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Welcome

Custom PC Issue 196

/ FROM THE EDITOR

Take your time

Despite being 42 years old and having enough white body hair to start worrying that I'm turning into the Wampa from The Empire Strikes Back, managing excitement is still a problem for me when it comes to PC building. I'm a bit like a five-year-old ripping open a chocolate wrapper – I want my new gear up and running now – I don't want to have to spend days setting it up properly first.

However, taking your time makes the difference between having a neat and tidy build, and a box full of messy wires, as we show you in our masterclass on p76. It means you don't block your case's airflow, and that you can easily add upgrades in the future. I've written before about how much I love the process of tidying cables when I actually put my mind to it, and I heartily recommend that you do the same – allow for some proper planning time when assembling your PC build.

Knowing where to plug in the various plugs and components is an important part of the PC-building equation, but there's no substitute for taking a couple of hours looking at all the cables with your CPU cooler and power supply, checking them with the sockets and headers on your motherboard, and planning how you're going to route them.

Once you know that all your core gear works, clear your work area, and really think about every single cable and where it's going to go. Once you've done that, you also need to think about the logistics of connecting and routing which parts and when to do it. For example, if you're installing an all-in-one liquid cooler in the roof, it will block access to the top cable-routing holes, so you'll need to route any cables through those holes before you fit the radiator.

Sometimes installation involves careful coordination, while you thread cables through holes with one hand, and hold your radiator out of the way with the other. In most cases, it involves having to carefully work out the order in which to fit some of your components. Plan it all out step by step, place by place, and you should be able to construct a smart PC with minimal swearing and cut fingers in the process. CPC

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Custom PC

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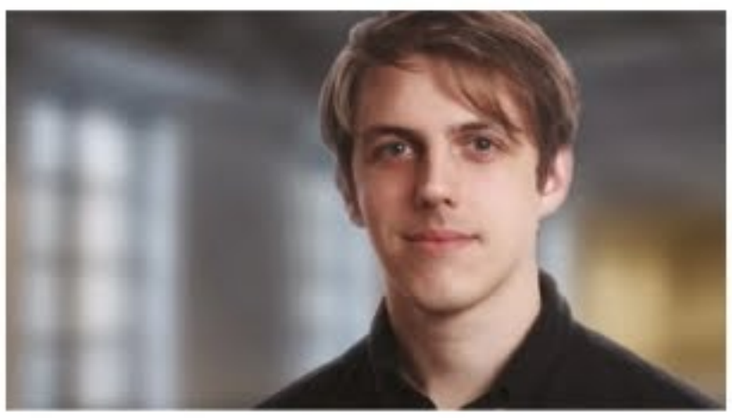

RICHARD SWINBURNE / VIEW FROM TAIWAN

POSTPONE THREADRIPPER

Hot benchmark numbers are all well and good, but AMD really needs to address the holes in its Zen 2 line-up first, argues Richard Swinburne

I know this column will get me some angry tweets, but seriously, hear me out. I understand that creating Threadripper is like grabbing low-hanging fruit when AMD is already making EPYC chips that are practically the same. However, it's missing out on bigger opportunities by focusing its scant resources on a new Threadripper platform, which the forthcoming 16-core/32-thread Ryzen 9 3950X will already sufficiently serve.

That's because, at the other end of the market, Intel's recent price drops mean AMD has no products to effectively compete with the Intel Core i3-9100F and Core i5-9400F. While a lot of enthusiasts will indulge in a Core i9-9900K or Ryzen 9 3900X, more CPUs at the other end of the scale are sold to DIY folks building capable rigs on a budget. AMD has its Ryzen 3 3200G and Ryzen 5 3400G here, but they're based on the Zen+ core, rather than the considerably more appealing Zen 2.

According to data from **mindfactory.de** (one of the few places that provide insight into individual CPU sales), sales of these APUs represent only a fraction of those of the 6-core/12-thread Ryzen 5 3600, which is the next CPU up the stack. To me, it's evident that a quad-core/8-thread Zen 2 option at the £100-125 mark would be very attractive, especially when the Intel alternatives lack Hyper-Threading. AMD did recently launch the 6-core/6-thread Ryzen 5 3500X, but it's an exclusive chip for its system partners only – it needs to be available to the rest of us!

It's possible, of course, that AMD is waiting to clear the channel of old Ryzen 2000-series parts, which are now being heavily discounted. If so, I hope it will launch more affordable Ryzen 3000-series chips in sync with the upcoming B550 chipset release. Even if entry-level chips don't have huge profit margins, they'll help to grow AMD's market share even further, and re-establish the mindset that AMD isn't just the cheap option, but a real blow-for-blow competitor with Intel, which will ultimately benefit customers.

The place for better profits is the gaming laptop market, which is one of the few PC spaces that's still growing. Thanks to Intel's prior supply issues, AMD has finally got its foot in the door of the laptop market this year. However, again, it's sadly only serving it with older Zen+ products instead of its latest and greatest Zen 2 microarchitecture.

> It's evident that a quad-core/8-thread Zen 2 option for £100-125 would be very attractive

On the plus side, AMD has just launched its Radeon RX 5500M GPU, which is based on the latest Navi architecture and is proving to be competitive in mid-range performance. However, it's often being paired with Ryzen 7 3750H and 3850H processors, which are slower than Intel's alternatives. AMD needs to push Zen 2 into its laptop platform as soon as possible to hit the hottest-selling season (Nov-Dec), or it will lose momentum. These chips don't need to be APUs – they just need to be versions of the desktop parts with TDP optimisations via clock speeds and boost algorithms to limit them to 35-45W.

I'm not saying Threadripper isn't great, but most people are never going to need one, whereas lots of people buy high-performance laptops for gaming, creative work and a close-to-desktop experience. Instead of satisfying our salacious need for the hottest benchmark numbers, AMD needs to push into budget rigs and gaming laptops. 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

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TRACY KING / SCEPTICAL ANALYSIS

POLITICAL PROTESTS

Tracy King analyses Blizzard's sanctioning of a Hearthstone player for protesting against the Chinese government at a tournament

Unless you look for them, politics aren't usually obvious in mainstream video games. Developers and publishers want to reach the largest possible audience so, as with any other business and product, games developers like to avoid controversy. But what happens when 'avoiding' politics involves actively taking the side of an authoritarian regime?

Enter Blizzard. You've probably heard by now that professional Hearthstone player Ng Wai Chung, aka Blitzchung, was punished by Blizzard for undertaking a protest during a tournament. His words explain his politics, 'liberate Hong Kong'. In response, Blizzard banned him for a year (later reduced to six months) and confiscated his 2019 winnings (which were then reinstated after a backlash). Blizzard cited some of the tournament rules, which say that 'engaging in any act that, in Blizzard's sole discretion, brings you into public disrepute, offends a portion or group of the public, or otherwise damages Blizzard's image' is forbidden.

I'm not here to debate the merits of the Hong Kong protests, but to examine whether esports players are allowed to use their platform for political protest, and whether Blizzard's response to this specific protest is fair or equitable.

Protests during sporting events aren't new. In August this year at the Pan American Games, fencer Race Imboden, and women's hammer winner Gwen Berry both used their moment in the podium spotlight to protest Donald Trump. The Olympics committee is 'considering' sanctions. In 2016, American footballer Colin Kapernick started an entire movement, #TakeAKnee, in protest against racism and gun violence. In 1996, American basketball player Mahmoud Abdul-Rauf was heavily sanctioned for refusing to stand for the national anthem. Sporting history is full of athletes using their platform for protest. It was inevitable that esports would join them, and also inevitable that punishment would be the response.

But for the purposes of enforcing its rules about disrepute and offence, is Blizzard being objective here? Well, no. China is a major market for Hearthstone and also has a government that likes to censor, and there's no chance that Blizzard is unaware of this situation.

But there's also no chance that Blizzard as a company doesn't have politics. It has an equal opportunities policy, an environment policy, and published core values that include 'think globally' and 'every voice matters'. These are all examples of politics. When deciding what qualifies as something that 'offends a portion or group of the public', Blizzard has to actively take the side of China. That's not politically neutral.

> Blizzard couldn't do nothing, because then it would be open season for political protests of all sorts

I would also argue that Blizzard has done more to damage its image than Blitzchung. By Blizzard's own admission, its original punishment was overkill. That's not to say it was wrong to sanction at all though. Blizzard couldn't do nothing, because then it would be open season for political protests of all sorts at its tournaments, from the left, right and everything in between. Doing nothing would be taking the side of the Hong Kong protests, by omission. But by being so heavy-handed, Blizzard made it look like it's on China's side, and that's not okay.

That said, if Blitzchung truly cares about Hong Kong then Blizzard's overreaction is the best outcome that could have happened. By making the sacrifice, Blitzchung has created publicity and support for his cause where otherwise it wouldn't have existed. The games community wasn't going to pick up the mantle of Hong Kong without a martyr, and Blitzchung is it. CPC

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

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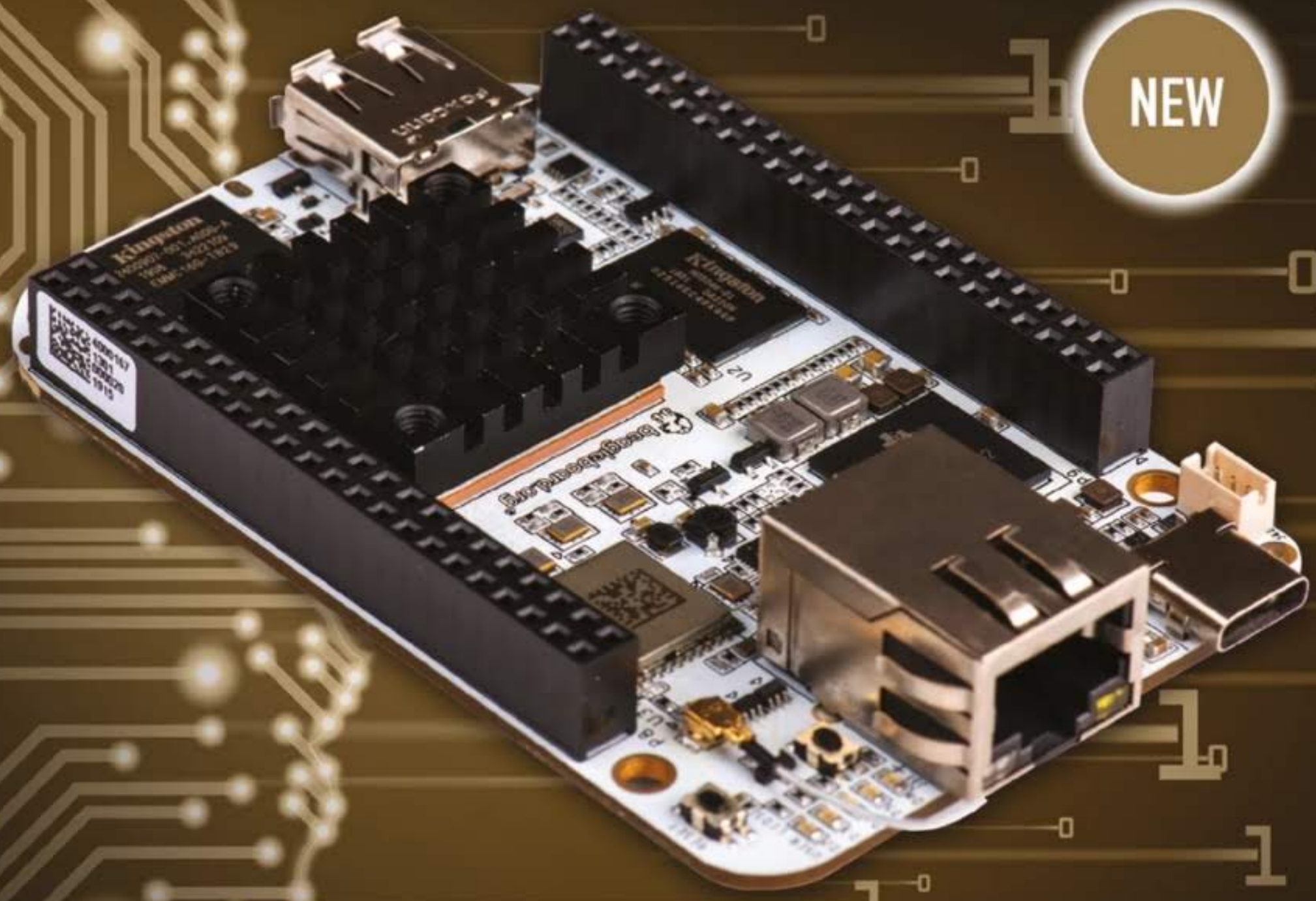

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Incoming

Razer launches first gaming monitor

Razer is known for making all sorts of gaming peripherals and accessories, but the Raptor 27 represents its first foray into monitors. It has a 27in IPS panel with a 2,560 x 1,440 resolution, along with a 144Hz refresh rate. According to Razer, the Raptor 27 boasts a DCI-P3 colour range and a 1,000:1 contrast ratio. Meanwhile, its wide standing foot is equipped with RGB LEDs, and there's hardly any visible bezel around the edges of the screen.

There's also a built-in cable management system in the back of the foot for HDMI, DisplayPort, USB 3.2 Gen 2 and headphone cables, and the foot flips up a whole 90 degrees. There's no word on final pricing yet, but the price at the original time of announcement at the beginning of the year was $700 US (around £645 inc VAT).

PHIL HARTUP

ARCTIC launches Threadripper air cooler

ARCTIC has released its Freezer 50 TR, a cooler specifically designed to handle the formidable demands of AMD's Threadripper CPUs. To this end, it has a dual-tower design with eight heatpipes and two PWM-controlled fans. There's also an addressable RGB (ARGB) lighting system with 13 LEDs, which means the cooler isn't just extremely powerful, but also easy on the eye.

The heatsink itself is aluminium, with a dense phalanx of 104 fins and a large surface area, with the heatpipes making direct contact with the CPU. The radiator. Meanwhile, the asymmetrical pair of fans work in tandem in a push/pull setup.

There is a 120mm fan on one side of the heatsink, a 140mm fan in the centre, with the opposite side used as a vent. The Arctic Freezer 50 TR is available now for £60 inc VAT.

PHIL HARTUP

Corsair RAM hits 5000MHz

Corsair has announced that its newest and fastest Vengeance LPX RAM kits can now run at up to 5000MHz. This makes it the fastest commercially available RAM at stock speed, overtaking G.Skill's 4800MHz Trident Z Royal memory.

Not surprisingly, the 5000MHz Vengeance RAM gets a bit toasty, so it's supplied with a Vengeance Airflow cooling fan, which can be clipped onto the DIMMs to provide a degree of active cooling. It's not cheap though – the price for a 16GB (2 x 8GB) dual-channel kit is currently £1,055 inc VAT from corsair.com

Rumour control

PHIL HARTUP'S ROUNDUP OF THE LATEST UNCONFIRMED TECH GOSSIP. TAKE THESE STORIES WITH THE APPROPRIATE PINCH OF SALT

NVIDIA BEEFING UP ENTRY-LEVEL GPUs

According to a report at **igorslab.media**, Nvidia will soon be updating its budget Turing GPU line-up with the GTX 1650 Super and the GTX 1660 Super, the former of which may even be available by the time you read this magazine.

According to the leaks, the GTX 1660 Super will have 1,408 CUDA cores, a 1530MHz base clock and a 1785MHz boost clock, just like its predecessor. However, its memory is being switched up from GDDR5 to GDDR6, although there will still be 6GB of it. This means the only notable changes are the memory and an extra $10 US on the retail price.

Meanwhile, the GTX 1650 Super apparently represents a more substantial step up. The GPU is changed from a TU117-300 model to a TU116, bringing 1,280 CUDA cores vs 896, a 1530MHz core clock vs 1485MHz and a 1725MHz boost clock vs the 1665MHz on its predecessor. There will still be 4GB of memory although, as with the 1660 Super, it's beefed up to GDDR6.

SKYLAKE-X PRICES TO FALL

According to German hardware website **Computerbase.de**, prices for the current line of Intel Skylake-X CPUs could be about to undergo a radical rebalancing, with a rumoured price reduction of up to 50 per cent per core. Such a move could help the company to battle against fierce competition from AMD in the HEDT arena, with the company's first 16-core Ryzen CPU due to be released soon, as well as new Threadripper chips.

A be quiet! DARK BASE PRO 900 CASE!

Nvidia to ray-trace more classic games

Nvidia is recruiting for a new division, called Lightspeed Studios, with the apparent intent of adding real-time ray-tracing effects to classic games. The story comes from a job listing spotted by **dsogaming.com**, which states an aim to bring state-of-the-art visuals to classic games without affecting gameplay.

Quake II RTX (pictured) demonstrated that retrofitting games in this way is possible, but it also showed that, having injected lovely RTX effects into the game, you're still dealing with a lot of chunky low-polygon characters with chunky low-resolution textures, blasting each other into chunks with some pretty lighting effects.

PHIL HARTUP

What's that?

Our pals at be quiet! are offering a Dark Base Pro 900 Rev. 2 Silver case to one Custom PC reader. The image above is a distorted close-up of a piece of hardware featured in this issue. If you identify it, email the name and page number of the product to competition@custompcmag.org.uk, with 'What's that? 196' in the Subject field.

Previous winners

The winner from our Issue 194 competition was James Leppard, who correctly identified the M.2 heatsink from the Gigabyte X570 Gaming on p26-27. Congratulations James, we'll be in touch shortly to get your prizes sorted out.

Terms & conditions

Competition closes on Friday 6 December. Please see p34 for our competition terms and conditions.

Letters

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

Readers' drives pics

I would like to congratulate you and your team for the very impressive turnaround in **Custom PC**'s fortunes. I know from other feedback that I was not alone in being close to cancelling my subscription in the months leading up to the sale to Raspberry Pi, as the magazine had felt a little stale. As a PC Pro subscriber, I also found the duplication of content infuriating. The quality of the magazine – physically as well as content – has been steadily improving ever since, and I have happily renewed my subscription recently.

However, I have one request. I really enjoy reading about (and being inspired by) the hugely impressive machines featured in 'Reader' drives' but I am equally frustrated because it's so often difficult or even impossible to actually see the details of them because of the black background used on the pages. Unfortunately, all too much detail and contrast is lost, even with the recent paper stock and print quality improvements.

Maybe my 50ish-years-old eyes don't help, but I wish you'd use a nice white background and let the hardware speak for itself rather than being overwhelmed by the page design. You do that for the professional product shots elsewhere in the magazine, so can you please show your amateur contributors the same respect?

KEITH SULLIVAN

Ben: Thank you for your kind words, Keith, we're very pleased with what we're doing with **Custom PC** now.

When's the next issue out?

CUSTOM PC

DEC 5

Issue 196
on sale on Thursday, 5 December

Generally, the Readers' drives photos are either taken by the entrants themselves, or we send a photographer round to their house. People generally don't want to risk couriering their pride and joy to our photography studio, and it's also not always practical to do so. As a result, the background for the PCs is usually the reader's home – we then cut them out in Photoshop.

Obviously, using a different coloured background for the page would make no difference here – it's more a case of getting the best possible result you can get in someone's home. However, we'll explore other ways of doing the photography in the future.

CPU fight!

I've been reading **CPC** for nearly 15 years and wanted to ask you a big question. Will there be a CPU Labs test? There are so many different options, including K versions of Intel CPUs and different models of Ryzen 3? I would love to see a massive CPU shootout between AMD and Intel!

HARKIRAT JANAGEL

Ben: Don't worry, a CPU Labs is definitely on the list for the near future – we're just waiting to get as many of the new launches out of the way first, so that we're testing the newest CPUs possible. Watch this space.

Competition exorcism

For the past two issues (193 and 194) I've been unable to enter any of the 'For the win' competitions. On both occasions, the page said 'Sorry, this promotion is not available in your region', even when I set my location as York, UK! Now, I know us Yorkshire folk can be a bit backward at times, but I never knew it extended to exorcising us from (presumably) UK-based competitions. What gives, **CPC**?

ALEX BARDY

Ben: This is likely a problem with the platform we use to run the competitions detecting IP addresses to determine your location. Regardless of where you set your social media location, if it thinks you're not in the UK it won't let you in. Some ISPs don't use UK IP addresses, and some systems also mask IP addresses. One possible way around it to use your mobile network, rather than your home broadband, to enter the competition. I assure you that our competitions are definitely open to everyone in the UK and Channel Islands, including Yorkshire!

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Reviews

SOCKET AM4 PROCESSOR

AMD RYZEN 7 3800X / £390 inc VAT

SUPPLIER overclockers.co.uk

There are currently two options if you want an 8-core CPU based on AMD's 7nm Zen 2 architecture. The Ryzen 7 3700X (see Issue 192, p16) is a beast, especially once overclocked, while the Ryzen 7 3800X we're reviewing here has higher all-core boost and peak boost clocks at stock speed, as well as a higher TDP. Whether it's worth the extra cash is another matter, though, as the Ryzen 7 3700X is £50 cheaper, but sports a largely identical set of features.

As both CPUs have eight cores and 16 threads courtesy of Simultaneous Multithreading (SMT), let's start with the frequencies, which are the main areas to consider. The Ryzen 7 3800X has a base frequency of 3.9GHz, which is 300MHz higher than that of the Ryzen 7 3700X. It also has a 100MHz boost advantage at 4.5GHz. While the Ryzen 7 3700X's all-core boost isn't officially listed by AMD, it sat at 4GHz in our water-cooled test system, and the Ryzen 7 3800X has a sizeable advantage here too, with our sample hitting 4.2GHz under load.

Those higher frequencies have an impact on thermals and power though. The Ryzen 7 3700X has a TDP of just 65W, but the 3800X sits at 105W. Both CPUs include the same Wraith Prism RGB cooler despite that TDP difference, however. The cache sizes are also identical, with both chips having 512KB of L2 cache per core (for a total of 4MB).

SPEC

Base frequency 3.9GHz
Max boost frequency 4.5GHz
Core Zen 2
Manufacturing process 7nm
Number of cores 8 x physical (16 threads)
IGP None
Simultaneous Multithreading (SMT) 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, SSE3, SSE2, SSE

Comparatively, AMD's two 6-core 3rd-gen Ryzen CPUs, the Ryzen 5 3600 and 3600X, have two fewer cores so they have 1MB less L2 cache than the 8-core CPUs. All four of the above CPUs have 32MB of L3 cache, and are made up of two quad-core Core Complexes, with two cores disabled on the 6-core chips.

In terms of the competition, the Ryzen 7 3800X is around £40 more expensive than Intel's Core i7-9700K thanks to Intel's recent price cuts, but it still remains far cheaper than the blue team's flagship mainstream CPU, the Core i9-9900K. The latter will set you back another £60 or so over the price of the 3800X, but it too has seen a price fall, so it now leaves you with plenty of change from £500.

Performance

It's clear from the limited availability of the Ryzen 9 3900X, and the delay to the Ryzen 9 3950X, that there's a high degree of speed-binning going on with AMD's 3rd-gen Ryzen CPUs and we were hopeful that our Ryzen 7 3800X, being in the upper echelons, might reach a higher overclock than the 3900X, especially as it has fewer cores.

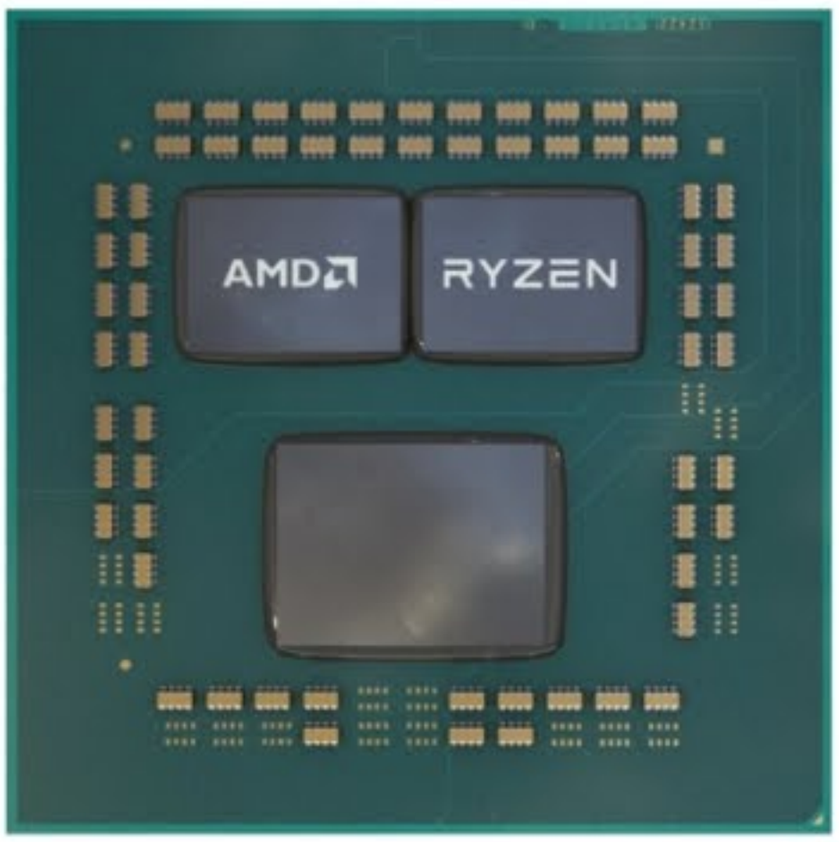
We weren't disappointed, with our 3800X sample reaching 4.4GHz across all cores using our maximum vcore of 1.425V – you may be able to drop the latter a bit for a more long-term overclock as well. This means that, unlike many other recent AMD CPUs, an all-core overclock only loses you 100MHz compared to the peak boost of 4.5GHz. As such, it's definitely worth manually overclocking the Ryzen 7 3800X for heavily multi-threaded workloads, and you won't lose much lightly threaded performance compared with running at stock speed either.

This overclock only saw the load power consumption rise from 215W to 233W, and the chip was easily tameable by our 240mm all-in-one liquid cooler. By comparison, both of Intel's 8-core CPUs drew a similar amount power at stock speed and significantly more when overclocked, although admittedly hitting much higher frequencies.

In our RealBench image editing test, the Ryzen 7 3800X actually managed to outstrip the Ryzen 9 3900X, albeit within the margin of error we generally expect for this test, and it wasn't that much faster than the other 3rd-gen Ryzen CPUs we've tested. However, it definitely had the measure of the two 8-core Intel CPUs. Our heavily multi-threaded video encoding test painted a clearer picture, with the Ryzen 7 3800X outstripping the Core i7-9700K by more than the price difference suggests, with a score of 610,355 compared to just 498,461. Similarly, despite costing another £60 or so, the Core i9-9900K was only a small amount faster.

The system score of 241,240 is only just short of the Core i9-9900K and not a whole lot more than the Ryzen 7 3700X, but the Ryzen 9 3900X does offer a fair amount more grunt here, easily topping 300,000. Once it was overclocked on all cores, the 3800X's system score rose to 253,121, with the biggest gain being seen in the video encoding test, but it was slower in the image editing test, due to our all-core overclock being slower than the single-core stock speed boost frequency.

Overclocking also offered sizeable increases to the Far Cry 5 benchmark, with the minimum frame rate rising from 91fps to 97fps. Even so, this test is an area where Intel still reigns supreme, although bear in mind that not all games respond so strongly to using different CPUs, and that this is a deliberately CPU-limited test.



Conclusion

Compared with Intel's offerings, the Ryzen 7 3800X is a beast, usually matching or bettering the Core i9-9900K in multi-threaded benchmarks and trouncing the Core i7-9700K. The latter, though, can be bought for less than £350, so it's definitely worth considering if gaming is your top priority. However, you won't see benefits in all games, and as soon as you dip into multi-threaded workloads, the Ryzen 7 3800X completely outstrips both Intel CPUs in terms of value and very often in raw performance too.

The Ryzen 7 3800X's pricing is the main factor in deciding whether it's worth buying over the Ryzen 7 3700X. The latter is a little slower at stock speed, especially in multi-threaded tests, and it doesn't overclock as far. The price difference is fluctuating too, going between £40 and £60 over the past month.

If it's a £60 difference, that's money that would be better spent on a bigger SSD, a more premium case or a better CPU cooler. However, if the difference is small, the promise of a higher overclock or stock speed boost frequencies is worth a small amount of extra cash. Either CPU is currently a great buy, though, especially if you'll be throwing a range of tasks at your PC.

ANTONY LEATHER

CORES

- \+ Most overclockable Zen 2 CPU yet
- \+ Faster than Core i7-9700K in most tests
- \+ Excellent all-rounder

CHORES

- – Intel chips quicker in some games
- – Cheaper Ryzen 7 3700X isn't much slower
- – Limited overclocking headroom compared with Intel

VERDICT

One of the best 8-core CPUs around, but the cheaper Ryzen 7 3700X isn't much slower.

PERFORMANCE **44/50**

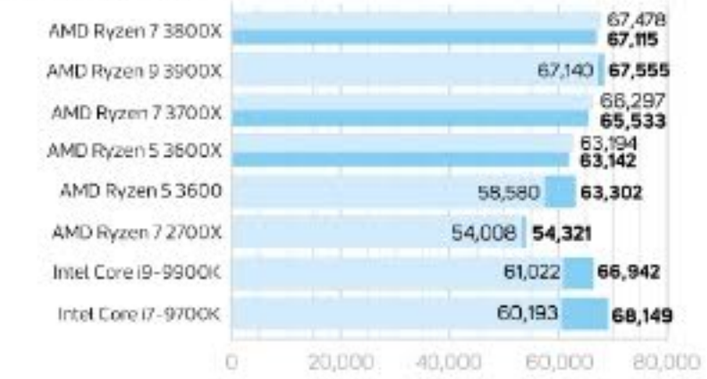
FEATURES **15/15**

VALUE **29/35**

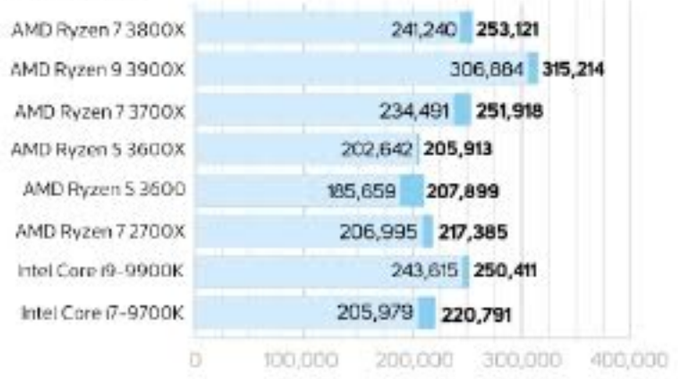
OVERALL SCORE **88%**

AMD RYZEN 7 3800X RESULTS

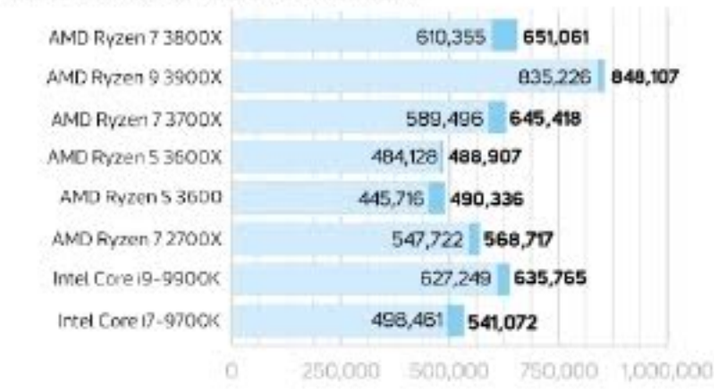
GIMP IMAGE EDITING



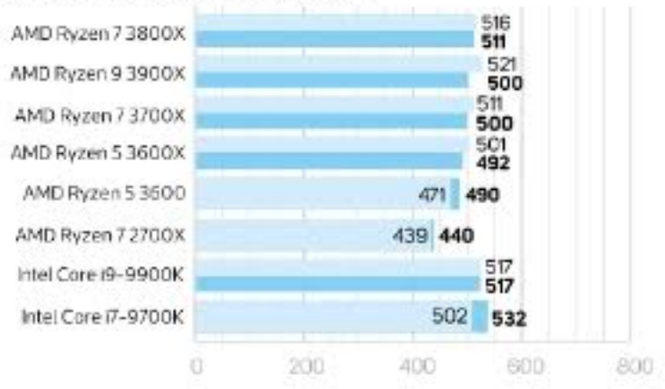
SYSTEM SCORE



HANDBRAKE H.264 VIDEO ENCODING

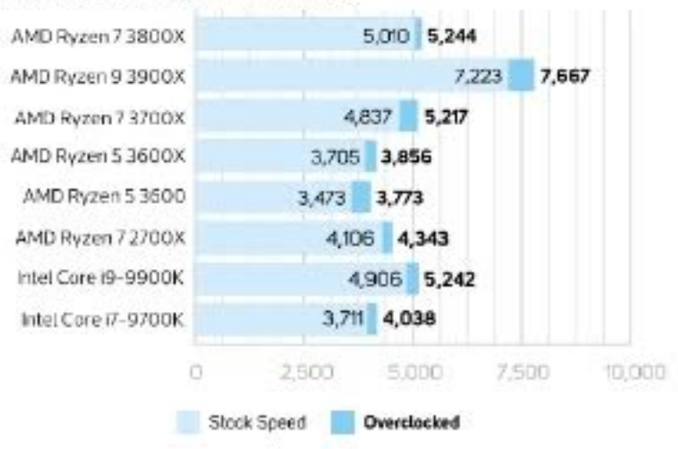


CINEBENCH R20 SINGLE-THREADED

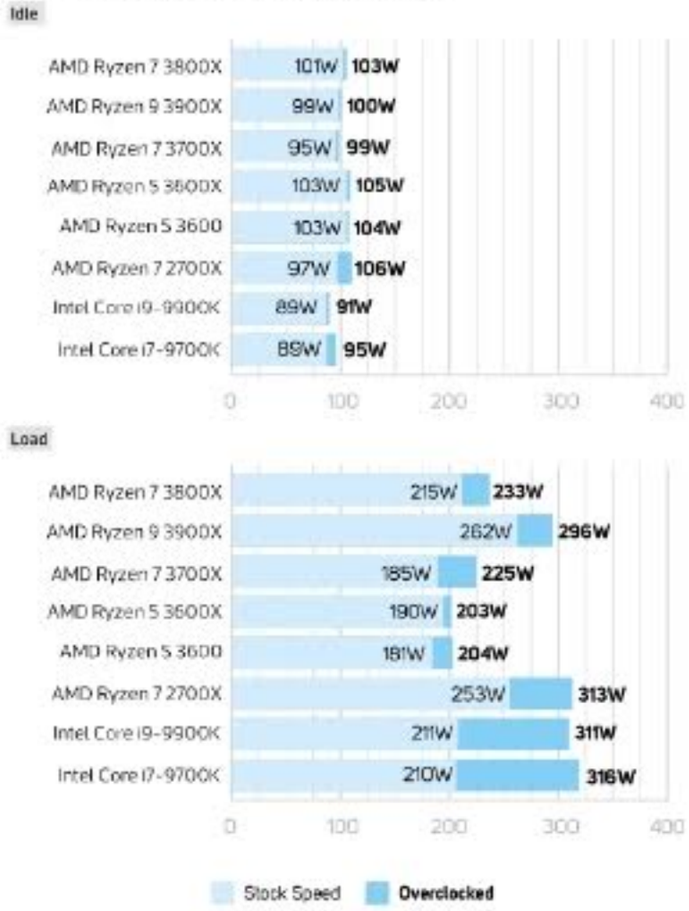


HEAVY MULTI-TASKING

CINEBENCH R20 MULTI-THREADED

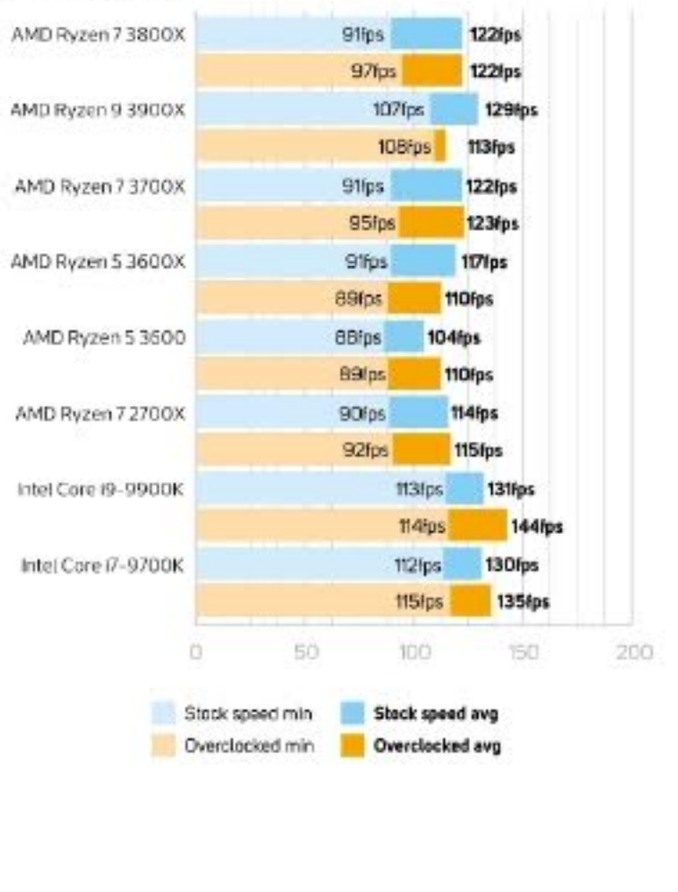


TOTAL SYSTEM POWER CONSUMPTION



FAR CRY 5

1,920 x 1,080, Ultra settings



LGA1151 PROCESSOR

INTEL CORE i9-9900KS

/ **£500** inc VAT

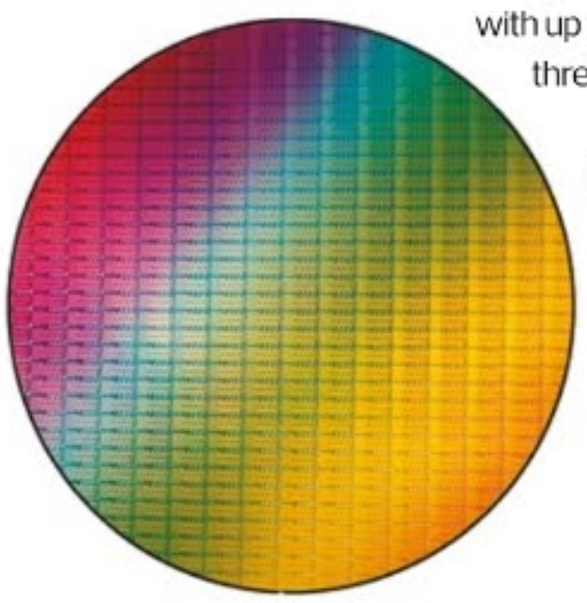
SUPPLIER overclockers.co.uk

Back in early summer this year during the Computex trade show, Intel announced, much to our surprise, the Core i9-9900KS. The CPU, which was completely unexpected, came just as AMD was launching its 3rd-gen Ryzen products, which have done rather well since launching in July. The Core i9-9900KS, though, only landed in our lab hours before we went to press near the end of October, so it's rather late to the 2019 CPU war.

While we've grabbed a full suite of benchmark results before these pages flew out the door, there is one aspect of the new CPU we're not sure about and that's the price. The review embargo sat a week in the future of when we were writing this review, so there were no concrete retail prices available. However, several US websites have revealed initial figures in the $550-600 US price range, meaning that the Core i9-9900KS is likely going to tip the scales at a little over £500 inc VAT. The Core i9-9900K, meanwhile, retails for under £460 inc VAT, and the GPU-free Core i9-9900KF going for around £15 lower still?

On the plus side, that extra dough gets you the first desktop CPU with a stock speed all-core turbo boost clock of 5GHz. Unlike the Core i7-8086K, which could boost to 5GHz on a single core, the Core i9-9900KS can get there across all eight cores out of the box. By comparison, the Core i9-9900K and Core i9-9900KF can only reach 4.7GHz in their all-core boost state, although they can also hit 5GHz with up to two cores in lightly threaded workloads.

The main benefit of the 9900KS, then, is mainly seen in multi-threaded workloads,



Intel is essentially binning CPUs, cherry-picking the very best batches from its eight-core wafers

which will gain a 300MHz boost over the other two CPUs. In fact, most of the old Core i9-9900K CPUs will only reach 5GHz with an all-core overclock, so here, you're essentially getting a pre-overclocked version of Intel's former mainstream flagship. That 5GHz clock was certainly the limit with our old 9900K sample – we could only get to 5.1GHz on the Core i5-9600K and Core i7-9700K.

Intel is essentially binning CPUs, cherry-picking the very best batches from the Core i9-9900K silicon lottery and putting the Core i9-9900KS name on them. However, that status also brings the possibility of even higher overclocks, since these chips will be the more favourable ones to have come off Intel's 14nm production line.

Otherwise, the Core i9-9900KS and Core i9-9900K are practically identical. They both sport 16MB of L3 Cache – admittedly far less than AMD's similarly priced Ryzen 9 3900X, which has 4MB of L3 cache per core, compared to 2MB for the Core i9-9900KS. The Core i9-9900KS' single-core peak boost limit is also 5GHz, so single-threaded performance is unlikely to see much of a boost – only loads that stress three or more cores will benefit.

The downside to the extra grunt is that it comes with additional power consumption. Intel states that the Core i9-9900K has a TDP of 95W. The Core i9-9900KS, though, comes with a TDP of 127W, which is significantly higher than that of the 12-core Ryzen 9 3900X. The trouble here, though, is that the Core i9-9900K was already a toasty customer when it comes to high-load tests and even more so when overclocking. It doesn't look like the Core i9-9900KS is going to change that situation.

Performance

Starting with those power numbers, we measured a peak power consumption of 275W with the Core i9-9900KS in our test rig, which is over 60W higher than with the old CPU. There certainly seemed to be a fair bit more voltage too, with the peak vcore being reported as over 1.4V in CPU-Z.

Overclocking was fruitful, but not epic, with the Core i9-9900KS reaching 5.1GHz on all cores, and without us having to touch the vcore, which goes to show how much voltage is already being applied to the chip. One possible explanation for this high voltage is that MSI has released a BIOS tailor-made for the Core i9-9900KS and our test motherboard, MEG Z390 Ace, which might explain it, although we didn't have enough time to investigate this situation further before going to press.

At stock speed, the CPU was a little quicker than the old 8-core flagship, but never by huge amounts. The single-threaded image editing test score rose by nearly 2,000 points, the system score by nearly 3,000 points and Cinebench R20's multi-threaded test increased from a score of 4,906 to 5,149. Bizarrely, there was hardly any difference between the Core i9-9900KS and its predecessor in our Handbrake benchmark, which should benefit from the extra boost speed across all cores.

Once overclocked, there was only a difference of 100MHz over the stock speed, so the gains are slim, even when compared with the Core i9-9900K. We saw nearly a 1,000-point advantage in the image editing test. Far Cry 5, meanwhile, again saw modest gains at stock speed and when overclocked, with the biggest leap being an extra 4fps in the average frame rate.

SPEC

Base frequency 4GHz

Max boost frequency 5GHz

Core Coffee Lake refresh

Manufacturing process 14nm++

Number of cores 8 x physical (16 threads)

Hyper-Threading Yes

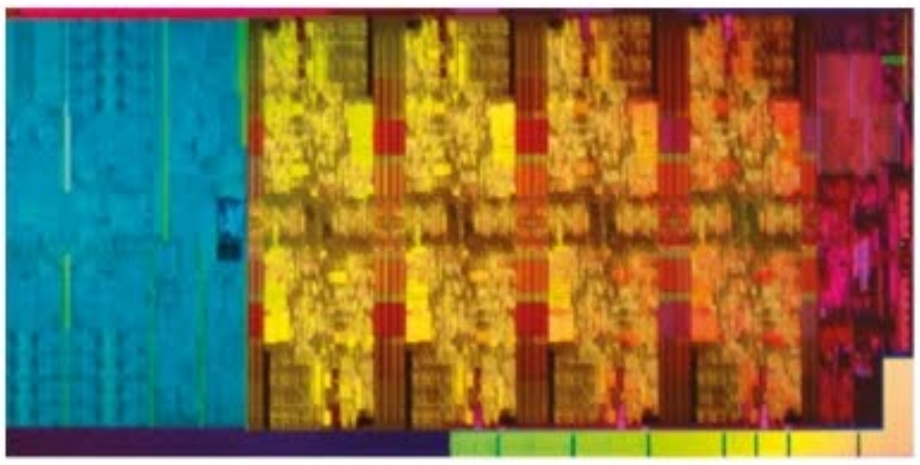
Cache 16MB L3 cache, 8 x 256KB L2 cache

Memory controller Dual-channel DDR4, up to 2666MHz

Packaging LGA1151

Thermal design power (TDP) 127W

Features Turbo Boost 2, FMA3, F16C, SHA, BMI / BMI1 + BMI2, AVX-512, AVX2, AVX, AES, SSE4a, SSE4, SSE3, SSE2, SSE, MMX



Under the hood of the Core i9-9900KS – all those cores (the yellow/orange bits) can boost to 5GHz

Conclusion

The trouble with the Core i9-9900KS is that it can't really do much more than an overclocked Core i9-9900K. Many of the latter will hit 5GHz, but even at 4.9GHz, it won't be far off the new flagship. The gains from the 9900KS at stock speed are minimal and certainly nowhere near enough to rein in the power of AMD's Ryzen 9 3900X in multi-threaded tests.

We're not all overclockers, of course, but the Core i9-9900K can still hit 5GHz on two cores at stock speed, which means lightly threaded games (that's most of them) probably won't see much benefit from the 9900KS either. Intel's new flagship is more of a trophy CPU, much like the Core i7-8086K before it.

However, while Core i9-9900KS doesn't offer a meaningful upgrade from the Core i9-9900K, if it doesn't have a silly price, the new CPU could be worth considering if frame rates are your absolute top priority. If there's less than a £40 difference between the two CPUs, the higher stock speed frequencies, promise of more overclocking potential and bragging rights could just about make it worth the premium. If the price goes any higher, though, the venerable Core i9-9900K is still your best bet.

ANTONY LEATHER

VERDICT

The best gaming CPU available, but it's only just behind the cheaper Core i9-9900K, and AMD's 3rd-gen Ryzen CPUs offer better multi-threading value.

