Make:

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28 HOW-TO BUILDS

- High-Speed Splash Photography
- Raspberry Pi Gaming Arcade
- Kids' DIY Play Furniture

3D PRINTABLE HUMANOID

MEET INMOOV: Your Life-Size Animatronic Helper **Sees, Hears,** and **Speaks**

HOW **SHENZHEN** BECAME THE CENTER OF MAKER MANUFACTURING

COMBAT BOTS:
They're Big, They're Bad, and They're Back!

Vol. 45 June/July 2015

COMPUTING WAS PRETTY BASIC

THEN ADA LOVELACE TRIED AN ALGORITHM

What will you try?

googlesciencefair.com

Parrot
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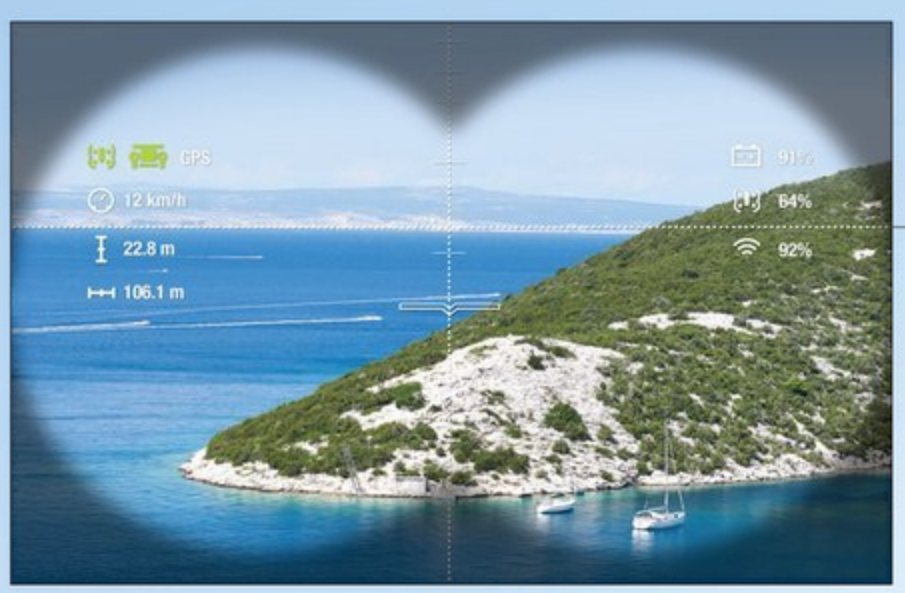
SKYCONTROLLER

180°



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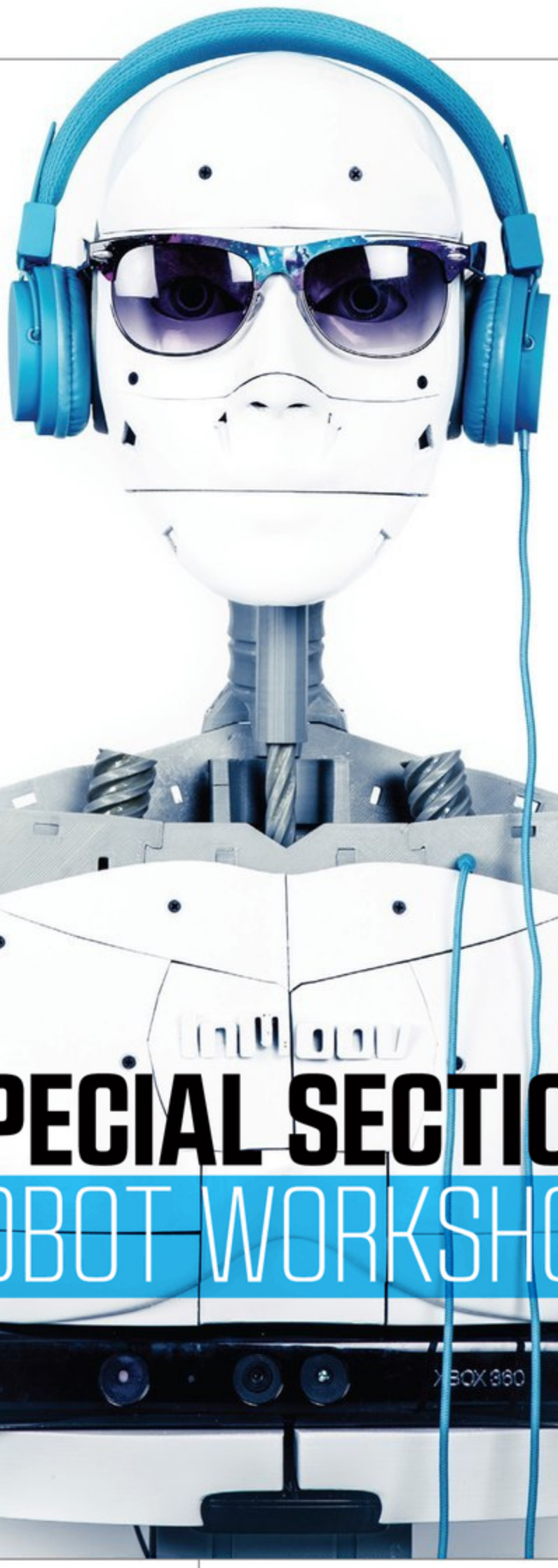
CONTENTS

COLUMNS

FEATURES

24

34



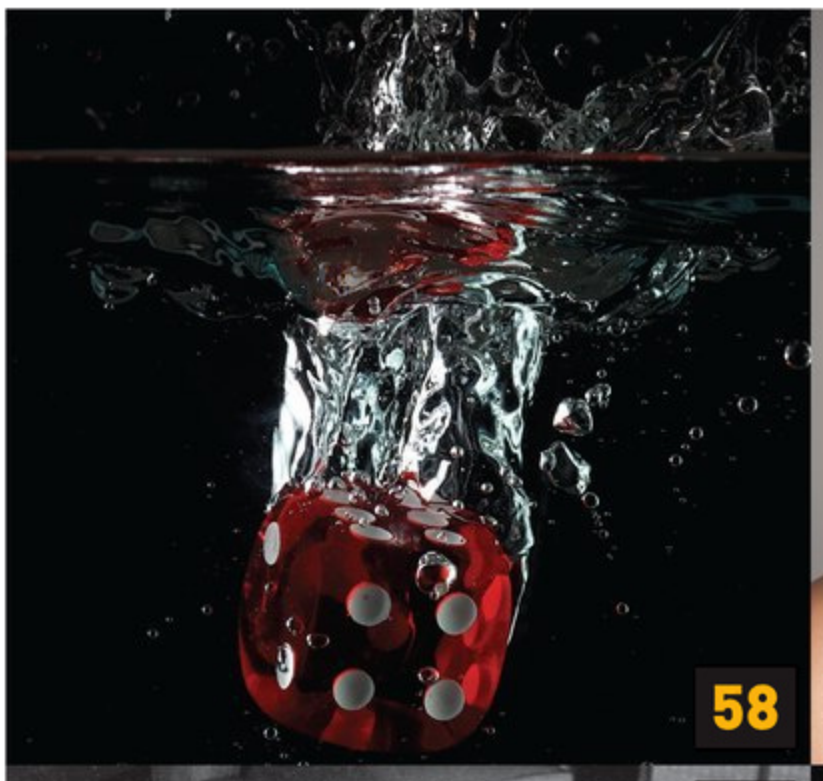
ON THE COVER:
"Gray" by Alan Timm is part of the InMoov Project, an open source, life-size, 3D-printable robot designed by Gael Langevin.
Photo: Hep Svadja

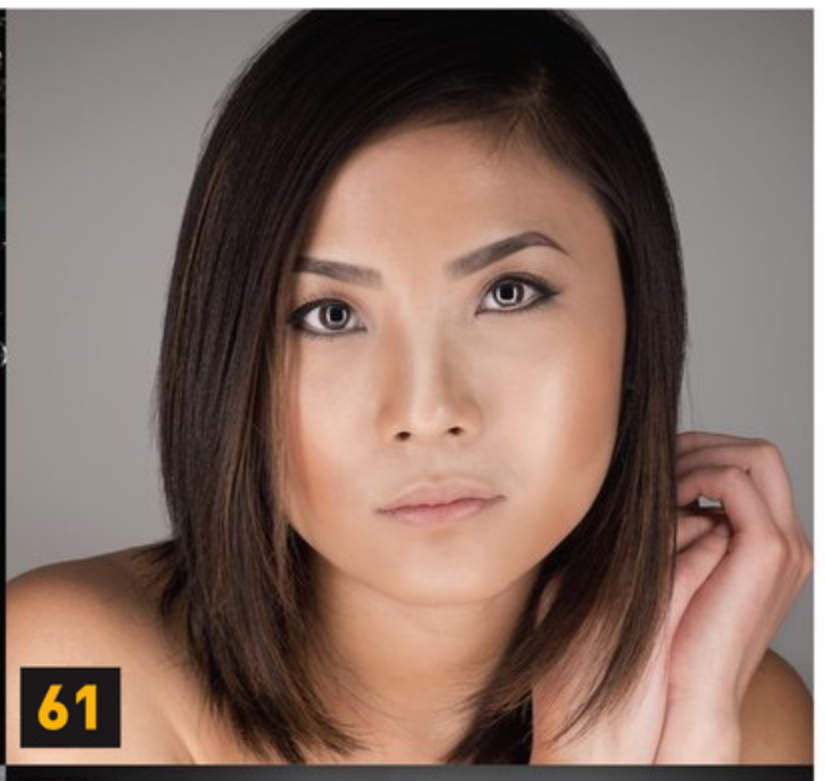
SPECIAL SECTION
ROBOT WORKSHOP

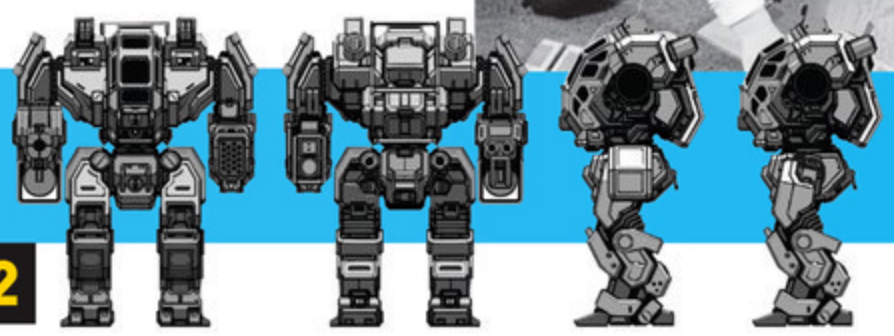
30

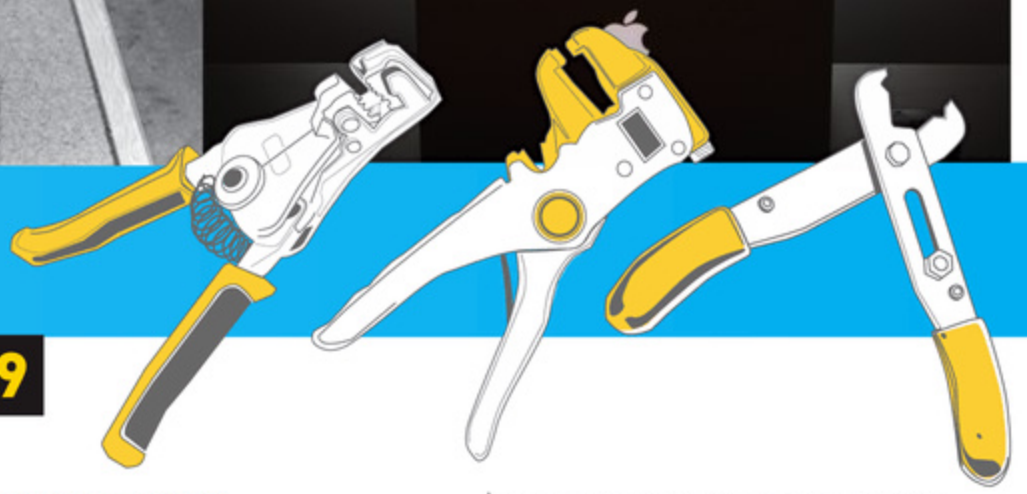
SKILL BUILDER

PROJECTS









TOOLBOX

OVER THE TOP

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Make:®

"Indestructible robot gangsta number one, son!" — Ninja, *Chappie, 2015*

CONTRIBUTORS

Your robot overlords have arrived. Why should they spare you?

Andrew J. Nilsen
San Francisco, California [Illustrator, Clothes Folding Board]
I wouldn't need to say anything — the robot overlords already know I designed their logo.

Krista Peryer
Springfield, Missouri [Magic from Metal]
In the words of Brain, from *Pinky and the Brain*, "We'll try to take over the world!" If you can't beat 'em, join 'em ...

Thomas Burg and Johannes Gottwald
Wiesbaden, Germany [High-Speed Splash Photography with Arduino]
We were sent here to distract the human race from building an interstellar super-shield. And it worked!

Geeta Dayal
San Francisco, California [In Our Image]
I'm an expert in robot music, and I could teach the robot overlords how to build synthesizers and dance to some Kraftwerk jams.

Shelley Bunyard
Galena, Ohio [Crochet a Mermaid Lapghan]
The robot overlords should spare me because I can make them awesome hats, of course.

Bringing the Family Together

Amanda Villaveces

From left: Theo, Joe, and Max Villaveces are engrossed by *Make:* Volume 43.

» Just wanted to say thanks for keeping our entire family inspired. This is what it looks like in our house the day your magazine arrives!

— Amanda Villaveces

» *MAKE:* READER MODS

Make: reader Lavon Phillips added his own spin, literally, to the Infrared Shooting Arcade (*Make:* Volume 43, page 76) for the inaugural New Jersey Makers Day on March 21. Phillip's mod boasts a carousel of moving targets, custom PVC IR guns, and pop-able balloon targets inside a fold-up, travel-ready case. See it in action at makezine.com/go/ir-arcade-mod.

» A QUADCOPTER IS NOT A DRONE

I loved the issue you put out a few years ago on quadcopters right as the fad was starting. Despite my enthusiasm about *Make:*, I have a serious problem with your newest issue, *Make:* Volume 44. On the front cover and regularly through the magazine, *Make:* uses the word "drone" rather than quadcopter, multicopter, or multirotor. Although it is unmanned and it flies, so do many other types of R/C model planes. By calling these aircraft drones they are put in the same category as military drones.

Quadcopters, multicopters, and multirotors are simply entertainment, and they should be treated as such. It seems important to emphasize that they are harmless and avoiding terms with negative connotations is one way to convey their innocence. Relabeling anything that flies via remote control to "drone" will only destroy the hobby that *Make:* tries to promote.

— Sam, Charlottesville, VA

EXECUTIVE EDITOR MIKE SENESE RESPONDS:

Thanks Sam. We agree "drone" shouldn't be a catchall for anything that flies — we use the word for the new type of small hobbyist aircraft that have autonomous capabilities, from sensor-controlled stabilization to flight-path navigation. But we don't see them as just toys; they're powerful tools that are enabling incredibly beneficial missions, such as finding missing persons and monitoring endangered wildlife. It's helpful to reference the specific type of a UAV when referring to it, but we're not afraid of using the word "drone" for the general category — in fact, we encourage the community to reclaim the word and help promote all the good these machines can do.

» PRAISE FOR *MAKE: BASIC ARDUINO PROJECTS*

Hello! I have read the book *Make: Basic Arduino Projects*, and it was awesome! I am "playing" with my Arduino Uno every weekend.

The book got more interesting as I progressed. All the projects in the book were fun! This book was so interesting, I got my dad to read it! He will be my partner and helper when we do projects together!

When I first got my Arduino (my uncle got one for me as a birthday present), I wanted to experiment with the LCD display. But I did not know how to hook it up. A few weeks later, my dad got me this book. Once I read it I could not wait to get started!

Thank you very much for writing a very entertaining and enjoyable book!

— Tyler, Torrance, CA

AUTHOR DON WILCHER RESPONDS:

Thank you for the kind words regarding the *Make: Basic Arduino Projects* book. I really enjoyed building the projects and writing the discussions. I hope you continue to learn through making and sharing your new electronics knowledge with school faculty, family, and friends. Just remember Tyler, there is Power in Making.

— Don Wilcher

Matt Skoufalos/NJ Pen

To Build a Better Robot, Build a Better Team

IN THE MONTH OF APRIL, ROBOTICS TEAMS PARTICIPATE IN COMPETITIONS such as FIRST in St. Louis and Vex in Anaheim. I met Kate Azar last summer and heard her talk enthusiastically about FIRST robotics. While her experience was positive, she realized that young women struggle to gain respect as competitors and team members. I asked her to share her insights.

Last year, I graduated high school after three years on the Robettes, an all-girls FIRST Robotics Competition team from St. Paul, Minnesota. Amidst metal shavings and solder droplets, I learned quickly that boys in engineering would assume my ignorance and downplay my success. At the same time, I discovered that these same males desperately wanted more female makers to participate.

What a huge disconnect! The disrespect, the misogyny, the labels — the various forms of bias were expressed within the very group trying to fight them.

Before my first competition, my teammates told me that boys were out to get me: I would receive no respect as a female in engineering, and I had to "go into competition prepared." It was ominous, really. While I mostly shook it off, a part of me listened, and, knowing no better, I showed up at my first competition prepared for battle.

The battle never came. For me. I saw males disparaging my teammates, and it generally came down to the fact that the girls, brilliant as they were, didn't assert themselves as competent — yet they always cried sexism. There I was, ready to verbally spar with anyone who got in my way, and my defenses were totally unnecessary.

After consulting multiple young women in FIRST Robotics, I found that my experience was far from normal. Two members of Fish in the Boat, FIRST Tech Challenge World Champions of 2013, are quoted below.

"Being the only female in a STEM class or program sucks. It's discouraging, it's disheartening, [and] it made me feel like I was flat out not good enough to want to go into STEM ... [H]ow many other girls don't feel good enough because the guys in the class are discriminatory, make uncomfortable comments, are sexist, and in one case flat out tell you they don't think you should be in the class?"
—Erin Mitchell

"While my good memories outweigh the sexist ones, it's horrible at competitions when you're trying to discuss strategy with a guy on a team, and he totally disregards anything you have to say — because you're a girl."
—Crystal Huynh

KATE AZAR is a student in the College of Science and Engineering at the University of Minnesota, Twin Cities. She continues to participate in FIRST at the collegiate level as Director of Programs of GOFIRST, a FIRST Support Organization.

With 40% of females leaving engineering just after entering the field, it's clear that those experiences add up. So why, then, was mine different? The issue runs deeper than simple finger pointing. A slap on the wrist "because it's the boys' fault" won't fix anything.

When there are 50 people on a robotics team, 48 male and two female, if one male has a terrible attitude and no technical ability, 47 counterexamples exist to validate his gender's skill. If one female suffers the same, she spoils 50% of the data pool. And it happens. As a mentor once told me, "it's human nature to stereotype."

Is there a solution? Surely, females must be confident in their ability to perform, and they must display that confidence — or they will never receive respect. As stated by Madeleine Logeais, 2014 FIRST Dean's List Winner, "Expectation translates to invitation." When a girl enters a situation guarded, others will perceive it as a lack of confidence in her own ability. (Similarly, boys can be overconfident in their ability, yet it can be driven also by the same underlying insecurity.)

After that first competition, my experience in robotics shifted dramatically. Because I joined the team as a high school sophomore, rather than as a freshman, I brought a new perspective to my team, and I re-evaluated a situation others had not questioned. What I found surprised me. Now, I enter competition openly, asserting my intelligence in a friendly way, and have had few poor experiences dealing with prejudice.

My advice to girls: Be clever, friendly, and assertive in equal measure. Be makers.

My advice to boys is the same. However, know that your words and actions can diminish, if not undermine, female participation, which will ultimately make you, your team, and the fields of engineering and robotics less successful.

Let's improve how we work together, getting to know people as individuals and learning not just how to build robots but how to build more capable teams based on mutual respect.

Vik Orenstein

BY DALE DOUGHERTY, founder and Executive Chairman of Maker Media.

MADE ON EARTH

The world of backyard technology

Know a project that would be perfect for Made on Earth? Email us: *editor@makezine.com*

MAGIC FROM METAL

FACEBOOK.COM/VERNIYART

Siberian artist **Igor Verniy** creates explicitly detailed steampunk sculptures of animals, from birds to bugs to puffer fish. Verniy has been crafting since he was a young boy, starting with small wooden toys and returning as an adult to work with metal, which he uses to create textures that bring to mind realistic attributes of the animal, from tattered bat wings to flexible octopus tentacles.

The poseable sculptures are created from scrap metal like silverware, spare watch parts, electronics, car and bike parts, and more that he collects from the market, or that his friends bring him. Their sizes vary, with the largest stretching more than 3 feet and weighing almost 20 pounds.

Although the sculptures aren't currently robotic, Verniy dreams of bringing them to life. "A live metal android with artificial intelligence is my highest dream," says Verniy. "And I will never stop until he appears." — *Krista Peryer*

Igor Verniy

WOODYJONES.COM MECHANICAL MIND

Woody Jones

You could hear the laughter of the kids turning the cranks on **Woody Jones'** handmade automatons at the October 2014 Atlanta Maker Faire long before you approached his large wooden sculpture, called simply *Big Head*.

Jones creates custom-made dioramas full of bits and pieces that reference important milestones in his clients' lives. "It's the most enjoyable job I've ever had," he says of his 30-year career as an artist in Decatur, Georgia.

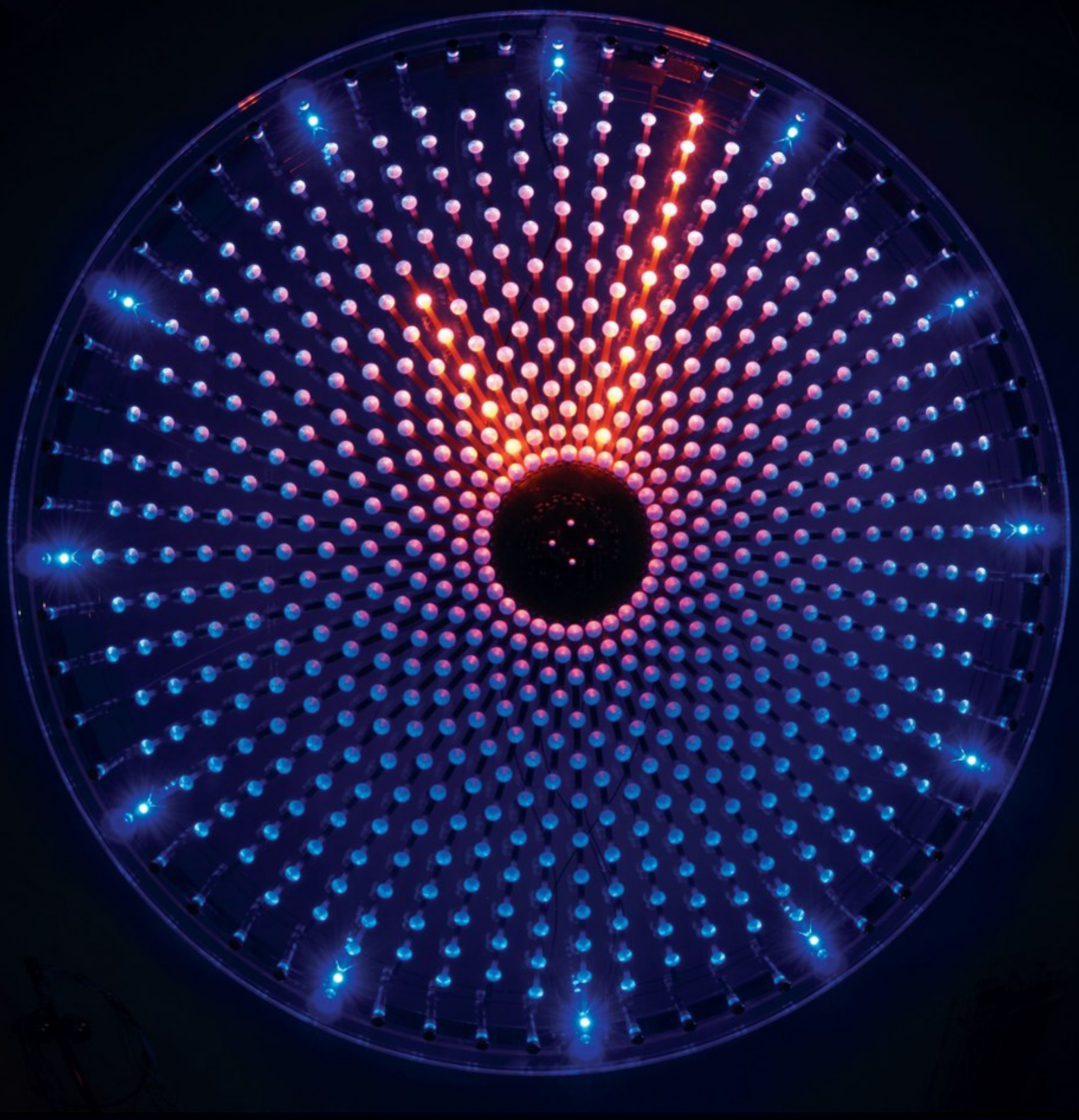
"I look for the unique characteristics in people that make up their real stories," Jones says. He then uses a band saw, grinder, and belt sander to create scenes that bring a story to life. Turn a crank and two wooden people dance and spin, an animal jumps, and a man in a hammock gently swings.

While Jones typically creates smaller, shoebox-sized dioramas, *Big Head* is his biggest hit — this eight-foot-tall wooden noggin contains dozens of scenes. Most are specific to Jones and his own life story, with hundreds of figures and objects controlled by a number of cranks, levers, and gears.

Approachable and always willing to share his own stories, Jones knows the enjoyment his creations bring. "When you leave my booth," he says, "my goal is that you leave happy."

—James Floyd Kelly

THE ACCIDENTAL CLOCKMAKER



James Bastow

KWARTZLAB.CA/2010/05/BERNIE-ROHDE-ART-EXHIBIT-SUCCE

Bernie Rohde became obsolete as a TV repairman almost 30 years ago, having only gone to school for analog appliance repair. To catch up to a growing tech world, he decided to teach himself how to build digital circuits.

He liked to play around with components, so he built exploded views of what was going on inside computer chips. He used discrete transistors, diodes, resistors, capacitors, and LEDs to build his circuits. Rohde didn't have a plan for what he was going to make with all these pieces, but eventually he realized, intuitively, that they could become clocks.

He makes acrylic faces, copper body parts, printed circuit boards, and wiring, all by hand. It's a perfect fusion of analog and digital technologies — a clock that displays hands to tell time, yet with guts that are completely digital.

There is a futuristic, extra-terrestrial feeling in his work. To see one of these glowing spheres floating in a dark room is like peering through a portal to another world, or like viewing something underneath a microscope.

The theme of using tech to make art runs through Rohde's work. "Engineers decide what they want to make," he says. "Art is about letting it happen. I wait to see what needs to be done — I let the circuit show me."

— Agnes Niewiadomski

Two Bit Circus

REAL LIFE ASTEROIDS

STEAMCARNIVAL.COM

Human Meteors is an immersive re-creation of the classic Atari game known as *Asteroids*. It takes the original gameplay and turns it into an interactive experience by introducing an old school computer projector, a regular office chair, a motion-sensing camera, and a Wii Remote along with some custom code.

Gamers sit on a modified swivel chair with a Wiimote attached to the top while a 1980s projector displays the virtual objects on the floor. When a person moves the chair, a Microsoft Kinect tracks their location and changes the direction of the "spaceship." The button on the Wiimote fires lasers directly in front, taking down anything in the way.

Atari founder Nolan Bushnell even tried it out. "To be actually the ship is really wonderful," he says. "This way it was real, and that makes it even more fun." The game was developed by **Two Bit Circus — Eric Gradman and Brent Bushnell** (Nolan's son) — for their STEAM Carnival, and draws a crowd wherever they take it.

— Matthew Terndrup

sprout by hp

Hep Svajda

Getting Started with Sprout

ADVERTORIAL

SINCE THE BIRTH OF THE COMPUTER, OUR WORK HAS BEEN SPLIT INTO TWO VARIETIES: THE PHYSICAL AND THE DIGITAL. The sketches in your notepad rarely appear on your computer, and even if they do, it's only after considerable effort. This divide has frustrated all of us from time to time, sometimes to the point of avoiding it altogether.

Of course, one of the main benefits of working with a computer is the ease with which you can manipulate digital content. Since bits are inherently easier to change than atoms, we can let our creativity run wild, and we are free to make as many mistakes as we need to. Thanks to the almighty "Edit – Undo," we aren't punished for our mistakes like we are with a pen on paper. The holy grail, then, is to make it easy to seamlessly merge the two worlds, to bring the physical world into the digital workspace.

HP'S BLENDED REALITY

We've been using the clunky mouse and keyboard in front of a display for more than 30 years. Despite this fact, most computer manufacturers are content to focus on making computers faster and smaller, rather than addressing the elephant in the room. The desktop computer is long overdue for a redesign, one that enables us to rethink the way we do work. We need to bring the ease of interacting with people and objects in the physical world into the digital world. This is the heart of the vision HP calls "Blended Reality."

HP's Blended Reality is an innovative approach to the way we interact with computers. It's a way to merge the physical world that we live in with the digital world that we work in. With new ways to bring physical objects into the digital workspace, HP's Sprout is poised to change the way that we interact with computers, and each other.

FUTURISTIC HARDWARE

The HP Sprout is far from your average desktop PC. Sitting atop the 23-inch LCD touchscreen is a device HP calls the "Illuminator," containing a 3D scanner, a DLP projector, and several high-resolution cameras to capture images, depth, and more. The image of a digital workspace is projected from the Illuminator down onto an integrated Touch Mat. This turns the Touch Mat

THE ILLUMINATOR

- A three-camera system including a high-resolution 14.6 megapixel camera, an Intel RealSense 3D camera, and an RGB camera. The cameras can be used to capture small objects placed on the Touch Mat in both 2D and 3D.
- An integrated desk lamp with three levels of touch-controlled brightness for illuminating those late-night build sessions
- A 1024 x 768 DLP projector shines from the rear column behind the LCD screen, and projects down onto the Touch Mat.

THE LCD SCREEN

- Dual digital MEMS microphones and a front-facing web cam hidden behind the bezel are perfectly positioned for video sessions when remotely collaborating on projects.
- A 23" diagonal 1920 x 1080 LCD touchscreen is used as the primary vertical display.
- Four front-firing speakers and a 10-watt subwoofer provide ample sound for blasting your favorite music while you work.

sprout by hp

THE TOUCH MAT

- A capacitive touch mat works as a second display that can track up to 20 individual points, meaning two people can work on a project together on the same surface. The ultra-resistant top coating deflects spills, cuts, glue, and even ink.
- Three touch controls enable and disable the digital keyboard, Workspace app, and projector.
- The Touch Mat attaches to the base of the Sprout with a magnetic USB connector. This makes it easy to remove and replace it whenever necessary.

into a second display that is touch-sensitive, and able to track up to 20 independent points at once. This unique combination of integrated hardware sets the Sprout apart from other desktop PCs, and gives us a glimpse into HP's vision for a new, immersive computing platform.

INNOVATIVE SOFTWARE

Of course, hardware is only as good as its software, and the Sprout doesn't disappoint. The Sprout runs on Windows 8.1, making it every bit as powerful as your average desktop computer, but the included Workspace software platform is the environment where HP's vision of Blended Reality begins. From here, you can launch apps to scan documents, take photos, capture 3D objects, and collaborate on projects with remote friends or co-workers.

The Capture app lets you take pictures of multiple objects on the Touch Mat in seconds. The app will even remove the background automatically, and saves the images in the Workspace for use in other projects later. Whether you're inputting pen and paper sketches, project idea notes, or snapping pictures of physical objects, the app makes the process simple and easy. It's a great way to document progress on a project, or to take beautiful step-by-step shots for creating instructions.

Using the 3D Snapshot app, you can quickly create a 3D OBJ file of any small object that fits onto the Touch Mat. The 3D scanner built into the Illuminator uses Intel's RealSense depth-sensing technology, and combined with its DLP projector, uses structured light 3D scanning techniques to create a 3D snapshot of an object. Having a 3D model to work from makes creating custom enclosures, component mounts, or duplicating existing objects much easier.

The Create app is so much fun that it's likely where you'll spend the most time interacting with the Sprout. Acting as part photo editor and part design tool, you can create digital collages of images from the Workspace or the web with the swipe of a finger. With the included stylus, you can sketch or write notes on the page. Each image pasted or drawn is placed on its own layer, so you can easily edit and manipulate them individually.

COLLABORATE IN REAL TIME

For many people, creation is not a solitary activity, and collaboration is an important part of the creative process. The Collaborate app leverages HP's MyRoom virtual room technology to deliver true remote collaboration, streaming video and sound from the front-facing camera while you

Hep Svajda

ADVERTORIAL

work with others to manipulate a single piece of content in real time. You can also stream from the camera in the Illuminator above the mat. This is perfect for sharing projects you're working on, or for getting help troubleshooting tricky breadboard circuits from your techie friends.

EMPOWERING MAKERS

As the first step into Blended Reality, the Sprout is still very much in its infancy, but it is already a powerful tool being used by designers and tinkerers. In addition to the apps already included in the Workspace, the Sprout Marketplace features applications that unlock even more uses for the Sprout's hardware. Here you'll find apps for composing music, designing 3D characters, playing games, and more. For developers who would like to create new apps for the Sprout, HP has even made the Sprout Software Development Kit available on their website, and hopes to see new and creative applications developed for the Sprout.

Any one of these features and applications would be impressive alone, but the innovative combination of them in the Sprout shows immense potential for the future of computational creativity. HP has created a tool for empowering Makers of all types to create, interact, and inspire like never before. The Sprout promises to amplify our creative power in a way that no previous computer has, and in upcoming issues, we'll be exploring more ways it can help you in your projects.

INNOVATED IN CHINA

Written by Gareth Branwyn ■ Photographed by Dale Dougherty ■ Illustrated by Huan Liu

A MAKER'S INTRODUCTION TO SHENZHEN

TIP:
Trust, relationship, and communication are everything in China. Find suppliers, manufacturers, and support services that you like and stick with them. Once trust is built, these business associates will work with you, be flexible on pricing, give you samples, and more.

TIP:
Smile. A lot. And be kind and respectful. It will carry you far in China.
—Bunnie Huang

TIP:
Don't buy and prep your own food. It's easier and cheaper to just eat out.
—Lisa Fetterman

THE CHINESE HAVE A SAYING: "IT DOESN'T MATTER IF THE CAT IS BLACK OR WHITE AS LONG AS IT CAN CATCH MICE." While often attributed to the late Chinese leader and architect of economic reform, Deng Xiaoping, it is older. But it is fitting that people attribute it to Xiaoping because it was his push for a more pragmatic, results-based approach to economics and politics that gave birth to the mutant urban marvel that is Shenzhen, a southern Chinese city that's become not only a global mass market electronics manufacturing juggernaut, but also a place where tiny startups flock to incubate their products and get them to market as quickly and inexpensively as possible.

"The world's tech incubator," "Silicon Valley for hardware," "the electronics capital of the world," "mecca for makers," "'easy' China," "a sprawling electronics ecosystem," and "the Digi-Key catalog meets *Blade Runner*" — these are just some of the ways that Shenzhen has been characterized. If you've spent any time in maker circles, you've undoubtedly heard of Shenzhen and how it's apparently some sort of Shangri-La for hardware startups. So what actually makes it such a unique and valuable location, prone to such breathless labels?

Shenzhen is a relatively new Chinese city purpose-built to cater to electronics manufacturing. If you're serious about taking any type of consumer electronics product to market — robots, microcontroller-based projects, mobile phones, laptops, internet appliances, 3D printers, etc. — there is only one city where you need to be, and that's Shenzhen.

Thirty years ago, Shenzhen was a relatively small fishing village and border town. But then it was designated as the first of China's Special Economic Zones, a "reform and opening" policy that prescribed little interference from the communist government, allowing Shenzhen to practice market capitalism "guided by the ideals of Chinese socialism." Over the decades, this experiment in special economics has allowed Xiaoping's pragmatic cats to take up residence there. And they've bred. The result is a booming, modern south China city unlike any other — an international port, a marketplace and manufacturing center targeted at the electronics industry, and increasingly, a magnet for makers, innovators, and startups. Shenzhen's proximity to Hong Kong (a major source of the city's investment capital), right across the Shenzhen River, also make it an ideal location for making things happen.

GARETH BRANWYN is a freelance writer and the former Editorial Director of Maker Media. He is the author or editor of over a dozen books on technology, DIY, and geek culture. He is currently a contributor for Boing Boing and WINK Books. And he has a new best-of writing collection and "lazy man's memoir," called *Borg Like Me*.


生产力
EXPORT

Shenzhen for Noobs

Shenzhen is in the Pearl River Delta of Guangdong province (the old Canton region), just north of Hong Kong across the Sham Chun River (aka the Shenzhen River). Thirty years ago, Shenzhen was a little fishing village and border town with some 300,000 people. Today, it has an ever-growing population of 15 million.

Shenzhen is mainland China's southern financial center, and is home to the Shenzhen Stock Exchange.

Because Shenzhen is a Special Economic Zone, it has been granted provincial-level economic administration status and is allowed to practice market capitalism with a relaxing of the rules and regulations that exist outside the zone.

There are a total of 17 ports, the most of any city in mainland China. The turnover rate of containers in Shenzhen's ports is the fourth highest in the world.

Shenzhen is a multilingual city. Cantonese is the original language of the area, but Mandarin (the lingua franca of China) has become dominant over the last 30 years. There are also a number of local indigenous languages that are still spoken, mainly by senior citizens.

Shenzhen's climate is humid, subtropical with mild winters. Frost is rare.

Shenzhen is an industrial town. People come from all over China to work there, and bring their regional cuisines with them, so the city is an amazing opportunity to sample the country's diverse foods.

Postal code: 518000

Area code: 755

Time zone: China Standard (UTC +8)

The currency is the yuan renminbi (abbrev: RMB), called the "people's money."

When opening a bank account, don't say "open" — the concept is meaningless. Say "new" account.

Over 35 years ago, Shenzhen was a fishing village. Now it's the top manufacturing center for high-tech products.

Multistory electronics stores in Huaqiangbei have everything.

Bunnie Huang on a walking tour of the electronics market, Huaqiangbei.

Rows of pick-and-place machines in a Shenzhen factory.

TIP: Quality, schedule, price: pick two. *—Liam Casey, CEO of PCH*

TIP: Since Huaqiangbei is right there, you don't have to rely on your manufacturer for parts; go to the market and see for yourself if you can get better prices.

TIP: Create a chart with your bill of materials, listing each component with the price from Digi-Key (or another U.S. supplier), the manufacturer-direct price, and the upper limit of what you expect to pay in the market. Frequently, in Huaqiangbei, you'll only end up paying a tenth of your limit. *—Bunnie Huang*

At nearly 800 square miles, Shenzhen is more than double the geographic size of New York City. That real estate hosts a sprawling ecosystem that has grown up to support the city's electronics industry. At the heart of this ecosystem beats the world-renowned Huaqiangbei electronics marketplace, a hacker's wonderplanet where you can buy just about any type of electronic component, tool, or equipment that you desire, in any size lot, at wholesale prices. Got a bill of materials for your product with prices spec'd from U.S. factories or suppliers? Chris Wang, (aka Akiba), founder of Freaklabs, which makes Freakduino boards, says if you take that BOM to Huaqiangbei and spend a day in the market, you will likely cut that bill by half or more. The close proximity to the supply chain and component marketplace, manufacturing facilities, plentiful and fast international shipping, and the willingness of all of these concerns to cater to small startups, has proven an irresistible cocktail for professional makers.

So, how do you get started exploring manufacturing opportunities in Shenzhen? "You buy a ticket," says Bunnie Huang, matter-of-factly. Huang, the engineer and maker's maker behind such products as the open-source laptop Novena and Chumby, the enigmatic internet appliance, has been helping others break into business with Shenzhen for years. "So, you go and you look around," he says. "And you look around some more. You make calls, establish connections. You take like a week, and essentially, you speed date the factories of Shenzhen. Going to the factories gives you a good sense of what's going on, the conditions there, the media that you have to work with, the manufacturing processes." He adds: "It also gives you new ideas. You see things you didn't know were possible in the manufacturing process and that gives you ideas for what you can do with your product that you hadn't considered before."

It might be tempting to work long-distance with the factories in Shenzhen, rather than traveling there in real life. But if you're undertaking a serious endeavor and you're looking to make mission-critical parts, you have to visit to really know the situation at your suppliers, to establish relationships with factory owners and staff, and to get a sense of their quality control standards. (If you can't make the trip, you may be better off working with local manufacturers.) "It's not about 'outsourcing,'" says Huang, dismissively. "I hate that word — like you're just going to ship CAD files to China and magic elves are going to make Christmas happen for you. You're really building a relationship," he says, "A partnership." And that relationship needs to be built in person.

Doing business in China, or, God forbid, moving to China to be closer to your factories and suppliers (which many of the people we talked to ended up doing) can open makers to severe criticism. Makers inevitably get asked pointed questions about taking work out of the U.S., and about labor and environmental concerns. "I get asked why I don't promote 'Made in the USA' a lot," says Akiba. "I think that corporate America created this problem about two decades ago when 'management gurus' and *Harvard Business Review* writers started telling companies to focus on their core competencies and outsource everything else to low-wage countries like China. One thing those managers didn't understand was that the employees in their companies, with a detailed understanding of their manufacturing process and its quirks, were some of their core competencies. It's sad that most corporations in the U.S. — especially in the Bay Area — gave all of that up, and in the process, depleted the manufacturing ecosystem there, as suppliers, equipment makers, and the like either disappeared or moved to where that manufacturing was still happening."

