fabricate AMD's latest Zen 3 CPUs hardly seems worth mentioning now – it's hard to keep track of the numbers of transistors when they get into billions. However, you only have to look at early PC CPUs to see just how far silicon manufacturing has come. Intel's 80286 processor was released in 1982, and fabricated on a 1.5μ (1,500nm) manufacturing process, compared to the 3μ (3,000nm) process used by its predecessor, the 8086. It packed in 134,000 transistors: 4.6 times as many as the 8086. By comparison, AMD's 7nm Zen 2 processors contain up to 9.8 billion transistors.

The 80286 was introduced with an entry-level-model clock speed of just 6MHz. This figure would go as high as 12.5MHz for the popular Intel 80286-12, and up to 25MHz for late-era takes on the CPU by other manufacturers, such as AMD and Harris. It would be the last, fastest 16-bit PC processor Intel made.

Its successor, the 80386, was a true 32-bit processor, with a 32-bit data bus and memory addressing to match. But even as its technology was superseded, the 286 was just hitting its stride in the home PC market, which it would dominate until 386 and 486-based PCs started to become vaguely affordable in the early 1990s.
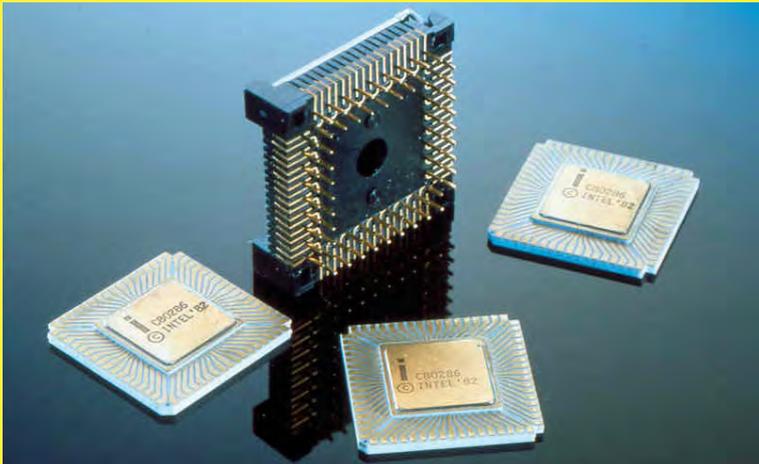
A VISION FOR THE FUTURE

When development began on the 80286 in 1979, Intel's product requirements document envisioned that the powerful new processor would be primarily used in industrial applications, from telecoms to manufacturing automation and medical instruments. It was explicitly designed to be compatible with the 8086, ensuring that software for the older processor would run without modification on the new device. But unlike the 80186 (see opposite), PCs weren't on the 286's original roadmap.

In Intel's 1984 annual report, which details the 286's development, release and nascent domination of the industry, the company admits that in hundreds of pages of planning materials 'the personal computer – which would eventually become its biggest user – wasn't mentioned *once*'.

The 80286 was announced in February 1982, and the designers had a working prototype to show industry partners that spring, promising 'about three times the performance of any other 16-bit microprocessor'. However, after initial testing of the first 286 wafers, 'progress just seemed to drop to a snail's pace', according to logic design supervisor Jim Slager, again quoted in Intel's 1984 annual report. The processor wasn't yet running fast enough, and the testing programme for CPUs that would come off the manufacturing line was running late.

But in June 1982, IBM – then the world's largest maker of computers – came calling. IBM had been using Intel's 8088 since 1979 and it was looking to give a power boost to its next generation of PCs: the IBM model 5170, better known at the IBM PC/AT.

THE 80287 COPROCESSOR

Since the 8086, floating-point coprocessor chips – popularly known as maths coprocessors – had been made available as optional additions via a motherboard socket. They allow addition, subtraction, multiplication, division and square root calculations on numbers with decimal points to be carried out more quickly than on a standard integer unit, improving performance in arithmetic-intensive applications.

Originally, that was mostly accounting and computer-aided design (CAD) software, but later games were also able to take advantage of the hardware, notably including 1989's SimCity and flight sims such as Falcon 3 in 1991. The 486SX series was the last range of Intel CPUs to be released without a built-in maths coprocessor – its sibling 486DX integrated a floating point unit into the CPU.