OVERCLOCKED

- \+ 5GHz on all cores at stock speed
- \+ Excellent gaming performance

OVERCOOKED

- – Not much faster than Core i9-9900K
- – Tiny overclocking headroom
- – AMD offers better multi-threading value

PERFORMANCE **43/50**

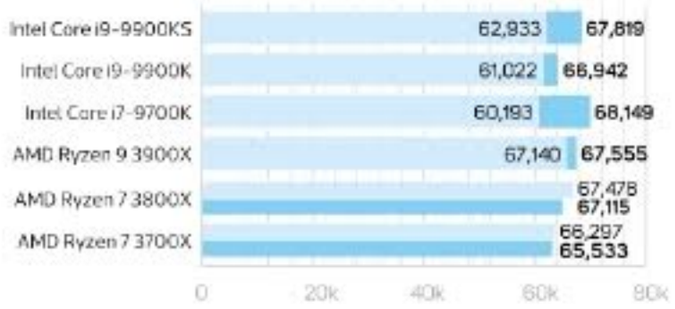
FEATURES **15/15**

VALUE **21/35**

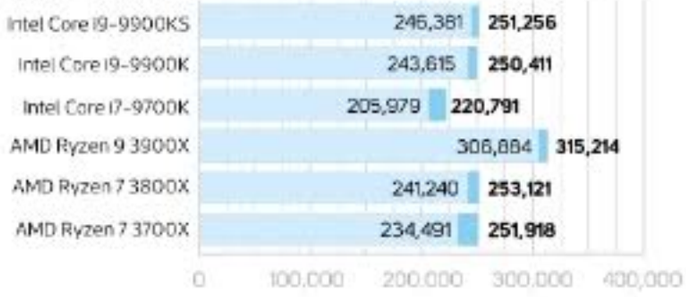
OVERALL SCORE **79%**

INTEL CORE i9-9900KS RESULTS

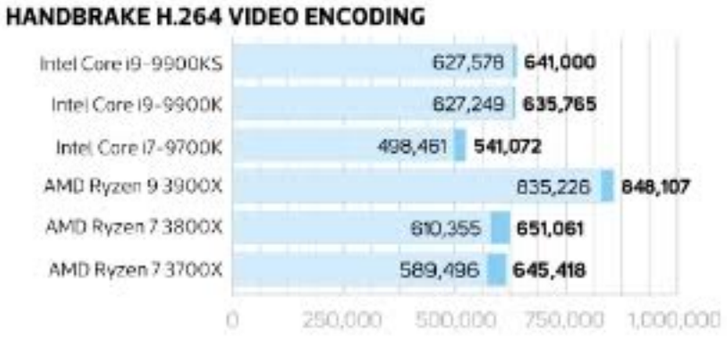
GIMP IMAGE EDITING



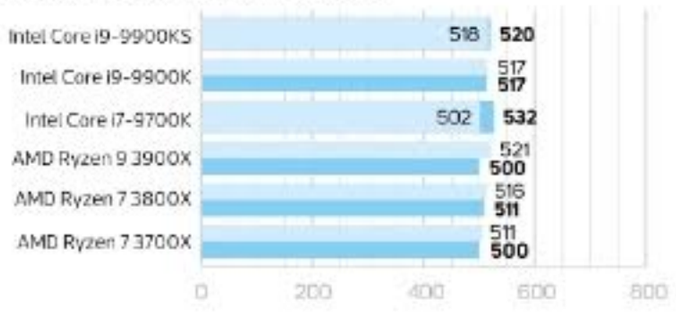
SYSTEM SCORE



HANDBRAKE H.264 VIDEO ENCODING

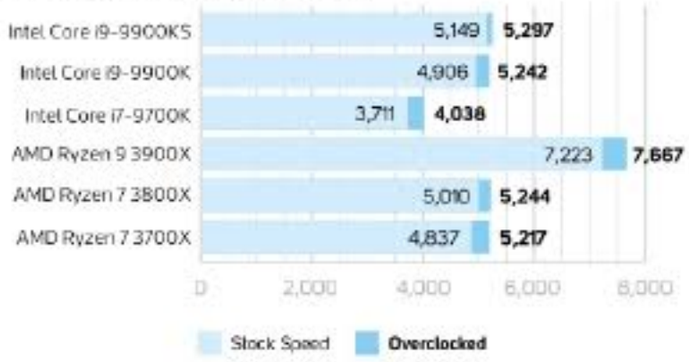


CINEBENCH R20 SINGLE-THREADED



HEAVY MULTI-TASKING

CINEBENCH R20 MULTI-THREADED



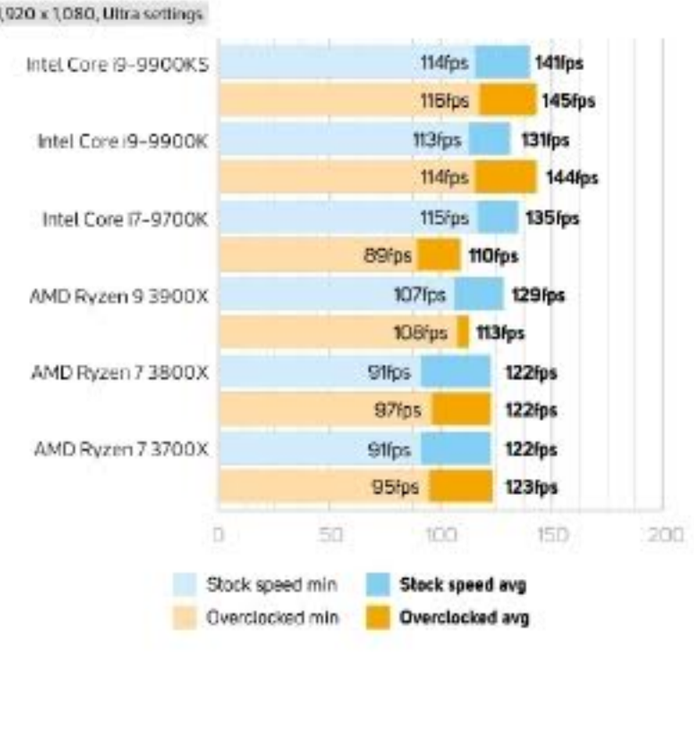
TOTAL SYSTEM POWER CONSUMPTION

Idle

Load

FAR CRY 5

1,920 x 1,080, Ultra settings



ATX CASE

CORSAIR ICUE 465X RGB / £110 inc VAT

SUPPLIER novatech.co.uk

It was only a matter of time before Corsair started incorporating its various RGB-enabled ecosystems into its cases, and the Corsair iCUE 465X RGB is one of the first to include not just a bunch of RGB fans, but also the company's 6-channel Lighting Node Core RGB controller.

However, unlike the Commander Pro controller, there's no fan speed control on offer here, only lighting, so it's not as 'smart' as the likes of NZXT's H500i, which ties all its fans' speeds and RGB lighting into software fan control. Out of the box, the iCUE 465X RGB includes three visibly punchy 120mm LL120 RGB fans all installed in the front fan mounts, which shine through the glass front panel. They can spin up to a reasonably high 1,500rpm, and they remain fairly quiet even at full speed.

In terms of size and features, the case shares much of its design with Corsair's Crystal Series 460X, but the latter is slightly shallower in depth and height. The iCUE 465X RGB's bigger dimensions offer advantages in some areas, but steps backwards in others. For example, the older case had less ventilation at the front – a situation that has been improved this time around, which bodes well for both air and water-cooling systems.

However, the Crystal Series 460X had greater radiator clearance at the front. With the iCUE 465X RGB, you're limited to half-height 360mm or 280mm radiators here, but if you downsize to a 240mm radiator in this location, it will clear the PSU cover, which was partly removable on the older case. There's also room to mount a pump and reservoir combination on a 240mm radiator in the iCUE 465X's front mount, although you could also do this on the bottom mount of a 360mm radiator in the Crystal 460X.

Meanwhile, the roof section has space for two 120mm fans or a single 140mm fan, again with the possibility of installing half-height radiators, which Corsair uses on most of its all-in-one (AIO) liquid coolers. Its water-cooling options might not be as flexible as those of the Crystal 460X, but there's still plenty of room for water-cooling gear. The rear fan mount only offers space for 120mm fans, but lacks a rear fan out of the box – this case is clearly designed for positive airflow.

The case has plenty of dust protection too, with filters covering the PSU intake and front intake. You can access the latter by removing four screws on the front, and lifting off the glass panel to reveal the filter and fan mounts. The roof is also equipped with a magnetic mesh filter. Screws also hold the side glass panel in place but, given the price, we'd expect a more convenient hinged design here.

Get inside, and you'll find a spacious interior with plenty of cable-routing holes. Building a system into the iCUE 465X RGB is mostly painless. Once your system is built, the PSU cover offers a good deal of stowage space for cables, but the anchor points behind the motherboard tray employ the usual cable ties, rather than the reusable Velcro straps seen in some Phanteks cases.

SPEC

Dimensions (mm)
216 x 467 x 465 (W x D x H)

Material
Steel, plastic, glass

Available colours
Black, white

Weight
8kg

Front panel
Power, reset, 2 x USB 3, 1x stereo/mic

Drive bays
3 x 2.5/3.5in, 4 x 2.5in

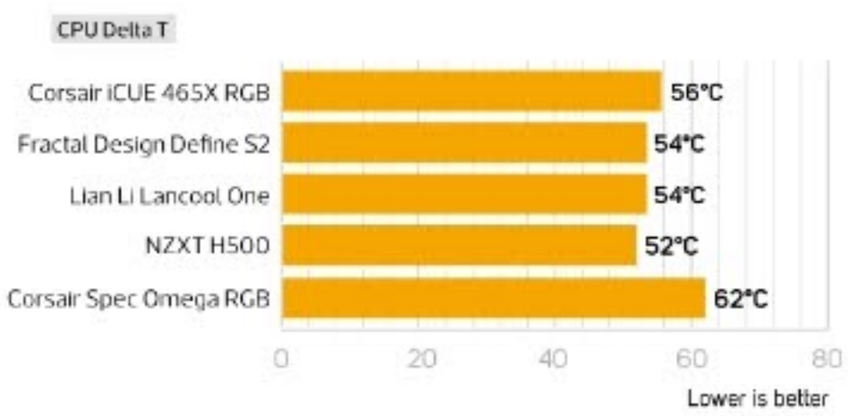
Form factor(s)
ATX, micro-ATX

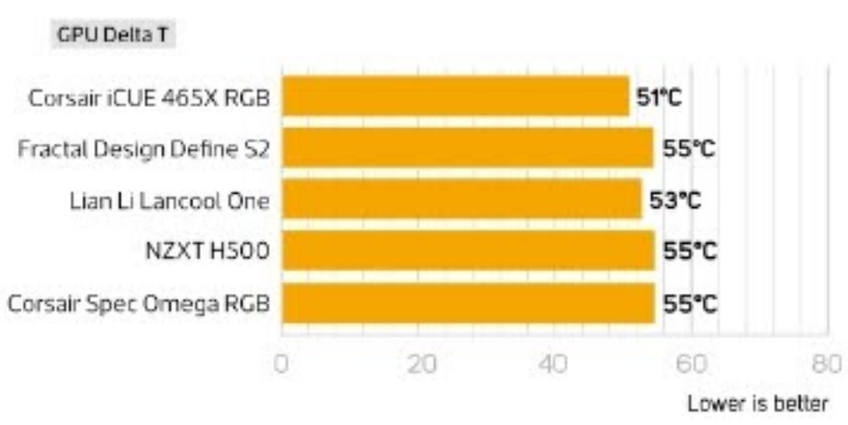
Cooling
3 x 120mm/2 x 140mm front fan mounts (3 x 120mm fans included), 1 x 120mm rear fan mount (fan not included), 2 x 120mm/1 x 140mm roof fan mounts (fans not included)

CPU cooler clearance
170mm

Maximum graphics card length
370mm

TEMPERATURE RESULTS





Meanwhile, the CPU cooler height limitation stands at the same 170mm as the 460X, which covers even exceptionally large air coolers, such as Noctua's NH-D15. There's 370mm of clearance for graphics cards too, which means you'll still have plenty of space even if you add a radiator to the front of the case.

In terms of storage, there are four dedicated 2.5in SSD trays secured using thumb screws, two of which sit behind the motherboard tray, with an additional pair in the side of the case at the front. These mounts, sadly, don't include Corsair's tool-free system that we've seen on previous cases, so you'll need to screw your SSDs to the trays first. There's a cage in the bottom of the case that houses two hard disks too, which doubles as a secondary mount for SSDs.

The Lighting Node Core module sits behind the motherboard tray as well, with the three included 120mm fans already hooked up to it. There are three more spare lighting channels, on it, and the module is powered by a SATA connector, while its data connection comes from a spare USB 2 header. As the lighting control now goes through software rather than a bunch of buttons, the front panel is a trimmed-down version of the one found on the 460X. As such, there's not much else on the front, other than the combined microphone/headphone jack, plus power and reset buttons.

Performance

The 465X's CPU delta T of 56°C was average compared with recent cases we've reviewed, but this figure is undoubtedly down to the lack of a rear exhaust fan, which we know aids cooling with tower air coolers. Cases with a rear fan, such as the Fractal Design Define S2 and Lian Li Lancool One, all performed slightly better. However, the 465X's trio of front fans and improved ventilation did give it an edge over some other cases with closed front panels, such as the Lian Li Alpha 550X and Corsair Spec Omega RGB. The GPU delta T benefited from those fans too, with the 465X's 51°C result being a few degrees lower than that of the Fractal Design Define S2.

Conclusion

With the addition of a rear exhaust fan, the iCUE 465X RGB would offer top-notch cooling for both the CPU and GPU, but as it stands, it's still a good case for the cash. There's plenty of scope for installing AIO liquid coolers or fully fledged water-cooling systems, and the lighting looks fantastic. The latter ties into Corsair's ever improving software, and the inclusion of three premium 120mm fans as standard is great too.

Unlike other cases of its size and price, there's a little extra CPU cooler clearance if you're a fan of big tower coolers too. It does have some shortcomings, though, including the lack of software fan control, limited room for hard drives and the inability to remove part of the PSU cover. Its familiar design is also unremarkable, showing not much innovation since previous Corsair cases. However, it's still a good case for the money, especially if you add an exhaust fan.

ANTONY LEATHER

CUE

- + Good cooling
- + Software-controlled lighting
- + Decent water-cooling support

QUEUE

- – Average storage options
- – Not particularly innovative
- – No software fan control

COOLING 26/30

FEATURES 16/20

DESIGN 25/30

VALUE 17/20

OVERALL SCORE 84%

VERDICT

Software-controlled RGB lighting and plenty of cooling options, but it's a little unremarkable.

ATX CASE

BE QUIET! PURE BASE 500 / £72 inc VAT

SUPPLIER aquatuning.co.uk

Despite being a relative newcomer to the case scene, and one that doesn't have a large number of models to its name, be quiet! has consistently tried to tweak its case designs to offer new and interesting features. The Pure Base 500 might seem too cheap at just £72 to include much beyond the basics, but it turned out to be refreshingly different compared with the usual bland budget boxes. For starters, it includes a top vent cover that can sit in place for a clean look, or be removed to allow for better airflow, especially if you plan on installing a radiator in the roof.

The case sports what appears to be brushed aluminium on the front panel, but it's actually carefully crafted plastic. It's available in black and white, and the front panel's curved edges make it look quite striking, plus there are both solid or glass side panel options.

Meanwhile, there are noise-absorbing materials in the side panel, roof panel and front section – a feature you'd expect on more expensive cases, and inside there's an innovative cable cover that hides much of the mess passing through the motherboard tray to the ports on the motherboard. As well as the cable cover, you get large Velcro cable ties to anchor big bunches neatly, plus a handful of plastic ties to deal with smaller cables. Combined with a decent amount of clearance between the side panel and motherboard tray, the Pure Base 500 does its best to help you tidy those cables.

It's clearly a well thought-out design, and there's plenty of space for your hardware too. It has 190mm of CPU clearance, which is largely down to a hefty width of over 230mm, and there's nearly 370mm of GPU clearance. As an added bonus, be quiet! has sensibly left out a portion of the PSU cover at the front to allow for large radiators to be installed.

There aren't many other unique or premium features, though, with the usual audio mini-jacks and a pair of USB 3 Type-A ports on the front panel. There's also no RGB lighting, but be quiet! does include a pair of 140mm Pure Wings 2 fans acting as an intake and an exhaust. However, they only spin at a rated maximum of 900rpm, so while they're also extremely quiet at full speed, they don't shift much air.

In terms of storage, there are four dedicated 2.5in SSD mounts spread across two plates – one behind the motherboard tray, and the other being a part of the cable cover. They're fairly basic, with four screws required per SSD and nothing more elaborate to mount them.

SPEC

Dimensions (mm)
216 x 450 x 463 (W x D x H)

Material
Steel, plastic, glass

Available colours
Black, white

Weight
8kg

Front panel
Power, 2 x USB 3, 1x stereo/mic

Drive bays
2 x 2.5/3.5in, 4 x 2.5in

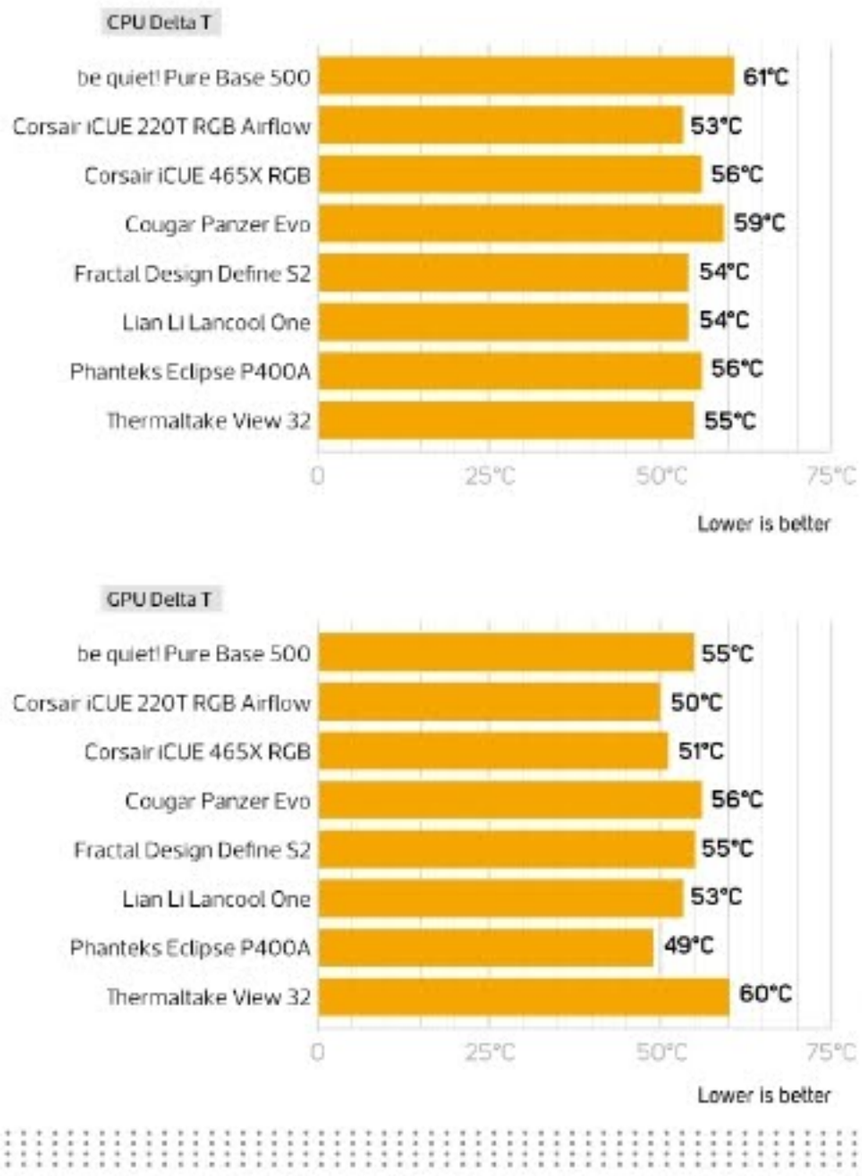
Form factor(s)
ATX, Micro-ATX

Cooling
3 x 120mm/ 2 x 140mm front fan mounts (1 x 140mm fan included), 1x 120/140mm rear fan mount (140mm fan included), 2 x 120mm roof fan mounts (fans not included)

CPU cooler clearance
190mm

Maximum graphics card length
369mm

TEMPERATURE RESULTS



There's also a removable, noise-dampened 3.5in hard disk cage in the base. If you're planning to use more than two hard disks, though, there's no option to upgrade or add another cage. Removing the cage allows for a 360mm radiator to be installed in the front fan mounts, which support either three 120mm fans or two 140mm fans, as well as 240mm and 280mm radiators. The roof is limited to a 240mm radiator, but that's fairly typical in this price league.

Finally, to protect the interior from dust there's a large pull-out filter in the base, plus two layers of filters in the sides of the front panel. The latter pops off easily for cleaning and provides access to the fan mounts behind it. However, the vents here are quite small, and airflow is further hampered by excessive layers of filtering.

Performance

This minimal venting, combined with the slow-spinning fans, impacts on the CPU cooling. The Pure Base 500's delta T of 61°C is getting on for 10°C warmer than the better-performing cases we've seen, such as the Corsair iCUE 220T RGB Airflow. Even the airflow-restricted Corsair iCUE 465X RGB beats this result by 5°C.

The GPU delta T was much more competitive, likely helped by the front fan directing airflow at our graphics card. The result of 55°C was still no match for the Corsair iCUE 220T RGB Airflow or Phanteks Eclipse P400A, though, which managed 50°C and 49°C respectively. Again, the Corsair iCUE 465X RGB also managed to knock 4°C off the delta T of be quiet! case.

As we suspected, though, the case was far quieter than any other fan-equipped cases we've tested recently.

Removing the top vent cover also shaved 5°C off the CPU delta T, so while the case looks sleeker with it installed, it definitely hinders cooling.

Conclusion

That mediocre CPU cooling result is certainly a concern for air-cooled systems, especially those looking to cool an overclocked CPU using a modest air cooler. In fact, it's likely even a high-performing air cooler will be hampered here. That's a shame, even with the super-low noise levels on offer. Meanwhile, the GPU delta T is acceptable, but not brilliant. Basically, the Pure Base 500 sacrifices airflow and cooling for lower noise levels.

It's also easy to work with this case, it has a reasonable amount of storage options, good water-cooling support and it has excellent cable-tidying features. Add in the very reasonable price tag, and it's a solid choice for a low-noise system, as long as you're not overclocking an air-cooled CPU, or if you're using a liquid cooler for your CPU. The latter will be less reliant on your case's airflow and the weak rear cooling fan. Shifting the rear fan to the front and adding a more powerful rear fan would likely improve this case's airflow dramatically too.

ANTONY LEATHER

VERDICT

A solid low-noise case with some decent features for the money, although its low airflow means it's not for overclocked air-cooled systems.

BE QUICK

+ Unique looks
+ Excellent cable routing
+ Very quiet

BE DEAD

- Meagre CPU cooling
- Low airflow
- Only two hard disk mounts

COOLING **23/30**

FEATURES **16/20**

DESIGN **25/30**

VALUE **18/20**

OVERALL SCORE **82%**

240MM ALL-IN-ONE LIQUID COOLER

ARCTIC LIQUID FREEZER II 240 /

£65 inc VAT

SUPPLIER scan.co.uk

We were big fans of ARCTIC's last foray into liquid cooling, with the Liquid Freezer 120 grabbing the top spot in several group tests with its low price, quiet operation and good cooling. With the original Freezer line of liquid coolers now end-of-life, ARCTIC has finally ushered in a new range of liquid coolers, rather unimaginably called the Liquid Freezer II series.

There are more models this time, with 120mm, 240mm and 360mm radiator models covering 120mm fan sizes, but the Liquid Freezer II 280 also covers 140mm fan sizes. We're looking at the Liquid Freezer II 240, which costs £65 inc VAT – a very reasonable price for a 240mm all-in-one (AIO) liquid cooler. The 120mm version costs under £50 inc VAT too, so it seems ARCTIC is maintaining its great value here.

The Liquid Freezer II range also keeps its thicker than average radiators. At 38mm thick, they're certainly beefier than your typical AIO liquid cooler – Corsair's H100i RGB Platinum is only 27mm thick, for example. However, they're not as large as that on the old Liquid Freezer 120, which sat at 49mm thick. Of course, thicker isn't always better – it takes far more static pressure and airflow to reach efficient thermal transfer in thicker radiators, requiring high-power fans or multiple rows of fans for the most effective performance.

With a 38mm-thick radiator, ARCTIC is going for a happy medium, shaving a centimetre off the depth and allowing the two included fans, which can spin up to 1,800rpm, to work more effectively throughout their speed range, but in particular at lower speeds. You'll have to check if your case has enough clearance to house its thickness, although the length of 277mm is typical, and identical to that of the Corsair H100i RGB Platinum.

Meanwhile, the fans are from ARCTIC's P-fan range and sport a reasonable claimed static pressure of 2.2mm H20. However, just as importantly, hearing them isn't unpleasant at full speed, unlike the monstrous noise from the 2,400rpm fans included with Corsair's cooler at top speed. At lower speeds the cooler drifts back to practically inaudible sound levels, and the pump is exceptionally quiet too.

The pump looks a little like it has a missing fascia and an exposed impeller, but those blades are actually part of an integrated fan that dishes out air to cool your motherboard's VRMs. Thankfully, it was barely audible even at full speed, but it didn't seem to shift a great deal of air. Even so, the VRMs on our LGA2066 motherboard took noticeably longer to reach a peak temperature of 89°C with this impeller, although they did still hit that temperature after our lengthy stress test.

At this price, though, it's a welcome if slightly limited feature. The pump and fans are all PWM-controlled and ARCTIC has also wired the pump and radiator fans together, routing the cables within the braided tubing. This means you just need to

SPEC

Compatibility
Intel: LGA2011/v3, LGA2066, LGA115x; AMD: AMD: Socket AM4, AM3/+, AM2/+, FM2/+, FM1

Radiator size with fans (mm)
120 x 277 x 63 (W x D x H)

Fans
2 x 120mm

Stated noise
0.3 Sone

connect a single 4-pin connector to your motherboard to control all three parts, which is a huge benefit when it comes to cable tidying. However, if you prefer to control them separately, the fan cables can be detached on the radiator where they link up with the pump section.

Installing the pump is fairly easy. Two plates attach to the pump and are secured by pins or thumbscrews to the motherboard, depending on your CPU socket. Both methods were a little fiddly compared with the usually spacious designs on Corsair and NZXT coolers with their larger thumbscrews, but it was still straightforward enough, and we had the cooler up and running on all our test systems within a few minutes.

Performance

Our AMD test system showed some stellar cooling using the Liquid Freezer II 240, with a delta T of 45°C. This figure is just behind the monstrous Corsair H100i RGB Pro, which has much faster-spinning fans and a much higher price. It was also 2°C cooler than the Deepcool Castle 240.

We've recently updated our LGA1151 system to use a Core i5-9600K since we last tested any other 240mm liquid coolers, so we only have results for a smattering of other coolers. However, the Liquid Freezer II 240 was still significantly cooler than the Deepcool Gammaxx GT BK air cooler and only a few degrees warmer than the mighty Corsair H150i RGB Pro and NZXT Kraken X72. That said, the Corsair cooler was quieter at full speed.

It was a similar story in our LGA2066 system, which is the socket with the easiest mounting system for this cooler. With our overclocked Core i9-7900X, the CPU delta T of 56°C slipped a little compared with the pricier and more powerful 240mm coolers we've tested. The H100i RGB Pro was 2°C cooler while the EK Water Blocks Phoenix 240 was 5°C cooler. However, the ARCTIC cooler was still 2°C cooler than the Deepcool Castle 240, punching well above its price tag while remaining reasonably quiet at full speed.

Conclusion

We're pleasantly surprised by the ARCTIC Liquid Freezer II 240. Its deceptively low price tag hides an excellent 240mm AIO liquid cooler in terms of noise and price. Build quality is on a par with the competition, it's quiet at low loads and not too loud at full speed. The VRM cooling fan is also a non-issue sound-wise, although it's only modestly effective. You have to spend considerably more money to get lower noise or better cooling too. If you're on a tight budget, we thoroughly recommend the Liquid Freezer II 240. If you don't need RGB lighting, software control or an expandable loop, it's a no-brainer for CPU cooling.

ANTONY LEATHER

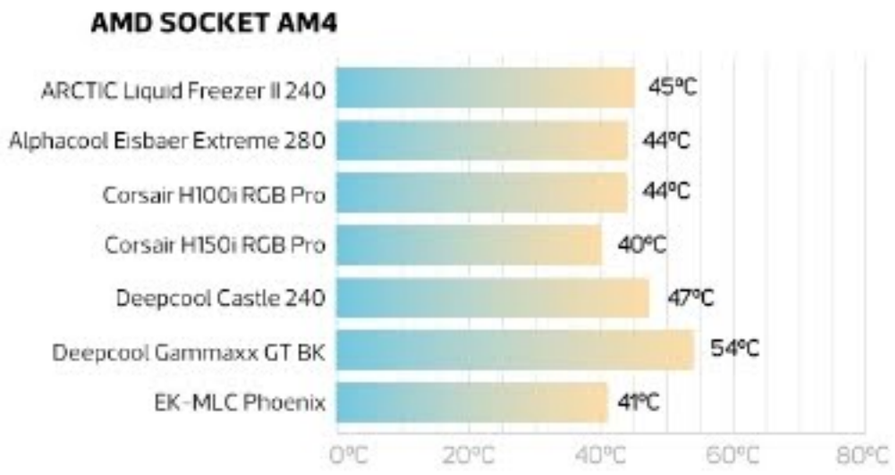
AURORA BOREALIS

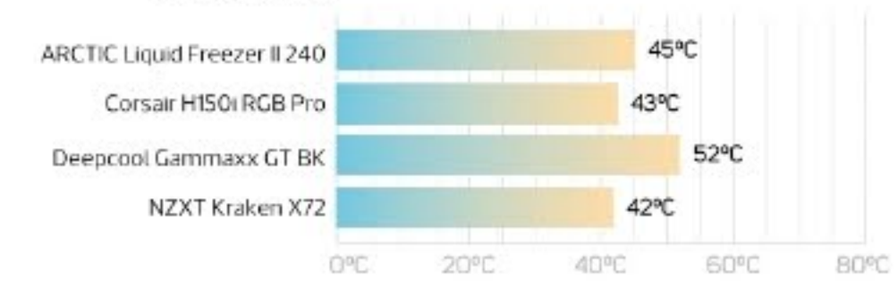
- \+ Excellent cooling
- \+ Single cable for fans and pump
- \+ Low price

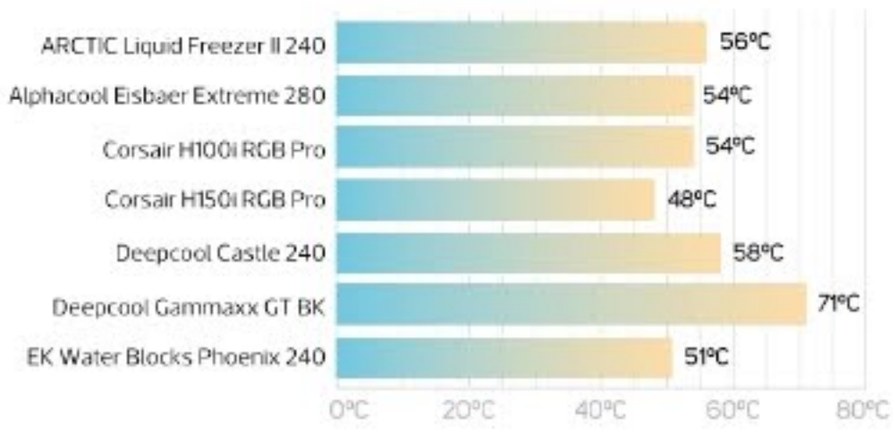
LIGHT POLLUTION

- – Radiator height might cause issues
- – VRM fan doesn't make huge difference
- – Larger coolers are quieter at high loads

TEMPERATURE RESULTS







LGA115x	LGA2066	AM4
FITTING: Easy	FITTING: Easy	FITTING: Easy
COOLING: 37/40	COOLING: 35/40	COOLING: 37/40
FEATURES: 16/20	FEATURES: 16/20	FEATURES: 16/20
DESIGN: 17/20	DESIGN: 18/20	DESIGN: 17/20
VALUE: 19/20	VALUE: 18/20	VALUE: 19/20
OVERALL SCORE: 89%	OVERALL SCORE: 87%	OVERALL SCORE: 89%

VERDICT

Easy to install, great cooling across the board and a very reasonable price.

PC Specialist recommends Windows Windows 10

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M.2

- + Consistently decent performance
- + Wide range of capacities
- + Excellent value

M25

- − Mediocre maximum read speed
- − Dull design

Kingston's new M.2 SSD is the latest drive to push the cost of entry into ultra-fast NVMe SSDs ever lower. The 1TB drive we're reviewing here costs just £108 inc VAT, making it just about the cheapest 1TB NVMe drive you can buy, costing nearly £100 less than the priciest options.

So, what do you give up in terms of speed and features for that low price? Well, surprisingly little. Sure, the peak rated speed of this drive tops out at 2,200MB/sec, compared to over 4,000MB/sec for the very latest PCI-E 4 drives. However, the Kingston's performance is still in the same ballpark as many other cheaper NVMe drives. For instance, the WD Blue tops out at just 1700MB/sec, although the WD Blue's capacity is limited to 500GB, so you might expect it to be a little slower.

What's more, the Kingston's 2,000MB/sec rated write speed is quicker than that of several other options, including Intel's 760p, and it matches the excellent Corsair MP510 in this respect. As you'd expect, there's very little in terms of physical features here, with no extras included in the box.

There are slightly smarter-looking drives, in terms of PCB colour and sticker style, but that's a minor consideration for such a small device, and you can always put a heatsink on it anyway.

As for internal features, the drive is based on the Silicon Motion SMI SM2263ENG, which is a quad-channel controller that offers XTS-AES 256-bit drive encryption. Meanwhile, the flash memory is Micron's latest 96-layer 3D NAND, which is configured to operate in a TLC mode. That's where three bits of information are stored in each cell, making for a higher data density. As ever, this means you're dealing with a drive that has lower write endurance than more premium options, but Kingston still rates this 1TB model as lasting for up to 600TBW, which will be plenty for most home users. You also get a five-year warranty.

The drive uses an SLC cache to achieve its peak write speed performance, and while Kingston hasn't specified the size of the cache, we saw the write speed drop to 500MB/sec after 150GB had been written continuously to the drive. Again, though, we considered that performance to be more than ample for home use.

In our own peak speed tests, the A2000 put in a solid performance, delivering 2,282MB/sec read and 2,190MB/sec write in the sequential speed test of CrystalDiskMark. Likewise, AS-SSD showed figures of 2,041MB/sec and 1,969MB/sec for its similar tests. This puts the drive behind the fastest drives in terms of read speeds, but its write speeds are still very strong.

This drive continued to impress when we tested random speeds. In CrystalDiskMark's 4K Q32 test, it delivered 290,036IOPs read and 289,429IOPs write. Meanwhile, in AS-SSD's similar test, it delivered 281,676IOPs read and 285,059IOPs write. These are all figures that compare very favourably with other drives in this price range.

If you've already taken the plunge on an NVMe M.2 drive then the Kingston A2000 doesn't bring anything particularly new to the table. However, it's a great option if you want an affordable upgrade to an old SATA SSD, or if you're building a new PC from scratch.

SPEC

Capacity
250GB, 500GB, 1TB

Interface
M.2 PCI-E 3

Protocol
NVMe

NAND
Micron 96-layer, 3D TLC

Controller
SMI SM2263ENG

Endurance
150TBW, 350TBW, 600TBW

Warranty
Five years

Extras
XTS-AES 256-bit encryption

Conclusion

The Kingston S2000 isn't the fastest or most capacious SSD ever, but it offers solid performance that's a good step up from SATA SSDs, while also providing enough capacity for a data-packed modern PC. The key, though, is the price, which undercuts just about all the similar contenders by a comfortable margin.

EDWARD CHESTER

VERDICT

With solid performance for a generous price, the A2000 is the new budget M.2 NVMe SSD champion.

PERFORMANCE **37/50**

£/GB **19/20**

BANG/BUCK **27/30**

OVERALL SCORE **83%**

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SCAN

43IN GAMING MONITOR

ASUS ROG STRIX XG438Q / £1,112 inc VAT

SUPPLIER overclockers.co.uk

Asus' ROG Strix XG438Q is a 43in monster with a broad feature set. It has a 4K VA panel with a 120Hz refresh rate and AMD FreeSync 2 support. It deploys DisplayHDR 600, and it claims support for 90 per cent of the DCI-P3 gamut. The panel delivers a 102ppi pixel density, which is still great for gaming, despite not matching smaller 4K screens. Meanwhile, the response time is rated at a reasonable 4ms, which is fine for anyone except competitive esports players.

Its size is overwhelming up close, but it's comfortably immersive if you're laying back on a sofa. The Asus has three HDMI inputs and one DisplayPort connection. The latter is required to run the 4K panel at 120Hz or with HDR, and in these modes, you're restricted to 8-bit colour – if you want 10-bit colour, you'll need to dial back the refresh rate.

Unusually, the XG438Q also uses an underlying BGR pixel layout, rather than RGB. From a distance you don't notice the difference, but it makes small on-screen text on white backgrounds look blurry up close. You can correct the blurriness to a degree by enabling ClearType, but this isn't a monitor for word processing.

The Asus is more comfortable being used like a TV from a distance, and it looks the part with its wide feet and deep frame. Build quality is great, but it's not small – it weighs 15.3kg and measures 975mm wide. Connection options are fine, with audio jacks and two USB ports, while the stereo 10W speakers have ample volume and punch.

Adjustment options are limited though – there's tilting and VESA 100 support but that's it. Meanwhile, display tweaks are made using Asus' usual, well-organised OSD. The conventional joystick is tricky to use on a display this size, so Asus also allows adjustment with a Windows app and a neat remote control.

Aside from text, image quality is impressive. In its default Racing mode, the Asus served up a stunning peak brightness of 412cd/m^2 and a black level of 0.11cd/m^2, creating a contrast ratio of 3,745:1. That's slightly below Asus' quoted 4,000:1, but it's high enough to deliver vast depth and punch. The 1.96 delta E means accurate colours, the colour temperature of 6,208K is solid and the panel delivered near-perfect Gamma. What's more, the Asus handled 99.9 per cent and 91 per cent of the sRGB and DCI-P3 gamuts, so it has excellent colour reproduction.

Enabling HDR ramped up the Asus' brightness to around 650cd/m^2, which means more high-end punch, but the black level hovered around 0.32cd/m^2. As such, while HDR content looks reasonable, and better than on most gaming screens, it doesn't have as much contrast and depth as a proper HDR TV. Not surprisingly, this large screen also has mediocre uniformity. The panel lost up to 20 per cent of its backlight strength on the left edge, and nearly as much on the right edge. Still, that won't have a huge impact on gaming, especially if you're sitting further back.

SPEC

Screen size
43in

Resolution
3,840 x 2,160

Panel technology
VA

Active sync
AMD FreeSync 2

Maximum refresh rate
120Hz

Response time
4ms

Contrast
4,000:1

Display inputs
1 x DisplayPort 1.4,
3 x HDMI 2

Audio
2 x 10W speakers

Conclusion

The Asus ROG Strix XG438Q combines great image quality with a 120Hz refresh rate and a high resolution. Its huge size makes for an imposing, immersive experience, and it enables you to sit further away from the screen. Text reproduction is poor, though, and its uniformity and HDR implementation are only middling. Still, the XG438Q is one of the few panels to deliver a big-screen 4K 120Hz experience. It's not for everyone, but it's a cracking gaming screen.

MIKE JENNINGS

DYNAMIC

- + Vast 4K panel
- + Great core image quality
- + 120Hz refresh rate

DULL

- – Extremely expensive
- – Blurry text
- – Middling HDR options

VERDICT

A huge gaming screen with great features and image quality, but this expensive display won't suit everyone.

IMAGE QUALITY **48/55**

FEATURES **14/15**

VALUE **21/30**

OVERALL SCORE **83%**

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A CORSAIR VIRTUOSO RGB WIRELESS SE HEADSET

Our pals at Corsair are kindly offering our favourite wireless gaming headset to one lucky **Custom PC** reader this month. The Corsair Virtuoso RGB Wireless SE delivers a high-fidelity audio experience, all-day comfort from its premium memory foam earpads, and hyper-fast connectivity with Slipstream wireless technology.

Uncompromising sound quality

From the lightest footstep to the deepest bass tone, you'll hear more of everything with the Virtuoso RGB Wireless. A matched pair of precisely tuned 50mm high-density neodymium drivers boast a frequency range of 20-40,000Hz – double what you'd get from most gaming headsets.

Comfort is king

The Virtuoso Wireless SE comes with premium memory foam earpads that conform to the shape of your head, along with a lightweight headband. It delivers pillow-soft, long-lasting comfort, enabling you to play for hours on end.

Premium lightweight construction

Machined aluminium construction means the Virtuoso RGB Wireless offers a perfect blend of lightweight design, strong durability and maximum comfort.

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Competition closes on Friday, 6 December. Prize is offered to participants in the UK aged 13 or over, except employees of the Raspberry Pi Foundation, the prize supplier, their families or friends. Winners will be notified by email no more than 30 days after the competition closes. By entering the competition, the winner consents to any publicity generated from the competition, in print and online. Participants agree to receive occasional newsletters from Custom PC magazine. We don't like spam: participants' details will remain strictly confidential and won't be shared with third parties. Prizes are non-negotiable and no cash alternative will be offered. Winners will be contacted by email to arrange delivery. Any winners who have not responded 60 days after the initial email is sent will have their prize revoked.

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GAMING LAPTOP

RAZER BLADE 15

/ **£2,530** inc VAT

SUPPLIER razer.com

Razer's latest Blade 15 doesn't initially look hugely different from its stunning predecessor, but there are significant internal changes. The 1080p IPS display has undergone a huge upgrade – it's now available with a 240Hz refresh rate. That makes it one of the fastest laptop panels in the world, and it makes the Blade a great option for esports.

While a 240Hz screen is impressive, though, it's also overkill for lots of players. This screen also doesn't have Nvidia G-Sync, so you still get occasional tearing artefacts. The upgraded screen is partnered with a new GPU too though. The RTX 2070 Max-Q includes 2,304 stream processors and 8GB of GDDR6 memory – the same hardware as the full-fat version. However, it has a boost clock of 1185MHz, compared to the desktop GPU's 1440MHz.

There's a new CPU too. The Core i7-9750H uses Intel's Coffee Lake architecture, just like last year's popular Core i7-8750H, and it still has six Hyper-Threaded cores – but its base and boost clocks have been increased from 2.2GHz and 4.1GHz respectively to 2.6GHz and 4.5GHz. Elsewhere, there's 16GB of 2666MHz DDR4 memory, a 512GB Samsung NVMe SSD and dual-band 802.11ax wireless, making the Razer the first laptop we've seen with Wi-Fi 6.

On the outside, the Razer is still hewn from anodised aluminium, and it retains the sleek lines and smart, unfussy design that makes it stand out from the excessive competition. There's also a Mercury White finish available for some specs of the Blade 15, which looks great.

The Blade weighs 2.15kg and measures 18mm thick, making it a little heftier than last year's model, but it's still impressively light for the spec. Build quality remains solid too, with hardly any give in the panels. Around the edges, you'll find three USB 3.2 Gen 2 ports and a USB Type-C port that supports Thunderbolt 3. There's also an HDMI output, a mini-DisplayPort connector and a sole audio jack, but sadly no Gigabit Ethernet port.

Meanwhile, the chiclet keyboard remains unchanged. It has per-key Chroma RGB lighting with loads of customisation options, and the lighting can synchronise with other Razer hardware. The buttons only have 1.2mm of travel, providing a fast, light typing action that lacks the weight or snap of more robust units. There's also no numberpad. Then there's the glass touchpad, which is huge and smooth, with a responsive surface. However, the in-built buttons are a little too soft.

As ever, Razer's specification can be customised. There's an option to upgrade further to a GeForce RTX 2080 Max-Q, and add an OLED 4K touch-screen. The RTX 2070 Max-Q version is also sold with 4K and 144Hz display options, while the cheapest options use the GeForce GTX 1660 Ti.

Performance

The RTX 2070 Max-Q is a great companion for a 1080p screen. It played Shadow of the Tomb Raider and Total War: Warhammer with minimums of 64fps and 58fps, and with averages beyond 70fps. It also rattled through Battlefield V at 73fps in DX11 mode, and never dropped below 43fps with ray tracing set to High. It's enough pace to handle demanding single-player games, and it's also enough speed to handle esports games at high frame rates. The processor also handled our benchmarks fine, with solid results in both

SPEC

CPU
2.6GHz Intel Core i7-9750H

Memory
16GB 2666MHz DDR4

Graphics
Nvidia GeForce RTX 2070 Max-Q 8GB

Screen
15.6in 1,920 x 1,080 IPS 240Hz

Storage
512GB Samsung PM981 M.2 SSD

Weight
2.15kg

Networking
Dual-band 802.11ax Wi-Fi

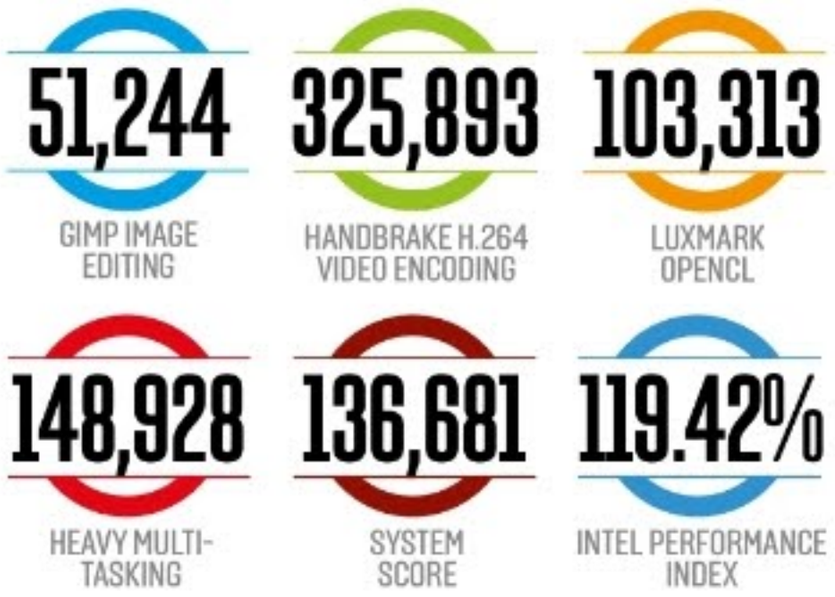
Ports
3 x USB 3.2, 1 x Thunderbolt 3, 1 x mini-DisplayPort, 1 x HDMI 2, 1 x audio jack, Bluetooth 5

Dimensions (mm)
355 x 235 x 18 (W x D x H)

Operating system
Windows 10 Home 64-bit

Warranty
One year parts and labour return to base

BENCHMARK RESULTS



SHADOW OF THE TOMB RAIDER

TOTAL WAR: WARHAMMER II

BATTLEFIELD V

our single-threaded image editing test and heavily multi-threaded Handbrake test.