Huang also emphasizes the often-overlooked importance of this support infrastructure that surrounds any world manufacturing center. "Manufacturing implies an entire ecosystem of suppliers, repair technicians, jobbers, shipping and delivery services, etc.," he says. To illustrate what makes Shenzhen so unique, he shared a story at the 2013 Shanghai Maker Carnival: "I'm in my apartment, in Huaqiangbei, and I get a call early in the morning. My factory is short of transistors. So I get up, walk downstairs, buy 3,000 transistors on the street, walk over to the factory, thread it into the reel on the line, and two hours later, the line's up and running again." In another city or situation, he says, your factory would be down for maybe 24 hours. Those 24-hour delays begin to mount and seriously slow delivery of your product.

TIP:
Negotiate in the marketplace using a calculator. You can use it to convert RMB to dollars (divide by 8), but also to communicate price or desired quantities.

TIP:
To climb over the Great Firewall of China, get a subscription to a VPN (virtual private network).
—Lisa Fetterman

Matt Mets, former MakerBot engineer and *Make:* blogger who now lives in Shenzhen and runs Blinkinlabs, offers a colorful analogy that also speaks to Shenzhen's unique ecosystem: "All of the things we're building are super-small compared to what the giant companies are making, so we're sort of clinging to the fur of a much larger animal that is big manufacturing, and that animal lives in southern China."

Labor practices are still a concern, but makers from Shenzhen pointed out that things are different there than they are in other parts of China. Wages are much higher in general, doubling in the last few years. The labor market in Shenzhen has become competitive as a result, and that gives workers leverage in insisting on better meals, better dormitories, and better working conditions. If they don't get these things, they leave for other companies offering them.

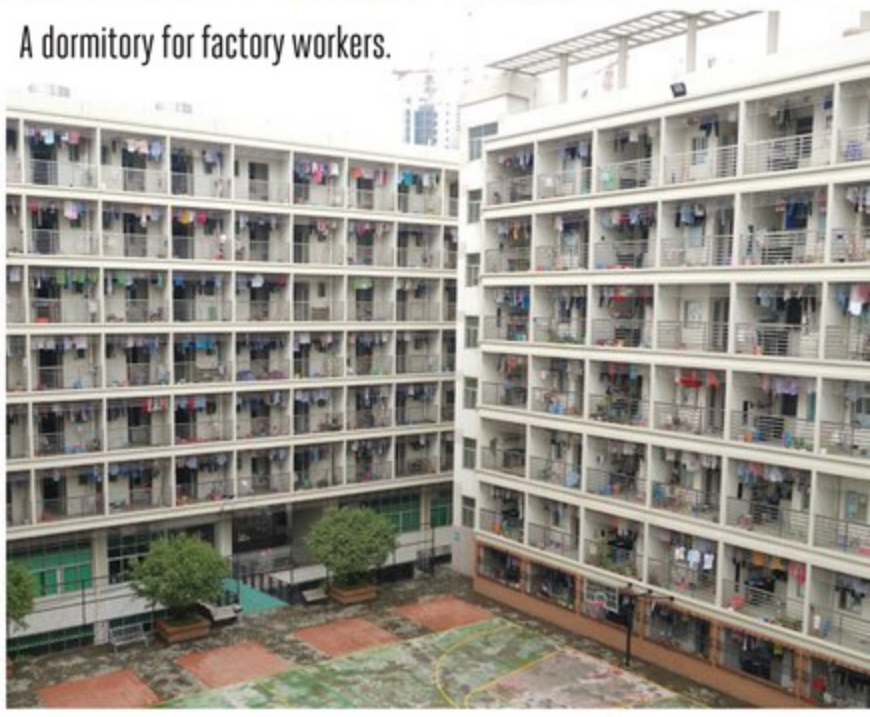
If you travel to Shenzhen to establish your relationships with suppliers and manufacturers, you can visit the factories and see conditions for yourself. While Shenzhen is home to electro-giants like Foxconn — mainly known for being the birthplace of your iPhone and for widely reported ill treatment of workers — you'll want to work with smaller factories. In scoping out factories, Huang offers a great rule of thumb: "If you go to a factory and you can't meet and have

Shenzhen at Home

Seeed Studio, an established "hardware innovation platform" has opened up a U.S. branch to bring Shenzhen a little closer to the States. The San Leandro, California, center will help makers manufacture small-batch electronics without having to go to Shenzhen.

Meanwhile, custom-manufacturing firm PCH has introduced Highway1, a hardware startup accelerator designed to connect entrepreneurs with the Shenzhen supply chain.

Between these two – and more that we'll see in the future – there are increasing options for makers who want Shenzhen-style manufacturing at home.



A dormitory for factory workers.

Six Things I've Learned
— Liam Casey, founder and CEO of PCH

1. Talk to lots of people
2. Visit factories
3. Don't learn Chinese
4. Know what you want
5. Focus on execution and delivery
6. Time is your number one currency

Hong Kong is adjacent to Shenzhen in the Pearl River Delta.

More Resources for the Shenzhen-Bound

There are many services, programs, and resources available to makers who want to gain a foothold in Shenzhen. Here are a few key examples:

HaxIr8r

haxlr8r.com

Our friends at Haxlr8r run a 111-day accelerator program for startups looking to take their hardware projects to market. Some fine companies have come through this program, including Blinkinlabs, Nomiku, Spark, and Makeblock.

Hacker Camp Shenzhen

dangerousprototypes.com/hackercampshenzhen

The open-source hardware company Dangerous Prototypes runs 3- to 5-day boot camps in Shenzhen to get maker pros quickly up to speed. The next camp will be June 16-18, leading up to Maker Faire Shenzhen. To view one of these camps in action, search "Hacker Camp Shenzhen" on YouTube.

Seeed Studio

seeedstudio.com

Seeed is a service provider assisting makers in bringing products to market. They provide prototyping and in-house engineering services, maker-friendly supply chain, and a marketplace for maker-made goods. They also have an excellent Shenzhen Map for Makers that you can download at seeedstudio.com/blog/2013/09/03/shenzhen-map-for-makers.

Factory for All

factoryforall.com

An engineering service bureau in Shenzhen, Factory for All provides part sourcing, PCB manufacturing and assembly, kit assembly, laser cutting, and engineering services.

dinner with the boss, that factory is too big for you. You want a company that has that level of access and personability. You want to be able to talk to the boss, explain your agenda, look around, sit in the tooling shop. You want them to believe in you (and you in them), as a partnership, as a co-investor."

Several maker pros living in Shenzhen said that, while environmental issues are still a major concern, there are hopeful signs there, too — at least in Shenzhen. The government-controlled *South China Post* is now talking openly, and often, about heavy metals in the food supply (a significant issue with the massive-scale rare earths processing happening in China). For the government to implicitly acknowledge the problem via the state-run news is usually a sign that it's being taken seriously and will be officially addressed. Huang says that many of the factories he works with are committed to being "green," and emphasize energy savings and recycling. And because Shenzhen has become something of a model for other Special Economic Zones (there are now six), and thanks to its international high profile, it's in China's best interests to keep the labor and environmental concerns of the city in check.

So, what's it actually like to take up residence in Shenzhen? Ian Lesnet from Dangerous Prototypes, who also runs Hacker Camp Shenzhen, paints a very enticing picture. "It's a very young, vibrant city," he says. "There are many outdoor barbecue places, street food, markets, and an active street life. People are super friendly, like the way everyone tells you when they go somewhere new, except here, it's for real. Walking down the street, people yell 'Hello, how are you?' in their best English, and I give my best *'Hen hao! Ni ne?'* in return. Most shops stay open until midnight. Clubs and street barbecue go all night. You can kick back at a barbecue joint and play Liar's Dice with the locals, many of whom are part of the supply chain that feeds Huaqiangbei."

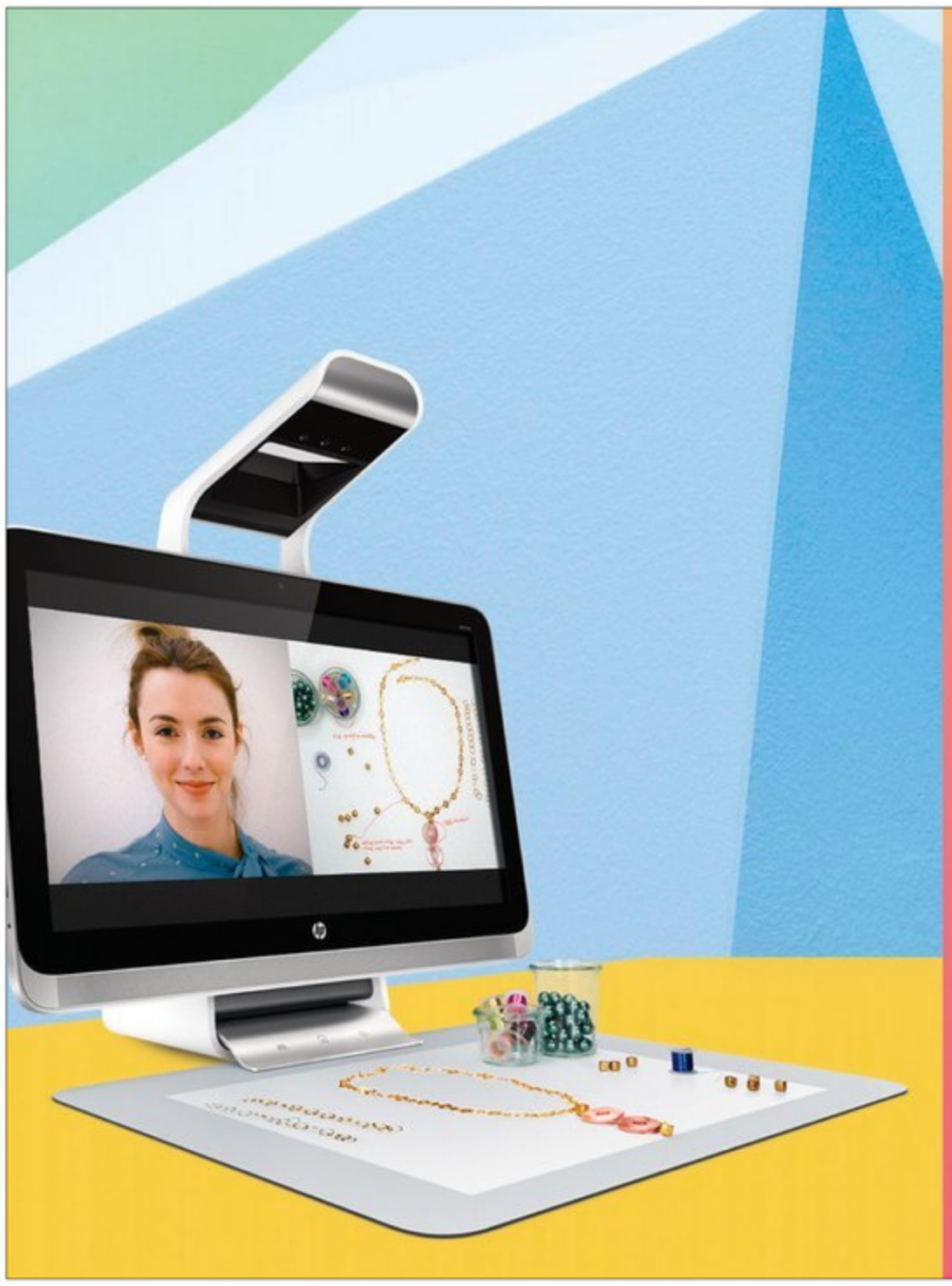
TIP:
Fapiao are like Chinese receipts on steroids. Part contract, invoice, tax receipt, and even scratch-off lotto card, they are important to Chinese citizens. Sometimes offering to give your fapiao back will get you a discount (*dazhe*) on food and other goods.

TIP:
Don't stay at Western hotels. Look for apartment hotels. They are cheap, convenient, and cleaner than a hostel.
—Lisa Fetterman

Lesnet started out commuting from Amsterdam every month, spending a week in China at a time, but after staying there for three weeks in a row, 10 minutes from the Huaqiangbei markets, he was hooked. Now he has an apartment in Shenzhen and spends most of his time there. But he's quick to point out, there's no path to permanent residency or Chinese citizenship.

"Shenzhen is a place to be right now," Lesnet says. "We're here while it's all happening, while it matters. It's not a fading star trying to win back its luster. It's not a city trying to break through to 'be something.' Shenzhen *is* that place right now. It won't be forever, but for the moment, it is."

To get an idea of what maker culture has to offer in Shenzhen, there's probably no better place than their Maker Faire. This year, the dates are June 19–21. makerfaireshenzhen.com



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THE NEW TECH TIMES

HOW MAKERS AT *THE NEW YORK TIMES* ARE INVENTING THE FUTURE OF MEDIA

Written by Bryan Lufkin

Noah Feehan meets with Alexis Lloyd (left) and Jane Friedhoff around *The New York Times*' Listening Table.

NOAH FEEHAN IS IN AN OFFICE WORKROOM THAT'S STREWN WITH SCREWDRIVERS, A DIGITAL OSCILLOSCOPE, AND FUME EXTRACTORS. On a desk sits a half-finished circuit printer, filled with cartridges of silver nanoparticle ink and ascorbic acid. It prints circuits on paper. Feehan and his co-workers have been floating in and out of the room to work on it.

"I like to organize by project," he says, gesturing to boxes filled with wires and scrap materials. Of the half-finished circuit printer: "I'd love to print an eight-and-a-half by eleven RF-harvesting antenna. Might be a good opportunity to experiment with algorithmic design."

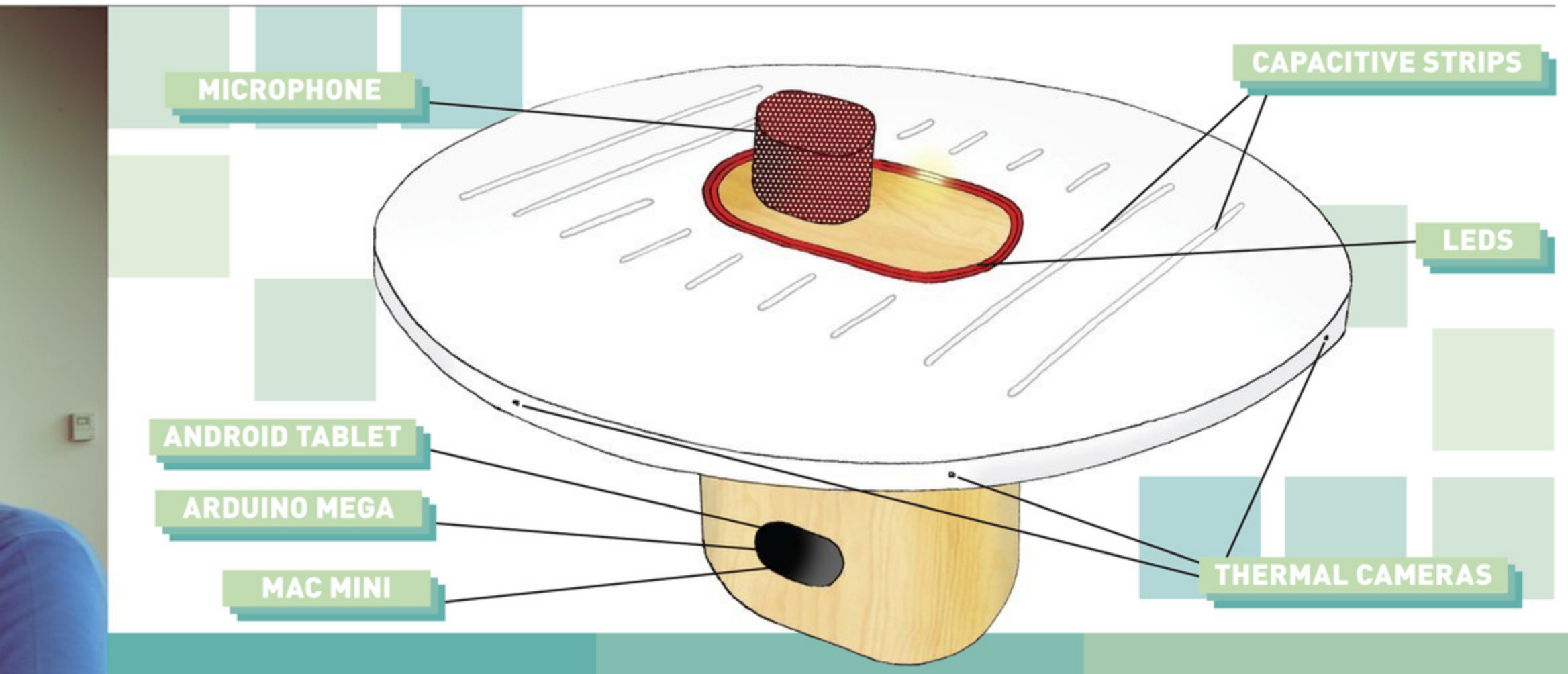
Feehan and his co-workers don't work at a hardware store, electronics workshop, or tech startup. They're standing on the 28th floor of 620 Eighth Avenue in Manhattan — the office of *The New York Times*.

Feehan — whose official, LinkedIn-approved, resume-topping title is *Maker* — isn't the only tinkerer who works at the 163-year-old newspaper. Seven other makers populate the *Times'* R&D Lab, which launched in 2006.

Their mission: to forecast game-changing technology trends that will unfold in the next three to five years. They then build prototypes to envision how these ideas will impact media's future — and how these ideas upend our notion of the communicated word. How will content be delivered? What sort of devices will bridge information and audience? How will platforms change? The idea is not so much to create products based on these questions, but to discover what creative director Alexis Lloyd describes as "tangible artifacts of potential futures that have relevance to the *Times*."

The lab is full of builders, coders, fixers, and the various things they've cooked up. "We all come from very different backgrounds, from video art to statistics," says Lloyd. "We all have a background that sits at the intersection of art or design, technology, and critical theory."

Their latest invention, which they finished last September, is



a 4-foot-wide table, dotted with 14 capacitive strips, that sits in the middle of the lab, surrounded by stools. This is the "Listening Table": part transcriptionist, part smart furniture, and part, well, table.

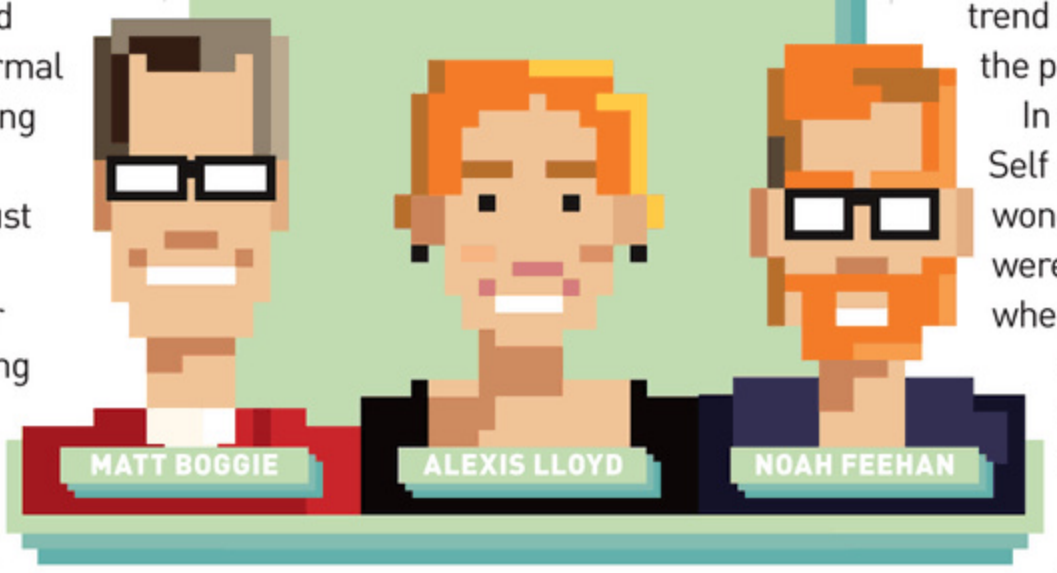
This puppy transcribes, in real time, what people say in meetings, using Android speech recognition. In the middle of the table is a microphone that captures every idea, pitch, suggestion, disagreement, digression, jabber, and joke. Around the edge are eight single-pixel thermal cameras that figure out who's talking or gesticulating.

But the table's a lot more than just a note-taker. On a flat-screen TV a couple feet away, the words appear on the screen nearly as they're being spoken. Each word is a varying shade: Lighter, grayer words are deemed less relevant (*the*, *a*, and other articles), while key topics are solid black.

And if you touch one of those capacitive strips on the table, the system recognizes the 30 seconds prior to the tap and the 30 seconds after to be key moments in the meeting, highlighting those important chunks of the transcript. The Listening Table is not just recording what's being said — it's recording why it's being said, and what's important about it.

The table was actually designed and built by François Chambard, a seasoned maker

THEIR MISSION: TO FORECAST GAME-CHANGING TECHNOLOGY TRENDS THAT WILL UNFOLD IN THE NEXT THREE TO FIVE YEARS.



the *Times* contracted for the job. (He's also known for creating keyboard stands for Wilco.) Chambard describes the proposed timeline as "aggressive": two months. On one hand, the project seems like a cinch — "It's a table," he says — but the challenge was making sure the seven hidden layers meshed perfectly together, to eliminate any looseness or gaps.

The surface is white Corian, like you see on countertops, and the base is custom bent-laminated and veneered plywood, with the central microphone sitting atop it, underneath a perforated cage. Inside the base is an Arduino Mega with a custom board, a Mac Mini that runs the server and an Android tablet that communicates with it, and some simple cabling.

In the same room with the table, video monitors display the R&D Lab's other projects. The table is just the latest effort in what the lab calls "semantic listening," a trend that they've been working on for the past several years.

In the footsteps of the Quantified Self movement, the team started wondering what quantifiable values were slipping under the radar. That's when they realized values that can be *qualified*, like meaning and context, needed to be examined, too.

Sure, your footsteps and budget can be tallied up — but what about those thoughts and feelings that were running through your head? How could the lab build a means to interact with that data?

So they made the table, to monitor not only *how much* data passes through an environment like an office or a meeting, but *why* that information is important. The table addresses how people, whether consumers or publishers, can answer those questions in a physical, tangible, touchable way. (And you can still scribble notes or plop your

coffee cup on it too.)

Surrounding the table is an arsenal of the lab's other projects, all designed to explore the way media will be delivered and consumed in the short- to medium-term.

One nearby monitor shows news articles annotated in real time with tags from a *New York Times* database, generated not just from article topics, but on the level of words and phrases. These words or key points are identified and then could be used as bullet points on a mobile app, or an interactive map can be built based on locations mentioned in the story. A particular location could even be contextualized on a wearable device. (The database of important words is manually compiled, continually, by *Times* librarians and word taxonomists.)

Back in 2011, the lab brewed up a different table-focused technology that used Microsoft's Surface interface, a touchable tablet and interactive bulletin board. On the lab's prototype, users can flick, twist, and drag photos (which open news stories) across the table and organize them into stacks. Tables, by nature, promote sharing, as colleagues can gather around a table over coffee. If a user places his or her cellphone on the surface, this table can automatically conjure articles that his or her friends have shared.

This stuff isn't actually used in the *Times* newsroom. There aren't any board meetings held around the Listening Table. But that's not the point. The point is to help the *Times* think about how emerging technologies will affect the industry. And makers are helping the centuries-old newspaper company do this.

"Having something tangible to stimulate ideas and conversation from is really useful. For us as designers and makers, in our research process, there's a lot of information and knowledge that we get from reading about topics, from thinking about them, from having larger discussions about them," Lloyd says. "But there's a whole different set of knowledge that you get from having to build a thing, and having to figure out what that button does." (The table aside, most stuff gets built in-house in the lab.)

> THE LISTENING TABLE IS NOT JUST RECORDING WHAT'S BEING SAID – IT'S RECORDING WHY IT'S BEING SAID, AND WHAT'S IMPORTANT ABOUT IT.

As the lab forecasts tech trends of the not-too-distant future, the team also considers the threats posed by information-slurping furniture.

"These are technologies that could pretty clearly be used for surveillance or nefarious purposes," says Lloyd. "One of our research goals is to develop a set of design principles: How can we allow for transparency, so I can have a sense of control over my participation with the system?" Knowing what kind of data is being collected, when it's being collected, and the ability to opt out, are key — thus, the moving lights on the table, which indicate whether it's listening.

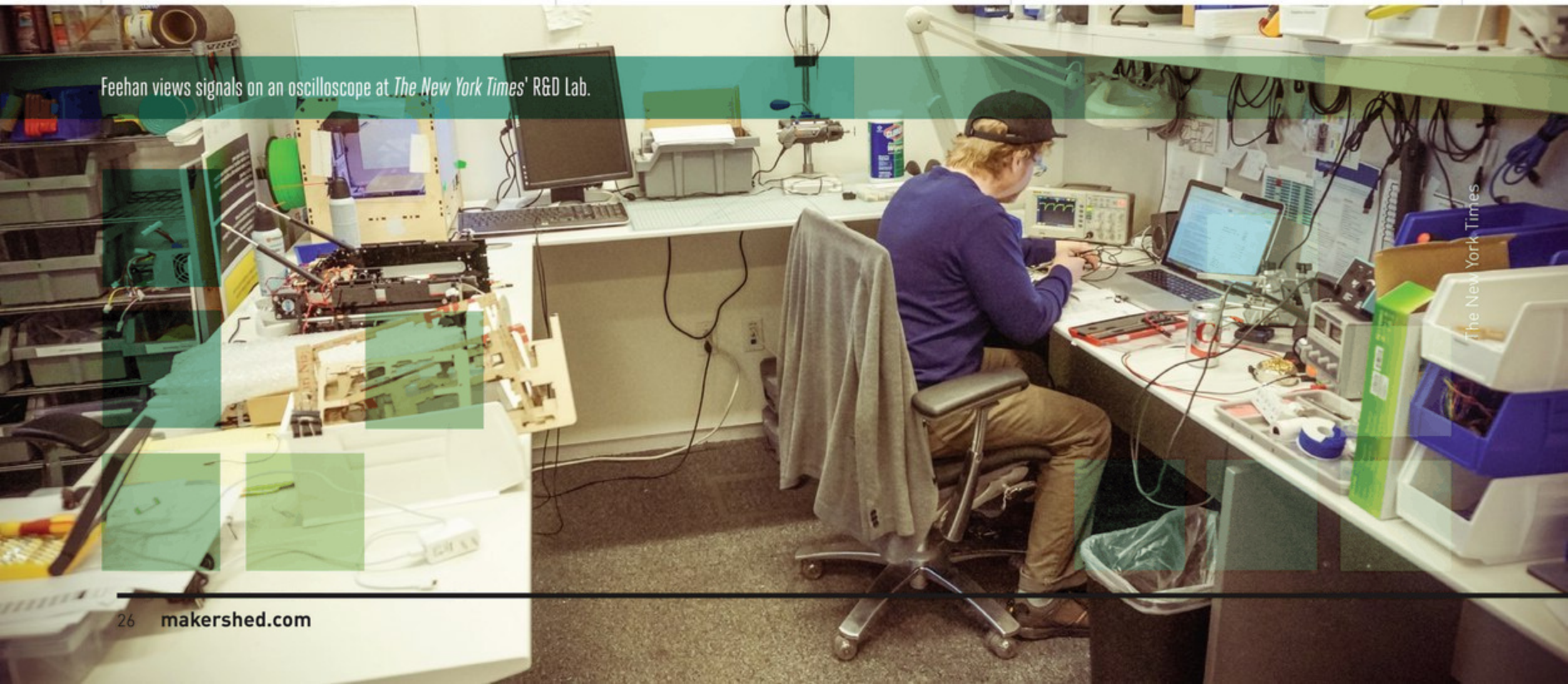
"One of the most valuable things we do is to be able to have a deep understanding of an emerging technology and a tangible interface or artifact that can stimulate a conversation within the organization about what we might see happening three to five years out," says Lloyd.

Matt Boggie is the lab's executive director. (He's also been tinkering with that circuit printer from before.) "We think about how you read an article, or how you watch a video, or how we report on news — and how that finds its way into other experiences." That's what the lab is all about, and why stuff like the Listening Table is a big deal.

But at the end of the day, the lab is really a roomful of scrappy, smart people who love to get their hands dirty.

"I've been doing a lot of strategy work for next year, which has been a lot of writing and a lot of PowerPoint," Boggie says. "And I come in here and start to screw things together or test some circuits."

"I'll get to a point around three in the afternoon when I'm like, 'I need to do something with my hands.'"



Feehan views signals on an oscilloscope at *The New York Times*' R&D Lab.

The New York Times

Drawn to It

3Doodler co-founder Max Bogue talks printing pens

Maker Pro Q&A

Written by DC Denison

A CROWDFUNDING CAMPAIGN IN EARLY 2013 FOR THE WORLD'S FIRST 3D PRINTING PEN RAISED $2.3 MILLION ON KICKSTARTER. More than 130,000 units of the 3Doodler have been sold. Earlier this year, a second campaign for a new, improved, slimmer 2.0 version, raised $1.5 million. We connect with 3Doodler co-founder Max Bogue to hear about his experiences.

You've created more than a dozen toys, but 3Doodler is the first one to really take off. Is everyone is a doodler?
Everyone is a maker. As a species, we make things. We started out making spears and bows and arrows. There's something internally that drives us to make and develop and to fix and to solve things.

3Doodler sparks imagination. It eliminates the barrier of software and hardware. What you have in your mind, you can physically create. And everyone has their own style, like everyone has their own handwriting.

3Doodler was invented in Artisan's Asylum, a makerspace in Massachusetts. How did that influence its creation?
It gave us a lot more freedom. We had people around that we could ask questions. At one point, we had a simple technical problem. Half a dozen people there could look at our circuit diagram and say, you need a 5K instead of a 10K resistor. Everyone has that creative spirit. It led to a better product from day one.

What's the most unexpected thing that people have done with 3Doodler?
The number one thing was how the visually impaired/low vision community used it. They wanted to write braille with it and to do raised line graphing for math class. Our initial response was, you can't do that — it's not accurate enough. They proved us completely wrong. That was powerful. It's not just some crazy cool piece of tech, it's transformative in someone's life.

Artists have really embraced it. There's lots of 3Doodled art on Etsy, for example.
Yes, we weren't expecting that. But I've discovered its appeal in my own projects. I get into detail that I never thought I'd do before. I downloaded the Brooklyn Bridge plan and 3Doodled it for a Museum of Modern Art window. Now I have such a new understanding of how the bridge works. The same goes for a suit jacket I made. I went to a tailor and I got the patterns for a suit jacket, doodled on top of the pattern and then peeled it off the paper, and joined the pieces together. I now know more about how suit jackets are constructed than I ever wanted to. It gives you a crazy, intimate understanding of how things are made.

How long before there was a Chinese knockoff of the 3Doodler?
[laughing] Maybe six months. We're aware of them — it's always the way with any successful product that there will be copycats. Imitation is the sincerest form of flattery.

Do you have an anti-knockoff strategy?
We have a certain amount of intellectual property protection, but I believe in our community, and we believe in innovating. One of the things we have is the ability to innovate. You have to keep continually innovating. Our new version 2.0 is an amazing example of that.

What's your advice to makers who would like to go pro?
My main piece of advice is to work for a company that makes products that reach the market. Learn from them.

It's one thing to make a prototype, and another thing to bring the prototype to market. Making a prototype is the first 5–10% of it; the next 90–95% of it is a whole other world. Having a great idea is the start. Being able to execute the idea — that's probably one of the hardest parts. A lot of people get caught up in the initial concept, which is wonderful. But once they've run a successful campaign, they get bogged down in the manufacturing. It's really important to understand the entire process.

Max Bogue

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DC DENISON is the editor of the *Maker Pro Newsletter*, which covers the intersection of makers and business, and the former technology editor of *The Boston Globe*.

SPECIAL SECTION

makezine.com/robot-workshop

ROBOT WORKSHOP

Now more than ever, it's the era of DIY humanoid robotics. Humanoids have long been the intricate and expensive domain of well-funded research labs, marching onto stages to demonstrate corporate and institutional engineering prowess. While the desire to build man-mimicking replicas is steeped in history, these advanced machines only started taking actual, functional form in the 1970s; the most famous of these, Honda's ASIMO, launched just 15 years ago.

Fast-forward to 2015. Rising to the complex challenge of combining mechanics, electronics, and software, robotics hobbyists have made enormous progress in their basements and garages, and we're now seeing impressive community-driven humanoid bots that come at a fraction of the price of their professional cousins.

In the next few pages we'll dive into how makers worldwide are contributing to the advancement of one such project, InMoov, that combines 3D-printable parts, common electronic components, and open-source plans into a show-stopping creation that responds to vocal commands with speech and movement. We'll also show you how to make an autonomously navigating, self-balancing robot; a tensegrity vibrobot that introduces the concepts of cutting-edge robotics research; and a wonderfully simple "jamming" gripper that eliminates many of the shortcomings of mechanical hands.

Oh yeah, and combat bots — they're back, and we're thrilled.

Photo by Hep Svadja, *Atlas* the robot sculpture by Brett Mich

ATLAS THE ROBOT

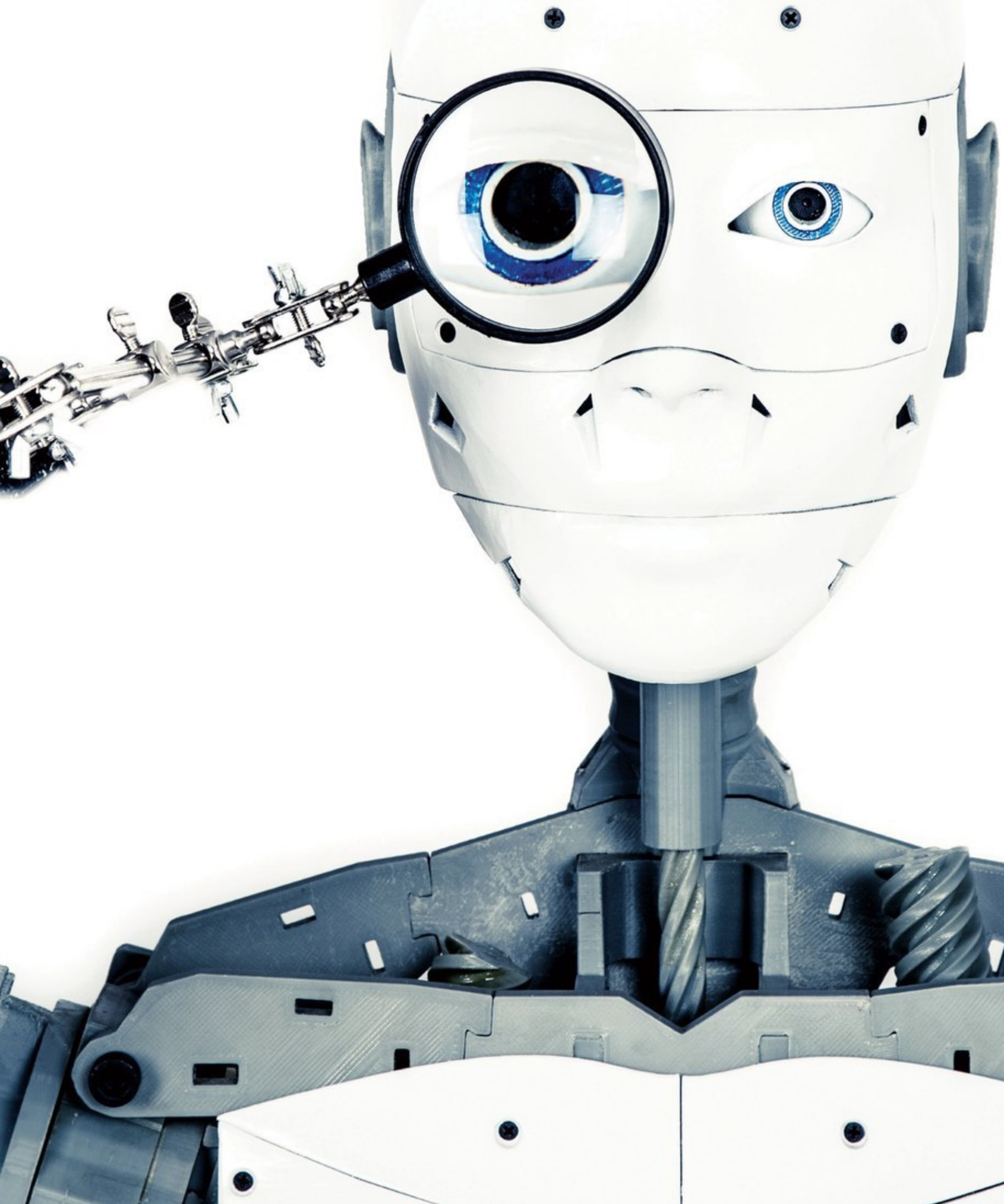
Atlas was created by Brett Mich, who uses hand-painted detailing to give his robot sculptures a unique futuristic flair. Mich grew up watching the creatures and robots in movies like *Star Wars*, *The Dark Crystal* and *Tron*, and was inspired to pursue a career where he could create and design his own. He attended the Milwaukee Institute of Art and Design and has started several companies, the latest being R2Deco, an Etsy shop that sells his custom robots. He is currently a toy inventor in Chicago by day, and R2Deco's robot designer by night.

IN OUR IMAGE

WRITTEN BY GEETA DAYAL

How an open-source, 3D-printed humanoid robot was born

GEETA DAYAL is an arts and technology journalist in San Francisco. She is the author of *Another Green World*, a book on Brian Eno.



THERE'S A HIGH BAR FOR HUMANOID ROBOTS. WE EXPECT THEM TO BE, WELL, human — or at least to live up to ideas we see in movies and pop culture. We want more than a toy. It's got to be a life-sized, high-powered machine with the capability to move, track faces, speak, and recognize voices. And one French tinkerer is working on exactly that: a life-size, open-source humanoid animatronic robot called InMoov.

InMoov is designed to be feasible for everyone. Depending where you source the parts, it can be built by anyone with a 3D printer for under $1,000. It uses common components, including inexpensive servos and sensors, and runs on freely available software. At Maker Faires for the past three years, we've watched the concept take shape, to what is now nearly the full form of your own personal droid.

Gael Langevin, the brains behind the ambitious project, started InMoov in 2012. The learning curve was steep — Langevin is mostly self-taught — and there's still a lot to do. But InMoov has already succeeded beyond Langevin's wildest expectations, capturing the imaginations of thousands across the globe.

InMoov's humanoid characteristics look impressively polished and realistic, not unlike the title characters from the movie *I, Robot*. The high production values make sense; Langevin spent 25 years working on set design and sculpture for commercial projects for some of Europe's biggest brands.

The concept for InMoov began when a French auto company approached Langevin, asking him to make a futuristic-looking prosthetic hand. Langevin designed the hand, printed it on his home 3D printer, and uploaded the parts to Thingiverse so that anyone could reproduce it. People did, and almost instantly the community formed. Spurred by his success with the hand, Langevin began to build a whole humanoid robot from scratch.

Langevin is passionate about keeping the project and his tools open source. He uses Linux and Blender software. He wants to give back to the community, he says, because he learned so much from the internet. "When I printed the first hand, I didn't even know Arduino at the time, and I didn't know how to use the servo," he says. "On the Arduino website, you see a little video ... you have all this info you can learn." Programming the robot, he says, was mostly trial and error. "I change the numbers, see what happens. If it works, that's great. If not, I change another line," he says. "I'm working on so many different levels — 3D printing, robotics, programming, and vision tracking — that I cannot learn everything deeply enough."

Langevin has designed a finger starter kit to provide an introduction for newbies. "You can fit in the Arduino with a servomotor, and once you know how to program the Arduino and the servo you can actuate the finger, and once you know how to build the finger you can build the hand and so on," he says. InMoov, he emphasizes, is not just a robot for engineers and roboticists. "It doesn't have to be that. It can just be a father with children doing it on Sunday — that's what I like about it. People are learning how to do it by themselves."

> "That's what I like about it. People are learning how to do it by themselves."

The InMoov parts were designed to be printed on consumer-grade 3D printers. "I'm trying to make parts that are not too complex to print," Langevin says. "I think it's an interesting challenge to take into consideration ... I'm used to working with companies in France that use professional 3D printers. They are very accurate machines, but I think it's more fun to print with a home printer. It's more DIY, and if it doesn't fit well you can still adjust the things."

"3D printing is now taking off in robotics," says Jacky Baltes, a computer science professor at the University of Manitoba who founded the HuRo Cup, a humanoid robotics competition. HuRo Cup has several teams that use 3D-printed parts, says Baltes, as does RoboCup, another international competition. He also points out Darwin, a small-scale 3D-printable humanoid robot that is used in most robot soccer competitions.

If you watch robot soccer, it becomes apparent that locomotion is difficult for a bipedal robot. It's a challenge Langevin is still working on — InMoov has an impressive head, torso, arms, and hands, but no legs as of yet. "It's been already a year and a half that I really wanted to build the legs, but I've slowed down a little bit on that because I worked on the new hands," says Langevin. He spent more than a year redesigning the InMoov hand to be a better fit for the Bionico open prosthetics project, helmed by his friend Nicolas Huchet (see "Helping Hands," *Make:* Volume 43). The electronics are now streamlined and more tightly designed, compacted in the palm of the hand. "That's the way I want the legs," he says.

One of the problems with the leg design is keeping the cost down. "I want them to have motors that can be supplied everywhere in the world that are low cost and fast enough to make the robot stand by itself and walk," Langevin says. "Every time I find a motor, it's expensive, or it doesn't go fast enough, or if it's fast enough then it's very expensive."

"A lot of the costs of the robot are not the mechanics, but the motors and electronics," Baltes concurs. A lot of people, he says, thought they could 3D-print their Darwin for $1,000, "until they realized that each Dynamixel MX-28 servo is $225 and they need 20 of them."

Another obstacle in designing an affordable leg: structural integrity. "You won't be able to print a major structural part with your MakerBot that will withstand the stresses of walking and falling," Baltes says.