An optional 80287 coprocessor provided the 286 with a floating point unit

Released at around the same time as the 286, the 80186 was fully software-compatible with the 8086, with an emphasis on increased performance at the lowest possible cost. It was an instant success, and Intel produced 30 times as many 80186s as 8086s in the new processor's first year of release.

Although Intel at one point envisioned the 186 being used in workstations, word processors and PCs, it was the 286 that ultimately came to dominate the desktop market. Unlike the 286, the 186 had its clock generator, timer and interrupt controller – previously motherboard components – built into the CPU.

However, these integrated components weren't compatible with the hardware used in the IBM PC, leading IBM to select the 286 for its PC/AT range of computers.

The 186 was nonetheless massively successful, due to its speed and ease of integration into other systems, appearing in coprocessors, communications controllers, flight management computers and general-purpose microcontrollers.

It did appear as the main CPU of a few PCs, including the 1986 Sega AI in Japan, the Tandy 2000 in the USA and the frankly inexplicable RM Nimbus schools PC in the UK. Intel ended production of the 186 in 2007, although fully compatible third-party clones are still available.

The 186 was hugely successful outside of the desktop PC world. Image credit: Konstantin Lanzet

Intel pulled together a cross-disciplinary task force to complete the testing tools, address bugs and complete the parallel development of motherboard components. Marketing focused on a new public presentation of the 80286, highlighting its superiority to Motorola's popular 68000 processor and emphasising that it was far more than a minor update to the 8086.

Intel emphasised the 286's multi-user and multi-tasking capabilities, including variable privilege levels to restrict access to specific parts of memory, as well as an instruction set designed to rapidly switch between programs, providing support for Unix as well as DOS.

The marketing push – and especially IBM's adoption of the processor – worked. Chip samples were delivered to customers later the same year and, in 1983, volume production of the 80286 began. The IBM PC/AT launched in August 1984, prompting a wave of AT-compatible computers from companies including Compaq and NEC. By the end of 1988, Intel estimates, there were around 15 million 286-based PCs in use worldwide.

Unlike the 80186, PCs weren't on the 286's original roadmap

A DIFFERENT MODE

Changes to memory handling were a headline feature of the 286, but software support was slow to emerge. The processor introduced protected mode memory addressing and retained real mode addressing to ensure compatibility with applications designed for the 80186, 8088 and 8086.

In real mode, like the 8086, the 286 can address up to 1MB of memory via a 16-bit address bus. In protected mode, it can address up to 16MB of memory using a 24-bit bus. This approach has security and stability benefits in that, in protected mode, different programs and users can't access memory segments in use by others.

Protected mode made the 286-compatible with Unix-based operating systems such as Microsoft Xenix, and its secure memory handling made it possible for up to eight users on terminals to be connected to a 286-based Xenix server.

To ensure backwards compatibility, the system has to boot in real mode and then be switched into protected mode by setting a status register bit. To get out of protected mode, you have to reset the CPU. This switching process was crash-prone in some versions of IBM's OS/2 operating system, where it was used to provide an MS-DOS compatibility mode. Some manufacturers put out specialised motherboards, which integrated additional 'warm reset' capabilities.

However, protected mode simply wasn't used by MS-DOS, the most popular operating system used with the processor. Instead, an undocumented instruction, LOADALL, allowed the CPU to access all memory from real mode. It was critical to the HIMEM.SYS file used to manage memory, and allowed real-mode processes to access up to 16MB of RAM by updating the segment-descriptor cache to point at an extended memory address.

▶

Sierra's King's Quest II: Romancing the Throne explicitly supported the 286-based IBM PC/AT

The 80287 add-on maths coprocessor could be used to improve performance in some games, including SimCity

Protected mode would evolve with the later adoption of 32-bit addressing in the 80386. By 1988, Windows 3.0 was able to take advantage of a 16-bit protected mode environment, compatible with both 286 and 386 processors, and Microsoft released compilers and SDKs for third-party developers.

Windows 3.0's use of 16-bit, rather than 32-bit, protected mode memory addressing ensured backwards compatibility with the 286, but this would be abandoned with the release of Windows for Workgroups 3.11, which requires the 32-bit protected mode introduced with the 386.