It's not a clean bill of health though. The Core i7-9750H should achieve a peak speed of 4GHz across all cores, but it sometimes throttled to speeds between 2.5GHz and 3.2GHz, with its scores sitting a little behind what we expect from this CPU – we've seen Handbrake results around 50,000 points ahead from competing machines using the older (and lower-clocked) Core i7-8750H.

The screen impresses, though. Its brightness level of 333cd/m^2 is high enough to handle any task, and the black level of 0.27cd/m^2 is low enough to give games sufficient depth. The contrast ratio of 1,233:1 is good too, providing great punch and vibrancy. The delta E of 1.91 is excellent, and it means colours are accurate – although the colour temperature of 8,560K is a little chilly, but you don't notice it in general use, and games still look great on this screen thanks to the colours and contrast.

Thermal performance is reasonable too. The Blade did produce noise during gaming, but it's a little quieter than last year's model and you'll easily drown it out with a headset. Similarly, while the metal on the outside does get warm during gaming, the heat levels aren't dangerous and they're a little cooler than last year. The CPU and GPU delta Ts of 57°C and 51°C are fine.

Meanwhile, the speakers have good volume, loads of high-end punch and a strong mid-range. However, bass is weak. One area that hasn't got better, though, is battery life. The Blade lasted around six hours in a low-intensity test, but only 90 minutes when gaming. You'll need to plug it into the mains for a gaming session.

SHARP

- \+ High-quality 240Hz screen
- \+ Fast RTX 2070 GPU
- \+ Robust and stylish design

BLUNT

- – Light and shallow keyboard
- – CPU occasionally throttles
- – High price

Conclusion

Razer has made decent changes to its latest Blade 15. The 240Hz screen offers good quality and sensational speed, and the RTX 2070 Max-Q is fast. It's cooler and quieter than its predecessor, and it still looks fantastic. However, the CPU sometimes throttles, the keyboard is light and shallow, and battery life remains weak.

The price is high too. RTX 2070 Max-Q laptops with bulkier, uglier designs can be found for under £2,000, and 240Hz models can be purchased for around £2,200. Still, the Razer justifies the extra outlay with its slick, lightweight design and a great screen . It's a solid option if you're willing to spend a little extra on a stylish, eye-catching laptop.

MIKE JENNINGS

VERDICT

Great gaming performance in a slick, lightweight package, although you pay a high price for it.

PERFORMANCE **22/25**

DESIGN **23/25**

HARDWARE **22/25**

VALUE **19/25**

OVERALL SCORE **86%**

GAMING PC

STORMFORCE CRYSTAL RTX 2080 SUPER / £1,999 inc VAT

SUPPLIER stormforcegaming.co.uk

The Stormforce Crystal serves up an impressive amount of power for a sub-£2,000 rig. The star piece of silicon is a GeForce RTX 2080 Super GPU, which fully enables every part of Nvidia's TU104 GPU, giving you 3,072 stream processors over the standard RTX 2080's 2,944, as well as two more RT cores.

Another big difference between the two GPUs concerns the 8GB of GDDR6 memory, which has seen a speed increase from 14GHz (effective) to 15.5GHz (effective) for the Super. The card inside the Stormforce machine is an Asus ROG Strix model, which means it has an imposing heatsink filled with RGB LEDs, three fans and an overclock that boosts the GPU boost speed of 1815MHz to 1860MHz. These high-quality Strix cards aren't cheap, and it's great to see one in a machine at this price.

Meanwhile, the Ryzen 7 3700X is fast becoming one of AMD's more popular Zen 2 chips. It has eight SMT-enabled cores, giving it 16 threads, and here, it runs at its stock base and boost speeds of 3.6GHz and 4.4GHz respectively.

All this gear is plugged into an Asus ROG Strix X570-F Gaming motherboard, which brings PCI-E 4 support with the X570 chipset, although the Stormforce's 500GB WD Blue SSD only supports PCI-E 3. There are several spare fan headers, and the rear is well stocked too, with seven USB 3.1 ports and a Type-C connector. You also get a spare M.2 socket, the usual large heatsinks and a bevy of RGB LEDs.

The specification is rounded out with 16GB of 3200MHz DDR4 memory, a 2TB hard disk and a dual-band 802.11ac wireless card. Meanwhile, the 750W FSP PSU has an 80 Plus Silver certification, but it isn't modular.

This system compares well with the Chillblast Fusion Axion (see Issue 194, p34), which arrived with a price of £2,200 inc VAT. That rig had the same processor and motherboard, and broadly the same memory and storage configurations. Crucially, though, the pricier Chillblast only included the original RTX 2080 – not the beefed-up Super version.

The Stormforce is housed in a Cooler Master MasterBox MB520 enclosure, which looks excellent. It has a tempered glass side panel and a plastic front panel with three RGB LED fans, which are synchronised with the lights on the graphics card, CPU cooler and motherboard.

Around the rear, you'll find two 2.5in drive mounts and a 3.5in drive bay, and cables are neat throughout. That said, upgrading won't always be easy, as the large graphics card blocks some of the SATA ports and PCI slots. You'll have to remove this card to add a second M.2 SSD too, because the Asus board has layered heatsinks.

It's also good to see a Cooler Master MasterLiquid ML240L all-in-one liquid cooler, but likewise, its fans and tubing can make it tricky to reach the memory slots. The case's build quality is sometimes inconsistent too. The metal used throughout is strong, but the plastic front panel is flimsy.

Finally, Stormforce's machine has a three year collect and return warranty that covers both parts and labour for the duration, which is a fantastic deal.

Performance

The RTX 2080 Super delivers a solid performance boost over the discontinued RTX 2080, particularly with the Asus overclock. The Stormforce's 42fps minimum in Shadow of the Tomb Raider at 4K was 5fps better than the Chillblast, and it maintained similar leads in Total War: Warhammer II and Battlefield V. The RTX 2080 Super is capable of handling almost any gaming task. Gaming at 1080p and 2,560 x 1,440 is easy for it, and it can cope with some 4K gaming too, although you'll only get beyond a 60fps minimum in top titles if you dial back the graphics settings.

SPEC

CPU
3.6GHz AMD Ryzen 7 3700X

Motherboard
Asus ROG Strix X570-F Gaming

Memory
16GB Kingston HyperX Predator 3200MHz DDR4

Graphics
Asus GeForce RTX 2080 Super

Storage
500GB WD Blue SN500 M.2 SSD; 2TB Seagate Barracuda hard drive

Case
Cooler Master MB520

Cooling
CPU: Cooler Master MasterLiquid ML240L RGB with 2 x 120mm fans; GPU: 3 x 80mm fans; front: 3 x 120mm fans; rear: 1 x 120mm fan

PSU
FSP 750-50ERN 750W

Ports
Front: 2 x USB 3, 2 x audio; rear: 3 x USB 3.2 Gen 2, 1 x USB 3.2 Gen 2 Type-C, 4 x USB 3.1 Gen 1, 1 x Gigabit Ethernet, 1 x optical S/PDIF, 5 x audio

Operating system
Microsoft Windows 10 Home 64-bit

Warranty
Three years parts and labour collect and return

BENCHMARK RESULTS

61,798 GIMP IMAGE EDITING

575,019 HANDBRAKE H.264 VIDEO ENCODING

122,999 LUXMARK OPENCL

235,764 HEAVY MULTI-TASKING

224,295 SYSTEM SCORE

SHADOW OF THE TOMB RAIDER

TOTAL WAR: WARHAMMER II

BATTLEFIELD V

Meanwhile, the Ryzen CPU marginally outpaces equivalent Intel chips in single-threaded tests and is far better in in multi-threaded applications. Its overall score of 224,295 is marginally behind the best results we've seen from this chip, but it's still fast. It has the power to handle any gaming situation alongside everyday computing, content creation and both photo and video work.

Also, while the WD Blue SSD's read and write scores of 1,626MB/sec and 715MB/sec are middling compared with the latest PCI-E 4 drives, it still offers a decent amount of storage space and is quicker than SATA drives. This machine has no thermal issues either. Its CPU and GPU delta Ts of 47°C and 51°C are fine. The Stormforce produces modest fan noise when idle, and it's a little louder when gaming, but the noise is never irritating.

Conclusion

The Stormforce offers an impressive amount of power for just under £2,000. The RTX 2080 Super delivers a reasonable performance bump over the RTX 2080, the CPU is fast and the supporting spec is solid for the money.

On the downside, the large components make internal access tricky and the SSD and PSU could be better, but these are minor complaints. In key areas, the Stormforce delivers great performance at a very reasonable price – it's a fast gaming system with a well-balanced spec.

MIKE JENNINGS

CRYSTAL CLEAR

+ RTX 2080 Super is fast
+ AMD CPU is quick and versatile
+ Decent motherboard and attractive case

MURKY

- Component access sometimes tricky
- SSD and PSU could be better
- Noticeable fan noise

PERFORMANCE 23/25

DESIGN 22/25

HARDWARE 21/25

VALUE 22/25

OVERALL SCORE 88%

VERDICT

Loads of power inside a reasonably built machine with a well-balanced specification.

GAMING PC

WIRED2FIRE PREDATOR

/ £1,299 inc VAT

SUPPLIER wired2fire.co.uk

Wired2Fire's Predator comes kitted out with Nvidia's latest RTX 2060 Super GPU, which improves on the original RTX 2060 by adding 256 stream processors and 2GB of GDDR6 memory, giving it the same 8GB total as several of its bigger siblings in the RTX range. Wired2Fire has used an MSI-made Armor OC card for this machine. As the name suggests, this boosts the GPU's stock 1650MHz boost clock by 30MHz.

The first system we saw with this card, the CyberPower Ultra 5 Super, was cheaper than the Wired2Fire, with a price of £1,179 inc VAT, but the Wired2Fire has a more potent CPU. The AMD Ryzen 7 3700X processor uses the Zen 2 architecture, and has eight SMT-enabled cores (giving you 16 threads), alongside a 3.6GHz base clock and 4.4GHz boost clock. Comparatively, CyberPower's cheaper machine had a Ryzen 5 3600, with two fewer cores and a lesser boost speed.

The Wired2Fire has a marginally better motherboard too. Its MSI B450 Tomahawk Max product looks flashier, with larger heatsinks and a military-style design. It has a USB Type-C port, which the cheaper CyberPower doesn't offer, and an extra RGB LED strip connector as well.

Elsewhere, the Tomahawk has four memory slots, several 1x PCI-E slots and basic Realtek ALC892 audio, and the use of the older B450 chipset means you don't get PCI-E 4 support, unlike the latest X570 boards. Wired2Fire's machine boots from a 500GB WD Black SN750 NVMe SSD, and its read and write speeds of 3,232MB/sec and 1,043MB/sec are still quick enough to ensure consistently fast boot and loading times. The Predator also has 16GB of memory clocked at a solid 3000MHz.

It's all powered by a Kolink Enclave 700W PSU, which has a fully modular design and an 80 Plus Gold efficiency rating – both rarities at this price. CyberPower's cheaper machine made do with a non-modular PSU, with only the entry-level 80 Plus rating. It's a good specification, although the absence of any secondary storage is a little disappointing. Installing a 2TB Seagate Barracuda in Wired2Fire's configurator will add £53 to the Predator's price.

Meanwhile, the Wired2Fire's Phanteks P400A chassis looks good, with a meshed front panel that contains a trio of RGB LED fans, feeding the radiator for the 240mm Cooler Master all-in-one liquid CPU cooler. The side panel is made from tempered glass, the metal used throughout is sturdy and the roof has a magnetic dust filter.

On the inside, there are rubber cabling grommets around the cable-routing holes, neat cabling and a PSU shroud. The Predator is well put together and there's plenty of room to work in the interior. At the rear, there are two tool-free 3.5in bays and two neat 2.5in caddies. The tidy construction continues, with Velcro ties used to lash down cables behind the motherboard tray. This case is better than the cheaper

SPEC

CPU
3.6GHz AMD Ryzen 7 3700X

Motherboard
MSI B450 Tomahawk Max

Memory
16GB Team Group 3000MHz DDR4

Graphics
MSI GeForce RTX 2060 Super

Storage
500GB WD Black SN750 M.2 SSD

Case
Phanteks P400A

Cooling
CPU: Cooler Master MasterLiquid Lite 240 with 2 x 120mm fans; GPU: 2 x 90mm fans; front: 3 x 120mm fans; rear: 1 x 120mm fan

PSU
Kolink Enclave 700W

Ports
Front 2 x USB 3, 2 x audio; rear: 2 x USB 3.2 Gen 1, 1 x USB 3.1 Gen 2, 1 x USB 3.1 Gen 2 Type-C, 2 x USB 2, 1 x Gigabit Ethernet, 1 x PS/2, 6 x audio

Operating system
Microsoft Windows 10 Home 64-bit

Warranty
Two years parts and labour collect and return, followed by three years labour only return to base

BENCHMARK RESULTS

62,440
GIMP IMAGE EDITING

561,525
HANDBRAKE H.264 VIDEO ENCODING

116,437
LUXMARK OPENCL

235,702
HEAVY MULTI-TASKING

220,738
SYSTEM SCORE

SHADOW OF THE TOMB RAIDER

TOTAL WAR: WARHAMMER II

BATTLEFIELD V

CyberPower's Cooler Master box, which had no tempered glass, no rubber grommets and untidy cables.

Wired2Fire's machine also has a better warranty. It's a five year labour deal with two years of collect and return parts and labour coverage.

Performance

At 1,920 x 1,080, the Wired2Fire's overclocked GPU delivered minimums that ranged between 57fps and 82fps, which are great. Those scores mean that any single-player title will run smoothly – and you'll often get beyond 60fps. Undemanding esports games will also likely run at triple-figure frame rates, which is important for high refresh-rate screens.

Dialling the resolution up to 2,560 x 1,440 saw the tweaked RTX 2060 Super run at minimums between 48fps and 58fps, which is perfectly playable. Even enabling ray tracing in Battlefield V is possible on this machine if you enable Nvidia's DLSS anti-aliasing mode. The Wired2Fire's performance was also consistently a couple of frames per second ahead of the aforementioned CyberPower system with its stock speed GPU.

Meanwhile, the Ryzen 7 3700X chip is reliably quick. Its single-threaded performance in GIMP is barely different to range-topping CPUs thanks to its high single-core speeds. In Handbrake, the Wired2Fire's score of 561,626 beat the CyberPower by more than 100,000 points thanks to its two extra cores, and the Wired2Fire's overall score 220,738 is solid. It's a great CPU to see included in a PC at this price.

There are no thermal issues either. The CPU and GPU delta Ts of 41°C and 47°C are fine. Noise levels are reasonable as well – you can hear fan noise during gaming, but the rumble is quiet and not irritating – you'll easily drown it out if you're wearing a headset.

Conclusion

The Wired2Fire Predator is a little pricier than other RTX 2060 Super systems we've seen, but it's still very keenly priced, and the company has used the extra budget wisely to deliver extra quality. The CPU is fast and versatile, and the case and power supply are great for a PC in this price league.

The Predator also provides a solid warranty. Problems are minor, with no secondary storage and the slightly limited motherboard being the only complaints, but you don't get everything you want in a £1,299 PC. The Predator is a high-quality 1080p and 2,560 x 1,440 gaming machine with a well-balanced specification and a very fair price.

MIKE JENNINGS

VERDICT

Solid design and well-balanced components deliver a high-quality gaming system for a very fair price.

VELOCIRAPTOR

+ Good components throughout
+ Excellent warranty
+ Tidy, quiet enclosure

COMPSOGNATHUS

– Cheaper rivals are available
– Relatively limited motherboard
– No secondary storage

PERFORMANCE **23/25**

DESIGN **20/25**

HARDWARE **21/25**

VALUE **22/25**

OVERALL SCORE **86%**

Custom kit

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

HAMSWAN VR HEADSET

/ **£21.99** inc VAT

SUPPLIER amazon.co.uk

The Hamswan is a relatively uncomplicated phone-based VR headset, but has the unusual bonus of coming with built-in headphones. This seems like a relatively minor inclusion, but the reduction in messing about is substantial. The headphones are attached to adjustable arms at the side of the unit, reaching backwards from the viewer, rather than over the top as you might expect for earphones. This keeps them out of the way of the separate strap that holds the unit in place. Keeping these parts separate also reduces faffing with audio outputs.

The viewer itself is remarkably good for the price. The phone is held with a secure folding door, and the headphone cable tucks away when it's not in use but is easily accessible when needed. The door can accommodate a phone even if it's in a case, within reason, and the control buttons and focus dials are all well placed and responsive. The Hamswan puts a simple addition on an established design and delivers it for a fair price.

Virtual ●●●●○ **Virtuous**

KLIM COMFORT LAPTOP COOLING PAD

/ **£25** inc VAT

SUPPLIER amazon.co.uk

The Klim Comfort combines a laptop cooler with a cushion, so you can have your computer comfortably on your lap while still keeping it cool. The Klim Comfort works in this respect, but not convincingly. The 120mm fan at the centre of the pad isn't particularly effective and it's also rather noisy. Plus there's only the one fan and no heat-conducting material, so you don't get much benefit unless all your laptop's air vents are right in the middle.

The cushion is fine and the pad is lightweight plastic, which provides some stability but not a great deal, even with a lip on the bottom edge to prevent your computer from falling off. The Klim Comfort is a decent idea, but it's flawed in the execution.

Cushion ●●○○○ **Beanbag**

ROCCAT SENSE AIMO / £34.99 inc VAT

SUPPLIER en.roccat.org

The Roccat Sense AIMO is an RGB mousepad that has a remarkably low profile for a pad that's largely defined by the inclusion of an array of bright LEDs. The surface is made from soft black cloth with a rubbery back, and it has a compact size, measuring 350 x 250mm with a depth of only 3.5mm. It works great as a fabric mousepad, and it's wrapped in bright, addressable RGB lighting, which is powered by a detachable USB cable and controlled by software on your computer. The sum of these two parts is a mousepad that delivers on what you want from a standard cloth pad, including its flexibility, while also looking the part in an RGB-illuminated desktop setup. It's expensive, but it looks good and works well.

Nonsense ●●●●○ **Sense**

STAGEEK MOUSE JIGGLER

/ **£14.99** inc VAT

SUPPLIER amazon.co.uk

The Stageek Mouse Jiggler is the kind of oddity that only makes sense if you've ever needed such a device. It's a USB-powered small black brick that's around the size of a mouse, with a rubber foot to anchor it on the desktop. When activated, a small dial on its surface rotates through 180 degrees, and then back again a few seconds later. The idea is that if you place an optical mouse on it then it will respond to the movement, so your PC thinks somebody is using it even if you've wandered off.

There are various reasons for needing a placeholder to prevent a computer from being idle, and there are ways to improvise the effect – keyboard macros, weights on keys, the old rubber band on the gamepad stick or just simply tweaking your power settings. However, most of them are a hassle. The Mouse Jiggler might be a weird concept, but it will jiggle your mouse for as long as you need, which is all you can ask from a device designed to jiggle mice.

Idle ●●●○○ **Jiggled**

SOUND BLASTER X3 USB DAC / **£109.99** inc VAT

SUPPLIER uk.creative.com

The Sound Blaster X3 USB DAC takes the concept of an external USB sound card and updates it to the latest generation of Creative's Sound Blaster technology. On a basic level, this means the Sound Blaster X3 DAC provides all the features you'd expect from a good sound card, including speaker outputs, microphone inputs, and optical outputs and headphone outputs, all packaged in what looks like a big desktop volume dial.

Used in this way it provides great sound quality without the need to use interior real estate for a sound card. However, the Sound Blaster goes beyond the norm with its inclusion of Super X-Fi technology, which allows it to adapt the headphone output in real time to create not just the illusion of surround sound, but also other acoustic effects. It effectively recreates the feeling of having a full surround speaker system in the room, without all the setup hassle. The X3 USB DAC is a great option for people who primarily use headphones, and as a solid upgrade on basic motherboard sound hardware.

Sand blaster ●●●●○ **Sound Blaster**

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

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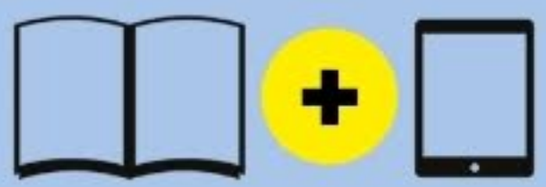

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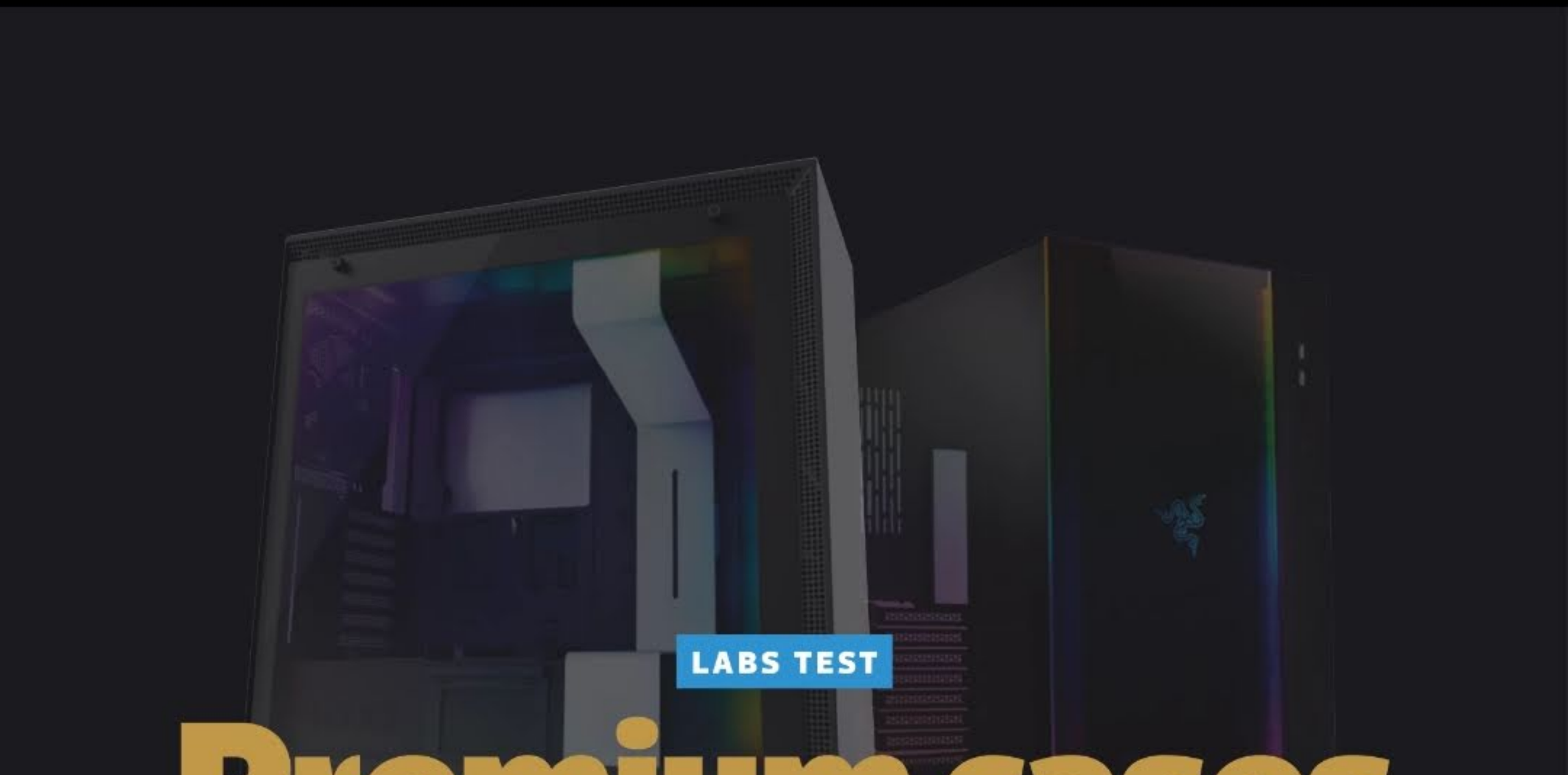


LABS TEST

Premium cases

Antony Leather tests six premium large cases featuring E-ATX support, tempered glass panels, high-end features and plenty of water-cooling potential

How we test

Our case testing method is simple – use real, overclocked hardware in a standard system to see how cases perform in terms of cooling. Our trusty test gear includes an Intel Core i7-870 overclocked to 3.4GHz using a vcore of 1.305V and CPU PLL of 1.9V, plus an AMD Radeon HD 5870 1GB. This is installed in a Biostar TPower I55 motherboard with 4GB of PNY DDR3 memory, a Corsair Force GT SSD and Antec Signature SG-650. It may be old hardware, but it tells us what matters when it comes to a case's cooling performance.

The CPU cooler is a Gelid Tranqullo, which is fairly modest – especially so, given that we've replaced the fan with a slow-spinning Noctua NF-S12B ULN, to really highlight the poorest and best-performing cases. We lock the fan speed at 30 per cent on the graphics card to prevent automatic fan control from interfering with the results. We leave each case for 15 minutes, using Prime95 v26.6's smallfft test (**mersenneforum.org**) to load the CPU and Unigine's Heaven benchmark (**unigine.com/products/heaven**) to load the GPU.

Results were taken from CoreTemp (**alcpu.com/CoreTemp**) and GPU-Z (**techpowerup.com/gpuz**), and we subtract the ambient temperature from the results to give a delta T reading that we can use to test in normal conditions across several days and varying temperatures. We also use a sound meter to help gauge the noise each case makes, so we can comment objectively in the reviews.

We test cases in their standard configuration with the included fans. Adding more fans will obviously improve airflow, but will cost you more. Where fan controllers are included, we test at the highest and lowest fan speed levels to see what impact the different fan speeds have on cooling. We score each case using weighted calculations for their cooling, design, features and value to give an overall score.

Contents

- Cooler Master SL600M / p47
- Corsair Carbide Series 678C / p48
- Fractal Design Vector RS / p49
- Lian Li PC-O11 Dynamic Razer Edition / p50
- NZXT H700i / p51
- Phanteks Enthoo Lux 2 / p52

Cooler Master MasterCase SL600M / £167 incVAT

SUPPLIER ebuyer.com

Externally, the MasterCase SL600M doesn't look significantly different to Cooler Master's other large tower cases, but inside it couldn't be less similar.

The case features a rotated airflow design, with no fans or even fan mounts at all in the front or rear of the case. Instead, there's a plethora of base and roof mounts, with a pair of 200mm fans included as standard and mounted in the base. It's a curious arrangement, not least of all because the hardware hasn't also undergone the same rotation.

As a result, the chimney-effect airflow system will be at odds with the usual direction of airflow for your tower heatsink CPU cooler and the one we have mounted to our test gear, so if you'll be air-cooling your system in this case, you'll want to point the CPU cooler at the roof instead of the rear of the case.

The MasterCase SL600M feels strikingly premium with aluminium panels and huge tempered glass side windows. In addition, you get USB 3.1 support and a 4-speed fan controller on the front panel, making it one of just two cases to offer fan control this month.

SPEC

Dimensions (mm) 242 x 544 x 573 (W x D x H)

Material Aluminium, steel, tempered glass, plastic

Available colours Silver

Weight 13.4kg

Front panel Power, reset, 2 x USB 3, 2 x USB 2, 1 x USB 3.1 Type-C, audio jacks

Drive bays 4 x 2.5in/3.5in, 4 x 2.5in

Form factor(s) Micro-ATX, ATX, E-ATX

Cooling 3 x 120/2 x 140/200mm base fan mounts (2 x 200mm fans included), 3 x 120/2 x 140/200mm roof fan mounts (fans not included)

CPU cooler clearance 191mm

Maximum graphics card length 318mm

Rather at odds with the airflow arrangement is a large aluminium roof panel. This can be removed if you need to boost airflow, which would be especially important if you want to install a radiator here, as using just the mesh underneath would drastically reduce resistance.

With the panel in place there are wide gaps around the edges, though, so some airflow is maintained if you'd prefer to keep the sleek aesthetics. Thankfully, as this is the main airflow intake, the lower fans are protected by a monster dust filter that pulls out from the rear of the case.

Like all cases this month, the MasterCase SL600M offers E-ATX support, but only up to a width of 271mm and here some of the cable routing holes will be blocked too. The PSU is squeezed into a box at the front of the case, which proved a bit tricky to deal with, but does a great job of keeping everything neat and tidy.

Something we particularly liked was the inclusion of two multi-function plates that allow pumps, SSDs or hard disks to be positioned in various locations in the chassis. In total, there's four 3.5in/2.5in storage mounts with four dedicated 2.5in mounts too. Both ranks of fan mounts can fit three 120mm or two 140/200mm fans with up to 280mm or 360mm radiators supported too.

The chimney-effect airflow arrangement worked well with this case providing the second-best CPU delta T on test (59°C) and the best GPU delta (48°C), trading places with the NZXT H700i, which offered a brilliantly low CPU delta T. Despite this, the MasterCase SL600M also maintained very low noise levels, with just a few degrees added to each result on the low fan speed setting.

ANODISED ALUMINIUM

- \+ Great air cooling
- \+ Decent potential for water cooling
- \+ Attractive design

PIG IRON

- – Unique layout and fittings can be fiddly
- – Lacks features compared with the competition
- – CPU cooler needs to be mounted vertically

Conclusion

The excellent cooling certainly helps Cooler Master to an award, and for an understated, sleek build, it fits the bill more than any other case here too. The MasterCase SL600M lags behind in some aspects of design and features compared with similarly priced alternatives, but it still comes highly recommended.

VERDICT

A stunning large chassis that can capably house an air or water-cooled PC.

COOLING	FEATURES	OVERALL SCORE
28/30	15/20	83%
DESIGN	VALUE	
23/30	17/20	

CORSAIR CARBIDE SERIES 678C / £150 inc VAT

SUPPLIER ebuyer.com

Rather than go all-out with clear panels and RGB lighting, the Corsair Carbide Series 678C goes down the same path as the Cooler Master MasterCase SL600M, with an understated design, unassuming closed front end and no RGB LEDs in sight. It also has noise-dampened roof, front and side panels, with the former being removable to boost airflow and the latter sitting in a swing-open door.

It's the first case that we've seen in a while to sport a 5.25in bay, which can be reached behind the front door. These bays can detract from the overall look of a case and limit its other storage options, but this case hides it well and you still have plenty of other storage options. Up to six hard disks or SSDs can be mounted in removable trays, with a further three 2.5in SSD locations in dedicated mounts. These sport clip-in mounts, so they're much easier to deal with than tiny screws.

Unfortunately, when it comes to the removable trays, you'll have to get rid of the lot if you choose to mount a 360mm radiator in the front, as there isn't quite enough room for the combined depth of the radiator and fans. Thankfully, the roof has support for up to a 420mm radiator, so you still have plenty of water-cooling options, if you want to retain several hard drive trays.

Three 140mm fans are included as standard and cover the roof, rear and front sections. The first of those acts as an intake, which at first seems a little odd, but given the restricted airflow for the front fan, which benefits from tiny vents in the sides and base, it's no wonder Corsair sought to balance things up here. However, with the roof panel installed, it's likely neither intake fan will be particularly useful.

The Carbide Series 678C includes a vertical GPU mount, although you'll need to invest in a PCI-E riser cable in order to use it. Actually building your system into the case is relatively pain-free too, thanks to a removable, hinged tempered glass side panel and plenty of cable-routing holes, although the complete lack of Velcro cable ties or cable-routing channels means that it's just you and a bunch of cable ties that will need to tidy things. Thankfully, some of the work is done for you, thanks to a 6-channel PWM fan hub that can control the three included fans and up to three more.

Sadly, the only cases worse than the Carbide Series 678C in the CPU cooling test were the two that lacked fans as standard, with the CPU delta T being a long way from the next best option, the Fractal Design Vector RS. The GPU delta T was better than the Vector RS, though, but still a long way from matching NZXT or Cooler Master's offerings and while it wasn't noisy, it wasn't as quiet as we'd hoped either.

.50 CALIBRE

- + Flexible layout
- + Good space for water cooling
- + 6-channel PWM fan hub

SPUD GUN

- − Poor cable-routing features
- − Average cooling
- − No stand-out features

SPEC

Dimensions (mm) 239 x 549 x 497 (W x D x H)

Material Steel, tempered glass, plastic

Available colours Black, white

Weight 13kg

Front panel Power, reset, 2 x USB 3, 1 x USB 3.1 Type-C, audio jack

Drive bays 6 x 2.5in/3.5in, 3x 2.5in, 1 x 5.25in

Form factor(s) Micro-ATX, ATX, E-ATX

Cooling 2 x 120/140mm base fan mounts (fans not included), 3 x 120/2 x 140mm front fan mounts (1 x 140mm fan included), 3 x 120/2 x 140mm roof fan mounts (1 x 140mm fan included), 1 x 120/140mm rear fan mount (1 x 140mm fan included)

CPU cooler clearance 170mm

Maximum graphics card length 370mm

Conclusion

As an understated, large chassis with great water-cooling support, the Corsair Carbide Series 678C is definitely worth considering, and has a good array of useful features and would probably have picked up an award in a stand-alone review. However, its air-cooling credentials aren't great, it's cable-routing tools are nearly non-existent and it just lacks the prowess and pizazz of an exceptional field this month.

VERDICT

A decent, flexible case for a water-cooled PC but the competition is better equipped.

COOLING	FEATURES	OVERALL SCORE
22/30	15/20	75%
DESIGN	VALUE	
21/30	17/20	

Fractal Design Vector RS / £170 incVAT

SUPPLIER overclockers.co.uk

Inside the Fractal Design Vector RS' packaging is the largest accessory box we've ever seen with a case. It houses this case's party trick: it can convert itself from a rather sealed design with a closed, see-through roof, to a vented design, with its roof equipped with fan and radiator mounts, as well as a dust filter.

It's an interesting inclusion, as it suggests Fractal Design was worried about its new case lacking airflow, in the same way as the Corsair Carbide Series 678C.

The Vector RS has RGB lighting, but it's done subtly with a line of diffuse digital RGB LEDs bisecting the centre of the Vector RS's exterior. The lights can be tweaked using an included controller or via your motherboard's software using the included cable. The lighting is punchy and helps to break up the otherwise bulky exterior that stretches to a depth of 55cm and height of 50cm.

SUMMER BREEZE

- + Excellent water-cooling support
- + Plenty of space for hard disks
- + Attractive RGB-equipped exterior

TORNADO

- − Fans locked at slow speed
- − Average GPU cooling
- − The competition is slightly more effective

SPEC

Dimensions (mm) 233 x 552 x 498 (W x D x H)

Material Steel, tempered glass, plastic

Available colours Black

Weight 12.64kg

Front panel Power, reset, 2 x USB 3, 1 x USB 3.1 Type-C, audio jacks

Drive bays 6 x 2.5in/3.5in, 2 x 2.5in

Form factor(s) Micro-ATX, ATX, E-ATX

Cooling 3 x 120/140mm front fan mounts (2 x 140mm fans included), 3 x 120/140mm roof fan mounts (fans not included), 2 x 120/140mm base fan mounts (fans not included), 1 x 120/140mm rear fan mount (1 x 140mm fan included)

CPU cooler clearance 185mm

Maximum graphics card length 440mm

While the case is all but sealed out of the box, there are top-to-bottom vents running down the sides of the case, feeding the front fan mounts that are equipped with two 140mm fans as standard and support an additional fan. You can also fit three 120mm fans, and there's space for 360mm and 280mm radiators too.

The roof, meanwhile, can house a 360mm or 420mm radiator thanks to the cooling bracket included in the box, with space for a 240mm or 280mm radiator in the base too. The case offers yet more flexibility thanks to six removable hard disk trays, and if that's not enough for you, there's space for five more using optional brackets. Each of these can also house a 2.5in SSD, but there are two dedicated 2.5in trays behind the motherboard, which may be enough for many users.

This area also houses a pair of large Velcro ties for stowing cables, but at this price, we'd have liked to see more of these and fewer plastic cable ties in the accessory box. However, cable routing was still easy thanks to numerous large routing holes.

A 9-port PWM fan hub is included too, but six of these ports only cater for 3-pin fans, three of which are included with the case. This means that if you use the hub, you won't be able to control their speed, which is set to an admittedly low 1,000rpm. This should mean they're very quiet as standard, but also won't be particularly powerful. The hub's other three ports are 4-pin PWM-compatible though.

The Vector RS had a decent lead over the Corsair Carbide Series 678C in the CPU delta T results and was only 2°C behind the Cooler Master MasterCase SL600M while being exceptionally quiet too. However, the GPU delta T was poor at 60°C, making it worse than a couple of fanless cases on test, undoubtedly thanks to the mass of hard disk strays suffocating the GPU. Sure enough, removing these saw a 4°C drop, matching the Corsair case.

Conclusion

The Vector RS is super-quiet, well equipped, stylish and ultimately feels like it's worth the cash. It's also a great choice of you need to house masses of hard drives. Cooling isn't exceptional but it can be improved by tweaking the internal layout. However, both the Phanteks Enthoo Lux 2 and NZXT H700i are slightly more appealing than the Fractal Design Vector RS for both air-cooled and water-cooled PCs.

VERDICT

A great effort from Fractal Design, the Vector RS is flexible and up to the task of housing high-end air or water-cooled PCs

COOLING	FEATURES	OVERALL SCORE
23/30	18/20	80%
DESIGN	VALUE	
23/30	16/20	

Lian Li PC-011 Dynamic Razer Edition / £155 inc VAT

SUPPLIER overclockers.co.uk

With no fans included as standard, the first consideration with the PC-011 Dynamic Razer Edition is just how much extra you're willing to spend to get your system up and running in terms of cooling.

A couple will get you going but, for a high-end PC, you may be looking at having to buy half a dozen fans. What's more, if you're planning to use an air CPU cooler, there's only 155mm of CPU cooler clearance, which limits your options. However, the PC-011 Dynamic Razer Edition isn't really designed for air cooling and has instead been geared towards liquid coolers and water cooling.

For such a compact chassis, at less than 45cm tall and deep, it's impressive that it can house three 360mm radiators. This is achieved by moving the PSU and storage drives to a different area of the case from the usual one.

Two of the three hard disk mounts sit in a cage in a second chamber of this cube-style case, with space for a third in a plate behind the motherboard tray. There are also SSD trays beneath the motherboard bringing the total amount of storage to three 3.5in mounts and six 2.5in mounts, all without limiting the water-cooling credentials.

One of the triple 120mm fan mount areas sits within the dividing panel of the case, with the back side of the case providing the ventilation for it. This arrangement allows you to present the top fans of the radiator to the front, windowed section of the case while keeping all the messy stuff behind the dividing panel, for a very clean overall look.

The roof and base offer similar radiator support, so there's some of the best potential for a water-cooling system here, despite the relatively compact dimensions for this E-ATX case. Externally, it's very attractive too, with the PC-011 Dynamic Razer Edition sporting digital RGB lighting around the glass-clad front and base of the case. It provides a subtle glow that looks fantastic, even if you do have to put up with a Razer logo in the front glass panel.

You also get a USB 3.1 Type-C port on the front panel, but other case mod cons such as cable tidying and fan controls are mostly non-existent in this clean slate of a PC case. With no fans included as standard, it wasn't surprising to see the case languish near the bottom of the pile in both CPU and GPU delta T results, although its GPU delta T was aided by the well-ventilated base, bettering the fan-assisted Fractal Design Vector RS and coming within a degree of the Corsair Carbide Series 678C.

SPEC

Dimensions (mm) 274 x 449 x 446 (W x D x H)

Material Steel, aluminium, tempered glass

Available colours Black

Weight 10.1kg

Front panel Power, 2 x USB 3, 1 x USB 3.1 Type-C, audio jacks

Drive bays 3 x 2.5in/3.5in, 3 x 2.5in

Form factor(s) Micro-ATX, ATX, E-ATX

Cooling 3 x 120mm side fan mounts (fans not included), 3 x 120mm base fan mounts (fans not included), 2 x 120/140mm roof fan mounts (fans not included)

CPU cooler clearance 155mm

Maximum graphics card length 420mm

GILLETTE

- + Superb water-cooling support
- + Attractive design
- + Decent storage support

CUT THROAT

- − Poor CPU air cooler clearance
- − No fans included
- − Lacks some modern conveniences

Conclusion

If money were no object and we had to pick from this month's line-up to build high-end water-cooled PC, we'd definitely choose the Lian Li PC-011 Dynamic Razer Edition. It lacks many conveniences and has no fans out of the box, but it's not designed to compete with the likes of the NZXT H700i.

Instead, you have a huge blank canvas to work with and considerable potential too. In addition, there are custom distribution plates available for the PC-011 Dynamic Razer Edition that take things to the next level in terms of water-cooling and modding. So, while the asking price is just a starting point, Lian Li has done the hard work and created a superb case for a liquid-cooled PC.

VERDICT

One of the best cases for water cooling we've seen and it's a looker too.

COOLING	FEATURES	OVERALL SCORE
21/30	13/20	82%
DESIGN	VALUE	
30/30	18/20	

NZXT H700i / £155 inc VAT

SUPPLIER overclockers.co.uk

Although NZXT's H700i has been the company's only extra-large tower case for the past year or two, it's still massively popular. Part of the appeal with the H700i is that it's available in a range of colour schemes to suit a variety of tastes , which combine the base colour of black with several coloured highlights.

Whichever colour you choose, the paint finish on the case is excellent. It adds a unique, clean style to the H700i that makes it one of the best-looking chassis on test this month. You can pick it up in versions with red, white or blue details, or in an all-black scheme.

The paint finish isn't the only stand-out feature of the H700i though. Another key bonus is its 3-channel, software-controlled fan controller, which is already hooked up to its trio of Aer F120 front fans and Aer F140 rear fan.

NZXT's CAM software also allows for complete control over the fan speeds according to CPU temperature, with several presets available. There's also a custom mode, which enables you to tweak the fan response curve. You can control the included RGB lighting strip too.

The case has solid panels all round except for the base, but large side vents are present in the roof and front to allow air in or out depending on your setup. The tempered glass side panel detaches by removing four thumbscrews, but the rear panel benefits from a push-button on the rear of the case that pops open the panel with a single press.

Beneath it we were met with one of the most elaborate cable-routing arrangements on test, with large cable channels and Velcro ties guiding your PSU cables to their targets. Inside the main chamber is a steel plate that hides these as they pass through the motherboard tray, but we found this a little fiddly to work around.

There's a decent amount of storage options as well, with three 3.5in hard disk mounts and up to seven 2.5in SSD mounts. These are dotted around the case, with some of them positioned in the main chamber, where they're visible through the side window.

Unlike the Lian Li PC-O11 Dynamic Razer Edition, the H700i is just as at home as an air-cooled PC as it is with water cooling, with 185mm CPU cooler clearance and space for 360mm or 280mm radiators in the roof and front fan mounts.

With reasonably powerful 1,200rpm fans up front, the H700i powered it's way to the top of the CPU delta T graph with a result of 54°C, which was 5°C clear of the next best case.

The Cooler Master SL600M was better at dealing with our graphics card, coming top by a margin of 3°C, but the H700i was still in a solid second place and remained very quiet, even with the fans running at full speed.

At low speed, the CPU delta T rose by 4°C and the GPU delta T went up by just 1°C, but as the noise difference was minimal, we recommend using the high-speed mode anyway.

SPEC

Dimensions (mm) 230 x 494 x 516 (W x D x H)

Material Steel, tempered glass, plastic

Available colours Black, black/white, black/red, black/blue

Weight 12.27kg

Front panel Power, 2 x USB 3, 2 x USB 2, audio jacks

Drive bays 6 x 2.5in/3.5in, 2 x 2.5in

Form factor(s) Micro-ATX, ATX, E-ATX

Cooling 3 x 120/140mm front fan mounts (2 x 140mm fans included), 3 x 120/140mm roof fan mounts (fans not included), 2 x 120/140mm base fan mounts (fans not included), 1 x 120/140mm rear fan mount (1 x 140mm fan included)

CPU cooler clearance 185mm

Maximum graphics card length 440mm

NZXT LEVEL

- \+ Good water-cooling support
- \+ Snazzy aesthetics
- \+ Software fan and lighting control

NZZDS WORK

- − Cable routing can be fiddly
- − Water-cooling potential not as good as the competition
- − Only three hard disk mounts

Conclusion

The NZXT H700i is reasonably priced, has plenty of space for a high-end air or water-cooled PC and comes in snazzy colours too. The software control is a boon, but you can save some cash by opting for the standard H700 if you'd prefer to use your motherboard's fan control. Even so, with excellent cooling and great features, it's the best all-rounder this month by a long way.

VERDICT

Brilliant out of the box and a superb, good-looking all-rounder.

COOLING	FEATURES	OVERALL SCORE
28/30	15/20	83%
DESIGN	VALUE	
23/30	17/20	

PHANTEKS ENTHOO LUXE 2 / £180 inc VAT

SUPPLIER overclockers.co.uk

As the biggest and most expensive case on test, the Enthoo Luxe 2 needs to top the charts, and on paper at least, it does appear to have most other cases on test trumped. This £180 behemoth stands nearly 60cm tall and deep, and ticks practically every box. You get four USB 3 ports and a USB 3.1 Gen 2 Type-C port on the front panel along with buttons to control the RGB lighting. This sits within tastefully thin lines of diffuse RGB-illuminated plastic that run around the front fascia and internal PSU cover.

There's also a huge number of upgrades available, with additional hard disk mounts and support for dual systems and dual PSUs being just some of the extras. Out of the box, there's still space for up to four hard disks with a maximum of 12 supported, via the optional cages, plus up to 11 SSD mounts. While it's clearly geared towards water-cooled systems, the Enthoo Luxe 2 is still a very capable air-cooled case with 195mm CPU cooler clearance and it bristles with fan mounts. However, unlike its predecessor, there are no fans included as standard so, like the Lian Li PC-O11 Dynamic Razer Edition, you'll need to factor your own case fans or liquid-cooling setup into the price.

The latter benefits from four locations (base, roof, front and side) that can house a minimum of a 360mm radiator, albeit with those at the front requiring the sacrifice of some storage mounts. The latter can stretch up to a 480mm radiator, drawing air in or exhausting it through a dust filter-covered vent in the side panel. It's a similar deal in the front of the case, except here you also get 140mm-size support up to 420mm radiators, while the roof and base are limited to 120mm-width radiators. You even get fill and drain port holes and an 8-port PWM fan hub with five 4-pin connectors that should make controlling your radiator fans much easier. Cable routing is also excellent and while we'd have liked to see a few more Velcro ties, you get a large hidden cable stowage area in front of the PSU mount, so creating a tidy system should be easy.