One alternative Langevin has explored is to give InMoov wheels instead. He has built feet, but they're an experiment — they won't work with the final design. Ankles, he adds, will be especially important.

When the leg project is done, Langevin plans to make kits —not for profit — so that anyone can build an InMoov. "Not everybody has printers," says Langevin. "If they want just the hand, if they want the head or the torso, they could buy it on the website."

The pace of progress on InMoov continues to accelerate, inspiring makers with its open-source idealism. "By sharing and giving information, it gives a message that we can build things," Langevin says. "We don't have to make money with everything. Maybe being the first 3D-printed robot of humanoid size, it's a message of hope."

Hep Svadja

INMOOV AROUND THE WORLD

WRITTEN BY GEETA DAYAL

From altruistic to entertaining, the community has stepped in with an array of applications

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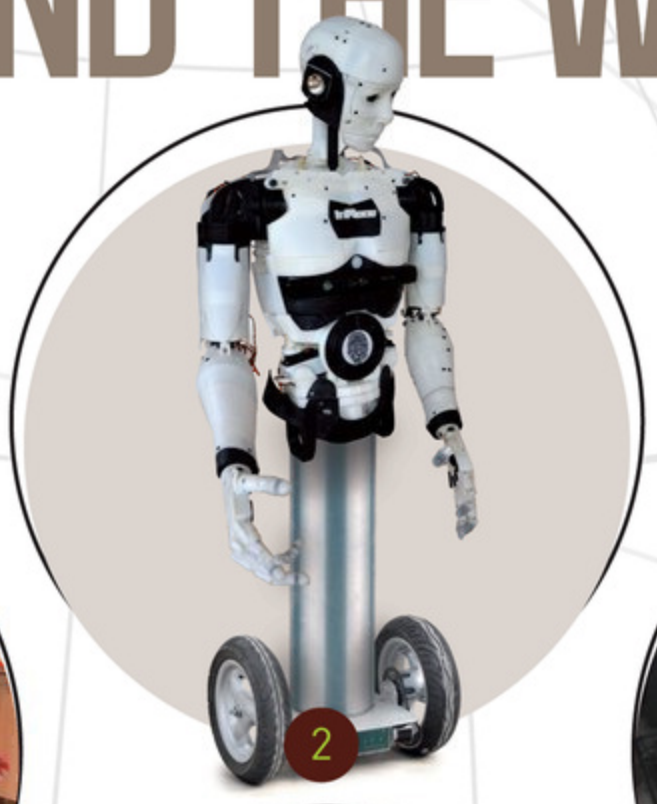
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1. Alessandro Didonna 2. Gael Langevin 3. Leonardo Triassi 4. University of Lincoln
5. Thomas Mortier 6. Bob Houston 7. Richard Ryerson

A GLOBAL COMMUNITY IS CONTRIBUTING EXPERTISE TO THE INMOOV PROJECT. They've created dozens of functioning robots, and many new builds are underway. Here are some interesting concepts from near and far:

1 LEAP MOTION-CONTROLLED INMOOV WITH DIY OCULUS

Rutigliano, Italy

Longtime InMoov supporter Alessandro Didonna has posted videos of himself delicately controlling the angle of the InMoov fingers with his own fingers via a Leap Motion 2 controller.

Didonna, a mechanical engineering student in Italy, also wanted to control InMoov in first-person view. He didn't have enough money to buy an Oculus Rift virtual reality (VR) headset, so he built a DIY version for under $50. "I decided to build one using an FPV monitor, two accelerometer/gyro/compass sensors, Arduino, and one elastic band (arm band) with another accelerometer in it, to move the arm and the head of the robot," Didonna says.

2 ROBOTS FOR GOOD

London, England

The InMoov Explorer, built by Robots for Good, is billed as a telepresence robot that will "allow children to explore the world from their room."

This project makes the InMoov mobile by joining the InMoov torso, head, and hands with Boris Landoni's Open Wheels project, lending the InMoov a set of self-balancing wheels that resemble a Segway. With the help of a VR headset, bedridden kids will be able to navigate and see the world through the robot's eyes.

3 BUILD A DIY SUPERHERO

Palermo, Sicily

Leonardo Triassi printed his InMoov with blue arms, red hands, and contrasting white and red shoulders and torso, giving it a Captain America feel. (He says the colors were chosen to match *Make:*.) Triassi, who runs inspirationrobot.com, used an open-source Java framework called MyRobotLab to give his captain the power to track motion with its eyes and respond to commands.

4 INTERACTING WITH INMOOV

Lincoln, United Kingdom

John Murray, of the University of Lincoln in the U.K., investigates how people interact with humanoid robots. Using the InMoov files, he and his team built a Multi-Actuated Robotic Companion (MARC), which is being tested with autistic children and as a companion for the elderly.

Murray's research could be useful for people who need high levels of care, but it may also teach us about how people form relationships with robots, and the biases we have about them. MARC will be programmed with personality traits and characteristics, but also relies on InMoov's humanoid form to explore those relationships.

5 BIONICO PROSTHETICS RESEARCH

Rennes, France

It was an obvious match to use the 3D-printed open-source InMoov for Bionico, the 3D-printed open-source enhanced myoelectric prosthetics project developed by Nicolas Huchet (see *Make:* Volume 43). Beginning in June 2013, InMoov creator Gael Langevin began redesigning the InMoov hand to better serve prosthetic uses — packing the Arduino, drivers, motors, and board into the palm — and gave the first printed hand to Huchet.

6 COUNTING ON ITS FINGERS

Grand Prairie, Alberta

Bob Houston made an InMoov that can count on its fingers and do simple math problems, controlled with EZ Robot controllers and software. To get the InMoov counting, Houston wrote a simple program that positions each finger in time with the sound of the robot counting. "I also like to add a little humor in my scripts — it gives the robot a more human characteristic," he says. When you compliment the robot on its skills, it responds with, "Thanks! It's my excellent programming."

7 ROBOT BARTENDER

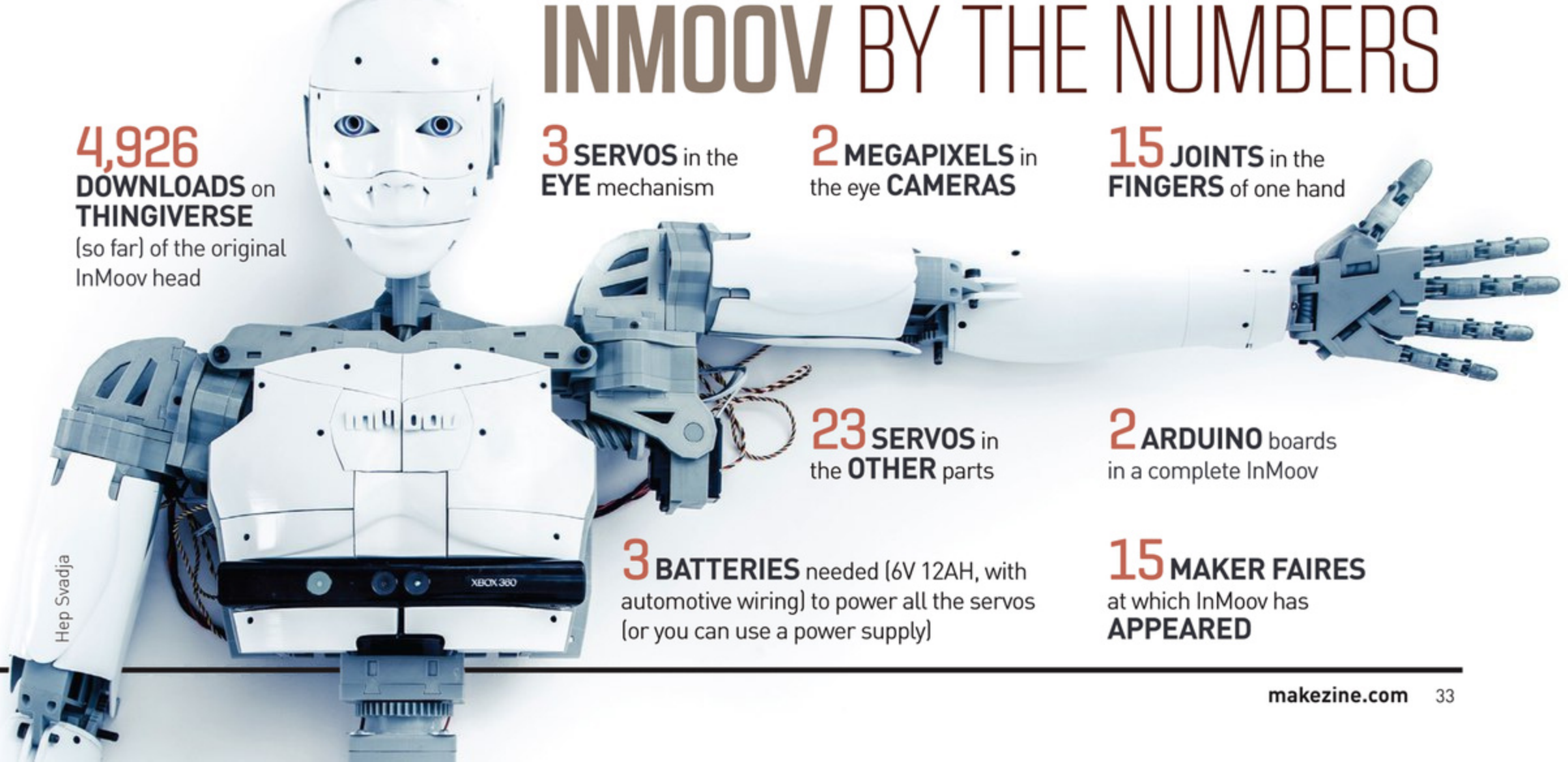
Baden, Ontario

Richard Ryerson spent three months building his own InMoov, then got to work on programming it to be a bartender.

"I saw a picture of [InMoov] holding a glass of water, so I thought if he could hold a glass of water he can pour," Ryerson says. With a few sensors on its face, Ryerson got the robot to move around the kitchen island. It knows the distance around the island, and can sense where there's open space. "He's basically doing what a Roomba does — he follows the wall," Ryerson says.

The robot grips the glass and does a pour routine. "It takes a lot of work, even though it doesn't seem like much," says Ryerson. He programmed human-like gestures, so the robot seems more like an actual bartender instead of fixing a steely stare straight ahead while slinging cocktails.

INMOOV BY THE NUMBERS



Hep Svadja

ARDUROLLER: SELF-BALANCING ROBOT

WRITTEN BY JASON SHORT

Hep Svadja

Build a balance bot with GPS and autopilot, and send it on fully autonomous missions!

JASON SHORT is design director at 3D Robotics and a veteran product designer with 20 years' experience creating consumer products and user experiences for HTC, Samsung, LG, Sony, and others. In 2009 he helped produce ArduPilot, the open-source autopilot for R/C aircraft; in 2010 he created ArduCopter, a multicopter version that's used by drone pilots across the world.

Time Required:
5–10 Hours
Cost:
$400–$500

MATERIALS

- **Autopilot, 3D Robotics APM 2.5 or 2.6** Maker Shed item #MK3DR05, makershed.com
- **Telemetry radios, 3DR Radio 915MHz (2)**
- **GPS module, 3DR uBlox GPS with Compass** To build a non-autonomous R/C bot, delete the telemetry radios and GPS module. If you use APM 2.6 you'll still need the GPS (or a DIY magnetometer from 3DR), as the 2.6 lacks a magnetometer.
- **Gearmotors, 34:1, with 48 CPR rotary encoder (2)** Pololu #2284, pololu.com
- **Wheels (2)** Pololu #1557
- **Arduino Pro Mini 328 microcontroller board, 5V/16MHz** Maker Shed item #MKSF8, or SparkFun #DEV-11113, sparkfun.com. Other Arduino compatibles will work, if they fit in the bot.
- **Ardumoto motor driver shield** SparkFun #RTL-09896
- **Level Translator Breakout board** SparkFun #PCA9306
- **R/C receiver, at least 4-channel** I prefer PPM format because it uses a single cable. I used a FrSky D4R-II, 4-channel 2.4GHz ACCST.
- **R/C transmitter, at least 4-channel** for manual control
- **Battery, LiPo, 3S 11.1V**
- **Power leads, power switch, and battery connector** such as Deans or XT60. It's included with a new APM 2.6.
- **Foamcore board, ¼"×3"×5"**
- **Acrylic sheet, clear, ⅛" thick, about 3"×5"** aka plexiglass
- **Plastic tree ornament** Amazon #B002WZIO4U

TOOLS

- **Soldering iron**
- **3D printer (optional)** Visit makezine.com/where-to-get-digital-fabrication-tool-access to find a machine or service you can use. Or shop for 3D printers at makershed.com/collections/3d-printing-fabrication.
- **Hookup wire**
- **Electrical tape**
- **Hot glue gun**

READY TO LEVEL-UP YOUR ROBOT SKILLS?
ArduRoller is a self-balancing, inverted pendulum robot that's also capable of autonomous navigation indoors or out. I created it as an entry for the annual SparkFun Autonomous Vehicle Competition: The goal was to create a nontraditional vehicle capable of quickly navigating an obstacle course including multiple turns, bumpy terrain, 50-gallon drums, and ramps.

I chose a surplus APM 2.5 autopilot from 3D Robotics because it contains all the sensors needed to create the bot on a single board. The build is straightforward and the software is free and open source, based on the ArduPilot system developed by the DIY Drones community. It's a great way to get started with autonomous robots.

The heart of a self-balancing bot is the *IMU* or *inertial measurement unit*, consisting of 3-axis rate gyros, accelerometers, and magnetometers. These 9 sensors are sampled up to 1,000 times per second and integrated with a piece of code called the *DCM* (*direction-cosine-matrix* algorithm), a mathematical filter that combines the best attributes of each sensor. The robot's higher-level code can simply ask the DCM the angle and the rate of rotation of the bot as needed for balancing.

HOW TO MAKE A ROBOT BALANCE

An inverted pendulum balance-bot is inherently unstable. Conveniently, the high center of gravity creates a large moment of inertia that slows the rate at which it will fall. We can leverage this slow fall by continually moving the wheels under the vehicle as it falls. If it leans forward, the wheels roll forward to counteract the fall.

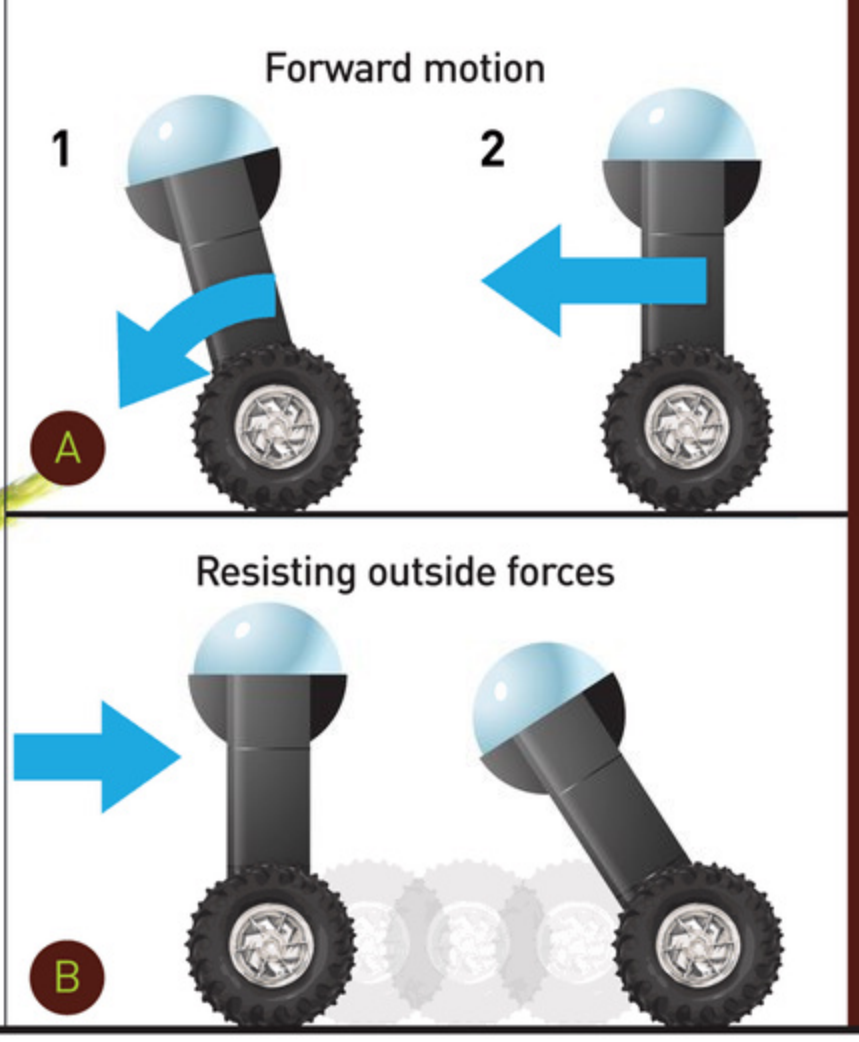
A simple *PID loop* in the robot's software is the basis of the balance control:

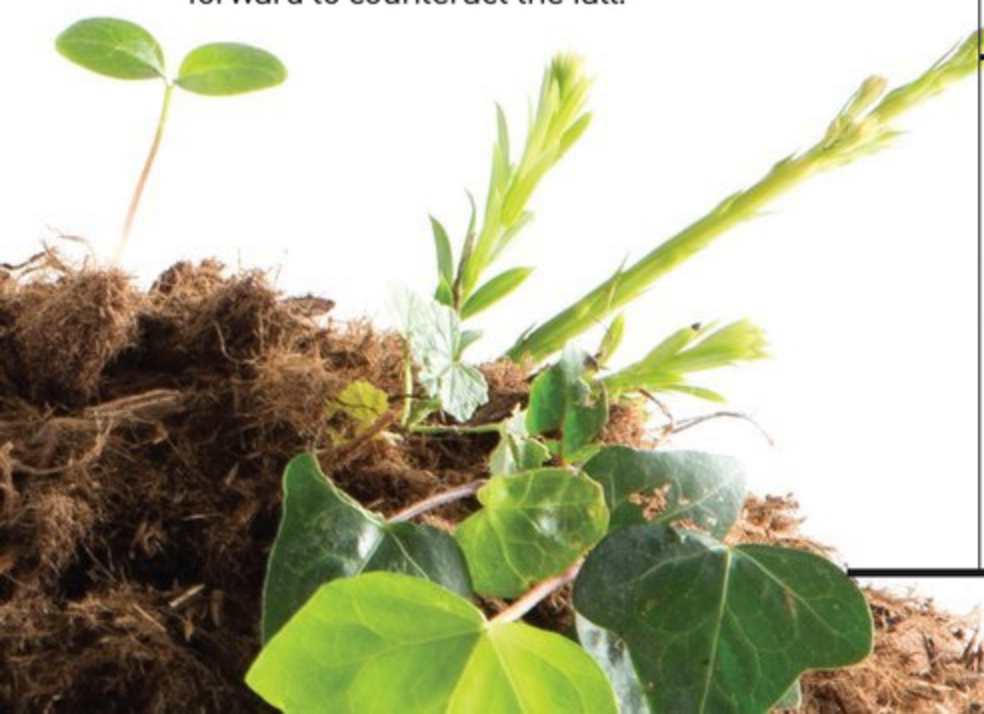
- The *proportional* term takes the angle error of the bot and sends that scaled value to the motors, to keep the wheels rolling into the fall.
- The *integral* term is used the same way, but is the sum of all angle errors over time and helps to cancel out center-of-gravity issues.
- The *derivative* term is critical. Without it, we couldn't control acceleration.

MAKE IT TRAVEL

A simplistic bot just leans into the direction of travel (Figure A). This works for a while, but the bot constantly accelerates and soon falls over (1). If the bot tries to right itself, forward motion stops.

Instead we need to move forward while rolling vertically (2). The first step is to make the wheels rotate at the desired speed while leaving enough power to keep the bot balanced and perfectly upright. Next we take the velocity of the wheels and feed that forward into the desired speed. This gives the bot the ability to resist rapid changes in angle, such as a person trying to push the bot over (Figure B). This algorithm was developed





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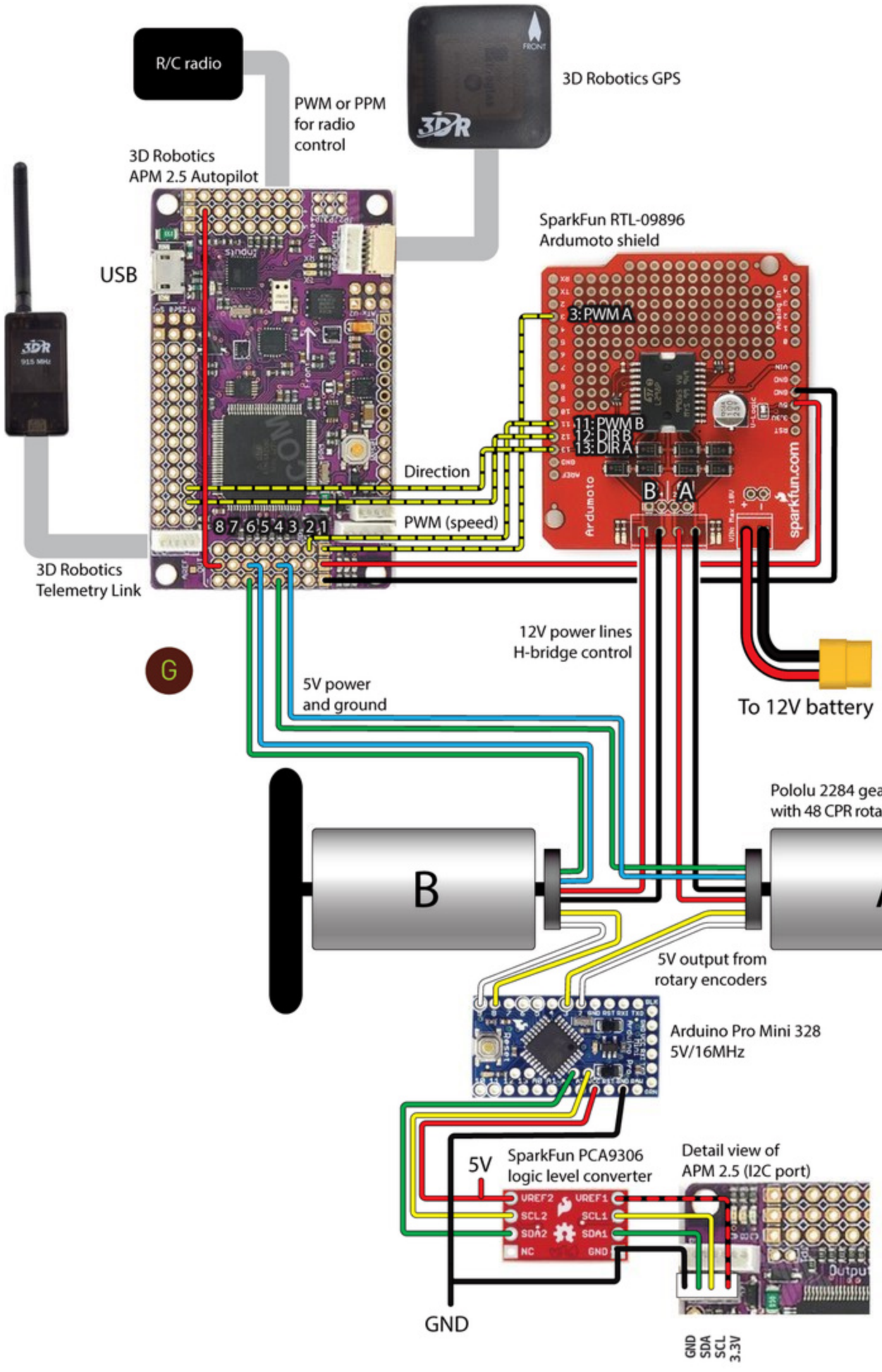


G

through observation of how people balance when being pushed. For example, a lineman in a football game throws his leg back and leans in when hit.

These two additional inputs are summed with the balancing algorithm and sent to the wheels, enabling the bot to gracefully accelerate and travel long distances.

MAKE IT NAVIGATE

In order to make the robot navigate, we need to know precisely where it is and where it's going. GPS is great, but only accurate to a few meters. We need far higher accuracy — down to centimeter scale.

Wheel encoders allow accuracy down to millimeters and are a good complement to GPS. Motors sold by Pololu have optional Hall effect (magnetic) sensors that work like a bicycle computer: Small magnets rotate past the sensor, giving us the speed of the wheels as they rotate. An Arduino Pro Mini reads the thousands of pulses per second sent by the encoders, and relays that data to the autopilot via an I2C interface. Once you measure the diameter of the wheels, the bot will know exactly how fast and how far it has traveled. Because the bot also knows its compass heading, it can plot its precise position in 2D space. When available, GPS is used to gently nudge this solution over time to ensure that wheel slippage or other errors don't build up and send it off course.

If the vehicle becomes stuck while roving in autopilot, it will sense the wheels have stopped. The bot will reverse course and try again, slightly to the right.

The rest of the robot's control software, including waypoint navigation, is simply a modified version of ArduCopter, the open-source drone project that I founded 4 years ago. This allows us to leverage a large volume of work built by a community of drone enthusiasts.

BUILD YOUR SELF-BALANCING ROBOT

1. Gather up the gear

Figure C shows the brushed DC motors from Pololu with their encoder units attached. A 34:1 gear reduction was chosen to increase torque.

The off-road wheels from Pololu (Figure D) come with adapters that perfectly attach to the 4mm motor shafts. The soft tires help the bot go over any terrain and absorb bumps that would normally knock it over.

2. 3D print the body sections

Grab the 3D files for printing at thingiverse.com/MAKE. I printed these (Figure E) on a MakerBot Replicator 2X (item #MKMB04, makershed.com).

3. Mount the motors

Fit the motors into the 3D-printed base (Figure F). They're held tightly by internal ribs, but I added hot glue between 2 ribs to help keep them from slipping.

4. Connect the electronics

Connect the APM autopilot, motor shield, logic level converter, and Arduino Mini as shown in the wiring diagram (Figure G). Connect the GPS module and telemetry radio for autonomous operation. To control the bot manually, connect your R/C receiver; for PPM receivers, use the jumpers that came with the APM.

Hot-glue the electronics to a foamcore board that easily slides into place inside the robot. Make sure the autopilot stands with its "Front" arrow pointing straight up (Figure H).

Finally, connect the electronics to the motors and slip the electronics board into the base (Figure I).

5. Final assembly

Slip the middle body section (with the window) over the electronics and press-fit it into the base. Then press the top section into place (Figure J). The battery is stored in the top section, under the dome. A power switch is a useful addition and can be mounted on the side of the bot. Mount the wheels if you haven't already.

The glass dome is actually a plastic tree ornament sold by Amazon. LEDs in the electronics light up the insides of the bot through the (optional) plexiglass window.

Mount the telemetry radio on the side of the bot (Figure K); you can use it to program missions or to control the bot directly.

7. Program your balance bot

Download the ArduRoller source code from github.com/jason4short/ardupilot/tree/ArduRoller and upload it to the APM 2.5, using a modified version of the Arduino IDE called ArduPilot-Arduino (Windows or Mac) from ardupilot.com/downloads.

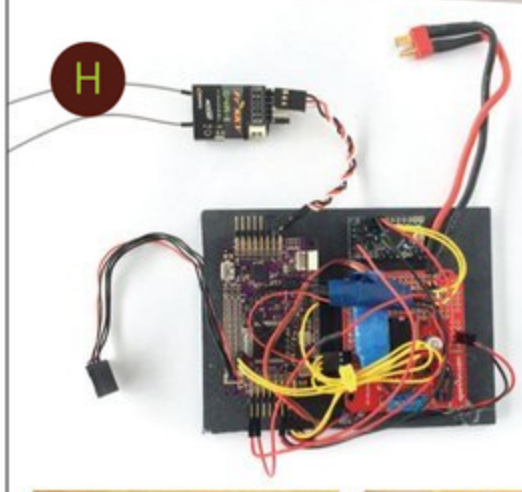
Download the wheel encoder source code from github.com/jason4short/WheelEncoder, then use the ordinary Arduino IDE to upload it to the Pro Mini.

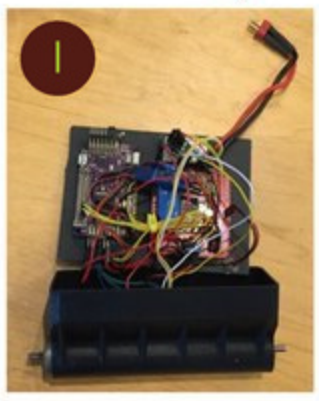
For autonomous missions, get Mission Planner for PCs (Windows only) at ardupilot.com/downloads, or DroidPlanner 2 for Android devices at play.google.com.

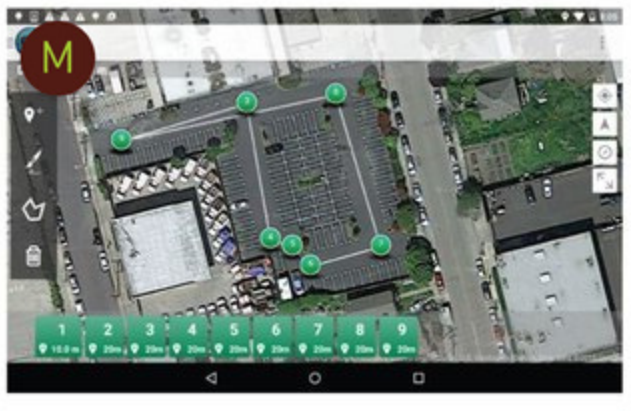
USE IT

Once the bot is built, you can drive it around with an R/C controller or send it on long, autonomous missions using GPS. The Mission Planner software (Figure L) lets you enter point-and-click waypoints using Google Maps; track your robot's location, speed, and heading; run your own Python scripts; download and analyze mission logs, and more. Lately I'm using Droid Planner (Figure M) on an Android tablet, and it works great.

Add a video transmitter to see your robot's view in first person, and a GoPro to record HD video. You could even add sonar to allow your ArduRoller to avoid obstacles entirely!







Share your build and see video of the ArduRoller in action at makezine.com/go/arduroller-self-balancing-robot

4 More Great Robots to Build makezine.com/projects

R/C OMNIWHEEL ROBOT
An easy holonomic "Kiwi drive" robot that moves instantly in any direction.

LITTLE YELLOW DRUMBOT
A funky little free-range drumbot that roams, makes beats, and samples sounds.

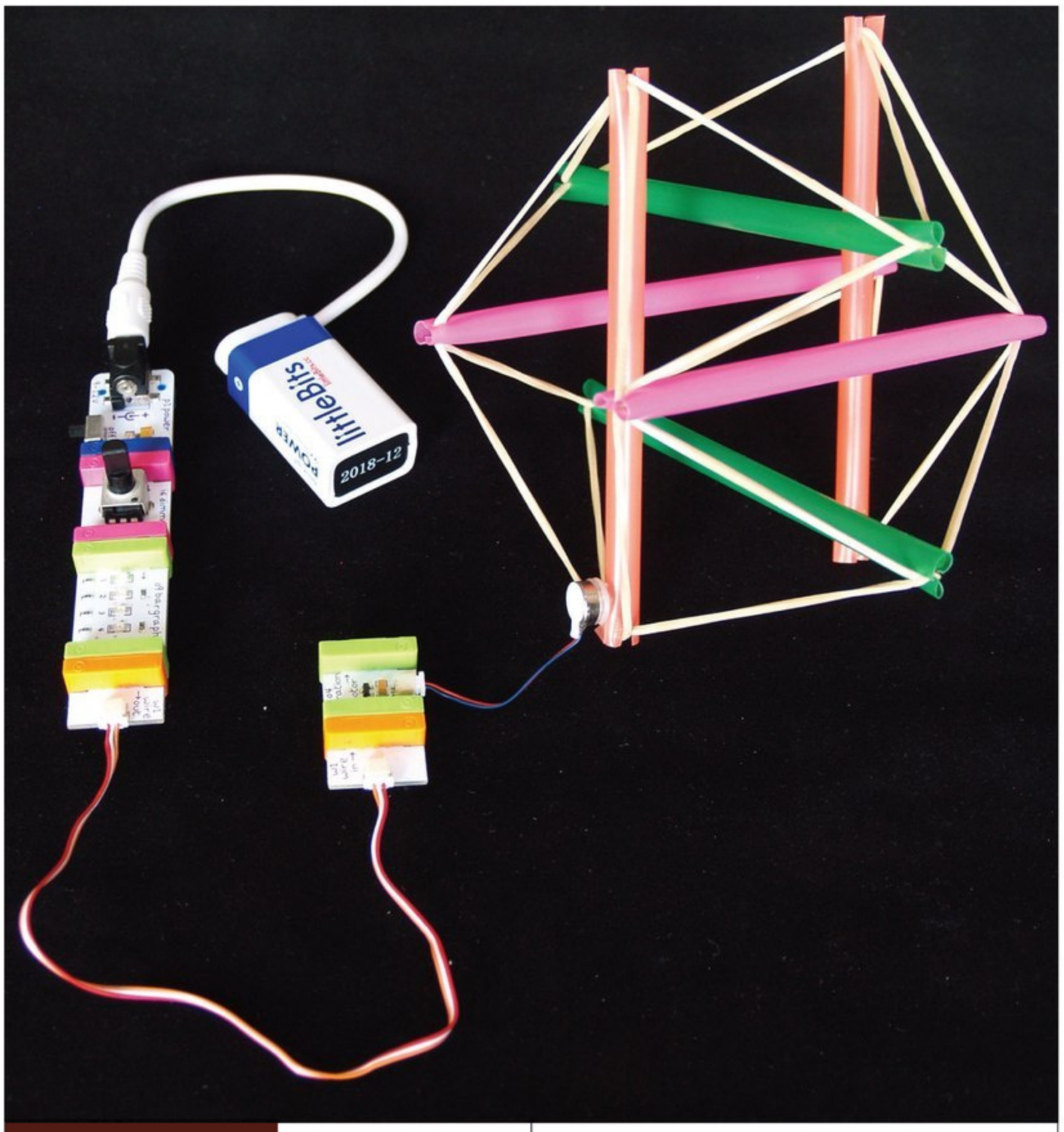
LAWNBOT 400
Hate mowing the lawn? Make an Arduino-controlled R/C lawnmower!

TRS DRAWBOT
Turn tunes into 'toons with a robot arm controlled via headphone jack.

COMPRESSIBLE TENSEGRITY ROBOT

Build this surprisingly resilient structure, then make it move. From our new book, *Making Simple Robots*.

WRITTEN & PHOTOGRAPHED BY KATHY CECERI



Excerpted from *Making Simple Robots* (Maker Media 2015), on sale now.

Time Required:
1 Hour
Cost:
$75–$100

MATERIALS

- Drinking straws (6 or more)
- Rubber bands, roughly 5" long (6)
- Rubber bands, shorter than 5" (6)
- Masking tape, glue dots, double-sided mounting tape or other removable adhesive
- littleBits modules :
  - Power, #p1
  - Dimmer, i6
  - Bargraph, o9
  - Wire, w1 (1 or more)
  - Vibration motor, o4

TOOLS

- Scissors

KATHY CECERI
is a STEAM educator, homeschooling expert, and the author of low-tech, no-tech books on subjects like robotics and video games.
craftsforlearning.com

A TENSEGRITY STRUCTURE CAN FLEX, STRETCH, COMPRESS WHEN DROPPED OR PRESSED, AND THEN SPRING BACK INTO SHAPE. It also has a high degree of *compliance*, which means it won't harm people or equipment around it. That, together with its resilience, makes tensegrity a useful framework for robots that need to withstand jolts or squeeze and twist themselves through irregular spaces.

The directions for assembling this six-strut tensegrity structure out of drinking straws and rubber bands are based on a tensegrity icosahedron holiday ornament project from Bre Pettis that appeared on the *Make:* website in 2007.

Once you've built your tensegrity structure, you can quickly put together a circuit to make your robot move using littleBits, electronic modules that snap together magnetically. The circuit consists of a tiny vibrating motor, a dimmer switch to

make it run faster or slower, and a bar graph indicator that shows how much power you're supplying to the motor. Attaching the motor to the tensegrity structure will make the structure vibrate and move across the table.

1. Cut 6 pieces of straw to no more than about 5" long (Figure A).

2. On each straw, cut a slit on either end, making sure that the slits are aligned (i.e., both vertical). The slits should be ¼" deep — enough to hold the rubber band in place, but not so much that the straw begins to weaken and bend.

3. Line up 2 straws and wrap a small rubber band loosely around each end of the pair. Do the same to a second pair of straws and slide them perpendicularly between the first 2 straws to form an X shape (Figure B).

4. Take the last 2 straws and wrap a small rubber band around one end. Slide them through the intersection of the other straws so that they're perpendicular to the first 2 pairs, and then wrap a small rubber band around the other end (Figure C).

5. Twist one pair of straws so their slits are horizontal and facing you, with one above the other. Stretch a long rubber band from the horizontal slit of the upper straw, up and over a pair of perpendicular straws, and to the other end of the straw, passing it through all 4 slits (Figure D).

6. Repeat Step 5 with the all the remaining straws. Adjust the rubber bands so they're even (Figures E and F).

7. Cut away the small rubber bands so that the tensegrity structure springs open. Adjust the pairs of straws so they're parallel and not touching (Figures G and H).

8. Now assemble the littleBits electronic circuit that will make your tensegrity bot go:

a. Plug the power module (or "Bit") into the battery.

b. Attach the dimmer switch module for turning the voltage up or down.

c. Connect the bar graph module to the dimmer switch. This is a Bit with 5 rows of miniature LEDs; as more power goes through it, more LEDs light up (Figure I).

9. Attach one or more wires. The wire modules are short, so use 2 or 3 to make sure your robot has room to move.

10. Finally, add the vibrating motor. This is a small disc, about the size of a pill, with 2 thin wires attaching it to a magnetic base.

MAKE IT MOVE

To try out your tensegrity robot, attach your electronic circuit to your straw model. Situate the vibrating motor so that none of the electronics get in the way of the tensegrity structure's motion.

Decide where you'd like to attach the disc end of your motor. Use tape or another adhesive to hold it onto one of the straws. Stretch the motor wire along the straw and attach the motor base and wire base to it.

Turn on the motor and slowly increase the power with the dimmer switch. You'll start to see the rubber bands vibrate in sympathy, and your tensegrity robot should start to shimmy along the table. See if you can steer it to the right and left by adjusting the power.

If your robot doesn't move, try attaching the motor higher or lower on the structure. Moving the robot's center of gravity a little off-center can help overcome its inertia.

Now that the robot works, experiment with placing the motor in different locations on the tensegrity structure — in the center, off on one corner — to see which position produces the most reliable and interesting movements. Varying the speed and placement of the motor will produce different kinds of motion, giving the robot a kind of physical intelligence.

GOING FURTHER

While this simple tensegrity robot moves through vibration, advanced tensegrity robots move by contracting their cables and changing shape so they can roll. For an even greater challenge, think about how you could design your robot to do the same. Or break out of the prototyping stage and build a new version of this circuit without using littleBits. Starting here, you'll be well on your way to making your own advanced tensegrity robots.

TIP: Keep some spare straws on hand while you're working. If a straw bends, you're better off replacing it than trying to fix it.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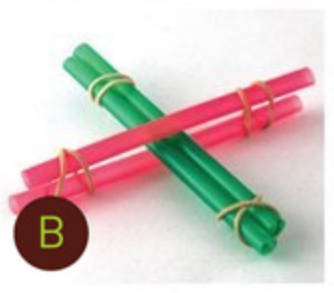
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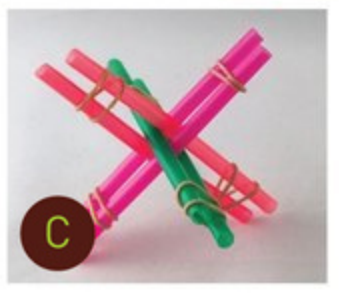
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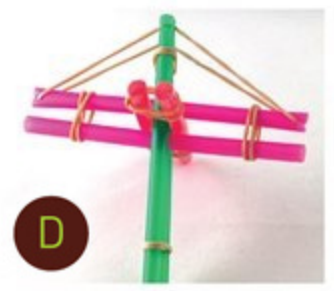
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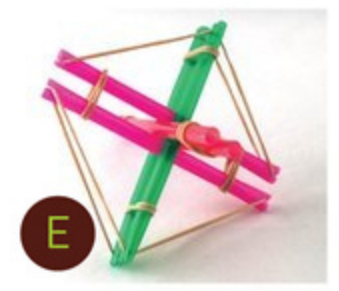
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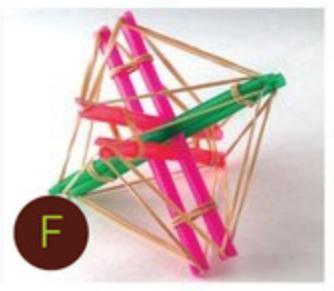
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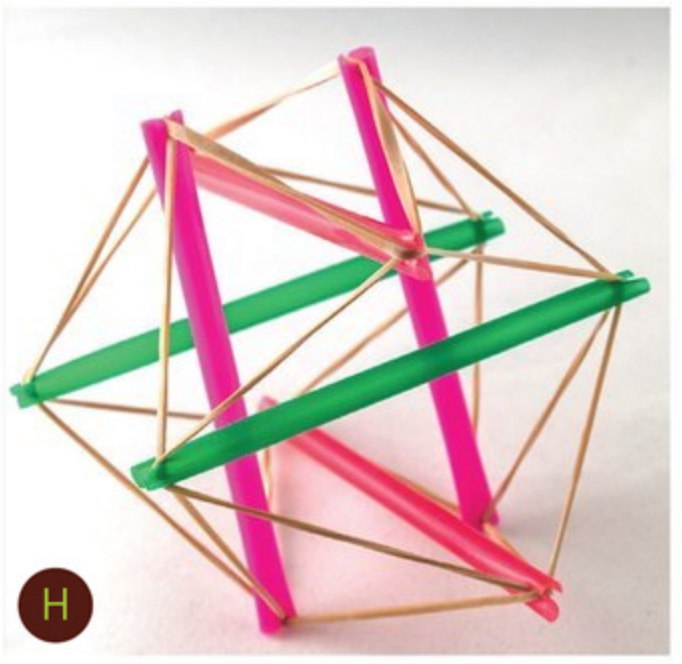
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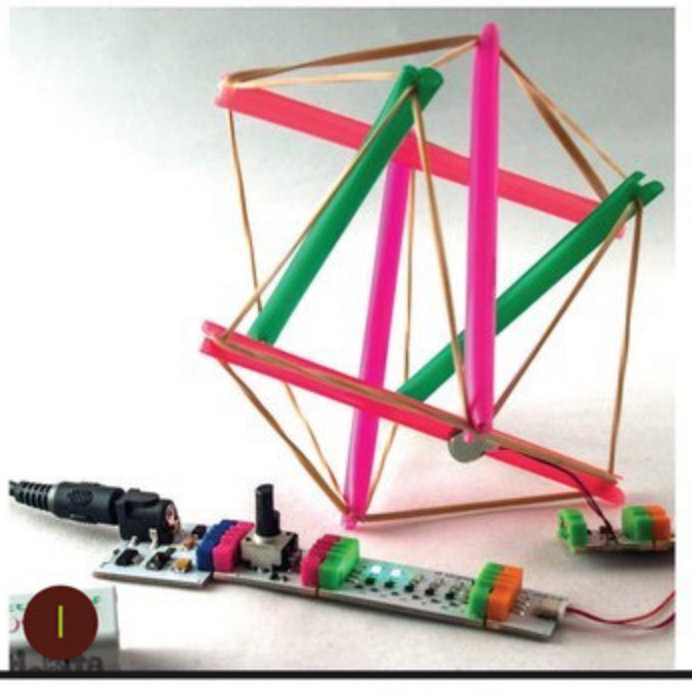
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Hep Svadja

Build a simple amorphous "jamming" gripper to pick up all kinds of objects

UNIVERSAL ROBOT GRIPPER

WRITTEN BY JASON POEL SMITH

THE USUAL STRATEGY WHEN DESIGNING A ROBOT HAND IS TO TRY TO REPLICATE THE human hand. However, in 2010, researchers at Cornell University and the University of Chicago developed a unique approach: They created an amorphous gripper that can mold itself to the object to be picked up. It's very versatile and it's easy to build.