The 80286 die was built on a 1.5-micron (1,500nm) process. Image credit: Pauli Rautakorpi / CC BY creativecommons. org/licenses/ by/3.0
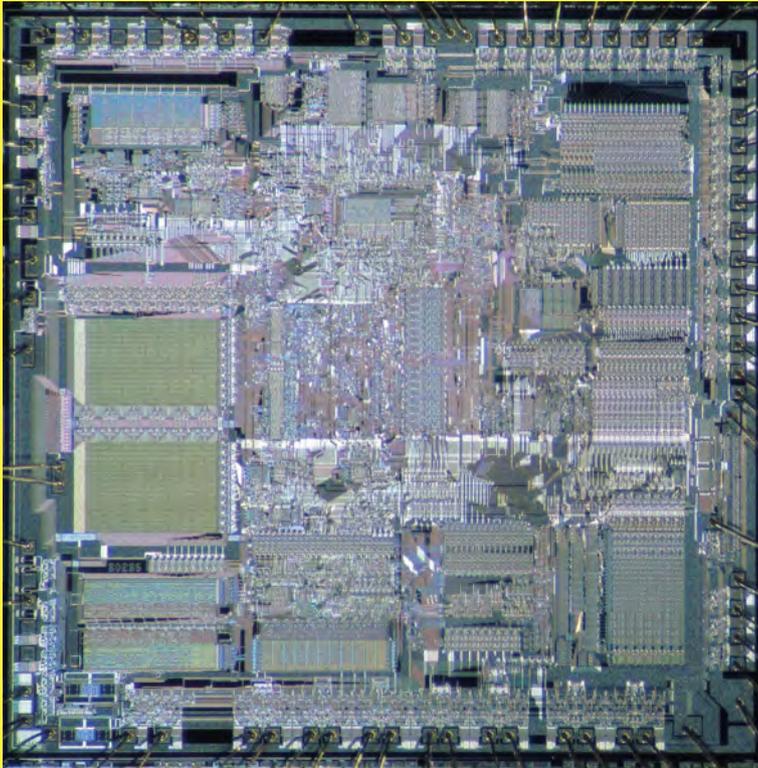
NEW INSTRUCTIONS

Developed simultaneously, the 286 and 186 shared a number of new additions to their instruction set architecture, above and beyond those of the original 8086. Like its predecessor, the 286 instruction set has a 16-bit word size – the number of bits (binary on/off switches) on which it can operate with one instruction.

Shared with the 80186 are the ENTER, LEAVE, BOUND, INS, OUTS, PUSHA, POPA, PUSH immediate and IMUL immediate

A 10MHz 286 could execute programs up to six times faster than a 5MHz 8086

instructions, and a range of immediate shifts and rotates. These include both mathematical operations, such as the signed integer multiplication of IMUL, and data handling operations. An example of the latter is PUSHA (push all registers), which saves the contents of all eight general registers, used to temporarily store data, to the stack, to and from which instructions can store or retrieve data.

The 80286 additionally added ARPL, CLTS, LAR, LGDT, LIDT, LLDT, LMSW, LSL, LTR, SGDT, SIDT, SLDT, SMSW, STR, VERR and VERW. Most of these instructions are used for protected mode memory handling, but a few, such as SMSW (store machine status word) and LMSW (load machine status word) are used in real mode.

By 1990, memory-hungry games, such as the US release of Sorcerian, advertised their need for 'AT-compatible' PCs
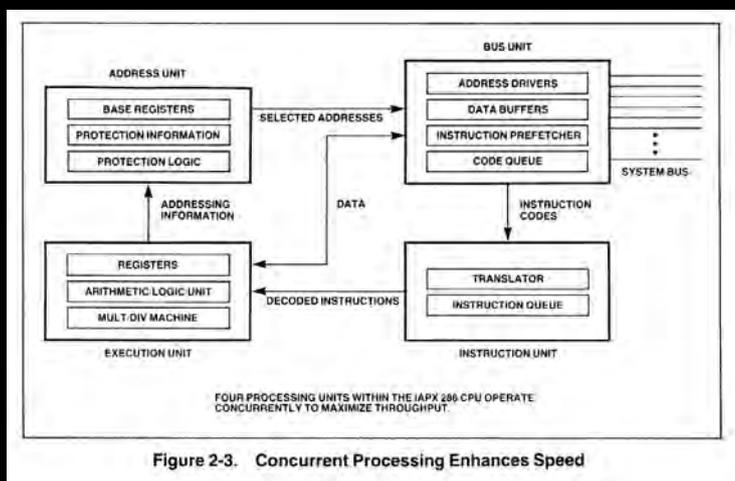