With no fans included, out-of-the-box cooling was never going to be a strong point and the CPU delta T was 12°C warmer than the best result on test; the CPU cooler really suffered from the lack of a rear exhaust fan. The GPU delta T of 55°C was reasonable and bettered the fan-equipped Corsair Carbide Series 678C and Fractal Design Vector RS, largely thanks to better ventilation and its cathedral-like interior.

SPEC

Dimensions (mm) 240 x 595 x 570 (W x D x H)

Material Aluminium, Steel, tempered glass, plastic

Available colours Black, gunmetal grey

Weight 14.3kg

Front panel Power, reset, 4 x USB 3, 1 x USB 3.1 Type-C, RGB controller, audio jacks

Drive bays 4 x 2.5in/3.5in, 7 x 2.5in

Form factor(s) Micro-ATX, ATX, E-ATX

Cooling 4 x 120/3 x 140mm front fan mounts (fans not included), 3 x 120/140mm roof fan mounts (fans not included), 3 x 120/1 x 140mm base fan mounts (fans not included), 1 x 120/140mm rear fan mount (fan not included), 4 x 120mm side fan mounts (fans not included)

CPU cooler clearance 195mm

Maximum graphics card length 503mm

LUXURIOUS

- + Superb water-cooling support
- + Massive upgrade potential
- + Excellent features

LUDICROUS

- − No fans included
- − Optional extras required to maximise hardware
- − Huge

Conclusion

Being pricier than the NZXT H700i and requiring more cash for fans and upgrades to make the most of its internal space, the Enthoo Luxe 2 is niche and high-end in its appeal.

The Lian Li PC-O11 Dynamic Razer Edition can be bought kitted with fans for the same price and is also great for water cooling, while Fractal Design's Vector RS and Cooler Master's SL600M offer good storage and water-cooling support. However, the sheer potential of Phanteks' new tower king in terms of building an insane PC means that it's truly deserving of our Extreme Ultra award.

VERDICT

Huge potential for masses of storage and hefty water-cooling systems but the competition offers better value for money.

COOLING	FEATURES	OVERALL SCORE
23/30	19/20	87%
DESIGN	VALUE	
28/30	17/20	

LABS TEST

Next-gen Wi-Fi

Edward Chester puts some of the latest high-end Wi-Fi 6 gear to the test

How we test

We'll cut to the chase, there's little to no point in trying to test the maximum speed of Wi-Fi 6 routers. For a start, the new standard doesn't actually push maximum speed all that high. The theoretical maximum speed of Wi-Fi 6 (802.11ax) is only 37 per cent faster than Wi-Fi 5 (802.11ac), which itself was already beyond the maximum speed of a Gigabit Ethernet connection, and you only get this maximum speed in specific circumstances at very short range.

Instead, Wi-Fi 6 is all about routers being able to better cope with multiple connected devices at once, providing a 75 per cent drop in latency and 4x overall throughput speed in densely populated networks. However, that's only if all the client devices have Wi-Fi 6 too. So instead, we've concentrated our testing on the real-world practical experience of deploying a Wi-Fi 6 router in a current typical home environment, testing for speed and range throughout a house.

We set up each router on the ground floor of a brick-built, semi-detached, three-storey house, over to one side next to the outer wall. We then tested Wi-Fi performance between a PC attached to the router via Ethernet and a laptop connected to the router over Wi-Fi, using three different test locations for the laptop. One is on the first floor, on the far side of the house, while the other two are on the second floor directly above the router and again over to the other side of the house.

We test throughput using LAN Speed Test, setting up a server on a computer attached to the Ethernet port of the router, along with a test client on our 802.11ax-equipped laptop. We don't test Ethernet speed, as any variance here is under 1 per cent with modern routers. We do, though, test USB speed, writing and reading a large file to any USB-attached storage. Outside of performance, we also look for ease of setup, as well as any ports, software and other physical features.

Contents

- Asus AiMesh AX6100 / p54
- Asus RT-AX88U / p55
- Netgear Nighthawk AX8 / p56
- TP-Link Archer AX6000 / p57
- TP-Link Archer TX3000E / p58
- Graphs / p59

ASUS AIMESH AX6100

/ £384 inc VAT

SUPPLIER scan.co.uk

If your primary concern when it comes to home Wi-Fi performance is getting enough range, then the best option isn't to spend big on a single fast router, but to get a mesh system. These systems use multiple routers that work together to extend and distribute the Wi-Fi signal, like a glorified Wi-Fi extender that's faster and more versatile. Asus' AiMesh AX6100 is the first Wi-Fi 6 router we've seen to offer this feature, with this £384 kit including two fully fledged Wi-Fi 6 routers.

SPEC

Weight
2 x 654g

Dimensions (mm)
2 x 155 x 155 x 151 (W x D x H)

Ethernet
4 x LAN + 1 x WAN 1000Mbps, use two ports for WAN link aggregation

Wi-Fi
802.11ax tri band (AX6000)

USB ports
1 x USB3.1, 1 x USB 2

Processor
1.8GHz quad-core Broadcom BCM4908

Extras
Two routers in one, dedicated band for wireless backhaul

Setting up the AX6100 is a little more complicated than some mesh systems. As the routers are identical, you need to set them up one by one, whereas the likes of the Netgear Orbi come readily paired up. It's easy enough, though, and we were up and running within 15 minutes.

The overall menu system of each RT-AX92U is basically identical to the RT-AX88U (see p55), with Asus' huge wealth of options being a little overwhelming. What's more, we encountered one particular issue that proved a problem for testing: we couldn't get the USB storage sharing to work.

You place one of them next to your internet connection, and the second one in an adjacent room or on the floor above. For instance, in our test scenario, the second router was placed on the first floor, in the centre of the house. Ideally, you want to find a location that's close enough to still get a strong, fast signal from the first router but that's far enough away to still offer a meaningful range extension.

The AX6100 consists of two RT-AX92U units, each of which has an identical set of features: four external aerials; four rear LAN ports; one rear WAN port; two USB 3 ports; and power, reset and WPS buttons. Around the front there's also a full array of LEDs to indicate power, LAN, WAN and Wi-Fi activity, with three separate lights for each of the three Wi-Fi bands (2 x 5GHz and 1 x 2.4GHz).

The units themselves are amazingly small, considering they're as powerful as any other router in this Labs test, and have a tri-band Wi-Fi system (the second 5GHz band is a dedicated channel for communication between the two routers). They measure just 155mm^2 by 151mm tall when their four antennae are raised. For this reason alone, they'll be considerably more appealing to some users than the much larger routers in this test.

On every other router, it's a simple case of plugging in the storage device and turning on the feature in the menus. Here, though, you're asked to create a user account with which to log in and jump through all sorts of hoops, all for it not to work anyway in our case.

Otherwise, the AX6100 seriously impressed when it came to Wi-Fi performance. It wiped the floor with the other routers on test, providing nearly double the performance of all the others in our first test location and getting on for 10x the performance at the longest range tests. We haven't recorded results for the 2.4GHz band, as the AX6100 automatically combines its bands into one signal.

Conclusion

If better range and coverage is your main concern when it comes to Wi-Fi, the AX6100 is the ultimate router right now (other Wi-Fi 6 mesh routers will no doubt arrive soon). Mesh router systems rule the roost in this regard, and the Asus AX6100 is the perfect example of why. Considering it only costs £60 more than most of the other routers in this Labs, it's a relative bargain too.

VERDICT

Surprisingly good value for money and superb performance make the AX6100 the Wi-Fi 6 router to beat.

DESIGN	FEATURES	OVERALL SCORE
14/20	14/20	84%
PERFORMANCE	**VALUE**	
30/30	26/30	

ASUS RT-AX88U

/ £300 inc VAT

SUPPLIER amazon.co.uk

The Asus RT-AX88U is the most traditional-looking of all the routers in this group test, but it doesn't give up anything in terms of features to its more exotic-looking rivals. In fact, it's just about the most feature-rich router of the lot (other than the pricier Asus AX6100 mesh system). It offers more USB functions than any other router this month, including the ability to plug in a USB modem so that you can even use your phone as your internet source. Plus it offers Alexa and IFTT support for easier home automation.

SPEC

Weight
987g

Dimensions (mm)
390 x 188 x 187 (W x D x H) (with antennae)

Ethernet
8 x LAN + 1 WAN 1000Mbps, use two ports for WAN link aggregation

Wi-Fi
802.11ax dual band (AX6000)

USB ports
2 x USB 3

Processor
1.8GHz quad-core Broadcom BCM4908

Extras
Removable antennae, USB modem support

Style-wise, the RT-AX88U is traditional both in terms of its flat, wide shape and four detachable antennae, as well as its fairly aggressive, angular lines. To an extent, all the routers in this Labs test share the same dark and moody design language, but the AX88U is the most extreme proponent. You at least get a few flashes of gold paint to liven up the exterior.

The unit itself is very wide, with its width measuring a whopping 390mm with the aerials attached. Add in the plentiful 188mm depth and 187mm height and you'll need a sizeable space to house this router.

For that girth, though, you do get plenty of physical features. A rank of eight Ethernet ports runs along the back, where they're joined by the WAN port, a USB 3 port, the power socket, and the buttons for WPS, reset and power. Around the front you get two further buttons for turning off the Wi-Fi and the indicator LEDs, and a second USB port behind a flap. It's an odd arrangement of buttons, consigning the far more useful WPS button to the back, while having enormous dedicated buttons on the front for features that most people are unlikely to ever use.

Likewise, while we're glad to see a second USB 3 port is available on this device, having it hidden behind a front flap isn't all that useful. You would seldom want to only temporarily plug a USB device into a router, compared with the number of devices you might want to attach more permanently, such as USB storage, a printer or a USB modem.

This router also supports the AiMesh system that powers the AX6100, so you can configure the RT-AX88U to work with other Asus routers to form a mesh network. As with the AX6100, the AX88U's menu system isn't quite as slick as the other routers on test, and can feel a little overstocked with features. Moreover, this router also suffers from the same problem as the AX6100 with setting up USB storage sharing. It probably works if you're prepared to faff with it, but it wouldn't play ball for us.

Inside, there's the same 64-bit, 1.8GHz, quad-core CPU that we suspect powers all these routers: the Broadcom BCM4908. This, along with the hefty external aerial system, enabled the AX88U to deliver the fastest speeds in our shortest-range tests. It also did well in the longer-range tests on the 2.4GHz band. However, using the 5GHz band (which has a shorter range than 2.4GHz), we simply couldn't record a result for the longer tests. The connection either wasn't available or the test failed part way through due to the weak signal.

Conclusion

The Asus RT-AX88U is a highly capable Wi-Fi 6 router, with a tonne of features and some impressive short-range peak performance figures. However, its interface isn't the easiest to use and it failed our longer-range tests on its 5GHz band. You can get a better-performing router elsewhere for this money.

VERDICT

Loads of features, and solid short-range performance, but disappointing 5GHz range puts a dent in this router's appeal.

DESIGN	FEATURES	OVERALL SCORE
14/20	16/20	70%
PERFORMANCE	**VALUE**	
18/30	22/30	

NETGEAR NIGHTHAWK AX8

/ £300 inc VAT

SUPPLIER amazon.co.uk

Hats off to Netgear for trying to make its router design a little different with the AX8. If you've ever wanted your router to invoke the stylistic spirit of a Star Wars imperial spacecraft, this is the router for you. The rather splendid-looking Nighthawk AX8 isn't all style over substance though. This is a highly powerful router.

However, it does trail the other models on test this month in one very obvious way: it has only five Ethernet LAN ports compared to the eight ports you'll find on all the other routers on test. For a high-end router priced at £300 inc VAT, that's quite the slip-up, even if more of people's internet-connected devices use Wi-Fi instead of wired connections these days.

Ethernet connections aside, though, the AX8 includes the expected dual-band Wi-Fi configuration, with a 4x4 antennae arrangement for each band. Inside there's an unspecified 1.8GHz quad-core processor. You also get two USB 3 ports that can be used to share printers and USB storage. Dual-function link aggregation is also supported, so you can either hook up two cables to the LAN ports for a faster (2Gbps) LAN connection, or one cable to the LAN port and one to the WAN port to create a faster internet connection.

Looking more closely at that design again, the exterior metallic grey surfaces are all plastic, while a black-painted metal grille covers the central portion, providing some ventilation. What's more, these vents are apparently not enough to properly cool the hot-running hardware inside, as Netgear has also seen fit to install a fan.

It's a long while since we've encountered a router with a fan inside it, and it was quite a shock to hear the surprisingly loud volume of this one, at least when the unit is powering up. It's easily audible over an adjacent PC, for instance.

However, once the unit has settled back down to normal operation, it's quiet enough to be largely unobtrusive. Nonetheless, none of the other units apparently needed active cooling, and we'd certainly prefer not to have it on a device that's going to be permanently powered on.

Meanwhile, those intriguing wings are permanently attached to the router, but fold down for stowing. The mechanism works well – you have to lift up the side slightly to unhook the wing and then fold it down. However, there's a slight concern that the wiring is exposed when a wing is folded in this way, as there's potential for the wire to get snagged or trapped.

Setting up the AX8 was simple enough, although Netgear doesn't overly hold your hand. The menus are fairly spartan and lack the slickness of the TP-Link's menus, for instance. In terms of key software features, Netgear offers the usual USB printer and storage sharing, QoS options and security features as the other routers on test this month.

When it comes to performance, the AX8 was actually more capable than we expected, given its slightly less beefy look compared with the competition. It was the slowest in our shortest-range test (which is still quite long-range), but it topped the chart (other than the Asus mesh unit) in our most challenging, long-distance test. Its USB speed was also the fastest we recorded, providing a plentiful speed of 832Mb/sec, although it didn't recognise our exFAT formatted USB drive, unlike the TP-Link.

SPEC

Weight
1281g

Dimensions (mm)
305 x 202 x 161 (W x D x H)

Ethernet
5 x LAN + 1 WAN 1000Mbps

Wi-Fi
802.11ax dual band (AX6000)

USB ports
2 x USB 3

Processor
1.8GHz quad-core

Extras
Fold-down sides

Conclusion

The Netgear AX8 is a sleek and high-performance Wi-Fi 6 router that largely delivers the performance and features you expect for its high price. However, the TP-Link AX6000 offers more Ethernet ports and slightly faster performance for less money, making it our top pick for an independent router this month.

VERDICT

Decent performance and features, but other options offer slightly more for less money.

DESIGN	FEATURES	OVERALL SCORE
16/20	14/20	74%
PERFORMANCE	VALUE	
22/30	22/30	

TP-LINK ARCHER AX6000 / £290 inc VAT

SUPPLIER amazon.co.uk

As the cheapest router in this Labs test, you might expect the TP-Link AX6000 to be lacking in a few areas. However, right across the board this router is about as good as it gets. For a start, it doesn't make the mistake of the Netgear AX8 of omitting any Ethernet ports – you get a full complement of eight of them.

However, instead of having various link aggregation options, all of the TP-Link's LAN connectors are standard Gigabit ports, while the WAN port offers a single 2.5Gbps connection. This is useful in the one specific instance where you have an extremely fast internet connection, but it's less versatile than the competition overall. For instance, you can't provide a single fast connection to a NAS with it, which would require a high-speed connection on the LAN ports.

Otherwise, the AX6000 really wants for little. On the side of the router you get one USB 3 port and one USB Type-C port for sharing USB storage devices or printers on your network. Meanwhile, up front there are buttons for WPS, Wi-Fi and LED functions – the gold TP-Link logo glows various colours to indicate the router's status.

Inside, you get the same 4x4 dual-band Wi-Fi configuration found in the other routers on test this month, with eight dedicated flip-up antennae arrayed around the outside.

We would prefer to see separate indicator LEDs for each part of the router – showing the status of LAN, WAN, Wi-Fi and so on – but it's not a deal breaker.

The Archer AX6000 is a hefty beast of a router too, with its square shape making it particularly deep, so you'll need a deep shelf or other place to stow it. Otherwise, it's neither as tall as the Netgear nor as wide as the Asus, so it offers a reasonable compromise in that regard. Unlike the Netgear, TP-Link hasn't felt the need to fit a fan to the AX6000 either, so there are no noise concerns.

Setup of the router can be performed either via a web interface (just plug in the router, connect a device to the Wi-Fi or Ethernet and navigate to 192.168.0.1 in your browser) or an app. Like all the routers on test this month, it also doesn't require you to either have an internet connection or sign up with an account to get going, unlike some mesh routers. This makes it much easier to set up your network and trace any problems you might be having. The web interface of the Archer AX6000 is also by far the slickest of all the routers in this Labs test, with a stylish white and light cyan colour scheme and intuitive menu layout.

All this and the AX6000 doesn't disappoint when it comes to performance. It topped the chart in our shortest-range 5GHz test (for the non-mesh routers) and performed consistently well in the longer-range tests too. It also did well in the 2.4GHz tests. USB speed was decent too, even if it didn't quite hit the maximum speed of the Netgear AX8. Crucially, though, it did recognise our exFAT-formatted drive, allowing us to connect our largest, fastest drive to it.

SPEC

Weight
1065g

Dimensions (mm)
261 x 261 x 119 (W x D x H)

Ethernet
8 x Gigabit LAN + 1 x 2.5Gbps WAN

Wi-Fi
802.11ax dual band (AX6000)

USB ports
1 x USB 3, 1 X USB Type-C

Processor
1.8GHz quad-core Broadcom BCM4908

Memory
1GB RAM, 128MB flash

Extras
2.5Gbps WAN port, exFAT USB storage support

Conclusion

The TP-Link Archer AX6000 offers all the performance and features you'd expect from a top-end Wi-Fi 6 router, yet it undercuts the price of its competitors, even if it is only by £10. For that reason alone, it's well worth considering. Add in the slick interface and chart-topping performance (for a non-mesh router), and you have a winner if you're looking for an independent single 802.11ax router.

VERDICT

Performance, features and value combine in this still pricey but powerful Wi-Fi 6 router.

DESIGN	FEATURES	OVERALL SCORE
16/20	16/20	83%
PERFORMANCE	VALUE	
25/30	26/30	

WI-FI 6 PCI-E ADAPTOR

TP-LINK ARCHER TX3000E / £60 inc VAT

SUPPLIER overclockers.co.uk

Wi-Fi 6, otherwise known as 802.11ax, is the new Wi-Fi standard in town, but while Wi-Fi 6 routers are slowly starting to appear, client devices that can connect to them are few and far between. Enter the first PC Wi-Fi 6 adaptor that we've encountered, the TP-Link Archer TX3000E.

It's a 4x PCI-E card, so sadly, it can't serve double duty as an adaptor for a laptop, unlike a USB adaptor. Otherwise, though, it's an easy enough device to install thanks to the card itself being very small. You also get a low-profile expansion bracket in the box, so you can mount the card in low-profile cases.

Its two gold-plated aerial sockets sprout from the back of the card, and they attach to the 1m cable that runs to the aerials themselves. These aerials are mounted onto a weighty and magnetised baseplate, but you can remove them from the plate and adjust their angles in order to fine tune performance.

The base is reassuringly solid too. Having a heavy, magnetised base with a grippy foam underside ensures that it has the best possible chance of not toppling over, or being pulled off your desk or PC by the weight of the cables.

Once the card and antennae have been attached, you'll need to install the driver. This can be downloaded from TP-Link's website or you can use the included CD. Intriguingly, the drivers for Wi-Fi and Bluetooth are kept separate (the card also provides Bluetooth 5 support), so you can choose to only install one or the other.

The driver doesn't install a taskbar-based app, but instead provides a host of configuration options for the adaptor properties' right-click menu. Some of the options include the ability to choose the type of connection mode to use (a/b/g/ac/ax), the channel width and MIMO power saving. Almost none of these settings will ever need touching in most instances.

To test the adaptor, we installed it in a PC alongside an Asus PCE-AC68 Wi-Fi 5 adaptor. This is an eerily similar-looking dual-band, 2x2 802.11ac adapter that can reach a theoretical peak speed of 1.3Gb/sec on its 5GHz channel and 600Mb/sec on its 2.4GHz channel. In comparison, TP-Link claims the TX3000E can hit a theoretical maximum of 2402Mb/sec (5GHz) or 574Mb/sec (2.4GHz).

We then connected, alternately, both wireless adaptors to our pick of the best Wi-Fi 6 routers from this month's Labs test – the TP-Link Archer AX6000 (see p57) – and tested its Wi-Fi speed and range.

We weren't able to test the peak speed of either adaptor, as doing so would require an Ethernet connection faster than Gigabit. However, we still saw consistently high results from both adaptors, with close-range speeds hitting 450Mb/sec. Moreover, we saw a consistent, if modest lead for the TP-Link AX adaptor, with it delivering 189Mb/sec compared to the Asus adaptor's 123Mb/sec on the 2.4GHz channel and 254Mb/sec compared to 219Mb/sec on the 5GHz channel, in our longest-range test.

Of course, the improvements with Wi-Fi 6 aren't primarily about raw speed, and the performance differences aren't huge. It's not really worth upgrading from the Asus Wi-Fi 5 adaptor to the TP-Link Wi-Fi 6 one, but it's worth buying the latter if you're starting out from scratch.

Conclusion

If you're looking for a powerful, high-speed Wi-Fi connection for your PC, the TP-Link TX3000E is a great option. It doesn't offer a huge leap in speed over the fastest Wi-Fi 5 adapters, but there's a small boost, and it's surprisingly affordable too. CPC

VERDICT

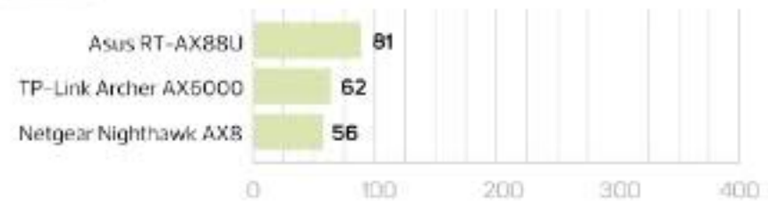
A surprisingly affordable way to equip your PC with the fastest Wi-Fi connection currently possible.

FEATURES	PERFORMANCE	VALUE	OVERALL SCORE
14/20	45/50	24/30	83%

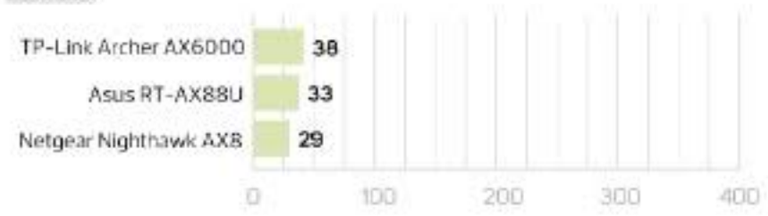
WI-FI 6 ROUTER LABS PERFORMANCE RESULTS

2.4GHz BAND (Mb/sec)

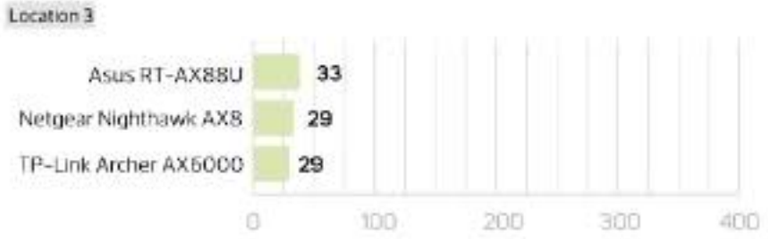
Location 1



Location 2

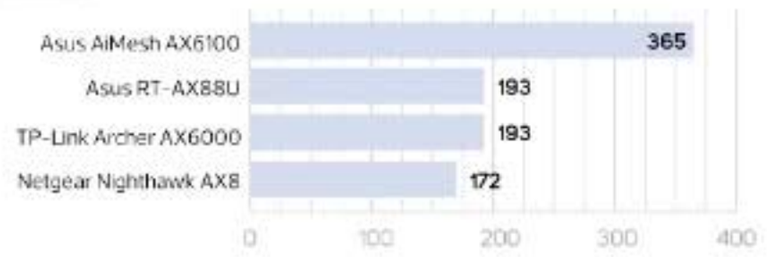


Location 3

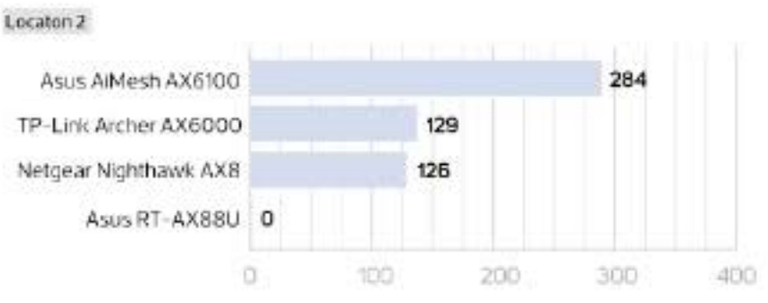


5GHz BAND (Mb/sec)

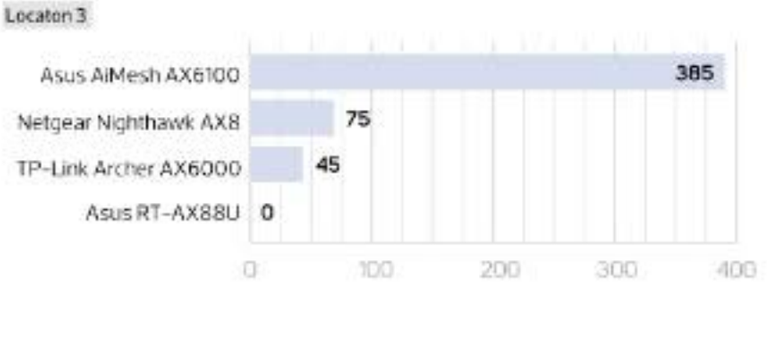
Location 1



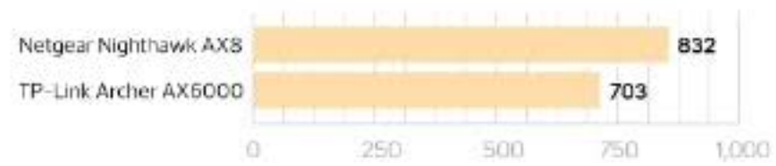
Locaton 2



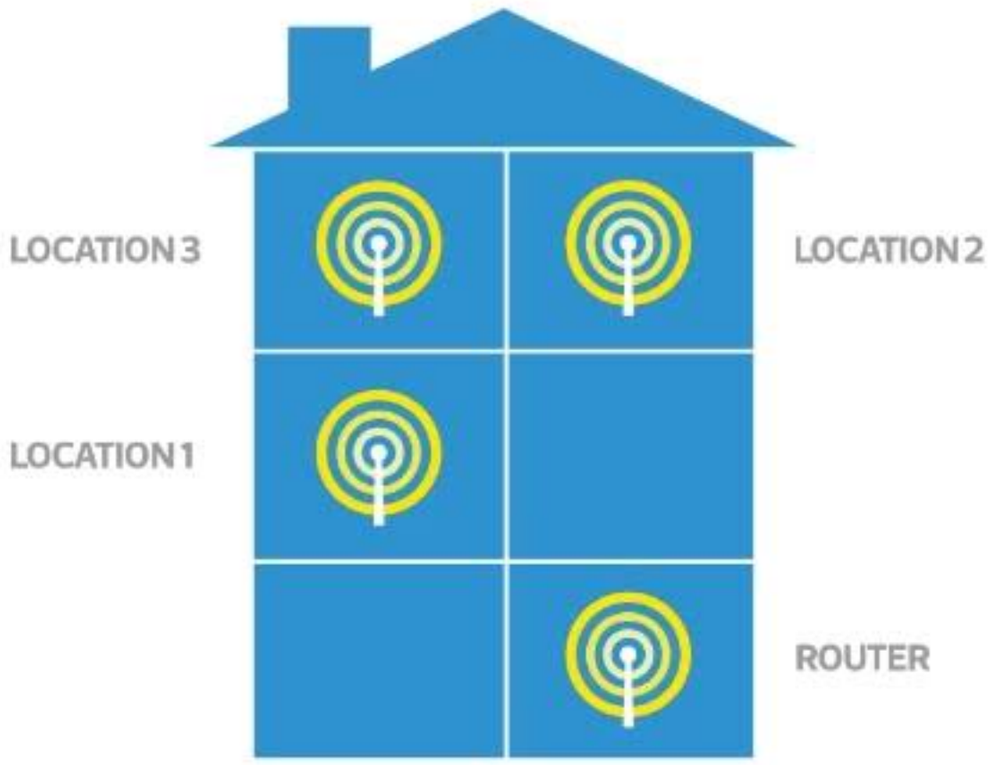
Locaton 3



USB TRANSFER RATE (Mb/sec)



TESTING LOCATIONS



How we test

MOTHERBOARDS

TEST PROCESSORS

- **Intel LGA1151** Intel Core i9-9900K
- **Intel LGA2066** Intel Core i9-7900X
- **AMD AM4** AMD Ryzen 9 3900X
- **AMD TR4** AMD Threadripper 2950X

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 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.

We use **Custom PC**'s own RealBench suite, and Far Cry 5 installed on Windows 10 Home 64-bit to test basic performance. We also test the board's SATA and M.2 ports, and record the noise level and dynamic range of the integrated audio using RightMark Audio Analyzer. We try to overclock our test CPU to its maximum air-cooled level on each motherboard, and record the performance results.

PROCESSORS

TEST MOTHERBOARDS

- **Intel LGA1151** MSI MEG Z90 ACE
- **Intel LGA2066** MSI MEG X299 Creation
- **AMD AM4** Gigabyte X570 Aorus Master
- **AMD AM4 (APU)** MSI X470 Gaming Pro Carbon
- **AMD TR4** MSI MEG X399 Creation

We otherwise use the same core spec to test each CPU. Our test gear comprises an Nvidia GeForce RTX 2070 Super Founders Edition (or an APU's integrated GPU for gaming tests) and a 2TB Samsung 970 Pro SSD. We also use Corsair Vengeance RGB 3466MHz DDR4 memory – a 16GB dual-channel kit for mainstream desktop systems, and a 32GB quad-channel kit for HEDT systems.

We use **Custom PC**'s own RealBench suite, Cinebench and Far Cry 5, installed on Windows 10 Home 64-bit, and record the power draw of the test PC. These tests cover a broad range of performance characteristics, including image editing, gaming, video encoding and 3D rendering. We run all tests at stock speed and at the CPU's highest overclocked frequency.

MONITORS

We test image quality with an Xrite 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. We also run games on them to assess their responsiveness, and to see how well any active sync tech works, and to gauge their performance at high refresh rates.

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 4.6GHz with 1.2V vcore, MSI Z370 PC Pro 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, Asus ROG Strix B350-F Gaming motherboard.

AMD TR4

AMD Threadripper 2950X overclocked to 4.1GHz with 1.425V vcore, AMD Threadripper 2990WX overclocked to 4GHz with 1.3375V vcore, ASRock X399M 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 real-time ray tracing. Every graphics card is tested in the same PC, so all 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 are unable to produce playable frame rates at this setting. We also try to overclock every graphics card we test to assess the performance impact.

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

Battlefield V Tested in DirectX 11 at Ultra settings on every card. If a GPU also supports real-time ray tracing, we then test it in DirectX 12 with DXR enabled on Low and High settings. We run through a one-minute custom benchmark in the 'Under No Flag' War Story, recording the frame rate with Fraps.

Shadow of the Tomb Raider Tested at the Highest settings preset, with TAA. We run the built-in benchmark, and record the frame rate from the GPU test.

Total War: Warhammer II Tested in DirectX 11, as the DirectX 12 beta currently causes stuttering issues on some GPUs. We test at Ultra settings with FXAA, and run the built-in 'Battle' benchmark.

Deus Ex: Mankind Divided Tested at the Very High preset in DirectX 12, running the built-in benchmark.

POWER CONSUMPTION

We run Unigine Superposition at 4K Optimized DirectX settings. We measure the power consumption of our whole graphics test rig at the mains during the test, and record the peak power draw. Bear in mind that 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.

Elite

Our choice of the best hardware available

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	overclockers.co.uk	**#194,** p20	£140
CPU COOLER	AMD Wraith air cooler included with CPU	N/A	**#176** p80	£0
GRAPHICS CARD	AMD Radeon RX Vega 11 integrated into CPU	N/A	**#194** p20	£0
MEMORY	8GB (2 x 4GB) Corsair Vengeance LPX 3000MHz (CMK8GX4M2A 3000C16)	scan.co.uk	**#176** p80	£45
MOTHERBOARD	MSI B450M Mortar (micro-ATX)*	ebuyer.com	**#182** p50	£90
STORAGE	500GB WD Blue SN500 (M.2 NVMe)	ebuyer.com	**#191** p78	£68
Total £343				

*This motherboard may require a BIOS update in order to recognise the new CPU, which can be performed without needing an old CPU, downloading the latest BIOS to a USB flash drive and pressing the Flash BIOS button

Budget gaming system

Quad-core CPU, 1080p gaming

Needs a micro-ATX case. We recommend a 450W 80 Plus power supply. See Issue 191, p78, for an example build guide.

COMPONENT	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
CPU	Intel Core i3-8100	scan.co.uk	**#191** p78	£118
CPU COOLER	Raijintek Juno Pro RBW	overclockers.co.uk	**#191** p78	£12
GRAPHICS CARD	Palit GeForce GTX 1660 StormX 6GB	cclonline.com	**#191** p78	£200
MEMORY	16GB (2 x8 GB) Corsair Vengeance LPX 3000MHz (CMK16GX4 M2A2666C16)	scan.co.uk	**#191** p78	£60
MOTHERBOARD	Gigabyte B360M DS3H (micro-ATX)	cclonline.com	**#191** p78	£70
STORAGE	500GB WD Blue SN500 (M.2 NVMe)	ebuyer.com	**#191** p78	£68
Total £528				

UPGRADES

SWAP GRAPHICS CARD	AMD Radeon RX Vega 56	ebuyer.com	**#190** p47	£230
SWAP STORAGE	Kingston A2000 1TB	scan.co.uk	**#196** p30	£108

Mid-range all-purpose system

6-core CPU, 2,560 x 1,440 gaming

Needs an ATX case. We recommend using a 550W power supply with 80 Plus Bronze certification. See Issue 193, p76 for a similar example build guide.

COMPONENT	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
CPU	AMD Ryzen 5 3600	scan.co.uk	**#195** p16	£180
CPU COOLER	Deepcool Gammaxx GT	scan.co.uk	**#192** p52	£30
GRAPHICS CARD	AMD Radeon RX 5700	overclockers.co.uk	**#192** p24	£320
MEMORY	16GB (2 x 8GB) Corsair Vengeance RGB 3466MHz (CMW16GX4 M2C3466C16)	scan.co.uk	**#192** p21	£132
MOTHERBOARD	MSI X570-A Pro (ATX)	cclonline.com	**#193** p48	£154
STORAGE	1TB Corsair MP600	scan.co.uk	**#193** p26	£228
	Total £1,044			
UPGRADES				
SWAP GRAPHICS CARD	Nvidia GeForce RTX 2060 Super (adds real-time ray-tracing abilities)	scan.co.uk	**#193** p16	£375
ADD SECONDARY STORAGE	Western Digital Blue 4TB	overclockers.co.uk	**#166** p54	£105
SWAP CPU COOLER	ARCTIC Liquid Freezer II 240	scan.co.uk	**#196** p26	£65

Mid-range gaming system

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

Needs an ATX case with room for a 240mm all-in-one liquid cooler. We recommend a 600W 80 Plus Bronze power supply.

COMPONENT	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
CPU	AMD Ryzen 7 3700X	overclockers.co.uk	**#192** p14	£300
CPU COOLER	ARCTIC Liquid Freezer II 240	scan.co.uk	**#196** p26	£65
GRAPHICS CARD	Nvidia GeForce RTX 2070 Super	scan.co.uk	**#193** p16	£480
MEMORY	16GB (2 x 8GB) Corsair Vengeance RGB 3466MHz (CMW16GX4 M2C3466C16)	scan.co.uk	**#192** p21	£132
MOTHERBOARD	Asus ROG Strix X570-E Gaming (ATX)	ebuyer.com	**#193** p44	£300
STORAGE	1TB Corsair MP600	scan.co.uk	**#193** p26	£228
	Total £1,505			
UPGRADES				
ADD SECONDARY STORAGE	Western Digital Blue 4TB	overclockers.co.uk	**#166** p54	£105
SWAP CPU COOLER	Corsair H100i RGB Platinum (240mm AIO liquid cooler)	cclonline.com	**#185** p82	£113

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 a 650W 80 Plus Gold power supply.

COMPONENT	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
CPU	AMD Ryzen 9 3900X	overclockers.co.uk	**#192** p14	£579
CPU COOLER	Corsair H100i RGB Platinum (240mm AIO liquid cooler)	cclonline.com	**#175** p20	£113
GRAPHICS CARD	Nvidia GeForce RTX 2080 Ti	scan.co.uk	**#189** p20	£999
MEMORY	16GB (2 x 8GB) Corsair Vengeance RGB 3466MHz (CMW16GX4 M2C3466C16)	scan.co.uk	**#192** p21	£132
MOTHERBOARD	MSI Prestige X570 Creation (E-ATX)	overclockers.co.uk	**#193** p48	£430
STORAGE	1TB Corsair MP600	scan.co.uk	**#193** p26	£228
	Total £2,481			
UPGRADES				
ADD SECONDARY STORAGE	4TB Western Digital Blue	overclockers.co.uk	**#166** p54	£105

Heavy multi-threading workstation

Serious multi-threaded power, 1080p gaming

Needs an ATX case with room for a 240mm all-in-one liquid cooler. We recommend a 700W 80 Plus Gold power supply.

COMPONENT	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
CPU	AMD Threadripper 2950X	scan.co.uk	**#182** p23	£730
CPU COOLER	Enermax Liqtech II TR4 240 (240mm AIO liquid cooler)	overclockers.co.uk	**#186** p44	£130
GRAPHICS CARD	Zotac Gaming GeForce GTX 1660 6GB	cclonline.com	**#190** p44	£210
MEMORY	32GB Corsair Dominator Platinum RGB 3200MHz (CMT32GX 4M4C3200C16)	scan.co.uk	**#188** p19	£242
MOTHERBOARD	ASRock X399 Taichi (ATX)	scan.co.uk	**#170** p47	£330
STORAGE	1TB Samsung 970 Evo Plus (M.2 NVMe)	ebuyer.com	**#188** p51	£192
	Total £1,834			
UPGRADES				
SWAP GRAPHICS CARD	Nvidia GeForce RTX 2070 Super (2,560 x 1,440 gaming with ray tracing, and some 4K gaming)	scan.co.uk	**#193** p16	£480
SWAP CPU	AMD Threadripper 2990WX (faster in some heavily multi-threaded software, not recommended for gaming)	scan.co.uk	**#182** p24	£1,700
ADD SECONDARY STORAGE	6TB Seagate BarraCuda Pro	overclockers.co.uk	**#166** p50	£215

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 Z390 (LGA1151)	ASRock Z390 Phantom Gaming-ITX/ac	scan.co.uk	**#185** p50	£187
AMD X570 (AM4)	Gigabyte X570-I Aorus Pro WiFi	overclockers.co.uk	**#195** p24	£227

Cases

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
BUDGET	Metallic Gear Neo Mini	amazon.co.uk	**#195** p48	£60
MID-RANGE	Phanteks Enthoo Evolv Shift Air	overclockers.co.uk	**#195** p49	£95
PREMIUM	Lian Li PC-Q37WX	overclockers.co.uk	**#195** p47	£225

CPU coolers

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
LOW-PROFILE	Noctua NH-D9L	amazon.co.uk	**#143** p17	£43

Power supplies

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
800W SFX	SilverStone Strider SX800-LTI	scan.co.uk	**#185** p82	£156

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	aquatuning.co.uk	**#196** p24	£72
BUDGET RGB	Phanteks Eclipse P400A	overclockers.co.uk	**#194** p24	£84
SUB-£100	Lian Li Lancool One Digital	overclockers.co.uk	**#184** p32	£95
MID-RANGE	Phanteks Eclipse P600S	overclockers.co.uk	**#187** p24	£128
HIGH-END	NZXT H700i	overclockers.co.uk	**#196** p51	£155
PREMIUM	Phanteks Enthoo Evolv X	overclockers.co.uk	**#187** p24	£200
LUXURY	Cooler Master Cosmos C700M	scan.co.uk	**#183** p28	£416

Micro-ATX

Motherboards

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
Intel Z390 (LGA1151)	Asus ROG Maximus XI Gene	overclockers.co.uk	**#189** p28	£320
AMD X399 (TR4)	ASRock X399M Taichi	scan.co.uk	**#179** p28	£330
AMD B450 (AM4)	MSI B450M Mortar	ebuyer.com	**#182** p50	£90

Cases

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
BUDGET	Fractal Design Focus G Mini	overclockers.co.uk	**#180** p46	£47
MID-RANGE	Fractal Design Define Mini C	scan.co.uk	**#161** p26	£80
PREMIUM	NZXT H400i	overclockers.co.uk	**#175** p32	£106

Networking

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
ROUTER (WI-FI 6)	TP-Link Archer AX6000	amazon.co.uk	**#196** p57	£290
MESH ROUTER (WI-FI 5)	Netgear Orbi 2-Pack (RBK50)	amazon.co.uk	**#172** p57	£246
PREMIUM MESH ROUTER (WI-FI 6)	Asus AiMesh AX6100	scan.co.uk	**#196** p54	£384
WI-FI ADAPTOR	TP-Link Archer TX3000E	overclockers.co.uk	**#196** p58	£60
SINGLE-BAY NAS BOX	Synology DS118	box.co.uk	**#174** p34	£155
DUAL-BAY MEDIA NAS BOX	Synology DS218play	box.co.uk	**#174** p34	£208

Monitors

AMD FreeSync

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
24IN BUDGET 1,920 X 1,080	AOC G2460VQ6	amazon.co.uk	#174 p52	£126
24IN MID-RANGE 1,920 X 1,080	AOC C24G1	cclonline.com	#191 p28	£173
24IN 240Hz ESPORTS 1,920 X 1,080	AOC AGON AG251FZ	overclockers.co.uk	#187 p48	£290
27IN 2,560 X 1,440	Samsung C27HG70	ebuyer.com	#171 p28	£474

Nvidia G-Sync

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
24IN 2,560 X 1,440	AOC AGON AG241QG	box.co.uk	#169 p55	£378
27IN 2,560 X 1,440	Asus ROG Swift PG279Q	scan.co.uk	#155 p48	£695
35IN ULTRA-WIDE 3,440 X 1,440	AOC AGON AG352UCG6	overclockers.co.uk	#180 p52	£730
27IN 4K PREMIUM	Asus ROG Swift PG27UQ	scan.co.uk	#181 p31	£1,999

AMD FreeSync and Nvidia G-Sync

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
24IN BUDGET 1,920 X 1,080	AOC G2590FX	overclockers.co.uk	#190 p53	£200
25IN MID-RANGE 1,920 X 1,080	Asus VG258QR	overclockers.co.uk	#190 p54	£290

Non-gaming

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
27IN 4K	AOC U2790PQU	scan.co.uk	#194 p30	£298
27IN 5,120 X 2,880	Iiyama ProLite XB2779QQS	scan.co.uk	#179 p34	£695

Peripherals and audio

Gaming keyboards

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
MEMBRANE	Corsair K55 RGB	overclockers.co.uk	#176 p52	£55
MECHANICAL	Corsair K68 RGB	ebuyer.com	#181 p53	£80
MECHANICAL MMO	Corsair K95 RGB Platinum	scan.co.uk	#164 p26	£170
PREMIUM MECHANICAL	Corsair K70 Mk.2 Low Profile	scan.co.uk	#193 p56	£150
LUXURY MECHANICAL	Razer Hunstman Elite	scan.co.uk	#193 p59	£189

Gaming mice

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
FIRST-PERSON SHOOTER	SteelSeries Rival 600	scan.co.uk	#184 p59	£74
MMO	Roccat Nyth	amazon.co.uk	#186 p53	£65
AMBIDEXTROUS	Razer Lancehead Tournament Edition	scan.co.uk	#177 p53	£65
ULTRA LIGHTWEIGHT	Glorious PC Gaming Race Model O	overclockers.co.uk	#195 p58	£45

Peripherals and audio cont...

Game controllers

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
STEERING WHEEL & PEDALS	Logitech G920 Driving Force	currys.co.uk	**#159** p55	£200
GAMEPAD	Microsoft Xbox One Wireless Controller	game.co.uk	**#191** p56	£50

Speakers

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

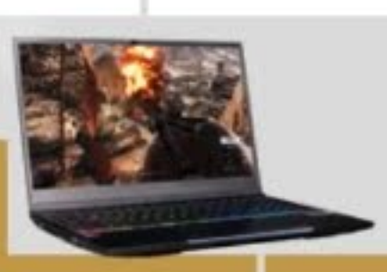
Gaming headsets

CATEGORY	NAME	SUPPLIER	ISSUE	PRICE (inc VAT)
STEREO	Sennheiser GSP 300	audioaffair.co.uk	**#194** p56	£79
SURROUND	Asus ROG Centurion	ccdonline.com	**#163** p49	£216
WIRELESS	SteelSeries Arctis 7	currys.co.uk	**#178** p58	£119
PREMIUM WIRELESS	Corsair Virtuoso RGB Wireless SE	scan.co.uk	**#195** p30	£180

PCs and laptops

Pre-built PC systems

CATEGORY	NAME	CPU	GPU	SUPPLIER	ISSUE	PRICE (inc VAT)
BUDGET PC WITH INTEGRATED GRAPHICS	Falcon Raptor RX	AMD Ryzen 5 2400G stock speed	AMD Radeon RX Vega 11	falconcomputers.co.uk	**#176** p52	£480
SUB-£1,000 GAMING	Chillblast Fusion Ryzen 5 GTX 1660 Ti	AMD Ryzen 5 2600 stock speed	Nvidia GeForce GTX 1660 Ti	chillblast.com	**#189** p58	£1,030
ENTRY-LEVEL RAY TRACING	Wired2Fire Predator	AMD Ryzen 7 3700X stock speed	Nvidia GeForce RTX 2060 Super	wired2fire.co.uk	**#196** p40	£1,299
GEFORCE RTX 2070 SUPER GAMING	PC Specialist Vulcan S2	Intel Core i7-9700F stock speed	Nvidia GeForce RTX 2070 Super	pcspecialist.com	**#192** p38	£1,612
GEFORCE RTX 2080 SUPER GAMING	Stormforce Crystal RTX 2080 Super	3.6GHz AMD Ryzen 7 3700X stock speed	Nvidia GeForce RTX 2080 Super	stormforcegaming.co.uk	**#196** p38	£2,000
PREMIUM MINI-ITX	Corsair One i160	Intel Core i9-9900K stock speed	Nvidia GeForce RTX 2080 Ti	corsair.com	**#190** p32	£3,399
DREAM PC	Scan 3XS Barracuda	Intel Core i9-9900X OC to 4.4GHz	2 x Nvidia GeForce RTX 2080 Ti	scan.co.uk	**#145** p58	£10,149



Laptops

CATEGORY	NAME	CPU	GPU	SCREEN	SUPPLIER	ISSUE	PRICE (inc VAT)
THIN AND LIGHT GAMING	Scan 3XS Vengeance GL2070	Intel Core i7-8750H stock speed	Nvidia GeForce RTX 2070 Max-Q	15.6in 1,920 x 1,080 IPS 144Hz	scan.co.uk	**#189** p34	£1,737
PREMIUM GAMING	Asus ROG Zephyrus S GX701GX	Intel Core i7-8750H stock speed	Nvidia GeForce RTX 2080 Max-Q	17.3in 1,920 x 1,080 IPS 144Hz G-Sync	amazon.co.uk	**#190** p28	£3,300

RICK LANE / INVERSE LOOK

EPIC FLAW

As it approaches its first anniversary, Rick Lane looks back at the Epic Store

This year has truly been an Epic one. After launching its storefront at the end of 2018, Epic Games has spent most of 2019 setting itself up as a direct rival to Steam. Its approach to this endeavour hasn't been without controversy. The studio's policy of offering large sums of money (£8 million in the case of Remedy's Control) to developers for exclusive rights to publish their games has come under criticism from many PC users.