JASON POEL SMITH
is a lifelong student of all forms of making, from electronics to crafts and everything in between. He creates the "DIY Hacks and How Tos" video series for *Make:* at youtube.com/make.

Time Required: 30 Minutes **Cost:** $5–$10

MATERIALS

- **Balloon**
- **Plastic funnel**
- **Ground coffee, dry**
  Fresh works best
- **Air hose/tubing**
- **Thin cloth**
- **Small plastic tube**

TOOLS

- **Air pump, reversible**
- **Knife**
- **Sandpaper or file**
- **Duct tape**

HOW IT WORKS

This gripper works because of a process called "jamming." When a granular material — such as rice, sand, or coffee — is compressed, it becomes very rigid. As the pressure increases, so does the amount of friction between the individual grains. This effectively locks the grains in place.

You may have observed this phenomenon while handling bags of ground coffee. A vacuum-packed bag of coffee grounds is rock-hard as long as the seal remains intact. But as soon as the seal is broken, the coffee becomes soft and pliable and can be poured like a fluid.

You can take advantage of this process to make an amorphous robot gripper. A rubber balloon filled with ground coffee is attached to an air hose. When the balloon is slightly pressurized, the coffee is loose and easily rearranged; if you press the balloon against an object, the grounds will move around it and take its shape. Then when the air is sucked out of the balloon, the grounds are compressed and grip the object. The rubber surface of the balloon also helps to keep a good grasp.

1. FILL THE BALLOON WITH COFFEE

Attach the balloon's neck to the end of a short tube or pipe, and insert the funnel into the other end. Note: A larger balloon lets you pick up bigger things, smaller balloons give you a tighter hold.

Scoop 1 tablespoon of dry, ground coffee into the funnel and let it pour down the tube. Then remove the funnel and blow into the tube to partially inflate the balloon, so that all the coffee falls to the bottom of the balloon. As you slowly let the air back out, the grounds will remain trapped in the balloon. Reinsert the funnel to repeat the process (Figure A).

Continue adding coffee. Periodically set the balloon inside the funnel to check its size. You want the balloon to stick out about 1" past the edge of the funnel (Figure B). Once you've added enough coffee, remove the balloon from the tube.

2. CUT THE END OFF THE FUNNEL

Now that you're done funneling, you'll use the funnel as part of the gripper. Cut the stem to ½" long, then smooth any rough edges.

3. ATTACH THE BALLOON

Insert the neck of the balloon down through the funnel and wrap it around the opening on the other side. Long tweezers can be handy here. Secure it with small strips of duct tape (Figure C).

4. ATTACH FILTER TO THE OPENING OF THE BALLOON

To prevent coffee grounds from falling out of the balloon, attach a small piece of fabric to the opening, to act as a rough filter. Use a fabric that breathes easily so that the air pump will be able to quickly move air in and out of the balloon.

Tightly wrap the fabric around the opening of the funnel, then secure it with small strips of duct tape (Figure D).

5. ATTACH THE AIR HOSE

Now you need to attach your air hose to the funnel. An easy way to do this is to place the funnel in the end of a wide hose and attach them with several layers of duct tape to create a (mostly) airtight seal.

6. PICK UP SOME OBJECTS!

You're ready to use your universal gripper. Start by partially inflating the balloon; this will make the grains loose so they'll move freely around the object. Then gently press the balloon onto the object you want to pick up.

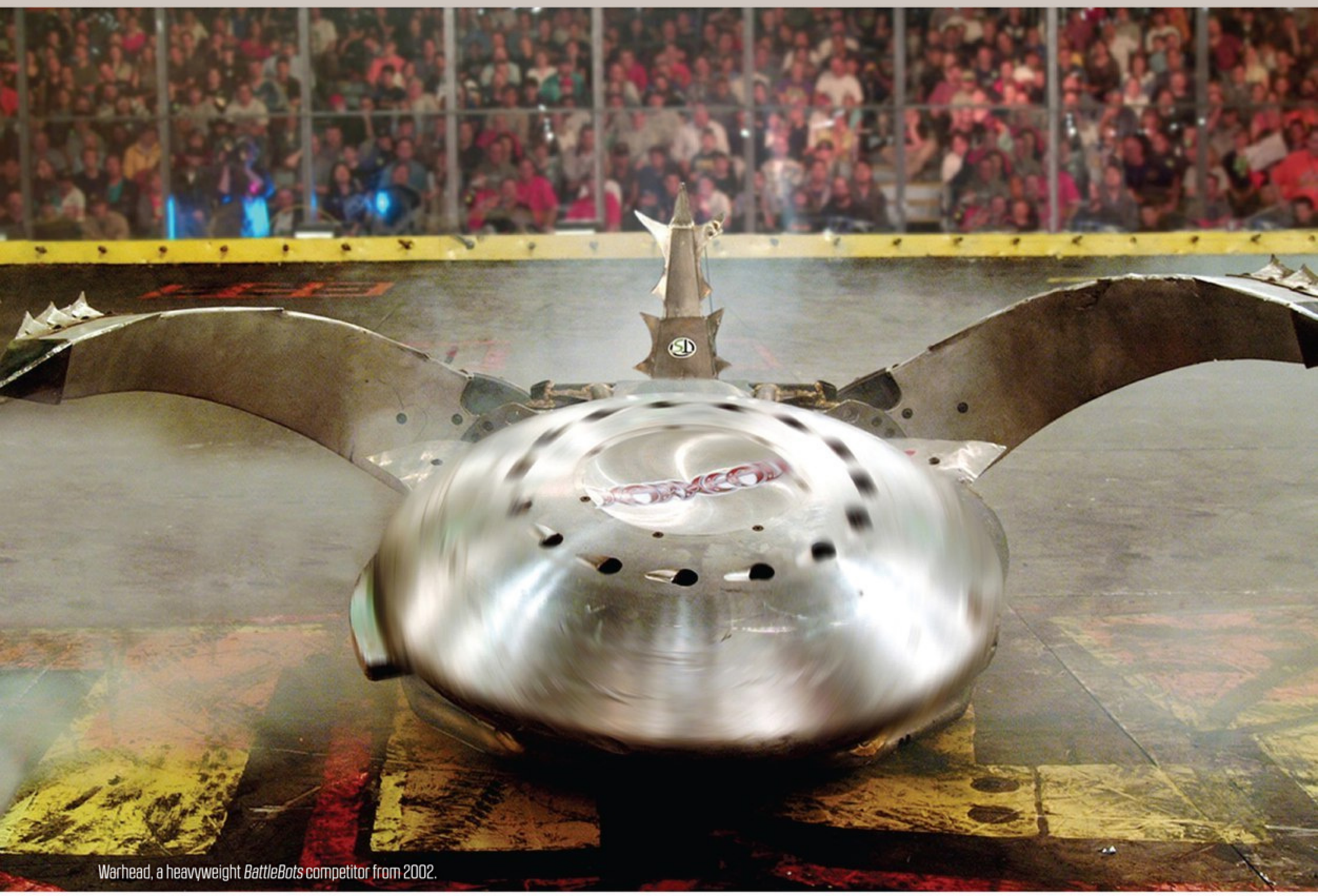
Now suck the air out of the balloon. Continue pressing down on the object as the balloon deflates. The balloon will shrink and the grounds will lock in place around the object. When all the air is sucked out, you can pick up the object. As long as the vacuum is maintained, the universal gripper should continue to hold the object firmly (Figure E).

To release the object, simply break the seal and let some air back into the balloon; the object will fall from the gripper. If you quickly blow air back into the gripper, it will forcefully eject the object. You can use this to shoot small objects across the room.

7. DEPLOY IT

This universal gripper is ideal for pneumatically powered robots; just hook the gripper up to the robot's air line and you'll be able to manipulate a wide variety of objects with ease.

View this project online, along with a companion how-to video, at: makezine.com/go/universal-robot-gripper

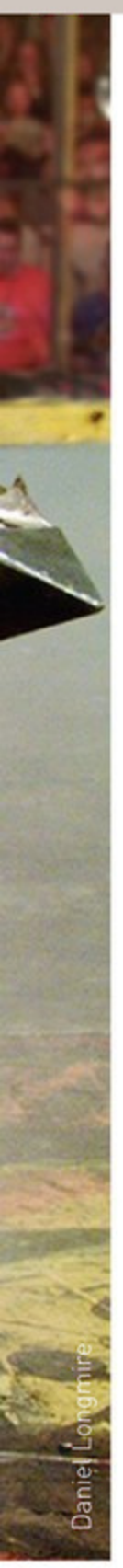


Warhead, a heavyweight *BattleBots* competitor from 2002.

ROUND 2 — FIGHT!

WRITTEN BY NATHAN HURST

BattleBots is coming back to TV — but fighting robots never really went away.


Daniel Longmire

ZACHARY LYTLE, A FORMER ROBOGAMES COMPETITOR AND CHAMPION, WAS HAVING TROUBLE WITH HIS NEW BUSINESS, BOT BASH. What seemed like a great idea — bringing robot combat to birthday parties — was foundering for a simple reason: The kids couldn't tell the robots apart. "I was making gray boxes that fought each other," he recalls.

His then-girlfriend (now wife) stepped in, telling Lytle he should give the robots some personality. Diana Lytle, now also a decorated RoboGames competitor, gave them names — Baby Bunny, Frost Bite — and even costumes. It's a funny priority for a robot (you'd assume the robots themselves care little what color they are), but an important one. Sometimes, a bot just needs to be black, or pink, or covered with a growling demon face.

Kind of like professional wrestling, all that theatricality is supported by the fundamental fun of bashing bodies against each other. Unlike professional wrestling, competitions between robots can lead to real advances in design, mechanics, and operator technique. Leagues and contests offer a sort of Darwinian incentive to building better bots, and require competing against — and sometimes, collaborating with — people with different ideas. The king, of course, was the beloved *BattleBots* series, Comedy Central's hit reality show that ABC is rebooting this year after more than a decade off the air.

"The zeitgeist is here, it's time for it to return," says Greg Munson, co-founder of *BattleBots*. "It's going to help inspire future innovators, future engineers, future makers, from not only America, but if the show goes international, from all over the world."

The new show, which premieres this summer, will be characterized by newer, better tech — especially batteries and motors — and by a few significant rule changes. For example, wedge-style robots, often blamed for the demise of the original series, will now be required to feature secondary weapons. "You have to change the engineering challenge to get new robots," says Munson.

TIP: Want to get involved? You don't need a machine shop or thousands of dollars. Start small — RoboGames and other competitions have lightweight divisions as small as 150 grams. It may not be as exciting as smashing 220-pound behemoths together, but the cost-to-fun ratio is much better. Prototype with a few servos and some cardboard — see "Combat Concepting with Cardboard," page 46 — and get building.

WHY WE THROW DOWN

Hobbyists and professionals have been pitting their robots against each other for decades, on and off TV, most visibly in *BattleBots*. "That visceral quality of two machines going at it to the death, without any humans being hurt at all, has this really fun essence to it," says Munson. "No one's getting hurt, but we can all enjoy the destruction."

BattleBots' other founder, Ed Roski, concurs, recalling his own experience fighting. "I can let go. I can destroy that thing. It gets all of that out of me, and there's no guilt," he says. "I can be friends with you, and beat the crap out of your robot."

In the mid 2000s, *BattleBots* waned and a string of copycats failed to gain much traction on TV. But now, nostalgia, crowdfunding, and web TV are helping robot combat come back for round two. RoboGames, which exceeded its $40,000 Kickstarter goal last year to hold a live event hosted by Grant Imahara this April, features 3-minute robot combat rounds, as well as more than 53 other competitions, including sumo and lift-and-carry.

MegaBots, a proposed new combat league, fell far short of its $1.8 million crowdfunding goal, meaning at least for now we won't be seeing 15-foot, piloted, humanoid robots fire bowling ball-sized paintballs at each other in arenas and stadiums. But they're getting help from Autodesk in the form of collaborative design challenges and the use of tools and space at Autodesk's Pier 9 shop in San Francisco, and they plan to bring a partially completed bot to Maker Faire Bay Area this May.

Gary Gin, whose wedge-style combat bot Original Sin is ranked #1 in botrank.com's heavyweight division, has competed in nearly every RoboGames, as well as a couple of the original *BattleBots* shows. "Robot combat right now is pretty much still a very maker sport," says Gin. "You've got to build something before you can get into the competition." And, he adds, the best way to get hooked is to see it live. "You can watch a lot of these fights on TV or on the internet, but it really is nothing compared to actually being next to the arena while a match is happening. The sounds that you hear, the smells, you can feel the entire floor shake sometimes."

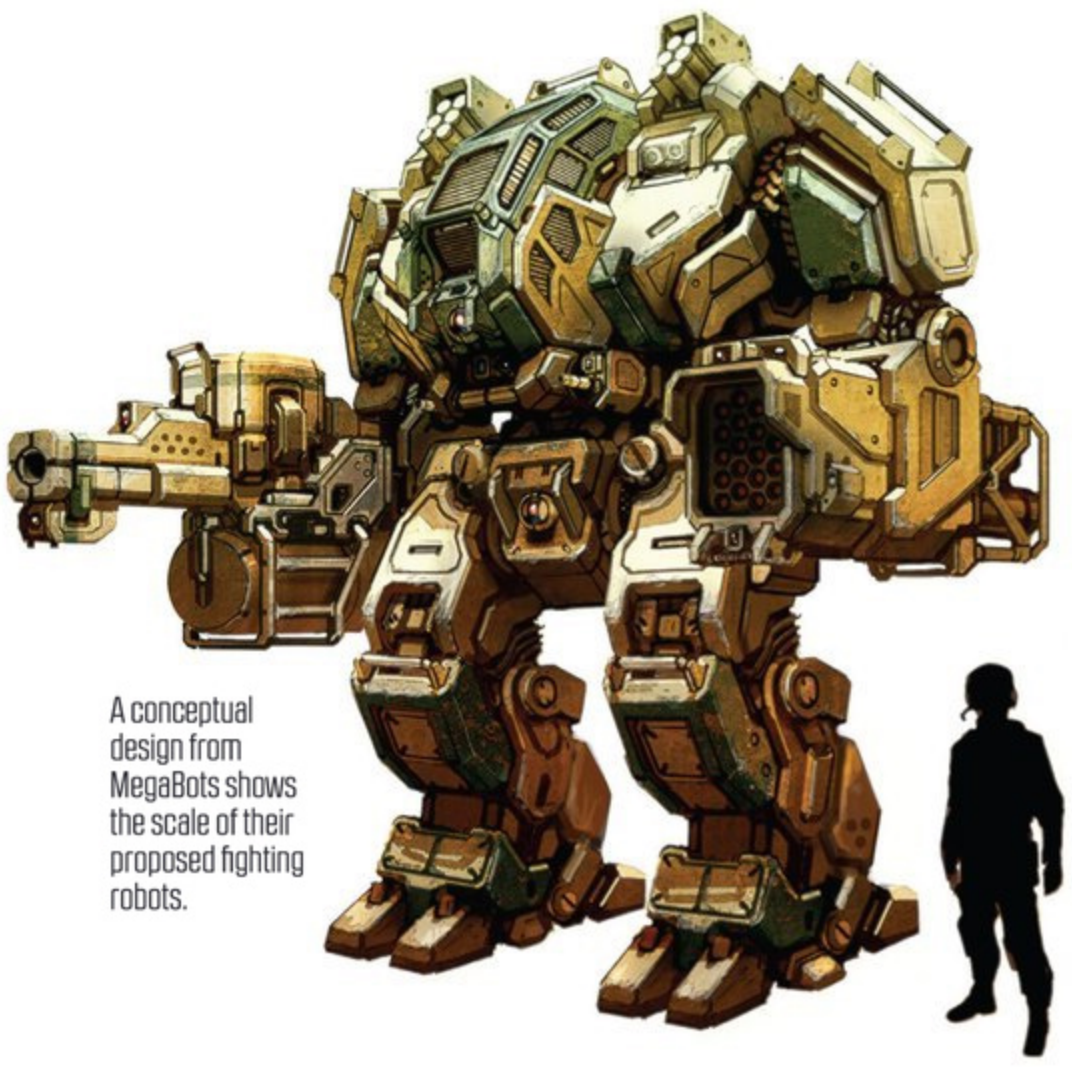
That may be why competitions have persisted in the event space, while recent TV shows have failed. It's not a lack of popularity, says David Calkins, founder of RoboGames. "I myself have always considered robot combat to be a sport," he says. "It's all the thrills and explosions of NASCAR without anybody dying. Whatever sport you're watching, you're watching it for the action."

Hep Svadja

Crescent Wrench grabs and flips Ringout for a knockout combo.

Micro Drive, Zachary Lytle's original champion, is a scale model of his full-size competition fighting robot, Over Drive.

The entire Bot Bash fighting crew.



A conceptual design from MegaBots shows the scale of their proposed fighting robots.

David Schumaker

The smells, the sounds, and the heat of competition are integral to robot combat live events.

Sparks fly at RoboGames as Last Rites, a spinning-bar type robot built by Ray Billings, takes out VD6 in the heavyweight combat division.

IT'S ALIVE!

But live TV hasn't worked out for RoboGames, which signed several deals only to have them fall through. Rather than sport, robot combat has fallen in the domain of reality TV, says Calkins, which is based on practically free content. That doesn't work out well for robot fights — he estimates RoboGames costs $100,000 to put on, not accounting for the bots that get destroyed. (Ray Billings, whose spinning-bar type bot, Last Rites, is one of Original Sin's most fearsome competitors, says it usually costs $5,000 to $10,000 in broken motors and machine parts per event.) That $40,000 Kickstarter won't even cover the venue rental, Calkins says, so they'll rely on selling tickets and producing their own content, which will be available online.

A VIRTUOUS CYCLE

Before Bot Bash, Lytle was a multiple-time RoboGames champion. When his sponsors pulled out during the recession, he struggled to fund his obsession. But he scrounged together nearly a decade of experience and spare parts to make Bot Bash happen.

He's carefully designed the bots to maximize entertainment and minimize actual damage. Motors are mounted on flexible materials so driveshafts and gearboxes feel less impact. Temperature sensors and voltage regulators shut the bots down before they heat up enough to get damaged.

That doesn't mean nothing breaks. After all, that's why we watch (and play).

"When a tire falls off, the kids have the biggest thrill. They're like, 'Oh my God, I wrecked you!'" he says. "In robot fighting, there are no cheat codes."

What Lytle has learned through Bot Bash has paid off at RoboGames, he says: When you're running the robots weekend after weekend, you get all the bugs worked out. In a single weekend his bots will fight up to 8 hours, which can be the full lifetime of some combat bots. It shows in his results too — his bot Micro Drive won the 150-gram division in 2006 and 2007, and his other, The Bomb, won the one-pound division in 2008, 2012, 2013, and 2015. Diana Lytle won in 2015 too, taking the 150-gram title with her bot Dust Bunny. So RoboGames influenced Bot Bash, which is now influencing RoboGames.

BATTLEBOTS-TESTED

But there's more to robot combat than titles and ratings. Jason Bardis is another former *BattleBots* competitor and champion. Now he's a senior mechanical design engineer for MDA US Systems, the company that builds robot arms for Mars missions.

Bardis earned his chops through years of small-time robot battles. He entered the 1996 and 1997 Robot Wars (before that competition was televised) and did poorly. He competed in Robo-Joust in a Las Vegas trailer park. Then *BattleBots* began, bringing with it more money and notoriety thanks to the Hollywood machine.

And Bardis started having more success. He won the 60-pound lightweight class twice, plus a 16-bot Robot Rumble, with Dr. Inferno Junior, an anthropomorphic wedge-like robot that pushed competitors into the arena's hazards. He even managed to make a profit, thanks to sponsorships and merchandising. "Part of my secret was I was a poor graduate student and I didn't

A Brief History of Robot Combat Games

ROBOT WARS:
1994–present
Televised: BBC, 1998–2003

BATTLEBOTS:
1999–2002, 2015
Televised: Comedy Central, 2000–2002; ABC, 2015

ROBOTICA:
2001–2002
Televised: TLC, 2001–2002

ROBOGAMES:
2004–2013, 2015
Televised: Science Channel (as *Killer Robots*), 2011 (one episode)

ROBOT COMBAT LEAGUE
Televised: SyFy, 2013

spend much money," he says. But after *BattleBots* went off the air, it was tougher to fund all that destruction. The arms race had escalated, and bots were doing more damage to each other. Bardis got married, had a kid, took out a mortgage, and retired from bot fighting.

But he took something important with him. All that time in his college's machine shop, designing competitors, building them, and fixing them wasn't wasted. He learned basic design principles: wall thicknesses, strength of materials and fasteners, how to do wiring, how to design for easy repair and maintenance and swapping out of parts. "I got a whole lot of hands-on, bloody-knuckles, dirt-under-the-fingernails experience that none of my colleagues got," he says. "I learned way more doing that than my Ph.D. dissertation, and it's helped me tremendously in my professional career — and my social life — more than my education did, or more than any other internship or experience." He learned to make things that could stand abuse. And when he went to job interviews with robotics companies, all his prospective employers wanted to talk about was *BattleBots*.

Now he mentors and judges contests, gives talks, and hopes to become a judge on the new *BattleBots*. Like Gin, Bardis touts the live event. "First thing anybody should do is find an event and see it in person. You can watch it on TV, you can watch it on YouTube, you can watch it live streaming ... it's like watching an Imax movie through a drinking straw," he says. "You're not seeing the whole picture. You're not smelling the robots, you're not feeling the robots, you're not feeling your feet shake, you're not looking at all the smiling faces of excited people all around you."

Gin, Bardis, and Munson all mentioned the smell. "It stinks," explains Munson. "It's burnt batteries, it's the smoke from internal combustion engines, it's the oil that's used to lubricate the moving parts, and it's just that sort of ozone-like quality when things smash into each other. It adds to the excitement. It would be nice to have some Smell-O-Vision."

They never really left, but whether you can smell them or not, combat bots are definitely back.

WHAT COLOR SHOULD YOU MAKE YOUR ROBOT?

WRITTEN BY CRAIG COUDEN • ILLUSTRATED BY NATE VAN DYKE

Why are all humanoid robots white nowadays? Perhaps it's the simple neutrality of the color. Or maybe Apple's dominance has assigned that color for high tech. Either way, we don't want you to forget that colorful bots in pop culture have laid the groundwork for what a certain-colored robot means. Plan accordingly!

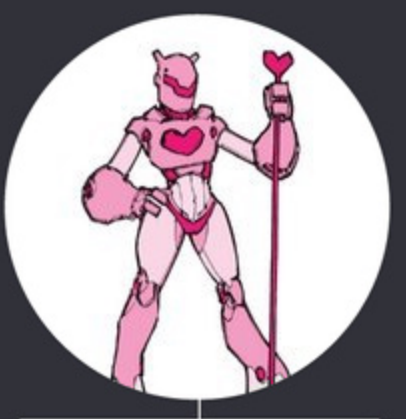
RED and BLACK robots are evil or authoritarian.
EXAMPLES: HAL 9000, *2001: A Space Odyssey*; Maximillian, *The Black Hole*; Sentinels, *The Matrix*

BLUE is for police robots and no one wants those right now.
EXAMPLES: Chappie, *Chappie*; URL, *Futurama*

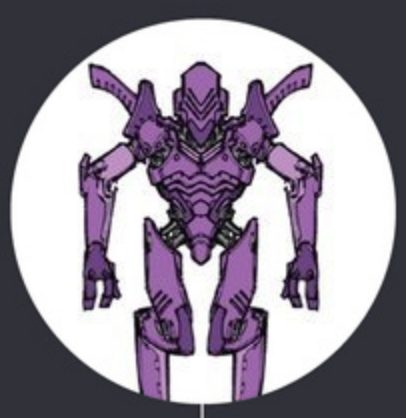
YELLOW and ORANGE are for construction bots.
EXAMPLES: WALL-E, *Wall-E*; one-armed assembly line construction robots

GOLD robots are just presumptuous, and you can't do better than C-3PO.
EXAMPLE: C-3PO, *Star Wars*

SILVER robots are aliens that visited in the 50s, 60s, and 70s to judge or kill us.
EXAMPLES: Gort, *The Day the Earth Stood Still*; Cylons, *Battlestar Galactica* (original)



Japan has cornered the market on PINK robots.
EXAMPLES: Fei-Yen, *Virtual On*; Arcee, *Transformers*



PURPLE is for giant psycho robots that are supposed to help us fight the alien invasion, but will really cause the destruction of humanity.
EXAMPLES: Eva Unit-01, *Neon Genesis Evangelion*; Sentinels, *X-Men*

For a color that's not yet typecast, try GREEN or RAINBOW. Rainbows are the new frontier!
EXAMPLE: Robot Unicorn, *Robot Unicorn Attack*

WHITE is adorable and is just looking for plant life so we can go back to living on Earth instead of getting fat in spaceships.
EXAMPLES: EVE, *WALL-E*; ASIMO

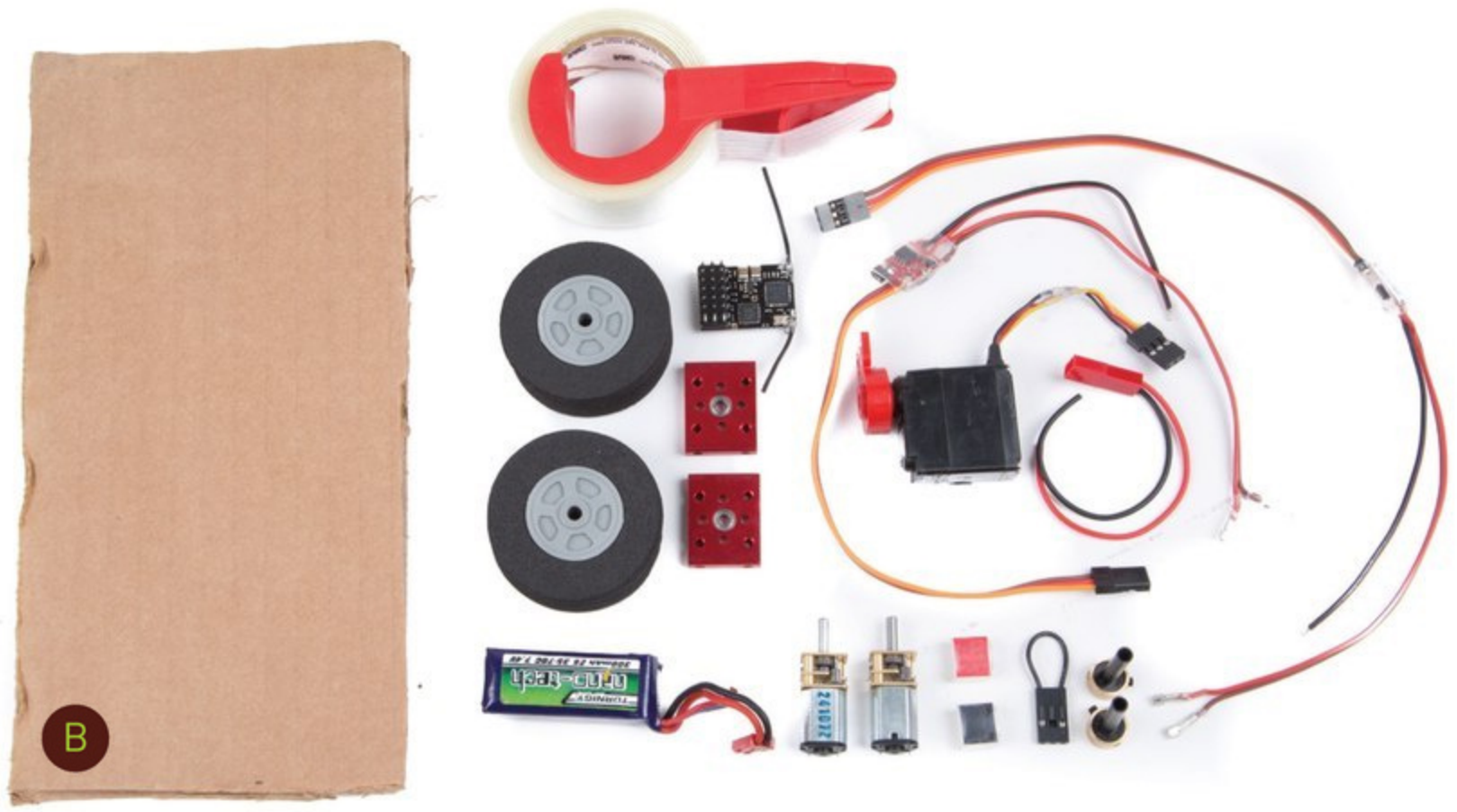
Mock up and test your bot ideas with this low-tech tool

COMBAT CONCEPTING WITH CARDBOARD

WRITTEN BY ZACHARY LYTLE

Hep Svadja

A



Time Required:
4 hours
Cost:
$200

ZACHARY LYTLE is a six-time RoboGames champion who has been building robots for more than 14 years. He is also the founder of Bot Bash Party, which brings mini bot fights to birthday parties and other events.

MATERIALS

- **ESCs (2)** FingerTech Robotics tinyESC v2, fingertechrobotics.com
- **Mini terminal block (pair)** FingerTech
- **Bearing block** FingerTech
- **Wheels (2)** FingerTech LiteFlite 1.75" diameter
- **Hubs (2)** FingerTech Lite Hubs
- **Battery** LiPo, Nano-Tech 2S (7.4V) High-Discharge 250mAh FingerTech
- **Connector** JST female FingerTech
- **Servo** Hitec high voltage HS-5087MH
- **Servo saver** Hitec Standard (131SS)
- **Gearmotors (2)** 50:1 Sanyo

ENGINEERING PROFESSORS CALL IT "HOBBY SHOP ENGINEERING," BUT MY ROBOTICS TEAM refers to our design method as "C.A.D.," nerd code for Cardboard-Aided Design, the low-tech tool for testing new robot designs.

Often, people ask how I get my ideas for making new fighting robots. New designs evolve in many different ways. It could be something I see, think of, dream of, or brainstorm with other people. Ideas can come from handling the materials and from fighting the robots, but you can try various methods.

In this process, you draw and cut out the pattern of the parts you plan to use and mock them up in actual size. This way, you can test your ideas in cardboard before cutting out the final materials.

DETERMINE MONIKER AND FUNCTION

I recommend coming up with an evocative name to describe something about the robot, like "Captain Hook" or "Jaws." Once you have that, pick the function of the robot — what it's going to do.

For example, you could make a clamp robot with a bottom jaw that moves up and down in order to lift its opponents' wheels off the ground. Or, you could feature a saw or hammer. Look up some past champions to spur creative ideas.

Whatever you decide, start with rough sketches to get an idea of what the robot will look like, then assemble a parts list. Select parts you are familiar with or ones that have received good reviews. For the robot you see here — called UnderBite (Figure A) — I used mostly FingerTech parts, along with a Hitec servo and a pair of 50:1 Sanyo motors (Figure B).

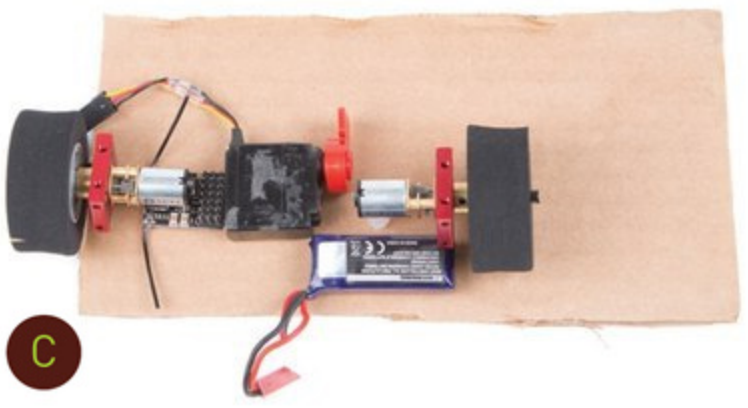
CREATE YOUR CARDBOARD TEMPLATE

Start by laying the parts out on a piece of cardboard; try to arrange them in the tightest possible orientation (Figure C). Trace out the shapes and cut out the pieces of cardboard — but cut carefully, as this will serve as a template when you start building. After cutting out the base piece, tape the parts to it and start working on the front wedge. (Use masking tape to avoid leaving residue on the parts.) Once the front wedge is cut out, tape it onto the front of the robot. Then attach the wheels and check the ground clearance.

On Underbite, I noticed something looked off after attaching the wedge — it was too large for the robot. I scaled it back about 20%, cutting ½" off all sides of the wedge.

This is the true beauty of C.A.D.; you can look at your robot and make modifications without having to take it apart. If you don't like the way something looks, simply get a pair of scissors and change it.

Next, I cut a hole in the frame for the servo horn. However, it did not turn out the way I pictured it: In order to make a hole big enough to clear the entire servo horn, I would need to cut the robot nearly in half, which would destroy the structural integrity of the design. In order to



SOFTWARE VS. PAPER

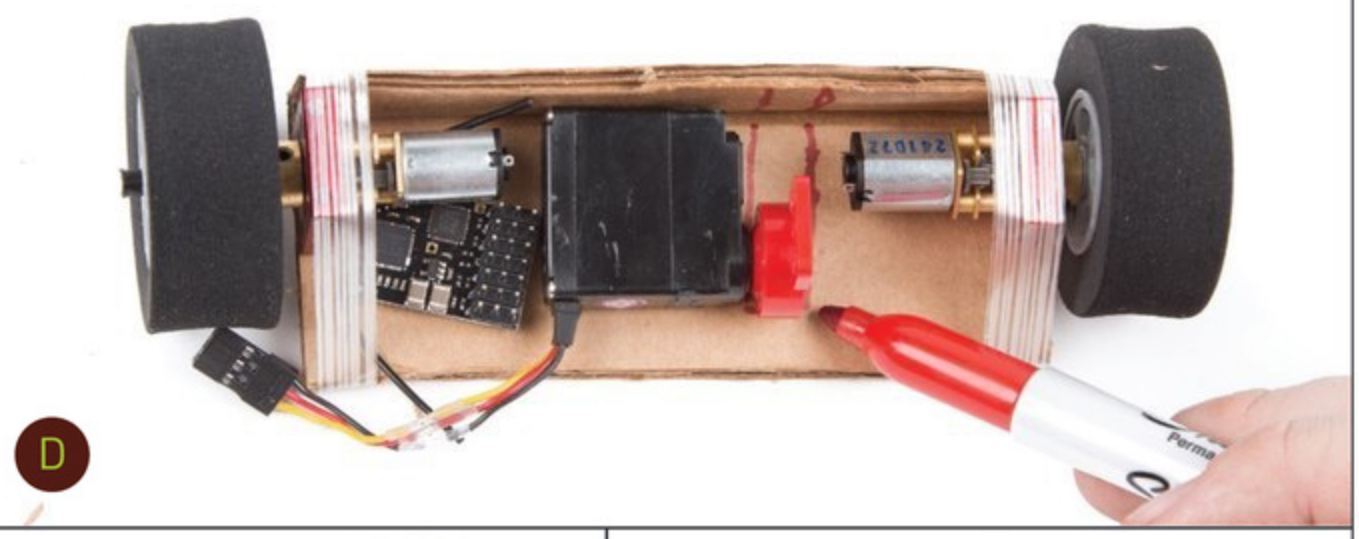
I have designed robots with computer models and every part precisely machined, such as The Bomb, which has won four RoboGames' gold medals. However, for another medal winner — my first champion, named Micro Drive — I used only one piece of cardboard and three pieces of graph paper. This took a fraction of the time the computer models did, and it won two gold medals and a silver. The real question: Would you rather spend your time in front of your laptop, or in front of your workbench?

WEIGH YOUR DESIGN OPTIONS

There is no one right way to design a robot, but there are some design hurdles to consider. There are endless debates on four wheels vs. two. Should the wheels be exposed or enclosed? Which weapon is best, and do you want more than one? The answers depend what you are comfortable with. Try to build one that fits your personality and drive style.

There will be trial and error. A two-wheeled robot turns quickly and is easy to build, but is difficult to drive straight. A four-wheeled robot turns slower, but is easier to control, and makes it tough for opponents to "high center" you. Exposed wheels can be torn off, but wheel guards can get bent, pinning the wheel. You may be better off losing a wheel and still having three good wheels.

Multiple weapons can overcomplicate the robot or make it too heavy. However, it is highly recommended to always have a wedge — they help get under your opponent and give you leverage. Every great saw, lifter, and crusher has to start as a good wedge. Even if your weapon is completely broken, you can still continue the match as a wedge robot.



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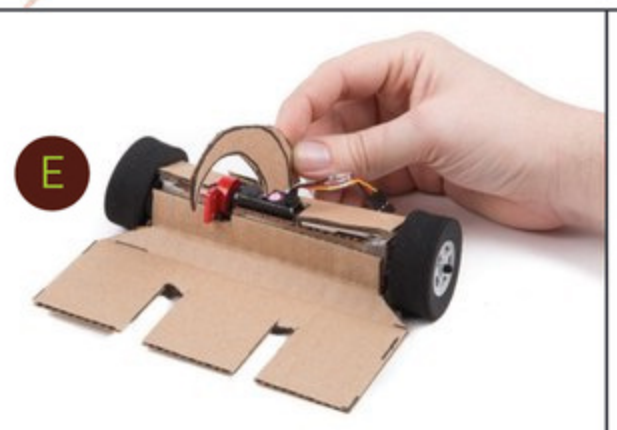

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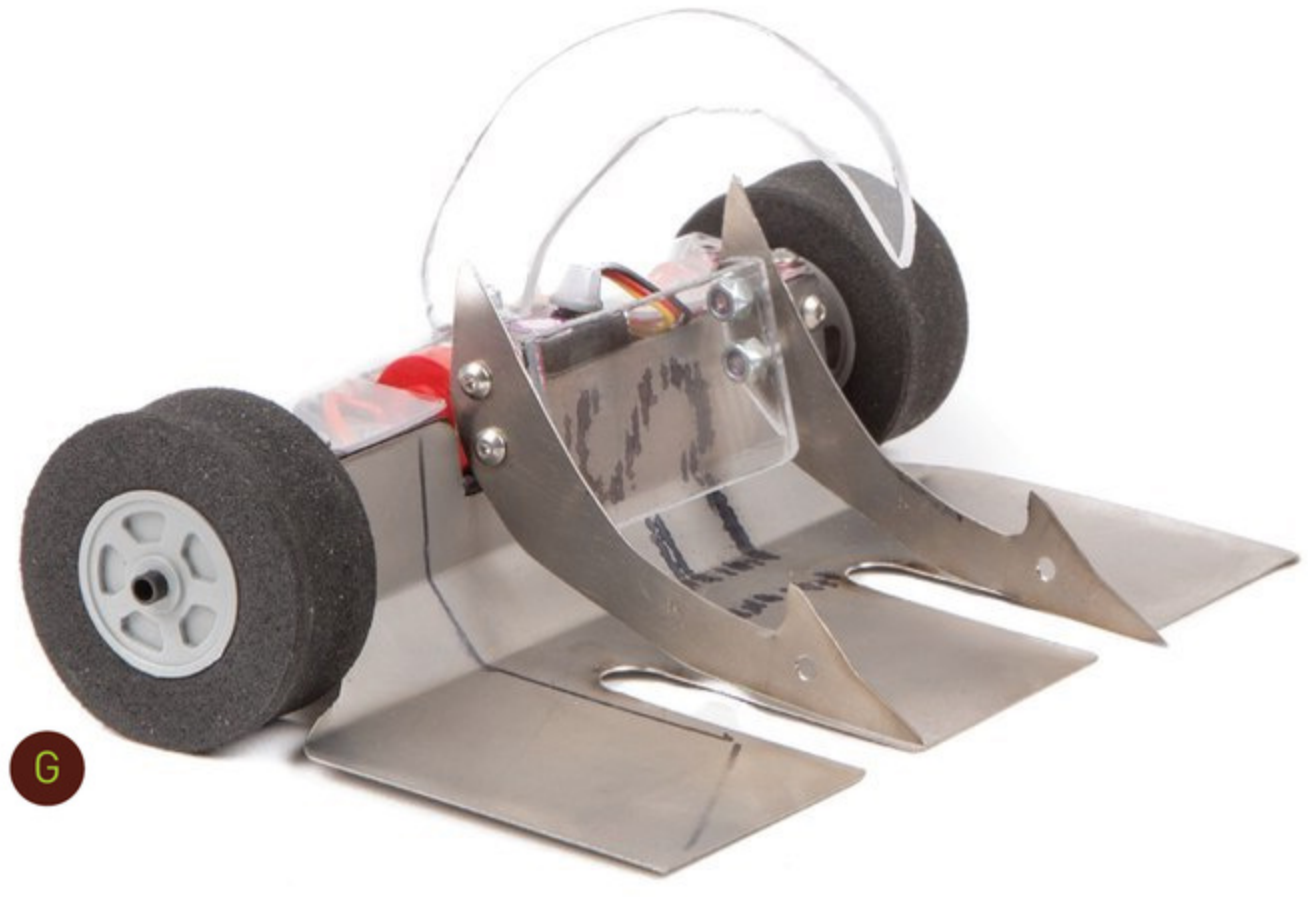


G

Ready to battle? Tell us your cardboard combat bot's name, and how you built it, at makezine.com/go/cardboard-robot-prototype

fix this, I flipped the servo 90° (Figure D). Once again, this illustrates the power of C.A.D.'s flexible design process. After rotating the servo, I only need a small slot to accommodate the servo horn.