Figure 2-3. Concurrent Processing Enhances Speed

The 80286 has a dedicated address unit, bus unit, instruction unit and execution unit

The 286's machine word status is used to indicate the presence of features such as an 80287 maths coprocessor (see p106), and whether the CPU is supposed to be running in protected or real mode. The introduction of instructions to efficiently end the execution of a task, save its state and switch to another, loading its last state, significantly improved multitasking performance.

PERFORMANCE

The 286 provided a marked performance boost over the 8086 and 8088. This was in part down to faster clock speeds, particularly when 12.5MHz, 16MHz and even faster 286 CPUs became popular. The CPU also benefited from significant architectural redesigns, enabling a 10MHz 286 to execute programs up to six times faster than a 5MHz 8086, according to Intel's Introduction to the iAPX 286 document.

A 12MHz 286 can calculate between 1.28 and 2.66 million instructions per second (MIPS), compared to 0.330 MIPS for a 5MHz 8086 and 0.750 MIPS for a 10MHz 8088. The 286's instructions per clock (IPC) count works out at 0.21 MIPS per megahertz. To help achieve this, the 80286 CPU comprises four independent processing units: address unit, bus unit, instruction unit and execution unit, compared with the two-unit execution and bus organisation of the 8086. It has demultiplexed address and data buses to improve bus efficiency, particularly in protected mode.

The instruction unit can decode and hold a queue of three prefetched instructions, which it sequentially feeds to the execution unit. Meanwhile, the presence of a dedicated address unit, which calculated the physical addresses in memory of the instruction and data being called upon, offered a key performance improvement over previous systems.

GAMING

The 286's extra power meant that more was possible for game developers. New instructions for moving data between stacks and registers benefited those working in high-level languages such as C. Although the increasing multimedia capabilities of PC systems through the 1980s also played a significant role, the PC's processor power was becoming apparent. That said, in the 1980s, 286 systems were still prohibitively expensive compared with more family-orientated microcomputers, as well as low-end 8086-based PC-compatible machines.

Despite this, the second instalment in Sierra's King's Quest series, 1985's Romancing the Throne, explicitly supported the 286-based IBM PC/AT, booting directly from a floppy disk. By 1990, popular series, such as Ultima and Wizardry, which had once been developed for rival systems, such as the Apple II and IIGS, were receiving MS-DOS first releases.

It wasn't all positive. Some older games whose performance was fixed to clock cycles became unplayably fast, which led to the widespread use of 'Turbo buttons', which would slow the system down to clock speeds comparable with 8086 and 8088 CPUs. Other 286 PCs had a BIOS option to do the same, and utilities such as Mo'Slo were developed in the 1990s to slow down overspeed games. **CPC**

Readers' drives

Cyberpunk 2077 (Neon)

After binge-watching Cyberpunk 2077 trailers, modder Richard Ord decided to transform an Antec DF600 Flux case into this technicolour water-cooled machine, with custom 3D-printed parts and a load of Kobra spray paint

SEE THE FULL PROJECT LOG AT
custompc.co.uk
/CyberPunkMod

/MEET THY MAKER

Name Richard Ord

Age 36

Occupation Quality assurance officer

Location Newcastle upon Tyne

Main uses for PC Gaming and CAD

Likes Gaming, modding, movies, cars, steaks and spending time with my family

Dislikes Vegetables and traffic wardens

CPC: So how did this project start? What inspired you to build a PC based on Cyberpunk 2077?

Richard: This project all started when Antec UK reached out to me to do a build in the company's new DF600 Flux case. When I received the case, I had just been binge-watching a lot of trailers for Cyberpunk 2077, and thought I could take some of those aspects I'd seen and incorporate them into the build.