Personally, I don't have an issue with developers signing up to the Epic Store. At a time when the gaming space is more competitive than ever, I can't imagine anyone turning away the stability that comes with such an offer, especially in the case of smaller indie developers.

That said, although it's great that some of Epic's money goes towards developers to help create the games they want to make, from a user perspective, the Epic Store is still far away from offering the quality of service that Steam currently provides.

For users, Epic's main selling point was that the Epic Store would offer a hand-curated selection of titles. This is the opposite of Valve's open-floodgates policy, where any software with a pixel in it can be sold on Steam.

To its credit, the Epic store does provide this curated selection. Launch up the storefront and you're almost guaranteed to find a quality title positioned front and centre. While that curation is nice, however, it simply doesn't make up for the Epic Store's sheer dearth of features compared with Steam.

Many of the most treasured Steam features are community-orientated, and it's in this area that the Epic Store is most lacking. The Epic Store currently lacks an equivalent to Steam's user reviews, Steam groups, voice chat, group chat, wish lists, achievements, forums, community pages for games and so on. It also lacks some incredibly basic features for an online store, such as a shopping cart and automatic refunds.

Aside from the hand-curation aspect, the only tangible benefit that the Epic Store offers over Steam is a regular influx of freely available games.

Again, that's a good aspect of the store, but it's not enough to account for the fact that players are forced into buying certain games from a storefront that's far less useful to them than the one they've already used for years. Almost a year into the Epic Store's existence, I honestly expected Epic to catch up with Steam a little faster, especially when you consider the resources that are clearly at the company's disposal.

> I honestly expected Epic to catch up with Steam a little faster

However, 11 months down the line, it's still missing a lot of basic features. I also expected it to be more conceptually ambitious. Even if Epic implements all the features I just listed, it's still only going to offer a service that's equivalent to Steam.

I'm still in favour of the PC having a direct competitor to Steam, and Epic is one of few studios with the resources to pull it off. However, the Epic store is still a long way off being as beneficial to players as it is to developers.

Valve has spent 15 years building a reputation as the benevolent granddaddy of online PC game sales, and it's going to take much more than a curated storefront and a big sack of cash for players to start viewing Epic in the same way. OPC

Rick Lane is Custom PC's games editor @Rick_Lane

Greedfall / £39.99 inc VAT

DEVELOPER Spiders / **PUBLISHER** Focus Home Interactive

Greedfall takes place in a fantasy world inspired by Europe's colonial age. You play De Sade, a male or female cousin to the freshly appointed governor of New Serene. This is one of several recently established cities on the island of Teer Fradee. Acting as a diplomat for the Confederation of Merchants, you entreat with rival factions as all three of them search for a cure to a disease ravaging the mainland, while also trying to navigate the delicate political situation with the island's native people.

Structurally, Greedfall borrows heavily from Dragon Age: Inquisition. Cutscenes and dialogue are both directed in a similarly cinematic fashion, while combat is a hybrid of real-time action and pausable tactics. The game world, meanwhile, is broken up into around a dozen large regions that can be explored freely, featuring side-quests, collectible loot and other points of interest.

Greedfall's most impressive features are the depth of its questlines and the variety it enables in resolving them. Even the simplest task, such as helping a native merchant to get a permit to trade in the city, will spiral out into a much larger and often higher-stakes story. At the same time, most quests can be solved through combat, dialogue, stealth or more off-the-wall solutions, such as blowing a hole in a jail-cell wall to help someone escape, or disguising yourself in an appropriate uniform to bluff your way into a specific area.

Sadly, there's no area in which Greedfall stands out over and above any other contemporary RPG. The story is interesting, but there's no pace or urgency to it. The writing is competent but flat. The combat is well animated but lacks spectacle. The stealth mechanics are functional but basic. Even the environment design, although undeniably pretty, is oddly drab, with the scenery all painted in the shame shade of russet.

In addition, Greedfall is thematically questionable. You're allied with a nation that has stolen the lands of a native island people, building cities and consuming resources that belong to them. The game tries to navigate this problem by giving you the opportunity to take the side of the natives in most relevant quests, and through certain plot devices we won't spoil. However, it never gets around the fact that, however nice you are about it, you're basically the bad guy from the start.

Greedfall is by far the most capable RPG Spiders has made, but it doesn't excel in any area. The end result is a tale that's intriguing, but not especially exciting. Nonetheless, if you've exhausted most of the big-budget RPGs, Greedfall is still a capable game.

RICK LANE

EXPEDITION

- + Pretty environments
- + Deep quests
- + Varied solutions

LAND GRAB

- – Generally lacks spark
- – Drab colours
- – Unexciting story

/ VERDICT

A competent RPG, but Greedfall's impressive array of features amounts to a strangely inert experience.

OVERALL SCORE

60%

Borderlands 3 / **£49.99** incVAT

DEVELOPER Gearbox Software / **PUBLISHER** 2K Games

Borderlands 3 is a celebration of excess. From its bajillion guns to its enormous cooperative campaign, to a script that seems to have been written on a toilet roll (both in length and in tone), it's an incredibly indulgent experience. If it was a Roman Emperor, Borderlands 3 would be Caligula – decadent, unhinged and prone to frequent massacres.

Unlike Rome's most infamous emperor, however, Borderlands 3 is annoyingly good at what it does. Beneath the glossy and often grimy extravagance, Borderlands 3 is a thoroughly entertaining shooter with a gimmick that, after three games, still hasn't stopped delivering.

Just don't expect much to have changed. Once again, Borderlands 3 kicks off on the desert planet Pandora, with you and up to three friends assuming the role of four new Vault Hunters. Your quixotic quartet are wannabe applicants to the mercenary band, the Crimson Raiders, and they soon discover that the Raiders have been all but obliterated by a group of bandits calling themselves the Children of the Vault, led by a pair of interplanetary Twitch streamers.

We'll get to the writing in a bit. For now, let's talk about the Vault Hunters, who are more or less the only truly 'new' introduction to Borderlands 3. Each of the four Hunters has a unique set of abilities that will fundamentally alter your approach to the game. Our main choice was FL4K, a 7ft-tall robot Beastmaster with the ability to command different AI pets, ranging from a dog-like 'Skag' to a 'Jabber' – an alien Monkey that wields guns.

Other highlights include Moze, a Gunner who can jump into a hulking Mech called Iron Bear, and Zane, who can create a holographic version of himself, essentially playing a cooperative game all of his own.

In addition to the different classes, each Hunter can be played in several different ways, with access to three individual skill trees. For example, the Beastmaster can be specced as an all-out assault character, but also can focus on healing, sending out his pet to revive downed comrades. The skill trees don't have the range of, say, Dishonored, with many unlocks simply improving your damage or healing rate, but they nonetheless offer a diverse range of play styles.

Otherwise, Borderlands 3 relies heavily on its colourful visuals and procedurally generated weapons to keep players interested, so it's just as well that it excels in both areas. It looks superb, with crisp and vibrant cel-shaded graphics that look *phenomenal* in 4K. It's also the first Borderlands game to venture beyond Pandora, offering a variety of planets to explore, including the Cyberpunk city of Promethea and the radioactive swamp world of Eden-6.

More importantly, Borderlands 3 feels satisfying to play. Movement is slick and responsive. Actions such as sprinting and sliding across the ground feel weighty and tactile.

BORDER

- \+ Looks fantastic
- \+ Rock-solid shooting
- \+ Delightfully daft procedural guns

BORED

- – Not much new
- – Too long
- – Grotty humour

However, the game's biggest success is the way it makes countless randomly generated guns feel fantastic to shoot.

Yes, the weapons remain the dark stars of Borderlands 3's show. You can barely walk 50 paces without stumbling on some bizarre and magnificent death contraption. From Gatling rifles that shoot with a crank, to shotguns that reload by exploding, Borderlands 3's arsenal is as eclectic as it is deadly. There are two crucial elements to the system.

Firstly, while some guns are more interesting or effective than others, the vast majority feel satisfying to fire. Secondly, the system delves deep, carefully distributing new types of weapons across the course of the game, which is impressive considering the game's length.

With four players, plus AI companions, firing absurd guns at dozens of enemies, Borderlands 3 is consistently entertaining. That said, it's a shame the game's many guns all do fundamentally the same job, namely shaving numbers off enemy health bars.

There's potential for Borderlands to be a more creative experience, perhaps with weapons that manipulate enemies in other ways, pushing them into one another, swapping them around, letting one player set up the pins for another to knock down. This would make the game a more actively cooperative experience, which would be beneficial in such a long game.

Borderlands 3 is an exhaustively huge game, lasting anywhere between 30 and 60 hours depending on how thoroughly you explore. For much of that time, it does a reasonable job of keeping up the variety, regularly throwing up new locations and, of course, weapons. There are times, however, when it pushes its core to breaking point. One mission set on an asteroid takes around two hours to complete in itself, which would be fine if it didn't very obviously draw out the time with multiple waves of enemies per encounter. Towards the end, it even begins to make jokes about how this is definitely, probably the last wave you'll be fighting.

Speaking of jokes, Borderlands 3 loves the sound of its own voice. The script is more of a screed, a relentless torrent of dialogue filled with frat-house humour and lazy parodies of modern society. That's not to say it's never funny. Some of the enemy death cries such as 'I'll see you in hell ... bring guac' genuinely made us laugh. At the same time, it can also be downright unpleasant, and we don't just mean there's a lot of swearing. Borderlands 3 has a particularly bizarre obsession with dwarfism. Almost every fight includes small enemies with squeaky voices and belittling names such as 'Tink' and 'Nog'. It's mean and unnecessary.

Borderlands 3 is at its best when it's being silly. When you have a big daft gun that kills big daft enemies in a big daft way, it's a hoot. The moment it tries to be edgy or clever, it runs into problems. It's also too long, and is largely a similar experience to Borderlands 2. Nonetheless, it's undeniably a well-made FPS, and while the procedural guns could be more creative, playing with them is a blast.

RICK LANE

/VERDICT

Big and daft, but still quite fun. Borderlands 3 is a satisfactory if not especially ambitious sequel.

OVERALL SCORE

70%

Blasphemous

/ £19.99 inc VATS

DEVELOPER TheGameKitchen / **PUBLISHER** Team17

DIVINE

- + Incredible art design
- + Interesting world and lore
- + Fantastic bosses

WICKED

- − General combat can become rote
- − Too many cheap deaths

/ VERDICT

Blasphemous' mechanics don't quite match the art, but there's still fun to be found in its dark and twisted world.

OVERALL SCORE

73%

From a stylistic perspective, Blasphemous is more interesting than most games inspired by Dark Souls. This challenging 2D platformer takes Dark Souls' theme of punishment, and broadens it out to become the focus of an entire game. If that makes Blasphemous sound horrible, well, it is, but not in the way you might expect.

Blasphemous takes place in the fantasy realm of Cvstodia, whose environment design and general aesthetic is heavily inspired by Catholicism (or at least a specific reading of Catholicism). You play the Penitent One, a conically helmeted paladin who is the sole survivor of a terrible massacre.

Making your way down from the charnel pile, you come across a being who tasks you with taking down the Miracle, a seemingly benevolent deity which has corrupted Cvstodia's populace into guilt-ridden, self-loathing forms. You must carve your way through the mysterious and non-linear environments, unpicking treacherous paths and battling huge bosses.

The main draw is Blasphemous' distinctive, grotesque visual style. Over the course of the game's 20-odd hours, you'll explore steep and snowy mountainsides, charred, dustbowl-like wastelands, toxic underground cisterns and the cavernous interior of Jondo, a giant, upturned bell sunk deep into the ground. These places can be explored in any order, with cleverly interconnecting paths that unlock as you progress.

It's not a lighthearted jaunt, however. Everywhere you go is decorated with human bodies, wracked and bound as they futilely pursue the Miracle's spiritual salvation. Some of them are the enemies you have to fight. Women bound to stone statues of angels try to crush you with their painful burden, while masked men try to rend your flesh using the scourge-like whips with which they flagellate themselves. Enemies often die spectacularly, engulfed in flames or suddenly crumbling.

The remarkable visual presentation is coupled with a rich and cryptic backstory that delves deeper into Blasphemous' pastiche and critique of the Catholic faith. Mechanically, however, Blasphemous is less compelling. Most enemies only have one attack, so fighting them quickly becomes rote. Indeed, Blasphemous' challenge stems less from fighting and more from its frequently treacherous platforming, so your own deaths tend to feel cheap rather than noble.

Fortunately, Blasphemous compensates with its stunning boss encounters, which is clearly where the majority of work on the game's combat has gone. Each boss has multiple attacks that it can mix up, and which evolve over the course of the fight. They're as satisfying as they are spectacular, embodying the corrupt majesty of the game's world. Ultimately, Blasphemous isn't quite as distinctive to play as it is to see, but that doesn't prevent it from being a darkly fascinating adventure.

RICK LANE

Untitled Goose Game

/ **£11.99** incVAT

DEVELOPER House House / **PUBLISHER** Panic!

Untitled Goose Game looks like a gimmicky joke, another Goat Simulator with feathers instead of fur. While there's some gimmickry about it, though, it's well made and genuinely amusing. The premise is straightforward. You're a horrible goose in a lovely British village, and your job is to waddle around said village ruining everyone's day.

Although the village is an open sandbox, you'll progress through its four or five locations along a specific route. At each location, there's a list of objectives to achieve. These include stealing the gardener's hat, chasing a local boy into a phone box and making an old man at the pub fall on his backside.

The game plays out like a smaller, more light-hearted version of Hitman. Each villager you encounter, from the gardener to the shopkeeper, has their own routine. Using a combination of your hardy beak and your loud honk, you need to disrupt this routine, either by picking up and moving an item, or by honking at the right moment. As a simple example, honking makes a boy playing in the street run away, so you can chase and direct him with your honk.

Much of the game's gentle yet daft humour comes from the presentation. House House is an Australian developer, but its pastiche of a prim and proper British village is spot on. Deliberately breaking all the village's unsaid social taboos in the guise of this obnoxious, honking bird feels gleefully liberating.

The animations are perfect, from the arrogant waddle to the way you can spread your wings in a natural yet incredibly aggressive manner. Perhaps the best aspect of the presentation, however, is the dynamic piano soundtrack. Based on a Debussy composition, it alters in both tempo and volume according to the on-screen action, and contributes enormously to bringing out the humour.

It's on the short side, offering merely a couple of hours, although you wouldn't want the joke to run on for too long. Also, the controls can be a little spongy, which makes it difficult to enact precise movements, such as taking an object off a person, or slipping through a narrow gap to escape being caught. It could also do with a few more open-ended objectives, and fewer 'drag X number of items to this spot' tasks.

Nonetheless, Untitled Goose Game is a rare game that deliberately uses its mechanics to create slapstick humour. The fact that it does it well (unlike Goat Simulator) and costs just over a tenner, makes it a treat. The broader concept also has much wider potential, so we can only hope House House explores them further.

RICK LANE

BEAUTIFUL SWAN

+ Great presentation
+ Enjoyable puzzles
+ Genuinely funny

UGLY DUCKLING

– Short
– Iffy control scheme

/VERDICT

Featuring daft puzzles and a wonderful sense of humour, Untitled Goose Game is a splendid little surprise, unlike its titular goose.

OVERALL SCORE

80%

REALITY CHECK

Rick Lane gets ready for hand tracking and takes a lesson from Darth Vader in our monthly VR roundup

OPINION

BEYOND HAND TRACKING

Oculus' announcement that the Quest will support hand tracking raises some interesting notions about how far such technology could be taken; namely, how much of the body can inside-out cameras reasonably track? Touch controllers already simulate the functions of the hand well enough; tracking technology simply makes games that don't require buttons more convenient to play.

But what if VR headsets could expand that technology to also track your feet? Imagine a martial arts game where it's possible not only to punch your virtual opponents, but kick them as well? Such technology would also make certain sports games such as football much more viable.

It even has ramifications for more fundamental elements in all VR games. Instead of scrolling forwards using thumbsticks or teleporting between locations, you could simply run on the spot. In addition, head-to-foot tracking would mean no longer needing to calibrate the floor height each time you play, or having to adjust a single headset for individuals of different heights. Either way, hand tracking alone is a fascinating development. Seeing a road to hapticless VR only a few years after VR arrived in the first place is quite an achievement.

REVIEW

STAR WARS: VADER IMMORTAL EPISODE II / £7.99 inc VAT

DEVELOPER ILMxLAB / **PUBLISHER** Oculus

The first episode of Vader Immortal (see Issue 193, p74) was an entertaining – if slight – slice of Star Wars fun. Episode II is simultaneously more entertaining and also slighter. The story is even shorter than the first episode's fleeting length, offering only half an hour of VR fun. However, it's a much pacier episode than the first, with less downtime and more action sequences. Meanwhile, the game's second iteration goes a long way to make up for the story's (literal) shortcomings.

Episode II picks up directly where Episode I left off, with our fledgling Jedi firmly in the clutches of Darth Vader, trapped inside his castle on the planet Mustafar. Having only just discovered you're capable of wielding the Force, the Dark Lord of the Sith offers a deal. He'll help you learn the ways of the Force in exchange for your help in finding the Bright Star, a powerful artefact Vader plans to use to bring Padme back to life.

As such, you get a lesson in Force use from the galaxy's sternest teacher, with Vader teaching you how to pick up and throw objects using the Force by chucking rocks at your head. Force-throw is the main new feature of Episode II and it's a satisfying one. Objects are levitated by squeezing the grip triggers of the touch controller, and can be drawn quickly into your grasp by pulling back your arm. You then simply throw the object as you would in real life, propelling it at lethal speeds across the room.

Vader's lesson plan is quickly cut short, however, when a four-armed rancor (a quad-cor?) attacks, separating Vader from his new protégé. From this point, you proceed to explore the underbelly of Vader's castle, an ancient temple guarded by robotic Sentinels. The remainder of the episode switches between being attacked by these Sentinels and being harassed by the rancor. Both problems are primarily resolved using your new Force-throw ability.

It's undeniably a fun ability, especially when you use both hands to pick up one of the droids, then slam it into another

Sentinel, turning both of them into a knotted pile of metal. However, the excellent lightsaber combat from the first game gets far less attention in this Episode, and there's no getting away from the fact that the whole experience is extremely brief.

Fortunately, Episode II makes up for the brief story mode with a much improved lightsaber dojo. Not only does it feature a much greater mixture of enemies, including lighstaber droids, remote, and what we can only describe as flying goblin things, it also adds the Force abilities from the story mode *and* the ability to throw your lightsaber at enemies, which is unbelievably satisfying. The only real downside is that you don't get to fight any Stormtroopers or other Jedi. Hopefully, we'll get some full-blown Jedi vs Sith combat in the final episode.

VADER WAY

- + Excellent production values
- + New force-throw mechanic is fun
- + Lightsaber dojo is excellent fun

FADE AWAY

- − Not long enough
- − Not much lightsaber combat in story

VERDICT

Vader Immortal remains entreatingly Star Wars, but this is a fleeting adventure even by VR standards.

OVERALL SCORE

74%

NEWS

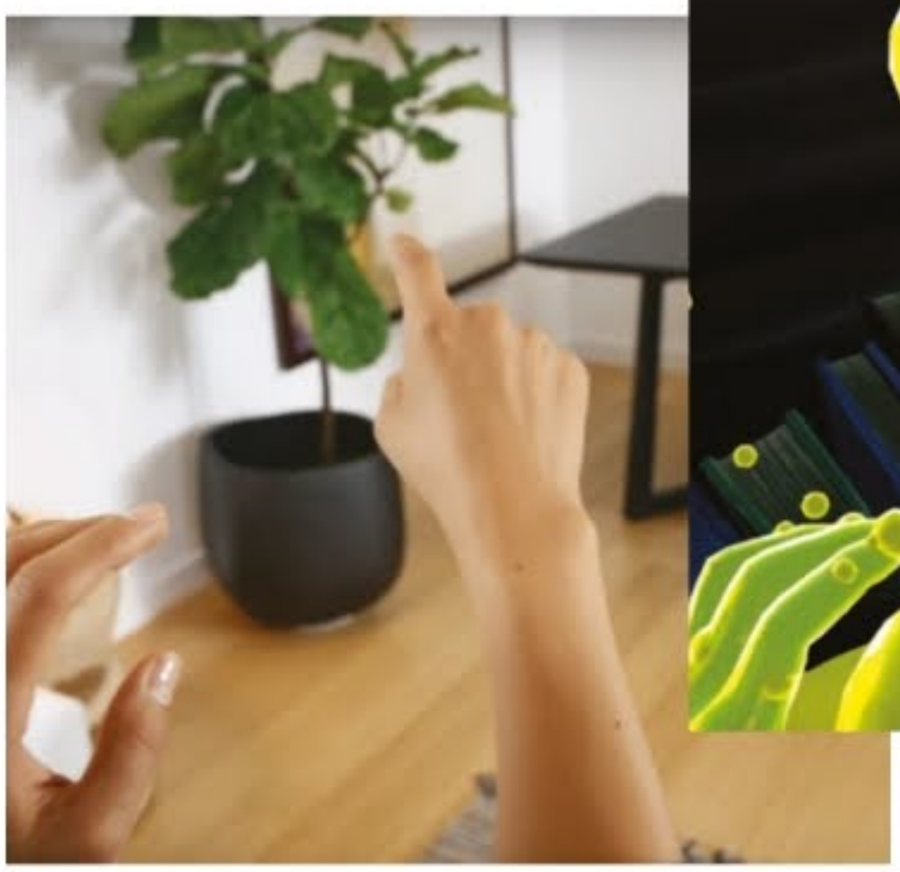
VALITY FAIR

The Oculus Quest is already the best all-round VR headset on the market, but it's soon to become even better with two updates. The first is Oculus Link, a software update that will enable the Quest to tether to a PC and play Oculus Rift games using a USB 3 cable. This essentially negates one of the Quest's main drawbacks – its separate and limited game library. How well the Quest will run Rift games is a question we can only answer once the feature is released, but if it works well enough, it will be a huge step forward for the standalone headset.

The second feature Oculus is hand tracking, which basically means you'll no longer require touch controllers to play VR games. That's right, you'll be able control VR games using just your own hands – picking up, throwing and manipulating objects exactly as you would in real life.

This doesn't come without issues though. Existing VR games may encounter compatibility problems, as they require buttons, which you obviously won't find on human hands. On the other hand (pun slightly intended), if the Quest's hand tracking is precise enough to track individual fingers, it could massively expand the potential for interaction in VR games. For example, imagine being able to rewire a circuit in VR using your fingers.

Hand tracking is set for beta in January, while Oculus Link should be available by the time you read this magazine. Any USB 3 cable will work for tethering your Quest to your PC, although Oculus has developed a special low-latency fibre optic cable specifically for the Quest that will cost around £50 inc VAT. CPC



PC BUILDING MASTERCLASS

BEN HARDWIDGE TAKES YOU THROUGH THE PROCESS OF BUILDING A SMART PC FROM START TO FINISH

Imagine that you're looking round a prospective new home, and instead of all the electrical wires being neatly hidden under floorboards and inside walls, they're snaking across the floors ready for you to trip over them. The pipes for the central heating are also climbing all over the walls and sticking out of the floorboards, and the extractor fan in the bathroom is the wrong way round, so it doesn't do its job. The house might technically have everything you need, but you wouldn't want to live there.

It sounds ridiculous, but we've seen plenty of home-built PCs with cables blocking upgrade paths and airflow, and with fans positioned in a way that will make your components run hotter. Building a PC properly isn't just a case of ordering the parts and slotting them together like a piece of IKEA furniture. You also need to know the basic theory about which bits should go where, and how to route cables and set up airflow properly.

That's where we can help. Building your own PC means you can choose the exact specification you want for your needs, and it can be hugely rewarding. There's nothing quite like looking at a neat and tidy build with the knowledge that you did it all yourself. Over the next few pages we'll show you how to construct a smart PC that you can proudly sit on top of your desk.

CHOOSE YOUR SPEC

For this feature, we're going to focus on the build process, rather than which components you should buy, but there are a few pitfalls to avoid. Firstly, before you buy any parts, make sure they're compatible. You need to make sure there's room for your chosen motherboard, CPU cooler and graphics card in your case, for example.

TOOLS YOU'LL NEED

NO. 2 PHILLIPS/ CROSSHEAD SCREWDRIVER

A No.2 Phillips screwdriver is essential for most of the large screwing jobs in your PC, from installing your motherboard to tightening up thumbscrews. Get a long, thin one, rather than a short stubby one, so you can easily get it into tight spaces and have plenty of reach. If your screwdriver doesn't already have a magnetic tip, slowly run a strong magnet up and down it several times. A magnetic tip is invaluable if you fumble any of the screws inside the case, where they then risk shorting out your motherboard.

CABLE TIES

These are the key to a neat and tidy system. You'll likely get a bag of cable ties with some of your components, but we find we nearly always need more and a bag of ties only costs a quid anyway.

MINI SCREWDRIVERS

Some screws require a smaller tip than a No.2 screwdriver, such as the ones often found on CPU cooler mounts. A simple pack of mini screwdrivers will stand you in good stead here.

PLASTIC CUTTERS

Although you can snip cable ties with scissors or pliers, dedicated plastic snippers do it really quickly and easily.

NEEDLE-NOSE PLIERS

A basic set of needle-nose pliers will be handy for unscrewing any stubborn standoffs, and any jobs where you need some grip.

You will also need to make sure your motherboard and CPU are compatible. If you want to use one of AMD's 3rd-gen Ryzen CPUs, you ideally want a board based on AMD's new X570 chipset. Alternatively, most B450 or X470 motherboards will support these new CPUs, but they may require a BIOS update – ask the retailer if they can update the BIOS to the latest version for you before you buy one. Meanwhile, we recommend a motherboard with a Z390 chipset for Intel's 9th-gen CPUs (or B365 if you're not planning to overclock your chip).

You'll also need to make sure that your chosen CPU cooler has mounts for your CPU socket, and that your power supply has enough power for your chosen setup. If in doubt, looking at our Elite list (see p62) is a good place to start, where we recommend particular component combinations for a few builds.

INSTALL CPU

Your first job is to get your basic system up and running, so you can test the core components. It's incredibly annoying to find out that you've got a faulty part *after* you've built the whole PC, so it's best to find out now. Start with the CPU.

On an AMD AM4 system, remove any cover from the CPU socket on your motherboard, and lift the handle next to it to loosen the socket's grip. There will be a gold triangle on your CPU, which denotes pin 1. Line up this corner with the corresponding triangle-labelled corner on your CPU socket and, holding your CPU by the edges, carefully place it in the socket without touching the delicate pins. Once it's in place, push down the handle to secure the CPU in the socket.

On an Intel LGA1151 system, remove any cover from the CPU socket, then push down

INTEL LGA1151 **AMD AM4**

Apply thermal paste to AM4 CPUs in a cross shape

the handle slightly, and lift it out and up to loosen the socket. You can then lift up the metal plate, and place your CPU in the socket. There are notches to ensure you can only install it the right way around, but you can also get it right first time by lining up the triangle-labelled pin 1 corners, as with AMD CPUs. Once the CPU is in the socket, flip the metal plate back down again, with the notches on the end going on either side of the motherboard's holding screw. You can then push down the handle to secure the CPU in place.

FIT COOLER

At this stage, you only want to quickly test your core configuration, so we recommend fitting the stock cooler made by Intel or AMD that comes in the retail boxes for some retail CPUs, rather than faffing with a more involved cooler mounting mechanism. If you don't have a stock cooler (irritatingly, a lot of Intel retail boxes no longer come with them), you'll instead need to check the instructions for your chosen CPU cooler and fit it now (see p81).

You may also need to apply some thermal paste at this point, to fill the microscopic pores in the CPU heatspreader and your cooler's contact plate, and to fill any gaps where these surfaces aren't completely flat. AMD and Intel's stock coolers often come with a layer of thermal paste screen printed onto the heatsink, in which case you can skip this step. However, if you need to apply your own thermal paste, you'll need to put it directly onto the CPU yourself. We have a full guide to thermal paste on our website at **custompc.co.uk/worldofgoo**, but we'll take you through the basics here too.

For AMD CPUs, apply a cross shape from corner to corner across the heatspreader. For Intel CPUs, a line down the middle of the heatspreader is best. When your cooler's contact point presses onto the CPU, the pressure will spread the paste across the heatspreader.

AMD's AM4 stock coolers are pretty easy to install. There are two plastic brackets on either side of your CPU socket, and two corresponding metal hooks on either side of the cooler, one of which will have a handle. Orientate your cooler so that the power cable is as near to your motherboard's 'CPU fan' power header as possible.

Place the hook without a handle over the clip on the nearest plastic bracket. Once that's in place, make sure the handle on the other metal hook is in the loose setting, and place its hook over the other bracket's clip. You can then push down the handle to secure the cooler in place, and plug the power cable into the CPU fan header.

Install your CPU's stock cooler if it has one, and connect it to the CPU fan power header on your motherboard

Intel's LGA1151 stock coolers aren't too hard to install either. There will be four holes on the motherboard around the CPU socket, and four corresponding plastic plugs on the cooler. Push the transparent plastic plugs through the holes. You'll then need to push down the black plastic part in one of the plugs, and turn it to secure it in place. Repeat this step with the plug diagonally opposite the one you've just done, then do the other two. You can then plug the cooler's power cable into the CPU fan header.

Flip back the clips next on the DIMM slots you want to use

Push firmly on the memory module until the clips flip up to grip it

INSTALL MEMORY

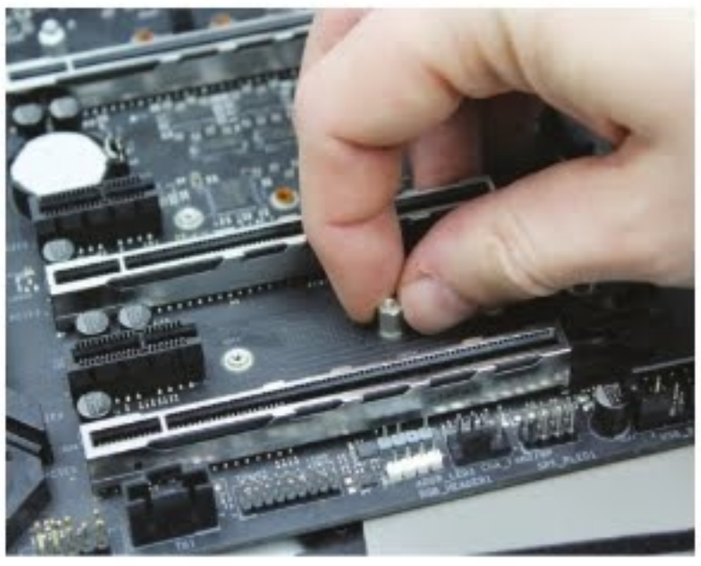
Check your motherboard manual to find out which DIMM slots you need to use to enable dual-channel mode. By installing two memory modules in this mode, rather than just one module, you can get a performance boost, as the two modules will interleave and give you more bandwidth.

Place your motherboard on a firm flat surface, then flip back the clips on the sides of the memory slots you want to use. Some motherboards only have a clip on one side of the slot, while some have one on either side, but the basic principle here is the same.

Once any clips are flipped down, look at the pins on the underside of your memory module and see where the notch is located. Line up the position of the notch with the corresponding slot to gauge which way around you need to install your memory – it will only go in the right way.

Place the memory into the plastic slot's surround, making sure the edges are both inside the area next to the clips. Push down firmly on the memory module to push it into the slot, which will force up the clips to grip it.

FIT M.2 SSDS



Screw in a standoff for your SSD

Insert the drive at an angle

Push it down

Screw it into place

Repeat this step with any other memory modules you want to install.

FIT M.2 SSDs

The latest NVMe SSDs can get hot, so if possible, we recommend fitting them to the slots furthest away from your graphics card. Check your motherboard manual first to see which of your motherboard's slots support your chosen SSD's protocol – some slots only support SATA or NVMe drives rather than both.

Your M.2 slots may also only be accessible by removing a shroud or heatsink from your motherboard. If your board includes individual M.2 heatsinks, and your drive isn't already fitted with a heatsink, we recommend fitting one to your SSD if it's an NVMe model.

To install your SSD, look at the slot and make sure there's a metal standoff screwed into the appropriate screwhole for your SSD's length – the standoffs will be in your motherboard box, and you'll need to fit one in the hole that will be under the notch at the end of your SSD. Then insert your SSD into the slot at an angle, push it down, and screw it into place using the screw that came with your motherboard standoff.

FIRST TEST

You now have the core system basically setup. The next step is to check that it works, which will mean plugging in your power supply, graphics card, keyboard and monitor. We recommend placing your motherboard on top of its box for this step, as it lifts the board off your table and gives you room around the edge for your graphics card's I/O plate. Once your motherboard is on its box, with the back right against the edge, carefully insert your graphics card into the 16x PCI-E slot nearest the CPU.

We now need to hook up the basic power connectors. The first one is the large 24-pin ATX connector on your power supply, which needs to go into the corresponding socket on your motherboard, it's normally on the right hand edge. It will only go in one way around, with the clip on plug hooking onto the socket on the motherboard.

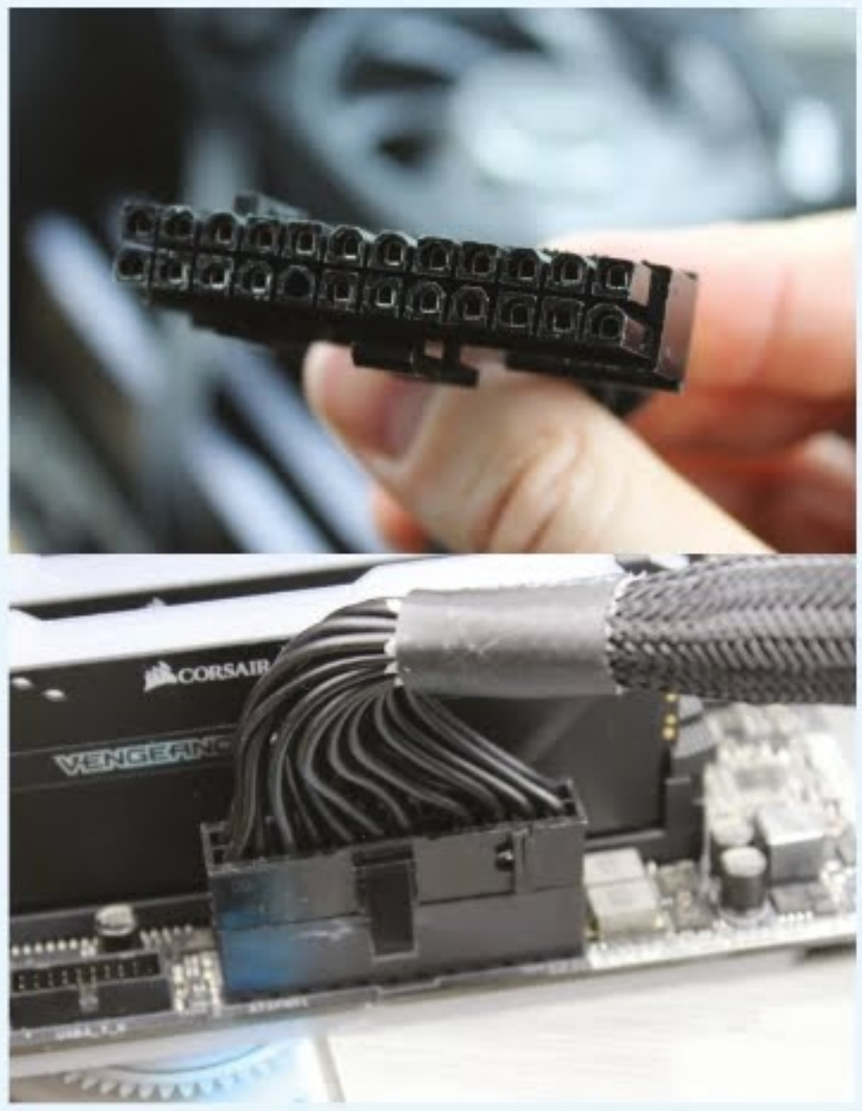
Next is the 12V CPU power connector, which usually has eight pins, but isn't to be confused with your power supply's 8-pin PCI-E

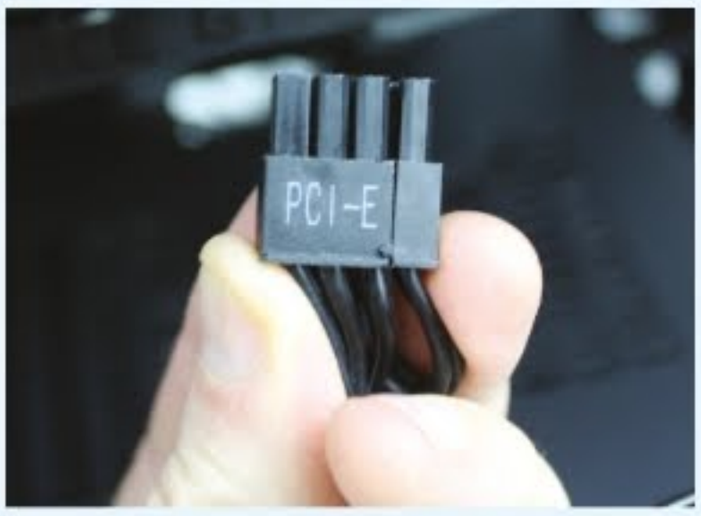
Your motherboard box makes an ideal surface for testing your core spec

power connectors. Your power supply's CPU 12V plug will usually have a larger clip than the PCI-E plugs, and it will often also be labelled 'CPU'. This plug goes into the corresponding socket on your motherboard, which you'll usually find on the top left of the board above the CPU socket.

Finally, plug in any PCI-E power connectors for your graphics card – they should be labelled 'PCI-E' on your power supply's plugs. You'll usually find the sockets on the top-right edge of the card, with either 6-pin or 8-pin (or sometimes both) sockets. Your PSU will likely have 6-pin plugs, with optional pairs of pins next to them, which you can push next to the 6-pin plug to make an 8-pin plug if you need one. You'll only be able to install the plugs one way around, and you can easily see which way by lining up the clips on the plugs with the protrusions on the graphics card's sockets.

Plug the large 24-pin ATX plug into the socket on your motherboard – it's usually on the right





You may need to push two parts together to make an 8-pin PCI-E graphics connector, then plug it into your graphics card

You now have a fully powered basic core system. Plug a keyboard and mouse into the USB ports on the back of the motherboard, then plug the power supply into the mains and connect your monitor to one of the DisplayPort or HDMI ports on the back of your graphics card. Then flip your power supply's rear switch to the on position.

If you're lucky enough to have a motherboard with an on-board power button, just push it to start your new machine. If not, find your motherboard's front panel headers, which are usually at the bottom right of the board. Check your motherboard manual to identify the two pins for the power switch. You can short them out by placing a metal screwdriver between the two pins and start your machine.

If your PC starts, enter your motherboard's EFI (usually by pressing Del on startup) and check that your motherboard has correctly identified all your memory, your CPU and your SSD. If all is working fine, go to the next step. If your PC doesn't start, you'll need to diagnose the problem. Start by switching off the power supply and double-checking that all the power connectors are plugged in securely.

If that doesn't solve the problem, try reseating the core components one by one. Start by carefully removing the graphics card (flip down the clip on the edge of the PCI-E slot first) and then placing it firmly back in the slot. If that doesn't solve the problem, do the same with the memory and, as a last resort, try the CPU.

It's also worth checking your motherboard manual at this point. If your motherboard has a POST code display, check the final code it displays with the chart in your motherboard manual – this will help to pinpoint the problem.

Use a screwdriver to short out the power switch pins and start your test system

If your motherboard doesn't have a POST code display, it may have error beep codes, emitting a series of beeps that can help you identify problems.

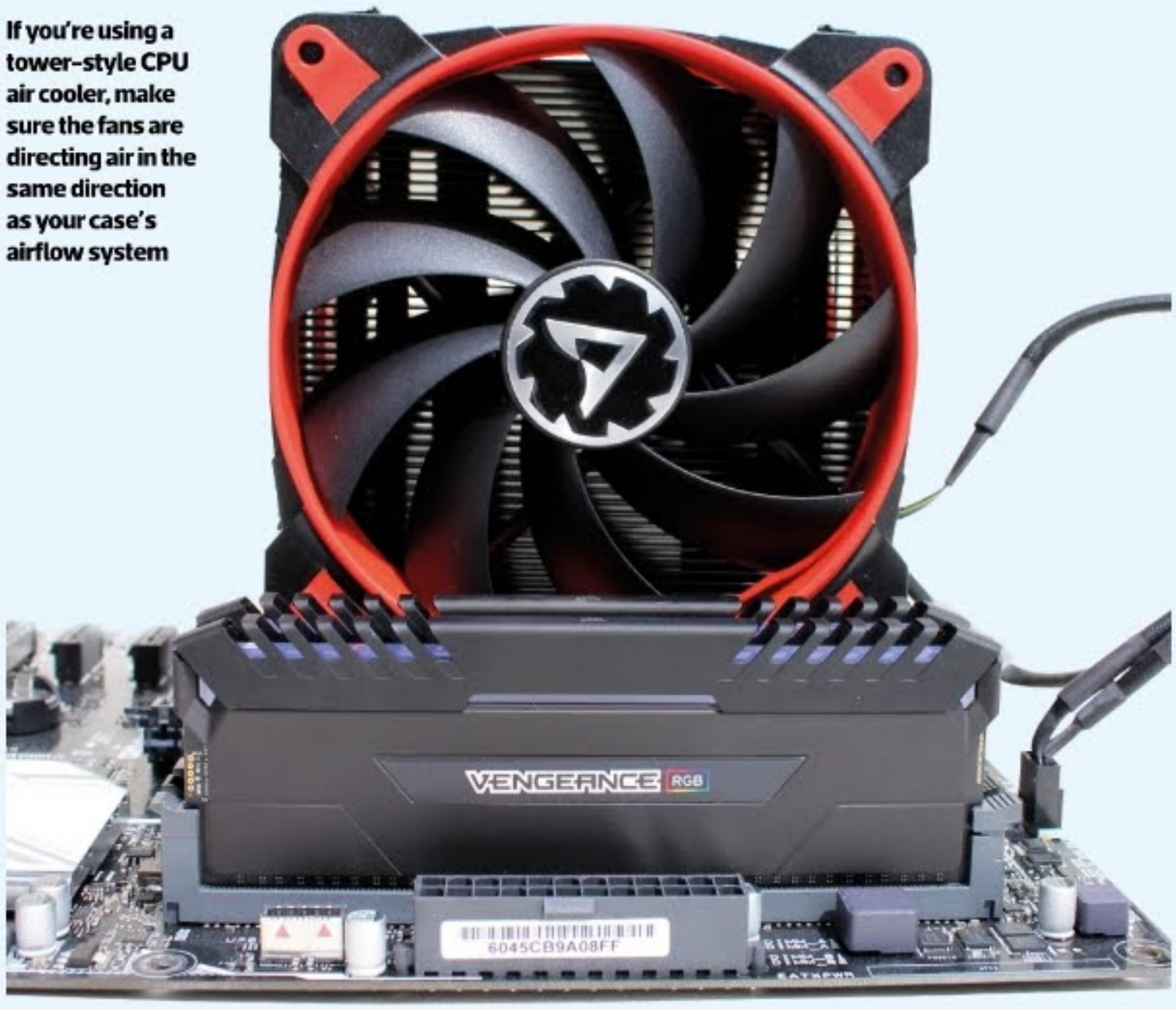
If you're still struggling, see if you can find a friend with a similar component setup to yours – they may be able to lend you a component or two so you can swap yours out and see if you have a faulty one. PCs can be a pain when they don't start, but if you do have a fault it's usually only one component that's to blame – it's just a question of finding it by process of elimination.

PLAN YOUR BUILD

Now put the core system to one side, take the side panels off your case, and have a

If you're using a tower-style CPU air cooler, make sure the fans are directing air in the same direction as your case's airflow system

The CPU 12V socket is usually found in the top-left corner of the motherboard



good look at. Before you even start thinking about grabbing your screwdriver, take a look at all the cables you'll need to plug into your system and think about where you're going to route them.

Most new cases come with holes dotted around the motherboard, through which you can thread your cables from the back of the case. The idea is that all the cables will be tied to anchor points behind the motherboard, and then threaded through these holes to the components in the main area.

Start with your power supply. If you have a modular or semi-modular PSU, you only need to connect the cables you require for your system. The bare essentials will be the power cables you just connected to your core test system. However, you may also need some SATA connectors for any extra storage drives, as well as the fan controllers or lighting systems that come with some cases and CPU coolers.

If you're using an all-in-one liquid cooler, have a good look at the cables before starting your build and work out where they'll go. You should be able to neatly thread every single one of your cooler's cables through to the back of the case.

