Introducing Raspberry Pi 4

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So here it is. The big secret is out and we can finally talk about it: Raspberry Pi 4! The new model is a serious step forward. Raspberry Pi has always been a capable computer, edging towards full desktop capability. That edge has arrived.

With up to 4GB of RAM, dual HDMI, quad-core ARM CPU, Gigabit Ethernet, and USB 3.0, Raspberry Pi 4 is a truly a desktop computer. I mean: Raspberry Pi has always been a computer, but now it’s a computer. Raspberry Pi 4 is a Linux-powered PC without compromise. Browsing the web is a breeze, apps start and videos play without stutter, and you can multitask several programs at once.

To celebrate its launch, we’ve got a full feature with benchmark tests and interviews with the engineering team (page 56).

For all its power, Raspberry Pi 4 remains a programmable computer. That bit is important. A tablet is a tablet, a phone is a phone, but a Raspberry Pi can become anything you want, used for any task.

This month, Raspberry Pi is a pop star’s TV wall (page 12), an earthquake-detecting robot (page 16), a smart greenhouse (page 22), a programmable console (page 44), a squeezable controller (page 54), and a spacecraft (page 66). Try doing that with your smartphone.

Raspberry Pi is, and always will be, a programmable computer. Only now, it’s a really fast one.

Lucy Hattersley  Editor
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WIN
ONE OF
TEN
RASPBERRY
PI 4 KITS
Raspberry Pi smart cars skip traffic jams

Cambridge University uses Raspberry Pi to build autonomous cars with superior self-management skills. Bring on a more efficient, crash-free future, exhorts Rosie Hattersley

Trials of autonomous cars on a track in Cambridge have proved that traffic congestion headaches could be largely avoided in the future.

The results of tests using a small fleet of Raspberry Pi-controlled cars by Cambridge University researchers were presented at the International Conference on Robotics and Automation in Montreal in June.

Mimicking motorway mayhem

Scale models of existing cars were fitted with motion-capture sensors and Raspberry Pi controllers, and communicated with each other over wireless LAN. Researchers were keen to establish the behaviour of self-driving cars when faced with obstacles, such as a broken-down vehicle.

Where the robot cars were operated independently from each other, a car stuck behind one that had broken down had to slow down or stop and wait for a gap in the traffic in order to pull out into the next lane and overtake the obstacle. So far, so similar to commuters’ everyday experience.

However, in scenarios in which it was possible for the robot cars to communicate, the cars were able to drive ‘co-operatively’. If a car in the inner lane slowed down or stopped, a signal was sent to all the other cars. Those in the outer lane slowed slightly so cars behind the slower one were able to pull out and avoid a collision, thus keeping both lanes of traffic flowing smoothly.

With improved road safety it was possible to pack cars more closely, improving efficiency by

Cooperative driving increases throughput by at least 35%

The fleet of miniature cars was built using Raspberry Pi
Between 35% and 45%, depending on whether the tests were modelling co-operative or 'aggressive' driving modes.

Cross-car communication

“Autonomous cars could fix a lot of different problems associated with driving in cities, but there needs to be a way for them to work together,” says report co-author Michael He, an undergraduate student at St John’s College who designed lane-changing algorithms for the experiment. The algorithm calculates whether it is safe to change lanes, and whether there’s a compelling advantage to doing so – a perhaps more rational approach than some human drivers.

The researchers now plan to trial larger fleets of cars with more complex scenarios such as road junctions and a wider range of vehicle types.

More information about the experiment can be found on the University of Cambridge website: magpi.cc/QGnWCY.
Young imaginations are fired with a powerful 3D animation tool running on Raspberry Pi, discovers Rosie Hattersley

Film fans have come to expect blockbusters to deliver incredible wow moments. Commercial success often depends on highly anticipated, technically challenging animation scenes. But big-screen visuals aren’t always the result of incredibly expensive animation tools. Blender is a free, open-source, visualisation tool developed 20 years ago by Dutch animation company NeoGeo and has evolved through community input across multiple computer platforms.

Blender is available for the Raspberry Pi, and pupils can also make great use of it to learn coding skills. Children at Elton Primary School in Cheshire recently embraced the opportunity to get hands-on animation experience when Craig Fisk, one of the volunteers at their Code Club, showed them how it works (magpi.cc/DdqXVz).

Blender was used in superhero films such as Wonder Woman

Students learn to use Blender by colouring in a 3D rocket

This snow scene can be animated to learn 3D animation skills
Club website, they are beginning to work on original animations of their own. Craig says, “My plan is to get them to work collaboratively to create a new scene which they will animate. Each student will build something to put into the scene, which we will then combine, and then they can all have a go at animating it.”

They were especially excited when they realised Blender is the building block for the 3D animation used in many games and films. Blender was used in superhero films such as *Wonder Woman* and sequences in TV show *The Walking Dead*.

Blender is also used in the visuals that complement the virtual reality of Google Expeditions. Pupils use a smartphone and a cardboard viewer to create incredible virtual journeys from the comfort of their classrooms.

**Model students**

Projects hosted on the Code Club website ([magpi.cc/iovwYo](https://magpi.cc/iovwYo)) allow Raspberry Pi users to create models and animations, such as making a car drive through a snow scene.

Craig says the pupils were so keen to use Blender that, once they’d mastered the basic controls to manipulate objects, they zipped through two projects in a single Code Club session. They then went on to master skills such as extruding and editing objects to create a 3D visualisation of a house, as well as creating an animated rocket.

Now that the group has worked through all the Blender projects showcased on the Code Club website, they are beginning to work on original animations of their own. Craig says, “My plan is to get them to work collaboratively to create a new scene which they will animate. Each student will build something to put into the scene, which we will then combine, and then they can all have a go at animating it.”
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DESIGN THE WORLD
Where would the Wizard of Oz have been without the visual artifice that kept his myth alive? Being confronted with Johanna Tano’s wall of TV screens surely has a similar disembodied effect to the sight that greeted Dorothy and pals when they entered the Emerald City. Harnessing the power of Raspberry Pi computers, Johanna has been able to sync up and independently control up to 30 analogue TV displays at once.

In her aptly named TV Wall, Johanna demonstrates the possibilities of using old tech and new in a highly engaging fashion. The TV Wall had its debut at Stockholm’s Fashion Week in 2017, where the likes of singer Kelis partied to a backdrop of multi-screen live video mash-ups.

The sun always shines on TV
In its most recent iteration, the TV Wall is central to Swedish singer Zacharias Zachrisson’s music video for Shadow. He says: “Together with the video director, Albin Eidhagen, we created custom-made videos and animations for the TV screens, which was live-mixed when we filmed it.” The result is a decidedly eighties video, not unlike something by A-Ha.

Appropriately enough, the video came about when the singer saw the TV Wall displaying live code-generated visuals on Instagram and got in touch with Johanna. She had only a week to assemble the build for the music video shoot and says things “get complicated, fast” as the installation is scaled up and more TVs – and more IP addresses – are added.

Those inspired by her project can follow in her footsteps by breaking it down. “Work out how to tell multiple Raspberry Pi boards to display different parts of the same video,” she advises. “Work out how to get a video signal from Raspberry Pi to a TV, then how to stream video from a computer to a Raspberry Pi,” she advises. “Work out how to tell multiple Raspberry Pi boards to display different parts of the same video. By solving each step, you end up having a quite advanced system without even realising it.”

Work out how to tell multiple Raspberry Pi boards to display different parts of the same video
Johanna once created a fortune-teller from a rotary-dial telephone. She harnessed real space data to generate visual art, controlled by an EEG. She was part of the Berlin-based tech-art collective Lacuna Lab.

Ber Ārst aspberry Pi project lit up Sweden with 45 LED light trees, users controlled remotely.

She views Raspberry Pi as the ideal way to control hardware used in conceptual art projects.

Some impressive visual effects can be achieved by sending a different video feed to each TV.

Quick FACTS

- Johanna once created a fortune-teller from a rotary-dial telephone.
- She harnessed real space data to generate visual art, controlled by an EEG.
- She was part of the Berlin-based tech-art collective Lacuna Lab.
- Her first Raspberry Pi project lit up Sweden with 45 LED light trees users controlled remotely.
- She views Raspberry Pi as the ideal way to control hardware used in conceptual art projects.

Raspberry Pi boards control the displays of up to 30 networked analogue TVs.

The TV setup can be reconfigured since output is dependent on each on-board Raspberry Pi’s instructions.

The custom-built web interface controls which bit of each video appears on-screen and when.

Some impressive visual effects can be achieved by sending a different video feed to each TV.

The TV Wall project uses Raspberry Pi boards to control the displays of up to 30 networked analogue TVs. The custom-built web interface controls the appearance of video bits on-screen. Some impressive visual effects can be achieved by sending a different video feed to each TV.
Automatic mapping is controlled through the web interface, meaning she can easily modify each Raspberry Pi’s settings, including which part of each video to use.

A TCP Syphon Server application connects to the TV Wall network, enabling the video or visual output generated by the VJ software to be displayed in real-time on the wall.
Stockholm-based Johanna is a self-taught programmer and maker. She was a web developer and digital producer at companies such as Acne and B-Reel. Four years ago she set up on her own, specialising in conceptual art and with a specific aim of working collaboratively across different media and learning new things. It led to her ongoing interest in Raspberry Pi.

“I started using Raspberry Pi [because] I wanted to find new areas where I could use my programming skills and wished to go outside the traditional computer screen with my output, bringing in more physical and real-world objects in my work,” explains Johanna. “Raspberry Pi has been the ideal solution to use in most of my interactive art installations to control the hardware.”

**Superstar VJ**

Those with designs on becoming video DJs themselves will need a Mac and software that supports video output for Syphon (magpi.cc/FVJQXh), an open-source client that works with lots of video streaming programs.

Johanna’s technical expertise is also a critical element. Behind the scenes of her TV Wall, she’s busy controlling which bits of video footage appear on which TV and when, via the web interface she built. She can modify each Raspberry Pi’s settings, including which part of each video to crop out. With such audio-visual control at her command, it’s no wonder she reminds us of a modern-day kind of Oz.
I
n the summer of 2018, engineers at NASA’s Jet Propulsion Laboratory built a mini planetary rover with the aim of letting students, hobbyists, and enthusiasts create one for themselves. It uses commercial off-the-shelf parts and has a Raspberry Pi as its brain. But despite costing about £2000 in total, the Open Source Rover Project has proven rather popular, including among people who actually work for the USA’s space agency.

One of those is Dr Jamie Molaro, a research scientist at the Planetary Science Institute. Her main focus is studying the surfaces of rocky and icy airless bodies such as comets, asteroids, and the moons orbiting Earth, Jupiter, and Saturn. So when she decided to create her mini-rover – which she dubbed PARSOEE, or Planetary Analog Remote Sensor and ‘Oil Electronic Explorer – she also sought to shake things up a little.

Brought to life
Constructing the robot itself was, she says, rather straightforward: the instructions were detailed and she was able to draw upon the help of others in a forum. Jamie also built the robot with her husband, a software engineer at Adobe. “My interest in the Open Source Rover Project was driven by my scientific background, but not my ability to build it,” she tells us, of what is essentially a miniature version of the Curiosity rover trundling over the surface of Mars.

Jamie’s interest in science led to her considering the rover’s potential payload before the couple had even finished building it. She added a GoPro camera and a Kestrel 500, which measures temperature, pressure, elevation, wind speed, and humidity. In addition, she opted to use a Raspberry Shake seismometer – a device costing a few hundred dollars which comprises a device sensor, circuit board, and digitiser – with a Raspberry Pi board and a preprogrammed microSD card.

The sensor records activity, converts the analogue signals to digital, and allows the recorded data to be read on Raspberry Shake servers. Jamie hopes to use PARSOEE to study the kinds of processes active at the surface of other planets.

“A seismometer helps us understand our physical environment in a very different way than images from a camera,” she says.

Seismic solutions
To that end, with funding, Jamie would like to heat and cool boulders and soils in the lab and in the field and analyse their seismic signature. “Thermally driven shallow moonquakes were recorded by instruments used by the Apollo astronauts,” she says. “We believe these quakes may reflect signals from a thermal fracturing process that breaks down lunar boulders, or from the boulders and...
PARSLEE is based on NASA’s Open Source Rover Project. It has a Raspberry Shake 4D seismometer on board. This incorporates a geophone and three accelerometers. Jamie will use PARSLEE for scientific experiments. Jamie intends to write her own data-collection software.

Quick FACTS

- **PARSLEE** is based on NASA’s Open Source Rover Project.
- It has a Raspberry Shake 4D seismometer on board.
- This incorporates a geophone and three accelerometers.
- Jamie will use PARSLEE for scientific experiments.
- Jamie intends to write her own data-collection software.

A seismometer helps us understand our physical environment in a very different way than images from a camera. Surrounding soil shifting and settling as it changes temperature throughout the day. We can do experiments on Earth that mimic this process and use what we learn to help us understand the lunar seismic data.

Jamie is also toying with optimum locations for the Shake-fitted rover. “The best planetary analogue environments are usually deserts, due to the lack of moisture and low vegetation,” she reveals. “Places like dry lake beds, lava flows, and sand dunes all provide good challenges in terms of testing the rover’s ability to manoeuvre and collect data, as well as to try out technology being developed with and for it.”

One thing’s for sure, it is set to travel and potentially make a scientific breakthrough: “Anyone can use the rover for DIY science experiments.”

Jamie has been working on a payload-laden version of NASA’s Open Source Rover (magpi.cc/tkOULg). Credit: NASA-JPL.
Community water sprinkler

At any CoderDojo Coolest Projects event, you’re bound to see incredible things built by young makers. At Coolest Projects USA, we had the chance to talk to Adarsh Ambati about his community sprinkler and we were, frankly, amazed.

“The extreme, record-breaking drought in California inspired me to think of innovative ways to save water,” Adarsh tells us. “While going to school in the rain one day, I saw one of my neighbours with their sprinklers on, creating run-offs. Through research, I found that 25 percent of water used in an average American household is wasted each day due to overwatering and inefficient watering methods. Thus, I developed a sprinkler system that is compliant with water regulations, to cost-effectively save water for entire neighbourhoods using a Raspberry Pi, moisture sensors, PyOWM (weather database), and by utilising free social media networks like Twitter.”