CPC: Take us through the painting process

Richard: I had to strip the full case right down in order to paint it all. I knew from watching the trailers that I wanted to use blue, yellow and pink, although I wasn't 100 per cent sure if it would work in practice. I normally use spray cans whenever I do any painting, but this time I wanted to try Kobra paint, as it doesn't require a lot of prep work – you just need to make sure the panel is clean.

CPC: How did you go about making the 3D Cyberpunk 2077 logo on the PSU shroud?

Richard: I'm always looking at technology to find new ways to mod, and I invested in a Prusa i3 MK3S 3D printer at the start of the year – I've used it for a few builds now and it's a great tool. For the logo, I had a look on **thingiverse. com** and found a logo that I liked – I then went into Fusion 360 and edited the file to fit the area I wanted, and then sliced the file to run on my 3D printer.

CPC: There's a logo on the graphics card backplate too. How did you make that one?

Richard: When I did the backplate for the graphics card, I went back into Fusion 360, and edited the file I used for the 3D printer to a DXF file, so I could cut out the design in vinyl on my plotter. Once I'd cut out the logo, I placed it on the backside of the graphics card backplate and stuck it down, making sure there were no air bubbles. Once all the bubbles had been squeezed out – I applied the first layer of yellow spray paint, which I then repeated a few times to get an even coat. Once it was dry, I just peeled off the vinyl and repeated the process with the blue paint.

Once all the bubbles had been squeezed out, I applied the first layer of yellow spray paint

CPC: Who made the distribution plate at the front?

Richard: The distribution plate in this build was made by Bitspower, but I also make custom ones.

CPC: What type of hard tubing did you use?

Richard: I used EK's 16mm PETG tubing, and there aren't any wild bends in it – I kept it simple with 90-degree bends.

CPC: Is that a Lian Li Strimer set on the power cables?

Richard: Yes it is – I thought it would look good in this colourful build.

CPC: There's barely a cable in sight. How did you plan the cable routing, and is it as tidy at the back?

Richard: It was very easy in this case – there's lots of space at the back and it even had a built-in fan and RGB hub.

CPC: Is the cooling system geared more towards cooling power or quiet operation?

Richard: I've slowed down the fans, so it's a very quiet system – I haven't tried to overclock the CPU yet. To be honest, with this build, I was also surprised by how much airflow the case produced.
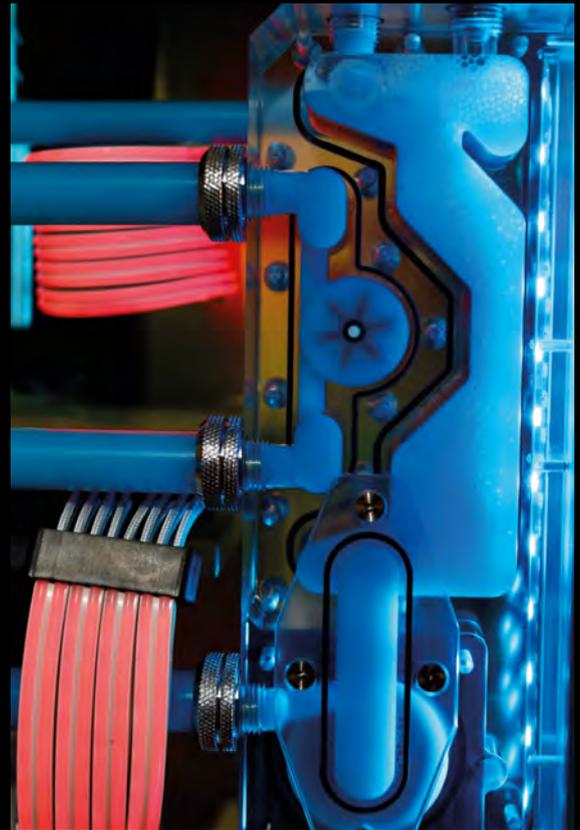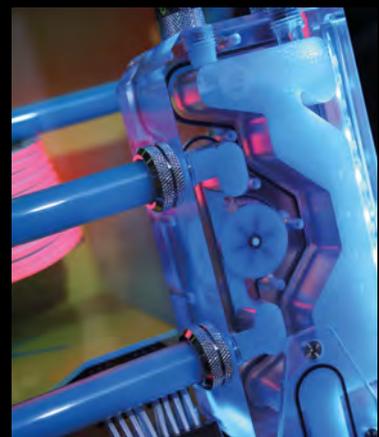
SYSTEM SPECS

CPU Intel Core i9-10900KF

Case Antec DF600 Flux

GPU MSI RTX 2080 Gaming X Trio

Storage 1TB Seagate Firecuda M.2 SSD

Memory 32GB G.Skill Trident Z Neo

Motherboard MSI MPG Z490 Gaming Carbon WiFi

PSU Antec HCG 650W

Cooling Custom water-cooling loop with parts made by Bitspower

CPC: How did you plan the lighting coordination, and where are all the lights?