INCORPORATE SELF-RIGHTING

A big concern for any fighting robot is how to flip back over if you get upended. In my rough sketch the idea was to do a static roll, where the top jaw is shaped in such a way that the robot naturally rolls back onto its wheels. To do this, the curve of the top hook will have to be very carefully designed. The robot's center of gravity must be low and to the back. This is where C.A.D. shines (Figure E).

First, I placed the battery (the heaviest component) near the back. Next, I cut a piece of cardboard into a hook shape and attached it firmly to the frame. I set the robot upside down, to see if it rolled back onto its wheels. After several attempts and careful trimming of the cardboard, it officially executed a self-right.

MOCK UP THE WEAPON

Finally, I needed to cut out two more pieces of cardboard for the weapon. I typically conceptualize the name and weapon together — it's usually the first thing people notice about the robot, and it makes it more memorable. I mocked it up in cardboard (Figure F), and moved on to the metal version.

For this version, I made UnderBite's weapon out of three parts: Two sharp, titanium rails that are filed to a point (to look like teeth) and a bulletproof plastic piece that will be bent into a "U" and mounted directly to the servo horn. The plastic piece will be flexible and allow the weapon to bend and absorb impacts. The titanium pieces will keep their edges, allowing you to get under your opponent's wedge. To make UnderBite live up to its name, I put teeth at the end of the forks. Now, I'm ready to cut the frame out of metal (Figure G).

GOING FURTHER

This is just one of many possible designs — you can use C.A.D. to experiment with your next robot. It is a quick way to test a new idea and is the method I've used to design most of my robots. It saves money and materials, is adaptable for most designs, and it gives you complete control over the aesthetics of your robot, making it easier to put some personality into your frame and weapon. Cardboard, scissors, and some free time are all you really need to start building a fighting robot.

Skill Builder

TIDBITS & TIPS ON ALMOST ANYTHING

BY JORDAN BUNKER

Have you ever seen a project that you wanted to make, but felt like it was too tough to tackle? In this section, we'll explore some tools and techniques that work together to give you the skills to take on those difficult projects.

SOLDERING IRON TIPS

There are hundreds of different soldering iron tip shapes and sizes used in everything from jewelry making to plumbing to even stained glass. We'll focus on the 3 most common for electronics work: chisel, conical, and bevel tips.

BEVEL TIP (AKA HOOF TIP)

While not as common as the chisel and conical tips, the bevel tip can be used for solder jobs that require pre-loading the iron with solder. The large flat surface can hold more solder than most other tips, and it's helpful when soldering small-gauge wires together or dragging solder across surface-mount chips to solder multiple pins at once.

CHISEL TIP

With its broad tip, the chisel tip helps to evenly deliver heat to component leads and pads. This tip is great for soldering wires, through-hole components, large surface-mount components, and for desoldering as well.

CONICAL TIP

Conical tips are usually used for precision electronics work, though they're also often used for general soldering. The pointed tip helps deliver heat to small areas, such as tiny surface-mount components.

SPECIALIZED TIPS

There are endless varieties of specialized tips designed for specific jobs — even if they aren't soldering related. For example, this spade tip is used to scrape UV glue off of LCD glass.

NOTE

Tips for one brand of soldering iron are often not compatible with others, so be sure to verify that tips are designed for your soldering iron before buying them.

FILES

The file is a basic tool, but it would be a mistake to call it simple. Files come in a variety of shapes, cuts, and coarseness depending on the job they're designed to do.

Whether you're sharpening tools or cleaning up rough edges, choosing the right file starts with knowing the basics.

CUT

Most files come in 4 basic cuts: **smooth**, **second**, **bastard** (originally called a "Barsted" file, after its English inventor), and **coarse**. The cut describes the size of the teeth, with smooth cut being the smallest, and coarse cut being the largest. Large teeth will leave behind a rough surface, while small teeth will leave a smooth surface.

TOOTH PROFILE

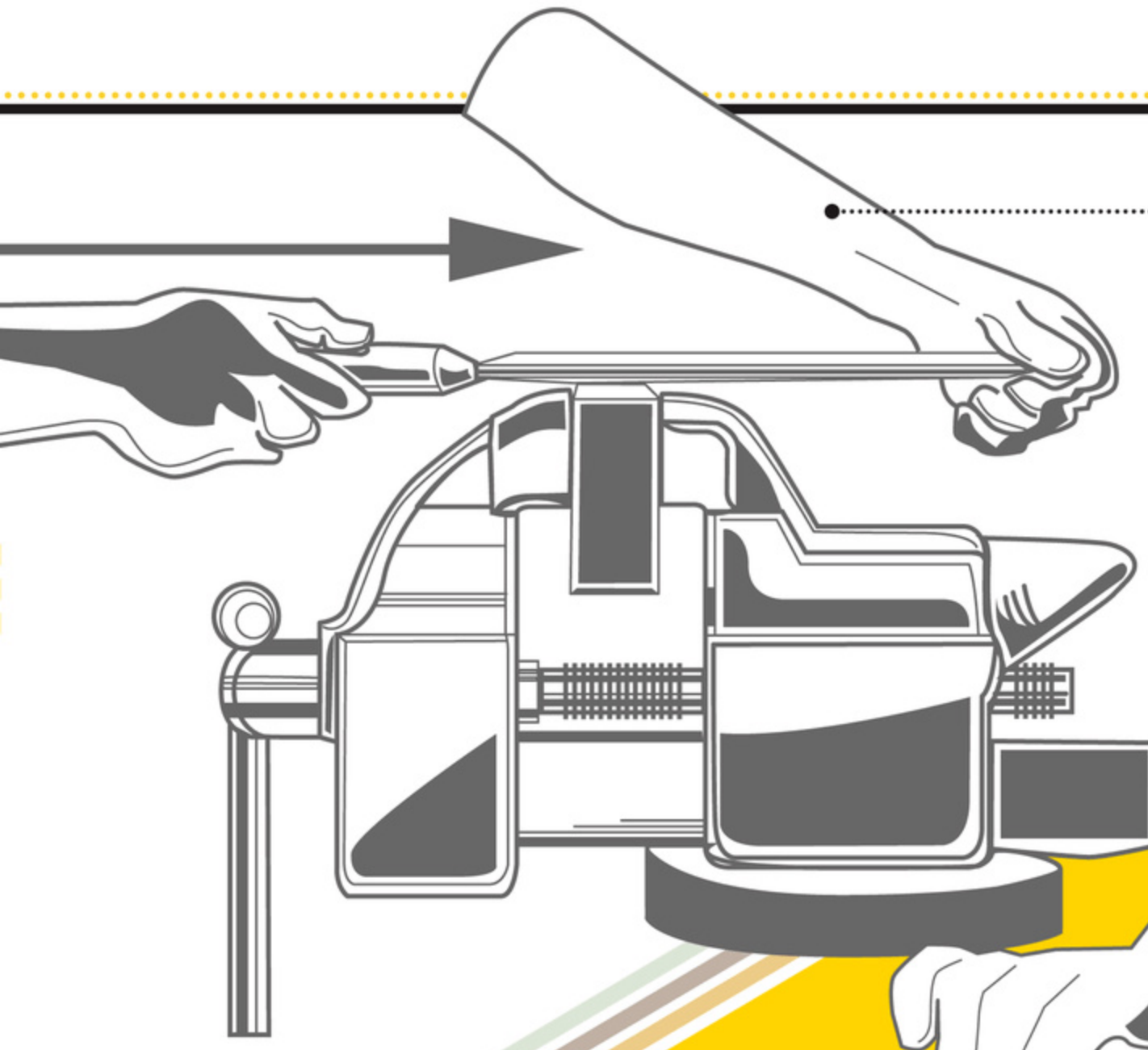
File teeth also come in **single cut** and **double cut** varieties. Single cut files have one set of parallel teeth, while double cut files have a second set of parallel teeth at an angle to the first set. Single cut files are typically used for sharpening tools and finishing operations, while the more aggressive double cut files are used for rapid material removal and rough shaping of material.

SHAPE

The shape of the file used should be similar to the profile of the cut being made. For example, you might use a flat file to smooth flat edges, and a round file to taper the inside edge of a drilled hole. Common file shapes include **flat**, **triangle**, **half round**, **round**, and **square**.

This is a Single Cut, Flat, Smooth File

This is a Double Cut, Flat, Bastard file.



STRAIGHT-FILING

The first and most basic filing technique is called straight-filing, and involves pushing the file lengthwise across the work, making contact only on the forward stroke. Straight-filing is typically used to rapidly remove material.

DRAW-FILING

If a smooth surface is what you're aiming for, then it's best to use the draw-filing technique. In draw-filing, the file is held on both ends and is pulled and pushed across the material crosswise.

CLEANING

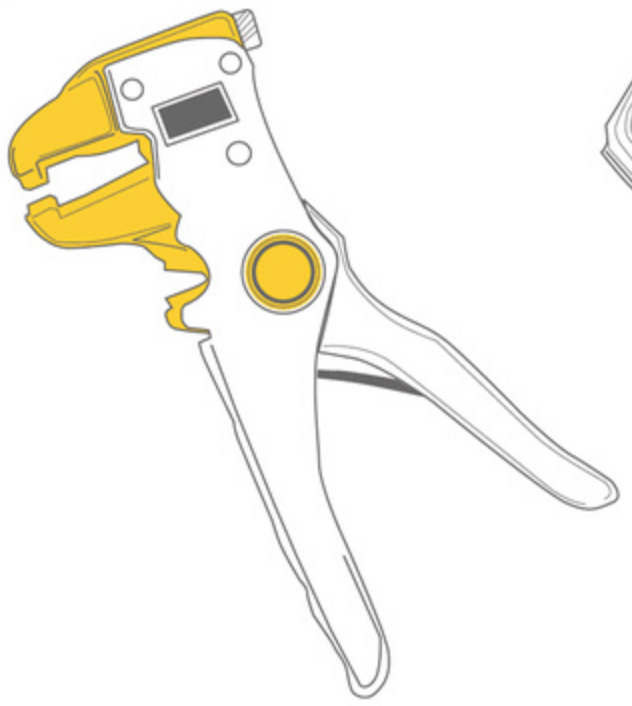
Inevitably, your file will become clogged with material, and won't work as well. One way to prevent material from sticking is to scrape a piece of chalk across the file before using it. To remove the bits of material stuck between the teeth, you can clean your file by using a tool called a file card, which you scrape across the file in the direction of the teeth.

WIRE STRIPPERS

The value of a good pair of wire strippers is often overlooked until they've disappeared from your toolbox. Here are the 4 basic types of wire strippers that you'll encounter.

GAUGED WIRE STRIPPERS

Gauged wire strippers are the simplest and most common type of wire stripper used. Each pair is only made for certain gauges of wire, so if you work with both small and large gauges of wire, you may need multiple sets.



ADJUSTABLE WIRE STRIPPERS

These wire strippers are probably the cheapest available, and can be adjusted for different gauge wire by changing the position of the stop-screw. They work well, but can be tedious to adjust when working with multiple wire gauges in a single project.

SELF-ADJUSTING AUTOMATIC WIRE STRIPPERS

While more expensive than most other wire strippers, these are the easiest ones to use. Just place the wire into the mouth of the tool, squeeze the handle, and the jacket of the wire will be removed from the end. These wire strippers are great when they work, but they will often have trouble with smaller gauge wire. If you have a lot of wire to strip, this tool can save you a lot of time.

GAUGED AUTOMATIC WIRE STRIPPERS

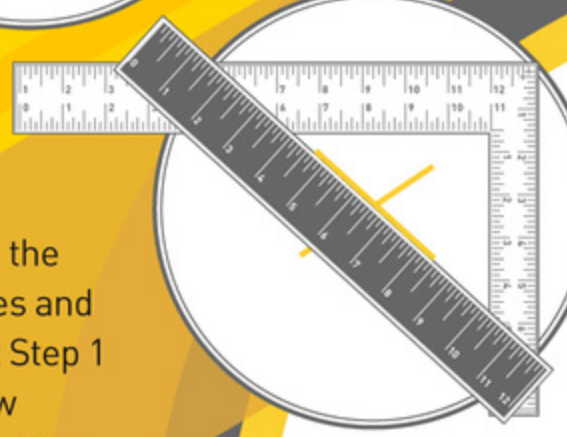
If you want to use professional-level wire strippers, look no further. These wire strippers are a combination of the gauged and automatic wire strippers, and will deliver the best of both worlds in a single tool. The blades can be swapped out for stripping other gauges, and watching the mechanism work almost makes stripping wires fun.

FINDING THE CENTER

If you need to drill a hole in the center of a circular material, you'll have to find it first. You could buy a fancy center-finding tool, or you can use simple measuring tools and these easy methods to mark the point.

CARPENTER SQUARE AND RULER

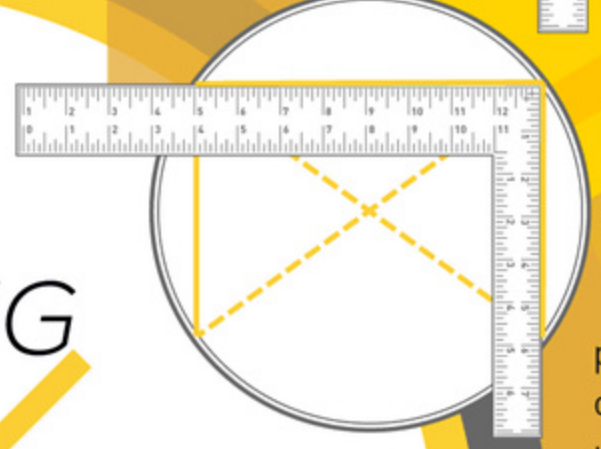
Place a carpenter square on the face of the material with the outside corner on the edge of the circle. Lay a ruler across the square where the edges of the square touch the outside edges of the circle. Draw a line along the inside edge of the ruler.



Rotate the squares and repeat Step 1 to draw another line.

CARPENTER SQUARE

Place a carpenter square on the face of the material with the outside corner on the edge of the circle. Trace the outside edge of the square on the circle to draw two perpendicular lines across the circle.



Use the straightedge to draw a third line perpendicular to one of the others. Then, using the square as a straightedge, draw lines from one end of the parallel lines to the opposite end.

Don't have a carpenter square? Use a piece of paper, book, or anything with a precise right angle to make your marks.

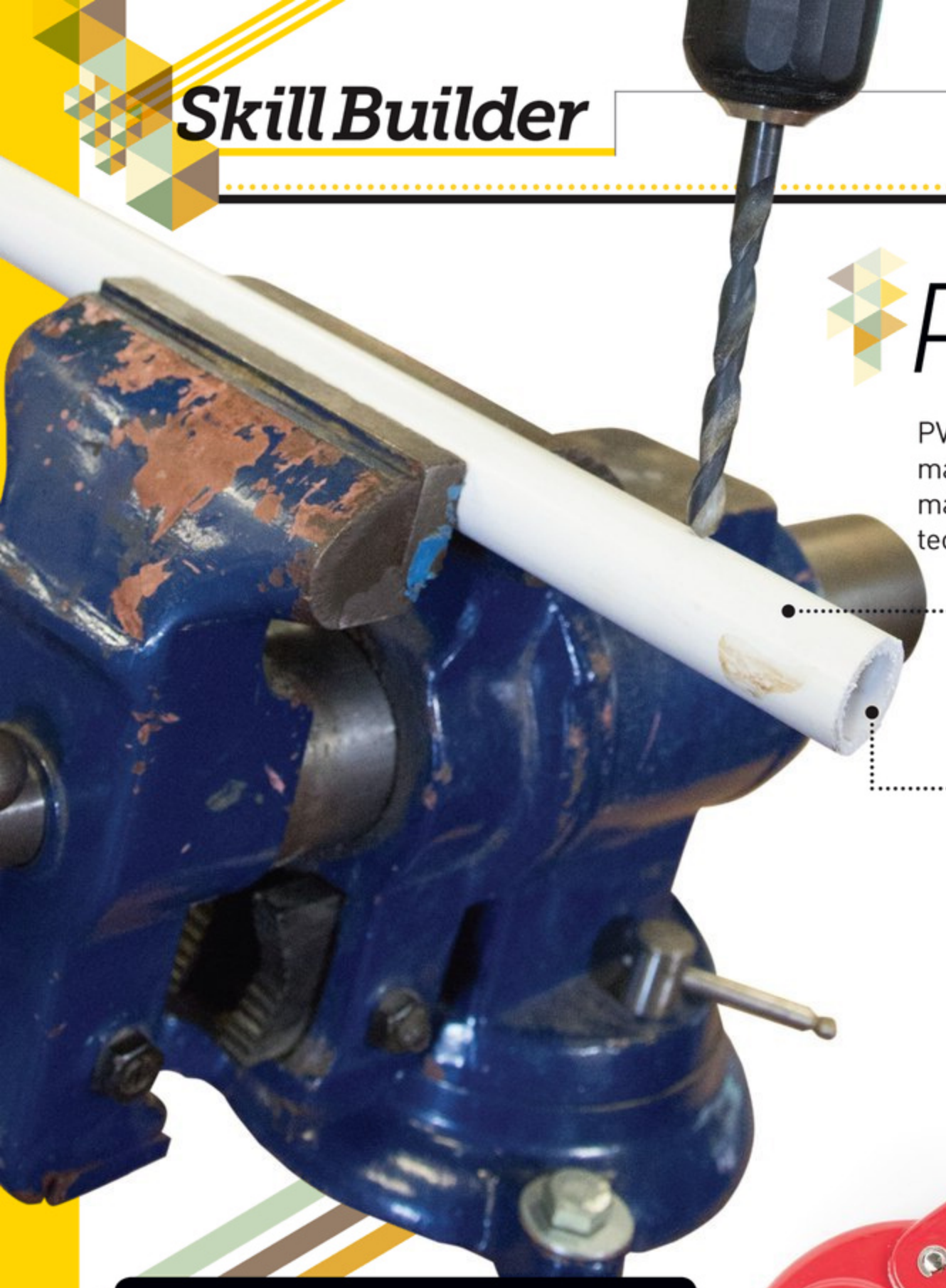
CARPENTER SQUARE AND SPEED SQUARE

Place the inside edges of the carpenter square against the edge of the circle. Place the base of a speed square against the carpenter square and align the angled side with the inside corner of the carpenter square. Draw a line along the angle of the speed square.

Rotate the material and repeat Step 1 to draw another line.

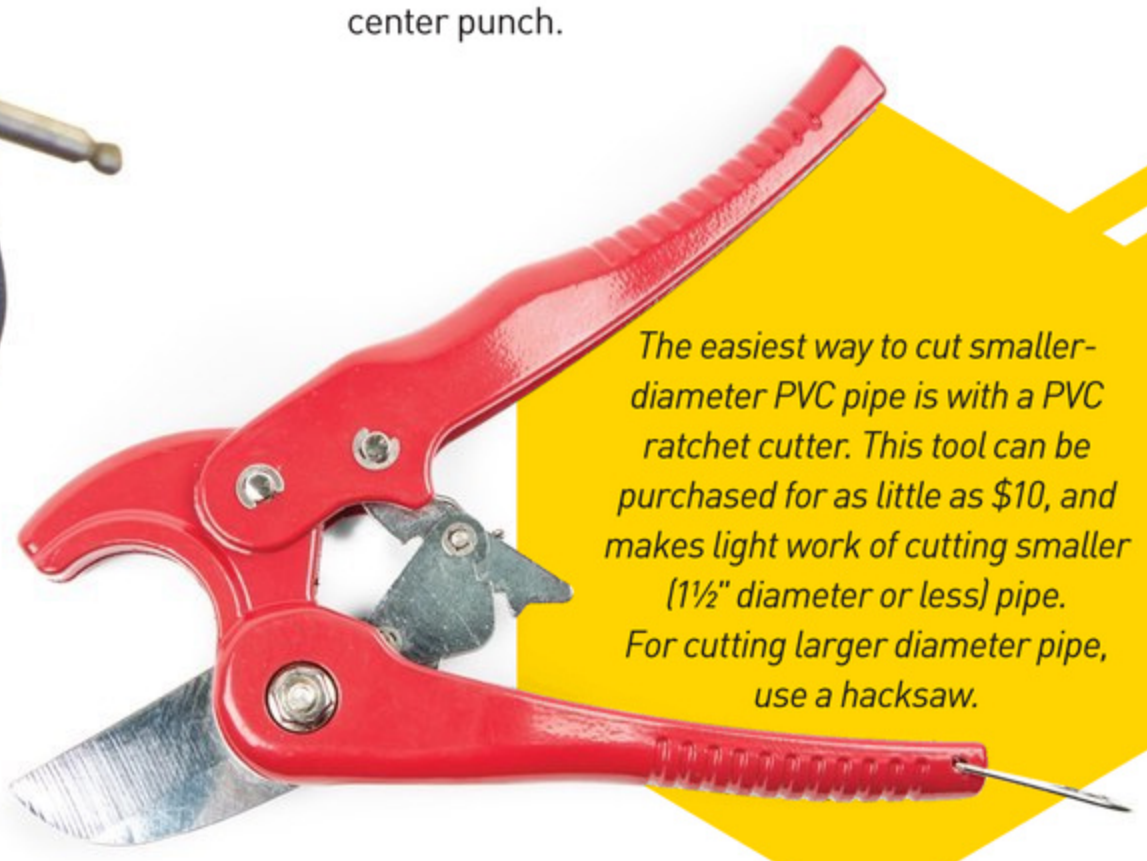
PVC PIPE

PVC pipe is a versatile material that finds its way into all manner of projects. Whether you're building furniture, making art, or even just plumbing your sink, here are a few techniques that will ensure that your project is a success.



Because PVC pipe is round, it tends to roll when drilling or cutting, so it's best to secure the pipe in a vise. You can also clamp the pipe to your tabletop in a V-shaped channel cut into a piece of wood, often called a V-block.

Because PVC is a soft plastic, you can use both wood and metal drill bits to make small holes, and spade bits can be used for larger holes. To keep the drill bit from slipping, make a small divot in the pipe using a hammer and nail or center punch.



The easiest way to cut smaller-diameter PVC pipe is with a PVC ratchet cutter. This tool can be purchased for as little as $10, and makes light work of cutting smaller (1½" diameter or less) pipe. For cutting larger diameter pipe, use a hacksaw.

TIP

Don't have a hacksaw or PVC cutter? Wrap a piece of string around the pipe and hold one end in each hand. Pull the string tight, and pull the ends back and forth in a sawing motion. The friction of the string against the pipe will cut right through it.

GLUING PVC

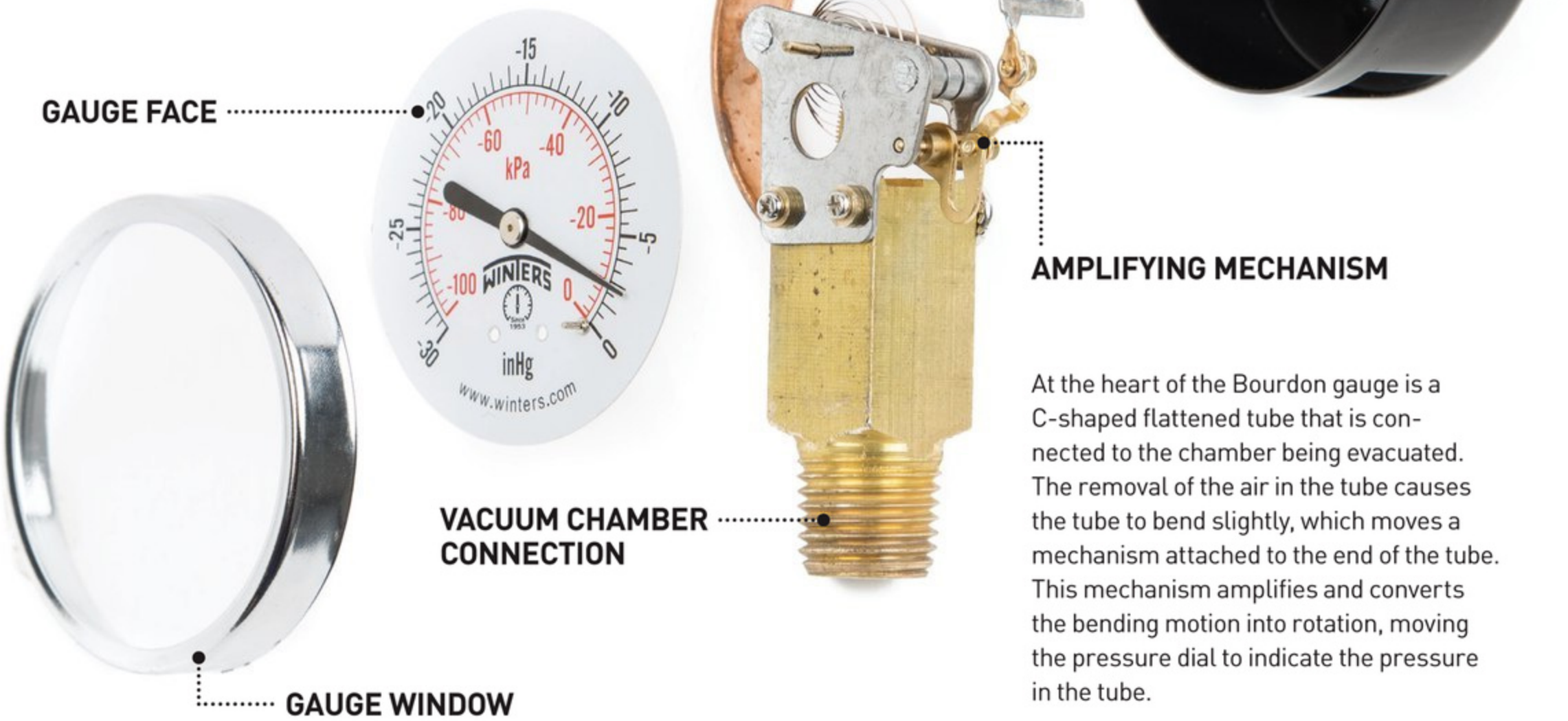
To make strong, sealed joints, use PVC primer and PVC cement. The primer cleans and prepares the PVC surface, and the cement uses a solvent to weld the PVC together. You can often find the primer and cement packaged together at your local hardware store.

CAUTION

If you're using PVC in a high-pressure project such as a potato cannon, proceed with extreme caution! In general, most PVC pipe is not rated for high pressures or rapid pressure changes. Take every safety precaution to protect yourself, and when in doubt, consult a professional.

VACUUM GAUGES

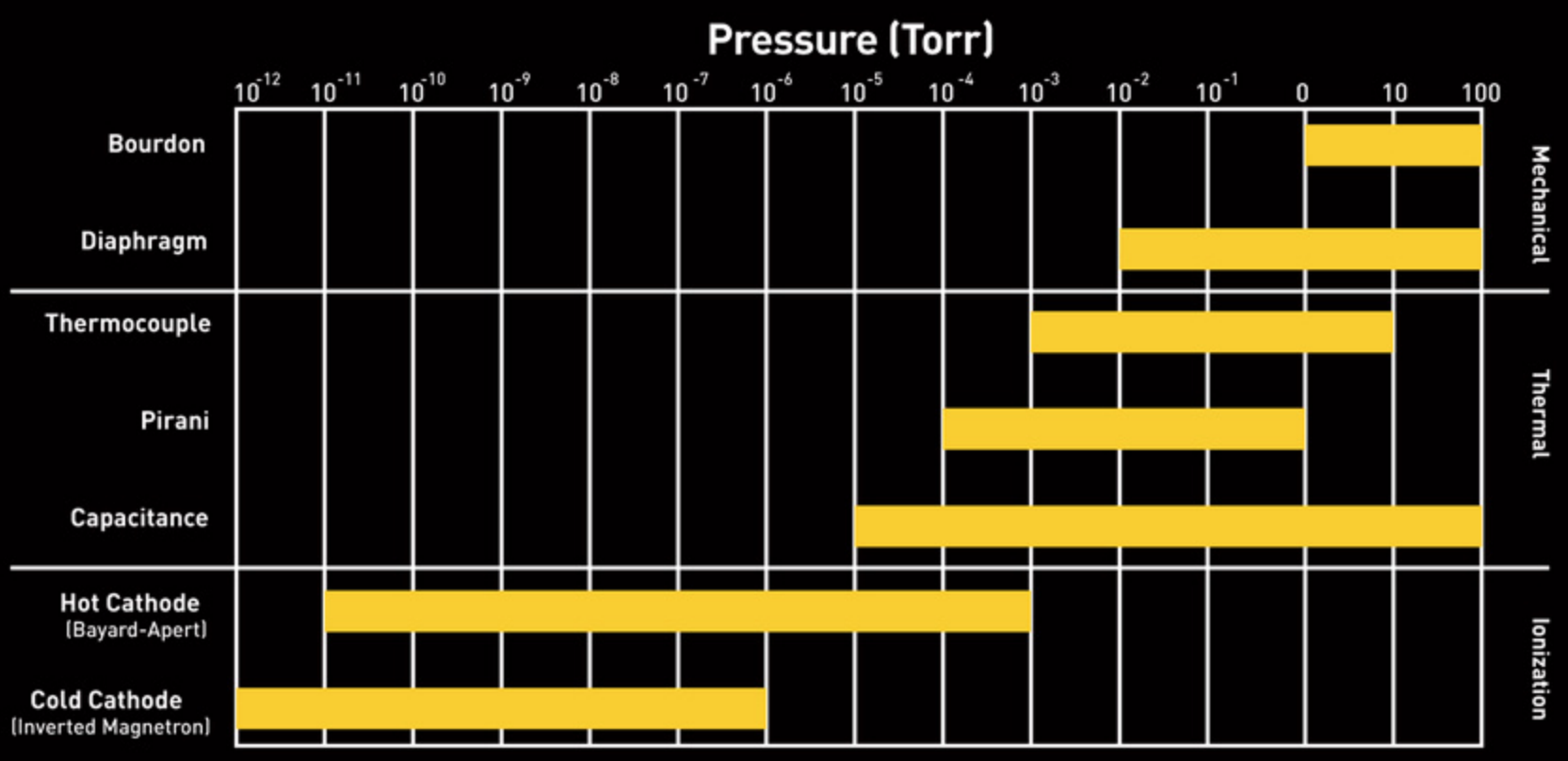
When you're working with projects involving vacuum pumps, a vacuum gauge will show you the pressure in the chamber being evacuated. There are many different approaches to measuring the pressure in a vacuum, but we'll focus on one of the most common, called the Bourdon pressure gauge.



At the heart of the Bourdon gauge is a C-shaped flattened tube that is connected to the chamber being evacuated. The removal of the air in the tube causes the tube to bend slightly, which moves a mechanism attached to the end of the tube. This mechanism amplifies and converts the bending motion into rotation, moving the pressure dial to indicate the pressure in the tube.

VACUUM GAUGE SELECTION CHART

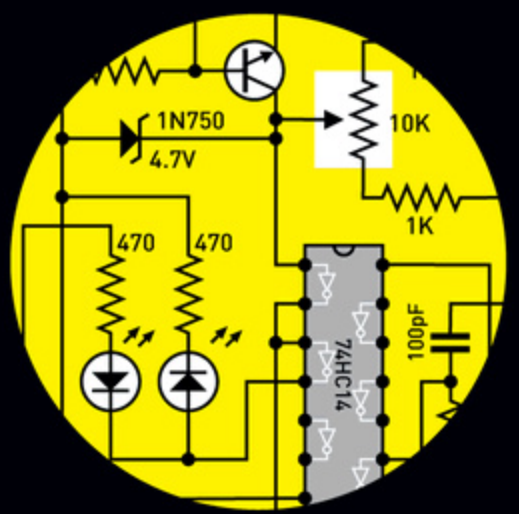
Different types of pressure gauges have different pressure ranges that they can measure. If you're trying to reach a specific pressure, the following chart can help you find a gauge that can read that pressure:

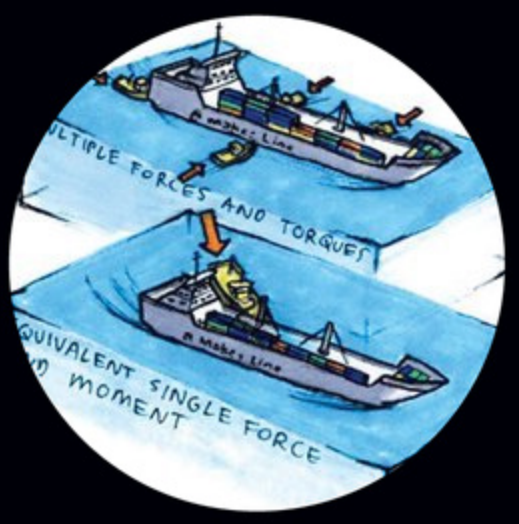


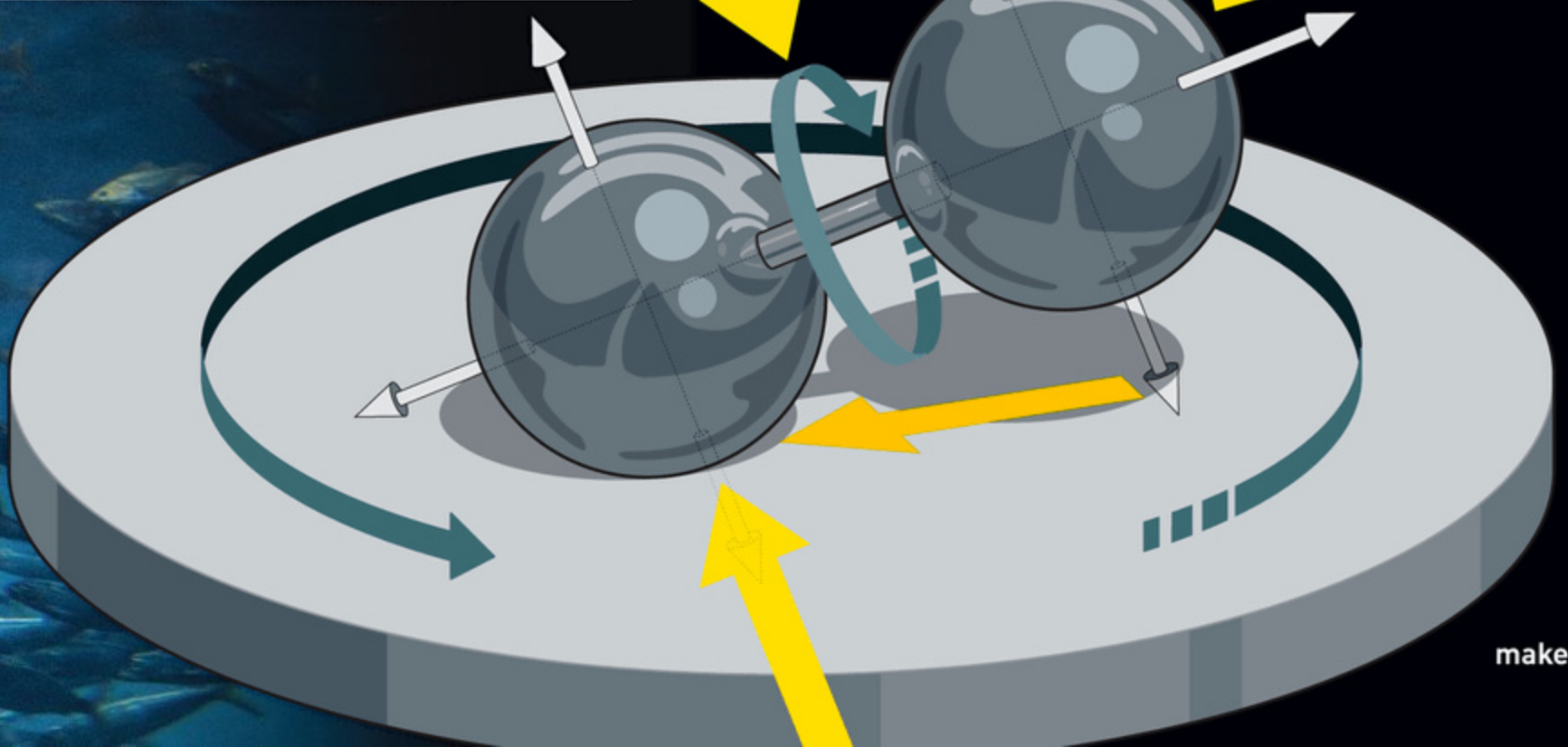
THE NUCLEAR FUSOR

Now use these skills to build yourself a star in a jar! The Nuclear Fusor project from Make: Volume 36 teaches you how to create a homemade atom-squeezing nuclear fusion reactor. Every tool or material covered in this section is used in the making of the fusor — but they'll also help you tackle any number of tricky projects that you've been waiting to build. makezine.com/go/nuclear-fusor

PROJECTS







Written and photographed by Thomas Burg and Johannes Gottwald

High-Speed Splash Photography with Arduino

Build this simple rig to capture stunning shots at the moment of impact

THOMAS BURG was a geek before it was cool. He studied physics in Mainz, Germany, and now works as CTO for a software company in Weisbaden. His hobbies include music and tinkering around with various objects.

JOHANNES GOTTWALD has been "infected" with photography since he got a set of Exakta macro equipment from his uncle at age 10. He studied physics in Mainz and started his own company (42-com.de) in Weisbaden..

PHOTOS OF ITEMS DROPPING INTO WATER (OR OTHER LIQUIDS) ALWAYS HAVE THE potential to fascinate — the dramatic splashdown, the explosion of flying droplets frozen in time. They're also increasingly seen in commercial images — look in your local supermarket and there's a high probability you'll find an image of a strawberry, chili pepper, or banana hitting the water, captured by a high-speed flash.

Together with a photographer buddy (like me, a physicist by training), I spent several long evenings trying to take great "water action" photos. We had some success, as Figure A shows, but we were doing it the hard way. This photo was one among hundreds we took in a single night — the vast majority of them showed the die cube not in the water yet, or too deep in the water.

In this project we'll instead show you how to take perfect splash photos, the easy way — by precisely timing the dropping of the object and the triggering of the flash, using an Arduino microcontroller board.

CATCHING THE MOMENT

There are three key elements in doing high-speed splash photography:

» **Using a flash to "freeze the action"** Modern electronic flashes emit light for only a tiny fraction of a second (less than 1 millisecond). If the room is otherwise dark, this will freeze the action.

» **Planning the shot** What happens, where's the camera, how does the lighting work, in detail?