Efficient watering

In California, it’s very hot year round, so if you want a lush, green lawn you need to keep the grass watered. The record-breaking drought Adarsh was referring to resulted in extreme limitations on how much you could water your grass. The problem is, unless you have a very expensive sprinkler system, it’s easy to water the grass when it’s not needed.

“The goal of my project is to save water wasted during general-purpose landscape irrigation of an entire neighbourhood, by building a moisture sensor–based smart sprinkler system that integrates real–time weather forecast data to provide only optimum levels of water required,” Adarsh explains. “It will also have Twitter capabilities that will be able to publish information about when and how long to turn on the sprinklers, through the social networks. The residents in the community will subscribe to this information by following an account on Twitter, and utilise it to prevent water wasted during general–purpose landscaping and stay compliant with water regulations imposed in each area.”

Using the Raspberry Pi, Adarsh was able to build a prototype for about $50 – a lot cheaper than ‘smart’ sprinklers you can currently buy on the market.

“I piloted it with ten homes, so the cost per home is around $5,” he reveals. “But since it has the potential to serve an entire community, the cost per home can be a few cents. For example, there are about 37,000 residents in Almaden Valley, San Jose (where I live). If there is an...
Based on two months of data, 83% of the water used for outdoor landscape watering can be saved. The average household in northern California uses 100 gallons of water for outdoor landscaping on a daily basis. The ten homes in my pilot had the potential to save roughly 50,000 gallons over a two-month period, or 2500 gallons per month per home. At $0.007 per gallon, the savings equate to $209 per year, per home. For Almaden Valley alone, we have the potential to save around $2m to $4m per year!”

The results from Adarsh’s test were presented to the San Jose City Council, and they were so impressed they’re now considering putting similar systems in their public grass areas. Oh, and he also won the hardware project category at Coolest Projects USA.

"Based on two months of data, 83% of the water used for outdoor landscape watering can be saved"
Smart doorbells have been ringing in the changes for home security for a while now, streaming video and audio to mobile devices whenever their button is pressed. They let you see and communicate with visitors regardless of whether you’re in or out. While one of the most popular devices is Ring, however, Martin Mander opted to create his own.

“I took it as a personal challenge to build something with similar functions to Ring with a Raspberry Pi for a much lower cost,” he says, indulging his passion for taking old tech and giving it a new lease of life using Raspberry Pi. And so, the idea for the PiNG video doorbell was born.

“At its most basic, it’s just a Raspberry Pi, a webcam, a button, and an amplified speaker, which many folks have lying around already,” Martin says. What’s more, he reckons it is simple enough for others to recreate and he actually created it with this in mind.

Securing the system
For a long time, Martin kept putting his project to one side as he sought an easy way to make video calls via Raspberry Pi. He noted the release of a browser-based version of Google Duo. “Before that, I was on the point of installing Android on a Raspberry Pi to see if I could use Duo that way,” he says. “But the first test of Duo’s web app was amazing. From that point, it was full speed ahead.”

Martin found Duo worked best on a Raspberry Pi 3, which he originally connected to a Logitech webcam, plus a screen, mouse, and keyboard (later swapping the webcam for a LifeCam HD-3000 which has an integrated microphone). The real challenge was to make the setup work with a

Knock knock. Who’s there? Martin Mander with a better way of announcing his arrival. David Crookes looks at his Raspberry Pi-based smart doorbell.
The first test of Duo’s web app was amazing.

headless Raspberry Pi and buttons. This involved coding mouse movements, clicks, and keyboard strokes using the Python module PyUserInput.

“When someone presses PiNG’s button (which is a standard doorbell I bought on eBay), the script uses the PyUserInput module to move the cursor around the screen, emulating mouse clicks and keystrokes to control the Google Duo web app, which is running all of the time,” Martin says.

“Once the call is ended, the script is ready straight away for the next button press.” Now, Martin was ready to find his new creation a home of its own.

Playing it safe

A few years ago, Martin bought three intercoms originally released in 1986, and he decided to use one of those. “It’s a bit unusual but still obviously a doorbell,” he says. But since he didn’t want Raspberry Pi or any components hanging outside the house “for security and connectivity reasons”, he decided on a two-part construction. “The outside part is just a case for the button, speaker, and webcam,” he reveals. The project’s Raspberry Pi, meanwhile, is housed in an old, stripped-out tape machine located inside the porch and connected to the intercom using a six-core alarm cable with connection blocks at each end. Once it’s fired up, the visitor presses the button and Martin can see and hear the person on his phone.

“I got a call from a delivery person while out for a lunchtime walk and it was a huge moment for me,” he recalls of its first real life test. “Thankfully, he seemed unfazed by his intercom experience and we had a good two-way conversation about where to leave the parcel.”

Quick FACTS

- PiNG uses the video-calling app Google Duo
- A GPIO-connected lever microswitch starts calls
- Raspberry Pi 3B+ sends calls to mobiles within four seconds
- It would cost less than £50 to build
- A chime also sounds inside the house

Once these components were placed inside the intercom, the box was mounted to the exterior of the house using strong Velcro pads.

Project Showcase
Thomas Geers is a fan of palm trees, although they’re not very common in Germany, where he lives. Seeking to help conserve an endangered species of palm tree – the Chilean honey (or wine) palm, *Jubaea chilensis* – he bought some seeds in the summer of 2018. One issue, however, was their long germination time: up to a year. This inspired Thomas to build a fully automated greenhouse to ensure stable conditions for the seeds and possibly encourage faster germination.

After purchasing a standard mini greenhouse from a hardware store, he modified it with a homemade housing. “The housing consists of a wooden frame and 1 cm-thick plywood, which are bolted together,” he tells us. “The wood is painted with a weatherproof wood glaze.”

He then equipped it with various sensors and automated systems for watering, heating, lighting, and air humidity – all controlled by a Python script running on a Raspberry Pi 3B+ linked to a relay board.

**Automatic for the plants**

“For automatic irrigation, there are twelve spray nozzles in the housing cover which will be activated as soon as the soil is too dry,” explains Thomas. “For this purpose, there is a capacitive earth moisture sensor (Giesomat) in the earth.”

Another key factor is maintaining an ideal temperature for the seeds. For this, Thomas placed a DS18B20 sensor in the soil and a heating mat underneath the container. “As soon as the earth temperature falls below a set value, the mat heats up the earth,” says Thomas.

The automated lighting system comprises two LED plant lights which are switched on and off via a day/night time control – 12 hours on, 12 hours off.

Last but not least, there’s an automated air humidity control system: “In the cover housing are two small fans, which are either time-controlled or, depending on the humidity in the greenhouse, allow an exchange of air to prevent mould.”

In addition, Thomas has installed four switches so that he can turn all devices on and off individually and manually, if needed. A small LCD screen shows the temperature and moisture/humidity levels for the soil and air, with arrows indicating which values are currently being adjusted.

Four of the germinated honey palm seeds. So far, out of 18 planted in the smart greenhouse, 11 have sprouted.
Triggered by dry soil, the automated irrigation system pumps water from a jug and sprays it through twelve nozzles.

Thomas built the housing from plywood; a rear compartment holds the Raspberry Pi and other electronics.

Sensors in the air and soil detect temperature and humidity/moisture.

The project took Thomas two months to complete. “The hardest thing for me was programming, as this was my first Raspberry Pi project and I had no experience with Python,” he reveals. “However, I had very good and friendly support from the German Raspberry Pi Forum.”

Sprouting seeds
Since the honey palms come from Chile, he set the greenhouse temperature range to the average for that country, and the soil moisture and air humidity values to what felt right.

So far, the results have been impressive, with a much improved germination rate. In the seven months before the smart greenhouse was ready to use, only six out of the 24 seeds germinated in a normal thermostat-controlled greenhouse. “In the eighth month, all remaining 18 seeds were placed in the [smart] greenhouse; eleven seeds sprouted this month,” says Thomas. “The palm trees will be planted in my garden someday.”

Quick FACTS
- The electronics are hidden in the rear of the housing.
- The housing cover and shell can be removed quickly.
- Sensors can be connected and disconnected outside the housing.
- Thomas also has a squirrel/bird box observed by a PiNoir camera.
- Two great tits make this their home. See the live stream at magpi.cc/DsAMqp.

Warning! Mains electricity
The lamps in this project use mains electricity. Please be careful!
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The dual-display Raspberry Pi 4 is here to redefine personal computing

By Gareth Halfacree

A new, 28 nm system-on-chip with powerful ARM Cortex-A72 processing cores. The first new graphics processor in Raspberry Pi’s history. Up to 4GB of high-speed LPDDR4 memory. Two high-bandwidth USB 3.0 ports. Dual HDMI 2.0 outputs, capable of driving a pair of 4K displays (at 30 fps, or one at 60 fps). In short: very new, very powerful, and very exciting.

Designed as a true PC replacement for a lot of use-cases, Raspberry Pi 4 is the most impressive Raspberry Pi yet – and benchmark testing proves it’s far from being all talk and no substance.
Get to know Raspberry Pi 4

Raspberry Pi 4 marks a major Raspberry Pi family redesign

Specifications

**SoC:** Broadcom BCM2711B0 quad-core A72 (ARMv8-A) 64-bit @ 1.5GHz

**GPU:** Broadcom VideoCore VI

**NETWORKING:** 2.4 GHz and 5 GHz 802.11b/g/n/ac wireless LAN

**RAM:** 1GB, 2GB, or 4GB LPDDR4 SDRAM

**BLUETOOTH:** Bluetooth 5.0, Bluetooth Low Energy (BLE)

**GPIO:** 40-pin GPIO header, populated

**STORAGE:** microSD

**PORTS:** 2 × micro-HDMI 2.0, 3.5 mm analogue audio-video jack, 2 × USB 2.0, 2 × USB 3.0, Gigabit Ethernet, Camera Serial Interface (CSI), Display Serial Interface (DSI)

**DIMENSIONS:** 88 mm × 58 mm × 19.5 mm, 46 g

QuickStart Guide

Raspberry Pi 4 is directly compatible with the 3B+ and all previous Raspberry Pi models, but the operating system has been updated to add support for the new system-on-chip which drives it. The easiest way to start from scratch is via our QuickStart Guide (page 38), which will guide you through setting up the latest NOOBS installer on a microSD card.

magpi.cc/quickstart

A | CPU
The new BCM2711B0 system-on-chip offers an impressive performance boost over its predecessors

B | POWER
The move to a USB Type-C connector for power allows Raspberry Pi 4 to support higher-current USB devices
**C | RAM**
A move to up to 4GB of LPDDR4 memory, from the LPDDR2 of previous designs, increases performance further.

**D | ETHERNET**
The Ethernet port, relocated to the top-right of the board, now offers full-speed network connectivity with no bottlenecks.

**E | DUAL DISPLAYS**
The two micro-HDMI connectors enable Raspberry Pi 4 to drive two 4K displays at up to 4Kp30, or a single display at up to 4Kp60.

**F | USB**
Two USB 3.0 ports, centre, offer high-speed connectivity for external devices including storage and accelerator hardware.
Eben Upton on Raspberry Pi 4

A brand-new processor, upgraded video capabilities, up to four times the memory – what did it take to make Raspberry Pi 4?

“I guess there’s a question, which is ‘why now, why not in a year’s time?’ Which is the sort of timeline we previously indicated,” says Eben Upton, co-founder of the Raspberry Pi Foundation, on the timing of Raspberry Pi 4’s release. “Broadcom has been working on silicon for it for a little while, and the silicon came good earlier than I was expecting.

“This is the B0 step of the silicon. BCM2835, which was new on 40 nm, was equivalently radical at the time. The version we shipped there is 2835C2, so we’d had an A0, a B0, a C0, a C1, and a C2 to get to a shippable product. This one got shippable by B0, and that’s taken a year out of the conservative schedule that we’d been communicating to people.”

Backwards compatibility

“It’s very substantially backwards compatible,” Eben promises. “You don’t like to say ‘perfectly backwards compatible,’ because I’m sure people will find ways in which it’s not. At launch, for example, I suspect there will be monitors that a Raspberry Pi 3 can drive that a Raspberry Pi 4 can’t, but that will be fixed over time.

“I think we’ve met our goals for backwards compatibility. Which is good, because otherwise you tear your software team apart. You either have to sunset old products, which you know we hate doing, or you end up with two software teams: one to move the old product forward, and one to move the new product forward.”

The pocket-sized PC

“It’s a PC replacement. I mean, we’ve always talked about Raspberry Pi as being a PC, and that’s become steadily more credible, I think, over the generations,” says Eben. “I think this one takes it over the line where a lot of users will sit down in front of it and not really perceive a difference.

“You talk about the things that take you into PC land? PCs drive two displays. You know, you’re not really a real PC if you don’t drive two displays, right? If you think about the person you’re speaking to on the phone in the bank, they’ll have two monitors: one to put your account details on, and one to put the product that they’re selling you on. We think this should break through very nicely into the thin client market and we’re working with Citrix to make sure that their stack works on it on launch day.”
A Raspberry Pi engineer’s desk, where hardware is tested thoroughly and bananas are eaten

A challenging design

“Obviously the ports have moved around, and that’s really a routing thing,” Eben explains. “The board is within a millimetre of not working, and there wasn’t enough routing resource to bring the Ethernet signalling down to the bottom-right of the board.

Building the BCM2711

“This has been a more complicated development than previous ones because previous ones have been on the same process node and we’ve basically just been ‘just been bolting larger ARM cores onto an existing chip,’” says Eben of the work that has gone into the new system-on-chip (SoC).

“The original prototypes, the Ao prototypes, are actually about five millimetres longer. They’re five millimetres bigger in X than the historical board, but he was able to squeeze it back down. My contribution was largely to go to his desk and say ‘is the board back at the right size yet?’ every day for about six months. I should have signed the board as well – I deserve half-credit!”

“The biggest challenge is the DRAM. If you look how close that SoC and that DRAM are to each other, you’ve got a 32-bit DRAM interface in that tiny little space, with some length-matching between the signals and the signals properly isolated from each other. If you were to desolder the USB-C connector, you’ll see James [Adams, director of hardware] has signed the board. So, the Easter egg is under the USB-C connector; it’s James’s signature, because I think he feels it’s the nicest piece of work he’s ever done, and it was very close to not being doable.