Richard: For this build, all the light comes from the case fans, motherboard, graphics card waterblock and distribution plate.

CPC: What spec is the PC, and how well do you think it will run Cyberpunk 2077 when it comes out next month?

Richard: I believe I won't have any issues with playing Cyberpunk 2077. The specs include an MSI GeForce RTX 2080 Gaming X Trio graphics card, as well as an Intel Core i9-10900KF CPU and 32GB of G.Skill Trident Z Neo memory.

CPC: Did you have to perform any custom modifications to the case, other than the paint job?

Richard: To be honest, no – I wanted to keep the case as close to its stock configuration as possible.

CPC: Did you come across any difficulties with this build?

Richard: Once I'd fitted all the hardware in the case, I hit a few issues with the length of the MSI GeForce RTX 2080 Gaming X Trio graphics card. I knew I didn't have a lot of space on the right of the case, and that's when I realised I needed to use a distribution plate in that location. It would give me the look I wanted to achieve, with the tubing running from right to left, and it would fit. Fitting the distribution plate wasn't easy either – I had to make a few custom brackets and spacers – this is where having a 3D printer comes in very handy.
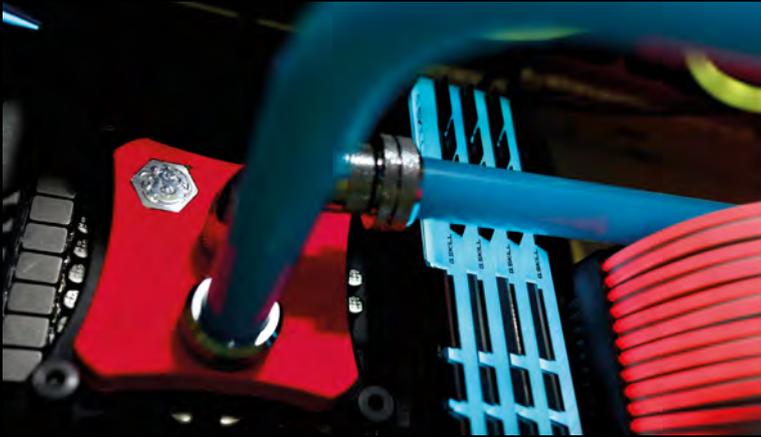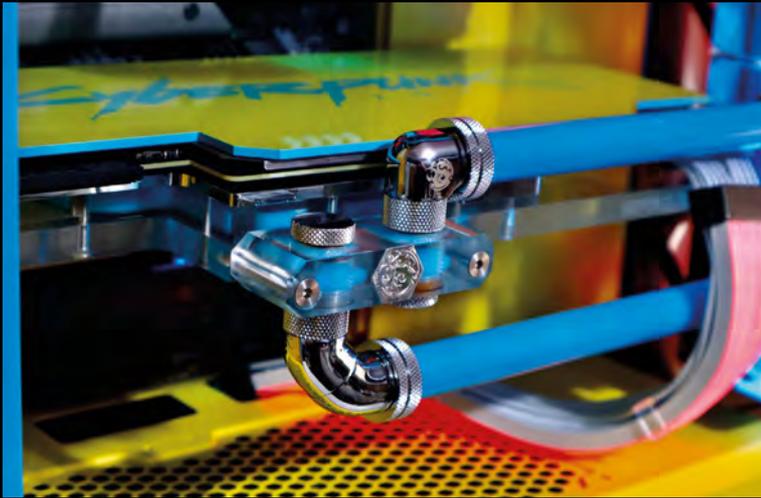
I had to make a few custom brackets and spacers – this is where having a 3D printer comes in very handy

CPC: How long did it take you to complete this build, from start to finish?
Richard: I wanted to have a quick turnaround with this build, so it took around two weeks, with me doing a few bits each night around my family and my day job.