The next factor to consider is airflow. Most cases work with a front-to-back airflow system that pulls cool air from the front, pushes it over your components and then expels hot air out the back of your case. For this feature, we're going to assume that you're using a case with a standard front-to-back airflow system. You ideally want at least one intake fan at the front (preferably two), with the back(s) facing the motherboard inside the case, and one exhaust fan with its back facing the rear of the case.

If you're using a tower-style CPU air cooler, you'll need to make sure the fans are directing air in the same direction as your case's airflow system, so the fan(s) should be on the side(s) of the cooler rather than the top or bottom, with their backs facing the rear of the case. If that's not possible, the best alternative is to have the backs of the fans facing the roof of the case, so they push hot air out the top.

That's also what we're doing with our example all-in-one liquid cooler, with the fans pushing air through the radiator and out the top of the case. The basic idea is that you're moving hot air out of your case, rather than letting it waft around your motherboard.

FIT FINAL CPU COOLER

Once you've worked out the optimal airflow setup for your components, and planned where your cables are going to be routed, it's time to start the final build. Your first step, if you're not using a stock cooler for your CPU, is to remove the stock cooler from your core test system.

With an Intel system, simply rotate and lift all the black parts of the plugs to loosen the cooler, and then gently jiggle it from side to side, so you can lift the cooler off the CPU. You can then carefully clean your CPU with some TIM cleaner or isopropyl alcohol and a lint-free cloth.

With an AMD system, loosen the handle on the stock cooler, and then very gently wiggle the cooler from side to side. Be very careful with this stage, as it's distressingly easy to accidentally yank an AM4 CPU out of its socket with the cooler stuck to it, and bend a load of its pins in the process.

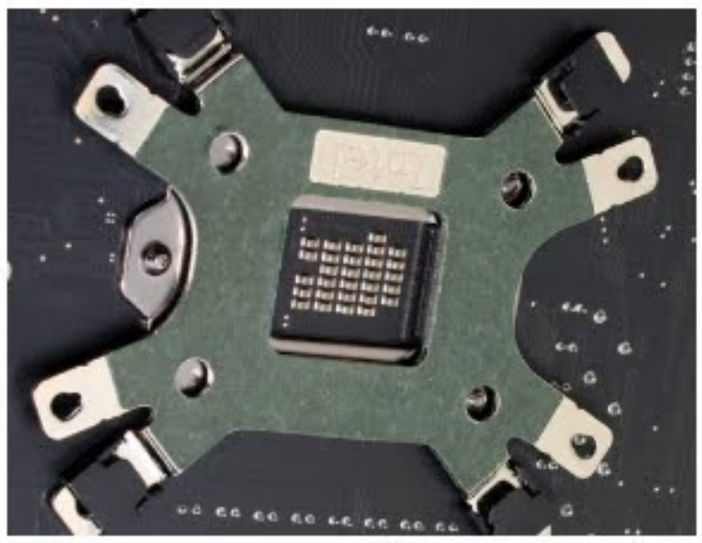
If you're facing resistance, try directing a hairdryer over your CPU for a little while to loosen the thermal paste. Only lift off the cooler when there's little resistance and you're confident the cooler will come off without taking the CPU with it. You can then carefully clean your CPU with some TIM cleaner or isopropyl alcohol and a lint-free cloth.

You now need to get your chosen CPU cooler ready, if you're not using a stock model. The mounting systems for many CPU coolers require a backplate to be fitted to the rear of the motherboard, in which case you need to follow your cooler's mounting instructions for your chosen CPU socket now.

Once any mounting backplates are in place on the motherboard, apply thermal paste to your CPU as we did on p78, then install your CPU cooler, making sure you remove any plastic sheet from the contact plate first. If you're installing an air cooler, point the fans so that they're directing airflow over your CPU and out the back of your case, or out the top of the case if that's not possible.

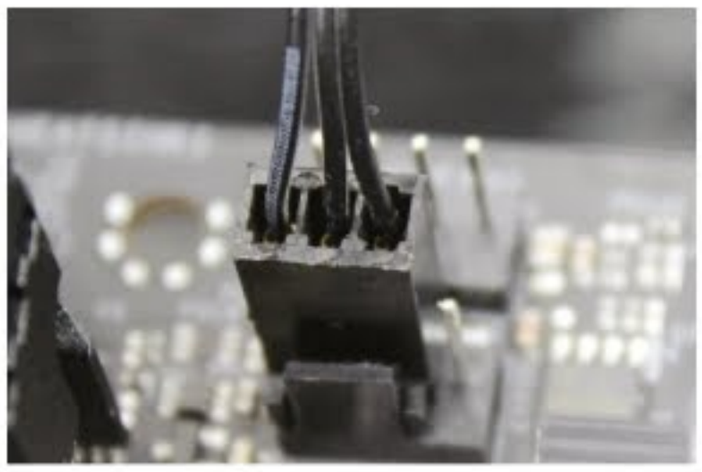
If you're fitting an all-in-one liquid cooler, you'll need to fit the pump/waterblock unit on top of your CPU, ideally with the tubing on the right of the CPU and any logos facing the correct way up, leaving the radiator for the moment. You then just need to plug the power cable from the pump into a header on the motherboard – these days there's usually a specific one for pumps, which you should be able to find by consulting your motherboard manual.

CPU COOLER



Some coolers require a backplate to be fitted to the rear of the motherboard

Fit the pump/waterblock unit to your CPU, following your cooler's instructions



If your motherboard has a dedicated power header for pumps, use it

Screw the fans to the radiator, ensuring that the power cables are on the right side to go through your case's cable-routing holes

If you have a modular or semi-modular PSU, you can cut clutter by only connecting the cables you need

Thread the cables through the back of the case, and push the PSU into place

Screw the PSU into place at the back

Finally, fit the fans to the radiator on the same side of the radiator as the tubing connectors, with the backs of the fans facing the radiator. Make sure the edges of the fans with power connectors are all facing the edge of the radiator that will face the motherboard tray, so you can easily thread the cables through the holes above your case's motherboard tray. Handle the radiator carefully, making sure you don't drop it or scrape it against your motherboard.

INSTALL POWER SUPPLY

Take a look at your case's power supply mount, and check your case's manual to see which way up your power supply should go. They usually slot into a bottom mount with the PSU's fan facing downwards, but some cases are optimised for different airflow setups.

Now remove both of your case's side panels, and thread all of your PSU's cables through the PSU mount and out the side of the case behind the motherboard tray. If you plan to install an all-in-one liquid cooler radiator in the roof, now is also a good time to remove any panels or covers on the top of your case. Once all the cables are in the area behind the motherboard tray, slot the PSU into place, and screw it into its mount at the back – it should need just four screws, but some cases also require an additional mounting plate to be screwed to the back of the PSU first.

CABLE ROUTING

Now take a look at the positions of the 24-pin ATX and 8-pin CPU 12V sockets on your motherboard, and compare them with the holes in your case around the motherboard tray. Thread the cables through the holes nearest where the sockets on the motherboard will be positioned when it's installed.

There should be a hole just outside the top-left edge of the motherboard tray for the CPU 12V plug, and a hole to the top right of the motherboard tray for the 24-pin ATX plug. Don't tie down any cables yet – you still want a little flex in them until the whole build is finished.

While you're here, locate your case's cables for its front panel lights and buttons, as well as any front-mounted USB and audio ports – they're often bunched together at the front of the case. Again, thread these cables from the back of the case to the front through the holes nearest the corresponding headers on your motherboard.

The front panel connectors are usually at the bottom right, the front panel audio header is usually at the bottom left, and the USB headers are usually on the right of the motherboard, as well as on the bottom. There should be holes below the motherboard tray for routing these cables. Similarly, if your case doesn't have a fan hub, route the power cables for your case's fans through the appropriate holes to meet your motherboard's fan power headers.

INSTALL MOTHERBOARD

If your motherboard has a separate backplate for the I/O ports on the back, push it into the large hole on the back of your case now, pushing in each corner firmly.

Next, double-check the screwhole layout on your motherboard, and compare it with the standoff layout of your case. Standoffs have a threaded hole in one end and a screw thread on the other end, and they create a gap between your case and your motherboard, ensuring that your metal case doesn't end up shorting out the solder traces on your motherboard.

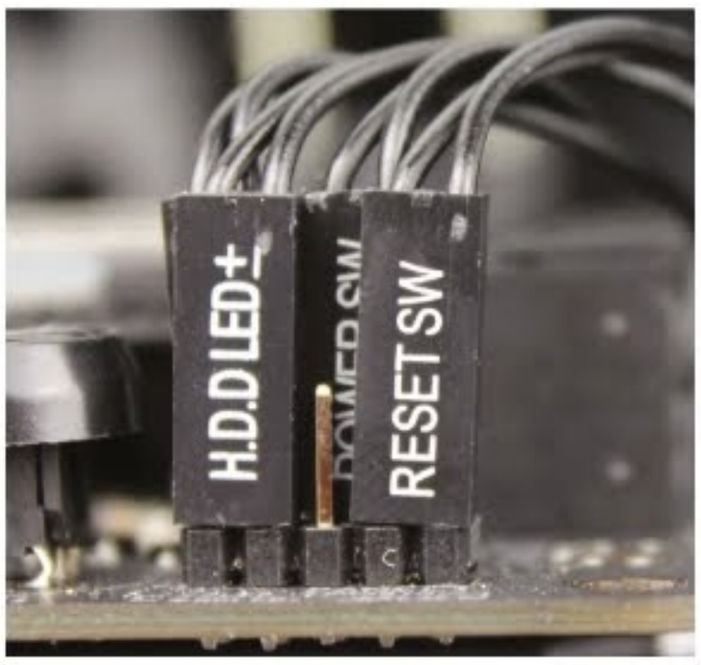
Some cases don't have standoffs fitted as standard, in which case they'll be in the accessories bag and you'll need to fit them to your motherboard tray, corresponding with the screwhole layout on your motherboard. Either way, make sure the standoffs and motherboard screwholes line up correctly – you don't want a standoff grating against a part of your motherboard. You can remove and install standoffs with a female hex tool, or with your pliers.

Now lay your case on its side, with the motherboard tray facing upwards, and locate the case's front panel connectors you threaded

There should be a hole by the top left of the motherboard tray for routing your CPU 12V power cable

Route your power and front panel cables through the appropriate holes to reach the sockets on your motherboard

INSTALL MOTHERBOARD



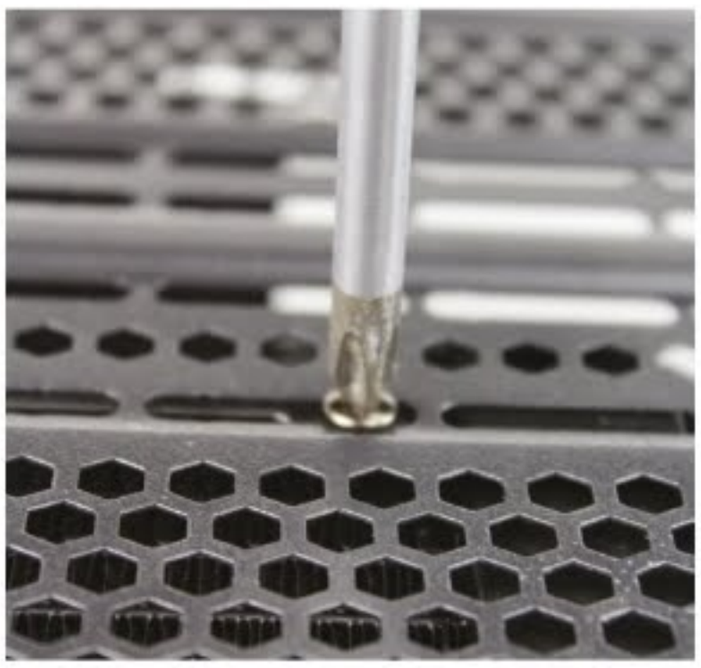
Connect the front panel headers before securing the motherboard in the case

Carefully install your motherboard in the case without scraping the bottom against your case's standoffs

Screw the motherboard into your case's standoffs using the screws that came with your case

Once your motherboard is secured, plug in the cables

Offer your radiator up to the roof area and line up its screwholes with the ones in the top of the case



Secure the radiator into place using the screws that came with your cooler

If your CPU cooler has multiple fans, it should have an adaptor cable that connects to a single power header

Connect the power to any lighting or fan controllers you're using, setting them up behind the motherboard tray

through the bottom cable-routing holes earlier. It's much easier to fit these connectors now than when the motherboard is screwed into your case, so offer up your motherboard to the case and hook them up. If you're using an all-in-one liquid cooler, make sure the radiator doesn't suddenly drop onto the motherboard and damage it.

You can now carefully put your motherboard in place, making sure it slots into the I/O plate at the back (if it uses one) and that the screwholes all line up with your case's standoffs. If you're using an all-in-one liquid cooler, rest it carefully on top of the motherboard, or over the top of the case, so it doesn't suddenly drop on the motherboard.

Be very careful not to scrape the bottom of your motherboard on the standoffs here – put the motherboard into the case at an angle and then drop it down, rather than sliding it across the standoffs. When it's in place, use your case's motherboard screws to secure it. You can then plug all the cables into your motherboard.

If you're using an air cooler for your CPU, you can now skip to the next step. If you're using an all-in-one liquid cooler, thread all of your CPU cooler's fan and lighting cables, except the one for the pump (which should be attached to the motherboard), through the holes above the motherboard tray.

SATA drives need two cables – one for power and one for data

Mounting 2.5in SSDs behind the motherboard is a great way to keep them (and their cables) out of the motherboard area

Unscrew and remove the expansion slot covers next to (and below) your top 16x PCI-E slot

If your CPU cooler has multiple fans that need to be hooked up to a single motherboard header, it should have an adaptor cable that takes all the fan cables and diverts them to a single cable. Connect this up now around the back of the motherboard tray, and route the cable back through to the front and plug it into your motherboard's CPU fan power header.

Now hold the radiator in the roof, and line up its screwholes with the corresponding holes in your case's roof. You can then screw it into place using the screws that come with the cooler. Finally, if your cooler has any cables for lighting, hook them up now – either to its own lighting controller, or to the RGB headers on your motherboard.

SATA DRIVES

Now is a good time to install any traditional SATA drives, such as 2.5 in SSDs or 3.5in hard disks. Each drive will require a SATA data cable that connects to the motherboard (usually in the bottom right corner), as well as a SATA power connector from your power supply. As with the rest of your cables, have a look at your case before you start and think about how you're going to route the wires to your drives.

Carefully plug your graphics card into the slot, lining up the I/O plate with the case's expansion slot holes

Finally, connect your power supply to your graphics card

Many cases, such as our Thermaltake Commander C34, have 2.5in drive mounts on the back of the motherboard tray, which are great for keeping drives and wires out of sight. You can hook up the power behind the motherboard tray, and route the SATA data cable through a hole next to the bottom right corner of the motherboard.

You won't be able to mount a hard drive behind the motherboard, as they get hot and ideally need some airflow. Most cases have hard drive mounts in cages at the front, and they're often removable. We recommend removing any cages that you're not using, so you can maximise airflow.

If you're installing a hard drive, choose a mount next to one of your case's front fans, so it gets plenty of airflow. If possible, mount the drive with its connectors facing the rear of the case, so you can hook up the power behind the main motherboard area, and route a SATA data cable through a cable-routing hole next to the bottom-right corner of the motherboard.

INSTALL GRAPHICS CARD

Once all your cables are connected to your motherboard, and none of them is trailing

Put the tapered end of your cable tie in its socket and pull it tight around your gathered cables

When your cables are tightly secured, snip off the end of the cable tie

The rear of your PC doesn't need to look amazing – it just needs to keep your cables securely out of the way

across the motherboard area, you can fit your graphics card. Remove your case's expansion slot covers next to the top 16x PCI-E graphics slot on your motherboard. Then line up the graphics card's metal I/O plate on the back so that it will slide between your motherboard and the back of your case, and slot it into the top 16x PCI-E slot.

Screw the rear metal I/O plate into the case using your case's provided screws or thumbscrews, and connect the PCI-E power plugs that you previously routed through to the graphics card area.

TIDY THE CABLES

Your final job is to tie down as many cables as possible to keep them out of the way. If the PCI-E power cable for your graphics card has a spare plug dangling, tie it to the cable behind the graphics card to keep it out the way. Your case should also come with numerous 'anchors' specifically for this purpose.

These anchors have a space on either side of a raised piece of metal in the middle, enabling you to insert a cable tie under the raised piece of metal, gather cables together next to it and then tie them together, securing them in place. Cable ties are simple to use – you just wrap them around your cables, preferably securing them to an anchor, put the tapered end of the cable tie through the socket, pull it tight and snip off the end with your plastic cutters.

Before you start, take a good look at the wiry mess in front of you and think about where it will be both tidy and practical to anchor the cables. Gently pull any cables tight so that only the plugs and a little bit of cable are visible in the main area. Also, remember that you need to put your side panel back on the case at the end, and this won't be possible if there are huge bundles of cables blocking the clearance. Try to keep your cables behind the motherboard tray or hard drive cages, so they don't protrude from the edges and spoil the look of the main interior area.

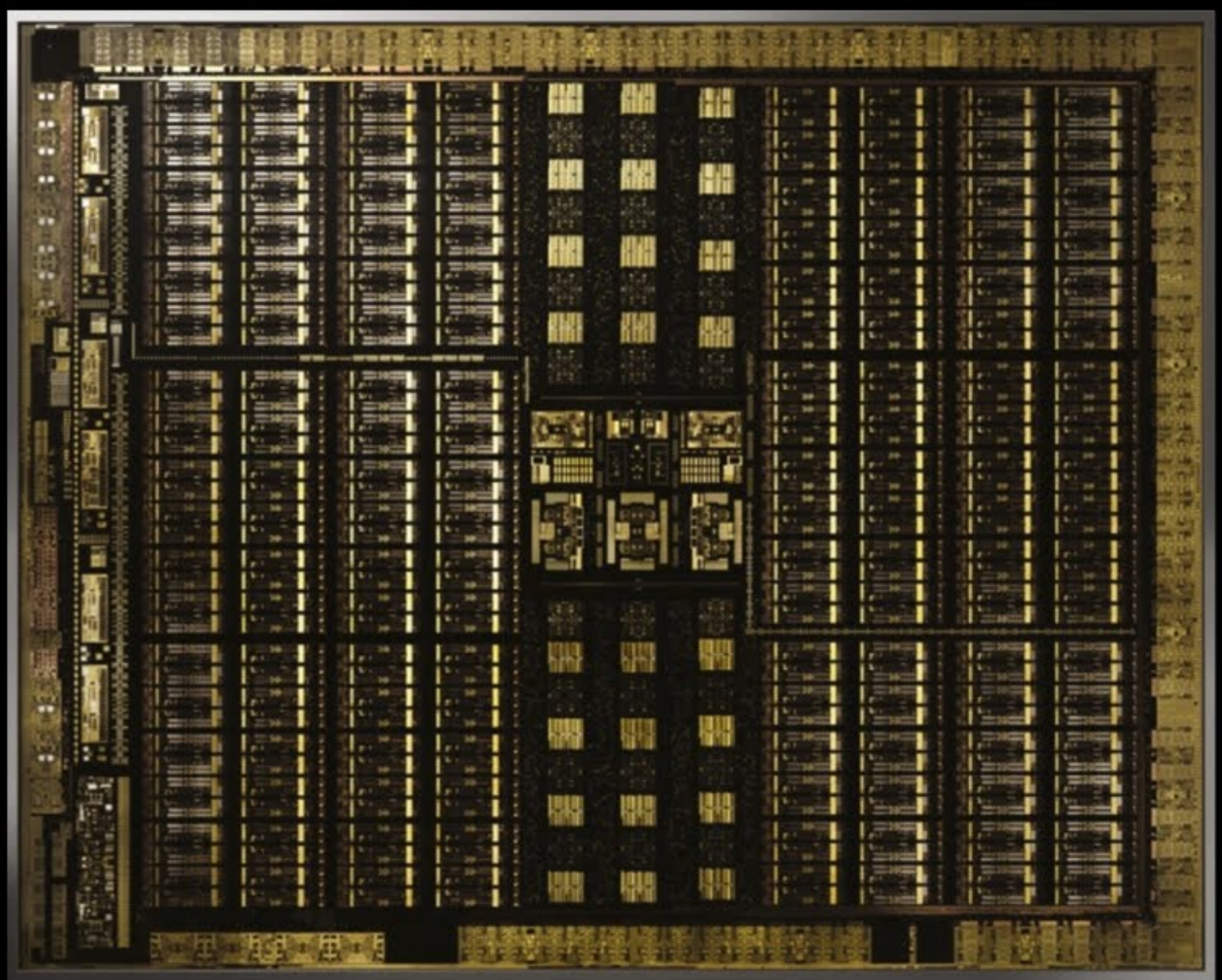
Look for any nooks and crannies where cables can be stored, and position some of the cables side by side, rather than having them all on top of each other to avoid unwieldy bunches. You'll also need to avoid routing cables in the way of holes for your side panel's catches.

Anchors at the top are ideal for gathering together cables for an all-in-one liquid cooler in the roof, while anchors on the top right are ideal for keeping your CPU 12V power cable out of the way. The crucial area will be on the left of the motherboard tray, where your ATX and PCI-E power cables get routed to your motherboard, along with your SATA data cables and often fan cables too.

Every now and then, turn your case around and look at the interior from the front. If you can still see any cables, turn it round again and think about how you can make them tidier. It's also worth test-fitting the side panel now and again to make sure it will close.

When you're happy with it, and you've double-checked all your power connections, plug your PC into the mains and switch it on. If it doesn't boot, diagnose the problem using the same procedure as the core test kit earlier, but at this point you at least know that your core spec works – it should just be a loose wire somewhere. All that's left now is to install your operating system of choice and enjoy your masterfully built PC! CPC

If you tidy your cables well, the interior will be clean and clutter-free



NVIDIA TURING DEEP DIVE

RYS SOMMERFELDT EXPLORES THE INNER WORKINGS OF NVIDIA'S LATEST GRAPHICS CARD ARCHITECTURE

Since 1998, Nvidia has taken a steady march through the pantheon of science when naming the architecture behind each of its GPUs. Those of the company's first (NV1 in 1995) and second (NV3 in 1997) publicly released GPUs didn't get that treatment, but each one since has carried the name of someone who legitimately changed the world with their scientific contribution.

Alan Turing, the British mathematician, logician, cryptanalyst and computer scientist lends his name to the architecture that underpins the company's current chip line-up, and his achievements in science and their impact on our world today undoubtedly put some extra pressure on them to deliver something great with it.

Indeed, the initial Turing-based GPUs were the first in over a decade to use something other than the famous GTX branding that Nvidia used for its flagship GeForce consumer products. In the world of consumer graphics products, that kind of move signals supreme intent and a real advance in the state-of-the-art.

The reason for this big change is rather given away with the new GeForce RTX naming scheme: for the very first time in any consumer GPU, Turing has support for hardware accelerated real-time ray tracing. To cover the history of real-time ray tracing would take a feature all of its own, but there's no hyperbole in saying that its arrival is a momentous event in GPU history.

Any key advance in graphics microarchitecture isn't something that just happens in hardware though. Software support is also key, and sure enough, Nvidia has also invested heavily in this area, working with Microsoft to add ray-tracing support to DirectX 12 via Direct X Ray Tracing (DXR). It has also partnered with several of the biggest game studios in the world to ensure some major games include a form of ray-tracing capability. Those DXR titles only run on Turing-powered GeForce RTX products today, since even a year later no other vendor has support.

Ray tracing isn't the only feather in Turing's cap though. Nvidia has also added hardware support for some other developer-friendly graphics pipeline changes that are less visible than ray tracing, but no less important to how games are rendered on Turing and future GPUs from all vendors.

The Titan RTX is the fastest consumer graphics card based on the Turing architecture

There's a real sense, then, that the Turing architecture is Nvidia's bleeding-edge vision of what should be possible in a GPU. Let's start with the products themselves, before we dive into the details.

THE TURING ARCHITECTURE IS NVIDIA'S BLEEDING-EDGE VISION OF WHAT SHOULD BE POSSIBLE WITH A GPU

THE PRODUCT LINE-UP

The benefit of writing about Turing around a year after the initial introduction is that we now have a very clear picture not just of the Turing GPUs and product line-up built on them, but how that line-up has been shaped over time by the competition Nvidia has faced from AMD.

Turing has been implemented in various forms in five separate GPUs to date, from the biggest TU102 to the smallest TU117, and that quintet underpins 11 separate desktop GPU products from the headlining Titan RTX to the GeForce GTX 1650 — that's right, there are still GTX, rather than RTX, named products in the family.

The largest Turing variant is TU102, which is a 754mm^2 chip made up of 18.6 billion transistors built using a special Nvidia-only variant of TSMC's 12nm process technology called 12FFN. That might sound huge, and it really is in semiconductor terms, but it's actually slightly smaller than the 815mm^2 GV100 Volta-architecture GPU used in the prior-generation Titan V.

TU102 implements six Turing-class Graphics Processing Clusters (GPCs) each with 12 64-core Streaming Multiprocessors (SMs) for a total of 4,608 Turing-class CUDA cores, and has a huge 6 MB L2 cache connected to a 384-bit wide GDDR6 memory bus with over 650 GB/sec of memory bandwidth in the fastest product it powers. That giant chip runs its stream processors at a boost clock of almost 1.8GHz out of the box, with staggering peak performance numbers.

TU102 was originally found solely in the GeForce RTX 2080 Ti, which launched in September 2018 and still hasn't fallen below £1,000 a year later. It 'only' had 4,352 CUDA cores enabled out of 4,608, though, and had 11 GB of GDDR6 memory connected to a 352-bit memory bus. However, a while later, the full TU102 was unleashed in the £,2500 Titan RTX.

This GPU is connected to 24 GB of GDDR6 memory on a full-width 384-bit bus. It may have launched just in time for Christmas last year, but at that eye-watering price we don't think Santa put them under too many trees!

One step down from the TU102 is the TU104, which powers the likes of the GeForce RTX 2080. Measuring 545mm^2, and again built on 12FFN, it's still a hefty GPU, by any standards other than comparison to Nvidia's very largest chips. Inside, there are still six GPCs, but each only has eight SMs compared to the 12 in TU102. However, there's still a huge 4MB of L2 cache for those SMs, and up to 8 GB of GDDR6 connected to its 256-bit memory bus.

Three desktop products use TU104. The GeForce RTX 2080 was there at launch in September 2018 and uses a slightly cut-down TU104 (46 of 48 total SMs) running at 1.71GHz. Then, to spoil AMD's Navi launch in late July this year, Nvidia discontinued that first config and introduced the GeForce RTX 2080 Super that uses a fully enabled TU104 with a 1.815GHz boost clock and 10 per cent faster GDDR6 memory. Finally there's the GeForce RTX 2070 Super, which removes a whole GPC, making a total of five GPCs and 40 SMs, while the core clock runs to 1.77GHz.

TU106 is the smallest 'full' Turing chip, at 445mm^2, but again, that's still pretty massive for a mainstream GPU. Three desktop products use TU106, starting with the GeForce RTX 2070 that came out a few weeks after the RTX 2080 and RTX 2080 Ti, and featured a full-fat TU106 configuration of three GPCs with 12 SMs each running at a boost clock of 1.62GHz.

	TU102	TU104	TU106	TU116	TU117
CUDA cores	4,608	3,072	2,304	1,536	896
GPCs	6	6	3	3	2
SMs	72	48	36	24	14
Texture units	288	192	144	96	96
RT cores	72	48	36	N/A	N/A
Tensor cores	576	384	288	N/A	N/A
ROPs	96	64	64	48	49
Memory bus width	384-bit	256-bit	256-bit	192-bit	128-bit
L2 cache	6MB	4MB	4MB	1.5MB	1MB
Memory type/ max size	24GB GDDR6	8GB GDDR6	8GB GDDR6	6GB GDDR6	4GB GDDR6
Die size	754mm^2	545mm^2	445mm^2	284mm^2	284mm^2

The Turing line-up spans the whole range of graphics card prices, but you lose some features in the cheaper products

It also housed 4MB of L2 cache paired to a full 256-bit bus with 8GB of GDDR6 memory on the other side.

In January this year, Nvidia pushed TU106 into service again in cut-down form, rounding out the GeForce RTX product line with the GeForce RTX 2060. This £329 configuration had only 30 SMs, 3MB of L2 cache, and a 192-bit wide memory interface. That cut-down bus width meant only 6GB of connected memory, although the SM boost clock remained at a healthy 1.68GHz out of the box. Then, for the AMD Navi spoiler party in July, the final full Turing product appeared in the form of the GeForce RTX 2060 Super, with its 34 SMs, the full 4MB of L2 cache, all 256 bits of memory interface and 8GB of GDDR6 connected to it.

AREA COST AND BABY TURINGS

When the original Turing products were released, their size and cost meant there was a sizeable gap at the lower end of Nvidia's product line, at least as far as new products were concerned. Starting at 445mm^2 and £329 for a TU106, the vast majority of overall GPU sales in terms of volume weren't accounted for by the Turing line-up.

The problem was that the additional die size and cost of ray-tracing acceleration hardware and AI-focused Tensor cores (more on which later) meant the full Turing feature set just wasn't scalable to lower-end products. As such, Nvidia decided to play it safe at the lower end of their product line by introducing smaller Turing-derived designs that omit the RT and Tensor cores.

As an aside, it's worth emphasising just how area inefficient the ray-tracing cores are for a current GPU. Unlike the GPU's general-purpose cores and even the Tensor cores, there's no secondary-use case for the RT silicon that would ensure it's still being used even when there's no ray tracing to do. As such, when ray tracing is off in your game, the cores are just sitting there doing nothing.

Power management circuitry means they aren't actually using any power, but the manufacturing and purchase cost has still been sunk into a feature that's idle except for in a handful of games. Greater ray-tracing support will come, but it's a futureproofing gamble that isn't well suited to the lower end of the market.

TU116 is a three-GPC part with eight SMs per GPC, a 192-bit GDDR6 memory bus, just 1.5 MB of L2 cache, and a very healthy 1.77GHz boost clock for the SMs. With 6.6 billion transistors on 12FFN, TU116 weighs in at a much more modest 284mm^2. A full-fat configuration powers the GeForce GTX 1660 Ti, and a slightly cut down configuration powers GeForce GTX 1660, both with 6GB of memory. Note that Nvidia dropped the RTX branding here because real-time ray tracing support is gone, but these are still Turing-class GPUs.

Last but not least is TU117, the real baby of the family. It's a two-GPC part with just seven SMs per GPC, only 1MB of L2 cache, a smaller 128-bit GDDR5 memory interface with just 4GB of the memory connected and weighs in with only 4.7 billion 12FFN transistors at 200mm^2. Just one desktop product uses TU117 in its fullest configuration: the GeForce GTX 1650, starting at around £145.

DEEP DIVE

Now we've taken a look at the product stack and how it evolved with the RTX Super line-

up that allowed Nvidia to head off AMD's first Navi10 products at the pass, plus the simpler TU116 and TU117 implementations of Turing, it's time to dive a bit deeper.

We've thrown a lot of top-level product configuration data at you, the GPC and SM counts in particular, so now it's time to take a look at what a Turing GPC actually is and what the SMs inside of a GPC look like, along with the rest of the GPC microarchitecture that makes up what Nvidia have named after our genius World War II code breaker.

THE GRAPHICS PROCESSING CLUSTER (GPC) IS THE TOP-LEVEL BUILDING BLOCK, IMPLEMENTING ALMOST ALL THE CORE PROCESSING

We'll include the flagship ray-tracing hardware, plus the more staid and expected bits of their design too, comparing and contrasting to Nvidia's prior designs and AMD's current hardware where it makes sense, to give you a view of why Nvidia put Turing together the way it did.

THE TURING GPC

The Graphics Processing Cluster (GPC) is the top-level building block in each of Nvidia's architectures in recent memory, and implements almost all of the core processing that the GPU undertakes. In fact, in a six-GPC part such as the TU102, you could disable five of the six clusters and the remaining one would run your games just fine! Let's look at what a GPC contains.

RASTERISER

Each GPC contains a single rasteriser that's responsible for generating pixels on which the SMs run pixel shading. It would be unremarkable compared to the rasteriser before it in Nvidia's Pascal architecture, if it weren't for the fact the addition of a new rasterisation feature: variable rate shading, or VRS.

Traditionally, every pixel gets shaded at the same rate, usually once unless MSAA is enabled, but with VRS, the rasteriser is capable of telling the SMs that for a given block of 16 x 16 pixels it generates, the SMs can shade them at a reduced rate. That reduced shading rate lets the GPU save on processing every individual pixel, saving power, and increasing performance and throughput.

There's support for several different rates, as you'd expect from the variable part of the name: 1x1 (do nothing different), 2x2 and 4x4 are the obvious ones, but there are non-square footprints too, with 1x2, 2x1, 4x2 and 2x4 all supported as well.

So for each 256 pixel block that the rasteriser would traditionally generate and send down to the SMs in a GPC, Turing can effectively say, 'for each 4 x 4 pixel footprint, I'll shade just 1 pixel and broadcast that result to all 16'.

The game developer has control over the rates in a couple of ways, and crucially for image quality, the shading rate patterns can be non-square and therefore carefully tailored to the kinds of geometry that are likely to fall inside a rasteriser tile. Say the developer knows that in a particular screen region, triangles are likely to be tall and skinny. They can apply one of the 'taller' shading rates — 2x4 and 1x2 — to take into account the shape of what's likely to be in that rasterised region.

The throughput of the rasteriser in a Turing GPC is unchanged from Pascal and can process a single input triangle per clock, generating 16 output pixels per clock from it for an SM to work on. That scales per GPC, so a six-GPC part such as TU102 has an aggregate rasteriser throughput of six input triangles per clock.

TPC

Each GPC contains a variable number of Texture Processing Clusters or TPCs. A TPC is a collection of two SMs that share a texture unit and polymorph engine. The sharing of texture processing and geometry processing (the polymorph engine) across several blocks of GPU shaders is a common arrangement these days that allows for a better balance of required processing for the different steps of the graphics pipeline.

Nvidia's texture unit in Turing is incredibly powerful and can send eight fully filtered texture samples (texels) to the SMs per clock, even with bilinear filtering and for wide HDR pixels with 64 bits of data each. It's also capable of servicing requests out of order, which is something Nvidia architectures have been offering for a while now, while competing designs are only just catching

The full diagram of TU102 hints at the sheer scale and complexity of this 18.6 billion-transistor chip

Variable rate shading allows a game to optimise the rendering complexity of different parts of the game to balance performance and visual fidelity

up with this. For example, AMD's latest Navi architecture, released just this summer, has only just gained the same ability.

What this allows for is that, say, the first SM in the TPC – let's call it SM0 – issues a texture sample request to the texture unit then shortly afterwards, the second SM (SM1) issues another request.

Ordinarily, the texture unit would only return the SM1's requested data after it has dealt with that for SM0 (because that was the order of operations sent to it), even if that means holding back data that's ready to be sent to SM1. However, with out of order processing, if the texture unit has finished processing the data for SM1 first, it can deliver it first.

This is so crucial because textures generally live off-chip in the GDDR5 or GDDR6 memory, and fetching that data can take quite a while. However, there's also a small on-chip texture cache that's much quicker to access. So, in our example, maybe the texture data for SM0 is in off-chip memory but the data for SM1 is in the texture cache. In this scenario, it would almost certainly be quicker to return the data for SM1 first.

In aggregate, that eight texels per clock rate leads to some monstrous total throughputs for a big configuration like TU102. Six GPCs with six TPCs, each able to deliver eight texels per clock and running at 1.35GHz base clock on an Nvidia RTX Titan, means a minimum of 388.8 billion textured samples every second. To put that into perspective, 4K60 is only around 500 Mpixels/s, so at full texturing rate, an RTX Titan could texture every pixel almost 800 times.

TURING'S SM

Turing's shader core inside a TPC is broken up into groups of vector processors that Nvidia calls Streaming Multiprocessors, or SMs, and it's the most complex, efficient and highest-throughput shader core in the company's history. Designed to chew through a wide mix of workloads as well as common graphics tasks, the Turing SM is a future-looking shader core design that's arguably overengineered for running your games.

Because of the inherently complex nature of a GPU, Nvidia can't really afford to specialise a different SM for each of the Turing-based products it wants to create. In an ideal world, it might want to leave the SM we'll describe here to products created for the professional compute, cloud compute, remote rendering, machine learning and other similar markets, and create a much simpler one for gaming products. But the engineering, validation, testing and associated costs with designing big GPUs today mean it's prohibitive in the extreme to do that, despite Nvidia's huge resources.

So even though we discussed that there are two Turing architecture derivatives earlier, one for the big variants and the other in the much smaller TU116 and TU117, there isn't a difference in their respective SM microarchitecture other than the removal of the Tensor cores and RT cores.

At the top level, each SM pair that shares a texture unit inside a TPC has 64 of what Nvidia calls 'CUDA cores'. However, they don't operate together as a monolithic block. It's actually four sets of a 16-wide arithmetic logic unit (ALU) structures that makes up the SM instead, giving Turing a machine width of 16. Why does the machine width matter? Branching and other forms of divergent processing. Because it's too expensive for each core to have all of the support logic to decide what it's doing — a cache, register storage, plus instruction decoder, scheduler and dispatch blocks — those things can instead be shared among a group of ALUs to make it cheaper to implement.

The wider the machine, the cheaper it is to make, because you need fewer instances of that supporting logic, but that means more performance is lost if one of the cores in a collective block wants to do something different from the others. Make the machine narrower and performance is more robust but cost rises. So the GPU designer chooses a compromise width that makes sense for the workloads they think will be executed. Nvidia chose 16, which makes for one of the narrower designs in a long time, with almost everyone else using 32 or higher. This is a testament to the company asserting that Turing should do well executing divergent shader code.

IT'S THE MOST COMPLEX, EFFICIENT AND HIGHEST-THROUGHPUT SHADER CORE IN THE COMPANY'S HISTORY

CACHES, THREAD SCHEDULERS AND REGISTER FILES

That quartet of 16-wide vector units shares a rather large 96 KB cache that Turing can partition dynamically depending on what's executing. When running graphics code, it's split 64/32 in favour of a general L1 cache and a combined texture cache and register overspill. In compute mode, it's

The SM, or streaming multiprocessor, is the processing heart of a Turing GPU

split either 64/32 or 32/64, between a shared memory – used so that each CUDA core can quickly share data with the others in the collective vector unit – and a general L1 cache. The compiler decides what to do based on the data being used and how it's shared between CUDA cores. No other vendor has this clever cache partitioning technology in its GPU.

The cache also has double the bandwidth compared with the similar L1 structure in Pascal's TPC, and there's a lower latency to service a hit if the data the SM requests is already in the L1 ready to be returned.

Each 16-wide vector unit has its own thread scheduler that takes care of tracking and managing all of the threads of work that are being processed, along with a very large, 16,384-entry, register file (RF) that's banked to support efficient register access. The scheduler can dispatch up to 32 ready threads per clock to the underlying 16-wide machine, and that 16K RF means that each thread can make use of up to 1,024 32-bit registers before the hardware has to cut down the number of threads that can run in parallel. That's a huge amount of RF space for a modern GPU of any kind, with the total for a TU102 chip being a massive 18MB.

TURING CUDA CORES

For the first time in any high-performance GPU each individual shader core, or CUDA core, on Turing can run both floating point and integer computation at the same time, and at full rate no less, by virtue of having two fully independent datapaths. Graphics code doesn't tend to have a lot of integer operations mixed in with the much more common floating point stuff, but that mix is on the rise as a general trend, so Turing's SM configuration is a future-looking bet.

On the floating point side, the most common operation is a fused multiply-add (FMA), but Turing has a rich instruction set architecture (ISA) and supports quite a bit more than just that fused 2-FLOP instruction and its decomposed multiply or add. Dual-rate 16-bit floating point is also present in the smaller Turing processors, so you don't miss out on this core performance improvement even on the cheaper parts. Lots of graphics computation can be done at lower arithmetic precision, and the little Turings are now well positioned to exploit that in a main SM datapath.

On the integer side, the Turing ISA is similarly rich, but the base throughput is just single 1-op stuff such as adds or selects, so the real innovation is being able to run it entirely in parallel with the floating point datapath.

TURING TENSOR CORE

The two biggest headline features that have been added to Turing, over previous Nvidia architectures are Tensor cores and ray-tracing hardware. Starting with the Tensor cores, these are for machine learning (ML) code and, as far as we're aware, the graphics compiler for Turing never emits code that runs on them.

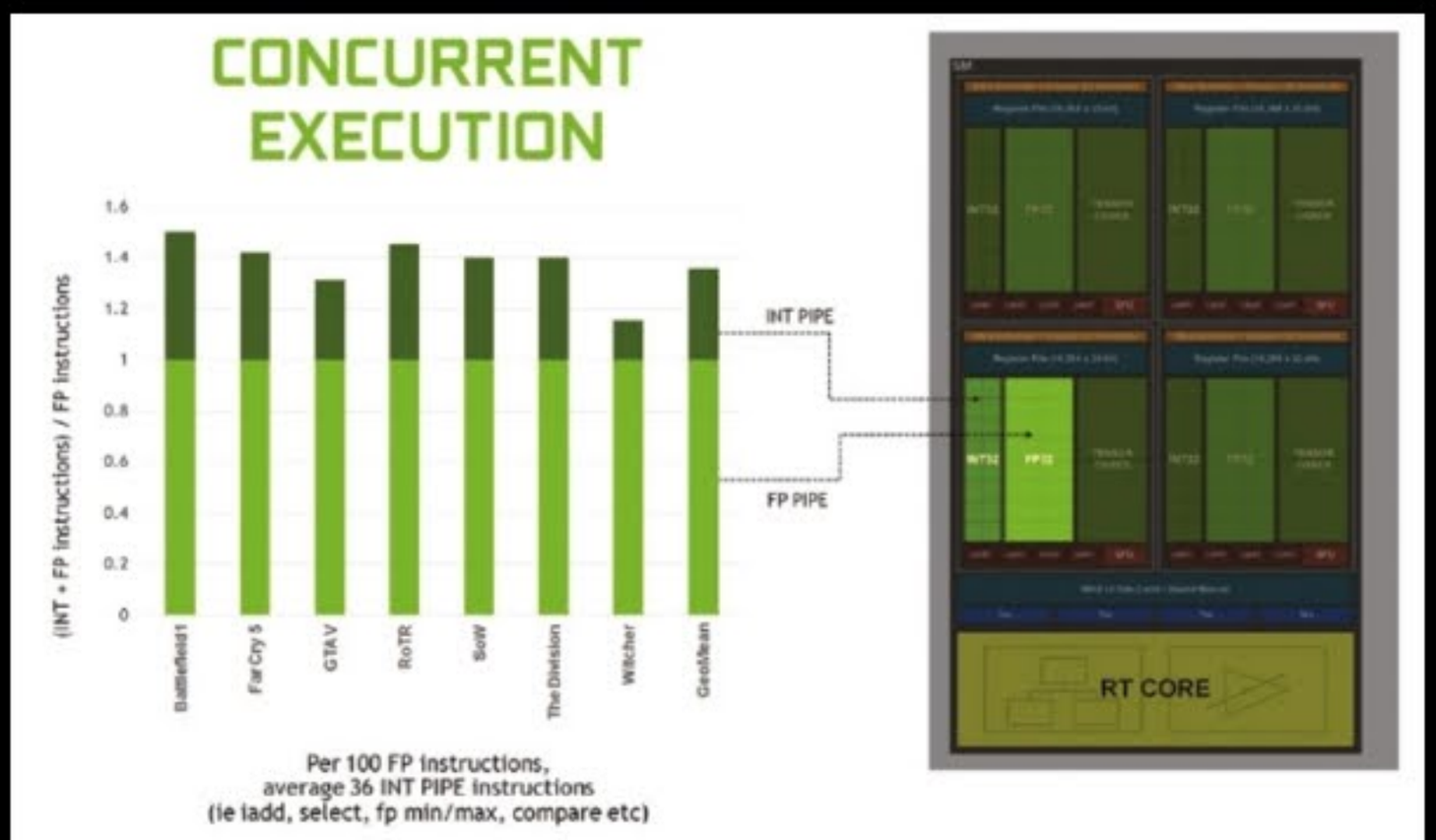
So what do they do? They're arranged in a fixed matrix arrangement, spread out across the total TPC hardware. Remember the 16-wide main vector datapath? Two Tensor cores ride alongside each of those vector units and probably share some of that main datapath hardware in some way, although Nvidia doesn't detail exactly how. Each one is able to run eight full-rate 16-bit floating point fused multiply-adds (FP16 FMAs). Not only that, but it can run 8-bit integer multiply-adds at twice that rate, and 4-bit integer multiply-adds at 2x again. So 16 INT8 and 32 INT4 multiply-adds, per core.

With 576 of those cores spread across the entirety of the chip, that equates to up to 113.8TFLOPS of Tensor processing on the TU102. In comparison, for normal floating point operations, it can only deliver 14.2TFLOPs for FP32 or 28.5TFLOPs for FP16. This massive step up in performance for these types of calculations means Turing-based GPUs are in huge demand for the ever-increasing world of AI computing.

RAY TRACING

Ray tracing is a completely different method for rendering aspects of a graphical scene, so it can't easily be accelerated by the general-purpose processors that make up the bulk of a GPU, but instead require some specialised hardware. Nvidia's initial implementation in Turing takes a couple of the key baby steps, accelerating parallel triangle and box testing, and the streaming in of the scene hierarchy into which your game traces rays.

In a nutshell, you aim a ray at a mesh of triangles organised into a hierarchy of bounding boxes, with a particular direction and maximum depth specified for the ray.



Profiling many workloads shows an average of 36 integer operations for every 100 floating point operations.

Turing is the first GPU architecture to introduce concurrent execution of integer and floating point operations

The GPU needs to do two things: stream in the hierarchy in the right order and test the ray against the outer boxes and then the triangles inside, up to that maximum depth. Turing accelerates both of those things, pulling in the hierarchy as efficiently as possible, and dedicating some fixed logic to test a couple of boxes or triangles in parallel for every ray it's working on.

As alluded to earlier, the logic is fixed function, so it can't be used for any other calculations, simply because of the arithmetic and dataflow complexity. You could run the intersection code on the SM, but it would be slow and consume the core when it could be running more common pixel, compute or vertex work. It's this fixed function hardware that isn't available on the smaller TU116 and TU117 variants as discussed earlier.

MEMORY HIERARCHY, EXPORT AND GDDR6

So that's the architectural machinery that Turing uses to get its main computational jobs done, but there's one last aspect to touch on before we tie it all up: the memory hierarchy and getting finished work out to graphics memory to be displayed. Each SM's L1 cache feeds into a partition of the L2. TU102, for instance, has a faintly ridiculous 6MB of total L2 cache, with a partition of that connected to each L1 unit in the TPC. The L2 is then connected to the outside world via a fabric and a set of memory controllers.