The Easter egg is under the USB-C connector; it’s James’s signature

This one’s on a new process node, so this one’s on 28 nm. Obviously, it’s got all these new features, so we’ve kind of moved it from being a 1080p-class chip to being a 4K-class chip. New process node, new memory technology, new multimedia IP [intellectual property], lots and lots of change. It’s a full-chip project.”
A full-chip redesign, the first in the history of Raspberry Pi, has unlocked new levels of performance.

It’s not hard to see where Raspberry Pi 4 improves on its predecessor. The brand-new BCM2711B0 system-on-chip has more powerful processing cores, the first upgrade to the graphics processor in the history of the project, and vastly improved bandwidth for both memory and external hardware. Gone is the single-lane USB bottleneck which hampered performance on older models, and Raspberry Pi 4 shines as a result.

**Spec comparison**

Internally, there’s little left unchanged between the Raspberry Pi 3 family and Raspberry Pi 4. The SoC is now built on a 28 nm semiconductor process node, down from 40 nm, and packs the significantly more powerful ARM Cortex-A72 processor cores. The memory has moved from LPDDR2 to LPDDR4, skipping a generation and improving bandwidth, and is for the first time available in capacities over 1GB with 2GB and 4GB versions available on launch day.

Even the graphics processor has been upgraded: the Broadcom VideoCore IV, which has been a staple since the original Raspberry Pi Model B, has been replaced with the more powerful VideoCore VI, unlocking both performance and dual-4K-display capabilities.

Add in the full-speed Gigabit Ethernet and USB 3.0 ports and you’ve got a significant upgrade on your hands.

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**Linpack**

A synthetic benchmark originally developed for supercomputers, Linpack offers a glimpse at just how far the Raspberry Pi family has come. This version – ported by Roy Longbottom – comes in three variants: the fast single-precision (SP), slower double-precision (DP), and a single-precision variant accelerated using the NEON instructions available in Raspberry Pi 2 and above (NEON).
**Python GPIO Zero**

Sitting somewhere between a synthetic and a real-world benchmark, here the Python GPIO Zero library is used to toggle a GPIO pin on and off as quickly as possible while a frequency counter measures the switching rate in kilohertz (kHz). This test is boosted by CPU speed.

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**File Compression**

An example of a real-world workload, this benchmark takes a file and compresses it using the bzip2 algorithm and measures the elapsed time in seconds. For Raspberry Pi models with more than one processing core – the Raspberry Pi 2 and 3 family, and Raspberry Pi 4 – the test is run a second time using the multi-threaded lbzip2.

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**Speedometer 2.0**

Speedometer 2.0 measures the responsiveness of the Chromium web browser by running a web application – a to-do list – and measuring how many times the application can be completed each minute. Here, performance hinges not only on CPU performance but on memory speed and capacity – the test proved too much for Raspberry Pi A+.

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**OpenArena Time Demo**

The new VideoCore VI gives Raspberry Pi 4 a significant boost over its predecessors, as demonstrated in this gaming workload test: the Quake III-based OpenArena first-person shooter runs through its built-in demo as quickly as possible at a High Definition (1280x720) resolution, while the average frame rate in frames per second (fps) is recorded.
**GIMP Image Editing**

Another real-world test, the popular open-source GIMP image-editing suite is used to process a high-resolution image and save it as a PNG. Like the Speedometer 2.0 benchmark, this is heavily reliant on both CPU and memory performance — and extra memory really helps some of the models on test.

**USB Storage Throughput**

Raspberry Pi 4’s new USB 3.0 ports offer a massive bandwidth boost, which has a big impact on the performance of external storage devices. Here, a solid-state drive (SSD) is connected via a USB adapter and the average read and write throughput measured in megabytes per second (MBps).

**Memory Bandwidth**

Although many workloads are primarily limited by CPU speed, others rely on memory bandwidth — the rate at which data can be written to and read from RAM. In this benchmark, the RAMspeed/SMP tool is used to measure the read and write bandwidth for 1MB blocks in megabytes per second (MBps).

**Ethernet Throughput**

While Raspberry Pi 3 Model B+ added Gigabit Ethernet connectivity, throughput on Raspberry Pi 4 is free from the single shared USB 2.0 channel to the SoC. The throughput of all Raspberry Pi models with a built-in Ethernet port is measured using the iperf3 tool, showing the average network throughput (in megabits per second) over several runs.
**Wireless LAN Throughput**

For this wireless networking test, an ideal environment is created: a Raspberry Pi is placed in line-of-sight of an 802.11ac router, and a wired laptop uses iperf3 to measure the average throughput over several runs. For models with dual-band 2.4 / 5 GHz radios, the test is run on both bands.

<table>
<thead>
<tr>
<th>Model</th>
<th>Wireless LAN Throughput, 2.4 GHz (Mbps)</th>
<th>Wireless LAN Throughput, 5 GHz (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raspberry Pi 3</td>
<td>24.4</td>
<td>976</td>
</tr>
<tr>
<td>Raspberry Pi 3 B+</td>
<td>49.2</td>
<td>97.6</td>
</tr>
<tr>
<td>Raspberry Pi 4 B</td>
<td>59.9</td>
<td>58.8</td>
</tr>
<tr>
<td>Raspberry Pi 4 A+</td>
<td>71.1</td>
<td>59.3</td>
</tr>
<tr>
<td>Raspberry Pi 4</td>
<td>97.1</td>
<td>59.3</td>
</tr>
</tbody>
</table>

*Higher is better*

**Power Draw**

More performance typically means more power, and here each Raspberry Pi model is left running a CPU-intensive benchmark while an HDMI display and a USB keyboard and mouse are connected. The peak power draw in watts is measured from the wall, and then an ‘idle’ draw with a Raspberry Pi sat at the Raspbian desktop is measured for comparison.

<table>
<thead>
<tr>
<th>Model</th>
<th>Power Draw Idle (watts)</th>
<th>Power Draw Load (watts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raspberry Pi A+</td>
<td>0.9</td>
<td>18</td>
</tr>
<tr>
<td>Raspberry Pi 3</td>
<td>2.2</td>
<td>18</td>
</tr>
<tr>
<td>Raspberry Pi 3 B+</td>
<td>4.2</td>
<td>17.6</td>
</tr>
<tr>
<td>Raspberry Pi Zero</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Raspberry Pi Zero W</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Raspberry Pi 2</td>
<td>0.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Raspberry Pi 3</td>
<td>1.5</td>
<td>2.1</td>
</tr>
<tr>
<td>Raspberry Pi 3 B+</td>
<td>2.9</td>
<td>2.9</td>
</tr>
<tr>
<td>Raspberry Pi 3 A+</td>
<td>3.7</td>
<td>3.7</td>
</tr>
<tr>
<td>Raspberry Pi 4 B</td>
<td>7.6</td>
<td>7.6</td>
</tr>
</tbody>
</table>

*Lower is better*

**Thermal Performance**

A higher power draw naturally leads to more heat. Here, Raspberry Pi 3B+ and Raspberry Pi 4 are left running a CPU-intensive benchmark for ten minutes before a thermal image is captured, demonstrating where the heat is generated and how it spreads throughout the board.
The launch of Raspberry Pi 4 brings not only new hardware but new software too: Raspbian ‘Buster’, a brand-new release – compatible, as always, with every Raspberry Pi model going right back to the pre-launch Alpha design – with a revamped, flatter user interface based on the upstream Debian ‘Buster’ Linux distribution.

Simon Long explains: “Due to the lack of obvious differences between Buster and Stretch, I wanted to do something to make it a bit more obvious that people actually had something new,” of his new interface design. When we moved from Jessie to Stretch, there was a similar lack of major differences, and people wondered whether or not they actually had the new version – I wanted to avoid that this time. Also, the overall UI design in terms of the appearance of buttons, controls, and the like really hasn’t changed significantly in the time I’ve been here – there have been some small tweaks, but it felt time for a change.”

Flatter is better

“The flatter appearance was driven by a few factors,” Simon continues. “First, it does seem to be a general tendency in UI design in recent years that flatter, simpler designs are in, and fussier, more complex designs are out – iOS, Windows, and Android have all done the same sort of thing. Second, Eben is a big fan of flatter UIs, and he kept nudging me in that direction!

“It’s a bit of a balancing act, though – you don’t want to go too far and end up with just boring square boxes everywhere, which is why while things like corner radii have been reduced, they haven’t been completely squared off.

“There’s been a lot of experimentation with new designs; we toyed with things like changing the system font and considered numerous different ideas for the appearance of buttons, sliders, and scrollbars, and I think we’ve ended up with something that looks modern without looking too boring.”

Mixing hardware and software

“Moving to a new Debian release is always a lot of work,” Simon notes. “We have to take all the changes and patches we had created for the previous version and apply them to new versions of software in the current version, test it all, make sure it is still stable and that we haven’t had performance regressions, and so on.

“That on its own is usually a challenge, but the fact that we were moving to new hardware at the same time added another dimension – when you find something has broken, you don’t know if it’s the new hardware, the new OS, or just that you’ve got something wrong yourself somewhere!”
The evolution of the desktop

“It’s really pleasing with the way the new user interface design has come out,” says Simon. “Because the design process was a gradual evolution over time, you don’t realise the difference between where you started and where you’ve ended up, but once it was finished and I was applying the changes to existing images, the sudden switch from old to new just made everything look instantly better.

“I’d never really thought there was much wrong with the old design, but when you suddenly change to the new one, you think ‘wow, that looks a lot better’ – or at least I do!”

Under the hood

Not all improvements are immediately visible: “We’re now using OpenGL to draw the desktop with hardware acceleration,” Simon explains. “This is something which we’ve had as an experimental feature for a couple of years now – it’s been an option in raspi-config to turn it on, but it’s now the default mechanism. It means that any applications which use OpenGL should run significantly faster, and it means that things like OpenGL games are now usable on Raspberry Pi out of the box.

“Some of the libraries which enable the OpenGL acceleration work much better in their Buster versions, so we have been using testing versions of Buster for several months and it makes more sense to release Buster software for Raspberry Pi 4 than it does to do all the work required to make this work on Stretch. Buster is in the final stages of testing by Debian – it is likely to be officially released within the next month or so – so this isn’t a particularly risky thing to do, but it does mean that anyone using this release is getting it a bit early!”

We are actually releasing Buster before Debian themselves do!

For a full list of approved resellers please go to raspberrypi.org/products
Setting up Raspberry Pi is pretty straightforward. Just follow the advice of Rosie Hattersley

Congratulations on becoming a Raspberry Pi explorer. We’re sure you’ll enjoy discovering a whole new world of computing and the chance to handcraft your own games, control your own robots and machines, and share your experiences with other Raspberry Pi fanatics.

Getting started won’t take long: just corral all the bits and bobs on our checklist, plus perhaps a funky case. Useful extras include some headphones or speakers if you’re keen on using Raspberry Pi as a media centre or gaming machine.

To get set up, simply format your microSD card, download NOOBS, and run the Raspbian installer. This guide will lead through each step. You’ll find the Raspbian OS, including coding programs and office software, all available to use. After that, the world of digital making with Raspberry Pi awaits you.

What you need
All the bits and bobs you need to set up a Raspberry Pi computer

A Raspberry Pi
Whether you choose a Raspberry Pi 4, 3B+, 3B, Pi Zero, Zero W, or Zero WH (or an older model of Raspberry Pi), basic setup is the same. All Raspberry Pi computers run from a microSD card, use a USB power supply, and feature the same operating systems, programs, and games.
You’ll need a microSD card with a capacity of 8GB or greater. Your Raspberry Pi uses it to store games, programs, and photo files and boots from your operating system, which runs from it. You’ll also need a microSD card reader to connect the card to a PC, Mac, or Linux computer.

You’ll need a Windows or Linux PC, or an Apple Mac computer to format the microSD card and download the initial setup software for your Raspberry Pi. It doesn’t matter what operating system this computer runs, because it’s just for copying the files across.

Like any computer, you need a means to enter web addresses, type commands, and otherwise control Raspberry Pi. You can use a Bluetooth keyboard, but the initial setup process is much easier with a wired keyboard. Raspberry Pi sells an official Keyboard and Hub (magpi.cc/keyboard).

A tethered mouse that physically attaches to your Raspberry Pi via a USB port is simplest and, unlike a Bluetooth version, is less likely to get lost just when you need it. Like the keyboard, we think it’s best to perform the setup with a wired mouse. Raspberry Pi sells an Official Mouse (magpi.cc/mouse).

Raspberry Pi uses the same type of USB power connection as your average smartphone. So you can recycle an old USB to micro USB cable (or USB Type-C for Raspberry Pi 4) and a smartphone power supply. Raspberry Pi also sells official power supplies (magpi.cc/products), which provide a reliable source of power.

A standard PC monitor is ideal, as the screen will be large enough to read comfortably. It needs to have an HDMI connection, as that’s what’s fitted on your Raspberry Pi board. Raspberry Pi 3B+ and 3A+ both use regular HDMI cables. Raspberry Pi 4 can power two HDMI displays, but requires a less common micro-HDMI to HDMI cable (or adapter); Raspberry Pi Zero W needs a mini HDMI to HDMI cable (or adapter).

Instead of standard-size USB ports, Raspberry Pi Zero has a micro USB port (and usually comes with a micro USB to USB adapter). To attach a keyboard and mouse (and other items) to a Raspberry Pi Zero W or 3A+, you should get a four-port USB hub (or use a keyboard with a hub built in).
Set up Raspberry Pi

Raspberry Pi 4 / 3B+ / 3 has plenty of connections, making it easy to set up

01 Hook up the keyboard
Connect a regular wired PC (or Mac) keyboard to one of the four larger USB A sockets on a Raspberry Pi 4 / 3B+ / 3. It doesn’t matter which USB A socket you connect it to. It is possible to connect a Bluetooth keyboard, but it’s much better to use a wired keyboard to start with.

02 Connect a mouse
Connect a USB wired mouse to one of the other larger USB A sockets on Raspberry Pi. As with the keyboard, it is possible to use a Bluetooth wireless mouse, but setup is much easier with a wired connection.