» **Getting the moment right** This is the real trick. Before building this project, we relied on trial and error, somewhat along the lines of:

a. Drop object

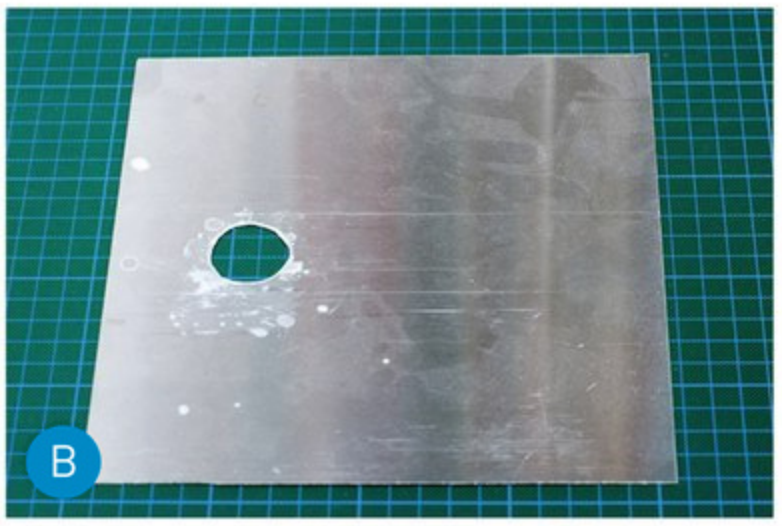
b. Do a mental count of how long it'll take for the object to hit the surface

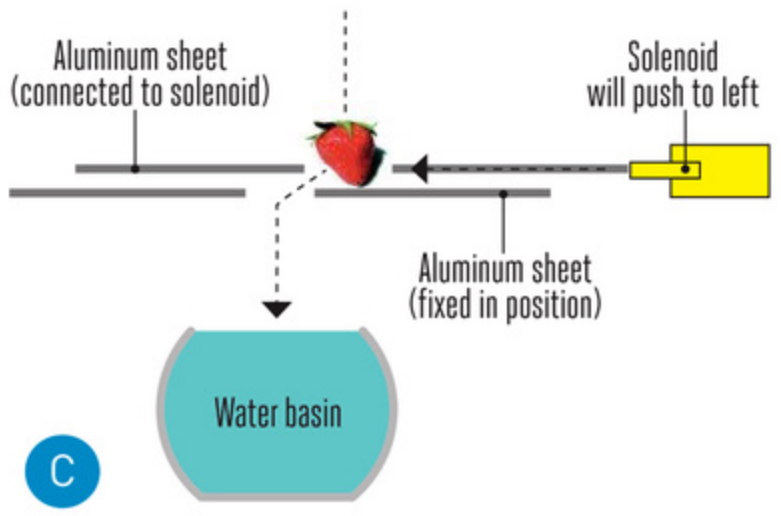
c. Manually release the flash

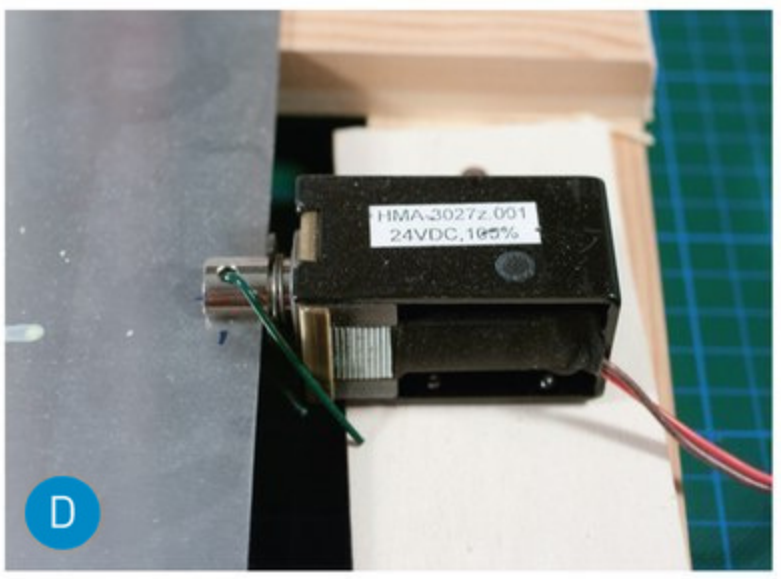
d. Pray for a "hit"

Having played with Arduino a bit, we wondered whether we could take the guesswork out of our shoots, and after a lot of tinkering we came up with the rig explained here. Now we can catch splashing photos in a repeatable fashion, thanks to an electromagnetic solenoid controlled by an Arduino Uno.

It's not hard to build, but you will need to do some experimenting to configure the rig. Our description here is not very precise, as your parts and photography needs may vary. But hopefully it's good enough that you get the idea and start making!







1. BUILD THE DROPPER RIG

From the aluminum sheet, cut 2 plates the same size. Then cut matching holes in each plate, as shown in Figure B. The holes should be big enough to clear whatever objects you intend to drop into the water. Note that the background grid shows centimeters (1" = 2.54cm).

Build a simple wooden frame for the plates to lie on horizontally. One plate will be stationary and the other will glide on top, moved back and forth by the solenoid. Figure C shows an overview of how the main parts are positioned. Figure D shows how our solenoid is mounted at one end; its plunger has a slot that accepts the edge of the top aluminum plate.

Time Required:
A Weekend
Cost:
$100–$200

Materials

» **Arduino Uno microcontroller board** Maker Shed #MKSP99, makershed.com

» **Relay Shield for Arduino** Seeed Studio #SLD01101P, seeedstudio.com. It's got 4 relays; you'll use 2 or 3.

» **Solenoid, pull type, 2cm path length, 24V DC, 10W** We used Conrad #HMA-3027z.001-24VDC. In the United States try PED #42-120-610-720 (newark.com), Digi-Key 527-1018-ND (digikey.com) or similar.

» **Power supply to match solenoid specs**, such as Triad Magnetics #WDU24-300. I bought mine on eBay.

» **Breadboard**

» **Hookup wire**

» **Switch, momentary pushbutton**

» **Fuse holder for breadboard (optional)** such as RadioShack #BNC010GY-RC. To protect the solenoid power supply.

» **Fuse, 250V, 1A (optional)** RadioShack #270-1005, highly recommended

» **Aluminum sheet, 1/16" thick, about 2'×1'**

» **Scrap wood**

» **Drinking glass or jar**

» **Small objects to drop fruit, coins, etc.**

» **Water or milk**

» **Food coloring (optional)**

» **Small aquarium tank (optional)** To protect the equipment from splashes.

CAMERA & ACCESSORIES:

» **Digital camera with macro lens** Must support manual setting of exposure time and f-stop. Ideally a DSLR.

» **Electronic flash**

» **Flash shoe to connect flash to Arduino setup,** such Nisha HTS-T (bhphotovideo.com)

» **Flash sync cable, 3.5mm to connect to flash shoe**, such as Nero Trigger #CABLE-FLASH (bhphotovideo.com)

Tools

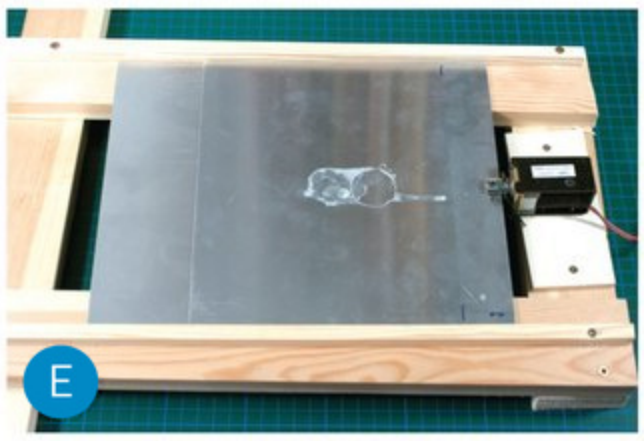
» **Soldering iron**

» **Handsaw**

» **Drill**

» **Fret saw or coping saw** for cutting holes in aluminum

» **Wood screws and/or glues**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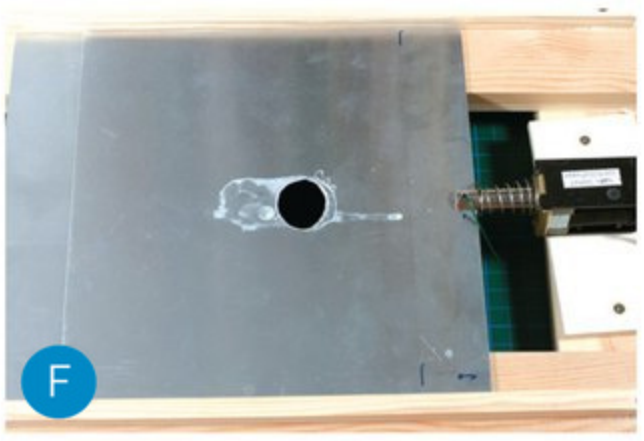
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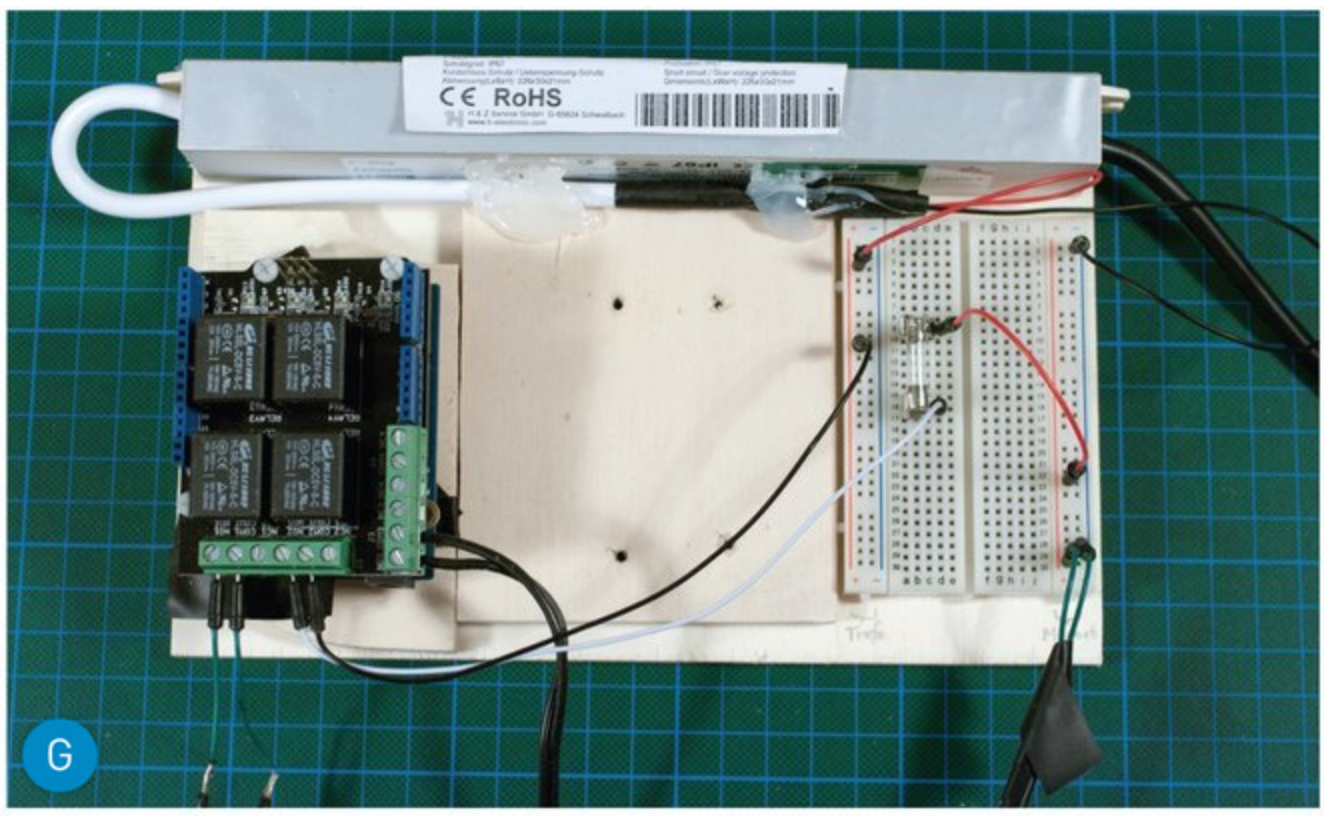


G


H

Figure E shows our completed frame, with small side rails to guide the plates. Here they're shown in the "loaded" position, ready for the solenoid to "fire."

2. TEST THE DROPPER RIG

To test the rig, connect the power supply to fire the solenoid. Polarity will determine whether the magnet pulls the plunger or pushes it; you want it to push. We recommend you do this via a simple breadboard setup using a pushbutton switch together with a fuse.

Adjust the position of the 2 plates until the holes align when you fire the solenoid. This allows you to precisely control when your object will start to fall. Figure F shows our rig after firing.

3. BUILD THE ELECTRONICS

Figure G shows our circuit. At lower left is the Arduino Uno board with the Relay Shield plugged into the top of it. Relay #1 (with green jumper wires) is optional — it will drive the shutter of the camera in a future version of this project. Relay #2 (black and white jumpers) connects to the breadboard to control the solenoid. Relay #3 (black cables) triggers the flash.

At the top is the power supply for the solenoid, its AC input coming from the right, and its DC output on the left (thick white cable split into thin red and black wires going into the breadboard).

And on the right is the breadboard, which provides fuse protection for the solenoid and power supply. Power comes from the power supply, is driven through Relay #2 and the fuse, and finally connects to the solenoid (green jumpers in lower right of Figure G).

4. PROGRAM THE ARDUINO AND TEST THE ELECTRONICS

Now program the Arduino and it will all magically come together. Download the project code file, *PhotoMagnet.ino*, from github.com/thomasburg66/PhotoMagnet. This simple program makes use of the Arduino's serial interface with your computer, to let you control a set of timing variables (in milliseconds) for your splash shots:

```
int delay_before_magnet=1000,delay_
after_magnet=300;
int flash_duration=10;
int magnet_duration=50;
int camera_duration=0;
```

In a nutshell, you want to fire the flash about 300 milliseconds after the relay has fired the solenoid (electromagnet) and your object has started falling, for a fall distance of 20" (0.5m). But you'll

adjust these variables for your particular setup.

Connect the Arduino to your computer and upload the code to the Arduino. You'll be prompted to enter the variables. With the Arduino program running, hit the Enter key to start the sequence. Make sure that the various actions ("fire flash," "fire magnet") indeed happen as you execute the program. If not, you need to check your wiring.

5. SHOOT SPLASH PHOTOS!

Put your camera and flash in position, set them both to manual operation, then select your f-stop, exposure time, and flash intensity. Take a couple of test shots of a static object to make sure the exposure is right.

Now work on getting the timing right. Here's the suggested sequence:

» Start the Arduino program. It will prompt you for the first value to be entered.
» "Load" the dropper rig by pushing the top aluminum plate into the slot on the solenoid's plunger.
» Put the object in the "drop zone" (the hole in the top plate).
» Finish your selection of values.
» Darken the room and hit your camera shutter button — we use a 3-second exposure — and then quickly ...
» Hit Enter to start the sequence of events.

Watch events unfold closely: Is the flash fired too early (the dropped object is not in the water yet)? Or too late (the splash event is already over)? Adjust the timing variables until your flash is capturing your splash.

Once you've got the timing variables dialed in, you'll start getting great splash photos like Figure H. You can see more of our results at makezine.com/go/high-speed-splash or on our site, immeressen66.com/2014/06/08/experimental-photography-results.

GOING FURTHER

Next we're going to control the camera shutter from the Arduino as well. And ideally both the camera and the flash should be fully de-coupled from the Arduino by using an optoelectric coupler rather than a relay (though a relay has worked fine for us for both the camera and flash). Other ideas:

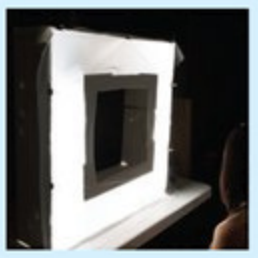
» Use multiple holes in both aluminum plates to drop multiple objects in parallel
» Use larger holes and objects
» Use tubes for objects to fall through in order to have them drop at angles.

Share your build and your splash photos at makezine.com/go/high-speed-splash.

The Square Ring Light

Capture unique eye highlights with a DIY rig

Written by Isiah Xiong



Time Required: 1 Hour

Cost: $15–$20

Materials

» **Foamcore boards, 20"×30" (4)** $1 at the dollar store
» **Aluminum foil** also $1 at the dollar store
» **Spray adhesive**
» **Duct tape, white**
» **Plastic tablecloth, white**
» **Binder clips**

Tools

» **Electronic flash units (2)** aka strobes or speedlights
» **Straightedge or ruler**
» **Utility knife**
» **Scissors**

PHOTOGRAPHERS ARE FAMILIAR WITH THE RING LIGHT, WHICH produces a pleasing ring-shaped highlight or "catchlight" in a subject's eyes. It's often used in the fashion industry to create images you see in many magazines. The Square Ring Light is just like that — except it's a square. I find it makes a unique catchlight that really draws attention to the eyes.

You'll need 2 speedlights (electronic flashes) as the light source. The rest of the project costs just a few bucks — it's mainly foamcore, aluminum foil, and duct tape.

1. CUT AND BEND THE FOAMCORE

Lightly score each foamcore board into thirds lengthwise. Bend each one into a U-shaped channel and reinforce the scores with duct tape.

2. ADD REFLECTIVE FOIL

Crumple the foil and flatten it out again. This helps to scatter the light when the flash fires. Attach the foil inside the foamcore channels using spray adhesive.

3. ASSEMBLE THE SQUARE RING

Measure in 6" from the end of a foamcore channel and make a cut so you can bend it into a second channel, then tape it down to create a corner. Repeat to make 4 corners.

4. ADD LIGHTS

Rest one speedlight in the top left corner, pointing down and slightly back. Rest the other at bottom right, tilted up and back. I have a radio trigger attached to one, and a slave unit to the other.

5. MAKE THE DIFFUSER

Trace your square ring onto the plastic tablecloth with a 1"–2" perimeter. Cut it out. Fasten with binder clips.

6. SHOOT SOME EYES!

You're ready to shoot. You can see some of my final results above. I'd love to see yours!

See build photos and share your shots at makezine.com/go/square-ring-light.

Isiah Xiong

Crochet a Mermaid Lapghan

Create your very own mermaid tail with this cozy couch blanket

Written by Shelley Bunyard

Abbreviations used in this guide

- sk — skip
- st — stitch
- sl st — slip stitch
- ch — chain
- sc — single crochet
- sc tog — single crochet together
- dc — double crochet
- dc tog — double crochet together
- * * — repeat instructions between asterisks

SHELLEY (MAD HOOKER) BUNYARD lives near Columbus, Ohio (by way of Alabama and Pittsburgh), with her wonderful husband and two young ones whom she often calls Pugsley and Wednesday. She works nights as a hospital unit coordinator and in her free time crochets at madhooker.com.

THIS ONE'S FOR ALL THE MERMAID LOVERS OUT THERE WHO ALWAYS WANTED THEIR OWN TAIL. The top part is a "lapghan" (small afghan) blanket and the bottom cocoons around your feet.

I tried buying a pattern for a mermaid tail but it was just awful. So I came up with this pattern using a 5-double-crochet shell stitch that looks a lot like fish scales.

This project, written in typical crochet shorthand, is moderately difficult but still doable for a determined beginner. (You'll find a list of abbreviations at left, and I'll walk you through specific stitches in the Crochet Notes below.) Get plenty of yarn — for the no-bind-off method that I use, you'll need at least 3 working strands of yarn changing to a different strand at the end of each row. And if you want a thicker tail fin, use 2 strands held together.

1. MAKE THE BODY

TO START: Ch 153.

ROW 1: Dc in 4th ch from hook and in each stitch across, ch 1 and turn.

ROW 2: *Sc in first dc, sk 2 dc, 5 dc in next, sk 2 dc* (this makes what I'll call the *5dc pattern*). The pattern ends on a sc, change colors (see Note 1, below). Ch 2 and turn (Figure A).

ROW 3: 2dc in first st (that last sc), sk 2 st, sc in the 3rd dc of the 5dc shell, sk 2 st, then follow the 5dc pattern until last sc. Here you only do 3dc, changing colors (Note 2), ch 1 and turn (Figure B).

ROW 4: Sc in first st, sk 2 st, then follow the 5dc pattern until the end where you sc in that last st/dc. Change colors, ch 2 and turn (see Note 3).

ROWS 5–73: Repeat rows 3–4 (see Note 4).

ROUND 74: From here you'll switch from *rows* to *rounds* in order to bring the lapghan around the feet. Sl st to the 1st dc of the row, ch 1, sc in joining, then proceed with 5dc pattern (Figure C).

ROUND 75: Sl st to 1st changing colors, ch 2 and 4dc in same as join. 5dc pattern to last sc. Now sc tog last sc to the 2nd dc from the beginning, making sure to change color (Figures D, E, F).

ROUND 76: Ch 1, sc in same as join then go on with the 5dc pattern (Figure G).

ROUNDS 77–94: From here you should be able to just go in a spiral, changing colors as you get back to the start of the spiral. That will mean changing colors in either the sc or the first dc, depending on where you are in the pattern. I did

Time Required:
A Weekend
Cost:
$15–$25

Materials

» **Yarn, worsted weight, 1,500–1,700 yards** depending on yarn type, how tightly you crochet, and other factors. I recommend getting plenty of extra yarn (because who doesn't need extra yarn?) until you've done this pattern a couple times and can judge yarn usage for yourself.

Tools

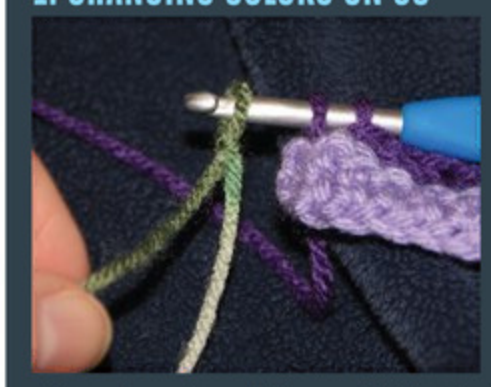
» **Crochet hook, Size H (5.00mm)**

» **Darning needle** for sewing

Shelley and Dan Bunyard

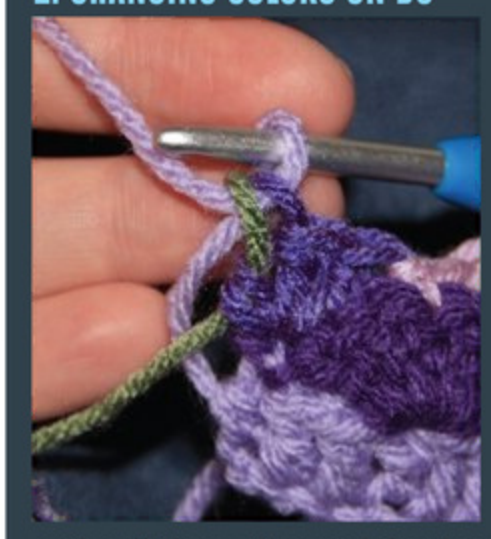
CROCHET NOTES

1. CHANGING COLORS ON SC



To change colors when last stitch is a single crochet, insert your hook into stitch, yarn over, and pull through the stitch. Now hook your new color strand, dropping the old strand, and pull through the last loop. When changing colors for the first time, I like to be cautious and do a simple knot with the tail and the dropped yarn. It keeps it doubly secure, but not exactly by the crocheter's handbook.

2. CHANGING COLORS ON DC



To change colors when the last stitch is a double crochet, you yarn over and insert your hook into the stitch. Yarn over and pull through the stitch then yarn over and pull through 2 loops. Now hook your new strand, dropping the old stand, and pull through remaining loops on your hook.

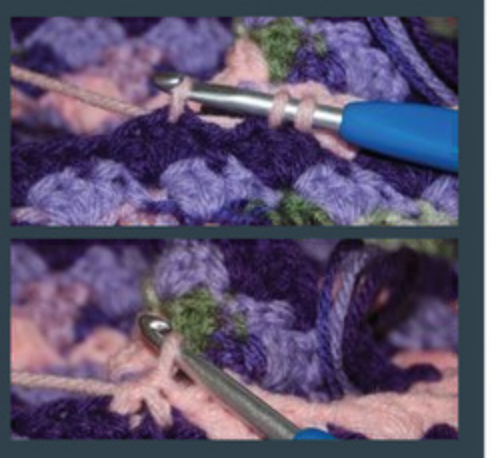
3. REPEATING COLOR CHANGE

By now your color change pattern might be ready to repeat, depending on the number of strands you're using. To make things easier, always bring up the next color behind the color you're dropping.

4. INCREASE/DECREASE

By making sure that on rows you start with a sc, you end with a sc and the rows you start with ch2, 2dc you end with 3dc you'll help ensure that you're not increasing or decreasing. You will also see the work is slightly raised and rippled. This is normal.

5. DO A SC TOG



To do a single crochet together (aka a single crochet decrease), insert your hook through first stitch, yarn over, and pull through stitch. You should have 2 loops on hook. Now insert hook into next stitch, yarn over, and pull through stitch. You'll have 3 loops on hook. Finally yarn over and pull through all 3 loops.

(Continued next page)

Hep Svadja

CROCHET NOTES, CONT'D

6. SINGLE OR DOUBLE STRAND

The fin can be done with 1 or 2 strands held together. I have done both ways and they both have worked and looked great. The 2-strand method will use more yarn, so keep that in mind. Here I'm showing the 2-stranded fin to show a little lesser known method than the typical one strand. Both will still use the size H hook.

7. HOW TO DO A DC TOG

To do a double crochet together (aka double crochet decrease), yarn over and insert your hook through first stitch. Yarn over and pull through stitch giving you 3 loops on your hook. Yarn over and pull through 2 loops, leaving you with 2 loops on your hook. Yarn over and insert your hook into the second stitch. Yarn over and pull through stitch giving you 4 loops on your hook. Yarn over and pull through 2 loops, then yarn over pulling through remaining loops.

a total of 20 rounds counting from the beginning of the original join. Make sure to carry the unused strands behind your work. When changing color bring your hook behind the unused strands, hook next color, and continue on from there (Figure H).

ROUND 95: Keep doing the pattern and color changing around, but instead of the 5dc, do only 3dc. Still skip 2 stitches in between the 3dc group and the sc (Figure I).

ROUNDS 96–98: Continue with 3dc group, but now only skip 1 stitch in between the 3dc group and the sc.

ROUND 99: Do 3dc, sc tog where the next 2 sc would go (in the 2nd dc of the 3dc group). Do your 3dc pattern, making sure to do a sc tog in every 3rd sc spot (see Note 5).

ROUND 100: Change colors in the first sc spot, 3dc then sc tog (in the 2nd dc of the 3dc group). Do your 3dc pattern with a sc tog in every 3rd sc spot. Continue around until back at the beginning of round.

ROUND 101: Change colors in first dc of the 3dc, sc tog over the next 2 sc spot. Do your 3dc pattern with a sc tog in every 3rd sc spot. Continue around until back at the beginning of round.

ROUNDS 102–103: Change colors in the first sc, then sc tog in every sc spot should be for 2 rounds. This should leave you with 12 stitches. Bind off, and leave a tail so you can go ahead and sew the tail closed (Figure J).

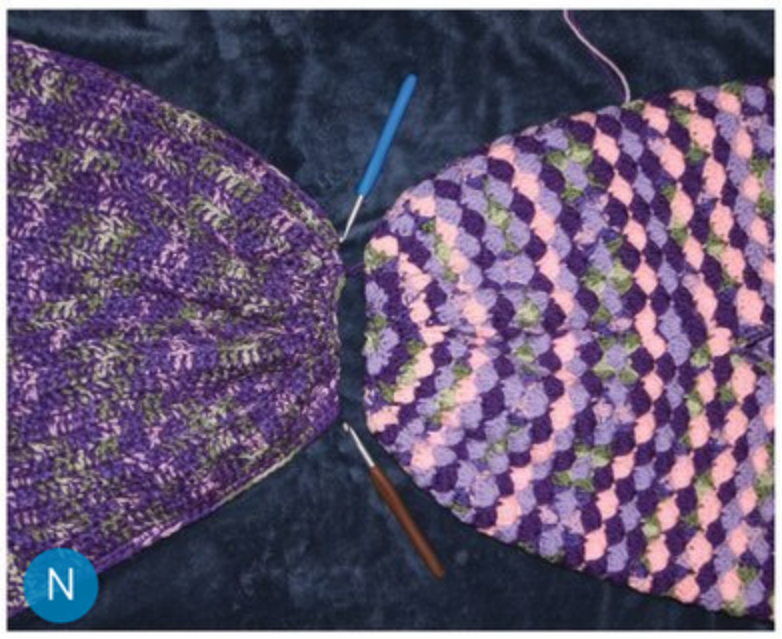
BORDER AROUND OPENING: Now you need to hide all the carried over yarn. I choose to use the variegated yarn. Join your yarn on the outside of the opening where you joined the rounds (round 74). Ch 1 and sc in same stitch then evenly around the entire opening. In the top corners, place 3 sc in the corners. Take care to make sure you're crocheting over the stands of carried yarn. Bind off and weave in the end (Figures K and L).

2. MAKE THE FIN

First, choose 1- or 2-strand method (see Note 6).

FIN ROW 1: Ch 43, dc in 4th chain from hook and dc across, ch 2 and turn.

FIN ROW 2: Dc tog, dc in rest of stitches, ch 2 and turn (see Note 7).



FIN ROW 3: Dc across, dc tog in last 2 dc, ch 2 and turn.
FIN ROWS 4–11: Repeat rows 2–3.
FIN ROW 12: Now do dc tog, dc tog, then dc in rest of stitches, ch 2 and turn.
FIN ROW 13: Dc across until the last 4 st where you will dc tog, dc tog, ch 2 and turn.
FIN ROW 14: 2 dc in each of the next 2 st, dc across, ch 2 and turn.
FIN ROW 15: Dc across, put 2 dc in each of the last 2 dc, ch 2 and turn.
FIN ROW 16: 2 dc in first dc, dc across, ch 2 and turn.
FIN ROW 17: Dc across, 2 dc in last st, ch 2 and turn.
FIN ROWS 18–25: Repeat rows 16–17.
FIN ROW 26: Dc across, ch 1 and turn.
BORDER OF FIN: Now sc around, making sure to put 3 sc in the corners except the last corner you come to, which should be your starting point. Ch 1 and turn, so that now you're working on the top/straight edge of the fin (Figure M).
TOP OF FIN ROW 1: Sc tog across, ch 1, turn.

TOP OF FIN
ROW 2: Sc tog across, ch 1 and turn.
TOP OF FIN ROW 3: *Sc tog, sc* across. Ch 1 and turn.
TOP OF FIN ROW 4: *Sc tog, sc* across. Bind off, leaving a long tail for sewing.

3. SEW FIN TO BODY

Lay the lapghan and fin both facedown and pin together. In Figure N I used 2 hooks to show actual beginning of fin to end of fin. Make sure to sew from technical beginning to end to give more stability to the fin. Whip-stitch the tail securely, including the sides of the sc rows, onto the lapghan. Bind off and weave the last one in.

Now celebrate because you're done! Go curl up with your feet cozy warm in your mermaid tail.

If you want to do another one (or are asked to replicate it), think about different color combinations, different boutique yarns, or fleece yarns you could use. A flashy option would be to sew sequins onto the final project. You're only limited by your imagination.

See more photos and share your version at makezine.com/go/crochet-a-mermaid-lapghan

Written by Larry Cotton with Phil Bowie

Kids' DIY "FUNiture" Kit

Let 'em build 5 different pieces with this color-coded set you can make in a weekend

LARRY COTTON is a semi-retired power tool designer and part-time math instructor who loves music, computers, electronics, furniture design, birds, and his wife – not necessarily in that order.

PHIL BOWIE is a lifelong freelance magazine writer with three suspense novels in print. He's on the web at philbowie.blogspot.com.

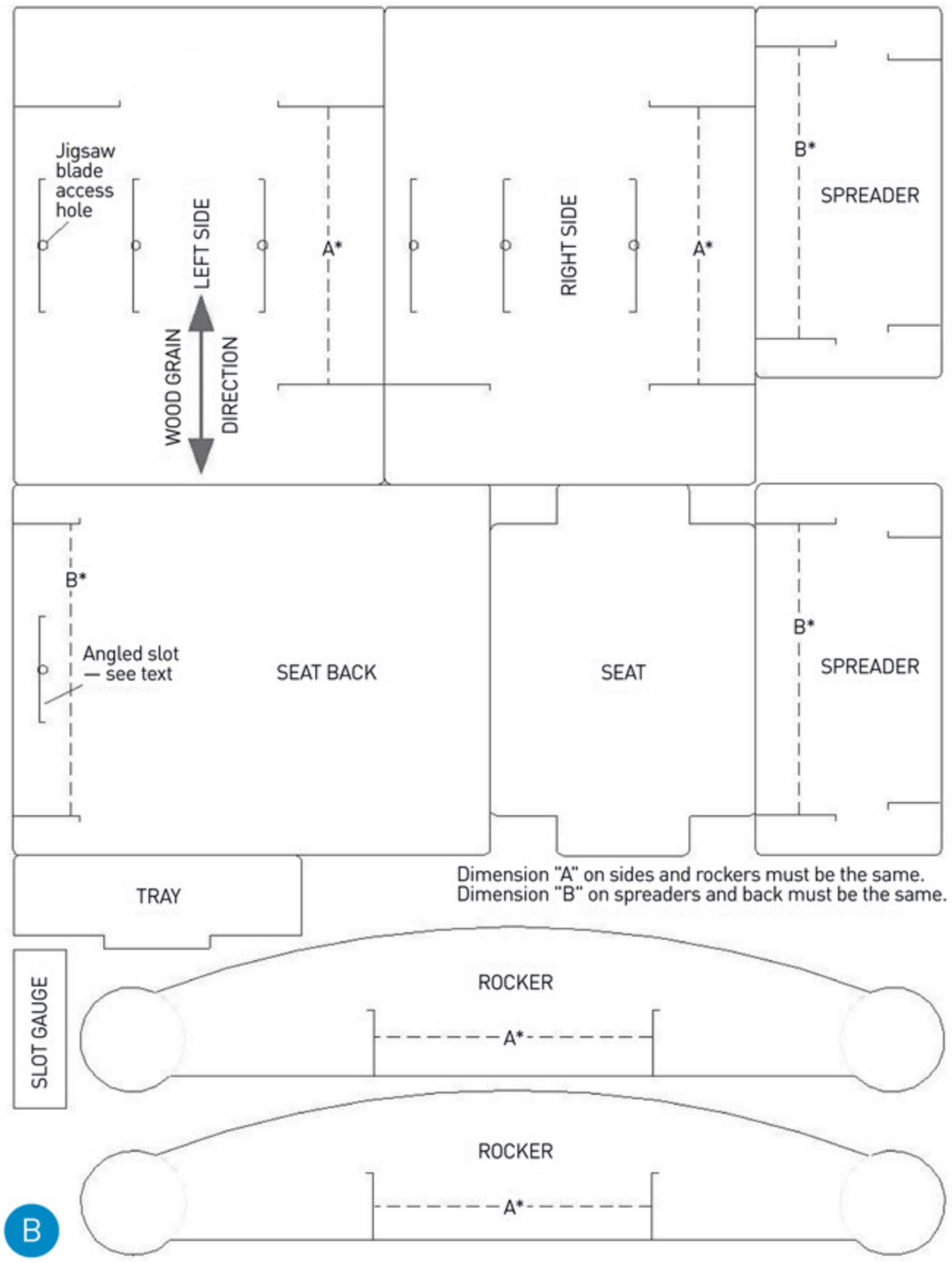
The author's cousins Bob and Cheryl – and Mr. Bim – enjoy the original FUNiture more than 50 years ago.

A "FEW" YEARS BACK, AS A FINAL-SEMESTER PROJECT AT THE NC STATE UNIVERSITY School of Industrial Design, I made a kit of plywood parts from which could be assembled several useful pieces of children's furniture. I called it "FUNiture" (Figure A).

Thanks to help from my good friend, prolific author and skilled craftsman Phil Bowie, this resurrected easy-to-make kit is now more ergonomically correct, safer, and suitable for ages 2 to 6. (The younger ones will need help with assembly.) The furniture needs no fasteners; gravity and cross-half lap joints do the trick. The parts can be stored flat, taking up very little space.

Colorful stickers at the joints help kids put the FUNiture together correctly by matching the colors of slots and tabs, to make a stool, chair, chalkboard, "boat," and rocking chair. Younger kids will probably ignore the color-coding, which can yield interesting, if impractical, creations.

Larry Cotton



Hep Svadja

Time Required:
A Weekend
Cost:
$40–$50

Materials

- **Plywood, ¼"×4'×4'**
- **Clear lacquer, 1qt** Deft or Watco
- **Round stickers, 2" (1 package)** Avery #22817
- **Elmer's Washable School Glue (2 bottles)** for using the printed template (recommended)
- **Chalkboard paint, green or black, 1 can** You can find it at Michaels craft stores.
- **Paint, orange or other bright color** for rocker ends
- **Chalk**

Tools

- **Jigsaw** to cut slots
- **Circular saw, table saw, or jigsaw** to cut parts
- **Drill and ⅜" bit**
- **Paintbrushes, small**
- **Sandpaper, assorted 60- through 320-grit**
- **Masking tape**
- **X-Acto knife with #11 blade**
- **Calipers** for measuring plywood thickness at store
- **Pencil or fine-tip marker**
- **Can or lid, 4" diameter** for a radius marker for rocker ends
- **Bottle cap, 1" diameter** for a radius marker for chalkboard

1. PREPARE THE PLYWOOD

All parts are cut from one 4'×4' piece of ¼" (nominal thickness) plywood, available from Lowe's, Home Depot, and others. Buy the thickest, flattest piece you can find. (We don't recommend fir because of its wild grain, relatively rough surfaces, and greater tendency to warp.)

To ensure the plywood is as thick as possible, bring your calipers to the store and measure the sheets' thicknesses. As with most wood, plywood is rarely sold at its nominal thickness. We measured so-called ¼" (0.250") plywood from 0.189" (just over 3⁄16") to 0.243" thick; we bought the latter.

Thoroughly lacquer-coat both sides and all edges of the plywood soon after bringing it home, to minimize warping. Let it dry, then sand both sides with 320-grit paper. You may want to apply an additional coat for extra scuff and weather resistance.

2. LAY OUT THE PARTS

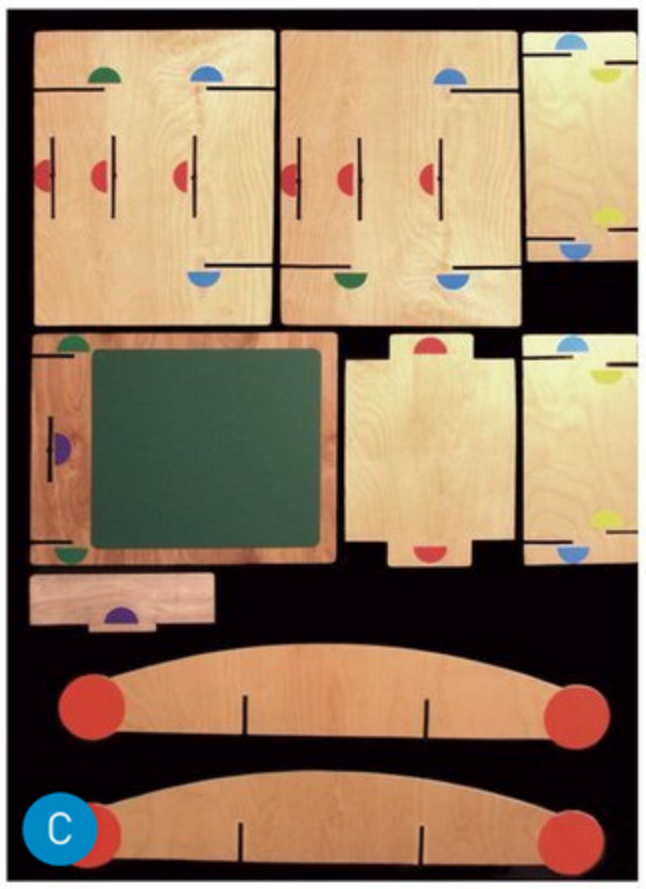
We offer 2 methods of transferring the parts' dimensions to the plywood. Once you decide which method you like, stay with it, because the two techniques' parts will probably not be interchangeable.

» Method 1: Template of full-size parts

Download our full-size parts template (Figure B) from the project page online at makezine.com/go/FUNiture; it's faster than laying out the parts by hand. It's in the DXF file format, so the line widths will be preserved when it's enlarged.

Ask an office supply store to print the drawing to fill a 36"×48" sheet of paper, with top and side margins no more than ½". Ask to see a preview before printing. (Other printer settings to be aware of: plot area/extents, plot scale/fit to paper, and centering the plot.) We paid about $8.