Finished work, usually pixels, has to be exported out to the very large GDDR6 memories in Turing in an optimal way. Graphics memory accesses come in bursts, as do pixel accesses. For instance, TU102 can output 96 finished pixels per clock in Nvidia Titan RTX form, and those can be HDR pixels without any performance penalty. So potentially 768 bytes (6,144 bits!) of data makes its way out of the back end of the hardware in any given cycle, and the GPU has to maintain writing that out to memory at full rate to achieve peak fill rate.

That means the last bit of the memory hierarchy, from the export hardware through L2 into the fabric and then out through the connected GDDR6 memory – each 32 bits wide and usually connected to a single GDDR6 chip – needs to be free-flowing and efficient. It might not sound like a lot of data at first glance, but given the clock speed of these GPUs, it amounts to a huge amount of data per second. This can be particularly tricky when it comes to marshalling those bits over actual wires to the GDDR6 chips that live next to the GPU.

STATE OF PLAY

Nvidia took several gambles with the launch of Turing. On the consumer side, it has added several brand-new rendering features, such as VRS and real-time ray tracing, and these will need developer support to bear fruit. We've already seen a few headline examples of games with ray-tracing support, such as Battlefield V, Call of Duty: Modern Warfare and Minecraft, so the signs are reasonably positive that it's here to stay. However, with the latest games consoles powered by AMD APUs, and future consoles looking like they might follow suit, we may yet see ray tracing flounder, if AMD doesn't add in this feature too.

Otherwise, Nvidia has continued to push the performance envelope far enough that the overall graphics card market situation remains much as it has been for the past many years; Nvidia rules the high end while AMD fights for the mid and low-range markets. Navi is the closest AMD has come in recent years to truly competing with Nvidia at the top, but it still isn't quite there yet, leaving Nvidia free to charge essentially what it likes for its top-tier Turing products.

What's perhaps most telling about Turing, though, is the inclusion of dedicated hardware for non-graphical calculations. The Tensor cores are an explicit nod to the explosive growth in requirements for fast training and inference hardware for machine learning. A big chunk of Nvidia's money now comes from that kind of customer, and it's growing faster than its traditional graphics business.

Likewise, the SM changes for integer co-issue and the strong optimisations in the memory hierarchy, especially around L1 partitioning, bandwidth and latency, and the overall L2 size, hint at optimising for other workloads being run not by games in a machine like your PC, but on a giant grid in a supercomputer or in the cloud somewhere. We said in our recent RDNA deep dive (Issue 193) that AMD had remembered how to build a GPU, rather than a compute monster. In many ways, Turing swings the other way but crucially Nvidia hasn't sacrificed gaming performance in the process.

THE FUTURE OF NVIDIA'S GPU ARCHITECTURE — AMPERE

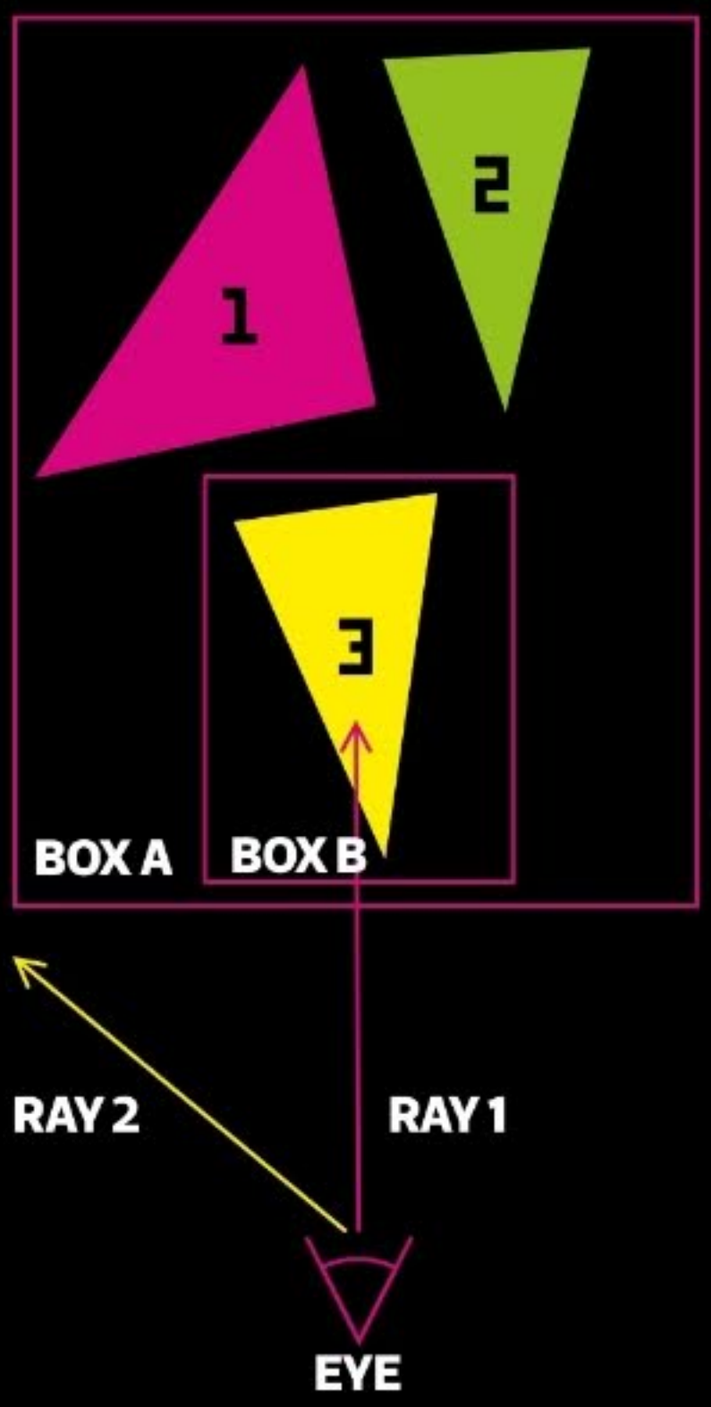
Looking to the future, and what might be in store for Nvidia's next GPU architecture, it will be interesting to see just how much further the company pursues the dedicated compute market and whether we finally see a more direct split in hardware designs. It seems unlikely at this stage that its top-tier chip designs will be split up, but when ray tracing hardware is no use to compute applications (as far as we're aware), and Tensor cores are no use for gaming, there's clearly some silicon area to be saved by making the break.

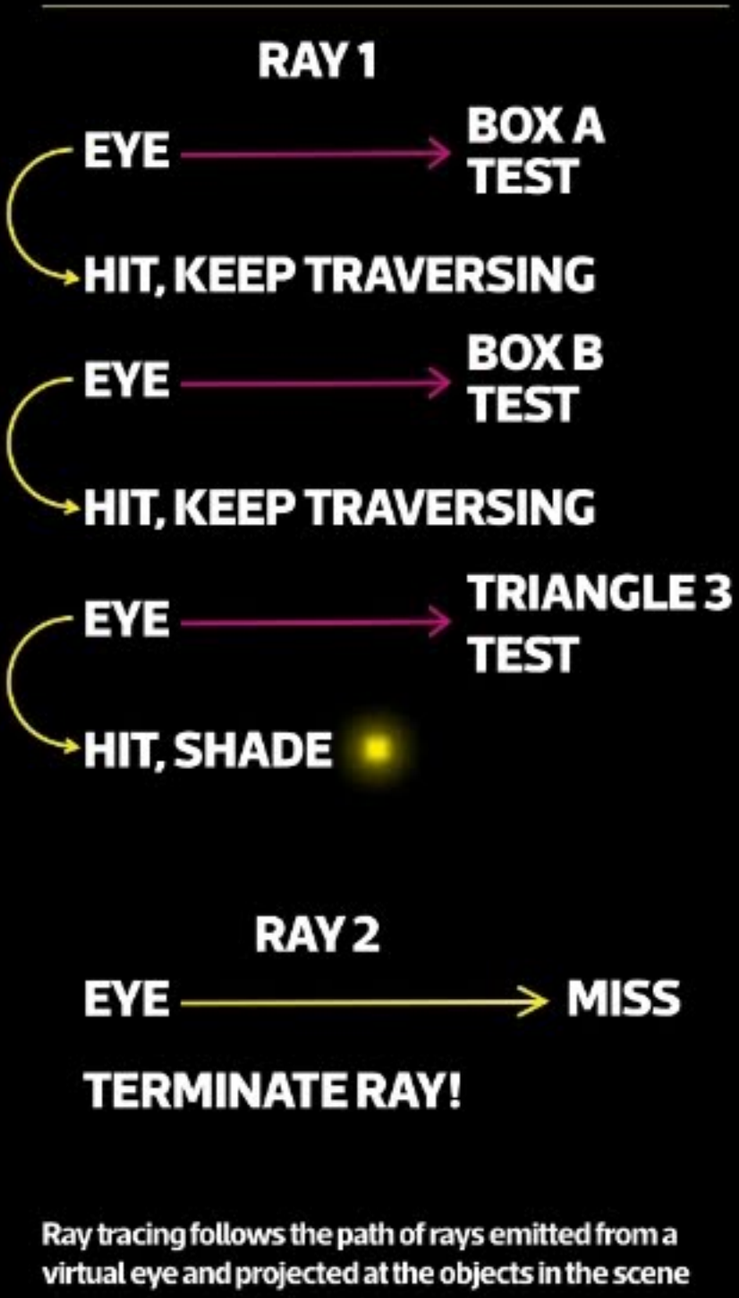
Ray tracing can transform the look of even otherwise basic-looking games such as Minecraft

What's perhaps more likely is that we'll see even more of a split between the highest-end parts that will serve double duty for compute and gaming, and lower-end parts that are just for gaming. Of course, what consumers will probably care most if this happens is whether ray-tracing support gets added to these cheaper cards.

We can certainly see the logic in continuing to omit it, as ray tracing still impacts performance considerably, and these less powerful cards just won't have the grunt to deal with it. Especially as the RT hardware is spread out across the GPU (and so its performance scales along with the size of the rest of the GPU), and not just a single dedicated unit. However, when you look at the difference ray tracing can make to an otherwise graphically simple game such as Minecraft or Quake, it's clear there's a market for a GPU that provides more basic general rendering performance but still has some RT chops.

Whatever happens, it feels like the GPU market is entering one of its more exciting periods in some time, and we can't wait to see what both AMD and Nvidia (not to mention, Microsoft, Nintendo and Sony!) have in store for us next. **OPC**





Ray tracing follows the path of rays emitted from a virtual eye and projected at the objects in the scene

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

TUTORIAL

Inky wHAT secondary display

Pimoroni's Inky wHAT add-on for the Raspberry Pi (see Issue 195, p96) is an undeniably clever piece of kit, but out of the box it lacks one key feature: the ability to display arbitrary text. Thankfully, adding that feature is straightforward and, when combined with a cheap box frame, colour printer and a sharp knife, the result is a handy network-attached secondary display.

1. Install the Inky wHAT

Assembling the Inky wHAT and Pi Zero WH is straightforward, but to minimise the project's depth – and thus the likelihood of it fitting into your box frame when you're done – isn't quite the same as installing it on a full-sized Raspberry Pi. First, discard the bundled mounting hardware and Booster Header. Instead, slide the Inky wHAT directly onto the Pi Zero WH's GPIO header, making sure to install it the right way around.

2. Install the software

If you haven't used the Inky wHAT before, you'll need to install its libraries. The easiest way to do so is to open a Terminal window – or, if you're using the Raspberry Pi headless, an SSH connection – and type:

```
curl https://get.pimoroni.com/inky | bash
```

Follow the on-screen instructions to install the software. You'll also need to enable the inter-integrated circuit (I2C) communication bus. Type:

```
sudo raspi-config
```

Scroll to '5 Interfacing Options' and press Enter, scroll to 'P5 I2C' and press Enter, scroll to 'Yes' and press Enter, press Enter again to confirm, then press Tab twice to close the tool. Finally, download the inkywhat-writer tool by typing:

```
git clone https://github.com/ghalfacree/inkywhat-writer.git
```

Reboot the Pi with:

```
sudo reboot
```

3. Testing

Inkywhat-writer is a simple tool that writes text to the Inky wHAT's display. Turn the Pi and Inky wHAT to portrait orientation, then type the following in a Terminal:

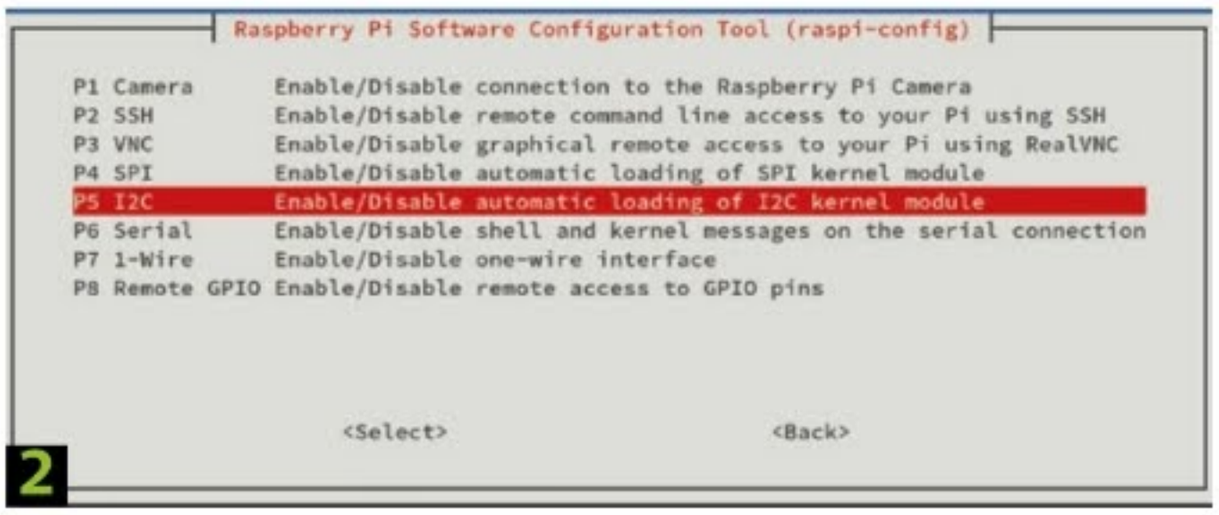
The Inky wHAT comes with a Booster Header and mounting hardware, but it's not necessary to use the Pi Zero WH

```
cd inkywhat-writer
./inkywhat-writer.py < scheduleexample.txt
```

After a few seconds, the Inky wHAT display will update with the scheduleexample.txt file's contents – santised output of the daily schedule printer from Issue 183. You may notice that not everything translates to the ultra-small font used to cram data onto the screen. You can fix this with a couple of tools: 'sed' and 'iconv'. Type:

```
sed 's/← \|→ \|↓ \|↑ \|↘ \|↙ \|↖ \|↗ //g' scheduleexample.txt | iconv -f UTF-8 -t ISO-8859-1//TRANSLIT | ./inkywhat-writer.py
```

> **This symbol means the command should all be on one line.**



You'll need to turn on the inter-integrated circuit (I2C) bus to use the Inky wHAT

```
pi@raspberrypi:~ $ cd inkywhat-writer
pi@raspberrypi:~/inkywhat-writer $ ./inkywhat-writer.py < scheduleexample.txt
pi@raspberrypi:~/inkywhat-writer $ sed 's/← \|→ \|↓ \|↑ \|↘ \|↙ \|↖ \|↗ //g' scheduleexamp
le.txt | iconv -f UTF-8 -t ISO-8859-1//TRANSLIT | ./inkywhat-writer.py
```
3

Using 'sed' and 'iconv' lets you strip characters that otherwise wouldn't print well

This uses 'sed' to remove the wind-direction arrows, not present in the Tom Thumb font used for this project, then uses 'iconv' to transliterate the text from UTF-8 to ISO-8859-1 (Latin-1).

4. UI mock-up

To make the whole project prettier and more robust, you can enclose it in a box frame. The trouble is that a box frame deep enough for the Raspberry Pi and Inky wHAT is typically bigger than the Inky wHAT's display. My solution is a retrocomputing user interface mock-up.

The idea is to make the Inky wHAT look like it's running in a window of a classic computer. There's an example included in the inkywhat-writer directory: inkwhat-writer-amigamask.xcf, based on Commodore's Amiga Workbench.

If you're happy using an Amiga UI, you can simply print out this example. If not, find a screenshot of your favourite vintage operating system and build you own. Copy the corners of the window borders around a central mask sized to the Inky wHAT display, fill in the gaps with cloned borders and then label it appropriately using a matching typeface.

5. Hardware installation

Dismantle the box frame. Print out your chosen user interface and cut out the central portion to make room for the Inky wHAT display. Place the paper face down on the glass of the frame.

Next, take the Raspberry Pi and Inky wHAT and line it up behind the mask, so you can see the full display from the front. Take the rear cover off the frame and cut a corner off with scissors to make room for the power cable, then press the cover into place.

Depending on the size of your frame, it may hold the Raspberry Pi and Inky wHAT in place with no additional mounting hardware. If not, you'll need some nuts and bolts to hold the Raspberry Pi into place on the rear cover.

A few minutes in The GIMP and you can slap together a rough mask – in this case, Amiga Workbench

Once assembled, the display takes its updates over a wireless network connection

Using SSH, you can securely update the Inky wHAT over the network

```
blacklaw@shodan:~$ sed 's/← \|→ \|↓ \|↑ \|↘ \|↙ \|↖ \|↗ //g' yourtextfile.txt | iconv -f U
TF-8 -t ISO-8859-1//TRANSLIT | fold -w 72 -s |  ssh pi@raspberrypi.local "cat - | /home/pi
/inkywhat-writer/inkywhat-writer.py"
Enter passphrase for key '/home/blacklaw/.ssh/id_rsa':
blacklaw@shodan:~$
```
6

6. Network data transfer

Once it's assembled, you'll no longer have an easy way to connect a keyboard and mouse or monitor the Raspberry Pi. Thankfully, it's easy to transfer data over the network using SSH. On a Linux desktop, macOS or Windows with the Windows Subsystem for Linux installed, type:

```
sed 's/← \|→ \|↓ \|↑ \|↘ \|↙ \|↖ \|↗
//g' yourtextfile.txt | iconv -f
UTF-8 -t ISO-8859-1//TRANSLIT |
fold -w 72 -s |  ssh pi@raspberrypi.
local "cat - | /home/pi/inkywhat-
writer/inkywhat-writer.py"
```

This performs the arrow-replacement and codepage transliteration on an arbitrary local text file, wraps it at 72 characters, then transfers the result over SSH to the Raspberry Pi via the Wi-Fi network.

NEWS IN BRIEF

Sphero acquires LittleBits

Toy robot company Sphero, still recovering from a licensing deal with Disney being cancelled last year, has announced the acquisition of educational electronics concern LittleBits for an undisclosed sum. 'Sphero and LittleBits are on a mission to make hands-on learning fun and memorable,' says Sphero chief executive Paul Berberian. 'Together, we're able to make an even greater impact by delivering the best possible solution – whether it is programming a robot to solve a maze or building an electronic music synthesiser.'

Instead of playing games on the Switch, Fuze4 aims to get you making your own

REVIEW

Fuze4 Nintendo Switch

In the dim and distant past, if you wanted to play video games outside the local arcade, you had to have a home computer. These relatively low-cost 8-bit machines – from Commodore, Sinclair, Acorn, Amstrad and the like – all had one feature in common – when you switched them on, they dumped you at a programming language.

When the first cartridge-based games consoles landed, computer gamers viewed them with derision. If you can't program your own games on them, what's the point?

The birth of the graphical user interface, desktop environments, and all the bits and pieces that makes the modern operating system levelled the playing field. Now, neither home computers nor consoles boot into a programming language, but that doesn't prevent people from installing their own.

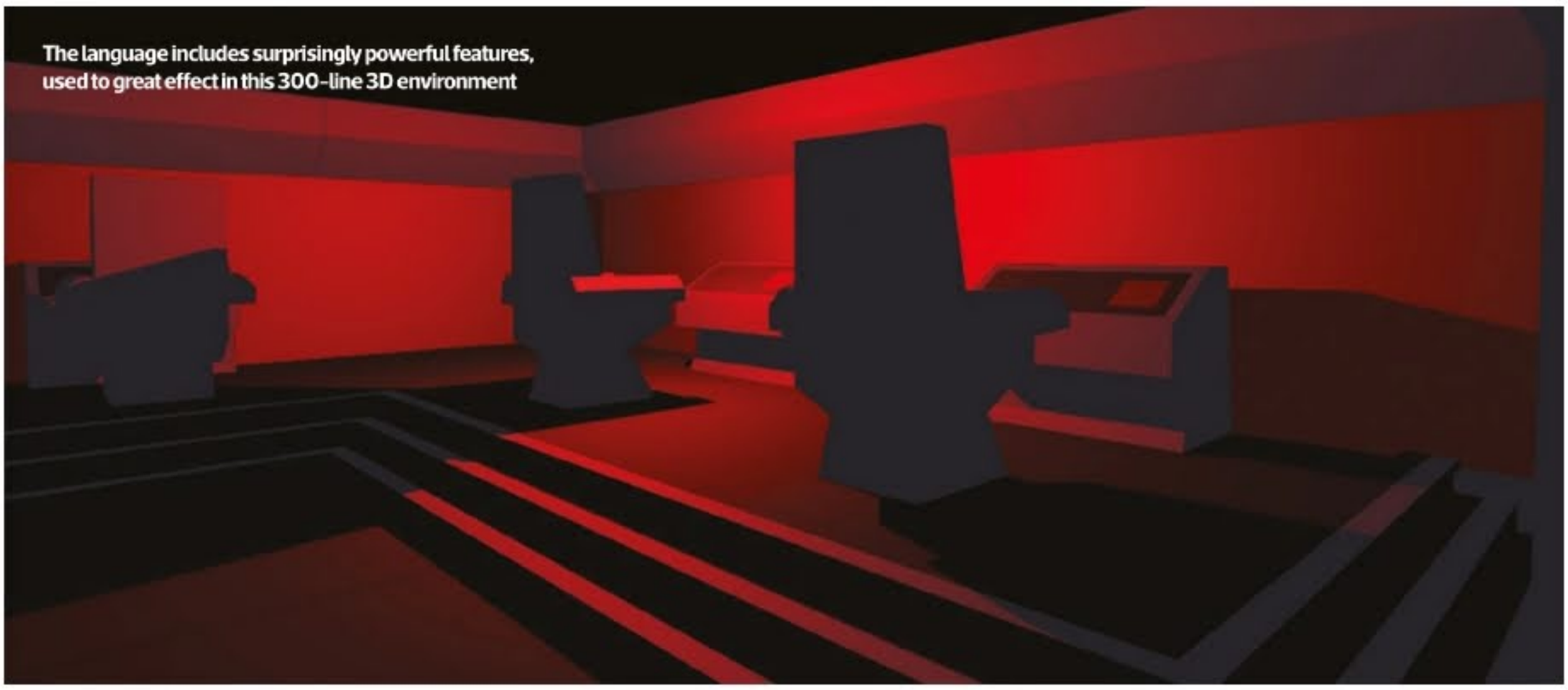
Regular readers may remember the Fuze (reviewed in Issue 124), a BBC Micro-inspired metal housing for the Raspberry Pi, which introduced the world to Fuze BASIC as an educational-focused programming language. Fuze4 Nintendo Switch isn't a case, and it isn't quite Fuze BASIC either. However, it is a fully functional programming language for Nintendo's popular convertible handheld console.

Fuze4 has undergone a wealth of changes since its original white-on-black Fuze BASIC days. Firstly, it's no longer quite as tied to the conventions of BASIC. Fuze4 is an in-house mashup of a range of programming languages, taking what it needs from BASIC, Python and even C. Like its predecessor, it's entirely text-based; there's no block-based editor here.

There is, however, a neat graphical interface that adapts a text-based programming language to the vagaries of the Switch. The on-screen keyboard can be modified, along with the rest of the user interface, using built-in themes, including ones inspired by the BBC Micro, the ZX Spectrum and the Commodore 64. It also allows for text entry, but for any programming except the simplest programs, a USB keyboard is a must.

Sadly, Nintendo's decision to place the Switch's only USB port on the bottom of the

Bundled assets, including 2D, 3D and audio files, enable you to get started quickly



The language includes surprisingly powerful features, used to great effect in this 300-line 3D environment

console means that Fuze4 Nintendo Switch is largely usable only when the console is docked to a TV; support for a Bluetooth keyboard would be welcome, but Nintendo seems unwilling to accommodate modern PC peripherals.

There are other barriers that result in Fuze4 being a little clunkier than necessary. Chief among them is the way the software handles the sharing of projects. To send a project to a third party or receive a project from them, you'll both need to have connected your Switches through Nintendo's clunky 'Friend Code' system. It's an issue Fuze Technologies is investigating, although the company's hands are largely tied by Nintendo's platform restrictions.

However, there's plenty of pros to balance the cons. The sample programs provided with the Fuze4 Switch, which load straight into a source code view, run the gamut, from 2D platformers and racing games to surprisingly fluid 3D environments.

A couple of tools are included to make creating your own games easier too – a map editor and an image editor. Both these tools are able to load assets from a 10,000-strong library – worth $1,000 (US), Fuze claims – bundled with the software, including 2D and 3D objects as well as audio. Sadly, there's no music editor to be found; Fuze4's rather limited internal synthesiser needs to be controlled wholly in-code, and is missing features such as attack, sustain, decay and release (ASDR) control.

The language itself can be a little clunky at times too. The lack of a 'switch/case' function and 'else-if' leads to clunky columns of nested 'if' statements in the majority of programs. Thankfully, work is already underway on adding a lot of the missing features - including 'switch/case' - and they may indeed be in place by the time this review is published.

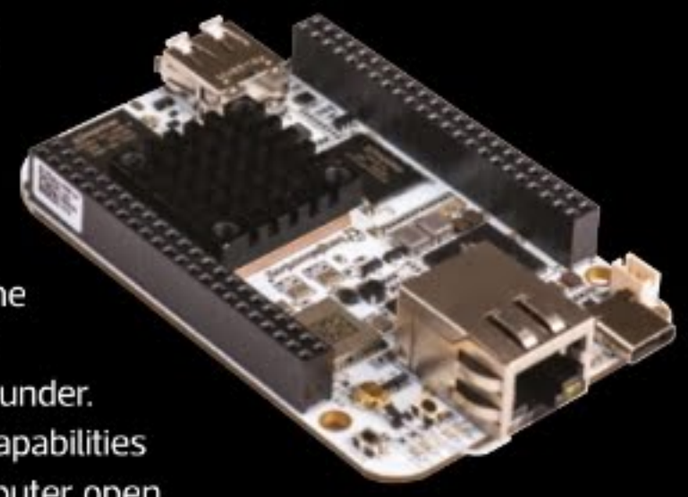
It's easy to concentrate on what you don't get with Fuze4, but it does have plenty going for it too. Code is syntax-highlighted live on the screen, there are monitors for frame rate and memory usage, and there's an internal context-sensitive help system. This, and on-device tutorials, are supported by the Fuze Arena (**fuzearena.com**) website, which includes a small but passionate forum and a range of video-based tutorials introducing basic programming concepts.

Fuze4 Nintendo Switch isn't the first programming tool to land on a Nintendo console – the Nintendo Entertainment System launched in Japan as the Family Computer (Famicom), after all, and the 3DS had the well-received SmileBASIC – but it may be the most impressive. With a broader ability to share content, it would be a must-have; as it is, though, it's only likely to appeal to people who want to program for its own challenge, rather than to create a program that will be enjoyed by a wider audience.

Fuze4 Nintendo Switch is available now from the Nintendo Switch eShop (**nintendo.co.uk**) for £29.99 (inc VAT).

NEWS IN BRIEF

BeagleBoard.org launches BeagleBone AI



The BeagleBoard.org Foundation, creator of single-board computers (such as the BeagleBone Black, reviewed in Issue 120), has launched a model aimed at artificial intelligence projects. 'This board is the answer to our community's request to see the next major advancement in the BeagleBone family,' says Jason Kridner, Foundation co-founder.

'Its feature set is jam-packed and offers capabilities unparalleled by any other single board computer, open hardware or not.' The BeagleBone AI, which includes a dual-core CPU, two VLIW digital signal processors, four vision engines, four programmable real-time units (PRUs) and two Cortex-M4 cores, is priced at $118 US (around £96 ex VAT).

REVIEW

The Secret History of Mac Gaming

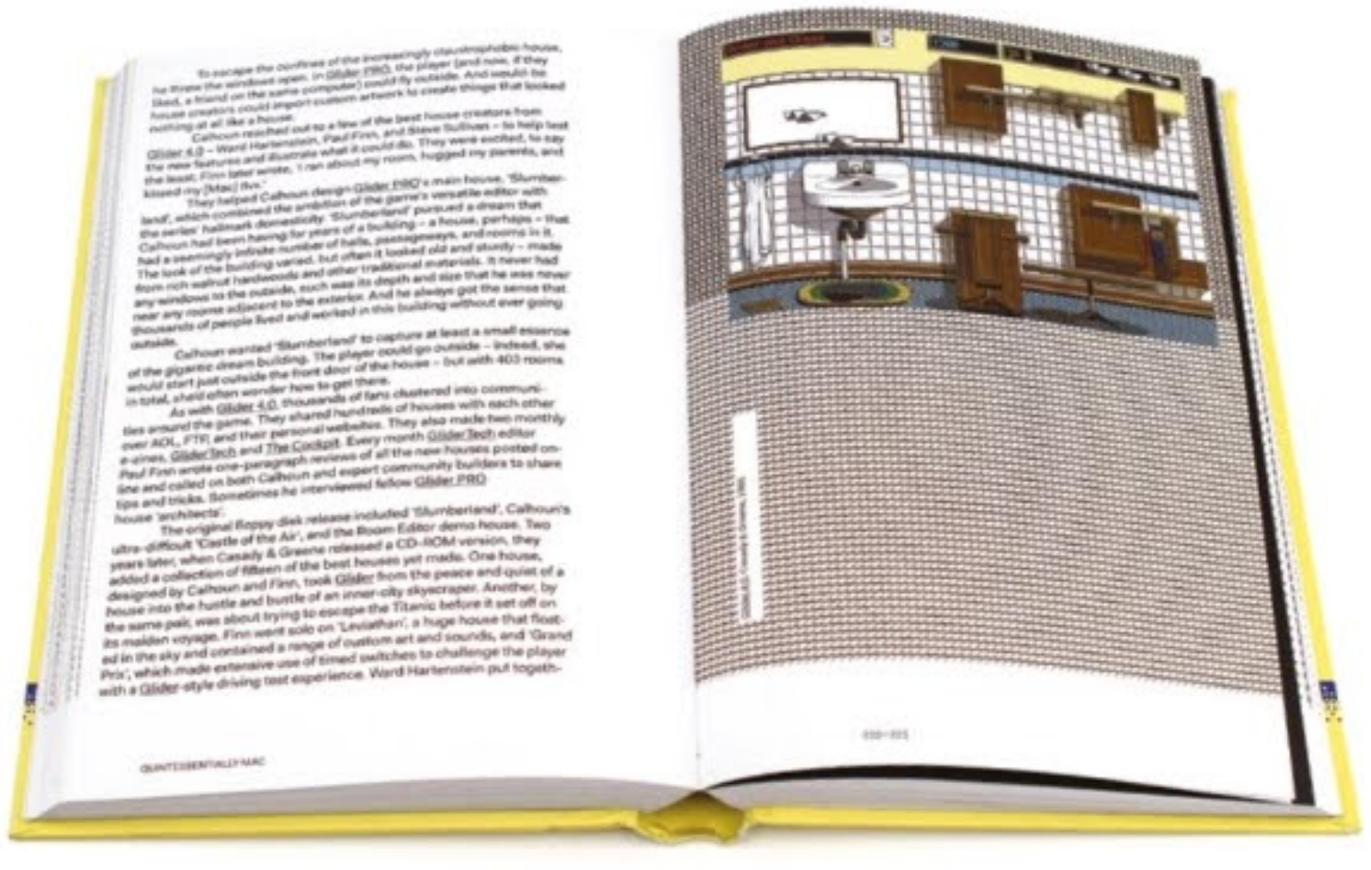
For years Mac gamers have been the butt of jokes. 'How to game on a MacBook Pro,' the image macro went, overlaid in stark white text on a picture of a wag using a closed MacBook as a mousemat for a Windows gaming PC. The Secret History of Mac Gaming by Richard Moss attempts to put the record straight.

Published following a crowdfunding campaign on publishing startup Unbound, the over-400-page hardback combines a dive into a range of game genres on machines ranging from the earliest Mac through to the Mac OS X era. It also has neat spot UV on the cover, which make the pixelated Mac's CRT display shine in the right light

Moss has a welcoming writing style, weaving interview content with factual descriptions of a (non-exhaustive) selection of the more popular or famous Mac titles. The text is split up by the inclusion of screenshots and photographs, as is common with books of this type, presented where appropriate in full colour on the matt-finish paper.

However, the formatting leaves a little to be desired. The outside margin of each page is razor-thin, while the gutter margin is gigantic.

The narrow margin and huge gutter are interesting design choices, but the screenshots certainly stand out

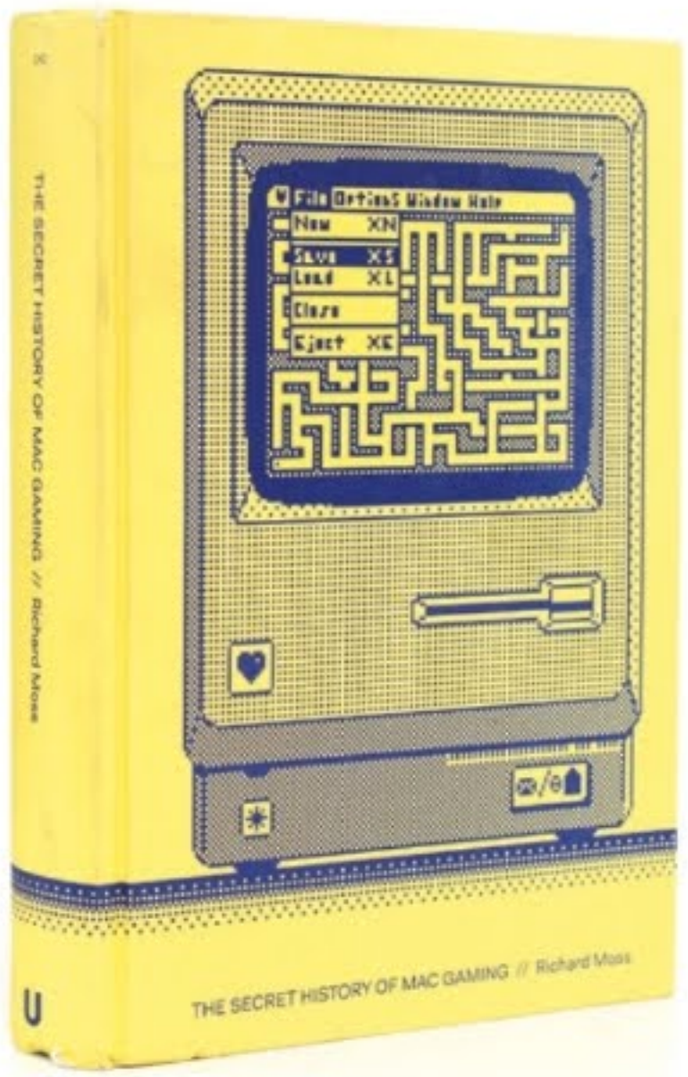


Meanwhile, the text is set in a tiring sans serif typeface rather than a more comfortable serif type, and game and publication titles are underlined rather than italicised, presented like they should be clickable links in an ebook.

The screenshots can be a little odd too. While presented in sharp quality for the most part, they're often positioned oddly. Sky Shadow's screenshots are placed long before the game is mentioned in the text, appearing even before the screenshots of its predecessor Crystal Quest. Also, some screenshots, such as A-10 Attack and Splat'ers, aren't mentioned in the text at all.

Although it can take a little while to get used to the book's idiosyncrasies, it's worth persevering. There are some big-name companies and individuals covered in the text, including Maxis co-founder Will Wright and Flash creator Jon Gay, and each chapter ends in a 'where are they now?' section.

Ross does, sadly, fall down a few holes in the telling of history. An introduction gives the Mac credit for many of the technologies that were 'inspired' by a visit to the Xerox Palo Alto Research Centre (PARC), although this is gently corrected in later chapters. A more telling omission is including the story of Steve Wozniak being subcontracted to work



Richard Moss' The Secret History of Mac Gaming puts paid to some myths about the platform

on the Breakout arcade board for Atari by Steve Jobs, without including the fact that Jobs lied to Wozniak about how much Atari was paying in order to keep the lion's share.

Some of the technical information presented can be a little shaky at times too. Ross at one point claims a developer 'got his hands on the source code – or collection of instructions – for the Motorola 68k processor', which would likely come as news to Motorola.

All this doesn't detract from a great read though. The Secret History of Mac Gaming, available now from amazon.co.uk for £14.26 (inc VAT) or your local bookshop under ISBN 978-1783524860, is recommended reading both for Mac gamers of a certain age and Windows gamers who don't credit the platform with the impact it deserves. The former will enjoy a walk down Nostalgia Lane, while the latter will perhaps learn a thing or two about the Mac's impact on the gaming industry. **CPC**

Gareth Halfacree is the news reporter at www.bit-tech.net, and a keen computer hobbyist who likes to tinker with technology. @ghalfacree

Readers' Drives

Snowblind

Paul Turton deliberately eschewed fancy water cooling and multi-coloured lights for this build, focusing on making a clean and tidy air-cooled rig with a white theme

CPC: What made you want to build a PC with an all-white interior?
Paul: I've always liked white builds. Not many people do them, as there's a lack of pure white parts. Most of the white cases that get released tend to have a black interior, but the SilverStone RL07 was pure white, so it started there.

/MEET THY MAKER

Name Paul Turton

Age 35

Occupation System builder/publican

Location Bexhill-on-Sea

Main uses for PC My daughter uses it for homework

Likes Anything tech, spending time with family

Dislikes Anything tech at times, working!

CPC: We see a lot of water-cooled PCs in the Readers' drives submissions, but your build stood out by being minimal and air-cooled. Do you prefer air cooling to water cooling?
Paul: I love air-cooled systems. I build lots of water-cooled systems for customers, and have a lot of friends in the community who all do the same thing – they're amazing systems. I just have a soft spot for silly big air coolers. I've done a lot of air-cooled builds to date, using coolers from Noctua, Cryorig, be quiet! and a few more. As far as I'm concerned, the smaller the better – trying to cram a Noctua NH-D15 into a mini-ITX build is just fun to me.

CPC: It looks like keeping the interior minimal is a big priority for you, and that's some amazing cable-tidying work. Take us through the process of creating such a clean interior.
Paul: Planning a build doesn't really take long once all the parts are there. I can usually see where the cables will go pretty quickly,

> I was going to paint the whole shroud white, but I thought it looked better with the end result I got

and where I'll need to make mods to make the cable tidying a little cleaner. It was really easy to work with this case – all the grommets were in the right places, and I didn't really have to worry about PCI-E power cables because of the way the graphics card is mounted – there's a grommet directly behind it.

CPC: Did you make the angled graphics card mount yourself?
Paul: The graphics card mount was an idea I'd seen a while back on another system, and I wanted to try it out. There's no advantage to positioning it like that; it's just different to having it mounted in the traditional way or with a vertical bracket. The mount is made from just a couple of coat hangers from B&Q, which I bent to shape. I then drilled the mounting holes in the PSU shroud, added a couple of bolts and bingo! It's just held in place by heavy-duty Velcro.

CPC: How do you access the graphics card's outputs at that angle?
Paul: As the system sits at the moment, the HDMI cable just passes through the rear of the case where the PCI-E expansion slot screws are located. However, I'm looking at getting wireless HDMI, which will remove the need for a cable altogether. If that doesn't work out, then I'll get an extension cable and run it down into the PSU shroud.

CPC: Some of those components, such as the Strix graphics card cooler, don't have white parts on them by default. How did you paint them?
Paul: With white PlastiKote paint. I stripped down the graphics card, then pulled off sections of the Strix shroud with a knife – they're only held in place by glue, so it's fairly easy. Then I painted these sections – it only takes a few light layers to get good coverage. I then glued all the bits back into place. I was going to paint the whole shroud white, but I thought it looked better with the end result I got. The SilverStone fan blades were also originally blue, but I painted them white.

CPC: What CPU is sitting under that massive DeepCool heatsink, and can you get a decent stable overclock from it?
Paul: The CPU is only a Core i5-6600K, so it runs fairly cool on cheap coolers. The DeepCool Neptwin is a decent little cooler, and the CPU is currently running at 4.8GHz with a 1.27V vcore. The temps while running OCCT for two hours peak in the low 70s (°C), but they sit in the low 60s during gaming.

SYSTEM SPECS

CPU Intel Core i5-6600k OC to 4.8GHz

GPU Asus ROG Strix Radeon RX 480, with BIOS flash to RX 580 specs

Storage 2 x 250GB Samsung SATA SSDs in RAID 0

Memory 8GB 3200MHz Crucial Ballistix

Motherboard Asus Z170 Mark S Sabertooth

PSU EVGA 750W G2i

Cooling DeepCool Neptwin CPU cooler, 4 x SilverStone SST-FQ121 120mm fans painted pure white

CPC: What specs did you choose for this PC, and why?
Paul: There was no reasoning for using those specific parts really – they were just what I had on my parts shelf at the time of building. The only ones I had to buy were the two Samsung SSDs. They're running in RAID 0 configuration, so they're really fast, despite using the SATA interface.

CPC: How long did it take you to complete this build?
Paul: Not too long really – around three hours, and most of that time was spent sleeving cables and making the graphics card mount. It's a fairly straightforward build.

CPC: Did you come across any difficulties? If so, how did you solve them?

Paul: I was originally going to use a Thermaltake Frio Extreme cooler, which is another dual tower cooler, but it's 140mm tall. The paint didn't go to plan on that one though – I think it has a coating on the cooler from the factory, so the paint didn't stick. The graphics card mount also clashed with that cooler, so I swapped it out in the end.

CPC: Are you completely happy with the end result, or do you wish you'd done some of it differently in retrospect?

Paul: The only part I'm not really too happy about is the graphics card. I wanted to use one of the Galax Hall of Fame cards, but when I was looking for parts, they were either really overpriced or just difficult to find. CPC

BE A WINNER

To enter your machine for possible inclusion in Readers' Drives, your build needs to be fully working and, ideally, based in the UK. Simply send us a couple of photos on Twitter (**@CustomPCMag**) or Facebook (**CPCMagazine**), or email low-res ones to **editor@custompcmag.org.uk**. Fame isn't the only prize; you'll also get your hands on some fabulous prizes.

Corsair K70 RGB MK.2 SE – Cherry MX Speed

The Corsair K70 RGB MK.2 SE is a premium mechanical gaming keyboard that's built to last. It has a silver anodised brushed aluminium frame, as well as stunning white precision-moulded, double-shot keycaps. It's built to turn heads and withstand a lifetime of gaming. There's a detachable, soft-touch wrist rest too.

Meanwhile, its Cherry MX Speed mechanical keyswitches provide the reliability and accuracy you demand, with blisteringly fast 1.2mm actuation. There's also stunning per-key RGB dynamic backlighting, 100 per cent anti-ghosting with full-key rollover, 8MB of on-board memory, plus dedicated media controls.

Alphacool water-cooling gear

Water-cooling hardware manufacturer Alphacool is offering a choice of £150 worth of gear to every featured Readers' Drives winner. For your prize, you can select from DIY water-cooling kits, the Eiswolf and Eisbaer all-in-one CPU and GPU liquid coolers, as well as a vast range of individual components, including waterblocks (pictured), fittings, reservoirs, pumps and radiators. Alphacool also makes coolant, tubing and fans, as well as modding and water cooling-related tools.

ANTONY LEATHER'S

Customised PC

Case mods, tools, techniques, water-cooling gear and everything to do with PC modding

Is mini-ITX too small for X570?

Last month I reviewed two new mini-ITX motherboards – the first models to use AMD's X570 chipset. However, neither of them blew me away, with Gigabyte's X570 Aorus Pro WiFi only just scraping an award. This situation has left me disappointed for a number of reasons.

Firstly, mini-ITX is usually where the innovation happens. You only have to look at previous models to see some interesting ways of cramming high-end audio, M.2 ports and heatsinks into a 170 x 170mm PCB. Mini-ITX motherboards were the first ones to have M.2 ports on the rear of the PCB – an idea that's since been adopted on some micro-ATX boards to save space. With X570, though, while the ASRock X570 Phantom Gaming-ITX/TB3 does have an innovative layout, it comes at the expense of one of the two usual M.2 ports you'd expect to see on premium mini-ITX motherboards.

Gigabyte's X570-I Aorus Pro WiFi is the best X570 mini-ITX board we've tested, but it didn't blow us away

Similarly, the Gigabyte X570-I Aorus Pro WiFi has a large fan-equipped heatsink and two M.2 ports, but it has just one system fan header. What's more, that heatsink and fan combination didn't offer particularly good cooling for our M.2 test SSD, or the motherboard's VRMs for that matter.

The ASRock board, of course, had other issues too. They include a pitiful number of rear USB ports and the lack of a modern fan control suite in the EFI, although its innovative approach of using Intel socket mounting holes did mean its VRMs were exceptionally cool. These issues all feel like backward steps for a form factor that's usually at the cutting edge of design and there's one common factor – the X570 chipset.

Asus' ROG Strix X470-I Gaming is cheaper than a mini-ITX X570 board, and has a great feature set too

This toasty bit of silicon has caused problems elsewhere, with noisy fans and high idle power consumption. It makes for an unwelcome hotspot on mini-ITX motherboards, where PCB real estate is always at a premium. I was especially disappointed with ASRock's design, since the company managed to squeeze three M.2 ports onto its X299E-ITX/ac motherboard, using a vertical port as well as two rear-mounted ports. Why could it not have used a similar design here?

Gigabyte's fan control suite in the EFI is excellent too, yet despite charging over £200 for its board, putting it firmly into premium territory, it includes just one system fan header. Again, I'd like to have seen a daughterboard offering additional fan headers, and at this price I'd definitely expect to see heatpipes linking the VRMs. A bigger chipset fan would also help to boost cooling, as the included one just isn't large enough.

The other option I tested was Asus' new Crosshair VIII Impact board. It's a

hugely expensive motherboard, and it doesn't adhere to the mini-ITX standard either, using a form factor subbed mini-DTX that extends the length of the board a bit. I just wonder if Asus' thinking here is that this extension is the only way to offer the kind of features you'd expect from a premium sub micro-ATX motherboard using the X570 chipset?