03 HDMI cable
Next, connect Raspberry Pi to your display using an HDMI cable. This will connect to one of the micro-HDMI sockets on the side of a Raspberry Pi 4, or full-size HDMI socket on a Raspberry Pi 3/3B+. Connect the other end of the HDMI cable to an HDMI monitor or television.

A regular wired mouse is connected to any of the USB A sockets. A wired keyboard is connected to another of the USB A sockets. If you have a Raspberry Pi 4, it’s best to keep the faster (blue) USB 3.0 sockets free for flash drives or other components.

A HDMI cable, such as ones used by most modern televisions, is used to connect Raspberry Pi to a TV or display. You’ll need a micro-HDMI to HDMI cable (or two) to set up a Raspberry Pi 4. Or a regular HDMI cable for Raspberry Pi 3B+ / 3 (or older) models.
Set up Raspberry Pi Zero

You’ll need a couple of adapters to set up a Raspberry Pi Zero / W / WH

01 Get it connected
If you’re setting up a smaller Raspberry Pi Zero, you’ll need to use a micro USB to USB A adapter cable to connect the keyboard to the smaller connection on a Raspberry Pi Zero W. The latter model has only a single micro USB port for connecting devices, which makes connecting both a mouse and keyboard slightly trickier than when using a larger Raspberry Pi.

02 Mouse and keyboard
You can either connect your mouse to a USB socket on your keyboard (if one is available), then connect the keyboard to the micro USB socket (via the micro USB to USB A adapter). Or, you can attach a USB hub to the micro USB to USB A adapter.

03 More connections
Now connect your full-sized HDMI cable to the mini-HDMI to HDMI adapter, and plug the adapter into the mini-HDMI port in the middle of your Raspberry Pi Zero W. Connect the other end of the HDMI cable to an HDMI monitor or television.
Set up the software

Use NOOBS to install Raspbian OS on your microSD card and start your Raspberry Pi.

Now you’ve got all the pieces together, it’s time to install an operating system on your Raspberry Pi, so you can start using it.

Raspbian is the official OS for Raspberry Pi, and the easiest way to set up Raspbian on your Raspberry Pi is to use NOOBS (New Out Of Box Software).

If you bought a NOOBS pre-installed 16GB microSD card (magpi.cc/huLdtN), you can skip Steps 1 to 3. Otherwise, you’ll need to format a microSD card and copy the NOOBS software to it.

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**You’ll Need**

- A Windows/Linux PC or Apple Mac computer
- A microSD card (8GB or larger)
- A microSD to USB adapter (or a microSD to SD adapter and SD card slot on your computer)
- SD Memory Card Formatter rpf.io/sdcard
- NOOBS rpf.io/downloads

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**Prepare to format**

Start by downloading SD Card Formatter tool from the SD Card Association website (rpf.io/sdcard). Now attach the microSD card to your PC or Mac computer and launch SD Card Formatter (click Yes to allow Windows to run it). If the card isn’t automatically recognised, remove and reattach it and click Refresh. The card should be selected automatically (or choose the right one from the list).

**Format the microSD**

Choose the Quick Format option and then click Format (if using a Mac, you’ll need to enter your admin password at this point). When the card has completed the formatting process, it’s ready for use in your Raspberry Pi. Leave the microSD card in your computer for now and simply note the location of your duly formatted SD card. Windows will often assign it a hard drive letter, such as E; on a Mac it will appear in the Devices part of a Finder window.

**Download NOOBS**

Download the NOOBS software from rpf.io/downloads. NOOBS (New Out Of Box System) provides a choice of Raspberry Pi operating systems and installs them for you. Click ‘Download zip’ and save the file to your Downloads folder. When the zip file download is complete, double-click to launch and uncompress the folder. You’ll need to copy all the files from the NOOBS folder to your SD card. Press **CTRL+A** (**⌘A** on a Mac) to select all the files, then drag all the files to the SD card folder. Once they’ve copied across, eject your SD card. Be careful to copy the **files inside** the NOOBS folder to the microSD card (not the NOOBS folder itself).
04 Assemble your Raspberry Pi

Now it’s time to physically set up your Raspberry Pi. Plug your PC monitor into the mains and attach its HDMI cable to the corresponding HDMI port on your Raspberry Pi. Plug in the power supply but don’t attach it to Raspberry Pi just yet. Use two USB ports to attach keyboard and mouse. Finally, remove the microSD card from the SD card adapter and slot it into the underside of your Raspberry Pi 4, 3B+, or 3. Raspberry Pi Zero W owners will need to attach a USB hub to connect mouse, keyboard, and monitor; the microSD card slot is on the top of its circuit board.

05 Power up

Plug in your Raspberry Pi power supply and, after a few seconds, the screen should come on. When the NOOBS installer appears, you’ll see a choice of operating systems. We’re going to install Raspbian, the first and most popular one. Tick this option and click Install, then click Yes to confirm. For more OS options, instead click ‘Wifi networks’ and enter your wireless password; more OS choices will appear. Installation takes its time but will complete eventually. After this, a message confirming the success installation appears. Your Raspberry Pi will prompt you to click OK, after which it will reboot and load the Raspbian OS.

06 Get online

When Raspbian loads for the first time, you need to set a few preferences. Click Next, when prompted, then select your time zone and preferred language and create a login password. You’re now ready to get online. Choose your WiFi network and type any required password. Once connected, click Next to allow Raspbian to check for any OS updates. When it’s done so, it may ask to reboot so the updates can be applied.

Click the Raspberry icon at the top–left of the screen to access items such as programming IDEs, a web browser, media player, image viewer, games, and accessories such as a calculator, file manager, and text editor. You’re all set to start enjoying your very own Raspberry Pi.
Get started with PICO-8 and Raspberry Pi

Turn your Raspberry Pi into the coolest console around with PICO-8! Play, make, and share 8-bit games

At the forefront of a new wave of ‘virtual’ consoles, PICO-8 packs a pixel-perfect punch of 8-bit delights. Containing everything you need to make your own games, from code to graphics to sound, it has a super-active and supportive community of makers and creators behind it. With its own built-in game browser, you’ll have access to a huge library of games straight out of the gate. The good news is you can get it running on your Raspberry Pi in just a few steps, meaning you’ll be sitting cross-legged in front of the living room TV in no time.

01 Prep a Raspberry Pi
First things first, you’ll want a Raspberry Pi set up and ready to go. These steps are tested on a fresh install of Raspbian Stretch with Desktop, so you’ll want to do the same. You can plug in your USB controller (PICO-8 supports one or two) and, for these first few steps, you’ll need to plug in a USB keyboard and mouse as well. Once you’ve got it all up and running, though, a controller and WiFi is all you’ll need to download and play games.

02 The Lexaloffle shuffle
Next, you will want to download a copy of PICO-8 from the Lexaloffle website (magpi.cc/PICO8). To do this, you’ll need to set up an account and buy a licence, which is a steal at around £12 at the time of writing. Once you’ve done that, go to the Downloads section of your new account on the website and download the Raspberry Pi version of PICO-8. You can use Chromium to download the zip file straight to your Raspberry Pi. Note: with your newly acquired licence, you can download Windows, macOS, and Linux builds of PICO-8 as well. A nice perk!
03 **3, 2, 1... launch!**
Extract the contents of the zip file into your `/home/pi` directory. Navigate to the newly unzipped folder and you will see a bunch of files. Most interesting for us is `pico8` (not the .dat), which is the virtual console itself, and `manual.txt`. The manual contains loads of valuable information, tips, and commands to get the most out of the console, and will help loads when you start to make your own games. But as we’re focusing on playing them in this tutorial, ignore that for now and launch PICO-8 by double-clicking the `pico8` file.

04 **Time to SPLORE**
Beepidy beep! Wasn’t that cute? All being well, you should be looking at the PICO-8 command prompt, complete with flashing cursor, begging for you to type something in. Type in **HELP** to see a list of commands, many of which might be familiar to you if you’ve used Terminal commands on Raspberry Pi before. Now that’s all well and good, you say, but where are the games? Thankfully, PICO-8 has its own built-in game browser called SPLORE. Type in **SPLORE** and hit ENTER.

05 **Taking control**
Plug in a USB controller if you haven’t already, and let’s take it for a spin. PICO-8 refers to its games as ‘carts’, as in cartridges (remember those?). Use the D-pad to navigate between the tabs. You’ll see a section for new carts, a search function, a tab for your favourite carts, and a file browser for your own creations. Let’s scroll to the Featured tab, select Update, and push a button. PICO-8 should now connect to the game library and present you with a list. Scroll down to find one that piques your interest and push any button to start.

"You should be looking at the PICO-8 command prompt, with flashing cursor, begging for you to type something in."
A veritable cornucopia
Congratulations! You now have access to hundreds of homebrew wonders. You’ll find everything from straight-out action arcade, to quirky indie titles, to demo-scene experiments, to de-makes of popular titles (where famous games are remade in 8-bit, just because). If you want to try something else, hit the Start button to open the menu, where you can return to SPOORE and jump into another title. You can also use this menu to ‘favourite’ carts, so that you can find them more easily.

My personal pick
You’re probably feeling a little overwhelmed at the number of carts out there and are wondering where to start. Well, here are handful of your author’s favourites. Enigmatic boss battler Just One Boss by Ayla Myers (@bridgs_dev), chunky squirmy puzzler Tomato Worm by Jose Guerra (@guerragames), mysterious puzzle platformer Dusk Child by Sophie Houlden (@SophieH), tear-jerking space-em-up Orbiter Suite by Andrew Anderson (@kittenm4ster) and aquatic action game SWORDFISH by yours truly (@danhowardgames). That should be enough to start with, but new ones are released almost daily.

Get dedicated
Now it’s working and you’ve tried a few games, let’s turn your Raspberry Pi into a dedicated PICO-8 console that launches straight into the cart browser when it boots. There are lots of ways to achieve this but the quickest, though possibly not the most elegant, solution is to edit .bashrc. This file contains a load of commands which run every time a new interactive shell is launched; for example, when opening a new Terminal window. Exit out of PICO-8, open a new Terminal, and enter sudo nano /home/pi/.bashrc to edit it.

Cart boot sale
Add sudo /home/pi/pico-8/pico8 -splore to the last line. This command will launch PICO-8 straight into the cart browser. Save the script and, on the desktop, go to the Raspberry Pi menu in the top left, then to Preferences, then Raspberry
Pi Configuration. In the System tab you’ll need to change ‘Boot: ’ to ‘To CLI’. Now on boot, we’ll go straight into PICO-8, no need for a keyboard or mouse. Save your changes and reboot to see your new favourite console in all its majesty.

You’ll now be staring at the code editor, and at the very code that runs the game you loaded.

**Behind the scenes**

Great, now you have a dedicated PICO-8 console, well done, but what’s next? Well, as mentioned, you can use PICO-8 to easily make your own games. We’ll go into more detail about that in the next tutorial, but for now if you are curious, why not take a look under the hood? Plug in a keyboard and mouse, launch PICO-8 and load up a game, then return back to SPLORE. Next, hit **ESC** to exit to the PICO-8 console; once there, hit **ESC** again to swap to the code screen.

**The tools at your disposal**

You’ll now be staring at the code editor, and at the very code that runs the game you loaded. At the top right of the screen you’ll also see icons that allow you to navigate between the other editors. From left to right, there are editors for code, sprites, maps, SFX, and music — all you could ever need! Have a click through to see what they look like. We’ll go into detail on these in later tutorials, but for now why not try editing some of the sprites, then hit **CTRL+R** to reload the game with your changes?

**Join the community**

One of the most unique and exciting aspects of PICO-8 is the enthusiastic community of makers, tinkerers, and developers that has built up around it. People are very passionate about the console and are always willing to lend a hand and offer help. We highly recommend getting involved. You can find them on the official Lexaloffle forum ([magpi.cc/hqxicL](https://magpi.cc/hqxicL)), the PICO-8 Discord server, or by searching **#pico8** on Twitter. There are plenty of resources out there if you simply can’t wait to get started making your own games. Happy making!

---

**Top Tip**

**Two players, one keyboard**

Don’t have a controller? Don’t worry! Play with a keyboard. P1 uses cursors + **N/M**, and P2 uses **SDFE** + **TAB/Q**.

---

**Features realistic gravity and inertia. Spaceman 8 sees a jet-pack-equipped astronaut transporting gems.**

**Celeste, indie game of the year 2018, actually started life on PICO-8.**
Make a self-healing Raspberry Pi

Get back to a fresh install with no need to wipe the microSD card, download images, or use another computer.

Most modern operating systems come with a ‘recovery partition’, a reserved area of the drive containing everything needed to get the machine back to a clean install. So, if something goes badly wrong, you can start over. In the world of Raspbian, this normally means overwriting the image on the microSD card. This is perfectly fine, but what if you have a large number to do, say a classroom’s worth, or you don’t have access to another device to do the burning? We’re going to create an alternative version of Raspbian featuring a recovery partition. Raspberry Pi, heal thyself!

01 Prepare your workspace

This tutorial will describe how to create a bootable image featuring a restore partition, but there’s also a script to automate the process that you can download from magpi.cc/junkPr. This also contains the code shown some of the trickier commands shown later.

Make sure you have uuidgen installed by running it from the command line. If not, run:

```
sudo apt install uuid-runtime
```

Most commands here will need to be run as root. To avoid having to enter ‘sudo’ every time, you can switch to root using:

```
sudo su
```

Create a working directory on your machine and make sure you’ve downloaded both the Raspbian Full and Raspbian Lite images (we’re using 2019-04-08). Unzip them as follows:

```
unzip 2019-04-08-raspbian-stretch-full.zip
unzip 2019-04-08-raspbian-stretch-lite.zip
```

02 Calculate the image size

Our image needs to be big enough for Raspbian Full, including its boot partition, and a second partition containing Raspbian Lite with an image of Raspbian Full. We measure disk sizes in sectors, each one 512 bytes in size. Find out how many sectors are required (see Figure 1, overleaf). The boot partition starts at sector 8192 to allow for the file allocation table. To calculate the size needed:

```
8192 + Raspbian Full Boot Partition + Raspbian Lite Main Partition + (Raspbian Full Main Partition × 2)
```

With these Raspbian versions, you will need 24,426,283 sectors.
03 Create the blank image

We now need to create an empty file to contain our disk image. First convert the number of sectors required into 4MB blocks like so:

\[
24,426,283 \times 512 \text{ bytes} = 12,506,256,896 \text{ bytes}
\]

\[
12,506,256,896 / 4,194,304 = 2,982 \text{ 4-megabyte blocks (rounded up)}
\]

Now create your target image:

```
dd if=/dev/zero bs=4M count=2982 status=progress > 2019-04-08-raspbian-stretch-full.restore.img
```

You now have a large file full of zeroes.