Select the lacquered plywood's better-looking



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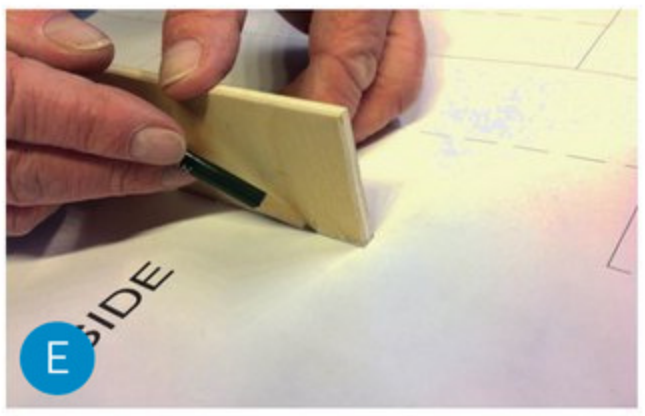

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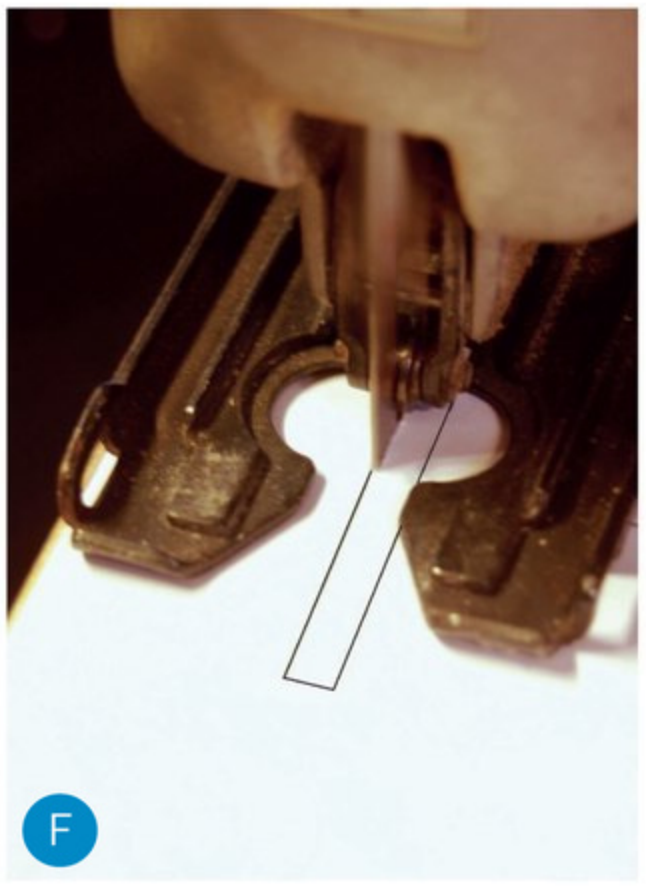

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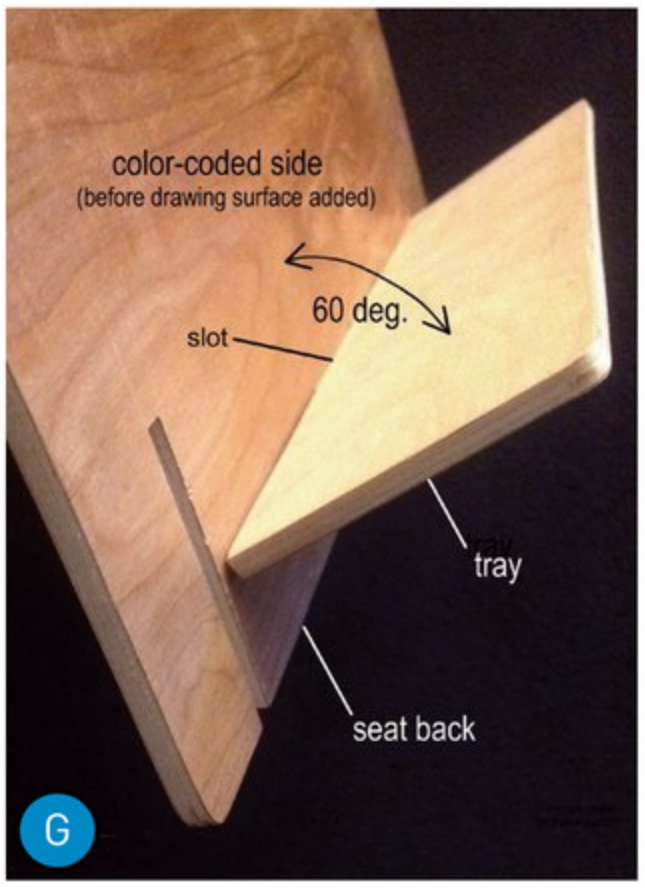

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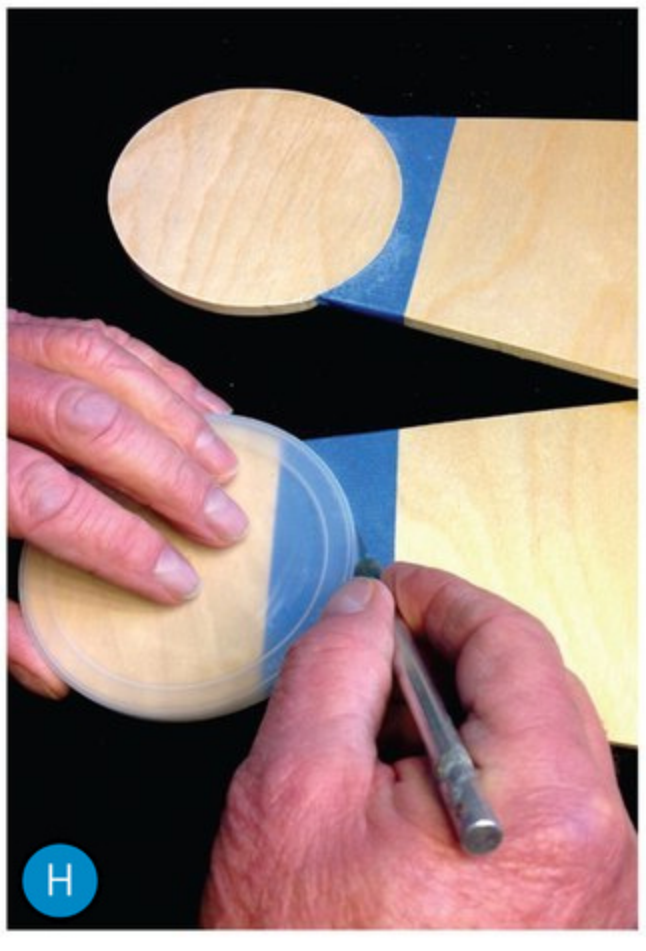

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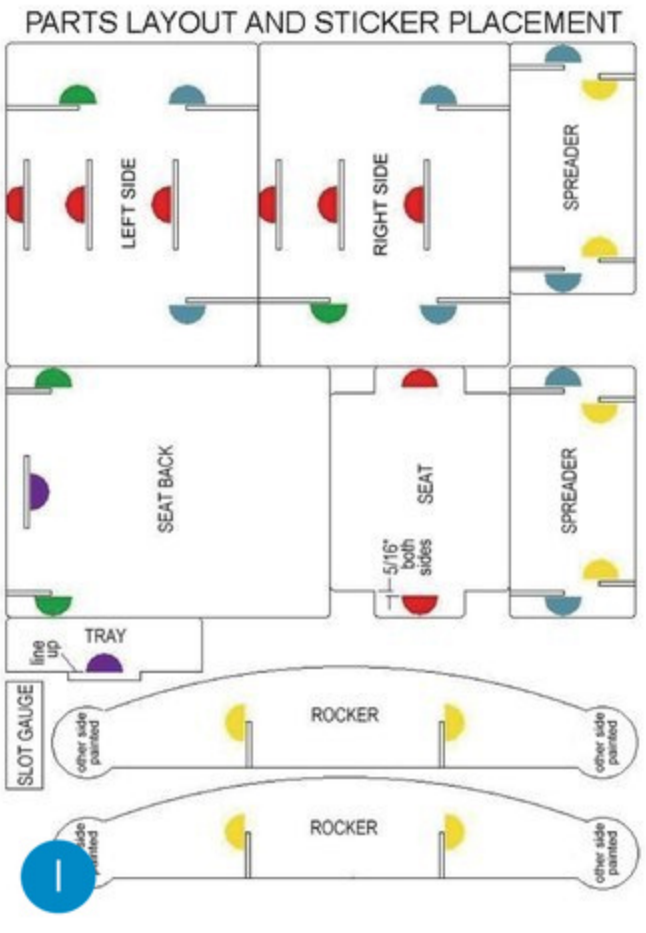

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face and, taking note of the wood grain direction as shown in Figure B, temporarily glue the template to it with a mixture of 1 part water to 2 parts Elmer's Washable School Glue. This ratio makes it relatively easy to remove the template after cutting. Line up one edge of the template with a plywood edge and tape it in place using masking tape. Brush the glue mixture onto the plywood as you (or a helper) roll out the template. A few minor wrinkles are OK.

» Method 2: Dimension drawings

You can also lay out the parts by hand, following our complete dimension drawings. Download all 7 drawings from the project page online at makezine.com/go/FUNiture.

Again, noting the grain direction of the lacquered plywood's better-appearing face, draw the parts on it with a sharp, soft-lead pencil or fine felt-tip pen. Pay particular attention to the slots' perpendicularity and parallelism to the sides. An efficient layout is shown in Figure C. (The 2 side pieces are identical, except that one is flipped to ensure the better side of the plywood faces out in the finished furniture.)

3. CUT OUT THE PARTS

Carefully cut out the parts with a portable jigsaw and a new plywood blade (Figure D). Do not cut the slots yet.

Sand all edges for comfortable and safe contact by little hands.

NOTE: If you have really little kids, you could round off the corners even more than we've shown here.

4. LAY OUT THE SLOTS

For easy, wobble-free assembly, all slots should be just slightly wider than the thickness of your sheet of plywood. Certain pairs of slots must also match in distance apart, length, and parallelism.

Open- and closed-end slots are shown on the template and drawings as one long line (an edge) and 1 or 2 short lines (the ends). Make a slot-tracing gauge from a scrap of plywood (roughly 2"×6") to draw the other long edges of the slots.

For each slot, place your gauge adjacent to (but not covering) the long line. Carefully trace your gauge to create the missing edges of the slots (Figure E).

IMPORTANT: The short lines also indicate which side of the long lines to place the gauge.

If you're using the template, some slots are

TIP: Use an X-Acto knife with a new #11 blade to mark all slot edges. This will slice through the outer-most layer of plywood and will result in burr-free cuts that require less sanding.

Larry Cotton

labeled "A" (on the sides and rockers) and "B" (on the spreaders and seat back). Dimension A on all 4 parts must be the same, and dimension B on all 3 parts must be the same.

Read the last few paragraphs again. Accurate slots are paramount to the success of this project. A misdrawn or badly cut slot is difficult if not impossible to correct, so go slowly here.

5. CUT THE SLOTS

Using the portable jigsaw, carefully cut all the open-end slots (Figure F).

Drill 3/8" blade-access holes in the centers of the 6 closed-end slots in the sides, then cut both ways with the jigsaw.

One slot in the seat back must be angled to hold the chalk tray (Figure G). Drill a centered 3/8" blade-access hole at a 60° angle from either side of the back. On the same side, cut half the slot with the jigsaw's shoe set to a 60° angle. Starting at the hole again, cut the other half of the slot with the shoe set to a 60° angle the other way.

TIP: To avoid flipping the shoe, you can drill the angled hole at one end, then make all cuts at the same shoe setting.

6. TEST-FIT THE JOINTS

For template users, slowly peel the paper off each part. If the glue adheres excessively, soak the residue with a wet sponge, let stand, then remove.

Check the slots with your gauge. Then, using the photos of the finished rocking chair as a guide, test-fit every joint. If they bind, find where the binding occurs, then sand the slots with medium sandpaper wrapped on a thin scrap of wood, say, 1/8" or so.

Brush or spray lacquer into the slots to seal them against moisture, allow the lacquer to dry, and test-fit the joints again.

7. PAINT THE ROCKERS

On the better side of each rocker, mask the circles at the ends with masking tape, then cut the curves with an X-Acto knife with a #11 blade guided by a 4" diameter object, such as a can or container lid (Figure H).

Paint them a bright color. We chose orange, which isn't a sticker color used for the assembly.

8. PAINT THE CHALKBOARD

Temporarily put the tray into its angled slot in the seat back so that it tilts upward. On that side of the seat back, mask your chalkboard shape for painting, leaving about a 1" border all around.

Similarly to the rockers, round the corners by applying masking tape, then cutting the curves using a 1"-diameter object (a bottle cap works fine) as a guide.

Remove the tray and apply 3 coats of chalkboard paint, lightly sanding between each, before unmasking. Wait 24 hours before using.

"Season" the chalkboard by rubbing it all over, in several directions, with the side of a piece of chalk, then erasing it. Now it's ready to use.

9. STICKERS!

Two half-circle stickers form a circle of the same color when a joint is correctly assembled.

Using Avery's label template, print fifteen 2" round labels (Avery 22817) in bright colors: 4 yellow, 4 red, 2 green, 4 blue, and 1 purple. Cut them in half to get 30 half-circles.

Apply the stickers as shown in Figure I. Center the stickers on the ends of open-end slots, and on the sides of the closed slots. (If the seat stickers drag on those slots, widen the slots slightly.)

On the seat back, the 3 stickers must be on the outside, i.e. the chalkboard side. On the rockers, stickers go on the inside, i.e. on the sides opposite the painted 4" circles.

You can make an optional sticker locator jig for perfect alignment (download the drawing on the project page), or just eyeball their locations.

10. ASSEMBLE

You can make 5 different creations by following the color-coded stickers.

STOOL

The simplest piece of FUNiture is a stool (Figure J), which uses the sides, seat, and spreaders. The 3 slots in each side allow 3 different heights. Follow the color coding; it's best to start with red. (Or you can let the assembler discover this.)

CHAIR AND CHALKBOARD

Add the seat back and its tray to the stool. Color coding ensures a seated child doesn't lean against any chalk art (Figure K).

"BOAT"

Build the stool with the seat in its lowest position, then add the rockers with painted circles facing out (Figure L).

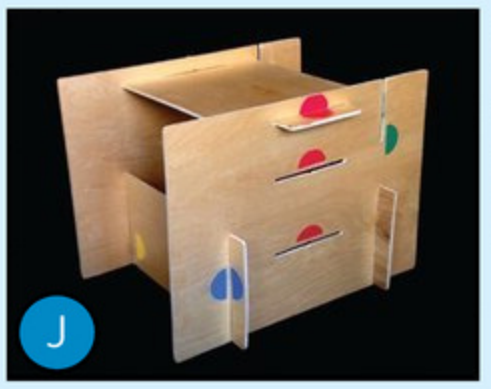
ROCKING CHAIR

Add rockers to the chair (Figure M). You're done. Rock on, kids!

Download the printable full-size template and/or dimension drawings, and share your build at makezine.com/go/FUNiture.

THE FUNITURE BEGINS!

Kids can just match the stickers to make these 5 different furniture pieces.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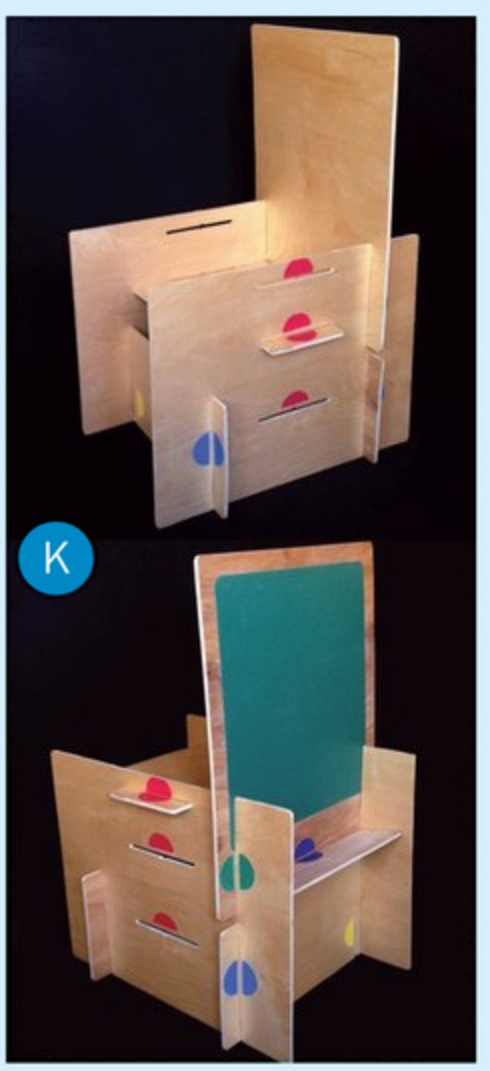
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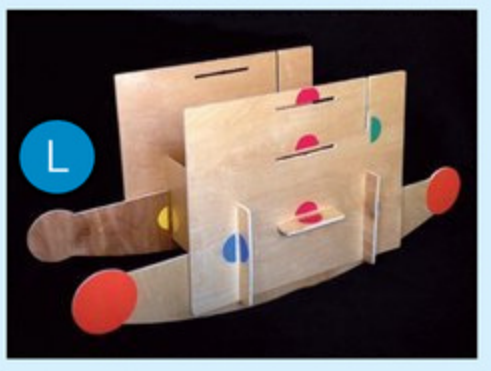
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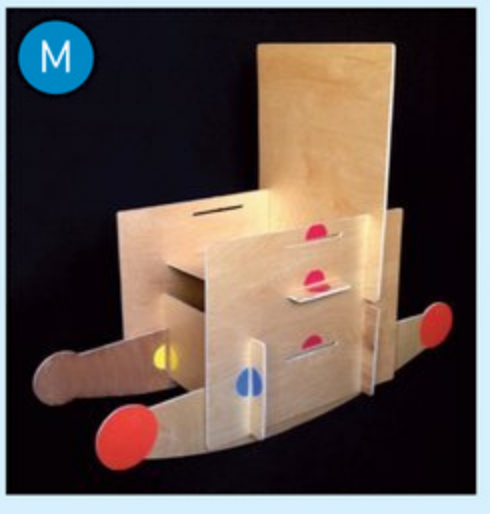
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Who's Watching You?

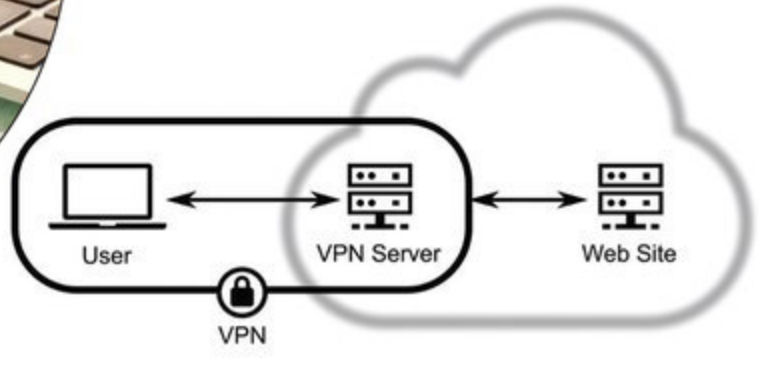
Protect your digital privacy with these DIY projects

CELLPHONE SNOOPING. NETWORK SURVEILLANCE. FACE RECOGNITION TECHNOLOGY. As the gadgets we search, watch, and read become more able to watch us back, makers are finding clever ways to guard their privacy and maintain anonymity online. Here are a few of our favorites.

BROWSE ANONYMOUSLY

DIY RASPBERRY PI VPN/TOR ROUTER

Surf the internet securely with your very own portable Wi-Fi VPN router. Simply configure a Raspberry Pi mini computer with Linux and some extra software to connect to a Virtual Private Network server of your choice. The VPN connections create a single encrypted tunnel between your computer and a website so that spies can't figure out what sites you're visiting, and the sites can't tell which computer you're surfing from.



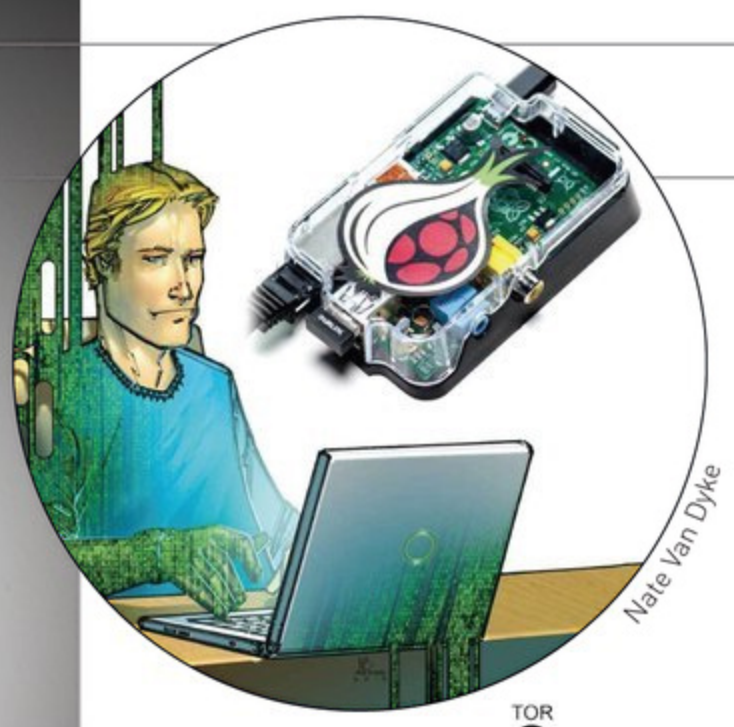
You can also set up this router to support Tor, The Onion Router (see next project). VPN is harder to configure, but it's faster, and can be more secure than Tor if you trust your VPN server.

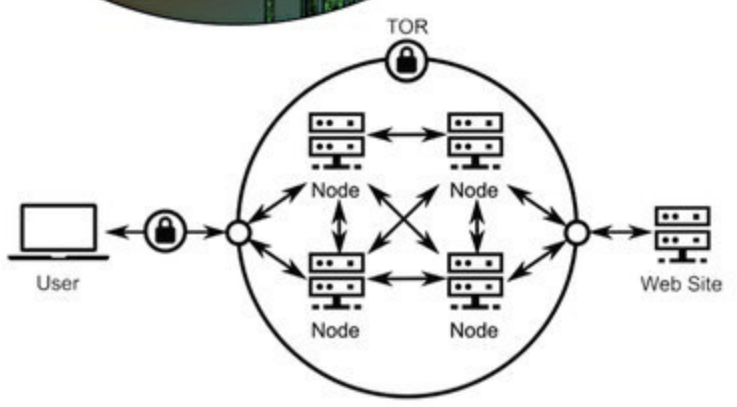
Assembly is easy — all you need is the Pi, two USB Wi-Fi dongles, an SD card, and a power plug. Get step-by-step instructions at makezine.com/go/pi-vpntor-router.

BUILD AN ONION PI ROUTER

Browse the web anonymously anywhere you go with the Onion Pi Tor proxy. This project uses a Raspberry Pi, USB Wi-Fi adapter, and Ethernet cable to create a small, low-power, portable privacy router.

Tor is easy to install but relatively slow because it encrypts and routes your internet traffic over several random nodes on the network before connecting your computer to a website. To use it, you


Nate Van Dyke



don't need a VPN server, just a Tor-enabled web browser. Tor also gives you access to a hidden layer of the internet called the Dark Web, unavailable over VPN.

When you power up the Onion Pi, it will create a new secure wireless access point. Connect to it and it will automatically route any web browsing from your computer through the anonymizing Tor network. Your tracks are swept clean.

To build your own, visit makezine.com/go/bake-an-onion-pi.

GET OFF THE GRID

MAKE A LIBRARYBOX FILE SHARER

Want to share files but bypass the internet? PirateBox is a mobile, anonymous file-sharing device, allowing anyone to upload and download from mobile phones, laptops, and plug computers. When PirateBox developers leveraged the project onto inexpensive 3G-to-Wi-Fi routers, Clayton Clark forked it to create LibraryBox.

Jason Giffrey

LibraryBox is a wireless digital download hub, unconnected to the web — simply put your content on a USB stick, plug in the stick, and power up the box. It'll even stream video and audio, and it runs all day on a rechargeable battery pack. Build yours at makezine.com/go/librarybox.

INTERNET KILL SWITCH

While you're away from the keyboard, your software can automatically update itself or back up data to a remote server. It can also get into lots of trouble — backdoors, bot-nets, spyware. Here's a simple, foolproof answer: a hardware kill switch. Put it on the wired connection between your computer and router and use it to isolate that computer from the internet whenever you want. Or between your router and ISP to disconnect the entire house. Make it at makezine.com/go/internet-kill-switch.

Gregory Hayes

MOVE UNSEEN

KILL YOUR PHONE

Sure, you can power down your cellphone — but spies can track a phone's location even when it's turned off. Guard your privacy by sewing a pouch of copper- or silver-coated fabric that acts as a Faraday cage to block radio waves to and from your device.

There's a good selection of EMF shielding fabrics at lessemf.com/fabric.html. Look for fabrics with 70dB+ shielding performance over a broad range of frequencies — cell networks operate at 380MHz–2.7GHz, Wi-Fi at 2.4GHz–5GHz. The pouches don't require special thread, but it's important to fold the fabric on all sides so no radio waves can escape. Learn more at killyourphone.com.

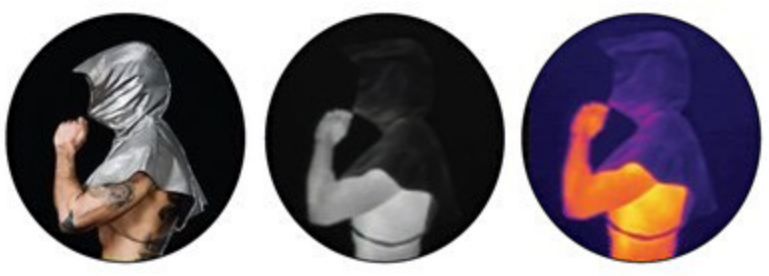

Aram Bartholl

DIY COUNTER-SURVEILLANCE "STEALTH WEAR"

Dress for low-visibility success! Mechanical engineer and artist Adam Harvey (ah-projects.com) designed an "anti-drone hoodie" using metallized fabric to counter thermal imaging used by drones to spot people on the ground. He also developed CV Dazzle face and hair make-up you can wear to stymie face recognition software.

Inspired in part by Harvey's projects, Japanese professors Isao Echizen and Seiichi Gohshi hacked goggles with an array of infrared LEDs (invisible to the eye) to foil face recognition cameras.


Japan National Institute of Informatics


Adam Harvey

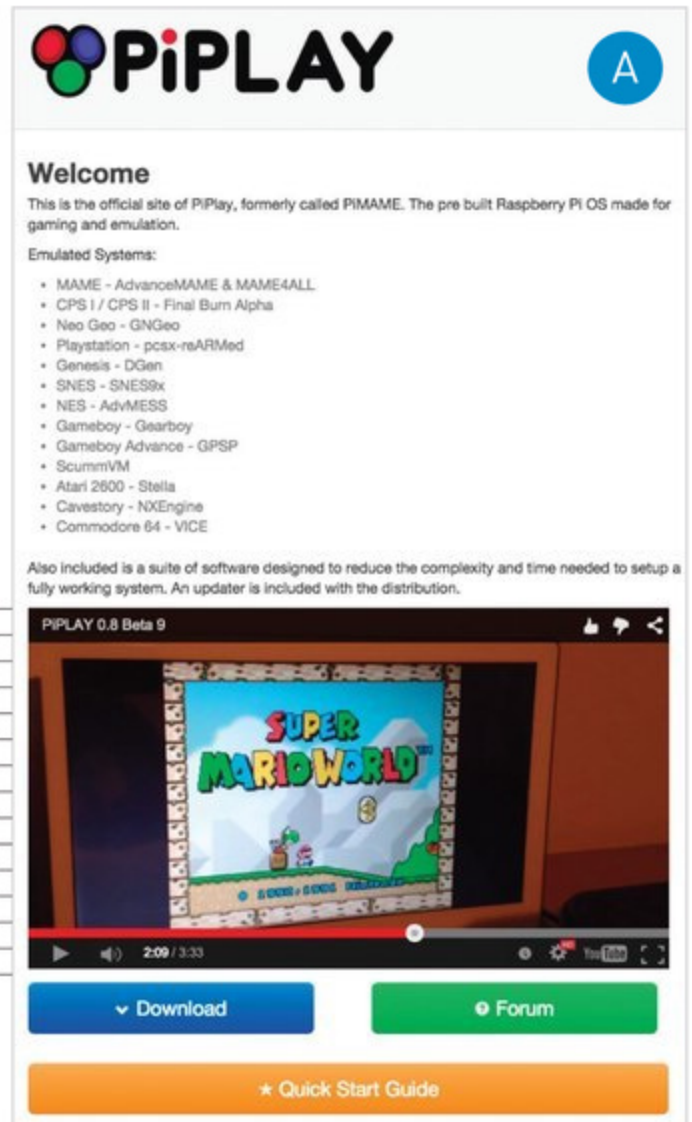
Home Arcade

RASPBERRY PI

Play all your favorite 8-bit video games with MAME and an Arduino Esplora controller

Written by Tyler Winegarner

Juliann Brown



THE RASPBERRY PI IS GREAT FOR ALL SORTS OF SMALL COMPUTING applications — 3D printing servers, in-car computing, and more. But the Pi can also be the beating heart of a classic video arcade machine. And who doesn't want one of those?

Using a distribution of Linux maintained by Shea Silverman called PiPlay, you will be up and running some of your favorite, classic games of the 8-bit era on your $35 ARM-based computer in no time.

To keep things simple, we'll use the Arduino Esplora as our game controller. The Esplora is a unique entry into the Arduino family of boards. It has a number of control inputs preinstalled, and the layout is familiar to anyone who has held a modern game controller. What's more, the Esplora is able to emulate a keyboard simply by plugging it into a computer. This makes it pretty ideal for fast, simple gaming.

1. DOWNLOAD PIPLAY AND FLASH AN SD CARD

First, download the PiPlay disk image from sourceforge.net/projects/pimame (Figure A).

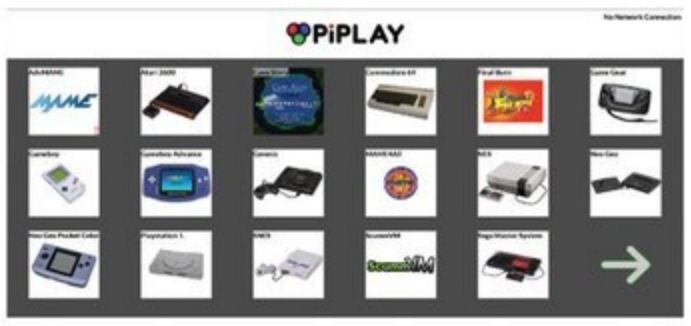
Then flash the PiPlay image to your SD card. (Head to the project page at makezine.com/go/raspberry-pi-home-arcade for complete platform-specific instructions.)

2. CONFIGURE THE RASPBERRY PI

Now you'll set up your Pi, ensuring that your keyboard is configured properly, and that you have the entire capacity of your SD card available to the partition.

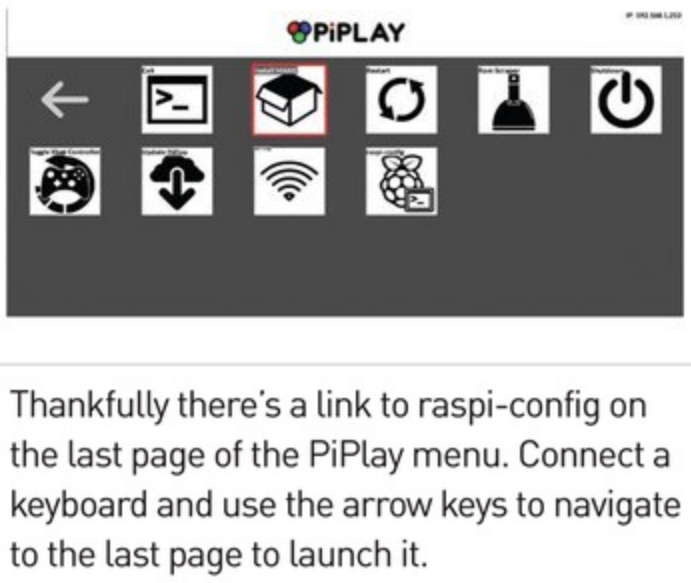
The first time you boot your Pi with a PiPlay-flashed SD card, the system boots straight into the PiPlay emulation hub, bypassing raspi-config, the configuration tool that is ordinarily run at first-boot on the Raspbian distribution of Linux (Figure B).

B



C

D



E

```
Converting to dictionary...
Fetching SNES rom list...
Connecting to thegamesdb.net...
No roms found...

show clones: False
Loading mame4all.dat...
No roms found...

Fetching Neo Geo rom list...
Connecting to thegamesdb.net...
No roms found...

show clones: False
Loading advmame.dat...
 alienar.zip - Verified
   joust.zip - Verified
 ripcord.zip - Verified
sinistar.zip - Verified
Checking images for 4 roms.
File already exists: alienar.jpg
File already exists: joust.jpg
File already exists: ripcord.jpg
File already exists: sinistar.jpg
--------------------------------
 Writing cache file:[100.00%]


show clones: False
Loading final burn.dat...
No roms found...
```

TYLER WINEGARNER is a video producer for *Make:*. A tinkerer, motorcyclist, and gamer. Reads the comments. Uses tools, tells stories. Probably a human. Tweets @photoresistor

Time Required:
1-2 Hours

Cost:
$100–$200

Materials

- **Raspberry Pi Model B with power supply and SD card, 8GB** Maker Shed #MSRPIESS, makershed.com
- **Arduino Esplora** Maker Shed #MKSP19
- **HDMI monitor and cable**
- **USB A-B cable and Ethernet cable**
- **Computer and keyboard** for setup only

Thankfully there's a link to raspi-config on the last page of the PiPlay menu. Connect a keyboard and use the arrow keys to navigate to the last page to launch it.

In raspi-config, expand the file system (Figure C) for the SD card. Next configure your region, so that your keyboard behaves the way you need it to: Go into Internationalization Options and set your locale and keyboard settings. Exit the raspi-config dialog, then confirm that you want to reboot. Make sure you have a working network connection before heading to the next step.

3. INSTALL MAME

One of the most robust programs for a home arcade is MAME — Multiple Arcade Machine Emulator. It can play hundreds of arcade games from the 1980s to the 2000s.

In the PiPlay menu, navigate to the Install MAME icon and select it (Figure D). The installation will take a few minutes, and then the PiPlay interface will reload.

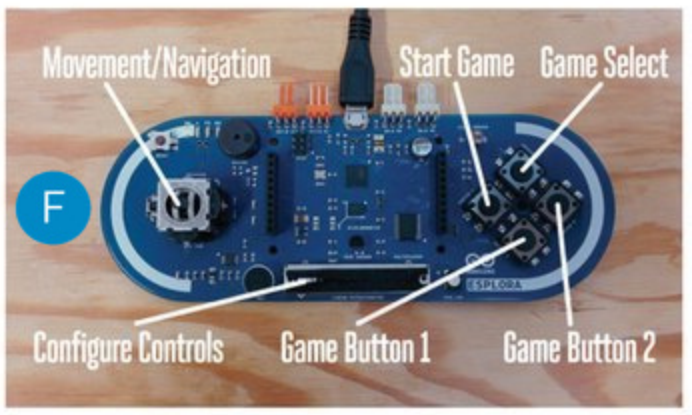
4. SET UP GAME ROMS

Once MAME is installed, you can load games onto your Raspberry Pi. These game files are stored in ROM images, which constitute the software found on an arcade machine's integrated circuits or a home game console's cartridge.

A small repository of free (to download and use) ROMs are available from MAME's website, mamedev.org. Others can be found by searching "MAME ROMs" online.

Once you've downloaded a few ROMs

CAUTION: While MAME is free to download and use, ROM images are not necessarily free or legal to use. It is your responsibility to make sure it is legal for you to download and use ROM images.



to your computer, look at the upper right corner of the PiPlay interface to find the IP address of your Pi. On your computer, type this address into a web browser to bring up the PiPlay remote manager.

Click on ROM Uploader and select the uploader for AdvMAME. Drop your ROM zip files into the drop window, and allow them to upload.

Finally, you'll need to "scrape" the ROMs you just uploaded. This properly installs them for use in the emulator and builds a nice menu interface for them. You'll find the ROM scraper in the PiPlay interface on the last page. You can opt to have it search for unscraped ROMs in every emulator, or just the ones of your choosing (Figure E).

5. SET UP THE ESPLORA AS A MAME CONTROLLER

On your computer, download the modified Esplora sketch found at makezine.com/go/piplay-esplora and open it in the Arduino IDE. Don't forget to select the Esplora as the target board in the Tools→Board dropdown menu. Then upload the sketch to the Esplora.

For full details of the Arduino code and a list of button mapping (Figure F), head to the online project page.

6. CONNECT THE PI AND ESPLORA

To get started gaming, plug your Esplora into one of the Pi's USB ports, using a USB A-to-B cable. In PiPlay, select AdvMAME and load the game you want to play.

Take a moment to configure the game you just loaded by rotating the potentiometer on the Esplora. Make sure you have keys mapped for inserting a coin, Player 1 start, and any critical gameplay controls. Once that's all sorted, simply press Start and it's game on!

NOTE: You'll need to configure the controls for each ROM image.

GOING FURTHER

For two-player action, you can add a second Esplora. Or you could replace the Esplora with an Arduino Leonardo, and wire it up with an arcade stick and buttons. Build your own arcade cabinet? There's a ton of potential here. Whatever you do, have fun and share it at the project page online!

Get more how-to photos and tips, and share your build at makezine.com/go/raspberry-pi-home-arcade

DIY Tripod Flashlight

This quick hack makes a stick-anywhere tripod for your favorite flashlights

Written by Jason Babler

Time Required:
10–20 Minutes
Cost:
$25–$30

WHEN I DISCOVERED MY STANLEY TRIPOD FLASHLIGHT HAD A BATTERY ACID LEAK, it was, unfortunately, exactly when I needed a tripod flashlight the most — for fixing a leak under my sink.

I went to my flashlight drawer and realized I already have plenty of flashlights, all I really needed was the tripod. I remembered seeing that Maker Shed sells a GorillaPod flexible camera tripod with magnetic feet, and that's when the light bulb lit up.

1. First, cut a PVC pipe in half lengthwise, and to your desired length. I used a 1" pipe about 4" long for the small MagLite shown here. If you have some time on your hands, feel free to sand down rough edges. Drill a 5/16" clearance hole in the center to make room for the tripod's universal 1/4"-20 mount, ensuring a better fit.

2. Dab your favorite quick-set epoxy (or hot glue if you want something less permanent) on top of the quick-release clip of the GorillaPod. Make sure the epoxy doesn't interfere with movement of the joints.

3. Lay down some velcro tape in the trench of the pipe, and add a small strip to your flashlight.

That's it! The magnetic-feet tripod (Maker Shed #MKJB01, makershed.com) gives you more options for mounting the flashlight, but it's not absolutely necessary; GorillaPod also has versions without magnets (and bigger versions too). Just be warned about buying cheaper clones, as most reviews I've read say they aren't as durable.

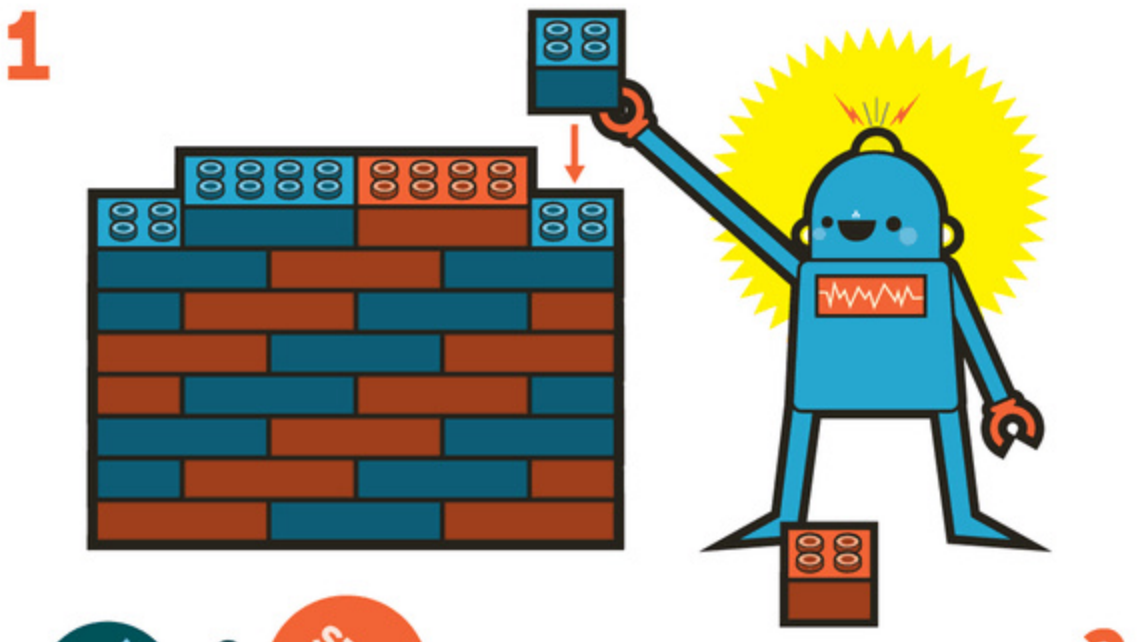
Hep Svadja

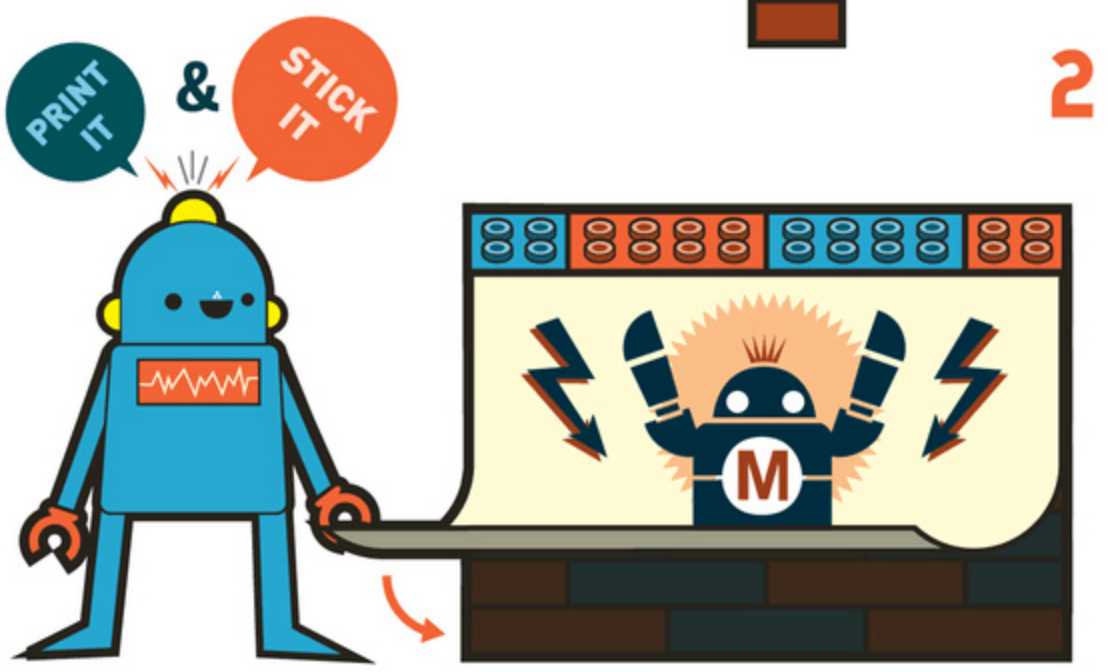
JASON BABLER
is creative director of Maker Media Inc.