It has two M.2 ports, and the same heatsink-clad daughterboard that provides them adds two more fan headers to the equation, bringing the total to five. It has exceptional VRM cooling too, but sadly, there's a lot of mini-ITX cases that won't accept a mini-DTX motherboard.

I have yet to get my hands on Asus' ROG Strix X570-I Gaming, and the Strix I-series boards has a long line of successful mini-ITX prowess behind it. I hope Asus has pulled off something special with it, because I'd honestly be a little disappointed if I bought either of the mini-ITX X570 boards I've tested so far. The Gigabyte X570 Aorus Pro WiFi is still award-worthy, but only just, and while the Impact is exceptional, it's just too expensive and niche to be considered mainstream. That said, I do hear that EKWB is working on a full-cover monoblock for it, which could make it very tempting if you have the money.

It's all a shame, because PCI-E 4 SSDs are relatively affordable, and I'd rather use a board with bolstered VRMs to deal with the likes of AMD's Ryzen 9 3900X and forthcoming Ryzen 9 3950X. However, I'm actually considering opting for an X470 mini-ITX board for a PC mod I have in mind, rather than deal with the cost and limited features of the X570 boards I've tested so far.

Asus' Crosshair VIII Impact offers a great feature set with the X570 chipset, but it's expensive and not compatible with all mini-ITX cases

In addition, for anyone that's not fussed with PCI-E 4 but wants a new 3rd-gen Ryzen CPU, I'd definitely suggest getting one of the several X470 or B450 mini-ITX boards available, such as the ROG Strix X470-I Gaming. These boards cost far less money and include similar or better features than their X570 counterparts.

Cooler Master World Series kicks off

Every year, Cooler Master hosts the world's biggest PC modding competition – the World Series – with $20,000 US up for grabs in prizes. Anyone is able to join, but the stars of the show are invariably the world-class modders, with riveting projects coming from both known and unknown names.

October this year saw modders completing their builds and posting them on Cooler Master's forums, and judging for the contest will go into early November. The winner will be announced on 14 November, but all the spectacular entries will be visible on the forum and the voting pages by the time you read this magazine. If you haven't taken a look at it already, it's definitely worth stopping by the website at **coolermaster.com/cmws19** to check out some of the best modding projects of 2019.

Cooler Master has also added a fourth category this year to encourage modding newcomers. The Apprentice League comes with a $1,000 US prize, and the idea is that if you haven't modded a PC before, you can still take part and rightly not be judged at quite the same level as more experienced or professional modders. The only requirements are that you use a Cooler Master case and you're not an experienced modder. If you think you'd like to take part and start on a mod ready for next year's competition, stop by the link above. CPC

Project AXE-R by neSSa was one of many awesome builds from the 2018 Cooler Master World Series

Antony Leather is Custom PC's modding editor @antonyleather

How to
Make your own Velcro ties

Antony Leather shows you how to revamp your PC's cable-routing system using DIY Velcro ties

TOTAL PROJECT TIME / 1 HOUR

One of our pet hates at **Custom PC** is cable tidying – specifically, having to deal with cases with too few anchor points and not enough cable ties included in the box. With PCs having more cables than ever thanks to RGB lighting, being able to easily stow and secure your cables makes for a much faster and more pleasant building experience.

Velcro ties make for useful and very easy-to-use cable anchors. Unlike cable ties, they're reusable and can be released without tools or scissors, so you can easily add or remove a cable from the bunch. In this guide we'll look at a simple way to add Velcro ties to your own PC case to give your build a clean, premium feel.

TOOLS YOU'LL NEED

6-32 PC screws
ebay.co.uk

Scissors
Most hardware stores

Drill and 2.5mm drill bit
Most hardware stores

Leather hole puncher
amazon.co.uk

Large screwdriver and scissors
Most hardware stores

Double-sized Velcro roll
overclockers.co.uk

1 / WORK OUT CABLE ROUTING

Remove the hardware from your PC case, but leave the power supply in place, so you can get an idea of the locations where Velcro ties will be most useful. To do this, practise tidying the cables first, so you can work out which arrangement will look the neatest.

2 / IDENTIFY STOWAGE AREAS

Any accessible large recesses can be useful for stowing large bunches of cables, as long as they're kept out of sight. You can add Velcro ties to these areas using longer strips to secure the cables.

3 / IDENTIFY ANCHOR POINTS

Now identify the best locations for your Velcro ties' anchor point, which is where you'll need to be drilling. The surfaces don't have to be flat, but should be easy to drill and not raised, so they don't reduce the clearance between the motherboard tray and side panel.

4 / MARK UP SCREW HOLES

With the locations of the anchor points confirmed, place masking tape over the spots. This will prevent scratch damage to your case if you slip with the drill bit. Place a cross on the spot where you want to drill the hole.

5 / CUT TO SIZE

We've used a roll of double-sided Velcro, which can be cut to length. There are various widths available, and we've opted for 16mm-wide strips to create a neat look. Place the Velcro at your anchor positions to judge the necessary lengths of your strips.

6 / DRILL SCREW HOLE

We're using standard 6-32 PC screws to secure the Velcro ties to your case, and a 2.5mm drill bit to create the hole. We can then create a threaded hole by using a spare screw to tap into the hole with a sturdy screwdriver.

7 / PUNCH HOLE IN VELCRO

A leather hole punch offers the neatest way to create a hole in your Velcro, and in a variety of sizes. Here we've used the 3mm punch in the centre of the Velcro strap.

8 / INSERT SCREW

The 6-32 screw should easily pop into the hole you just made in the Velcro, with its thread gripping just enough to hold it in place. This will make it easier to screw into the threaded holes you created earlier.

9 / SECURE VELCRO TIES

With the hole tapped to size using a spare screw, and a screw inserted into the Velcro tie, screw your contraption into the hole. You can now repeat the process for your other ties and then tidy your cables.

How to Install a motherboard monoblock

Antony Leather shows you how to cool your CPU and VRMs in one hit by using a water-cooling monoblock

TOTAL PROJECT TIME / 2 HOURS

Water-cooling your motherboard can be really beneficial, especially if you're overclocking, as it means your VRMs are no longer at risk of overheating. However, planting a small waterblock on each motherboard hotspot, and running tubing to each block in turn, results in a mass of tubing and ports, with your motherboard riddled with water-cooling components. It makes plumbing your loop a fiddly process, and it's also very tricky with rigid tubing.

There is a way to cool your CPU and VRMs in one hit and avoid dealing with nightmare plumbing jobs though. Motherboard monoblocks cool additional areas of your motherboard in addition to the CPU. Using one slashes the number of inlets and outlets you have to connect, making your life much easier and also resulting in a cleaner-looking PC interior. In this guide, we'll show you how to choose one that fits your motherboard and install it.

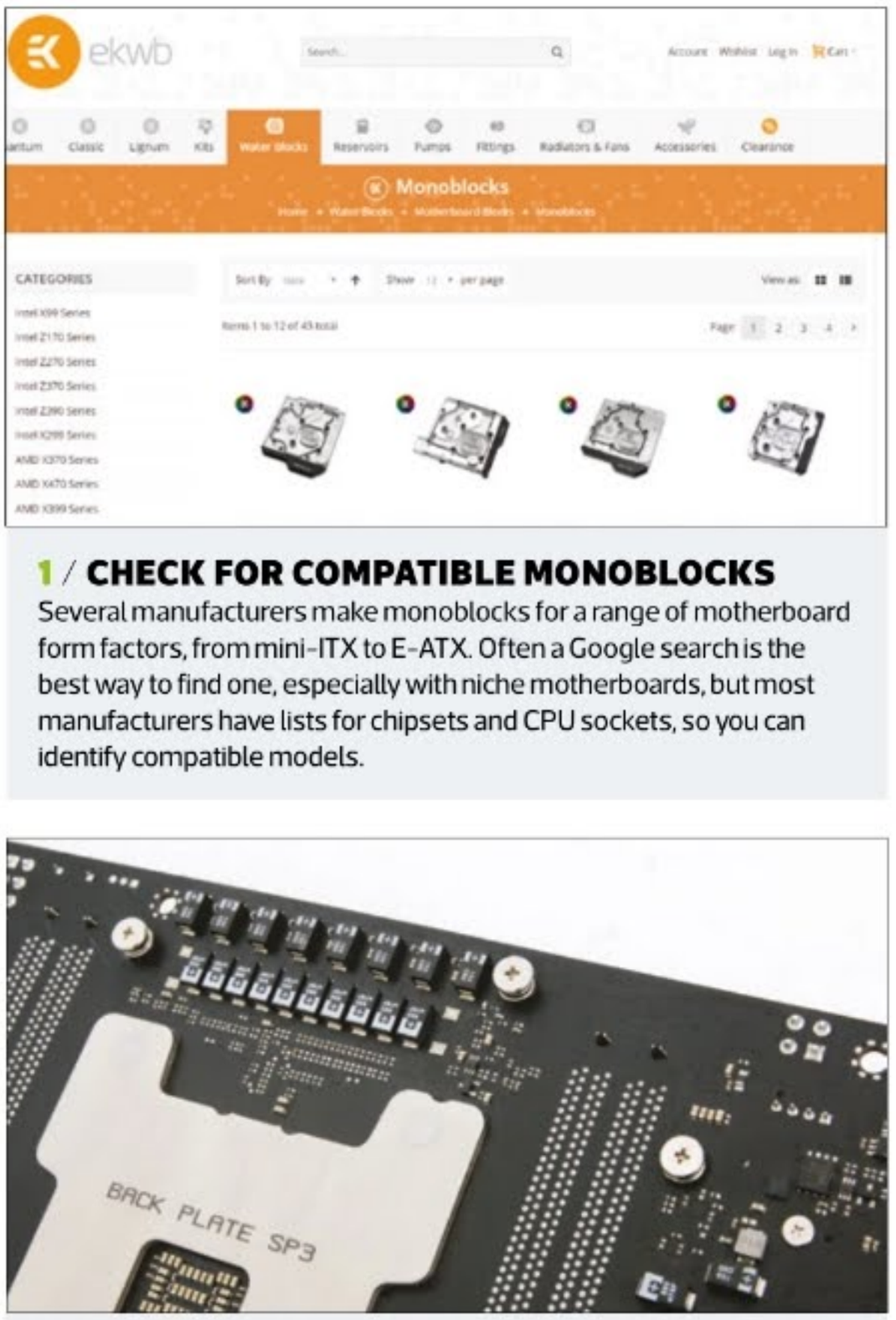
TOOLS YOU'LL NEED

Thermal paste
overclockers.co.uk

Micro screwdriver
Most hardware stores

Thermal paste cleaner and microfibre cloth
amazon.co.uk

Motherboard monoblock
overclockers.co.uk

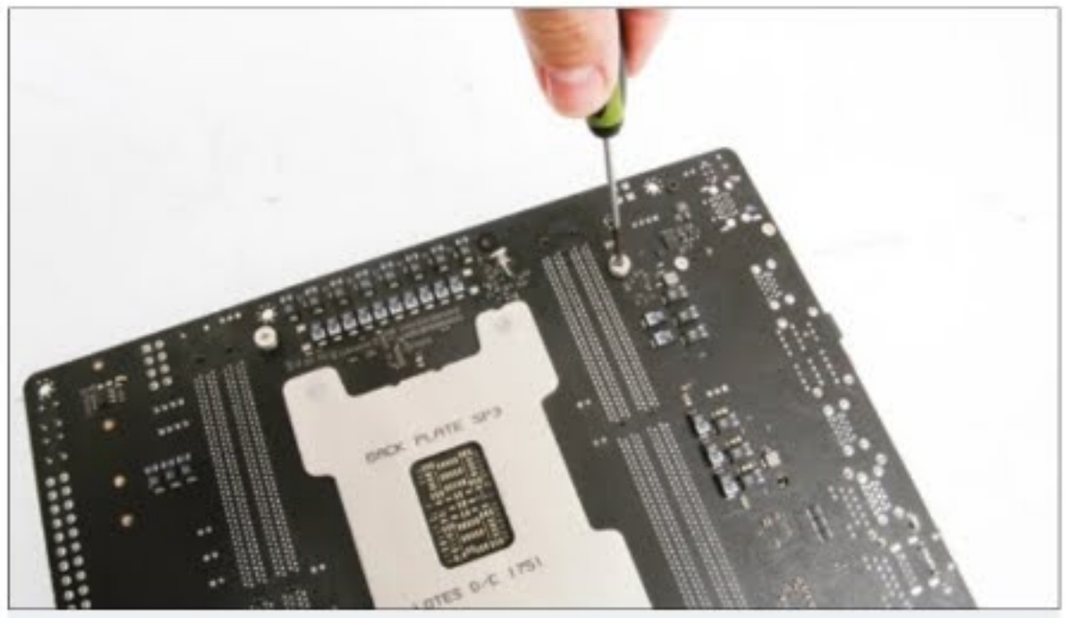


1 / CHECK FOR COMPATIBLE MONOBLOCKS

Several manufacturers make monoblocks for a range of motherboard form factors, from mini-ITX to E-ATX. Often a Google search is the best way to find one, especially with niche motherboards, but most manufacturers have lists for chipsets and CPU sockets, so you can identify compatible models.

2 / IDENTIFY HEATSINK SCREWS

Identify the screws on the rear of the motherboard that hold the heatsinks in place. Gaining access to these screws may involve removing a backplate, but be sure to only remove the heatsink screws; there will likely be others holding other components in place.



3 / REMOVE SCREWS

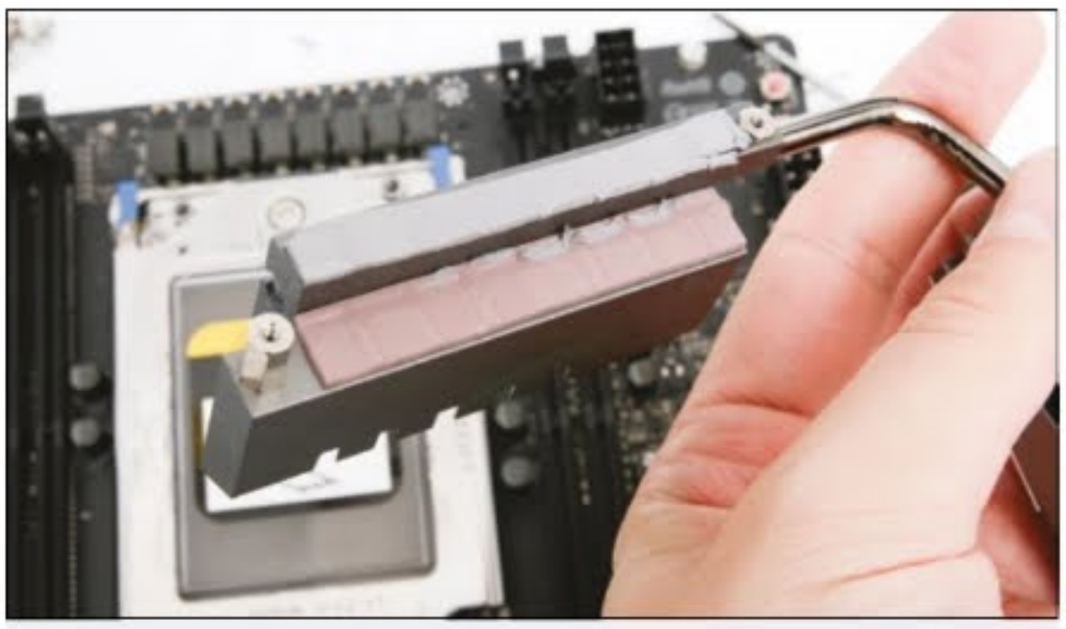
Use a precision screwdriver to remove the screws. If they prove difficult to remove, surround the area with masking tape to prevent any slips from damaging the PCB. Most of the screws should come off easily though.

4 / KEEP SCREWS SAFE

As you'll be dealing with lots of screws, it pays to keep them safe while you're dismantling your motherboard. Place the new components in one tray and the old screws in another one, placing them in a bag or box with the heatsinks when you're done.

5 / REMOVE STOCK HEATSINKS

With the screws removed, gently try lifting the heatsink off the motherboard. If it won't detach, check you've removed all the screws. If it still won't budge, try blowing a hairdryer onto the heatsinks for 60 seconds to loosen the paste or pads beneath.

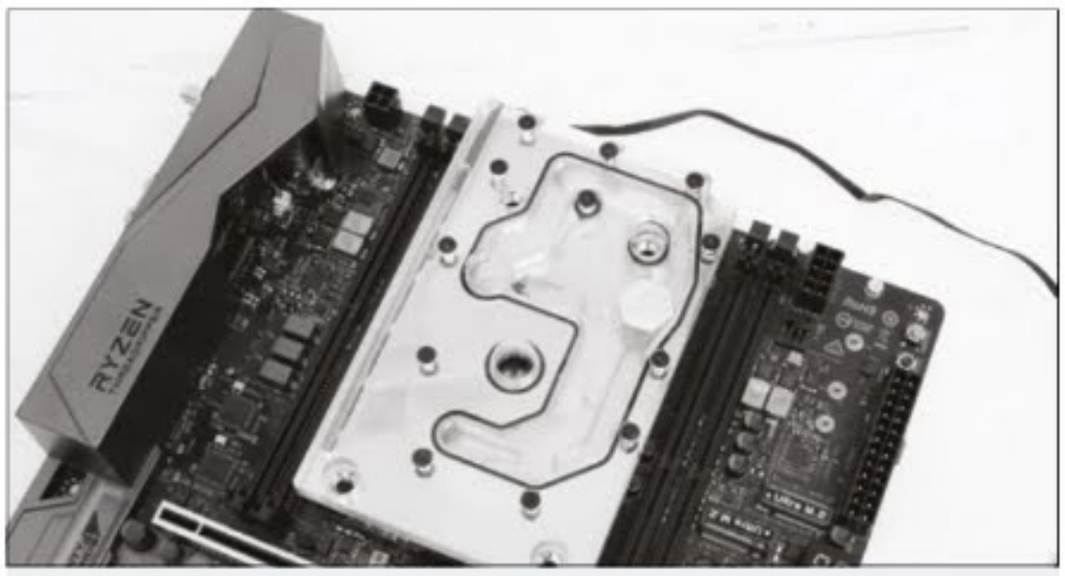


6 / REATTACH THERMAL PADS

If thermal pads were used to create the thermal layer between the heatsink and components, make sure these pads are all attached to the heatsink. Remove them from the motherboard if necessary, so you can reinstall the heatsink at later date if needs be.

7 / CLEAN VRMs AND CPU

Thermal pads and paste can leave residue behind, so it's important to clean them to ensure your new thermal material can work as well as possible. Use thermal paste cleaner or isopropyl alcohol to clean them with a microfibre cloth.

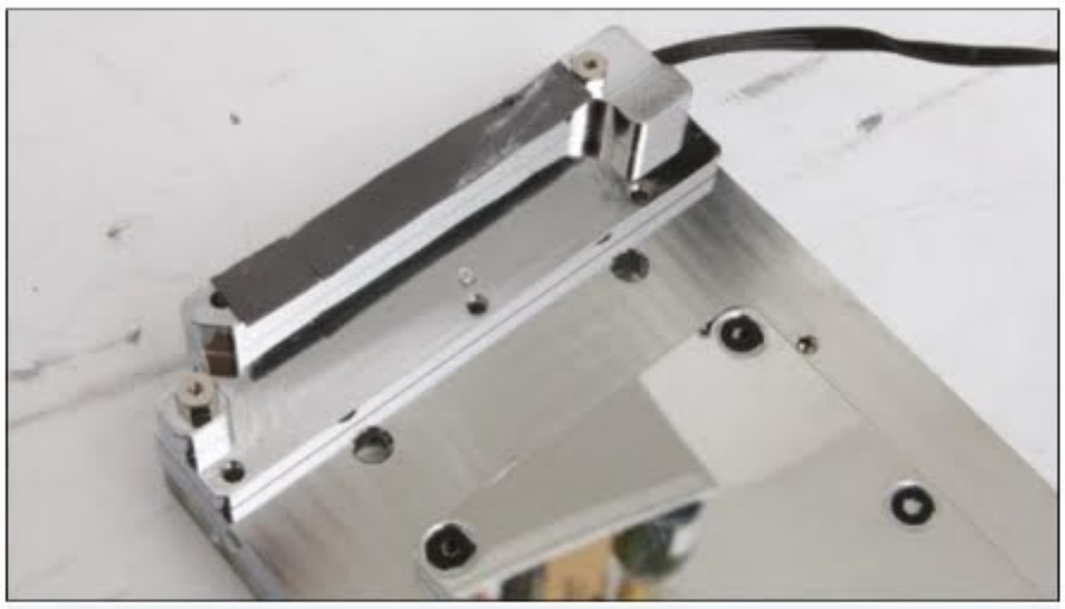


8 / TEST-FIT MONOBLOCK

Install your CPU in the socket, then place the monoblock in position and make sure it fits. This step will help you place it quickly once you've applied the thermal paste, which can sometimes be fiddly, as the monoblock is designed to fit around other components.

9 / APPLY CPU THERMAL PASTE

Apply thermal paste appropriately on your CPU as you would normally (see Issue 189, p91). The monoblock installs like any other CPU cooler; it just cools the VRMs too. You can use any paste, but most waterblocks include some in the box.



10 / APPLY THERMAL PADS

Thermal pads are usually provided to connect the VRMs and monoblock, but occasionally thermal paste is used instead. It's likely you'll need to cut the pads to size so that they sit on the appropriate section of the monoblock.

11 / INSTALL MONOBLOCK

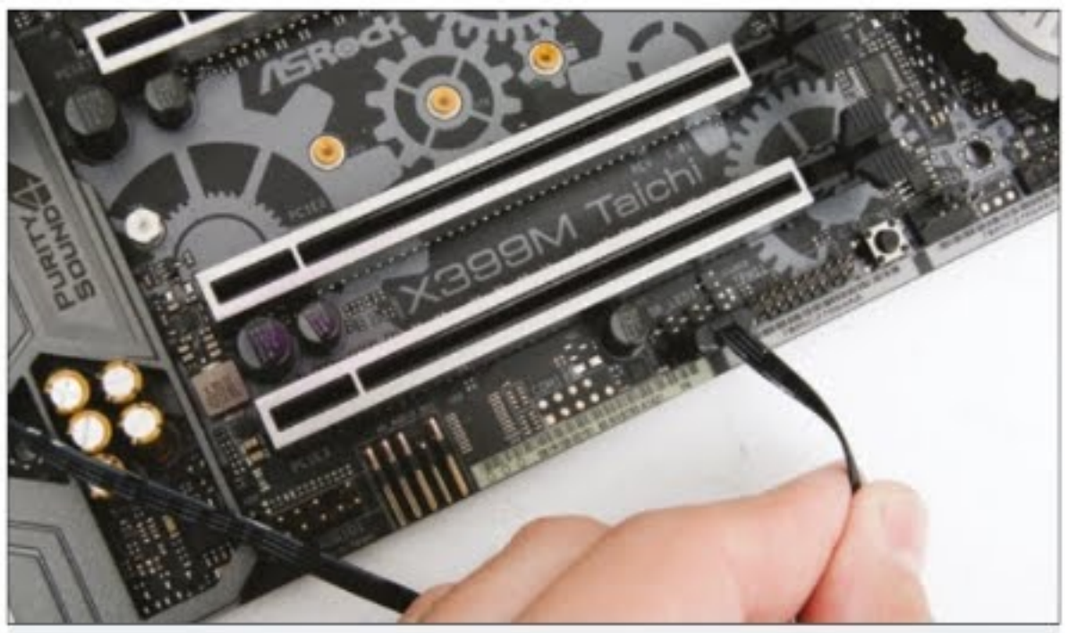
It's worth test-fitting the monoblock once you've applied the thermal paste. Use the included fittings and tighten them securely. You can also use this opportunity to work out your tubing routes to and from the monoblock.

12 / REMOVE AND CHECK CONTACT

Now remove the waterblock and check that good contact has been made with the pads and paste. You can then reinstall it in the knowledge that it's fitted correctly.

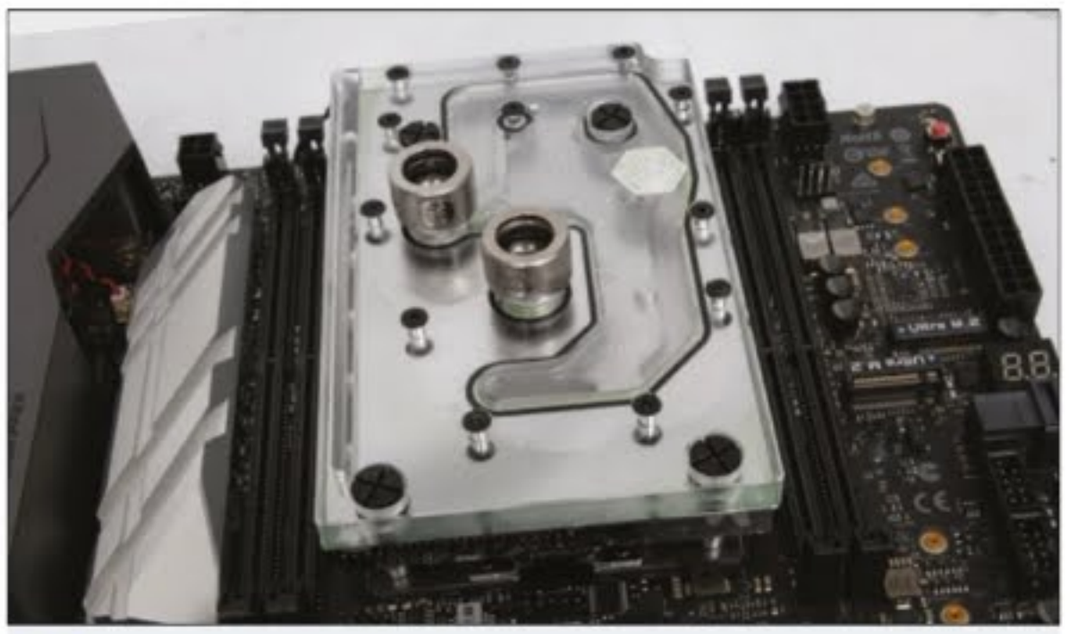
13 / INSTALL ADDITIONAL HEATSINKS

Some monoblocks are equipped with additional heatsinks for nearby components. These will replace any original components dislodged by the monoblock. Go ahead and install these heatsinks now.



14 / CONNECT RGB LIGHTING

Most monoblocks are equipped with RGB lighting. If so, it can often be useful to route the RGB lighting cable over the top and behind the motherboard, either to reach an RGB header on the bottom of the PCB, or simply to tuck the cable out of sight.



15 / INSTALL FITTINGS

Finally, go ahead and install your water-cooling fittings. It's usually a good idea to run one length of tubing from the monoblock to your graphics card, but pay careful attention to whether the monoblock has a specific inlet port, as using the right port can affect performance in these cases. **CPC**

These sketches, based on System Shock, Dungeon Keeper, Carmageddon and The Secret of Monkey Island, were drawn on Matilda's phone on the train

Bhaal Spawn

Ben Hardwidge talks to artist Bhaal Spawn (real name Matilda) about her work based on old PC hardware and DOS games

If you follow the retro PC gaming world online, you may well have seen Matilda's work shared in various forms. Her Lego models of the Sound Blaster Pro and 3dfx Voodoo cards have proved popular with those of us who remember the early days of PC gaming, particularly when Photoshopped onto a real Lego box to look like proper kits.

There's plenty of other nods towards DOS gaming in Matilda's portfolio as well, from her regular stream of Doom-inspired artwork, to pieces based on Monkey Island, System Shock and Dungeon Keeper. We caught up with Matilda to talk about early PC hardware, DOS gaming and what it is about the PC's early days that still excites so many people.

CPC: Why do you think there's so much nostalgic enthusiasm for early PC hardware and gaming at the moment?

Matilda: As you know, PC hardware changes so rapidly that this year's super-funky super graphics card is next year's novelty coffee mug coaster. Sometimes it can feel like the machines we used when we were little have more in common with a Victorian loom than the super-computers in our pockets or on our desks. And yet, because we used them so much when we were small, with our heads full of wonder at this new-found digital escapism, those old machines remain connected to that time and those feelings. I feel like revisiting them now is like revisiting that same sense of innocence. I think that's quite powerful.

CPC: What was it about the Sound Blaster Pro and 3dfx Voodoo that inspired you to make the Lego models?

Matilda: I created those in a fit of nostalgia myself. I'm a fan of Lego and had been talking about Sound Blaster cards earlier that day – the idea just popped into my head. It felt like a fun challenge, and the shape and colours of the cards are really attractive. I didn't really think about whether I had the pieces, let alone whether it would actually work!

CPC: Did you have those cards back in the day?

Matilda: Of course! I was still using a 486 by the time the first 3D accelerators showed up, so the first graphics card my family owned was a later Nvidia Riva TNT2. But, long before then, when I heard a friend's computer with an actual FM synth and digitised speech, I knew I had to have a Sound Blaster that Christmas (even if it meant lighting a fire while Santa was coming down the chimney and forcing him to hand it over on pain of death).

What's more inspiring than shooting demons in the face!?

CPC: What spec was your first PC, and what did you play on it?

Matilda: In primary school I became friends with a boy who had an Atari ST. It was watching him play games and later playing with him that got me interested in computers. When my dad bought a PC for home use, I was disappointed that it wasn't the same type of machine my friend had. It was an Amstrad 2086 – an 8MHz 8086 PC with a 32MB hard drive, 256-colour VGA and 640KB of RAM.

It wasn't intended for gaming, but still, I knew how to get my own way and my parents relented by buying me a few games, some of which are now considered classics. Sim City, Eye of the Beholder 2, Sim Earth, Castle Master and Lemmings were probably the first games I owned. Some ran as slowly as frozen treacle on our ancient hulk, but I didn't care!

CPC: The Monkey Island Melee Island picture is instantly recognisable, despite having a very different art style to the game. What was the process of recreating this image?

Matilda: When I first started on Twitter, I wrote a lot of poetry inspired by old MS-DOS games, including Monkey Island. I would write them on the train to work and would spend the inevitable half an hour stuck at a signal failure illustrating them with my iPhone.

The strokes were made by drawing them freehand with my finger on my 5in smartphone screen. I picked that particular image because I just find the art style of the Monkey Island games beautiful!

CPC: We love your Dune: Battle for Arrakis pastel recreation of the box art for Dune II. Why did you pick this picture?

Matilda: A friend of mine asked me to paint it. I'd never seen the David Lynch film at the time, but I had been a big fan of Westwood's game, Dune 2. The image is from a poster I had seen and it just felt so desolate, so I painted my own interpretation. The spice must flow!

CPC: Several of your pieces are based on LucasArts adventures. Which was your favourite adventure game from this period, and what is it about LucasArts' characters that makes them such great subjects for you?

Matilda: I have a strange relationship with those graphic adventures, because I often enjoyed watching and helping my friends to play them more than playing them myself. I could never really get on with the puzzles in those games. Sam and Max and Day of the Tentacle confused me a lot.

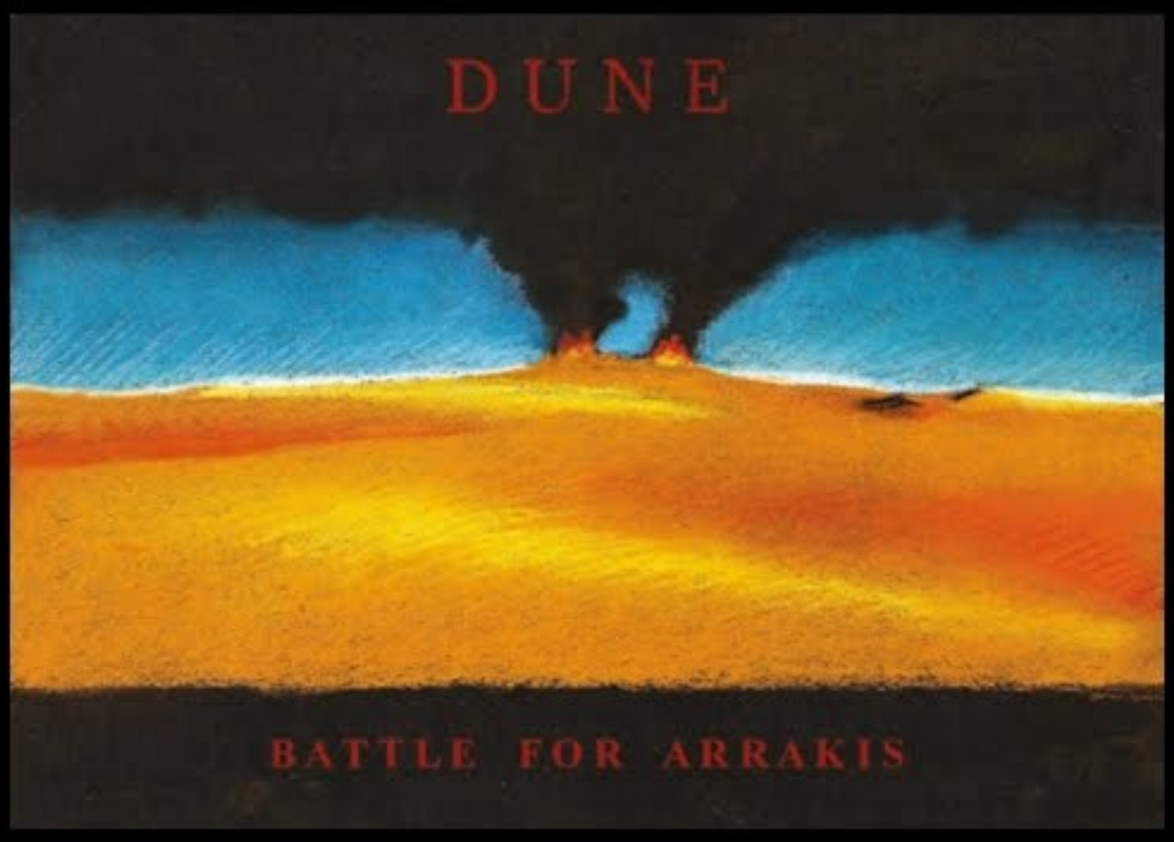
However, at the same time, the humour and the social element of playing the games together with friends was really absorbing. The Secret of Monkey Island was definitely a favourite. The thing they all have and that, as an artist, I find really interesting is the sense of fun and wacky atmosphere they all display with their style, as well as their characters. I think they're brilliant.

CPC: What were your favourite DOS PC games?

Matilda: Oh, so many! I loved some slower-paced, story-driven games, as well as games my dad (fortunately) expected to be educational, such as Sim City and Sim Earth. I also loved the escapism of roleplay games such as Ultima 7. These allowed you to almost inhabit a whole world, and it was so absorbing to play as a character meant to be *me* with whom I could identify with personally, rather than the generic male beefcakes that were painfully prevalent.

CPC: A lot of your artwork is based on Doom. What is it about Doom that inspires you?

Matilda: What's more inspiring than shooting demons in the face!?



This pastel piece was inspired by the poster artwork for Westwood's Dune II. The spice must flow!

CPC: Do you still play PC games today?

Matilda: Definitely! I don't tend to keep up with the latest titles or play the biggest games. I just make a list of whatever I've seen that I like and then get around to playing them eventually. I'm currently playing The Witcher III (still) and Darkest Dungeon, and I'm about to start Lands of Lore.

CPC: Some of your pencil images are really detailed. How long does it take you to create a piece such as your Ciri drawing, and how do you build up the image?

Matilda: I'm a weirdo, because I don't like to do any pre-drawing, outlines or measurements, and I don't use grids or lightboxes or any of those shenanigans. I usually just start with one of the eyes, drawing it in complete detail and then I just expand outwards, using judgement to get the proportions right. Usually, an A4-size drawing will take about five or six hours, although I can't bring myself to work in a studious way, sitting at a desk with a lamp and soothing music. I draw in front of the TV with my sketchpad on my lap.

You can follow Matilda on Twitter (@Bhaal_Spawn), and buy her art from **etsy.com/uk/shop/YavinPaints** CPC

Matilda's portfolio includes many detailed pencil drawings, including this image of Ciri from The Witcher III

The PC speaker

K.G. Orphanides delves into the bleeps and bloops of the PC's original primitive sound system

Before sound cards brought us polyphonic music and CD-quality PCM (pulse-code modulation) audio recordings, PCs could make exactly one noise: a square wave, output through a dynamic speaker driven by the computer's timer chip. Launched in 1981, IBM's first model 5150 Personal Computer had an internal 2.25in (5.7cm) speaker, designed to produce BIOS error codes to help diagnose problems at boot.

It was driven by the Intel 8253 Programmable Interrupt Timer, the same piece of hardware that handled system timing. While Timer Channel 0 was used for system synchronisation, Timer Channel 2 was used to send square waves to the internal speaker, making it beep.

By the 1990s, the 8252 had been superseded by the Intel 8259 Programmable Interrupt Controller (PIC), and these days, you'll find a modern hardware equivalent on your motherboard's southbridge in the form of an Intel Advanced Programmable Interrupt Controller (APIC) variant. All of them retain PC internal speaker functions.

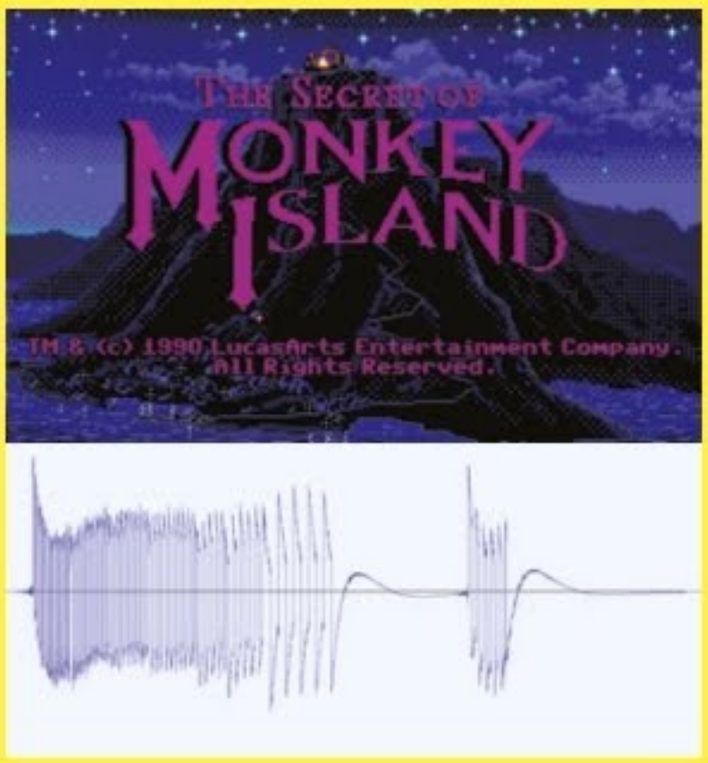
As PC sound card adoption grew through the 1990s, fewer games used the integrated beeper and smaller piezoelectric speakers would become more commonplace. These were quieter, and lacked the versatility and subtlety of a larger dynamic speaker, making some fancier audio effects far less distinct and often too quiet.

Many modern PCs no longer come with any kind of speaker. But motherboards still have the header connector, so you can still install one and listen to audio designed for an internal beeper as it was meant to be heard.

Quest for polyphony

Whichever way your PC beeper sound is implemented, it's monophonic, which means it can only produce one tone at a time. But, as with other very limited early computer audio standards, that wasn't going to prevent

The Intel 8253 chip drove the original PC speaker. Credit: Wikimedia Commons



An arpeggiated pseudo-polyphonic 'chord' from The Secret of Monkey Island

composers from doing remarkable things with it.

Beyond simple system beeps, the easiest music to persuade a PC speaker to reproduce is single-tone melodies. A series of instructions is sent to the timer via the CPU, using the programming language of your choice, telling to it produce a series of tones at a specified frequency.

Sound effects in games also started out as simple beeps, but programmers soon started getting clever, rapidly changing the tones being sent to the speaker to produce complex audio effects. Apogee Games mastered the art of creating convincing – or at least distinctive – PC speaker effects in titles including Commander Keen and Hocus Pocus.

You technically can't play polyphonic music on hardware that can only produce one voice at a time but, as it transpires, there are ways around this problem. Probably the most widely used approach to this is arpeggiation, where a pseudo-polyphonic effect is achieved by rapidly switching from one tone to another – anywhere up to 120 times a second – to give the impression of chords to the listener.

A number of games, including the 1990 PC version of The Bitmap Brothers' Xenon 2 Megablast in 1989, the PC port of Sega's Golden Axe in the same year and Magnetic Fields' Lotus III in 1992, create two or three virtual audio channels and alternate which of them is directed to the timer chip, allowing basslines to be rapidly switched into the music. The results often sound harsh and busy, but produce a rather effective impression of polyphony.

A classic PC speaker square wave from the theme to Space Quest III: The Pirates of Pestulon

A combination of these techniques was used to even better effect in LucasArts' PC speaker music, such as the remarkable beeper rendition of the main theme from The Secret of Monkey Island (1990), where the sophisticated use of fast trills and an alternating percussive channel created the impression of steel drum chords backing the main melody.

Other techniques made more direct changes to the way the PC speaker's sound output worked. Windmill Games' 1983 booter game Digger and its iconic use of Hot Butter's Popcorn as its in-game theme is thought to be the earliest title to use pulse width modulation (PWM) as a method of producing more sophisticated sound, with a variable volume and harmonies.

Also used in numerous ZX Spectrum games, PWM uses careful timing of the signals sent to the PC speaker to modulate its usually binary voltage levels, forcing the speaker into a range of partially on positions to produce sine waves. This can effectively turn the speaker into a 1-bit DAC (digital-to-analogue converter).

Also heard in titles including Hard Drivin' and Fantasy World Dizzy, this approach can be used to play a pre-generated soundtrack, rather than using the timer chip to directly generate square wave tones. However, even at 1-bit, this sound reproduction was often CPU-intensive and the resulting audio's low quality grates on many listeners.

Later, Access Software's RealSound technology used a near-inaudible carrier wave and fine-grained control of the PC speaker's displacement amplitude to produce 6-bit digitised audio, giving us surprisingly high-quality speech and music in games including Mean Streets, World Class Leaderboard Golf and Legend Entertainment's Spellcasting series.

By 1992, even Microsoft was in on the game, releasing a driver for Windows 3.1 that allowed any PCM WAV file to be output via the internal speaker. As sound cards, CD-ROM games, and then integrated motherboard audio became ubiquitous, the need to write dedicated timer chip music or kludge samples through the internal beeper evaporated, and PC speaker audio vanished from audio selection screens.

Back to the present

Today, PC speaker music isn't as dead as you might expect. Although less iconic than the C64 or NES audio systems, you can hear its influence in the modern chiptunes music scene.

In February 2019, Russian composer Shiru released System Beeps, an entire album written for the PC speaker and using some of the most sophisticated arrangement, arpeggiation and hearing perception tricks we've heard to create an illusion of polyphony. There is, of course, a DOS version of the album, but if you don't happen to have any classic PC hardware (or a copy of DOSBox), it's also available to buy in conventional digital formats.

Shiru used modern Digital Audio Workstation software to compose System Beeps and has made relevant plug-ins, projects and source code available for anyone else who wants to play with them.

Shiru isn't alone in working on music creation tools for your internal beeper. BaWaMI, created by Robbi-985, is a Windows MIDI synthesiser that will output via PC speaker. If you're so inclined, you can still hear and make new music for the PC's oldest audio device. CPC

FURTHER LISTENING

The Secret of Monkey Island
custompc.co.uk/MonkeyIsland

PCM audio through the PC speaker
custompc.co.uk/PCM

Album: System Beeps
custompc.co.uk/SystemBeeps

JAMES GORBOLD / HARDWARE ACCELERATED

COMPLEX EVOLUTION

James Gorbold explores the ways in which mobile and datacentre tech can influence PC gaming hardware, and vice versa

Throughout the varied history of the PC, its evolution has been driven by many different factors. One of the most notable, of course, was the development of the gaming market in the late 1980s from a cottage industry into the billion-dollar industry of today.

As we saw in last month's interview with the founder of Creative, a significant cause of this change was the emergence of sound cards, finally giving the PC sound capabilities in line with other home computers of the day, such as the Atari ST and Amiga. I still have very fond memories of my first Sound Blaster, not just because it was the first piece of hardware I bought, but because in conjunction with games such as Wing Commander, my 286 felt like a true gaming computer, rather than a clunky beige office computer.

It's been quite a few years since we've seen such a major seismic leap forward in technology as the sound card, with other notable leaps such as GPUs, multi-core CPUs and SSDs all occurring over a decade ago. However, there's one factor that continues to drive the PC forward, albeit sporadically, and that's the continuing game of leapfrog between the four sectors of the PC market: desktops, workstations, servers and laptops. Just as we saw the technology in a business machine used for games in the late 1980s, we see that technologies developed for one of these markets occasionally has unforeseen and unplanned effects on the PC market.

A great example was Intel turning to laptop CPUs to help save its desktop CPUs. The trouble came about because of the lengthy pipeline in Intel's NetBurst architecture, which was expected to reach the heady heights of 10GHz, but was so notoriously power-hungry that it simply wasn't possible to produce such CPUs.

Rather than persevering with NetBurst and its successors, Intel turned to the Pentium M, which had been designed for laptops, and could trace its highly efficient short pipeline design way back to the Pentium Pro, Intel's first dedicated server CPU. While Pentium M itself wasn't Intel's saviour, it led to the development of the first Core CPUs, helping Intel to regain competitiveness in the desktop market.

However, arguably the best example of one part of the PC market changing another was the discovery in the mid-2000s that GPUs could be used for a lot more than playing games, and were also incredibly potent tools for parallel compute tasks, such as video encoding, rendering, simulations and deep learning. This in turn led both AMD and Nvidia to develop billion-dollar datacentre GPU businesses in addition to the gaming GPUs reviewed in **Custom PC**.

> The Tensor cores in the latest Nvidia Turing GPUs only exist because they were first developed for datacentres

The story of the GPU has come full circle recently too, with the design of datacentre GPUs now influencing the design of gaming GPUs. For instance, the Tensor cores used for DLSS in the latest Nvidia Turing GPUs (see p86) only exist because they were first developed for the earlier Volta architecture, which Nvidia used to build datacentre GPUs. A true case of the tail wagging the dog.

It will be interesting to see how much future generations of gaming and datacentre GPUs have in common, especially with a third major player, Intel, due to enter the market in 2020. I've long believed that Intel will go after the datacentre market first, but that doesn't mean an Intel gaming GPU isn't also planned for some point in the future. CPC

James Gorbold has been building, tweaking and overclocking PCs ever since the 1980s. He now helps Scan Computers to develop new systems.

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