CPC: Have you got any tips for people who are interested in building a system with a custom paint job?
Richard: The best tip I can give you for doing custom paintwork is to make sure you prepare the area well for the type of paint you're using.

CPC: Are you completely happy with the end result, or do you wish you'd done some of it differently in retrospect?
Richard: That's a good question. When I first completed this build I was very happy with what I'd produced, and I also received a lot of very good feedback. However, anyone who knows me well will know that I always like to tinker with my builds, so I would be surprised if I don't end up changing something about it later.

Finally, I'd also like to just say a big thank you to all of the sponsors for this build – Intel, Antec, MSI, Bitspower and Seagate. **CPC**

JAMES GORBOLD / HARDWARE ACCELERATED

THE DEATH OF MANUAL OVERCLOCKING

Overclocking used to be the staple of enthusiast PCs, but it's no longer relevant for the average hobbyist, argues James Gorbold

When we first launched **Custom PC**, our willingness to embrace overclocking made us stand out. Pages and pages were dedicated to detailing how to achieve the best overclocks, while behind the scenes we encouraged PC manufacturers to produce pre-overclocked PCs with a warranty.

Over the following 17 years, overclocking evolved many times. It transformed from a dark art of DIP switches and socket mods with pieces of wire to a tweak that could be easily achieved with a few mouse clicks in the EFI or Windows. For a while, it even looked like it could become a sport in its own right, with competitors flying around the globe to take part in competitions and winning huge sponsorship deals.

Now it looks to me as if overclocking is evolving once more, but this time fading back into relative obscurity. The primary driver behind this change is the improved boost mode employed by AMD and Intel CPUs. First introduced over a decade ago by Intel, in its early day's, turbo wasn't that exciting, typically adding only a couple of hundred megahertz to the CPU frequency, while you could manually overclock CPUs much further.

However, over the years the turbo profiles employed by AMD and Intel have become far more aggressive, so much so that most CPUs can boost higher than you can manually overclock them. Take the Core i9-10900K for instance, which can boost from 3.7GHz to 5.3GHz, a massive boost in its own right, and noticeably higher than the typical 5GHz all-core overclock that most 10900Ks can achieve.

Plus, as most games still run on less than a handful of a threads, games run better on a turbo-boosted processor running at 5.3GHz than on a processor with an all-core manual overclock to 5GHz. This is true for quite a few consumer-level content creation applications too, such as image editing, which still remains stubbornly single-threaded.

The end result is that overclocking, at least for enthusiast PCs, is a dying trend. Just a few years ago, Scan used to sell the same number of overclocked gaming PCs as non-overclocked PCs. This was a remarkable achievement, given the price premium of overclocked systems due to their higher 'bill of materials' cost.

In recent years, however, our sales of non-overclocked PCs have pulled away from overclocked PCs and we now sell close to four times as many non-overclocked PCs. I expect this trend to continue too – thanks to the increased competition between AMD and Intel, both companies are expending more effort into boosting turbo profiles.

> We now sell close to four times as many non-overclocked PCs

While overclocking is dying among PC enthusiasts, though, it still has an important role to play for professional workstations. This is rather ironic, as for many years professional users shied away from overclocking, and it's still an abhorrent concept for servers, because of stability concerns. However, as most workstation applications, bar some obvious examples such as AutoCAD, are heavily multithreaded, overclocking offers a great way to boost performance.

When it comes to commercial content creation, time equals money, so an overclocked workstation that completes tasks in less time is also a money-saving tool. Who knows, in another 17 years, **Custom PC** may not be covering overclocking at all, while content creator magazines could still be writing about overclocked workstations. **CPC**

James Gorbold has been building, tweaking and overclocking PCs ever since the 1980s. He now helps Scan Computers to develop new systems.

Fibonacci was fascinated by the complex, yet simple hexagon
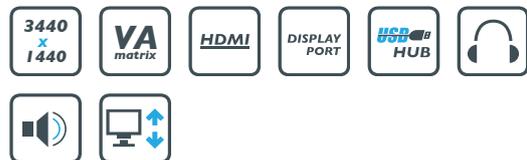
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