04 Partition the image

Let’s turn our blank file into a disk image. Start by generating some unique identifiers for the partitions:

```
UUID_RESTORE=$(uuidgen)
UUID_ROOTFS=$(uuidgen)
PARTUUID=$(tr -dc 'a-f0-9' < /dev/urandom 2>/dev/null | head -c8)
```

Now create the partition table:

```
sfdisk 2019-04-08-raspbian-stretch-full.restore.img <<EOF
label: dos
label-id: 0x{PARTUUID}
unit: sectors
2019-04-08-raspbian-stretch-full.restore.img1 : start=8192, size=87851, type=c
2019-04-08-raspbian-stretch-full.restore.img2 : start=96043, size=13877248, type=83
2019-04-08-raspbian-stretch-full.restore.img3 : start=13973291, size=10452992, type=83
EOF
```

Careful! The sizes used here are specific to the version of Raspbian used. Other versions will have different sizes. Use fdisk to calculate them.

05 Mount the images

Our file of zeroes can now be accessed as a disk. We’ll use the ‘loopback’ system so we can access it, along with the two versions of Raspbian.

```
losetup -v -f 2019-04-08-raspbian-stretch-full.restore.img
partx -v --add /dev/loop0
```

"This tutorial will describe how to create a bootable image featuring a restore partition"
Now copy over the boot and root partitions from our Raspbian Full image to partitions one and three of the new image:

```
dd if=/dev/loop2p1 of=/dev/loop0p1 status=progress bs=4M
```

```
dd if=/dev/loop2p2 of=/dev/loop0p3 status=progress bs=4M
```

We can now install Raspbian Lite on the second partition:

```
dd if=/dev/loop1p2 of=/dev/loop0p2 status=progress bs=4M
```

### 06 Configure and mount partitions

First, assign new unique IDs to the partitions and rename the recovery partition so we can tell them apart.

```
tune2fs /dev/loop0p2 -U ${UUID_RESTORE}
e2label /dev/loop0p2 recoveryfs
tune2fs /dev/loop0p3 -U ${UUID_ROOTFS}
```

Although we have allocated enough space for the recovery partition to hold a copy of the Raspbian Full image, copying over the Lite image has reduced it. Luckily it’s easy to fix this:

```
e2fsck -f /dev/loop0p2
resize2fs /dev/loop0p2
```

Now we’re in a position to mount the new image’s file systems:

```
mkdir -p mnt/restore_boot
mkdir -p mnt/restore_recovery
mkdir -p mnt/restore_rootfs
mount /dev/loop0p1 mnt/restore_boot
mount /dev/loop0p2 mnt/restore_recovery
mount /dev/loop0p3 mnt/restore_rootfs
```

### 07 Set the boot partition

Currently our image would not boot as it doesn’t know which partition to use. Run this command and make a note of the eight characters after ‘Disk identifier: ox’.
Then edit the `cmdline.txt` file to reset it:

```bash	nano mnt/restore_boot/cmdline.txt
```

Change the eight-character code after `PARTUUID=` to the value you noted and change the following `-02` to `-03`, telling Raspbian to boot to the third partition.

### 08 Create the reset scripts

To restore Raspbian your Raspberry Pi needs to boot to the second partition, containing Raspbian Lite, then overwrite the third partition with a snapshot image. We can automate this using scripts. Create the three scripts here in the `mnt/restore_boot` directory and make them executable:

```bash
chmod +x mnt/restore_boot/boot_to_root
chmod +x mnt/restore_boot/boot_to_recovery
chmod +x mnt/restore_boot/restore_root
```

Now make `restore_root` run at boot time on the recovery partition:

```bash
nano mnt/restore_recovery/etc/rc.local
```

Before the `exit 0` line, add:

```bash
/boot/restore_root
```

### 09 Fix fstab

Each of the main partitions has an `fstab` file which tells Raspbian what disks to mount and where. This needs correcting to match our new layout:
**10 Take a snapshot**

As Raspbian Full has never been booted, it’s a perfect time to make a copy of it for restoration. This command makes a copy of the main partition and saves it in the recovery partition as a file.

```
dd if=/dev/loop0p3 of=mnt/restore_recovery/rootfs.img status=progress bs=4M
```

Now unmount everything:

```
umount -f mnt/restore_boot
umount -f mnt/restore_recovery
umount -f mnt/restore_rootfs
losetup --detach-all
```

**11 Burn and test**

You should now have a complete and ready-to-go image. Copy it over to a suitably sized microSD card (Raspbian-specific example):

```
dd bs=4M if=2019-04-08-raspbian-stretch-fullrestore.img of=/dev/sda conv=fsync status=progress
```

...or you can use any burning tool, such as Etcher. Your SD card should now boot as normal. To test partition swapping, open up a Terminal and type:

```
sudo ./boot/boot_to_recovery
```

The Raspberry Pi should reboot into Raspbian Lite. To go back:

```
sudo ./boot/boot_to_rootfs
```

To perform a fully automatic restore:

```
sudo ./boot/boot_to_recovery restore
```

**12 Physical reset**

What if you can’t get terminal access to your Raspberry Pi? A Python script that runs on boot can check the state of a GPIO pin; if shorted, the restore process is triggered. Enter the `check_reset_gpio.py` code in `/boot` and make sure it runs on boot:

```
import os
from gpiozero import Button

button = Button(21)
if button.is_pressed:
    print("Restore button is pressed")
    os.system("/boot/boot_to_recovery restore")
else:
    print("Restore button is not pressed")
```

To trigger the restore, use a jumper wire between GND and GPIO 21 pins and boot your Raspberry Pi.
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The Squeeze: A new way to play

Is it a joystick? Is it a paddle? No it’s ‘The Squeeze’ – a new type of games controller

Have you seen those dynamo torches, the ones that you repeatedly squeeze to light three white LEDs? Well, this month we are going to take a pair of these and turn them into a unique games controller. A new type of controller offers the possibility of new types of games, or a better way to control some existing types of games.

01 The torch

The torch, or flashlight for our American cousins, can come in many forms. These days there are lots of self-powering devices which involve actually generating the power needed to drive them by the efforts of the user. With a dynamo torch, the user repeatedly squeezes a lever to spin a magnet in a coil and generate electricity. We took one apart and measured the voltage the generator produced. As you can see in Figure 1, the output is AC with a peak-to-peak voltage of almost 80 V; when squeezed, the frequency rapidly rises to about 170Hz.

02 The dynamic signal

This voltage is very high, but is loaded down by putting a white LED across it; this shorts the negative voltage and limits the positive voltage to about 3 V, which is the forward voltage drop across the LED. This is a cheap and nasty design. You can

You’ll Need

- Two dynamo torches
- A/D converter (ADC), e.g. MCP3008
- Assorted electronic components

![Dynamo torches transformed into games controllers](image1.jpg)

[Signal-conditioning circuits and A/D converter](image2.jpg)

---

Mike Cook
Veteran magazine author from the old days, writer of the Body Build series, plus co-author of Raspberry Pi for Dummies, Raspberry Pi Projects, and Raspberry Pi Projects for Dummies.

magpi.cc/TPaUfT

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**Warning! High voltage**

The dynamo torches in this project can produce high voltage, so be careful.
pump the leaver to sustain a voltage or just squeeze once for a pulse, as shown in Figure 2. This shows 24 rapid squeezes followed by a single squeeze and release; it is measured over five seconds. Note how the trace is changing so rapidly that we can’t see the individual waveform, only the envelope.

The idea is that we can condition the electrical signal from the dynamo torch to make a games controller.

### Conditioning the signal

The idea is that we can condition this signal to make a games controller. Basically, we need to make it into a DC signal by adding a series diode and then getting just the peaks of this signal with an envelope follower, which is sometimes called a peak detector. This uses a capacitor to hold the peak voltage and a discharging resistor which

```python
#!/usr/bin/env python3
#Tug of war using squeeze controller
# By Mike Cook June 2019

import math, spidev, time
import os, pygame, sys, random

pygame.init()
pygame.mixer.quit()
pygame.mixer.init(frequency=22050, size=-16, channels=2, buffer=512)

os.environ['SDL_VIDEO_WINDOW_POS'] = 'center'
pygame.display.set_caption("Tug of War")
pygame.event.set_allowed(None)
pygame.event.set_allowed([pygame.KEYDOWN,pygame.QUIT])

screenWidth = 960 ; screenHight = 280 ; cp = screenWidth // 2

screen = pygame.display.set_mode([screenWidth,screenHight],0,32)
textHeight=22 ; font = pygame.font.Font(None, textHeight)
backCol = (160,160,160)

lastValue = [-10, -10, -10] # so you show on the first reading
screenUpdate = True ; random.seed()

nAv = 10 # number of samples to average
avPoint = [0,0,0] ; p1 = [0] * nAv ; p2 = [0] * nAv
runningAv = [p1,p2,[[0]]] ; average = [0.0] * 3

target = 0.5 ; timeChange = 0 ; scale = 700

def main():
    global tugState, gameOver, winner
    print("Tug of War")
    init()
    while(1): # do forever
        timeChange = 0
        tugState = -cp # middle of screen
        checkTarget()
        gameOver = False
        winner = -1 # no winer yet
        whistle.play() # start sound
        time.sleep(2.0)
        while not gameOver:
            checkForEvent()
            readVoltage()
            checkTug()
            checkTarget()
            if screenUpdate :
                drawScreen()
                updateMeters()
            if winner == 0:

001. #!/usr/bin/env python3
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024. target = 0.5 ; timeChange = 0 ; scale = 700
025.
026. def main():
027.     global tugState, gameOver, winner
028.     print("Tug of War")
029.     init()
030.     while(1): # do forever
031.         timeChange = 0
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033.         checkTarget()
034.         gameOver = False
035.         winner = -1 # no winer yet
036.         whistle.play() # start sound
037.         time.sleep(2.0)
038.     while not gameOver:
039.         checkForEvent()
040.         readVoltage()
041.         checkTug()
042.         checkTarget()
043.         if screenUpdate :
044.             drawScreen()
045.             updateMeters()
046.         if winner == 0:
```
controls the release of the peak. The schematic for this is shown in Figure 3. When the signal is passed through this circuit, you get the waveform shown in Figure 4. You will need two of these circuits.

04 Building the circuit

We used a piece of 14 hole, by 10 row, stripboard and a single pin header row. This plugs into our ADC (see issue 68, page 42 – magpi.cc/68), component side down. The components were wired up as in Figure 5. Note that the track side shows where to cut the tracks and is flipped over right to left, just like you would see it. Figure 6 shows a photograph of the conditioning circuit. The band on the diode marks the cathode, and the strip down the capacitor marks the negative wire. Make sure you get them the right way round.

05 Hacking the torch

First off, drill a 2 mm hole in the body of the torch, close to the front, as shown in Figure 7. Then flip off the front cover and pull out the LED and battery assembly (Figure 8, overleaf). Be careful, because some of the wires are very thin and you don’t want to snap them. Undo the two tiny screws holding the battery cover and remove the batteries. Now insert a length of 1.5 mm screened cable through the hole you previously drilled and strip off a 20 mm length at the end. Gather up the screen, twist it, and tin it.
Top Tip ✅

Torches

We used two blue torches and identified the yellow player with a bit of painted card stuck on the lens cover. However, you can get other colour torches of the same type, so it would look better with a yellow torch.

Finishing off the torch

Use the cable’s sleeving (that you cut off) to insulate the twisted screening and solder this to the sleeved side of the LEDs (Figure 9, overleaf). Then solder the core to the other side of the LED. Cut off the wire that used to go to the top of the battery housing and give all those long wires from the LED a bit of a trim. Glue the plastic lenses to the inside of the cover and slowly pull the cable back out of the torch. Fix the cable with a dab of hot-melt glue on the inside, before clipping the cover back in place.

TugOfWar.py (continued)

```python
print("Blue Player is the winner")
drawwords("Winner       ",123,159,(0,0,0),(20,178,155))
else:
    print("Yellow Player is the winner")
    drawwords("Winner       ",742,159,(0,0,0),
             (20,178,155))
pygame.display.update()
end.play() # end sound
print("Press space for another game")
while gameOver:
    checkForEvent()

def checkTug():
global tugState,screenUpdate,gameOver,winner
    #check to see if anyone has won
    if tugState <= -869:
        gameOver = True
        winner = 0
        return
    if tugState >= -37:
        gameOver = True
        winner = 1
        return
    #check to see if anyone has scored
    p1 = abs(average[0] - average[2])
    p2 = abs(average[1] - average[2])
    if p1 < p2 : #player 1 closest
        if p1 < 40:
            tugState -= 1
            screenUpdate = True
        else:
            if p2 < 40:
                tugState += 1
                screenUpdate = True
    else:
        if p2 < 40:
            tugState += 1
            screenUpdate = True
        else:
            tugState = 0
            screenUpdate = True

def checkTarget():
    global target, timeChange
    if time.time() < timeChange:
        return
    temp = random.uniform(0.2,0.8)
    target = int(temp*scale)
    average[2] = target
    timeChange = time.time() + random.uniform(3.2,6.8)
    drawScreen()
    updateMeters()
```

Figure 6

Photograph of the signal-conditioning interface

Figure 7

Drilling a hole for the connection wire
08 A look at the code

The code follows the normal Pygame structure, and requires three images: rope, knot, and meter. It also requires a start sound and end sound. To smooth the input, a running average of the voltage readings is used. The `scale` variable is a sort of fiddle factor that allows you to adjust the output, so that you can get maximum meter deflection at the peak value from the torch. The `checkTarget` function will change the target you are aiming for at random intervals, to make the game a bit more challenging, so you need to look at the target and your input.

In conclusion

We hope you have fun with this. Another good game to implement using this interface would be a SpaceX rocket landing game similar to the classic Lunar Lander. However, next month we will show you how to use this interface to make a rather large LED Racer game.

Top Tip

Removing the torch front

This can be tricky, but with a flat-blade screwdriver and some determination it can be removed. Mind that you don’t stab yourself with the screwdriver – always push away from your body.
```python
def drawScreen():
    screen.fill(backCol)
    for i in range(0,3):
        screen.blit(meter, (meterPositionX[i],
                        meterPositionY[i]) )
    screen.blit(rope, (tugState,190) )
    drawWords("Target",447,159,(0,0,0),
               (20,178,155))
    drawWords("Blue Player",123,159,(0,0,0),
               (20,178,155))
    drawWords("Yellow Player",742,159,(0,0,0),
               (20,178,155))
    pygame.draw.line(screen,(0,0,0),(64,188),
                     (64,272),4)
    pygame.draw.line(screen,(0,0,0),(896,188),
                     (896,272),4)
    pygame.display.update()

def drawWords(words,x,y,col,backCol):
    textSurface = font.render(words, True, col, backCol)
    textRect = textSurface.get_rect()
    textRect.left = x # right for align right
    textRect.top = y
    screen.blit(textSurface, textRect)
    return textRect

def init():
    global meter, rope, meterPositionX,
    meterPositionY, spi,whistle, end
    whistle = pygame.mixer.Sound("sounds/whistle.ogg")
    end = pygame.mixer.Sound("sounds/end.ogg")
    meter = pygame.image.load("images/MeterPC.png").convert_alpha() 
    rope = pygame.image.load("images/rope.png").convert_alpha() 
    meterPositionX=[10,638,324]
    meterPositionY=[10,10,10]
    spi = spidev.SpiDev()
    spi.open(0,0)
    spi.max_speed_hz=1000000

def readVoltage():
    global screenUpdate, average, avPoint,lastValue,
            runningAv
    for i in range(0,2):
        adc = spi.xfer2([1,(8+i)<<4,0]) # request 
        channel
        reading = (adc[1] & 3)<<8 | adc[2] # join two 
        bytes together
        runningAv[i][avPoint[i]] = reading
        avPoint[i]+=1
        if avPoint[i] >= nAv:
            avPoint[i] = 0
        average[i] = 0
        for j in range(0,nAv): # calculate new running
            average[i] += runningAv[i][j]
        average[i] = average[i] / nAv
        if abs(lastValue[i] - average[i]) > 8 or ( 
            average[i] == 0 and lastValue[i] !=0):
            lastValue[i] = average[i]
            screenUpdate = True
    def updateMeters():
        global screenUpdate, average
        for i in range(0,3):
            plot = constrain(average[i]/scale,0.0,1.0)
            angle = (math.pi + 
            (1.0 * math.pi) + 
            (1.0 * math.pi)) + 
            mpX = 146 + meterPositionX[i]
            mpY = 146 + meterPositionY[i]
            dx = mpX + 140 * math.cos(angle)
            dy = mpY + 140 * math.sin(angle)
            pygame.draw.line(screen,(50,50,50),(mpX,mpY),
                             (dx,dy),2)
            pygame.draw.line(screen,(50,50,50),(64,188),
                             (64,272),4)
            pygame.draw.line(screen,(50,50,50),(896,188),
                             (896,272),4)
            pygame.display.update()
        def constrain(val, min_val, max_val):
            return min(max_val, max(min_val, val))
        def terminate(): # close down the program
            print ("Closing down")
            pygame.mixer.quit()
            pygame.quit() # close pygame
            os._exit(1)
        def checkForEvent(): # see if we need to quit
            global reading, screenUpdate, average, gameOver
            event = pygame.event.poll()
            if event.type == pygame.QUIT :
                terminate()
            if event.type == pygame.KEYDOWN :
                if event.key == pygame.K_ESCAPE :
                    terminate()
                if event.key == pygame.K_SPACE :
                    gameOver = False
            if __name__ == '__main__':
                main()
```

TugOfWar.py (continued)

Language: Python 3
More advanced GUI layout

Learn how to expand your window, and position and resize buttons automatically, using C and GTK

As mentioned in last issue’s tutorial that boxes can be either horizontal or vertical. Just to see the difference, try changing the line (in last month’s code):

```c
GtkWidget *box = gtk_vbox_new (FALSE, 5);
```

...to:

```c
GtkWidget *box = gtk_hbox_new (FALSE, 5);
```

...and rebuild – you should then see a window like that in Figure 1.

This demonstrates the difference between a GtkVBox and a GtkHBox – they do exactly the same thing, but they just do it in different directions.

But what about those other arguments to `gtk_box_pack_start` that we glossed over earlier? These are designed to allow you to move things around within boxes and to give you more control over exactly where things end up within the window.

In the windows we have seen so far, this doesn’t seem particularly useful, as the button and label both take up as much space as they need but no more.

But GTK windows can usually be resized – the user can grab a corner of a window and stretch it to an arbitrary size in each dimension. GTK tries to resize windows and widgets intelligently so that things grow and shrink in proportion to each other; these additional arguments let you control what happens to the widgets when the window size changes.

The third argument to `gtk_box_pack_start` is called `expand`. If set to `TRUE`, then when a window is enlarged, the amount of space allocated for this widget is enlarged in proportion. If set to `FALSE`, the amount of space allocated for this widget is never more than the minimum it requires.

The fourth argument is called `fill`. This has no effect if `expand` is set to `FALSE`, but if `expand` is set to `TRUE`, it controls whether or not it is the space allocated to the widget or the widget itself which grows. If `expand` is `TRUE` and `fill` is `FALSE`, the widget itself stays the same size, but the space around it grows; if both `expand` and `fill` are `TRUE`, the widget itself grows to fill the increased space.

That is somewhat hard to follow when written down, but a few examples will help to get it straight. Change the GtkHBox back to a GtkVBox in the example above, and then set both `expand` and `fill` for all three `gtk_box_pack_start` calls in your example code to `FALSE`. If you then resize the window, the label and two buttons will all stay the same height, at the top of the window (Figure 2).

Now try the same thing, but change the `expand` parameter in the `gtk_box_pack_start` for `btn` to `TRUE` – the result should be like Figure 3.

An Introduction to C & GUI Programming

For further tutorials on how to start coding in C and creating GUIs with GTK, take a look at our new book, An Introduction to C & GUI Programming. Its 156 pages are packed with all the information you need to get started – no previous experience of C or GTK is required!

magpi.cc/GUIbook
The button now moves down the window to fit in the middle of the increased space; the extra space has been allocated to the button, but the button itself is the same size.

Finally, try changing both `expand` and `fill` to `TRUE` for `btn` to see a result like Figure 4 (overleaf).

Enlarging the window now causes the whole button to fill the extra space.

We can see that these parameters only affect the vertical size of the widgets; this is because they are used inside a `GtkVBox`. If we want to control the horizontal size of the widgets as well, we need to create a `GtkVBox` which contains a set of `GtkHBoxes`, which are then used to contain the widgets themselves.

The final argument in the call to `gtk_box_pack_start` is called `padding` – this is the amount of free space (in pixels) which is inserted at either end of this widget; this is in addition to the `spacing` which was requested between all widgets in the `gtk_box_new` call.

By careful tweaking of `expand`, `fill`, and `padding` parameters, you can create a window which displays all its widgets tidily and resizes exactly as you expect.

### Tables

You might be wondering how you put, say, four items in a window with two on each of two lines. Well, it is perfectly acceptable to put a `GtkHBox` as one of the items inside a `GtkVBox`, or vice versa. It’s even acceptable to put a `GtkHBox` as an item inside a `GtkHBox` (but it’s generally a bit pointless). Using a combination of nested `GtkHBoxes` and `GtkVBoxes`, you can lay out all the widgets in a window the way you want them.

While nesting `GtkHBoxes` and `GtkVBoxes` works perfectly well for laying out widgets in two dimensions, and actually gives you the best control over how they appear, there is a simpler alternative: the `GtkTable` widget.

A `GtkTable` is a two-dimensional box, which is defined as having a certain number of rows and columns when it is created. Widgets can then be located at various row and column coordinates.

A `GtkTable` is a two-dimensional box, which is defined as having a certain number of rows and columns

This is actually not as flexible as using nested `GtkHBoxes` and `GtkVBoxes`, because every widget has to be aligned in both a row and a column – this means that any row is always at least as high as the tallest widget anywhere in it, and any column is always at least as wide as the widest widget anywhere in it; this can lead to a lot of wasted space. But quite often a simple arrangement like this is all that is needed, so a `GtkTable` works fine.

Here are the changes to our example if we use a `GtkTable` to position the label and buttons:

```c
void main (int argc, char *argv[])
{
    gtk_init (&argc, &argv);

    GtkWidget *win = gtk_window_new (GTK_WINDOW_TOPLEVEL);

    GtkTable *win = gtk_window_new (GTK_WINDOW_TOPLEVEL);

    GtkWidget *win = gtk_table_new (2, 2, FALSE);
    gtk_table_set_homogeneous (win, FALSE);
    gtk_table_set_spacing (win, 3);
    gtk_table_set_row_spacing (win, 6);
    gtk_table_set_col_spacing (win, 6);
    gtk_box_pack_start (GTK_BOX (btn), "My label");
    gtk_box_pack_start (GTK_BOX (btn), "Close window");
    gtk_box_pack_start (GTK_BOX (btn), "Count button");
}
```
We create a new GtkWidget widget:

```
GtkWidget *btn = gtk_button_new_with_label("Close window");
g_signal_connect (btn, "clicked", G_CALLBACK (end_program), NULL);
g_signal_connect (win, "delete_event", G_CALLBACK (end_program), NULL);

GtkWidget *lbl = gtk_label_new("My label");
GtkWidget *btn2 = gtk_button_new_with_label("Count button");
g_signal_connect (btn2, "clicked", G_CALLBACK (count_button), lbl);
```

We create a new GtkTable widget with:

```
GtkWidget *tbl = gtk_table_new (2, 2, TRUE);
gtk_table_attach_defaults (GTK_TABLE (tbl), lbl, 0, 1, 0, 1);
gtk_table_attach_defaults (GTK_TABLE (tbl), btn2, 1, 2, 0, 1);
gtk_table_attach_defaults (GTK_TABLE (tbl), btn, 0, 2, 1, 2);
gtk_container_add (GTK_CONTAINER (win), tbl);
gtk_widget_show_all (win);
```

This will create a table with 2 rows and 2 columns, with labels, a count button, and a close button. The close button will span both columns, as described above.

To insert a widget into the table, we use:

```
gtk_table_attach_defaults (GTK_TABLE (tbl), btn, 0, 2, 1, 2);
```

In this case, the widget spans the first and second columns, because it is attached to 0 at the left and to 2 at the right.

For the sake of completeness, note that `gtk_table_attach_defaults` is a shortened version of the function `gtk_table_attach`, which has several other options. These other options include the ability to specify `expand`, `fill` and `padding` options for each widget, as in the `gtk_box_pack` functions described in the previous tutorial. But these function calls then get rather long-winded to type out — using `gtk_table_attach_defaults` sets `padding` to 0 and sets `expand` and `fill` both to `TRUE` for each widget. Feel free to play with the full versions if you want!

If you build and run this code, you’ll end up with a window that looks like the one in Figure 5. Note that the ‘Close window’ button spans both columns of the table, as described above.

We pass as arguments the names of the table and the widget we are putting into it:

```

Figure 4

Figure 4 The layout with both expand and fill set to TRUE for the ‘Close window’ button
```

More advanced layout
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UrsaLeo

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In 20 July 1969, humans set foot on the moon. It’s one of the most important moments in the history of our civilisation, and this month it will have been 50 years since the momentous occasion.

While manned space missions don’t leave a low Earth orbit these days, that doesn’t mean exploration of space has stopped. It’s only got better and more sophisticated. Experiments are performed daily on the International Space Station, while ground-based teams work through mountains of data from a vast network of satellites orbiting Earth, or spacecraft and rovers exploring our solar system.

Want to join in? We thought so – grab a Raspberry Pi and let’s take it to the final frontier.
From observing the stars, to flying among them

People of ancient times studied the movement of the cosmos using only the naked eye. Even so, they were able to map out star maps and even discover some of nearest planetary neighbours. The Babylonians and ancient Greeks became more sophisticated with their observation methods, and by the third century BCE, it was proposed that the Earth (and the other known planets) revolved around the sun.

The dark ages
Astronomy and astrology intertwined throughout the first millennium. By the end of the ninth century, Islamic scholars were setting up observatories to study the stars. The Andromeda Galaxy was described in 964 CE, while a supernova was observed around 1006 CE. Vitally important findings from the Middle East found their way to Europe, and by the 13th century medieval scientists were also making contributions to astronomy.

The telescope
The Renaissance brought about a scientific revolution in Europe. Copernicus proposed once again that the Earth revolved around the sun. Galileo, Kepler, and Newton all used telescopes, which let them peer even deeper into the heavens. People began seeing moons orbiting the other planets, and by 1781 Uranus was discovered, the first new planet observed since ancient times.

The modern era
Since then, planets, moons, celestial phenomenons, laws of motion, and more were being discovered; however, humans were still stuck on the ground. That was until the 1950s: advancements in technology during World War II resulted in the invention of rockets. Finally, there was a way for people to leave the Earth and explore space. By 1957, the first satellite, Sputnik 1, had been launched. In 1961, Yuri Gagarin became the first person to reach space. Eight years later, Neil Armstrong and Buzz Aldrin set foot on the moon.

Humans haven’t rested on their laurels, though, as robotic rovers are exploring far-off planets and moons, while spaceships zip around the solar system to uncover other secrets. Sometimes they land on comets, which is supremely cool. Slightly closer to home, astronauts perform experiments on the ISS (sometimes using a Raspberry Pi!), and powerful radio telescopes probe the depths of the universe. The more we know about the universe, the more we discover about ourselves.
The Raspberry Pi Camera Module is extremely versatile; however, you can’t attach a standard Nikon or Canon camera lens to it. Digital zoom is a bit rubbish, so how would you take a good photo of the moon with one? James Mitchell decided that, actually, he’d prefer to use a Canon DSLR lens, so he printed off a lens adapter. Then, with a bit of code, practice, and good luck, he was able to take some fantastic images of our very own natural satellite. How amazing is that?
SETI@HOME

With your help, we might find aliens.

Using software like BOINC (as seen in this tutorial from The MagPi: magpi.cc/2l2sQzI), you can turn your Raspberry Pi into one of thousands of nodes in a cluster of computers that crunch big numbers. SETI@home is one of the most famous examples of these, allowing you to aid in the Search for Extra Terrestrial Intelligence (SETI) using an idle Raspberry Pi. Here's hoping they're friendly.

LUNAR PHASE CLOCK

Know when it’s peak moon-watching time.

This project is one part art, one part science. Using a bit of code and a lovely-looking custom-built clock, you can make sure you know exactly what the moon’s phase is where you live. Whether you want to observe the moon when it’s full, or take advantage of no moon for stargazing, the phase clock will help you out.

ONGOING MISSIONS

Curiosity/Mars Science Laboratory

The Curiosity rover has been on Mars for nearly seven years now, with four main goals: search for any signs of life; improve understanding of Mars geology; determine the planet’s history; and keep an eye on surface radiation. It also likes to take selfies. We can relate to that bit.

Hayabusa2

Did you know that we’ve landed spacecraft on asteroids? And that it was done remotely from thousands of miles away? Hayabusa2 specifically was able to land several rovers on the surface of an asteroid, and it will be returning to Earth at the end of next year with samples from it.

Juno

The Juno probe was launched in August 2011, and arrived at Jupiter in July 2016. It’s currently in polar orbit of Jupiter, and has a suite of scientific instruments on board in an attempt to more precisely measure the composition of Jupiter’s gas clouds, the size of its core, its gravitational field, and more. In July 2021 it will plunge into Jupiter itself, so there’s a few years of Jupiter-based discoveries left for it.
Building a single, solitary ground station to listen in on satellites won’t be very efficient. You’ll only ever receive a signal intermittently, maybe even once every few days if you’re lucky. This is where SatNOGS comes in – it’s an open-source ground station project that offers several designs you can use to join a network of other ground stations. You can use the software to set your ground station to look for specific satellites, or see what other stations are receiving. Read more about it in HackSpace Magazine #18: magpi.cc/mynPsg.
Mars 2020 17 July 2020
Slated to launch in mid 2020 and land early 2021, Mars 2020 is a rover that will study the geology of the Jezero crater, which is thought to have once held water. It will see if there are any signs of ancient life, and bring samples back to Earth for further study.

Lucy October 2021
Lucy is planned as a probe that will study some of the so-called Jupiter trojans – asteroids that share Jupiter’s orbit around the sun. Thought to contain the same materials that built the planets, studies could give us more knowledge about how our solar system was formed.

JUICE June 2022
The Jupiter Icy Moons Explorer, or JUICE, will be sent to Jupiter to study some of its largest moons for bodies of liquid water, specifically Ganymede, Calisto, and Europa. The current plan is for it to orbit Ganymede by 2032, becoming the first spacecraft to orbit a moon other than our own.

Apollo 17 was the last manned mission to land on the moon, or any extraterrestrial body for that matter, on 7 December 1972. The expense of launching more moon missions makes the endeavour quite inhibitive; however Artemis 3, planned for launch in 2024, could end up as the first moon landing since Apollo 17. Next step: Mars in the 2030s.

Apollo Guidance Computer
Emulate the actual computer used on the Apollo spacecraft

It turns out that the code for the AGC (Apollo Guidance Computer) is open-source and on GitHub. This is the same code from the famous photo of computer scientist Margaret Hamilton standing next to the stack of paper, now in a more usable form. Use it to emulate the special computer the Apollo mission used, and learn about the early days of computers at the same time.

Back to the Moon?

Source: NASA
Source: NASA
Source: NASA

Science in Space | magpi.cc | 71
OPEN-SOURCE ROVER PROJECT

Build your own Curiosity rover

The Curiosity rover is very cool, and we love hearing about its various discoveries. While you won’t be able to send a rover to Mars just yet, you can create a Mars rover to use here on Earth using the Open–Source Rover Project! The designs from the Jet Propulsion Lab are available on GitHub. They’ve been adapted for making a Raspberry Pi version.

RASPBERRY PI-DRIVEN TELESCOPE MOUNT

Tracking stars precisely with a Raspberry Pi telescope

Computer-controlled telescopes are nothing very new; however, they are something that has always been relatively expensive. The benefits are pretty simple: you can easily program in a celestial body or just coordinates to look at, and the telescope will automatically look there. Using a Raspberry Pi Zero W, Dane Gardner was able to seriously upgrade his telescope and have it work wireless and flawlessly.
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SEND A RASPBERRY PI TO (NEAR) SPACE!

HIGH-ALTITUDE BALLOONS CAN HELP YOUR RASPBERRY PI TOUCH OUTER SPACE

Unless you have access to a rocket or other kind of spaceship, it’s a bit tricky to put your Raspberry Pi into space. However, with a very special balloon (and some luck with the weather) you can get pretty close. HABs (high-altitude balloons) can go over 30 km into the sky – high enough to get amazing photos of the curvature of the Earth.

**Required hardware**

*magpi.cc/BnFynV*

A HAB is made up of the balloon itself and the payload. At the very least you’ll need to pack a tracker: there are GPS trackers that also use mobile data, SPOT trackers that use satellites, APRS which uses radio signals, and UKHAS radio trackers.

For photos, you can use a Raspberry Pi Camera Module or USB camera. You’ll also need a parachute so it can land safely once the balloon bursts. A Raspberry Pi as the main computer will be required as well, along with a power supply for the electronics.

**Programming**

Software for the Raspberry Pi inside your payload is not too complicated: it’s popular to live-stream the view of your camera, so using any internet connectivity you have in conjunction with the camera you’ve installed can be a good idea. Otherwise, you can have images save onto the Raspberry Pi as it goes.

A lot of trackers will usually have a lot of software already set up for them. Do your research and make sure you’ve got everything tested before attempting a launch. Dave Akerman has a great guide: *magpi.cc/2tc4px2*.

**Launch preparations**

There’s a long list of things to consider prior to launching your balloon. In the UK, you need permission from the Civil Aviation Authority. You’ll need a location and date, and will need to watch the weather and flight path predictions.

For flight predictions, use the CUSF Flight Predictor (*magpi.cc/kmKTRA*). Use this to plan a safe flight path, where to launch, and where to try to retrieve the payload. Dave Akerman suggests making sure you’re away from big cities and bodies of water, such as the sea.

July is likely to be a very busy month for people in the space community, as the 50th anniversary of the Apollo 11 mission is celebrated by everyone! We got in touch with Pi HAB launcher extraordinaire Dave Akerman, who is working on an amazing launch for 16 July to commemorate the launch of Apollo 11 on 16 July 1969. Here’s a small preview of the special model ship in the payload...
Developed in conjunction with Dr Nate Adams, a molecular biologist at the University of Sheffield, the Enviro+ turns your Raspberry Pi into a complete environmental monitoring station. For this it features four built-in sensors, some of them multifunctional, so it can gather plenty of useful data, including for air quality. Not only that, but if using it in a headless Raspberry Pi setup, without a monitor, its tiny colour LCD screen offers a convenient way of displaying readings. There’s also the option of plugging in a particular matter sensor (not included).

Oike the earlier Enviro pHAT – reviewed back in issue 49 (magpi.cc/49) and still available – the new board has a slimline pHAT form factor that matches Raspberry Pi Zero, although it can be used on any Raspberry Pi model. This time no soldering is required, as it comes with a female GPIO header attached.

Lacking the earlier board’s motion sensors, the Enviro+ is intended purely for environmental monitoring. To this end, it incorporates a range of useful sensors.

**Sensory overload**

First up, a standard BME280 weather sensor is used to monitor temperature, barometric pressure, and humidity. This is positioned at the left edge of the board, away from the Raspberry Pi’s CPU. Even so, you’ll need to adjust its temperature reading (by measuring that of the CPU itself and deducting a factor of it).

A smartphone-style LTR-559 light and proximity sensor detects the ambient light level and also proves handy as a substitute for a push-button when you put your finger on it. A tiny MEMs microphone measures sound levels, useful for monitoring noise pollution, and can also be used to record audio.

Most notable is the inclusion of a MiCS6814 analogue gas sensor. This can detect three different groups of gases: reducing, oxidising, and NH₃ (ammonia). While levels of individual gases can’t be discerned for the first two groups, the major ones are carbon monoxide (reducing) and nitrogen dioxide (oxidising).
Near the gas sensor is a port to attach an optional particulate matter sensor, such as the Plantower PMS5003 (available separately for £25). This is used to measure numbers of tiny particles of sizes up to 1 micron (ultra-fine), 2.5 microns (combustion particles, organic compounds, metals), and 10 microns (dust, pollen, and mould spores). The board also features a nine-pin unpopulated header connected to selected GPIO pins. The finishing touch is the inclusion of a 0.96-inch colour LCD screen. It may be small, but it’s ideal for displaying data out in the field, in a headless setup. It can even show some cool-looking scrolling graphs for live data, as shown in one of the Python code examples provided.

Environmental examples
Several code examples are included with the Enviro+ Python library for the board. Installation is simple enough, involving three terminal commands. The install script enables I2C, SPI, and serial interfaces on your Raspberry Pi, disables the serial console, and also enables a mini UART interface for the optional PMS5003 particulate matter sensor. If you ever need to revert this configuration change, there’s an uninstall script.

The most impressive code example is all-in-one.py, which demonstrates most of the features of the board, taking readings from the various sensors (bar the mic) and displaying them in scrolling graph form on the mini LCD. To switch the latter between different readings, you simply tap the light sensor with your finger.

Another code example enables you to become a citizen scientist by uploading live data (from the BME280 and PMS5003) to the Luftdaten open-source air-quality monitoring project website (see ‘Citizen science’ box). While the Enviro+ may seem a little pricey for a pHAT, it does cram a lot of useful sensors – which we reckon, if bought separately, would cost around £40 or more – into a handy package, along with that cool LCD screen to display your data.

Verdict
If you want to create an air quality-monitoring project, this board is ideal, packing a raft of useful sensory tech into a small form factor, along with a handy LCD screen to display your data.

Citizen science
Luftdaten is an open data project with a worldwide network of citizen scientists monitoring the air quality of their local environment – and, equipped with an Enviro+, you can become a part of it. Just run the luftdaten.py code example, register on the website (including your Raspberry Pi’s displayed ID number), and you can start contributing your data – from the built-in BME280 weather sensor and add-on PMS5003 particulate matter sensor – which will then be shown on the site’s world map.
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**10 Best:**

**Raspberry Pi Zero projects**

Get making with your Raspberry Pi Zero

We absolutely adore Raspberry Pi Zero. We’ve managed to fit the tiny, tiny computer into so many bits of electronics over the years to improve them that we sometimes wonder if we need to keep one in our pocket at all times. You know, for maker emergencies. If you’ve not had a chance to use a Raspberry Pi Zero yet, here are some projects that might inspire you to pick up the $10 tiny computer.

### ZeroPhone

**Zero-sized mobile**

This is truly a feat of excellent engineering: the ZeroPhone is a functional mobile phone that is fully open-source and just needs you to add a Raspberry Pi Zero and a SIM card. You might want to think about 3D-printing a nice case as well.

- £50
- [magpi.cc/rXgkZf](http://magpi.cc/rXgkZf)

### Console-troller

**Console in a controller**

We made this in *The MagPi* way back when Raspberry Pi Zero launched, and it still works to this day, even if it is DIY. All it needs is a cheap USB game controller, a bit of Dremeling, and a touch of solder. A shout-out to RetroPie too for making this painfully easy.

- [magpi.cc/40](http://magpi.cc/40)

### Trinity Buoy Wharf Lighthouse

**A model rock warning**

Created for a wedding, these 3D-printed lighthouses not only light up very brightly, but also have a mini display at the base that lets people know the table number and the status of the meal. It’s very fancy.

- [magpi.cc/dUiqTP](http://magpi.cc/dUiqTP)

### The Seeing Wand

**Magic pointing stick**

This is a very DIY project, using some old PVC tubing as a device to hold a Raspberry Pi Zero and act as a guide to where you’re pointing at. It uses a Raspberry Pi Camera Module in conjunction with Microsoft Cognitive Services to tell you what it’s pointed at.

- [magpi.cc/pfpPwB](http://magpi.cc/pfpPwB)
Zoe the Zero

A tiny flier
This small drone was built using a Raspberry Pi Zero from the cover of issue 40 of The MagPi, and in record time as well. Andy Baker built it within the week. He unfortunately passed away very recently, but we’ll always remember his amazing Raspberry Pi work.

mage.cc/piDYPq

3D body scanner

A lot of cameras
The great thing about Raspberry Pi Zero is that it’s very small. Also, it’s cheap. So using a lot of them in one project is not tricky – like this 3D body scanner that takes incredible 3D photos.

mage.cc/Vrdgov

Green sea turtle tags

Track turtles with a Raspberry Pi Zero
Nature preservation is a wonderful endeavour, and the Arribada Initiative is using Raspberry Pi Zero camera trackers to keep an eye on the well-being of green sea turtles. They’re an endangered species and are at real risk from harm from discarded fishing nets, so this is vital work.

mage.cc/NDiSwn

PolaPi-Zero

A tiny, instant camera
Polaroid cameras are once again making a comeback of some kind, so it’s only natural that people try to emulate the concept with a digital camera. One of the many tries at this is the PolaPi-Zero, which uses a thermal printer to print out instant images.

mage.cc/ubWKNK

TinyPi Pro

The smallest console ever
This tiny DIY kit lets you turn a Raspberry Pi Zero into an absolutely minuscule handheld games console. Is it practical? Not entirely, but it’s still extremely cool, and the build process is quite fun as well.

£69
pi0cket.com

All-in-one computer mouse

Zero in a mouse
Putting a Raspberry Pi Zero into something is everybody’s dream. One person took this to the ultimate extreme and 3D-printed a mouse with a tiny screen, a pull-out keyboard, and a Raspberry Pi Zero inside. It’s a full computer.. only it’s a mouse.

mage.cc/kEzDbf
Learn to upscale old technology with Raspberry Pi

Take old, unused tech and give it a new lease of life with a Raspberry Pi. By David Crookes

Upcycled Technology: Clever Projects You Can Do With Your Discarded Tech

Half the battle of upcycling technology is coming up with a concept. The rest is identifying and working with devices that can help you achieve your aim.

This new book by creative technologist Daniel Davis hopes to inspire, guiding you through six projects that help you turn old webcams, laptops, CD-ROM drives, smartphones, iPods, and mobiles into backup cameras, projectors, 3D printers, security cams, and smartwatches.

In doing so, it examines key stages of the upcycling process, explaining why you should reconsider chucking away your old tech, and even describing where you may find stuff that others don’t want.

In that sense, it’s a handy resource. A crucial chapter picks apart a handful of tech and looks at the useful components they contain, and there’s a good look at the tools you’ll likely need for your projects – including a Raspberry Pi, of course.

That said, none of the projects actually uses a Raspberry Pi and, despite the steps clearly explaining the processes, it often skims when it could go in-depth. But you do get a solid grip of the various concepts and it’s a good introduction to upcycling, particularly in its cheaper e-book form.

See Raspberry Pi used in upcycled projects

INSTRUCTABLES CIRCUITS

There are loads of cool projects on Instructables, many of which upcycle old technology using a Raspberry Pi. The majority use videos to demonstrate the results alongside full instructions. magpi.cc/BvVkgm

TINKERNUT

Yes, it’s Tinkernut again (see the book), but for good reason: the site contains some lovely video tutorials about upcycled Raspberry Pi projects, a few of which are accompanied by step-by-step guides. tinkernut.com
You shouldn’t generally tackle technology like a bull in a china shop and hack away at products’ innards without thought. It’s always a good idea to see what goodies they contain first, so that you can determine what could be used in your upcycled technology projects and how they can best fit with a Raspberry Pi.

This wiki-based site has repair guides that take you under the skin of a device to look at specific parts. It also has full tear-downs which show you the safest way to dismantle lots of different technology – perfect for identifying any problems and every significant component you’ll come across. Full lists of tools used are available, and there’s a store where you can buy any you need, too.

As well as running the excellent YouTube channel Adam Builds (magpi.cc/mebsYy), IT technician Constantin Adam has created a wonderful three-hour online course dedicated to upcycling using a Raspberry Pi. Spread over eight multi-sectioned chapters, each of which lasts roughly 15 to 20 minutes, Adam carefully explains how to build a wireless Amazon Alexa from an old calculator, and an internet radio player from an original 1980s set. He converts a 1990s joystick into a games console, and turns an older television into a smart mirror. And that’s only half of it.

The course includes some upcycling vitals, including exploring appropriate platforms, as well as planning and writing code using APIs. Available to view on mobile and computer, it also covers some Raspberry Pi basics, which means even beginners can ease themselves in.

Wallace Smith learned to upcycle old technology with Raspberry Pi. magpi.cc
Want computers explained to you? Then meet Chris Barnatt, futurist and tech YouTuber

In the dark ages before YouTube, finding shows about technology, science, and computers on TV was a bit tricky. They were few and far between, so when Tomorrow’s World and How 2 were on, a lot of young people watched. Now, with 2020 just around the corner, there’s a wealth of video channels online to satisfy your cravings for tech knowledge – and one of them is ExplainingComputers, run by Chris Barnatt.

“I remember reading the Ladybird book [‘How it works’: The Computer] when I was six or seven years old,” Chris tells us. “[I was] fascinated by the pictures of magnetic core storage, which were still in use at the time. When I was about 13, my parents bought me a ZX81 – in some ways the Raspberry Pi of its day – and I soon learnt to program it in BASIC and assembler, and wrote my first articles for computer magazines. I subsequently spent 25 years lecturing in computing and future studies in the University of Nottingham.”

In 2007, Chris launched ExplainingComputers.com as an ‘online computing textbook’, which led to him starting the YouTube channel in 2008. This has covered a huge range of tech concepts and projects, and became a weekly show at the end of 2015. From last year, Chris has added Raspberry Pi videos. He makes use of his production experience at the BBC to add animations to his videos as well.

When did you first learn about the Raspberry Pi?
I remember watching a report on the Raspberry Pi on the BBC’s Click TV show shortly after the board was first launched. But I...
Chris Barnatt didn’t get one until a year or so later. Since that time, Raspberry Pi, and SBCs (single-board computers) more generally, have been an increasing part of my life! I now have about 40 SBCs, including every Raspberry Pi aside from the first Model A.

**What are some of your favourite videos that you’ve made?**

On ExplainingComputers, my favourite videos are often those that show viewers how to do things with low-cost hardware and/or free software – which is why I like working with Raspberry Pi, and why it is so popular with my audience. I remember making a video a few years ago called ‘Raspberry Pi Week’, when I used a Raspberry Pi 2 for a week as my only PC. This included delivering lectures for clients from a Raspberry Pi, which all worked, so this was a great experience. I’ve also enjoyed making videos about things like robotics and automation, often involving a Raspberry Pi, and have had great success with videos about Raspberry Pi cooling. Some of the techniques and test scripts I’ve shown in these cooling videos have been fairly widely adopted around the web, and it is always great to make YouTube content that others embrace like that, and which people find helpful.

More broadly, I’ve always like making videos – both on my ExplainingComputers YouTube channel, but also my other channel called ExplainingTheFuture – that show people something that does not exist yet, and where I can include a lot of CG animation. So I’m proud of the videos I’ve made on subjects like brain–computer interfaces, bioprinting, and asteroid mining, even though they are not always the most popular.

I think I now have about 40 SBCs, including every Raspberry Pi aside from the first Model A.


“**I think it’s a very exciting time in computing, with the lines between traditional desktops and SBCs continuing to blur as more computer power moves to the ‘edge’. In this context, the new Raspberry Pi 4 is, I think, a signature development, as it is clearly capable of being used as a device for doing most of the home computing basics – surfing the web, email, playing media, running office apps, and things like that. I’m pretty sure we’ll have desktop PCs for a good many years to come, but they will increasingly look more and more like a Raspberry Pi.”**
Did you know that HRH Prince Andrew, the Duke of York, is the Patron of the Raspberry Pi Foundation? He’s a big advocate of technology, and has hosted Raspberry Pi at Buckingham Palace and St James’s Palace. He made a visit to the Raspberry Pi HQ last month to see what the Foundation was up to.

01. The CoderDojo team from Ireland meet HRH
02. Foundation staff were on hand to show him what Raspberry Pi was up to
03. The Prince gets to know the Astro Pi
04. Code Club is an important part of the Raspberry Pi Foundation
05. The Prince and Raspberry Pi Foundation CEO Philip Colligan inspect the maker space
06. The Duke of York talks to the Foundation Members and staff in attendance
A royal visit
MagPi Monday
Amazing projects direct from our Twitter

Every Monday we ask the question: have you made something with a Raspberry Pi over the weekend? Every Monday, our followers send us amazing photos and videos of the things they've made. Here is a small fraction of them. Follow along at the hashtag #MagPiMonday.

01. This e-ink clock looks very nice!
02. A still image doesn’t do this time-lapse video justice – take a look here magpi.cc/sSPYiF
03. We always like seeing a nice, cleanly built robot
04. Robots are a good advertisement for Raspberry Pi
05. We wonder what the good Lady Ada has to say?
Crowdfund this! Raspberry Pi projects you can crowdfund this month

**Strawberry4Pi 2**

This IoT add-on makes it easier for you to control your Raspberry Pi home automation projects from a smartphone using a special app. Along with a temperature sensor and WiFi configuration button, it features four relays to switch connected devices on and off, which should make overall control a little simpler.

> kck.st/2wOHy4o

**INcase ONE**

The description as “The World’s Best Single Board Computer Housing System” seems like a grand claim, but it looks like a neat case either way. Designed for Raspberry Pi, Arduino, BeagleBoards, etc., it’s weatherproof and looks like it would make a good CCTV or motion sensor alarm.

> kck.st/30IKa0M

**Best of the rest!**

Here are some other great things we saw this month

**ANDROID AUTO VIA RASPBERRY PI**

This is a cool little hack – we much prefer Android Auto to some stock navigation and media software. Reddit user icucube45 was able to directly interface a Raspberry Pi 3 with the display’s input to make this work.

> magpi.cc/zMpAGQ

**DIY SMART GLASSES**

Official smart glasses products seem to be making a return, but that hasn’t stopped Reddit user Infranix from making his own amazing DIY pair using a Raspberry Pi Zero. We love the futuristic sci-fi look.

> magpi.cc/0dcZVG

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Raspberry Jam Event Calendar

Find out what community-organised Raspberry Pi-themed events are happening near you...

01. Exeter Raspberry Jam
- Saturday 6 July
- Exeter Library, Exeter, UK
  - magpi.cc/vhtijy
  Bring along your projects and Raspberry Pi problems for great conversations.

02. Potton Pi & Pints
- Saturday 6 July
- The Rising Sun, Potton, UK
  - magpi.cc/QFwrBbT
  Raspberry Pi-related fun in a relaxed setting. Meet like-minded people at Potton Pi & Pints.

03. Stafford Raspberry Jam
- Tuesday 9 July
- Stafford Library, Stafford, UK
  - magpi.cc/Swkveu
  Welcoming anyone that wants to show off their projects, or see other people's builds!

04. Egham Raspberry Jam
- Sunday 14 July
- Gartner UK HQ, Staines-upon-Thames, UK
  - magpi.cc/WJFgSU
  An opportunity to share what you have built, as well as the chance to learn from others.

05. Seattle Raspberry Jam
- Wednesday 17 July
- Bellevue Library, Bellevue, WA, USA
  - magpi.cc/NvsBzz
  Come and participate in the monthly project, share your knowledge, or show a project you've created.

06. Milton Keynes Raspberry Jam
- Saturday 20 July
- The National Museum of Computing, Bletchley, UK
  - magpi.cc/hJEwZS
  Meet other Raspberry Pi fans at the historic Bletchley Park, and make things over the summer break.

07. Preston Raspberry Jam
- Saturday 20 July
- Fulwood Library, Preston, UK
  - magpi.cc/UoMSpi
  A Saturday morning digital making event, with children, adults, and families, from beginners to experts.

08. York Pi Jam & Moonhack
- Saturday 20 July
- Acomb Explore Library, York, UK
  - magpi.cc/JybjiC
  A Jam for beginners, and also people who know a bit about Raspberry Pi computers!

FULL CALENDAR
Get a full list of upcoming events for July and beyond here: rpf.io/jam
Ben Nuttall – Manchester Raspberry Jam

Every Raspberry Jam is entitled to apply for a Jam starter kit, which includes magazine issues, printed worksheets, stickers, flyers, and more. Get the book here: magpi.cc/2q9DHfQ
Please can someone explain I2C and SPI? I want to attach an air quality monitor, and a set of LEDs to show the air quality state, to a Raspberry Pi Zero W. What do these terms mean, and how can I use devices with these two interfaces with Raspberry Pi Zero? I do have a Breakout Garden pHAT.

Anne via email

They’re different ways for peripherals, components, and other devices you connect to the GPIO to communicate with the Raspberry Pi. Usually, it’s a matter of adding the correct bit of code to your program to make sure you can read or control the thing you’ve connected to the Raspberry Pi, as well as connecting it to the correct pins.

Some of the pins on the Raspberry Pi’s GPIO are reserved for SPI or I2C, so it’s best to use those in conjunction with them.

As for the Breakout Garden pHAT, you’ll be able to use the specific plug-in sensor with it without too much issue.

The Breakout Garden pHAT makes it easy to add components to Raspberry Pi Zero
I recently got a new Raspberry Pi and was wondering how to back up the software and documents on my SD card for transferring to my new Raspberry Pi. If it matters, I upgraded from a Raspberry Pi 2 to a Raspberry Pi 3B+.

Charis via Twitter

If you’ve kept your SD card up-to-date with dist-upgrades, you may be able to slot your SD card into your Raspberry Pi 3B+ and just boot it straight up. This doesn’t always work, though, so you may have to install the software you need again.

However, you can easily transfer documents over manually using a USB stick or network folders. It might be an idea to create an image from your original SD card in case of issues in the future – then you can go back and see what you may have done differently.

I remember when you put out issue 40 with the Raspberry Pi Zero on it, and I was wondering if this is something you’re ever likely to do in the future?

Sayem via Facebook

As you can see, we didn’t include the Raspberry Pi 4 on the front of this issue of the magazine. Sorry! One of the reasons we were able to do it with Raspberry Pi Zero was because of its size – a full-sized Raspberry Pi board would make it extra-tricky.

Frankly though, we don’t know. We’re open to doing it again. Make sure you subscribe to ensure you get any special editions when they come out magpi.cc/subscribe.

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THE MAGPI #84
ON SALE 25 JULY
I started engineering at age seven when my dad bought me a soldering iron to take a TV apart. Mostly, I learnt about how hot things burnt your fingers, and how resistors and capacitors can be levered out of the board effectively.

But these first experiments (the TV never worked afterwards) were indicative of my approach to all engineering: take it apart and try to understand what it does, then use that understanding to develop new things.

My second computer was a BBC Micro Model B, and it was here that I tried to really understand how it worked: poring over the schematics in the advanced user’s guide and having to fix the printer port because I’d shorted out the GPIOs. I left school at 16 with four GCSEs, did an apprenticeship for the MOD, and went to college. It was here I realised how much I loved working on interesting things and worked out that it was worthwhile working hard (unlike at school.)

It’s all just maths

After my apprenticeship, I went to the University of York and did an MEng in Electronics. Here I learnt about how everything is really just maths, and that I really enjoyed really hard maths, finally ending up with a PhD (which was applying genetic algorithms to electronics to make circuits that fixed themselves).

Most recently, I’ve graduated from the University of Cambridge Judge Business School with an executive MBA. Here, I have learnt about things other than engineering. I learnt about how companies work, how they interact, and how we can make companies that create value. Also, I’ve learnt a great deal about the people I was working with.

One thing I’ve found is that I tend to think of everything – cycling, making companies, managing people – as an engineering exercise: taking things apart, understanding how they work, then using this understanding to make things better. This process is one of the things I really enjoy, and something I get to do on a daily basis at Raspberry Pi. So, kids, if you think you’re never going to make it because your GCSEs aren’t quite good enough, just remember, Gordon did it…
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