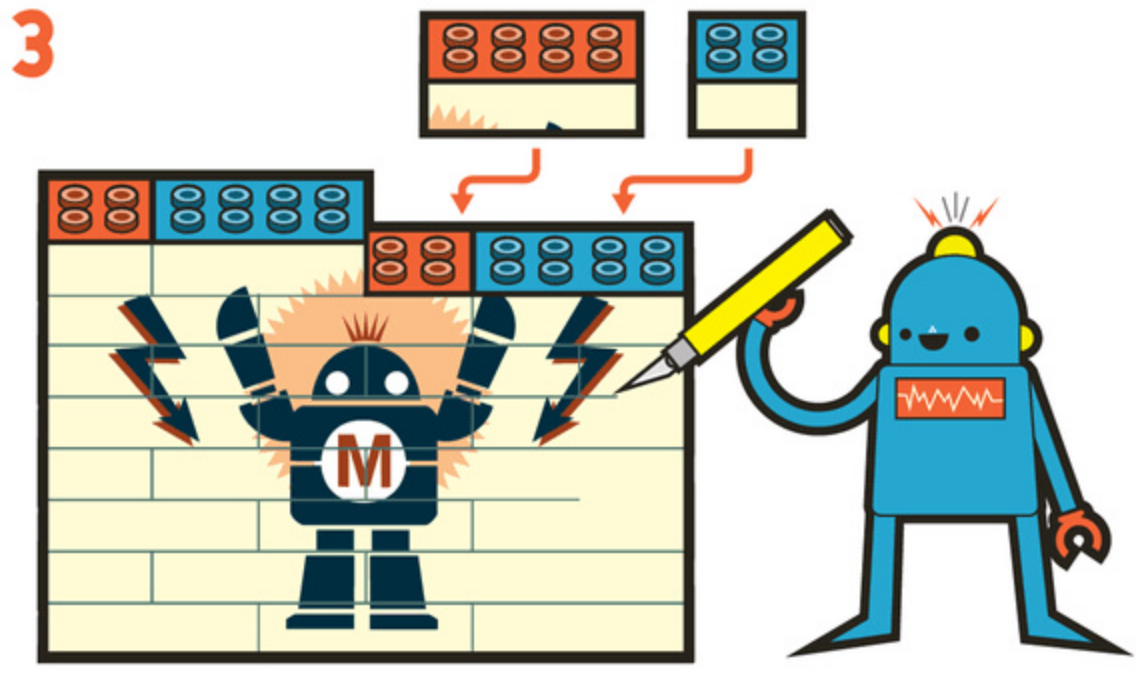
Send us your flashlight hacks and share your build at makezine.com/go/tripod-flashlight.

1 2 3 Building Block Picture Puzzles

Written by Jason Poel Smith ■ Illustrated by Julie West







TWO OF MY FAVORITE TOYS ARE BUILDING BLOCKS AND PICTURE PUZZLES. So naturally I decided to combine them to make building block picture puzzles.

1. BUILD THE BLOCK FRAME

Start by attaching a bunch of blocks together to form a surface for the picture. This can be a simple rectangle or any fiendishly complicated shape that you want to use. » Press the blocks firmly together so that the picture can be applied evenly.

2. APPLY THE PICTURE

Next, select a picture to use for the puzzle. » Scale it to the appropriate size on your computer, and then print it out on self-adhesive photo paper. Alternatively, you can use regular photo paper and spray adhesive. » Carefully apply the picture to the block frame. Press the picture down firmly to ensure that it's well adhered to the blocks.

3. CUT OUT THE PIECES

Finally you'll need to cut out the individual blocks. » Take a sharp knife and gently fit it into the groove between 2 blocks. Carefully slide the blade along the groove to cut the picture into pieces. » Once all the blocks are cut out, press down on all the cut edges to make sure they're properly adhered to the block.

You can use this basic procedure to make two-sided puzzles or even complex three-dimensional picture puzzles. Try it out and have fun.

See the how-to video at makezine.com/go/building-block-picture-puzzles

You will need:

- **Building blocks,** interlocking
- **Knife**
- **Photo paper, self-adhesive** or you can use regular photo paper and spray adhesive
- **Computer and printer**

JASON POEL SMITH makes the "DIY Hacks and How Tos" video series on *Make:*. He is a lifelong student of all forms of making, and his projects range from electronics to crafts and everything in between.

Written by William Gurstelle ■ Illustrated by Rob Nance

Louis Poinsot and the Dancing Spheres

Time Required:
30–60 Minutes
Cost:
$5–$10

Materials

- **Steel balls, soft (unhardened), ⅝" diameter (2)** A good source is craigballsales.com. Don't use ball bearings as the heat treatment makes them difficult to drill.
- **Hardwood dowel, ⅛" diameter, ½" length**
- **Flexible rubber or plastic tube, ¼" ID, 30" long**
- **BIC Round Stic ballpoint pen**
- **Glue, all purpose**
- **Scrap wood, ½" thick**
- **Pan, wok, or cookie sheet**

Tools

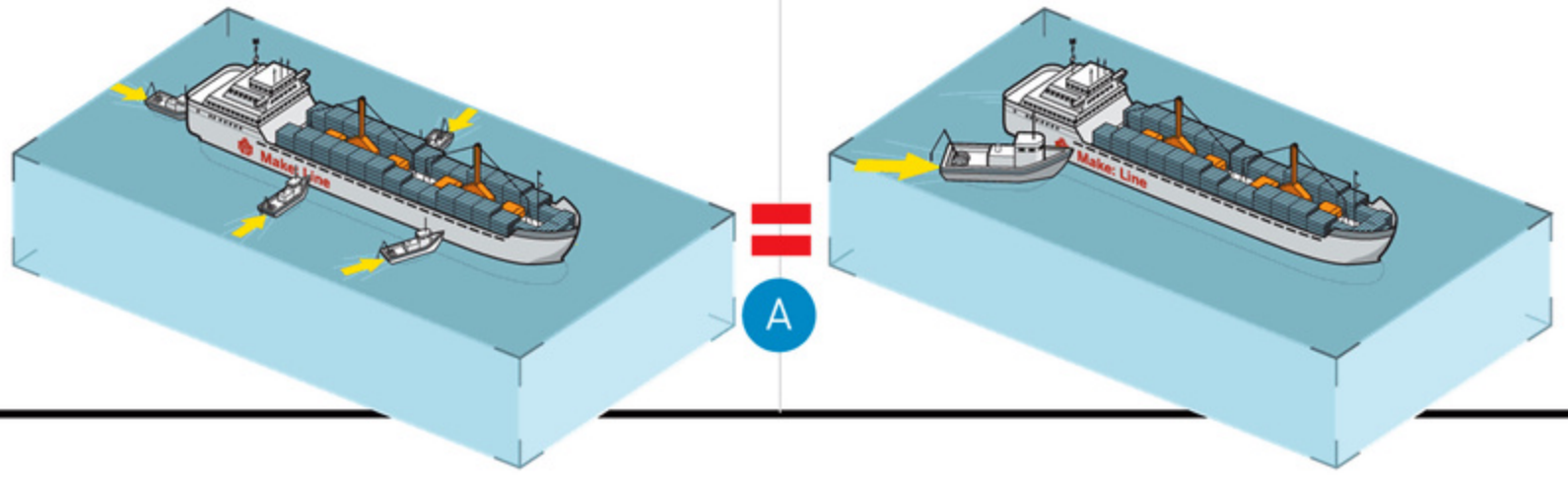
- **Drill press (recommended) or hand drill** With a hand drill, it's harder to drill holes perpendicular to the ball surface.
- **Drill bits: ⅛" and ½"**
- **Pliers**
- **C-clamps (2)**
- **Safety glasses**

Make a blindingly fast physics demo that's a wonder of geometrical mechanics

EARLY IN THE EDUCATION OF EVERY MECHANICAL AND CIVIL ENGINEER COMES A PERIOD OF long and detailed study of how forces cause things to move or not move. When you're talking about a car or an airplane, you want those forces to make the thing move, and the general term used to describe this is *dynamics*. For a bridge, a cellphone tower, or any other thing we don't want to move, we turn to the study of *statics*.

Whether moving or standing, a real-world thing can have a bewildering multitude of forces and loads acting on it, such as tension, compression, shear, and torsion. Add in the twisting forces of various torques (or *moments of force*) on an object, and the design of real-world things becomes a bit difficult. Luckily, the great minds of the past solved some of these difficult problems.

Louis Poinsot was one of those geniuses upon



whose work our built-up world is largely made. A French mathematician of the 19th century, he spent his career in the ivory towers of academia formulating the difficult-sounding, yet oh-so-important, field of geometrical mechanics.

Poinsot was the first to demonstrate that any number of individual forces pushing or pulling on a rigid thing can be simplified into just a single linear force and a twisting force called a *couple*. The great value of the idea, according to Poinsot himself, is that it allowed engineers to think of the motion that a large and complex rigid body undergoes in terms that are much easier to work with.

Why is this important? Consider the problems facing the engineer who attempts to design the hull of a sailing ship or the vanes of a windmill. Winds acting on these objects come from all directions, while frictional forces act on them too, as the vanes and hull slice through air and water. These forces and torques are of myriad magnitudes and directions. Optimizing the design might seem an intractable problem, given the complex interplay of forces.

But thanks to Poinsot, it's possible to understand what's going on. Poinsot figured out that all the forces acting on vanes, mast, sails, and keels can be manipulated mathematically, and instead of dealing with a hundred different quantities, you can use vector algebra to reduce them all down to a single resultant linear force and a couple (Figure A). This simplification was a breakthrough in the field of engineering and made possible the design of all sorts of complicated, moving, spinning things, from submarines and Mars rockets to the liquid-crystal display in your smartphone or flat-screen TV.

THE DANCING SPHERES

Here's a fun and novel demonstration of Poinsot's forces and couples at work. It's sometimes sold as a science toy called "hurricane balls" or the like. Connect two small steel balls by drilling a short hole in each and connecting them with a short steel or wooden rod. Place them on a flat metal pan and give them a flick with your fingers to make them spin merrily around at amazingly fast rotational speeds.

Now comes the interesting part. If you blow a jet of air on them, the balls' angular velocity reaches almost unbelievable speeds — thousands of RPMs! You've really got to see it; check out the video on the project page at makezine.com/go/poinsot-dancing-spheres.

The system of steel balls interacting with the pan surface, and the force and couple acting on them, is very complex — at high speeds, the force of gravity becomes negligible compared to the toy's enormous torques — but by using the work of Poinsot, it can be modeled, analyzed, and understood. Here's how to make your own and see:

1. Clamp the scrap wood to the drill press table and drill a ½" hole (Figure B). Swap the ½" drill bit for the ⅛" bit.

Place a steel ball in the hole you just made. Slowly drill a ⅛" hole, ¼" deep into the steel ball. If the ball begins to spin, carefully hold it in place using pliers. The hole in the wood will keep the ball aligned so you can obtain a centered hole (Figure C).

Repeat for the other ball.

2. Place a thin layer of glue on the dowel and insert it the full depth of the hole you've just drilled (Figure D). Insert the other end into the other steel ball, and let the glue dry (Figure E).

3. To make the blowpipe, disassemble the BIC Round Stic and remove the tip, which is the plastic piece that holds the ink ball. Fully insert the tip into one end of the plastic tube (Figure F).

4. With a motion similar to snapping your fingers, flick the steel ball assembly into the pan so it spins as quickly as possible. This action will impart a force and a couple on the assembly, causing the steel spheres to dance across the surface, spinning for 15–20 seconds or more, depending on how good a flicker you are.

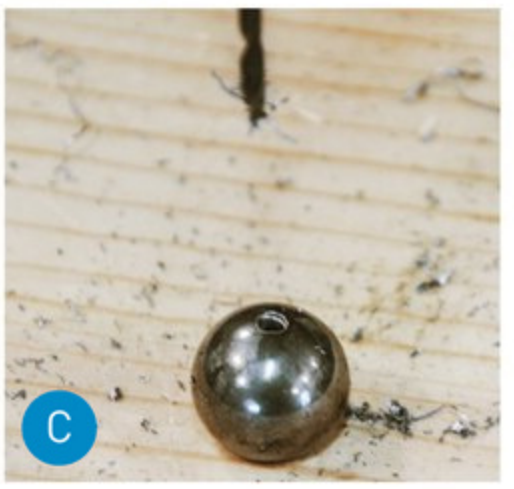
You can make the spheres dance indefinitely by directing a stream of air from your lungs through the blowpipe to one side of the spinning spheres (Figure G). Once you find the right spot, the jet of air produces a couple, and the steel balls spin faster and faster until they become a noisy blur!

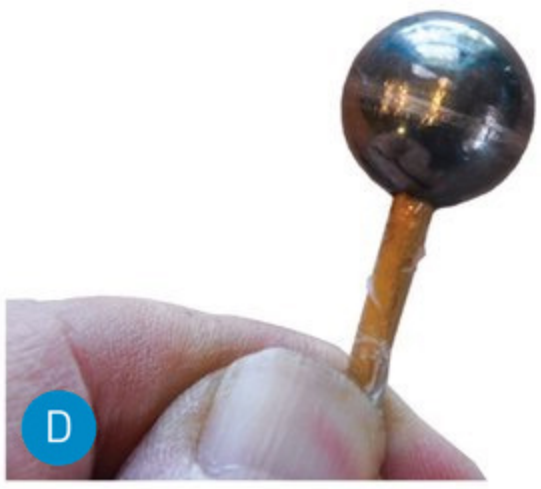
You can vary the experience by shining LED lights on them to make dazzling patterns, or by blowing on them with multiple blowpipes from different angles, or by increasing the length of the wood dowel.

WILLIAM GURSTELLE is a contributing editor of *Make:* magazine. His latest book, *Defending Your Castle*, is available at all fine bookstores.

Watch the blazing-fast Dancing Spheres in action and share your build at: makezine.com/go/poinsot-dancing-spheres.

William Gurstelle





CAUTION: The steel balls spin with incredible velocity. Safety glasses are recommended in case the glue joint comes apart.

Dice in GTA Screenshot by Matthew Billington, Schematics by Charles Platt

Time Required: 2 Hours **Cost:** $15–$20

Really, Really Random

Build an ingenious true random number generator from just a few hardware components

Written by Charles Platt with Aaron Logue

NO MATTER WHAT KIND OF GAME YOU'RE PLAYING — WHETHER IT'S *ANGRY BIRDS*, *GRAND THEFT AUTO*, OR AN INTENSE SESSION OF CHESS — YOU WANT THE COMPUTER TO BEHAVE UNPREDICTABLY. If it always responds the same way in the same situation, that's no fun at all.

This is why almost every computer game uses a random-number generator in its program code, to add an element of surprise.

In my book *Make: More Electronics* I showed how to satisfy this need in hardware, using a linear feedback shift register. It creates a pseudo-random stream of low and high states as a logic output — but the stream repeats after only 255 cycles, which is a significant limitation.

Searching for something better, I stumbled across Aaron Logue's Hardware Random Number Generator (www.cryogenius.com/hardware/rng), which creates totally unpredictable signal noise using a reverse-biased transistor. The noise can then be converted into an unlimited stream of random high and low digital states. Logue didn't invent this idea, but he has developed, tested,

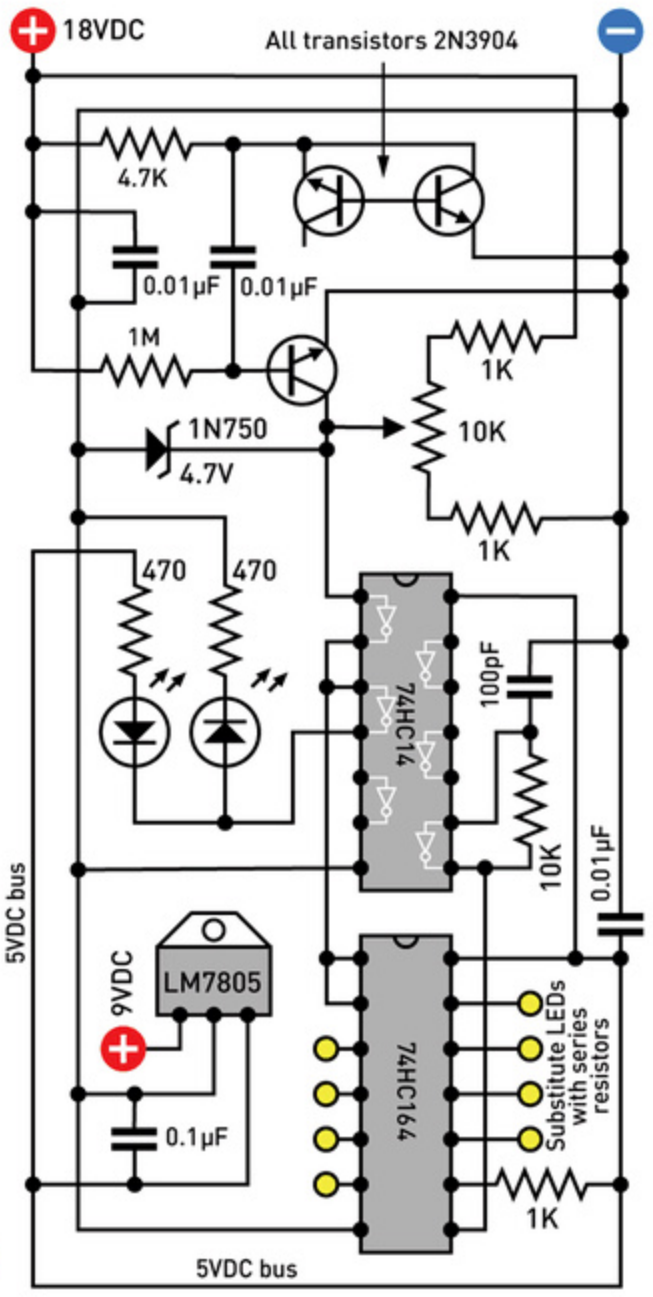


Figure A. In this simple schematic, a reverse-biased transistor generates electrical noise that is amplified by 2 more transistors, digitized through an inverter, and clocked into a 74HC164 shift register, where it can be accessed by a game program.

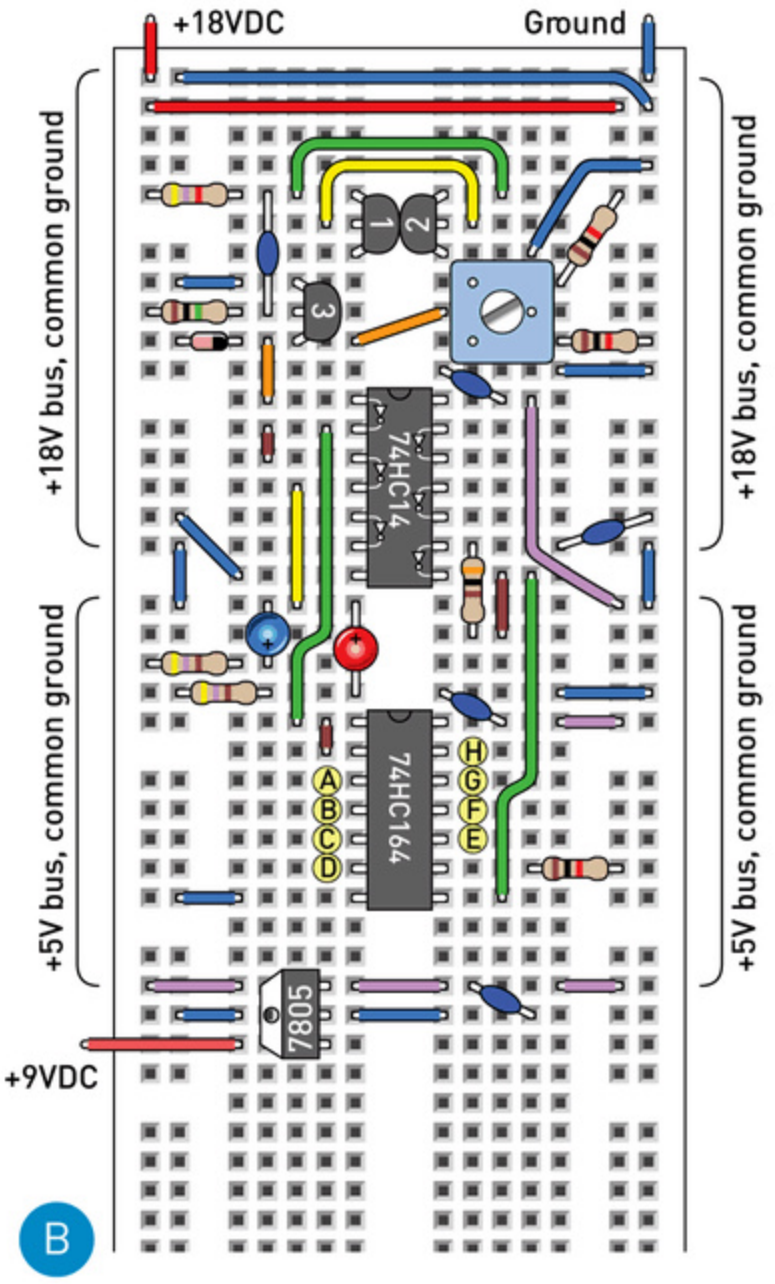


Figure B. Breadboarded version of the schematic in Figure A. This type of breadboard has a break in each vertical bus, allowing separate voltages to be used as shown.

and simplified it for us here. I think it's the best random source for literally thousands of games, from a simple yes-no decision maker to a more ambitious project such as the Ching Thing fortune teller, which I described in *Make:* Volume 31 (makezine.com/go/ching-thing).

GENERATING THE NOISE

The basic schematic is shown in Figure A, and an equivalent breadboard layout in Figure B. The transistor that creates the noise is at top-left, labeled number 1. Its emitter is reverse-biased using 18VDC passing through a 4.7K resistor. Normally you don't abuse a transistor in this way, but if the current is limited, no damage will occur, and random signals will be created by occasional electrons forcing their way through the silicon NP junction. Their behavior is absolutely unpredictable, being determined by quantum mechanics.

Another 2 transistors amplify the signals, and because this is a high-gain analog amplifier, you must use short wires to avoid picking up stray electromagnetic fields. Amputate the unused collector lead of the noise-making transistor, and place all the transistors and the adjacent capacitor as close to each other as possible. (The capacitor prevents switching spikes from the digital section of the circuit from contaminating the analog section.)

When installing the Zener diode, remember that its cathode stripe should point away from the negative bus, unlike a regular diode. The Zener shunts voltages above 4.7VDC to ground, so the remaining signals can pass into a 74HC14 chip containing 6 inverters, each of which has a Schmitt trigger input. The first inverter generates a digital output that alternates at unpredictable intervals between approximately 0V and 5V.

Figure C illustrates the steps in noise processing.

CHECKING THE NOISE

Connected with the last of the inverters in the 74HC14 you'll find a 10K resistor and a 100pF capacitor. This RC network generates pulses to clock the digitized noise into a 74HC164 shift register. You can use the states in the registers (or

CHARLES PLATT is the author of *Make: Electronics*, an introductory guide for all ages, and its sequel, *Make: More Electronics*. He is also the author of Volumes One and Two of the *Encyclopedia of Electronic Components*. Volume Three is in preparation. makershed.com/platt

AARON LOGUE is a Seattle-area software developer and hardware designer. Crypto, robotics, and network sockets are a few of his favorite things.

Materials

- **Breadboard** ideally of the type shown in Figure B
- **Hookup wire, 6' total length** in at least 3 colors. Maker Shed item #MKEE3, makershed.com
- **Batteries, 9V (2)**
- **Capacitors, ceramic disc: 100pF (1), 0.01µF (3), 0.1µF (1), and 1µF (1)**
- **Resistors, ¼W: 470Ω (10), 1kΩ (3), 4.7kΩ (1), 10kΩ (1), and 100kΩ (1)**
- **LEDs, 3mm or 5mm: red (1), blue (1), and yellow (8)**
- **Transistors, 2N3904 (3)**
- **Trimmer potentiometer, 10kΩ**
- **Zener diode, 1N750**
- **Voltage regulator, LM7805**
- **Logic IC chips: 74HC14 hex inverter (1), 74HC164 shift register (1), 74HC4015 dual 4-bit shift register (1), 74HC86 quad 2-input XOR (1), and 74HC08 quad 2-input AND (1)**

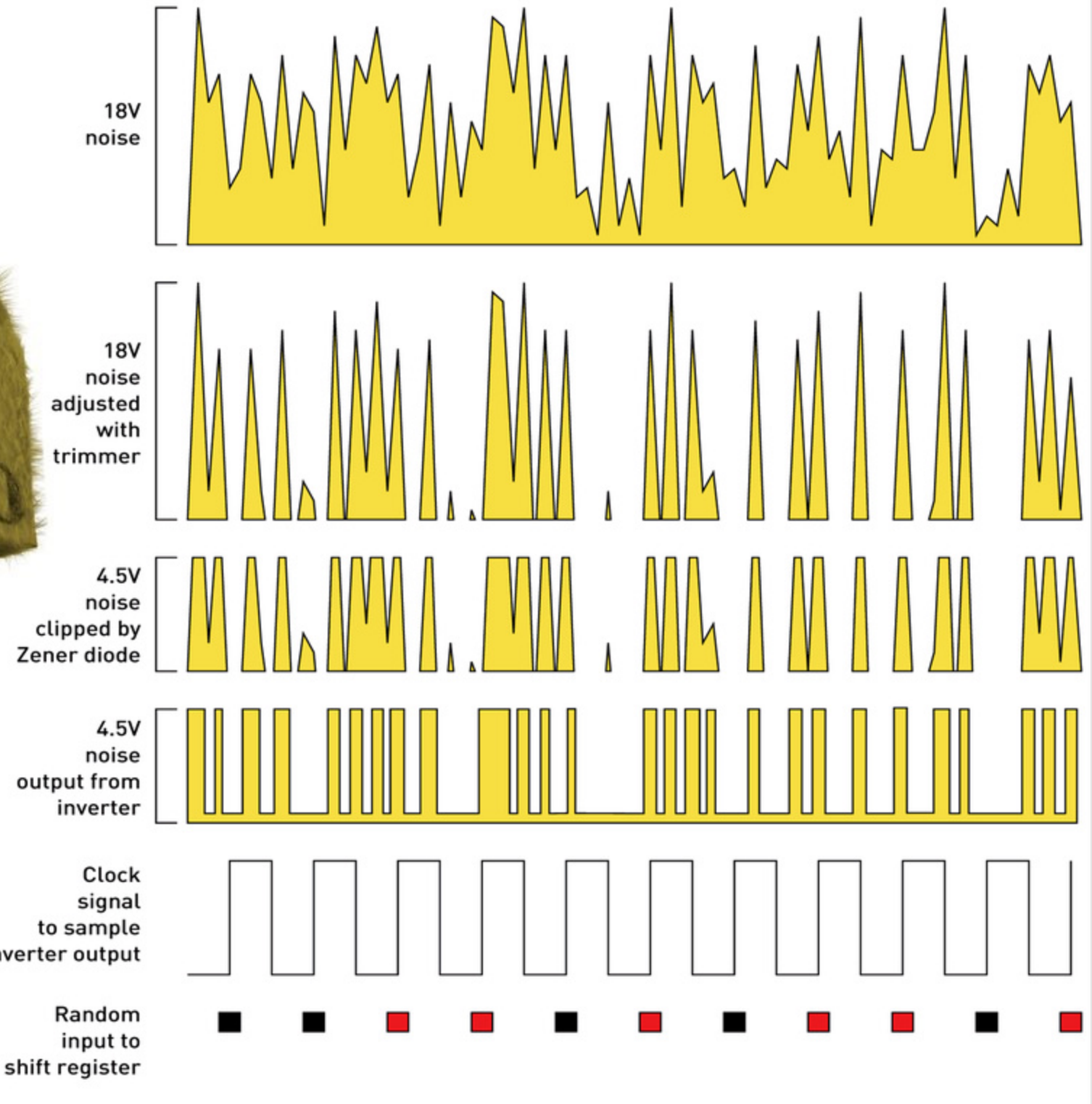
Optional extras for the full Aaron Logue circuit:

- **Diode, 1N1001**
- **Capacitors, 0.01µF (3)**
- **Resistors, 1kΩ (10)**
- **Logic IC chips: 74HC74 flip-flops (2), 74HC193 synchronous counter (1), 74HC595 shift register (1)**

Tools

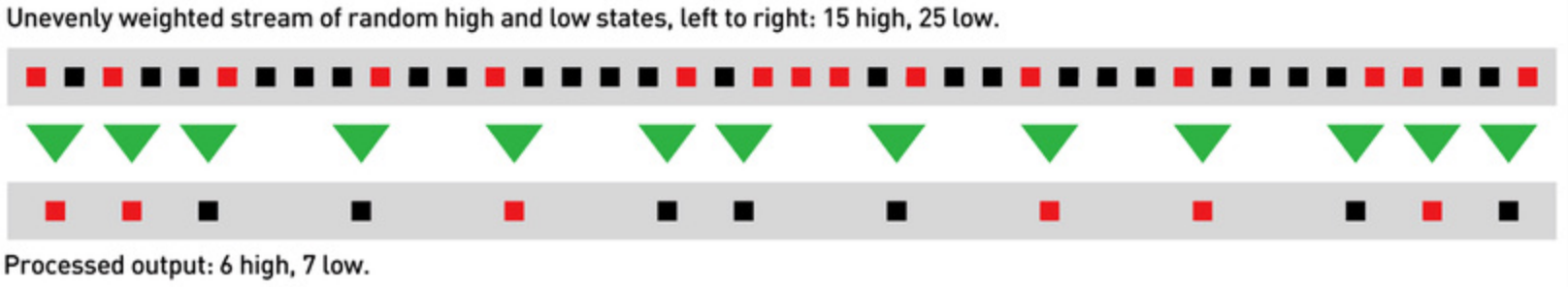
- **Multimeter** (optional)

Electrical noise is processed in 4 steps to create a random digital output.



C

Computer legend John von Neumann showed that a random series of states that are unevenly weighted can be converted to an evenly weighted output by sampling the states in pairs, ignoring identical pairs, and copying the first state in each unequal pair.



D

a subset of them) to randomize game behavior. If you need more states, simply chain another shift register to the first. You'll find a lot more information about shift registers in *Make: More Electronics*.

You can use two 9V batteries in series to create the 18VDC required by the transistors. Tap just one battery for 9V and pass it through the LM7805 voltage regulator to get 5VDC for the logic chips.

I'm assuming that your breadboard has a break in each of its vertical buses, allowing you to supply 18V to the top of the circuit and 5V to the bottom, sharing a common ground. Be careful about this! Test your breadboard, and if its buses are unbroken, you'll have to remove the purple jumpers in Figure B and run separate wires to deliver 5V to the power pins for the logic chips. Also, the blue LED requires a 5V positive supply.

To test the circuit, reduce the clock speed by using a 100K resistor and 1µF capacitor instead of the 10K resistor and 100pF capacitor shown. Substitute an LED and series resistor for each of the yellow circles in Figure A, and you'll see a random series of high and low states flowing through.

WHAT ABOUT WEIGHTING?

So far, so good. But how do you know if the number of high states will be the same as the number of low states, over a long period of time?

In other words, is the output evenly weighted?

You may feel that this isn't important, but if (for instance) you use the circuit to power a yes-no decision maker, maybe you won't be happy if it says "yes" more often than "no." Also, for serious applications such as cryptography, an unevenly weighted random source can allow someone to break the code.

The red and blue LEDs in Figure B address this problem. When the circuit is running at full speed, adjust the trimmer till the LEDs seem to be of equal brightness. This should give you approximately the same number of high states as low states in the logic output.

But how approximate is "approximate"? What if you want the number of high states and low states to be exactly equal?

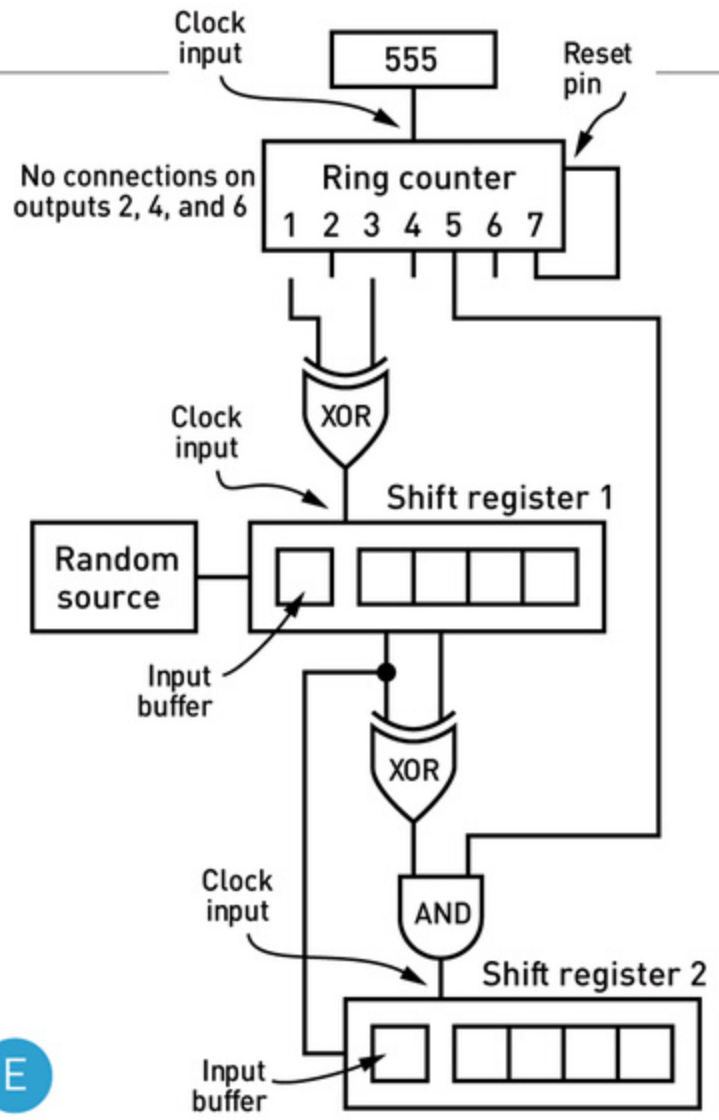
The great computer scientist John von Neumann came up with a way to achieve this very easily. If we have a stream of random 0s and 1s which is not evenly weighted, all we have to do is sample the states in non-overlapping pairs. Where 2 digits are the same, we ignore that pair and move on. Where 1 is followed by a 0, we create an output of 1. Where 0 is followed by a 1, we create an output of 0. Now, no matter how skewed the input is, the output will be evenly weighted. Figure D shows a hypothetical example.

Why does it work? Well, suppose we have a big bucket full of marbles, one-quarter of them black and three-quarters of them red. The odds of picking a red one at random will be ¾, while the odds of picking a black one will be ¼. What are the odds of picking a red one followed by a black one? Easy: ¾ × ¼ = 3/16. What are the odds of picking a black one followed by a red one? Equally easy: ¼ × ¾ = 3/16. Therefore if you pull out a red-and-black pair, the odds of the first one being red are the same as the odds of it being black. This remains true even when we don't know the ratio of red-to-black in the mix, so long as the mix remains consistent. The process is inefficient, because we'll be discarding identical pairs of marbles 10/16 of the time. But the result works.

UNWEIGHTING IT

Figure E shows how a few logic chips can apply the von Neumann principle, guaranteeing scrupulous equality of high and low logic states. This circuit replaces the 2 logic chips and their associated components in the original circuit in Figure A.

The 555 timer drives a ring counter which applies power to each of its pins sequentially. The even-numbered pins are not used, to allow



E

Figure E. A simple way to apply the von Neumann process to a source of unevenly weighted random states.

settling time between each output and the next. Pins 1 and 3 are processed through an XOR gate to clock in a couple of random bits of random noise from the transistors in the noise-generating circuit to the first shift register, which holds the data temporarily.

Another XOR gate has a high output if the 2 samples are different, and this clocks the first of the 2 samples into the second shift register, when prompted by pin 5 of the ring counter. After that, pin 7 of the counter restarts the sequence. The second shift register supplies your evenly weighted random digital output.

I used 4-bit shift registers because you can get 2 of them in a 74HC4015 chip, and I wanted to minimize the chip count. If you need more than 4 random bits, substitute an 8-bit shift register for the output. I'll leave it to you to figure out the placement of components in an actual circuit.

The goal is now fulfilled. You have a digital source that is really, really random, and can be applied to hundreds of games. Hook it up to an Arduino or Raspberry Pi and let the fun begin. For tips, visit the project page online at makezine.com/go/really-really-random.

✚ For perfectionists who want only the most sophisticated logic circuit, Aaron Logue has refined the von Neumann processor into a masterpiece of minimal design. To build this more ambitious circuit, visit makezine.com/go/really-really-random.

✚ Learn electronics with Charles Platt's ***Make: Electronics*** books and our companion parts packs from the Maker Shed, at makershed.com/platt.

Das Neunvoltzensvitcher!

Build a 9V battery clip with a built-in power switch

Vritten und votografed dur Sean Von Ragan

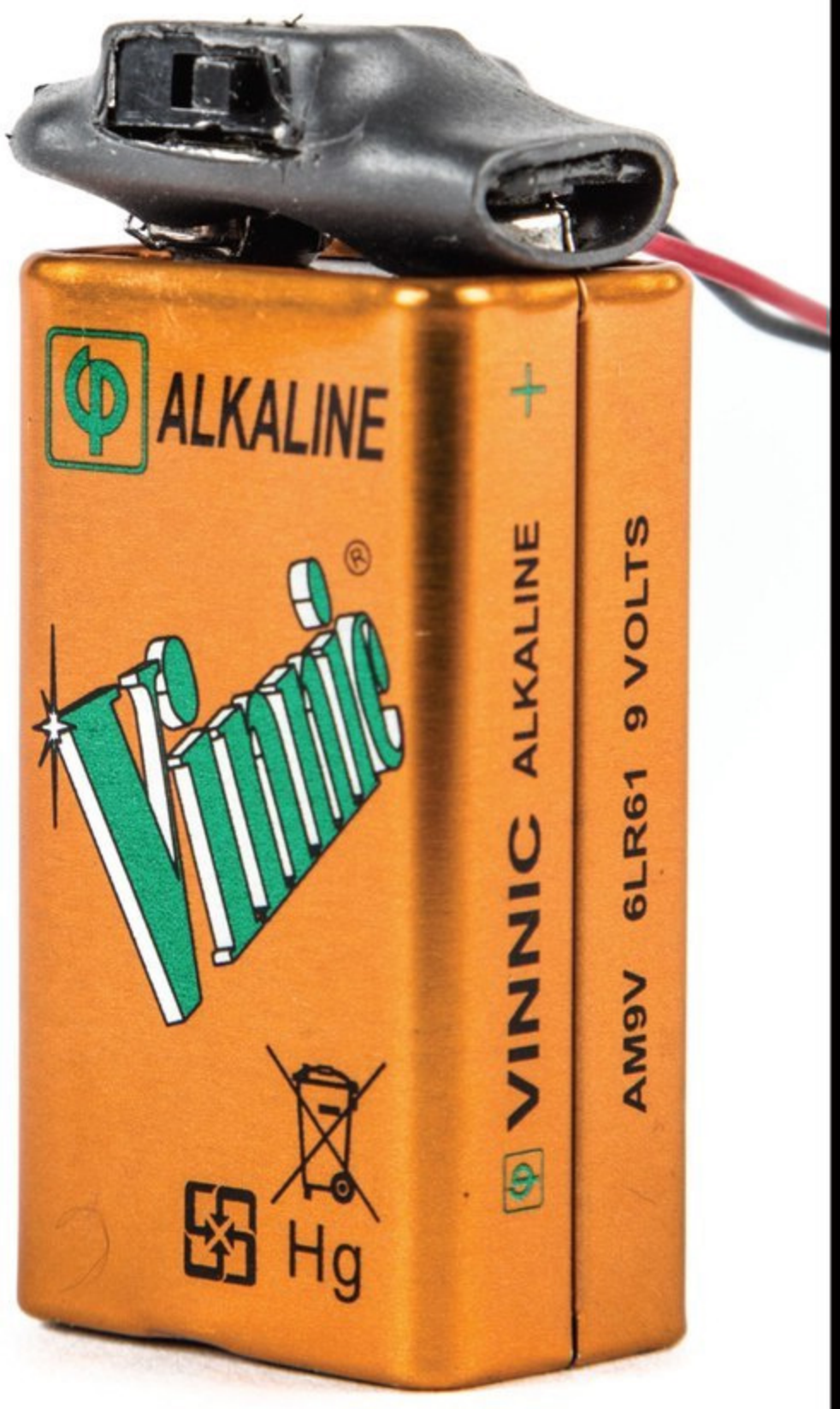
Materials

- **Dead 9V battery** You want one with the terminals riveted to the metal strips inside, not spot-welded.
- **Slide switch, SPDT, miniature, with plastic case** such as E-Switch #EG1218
- **Wire, 26AWG stranded** red and black
- **Heat-shrink tubing: 2mm and 12mm-14mm**
- **Epoxy, 5-minute**

Tools

- **Pliers, long-nose**
- **Drill with ⅛" bit**
- **Scissors**
- **Wire stripper**
- **Soldering iron**
- **Lighter**
- **Hobby knife**

SEAN MICHAEL RAGAN (smragan.com) is a writer, chemist, and longtime *Make:* contributor. His work has also appeared in *Popular Science*, *Chemical & Engineering News*, and *The Wall Street Journal*.



Hep Svajda

I RECENTLY BUILT A STYROFOAM PLATE HOVERCRAFT. I had visions of adding lots of features but I soon discovered that whatever I wanted to put onboard, it had to be super lightweight to keep the thing aloft.

The first feature I wanted was a power switch, so I wouldn't have to clip and unclip the battery. Looking for a convenient place to mount it, I realized that the battery clip itself presented the most minimal and elegant opportunity. I immediately thought of other projects — from breadboarding to BEAM robotics to Arduino — where a 9V battery clip with a built-in power switch would come in handy. But nobody seems to sell one. So I made my own.

1. DISMANTLE DER BATTERY

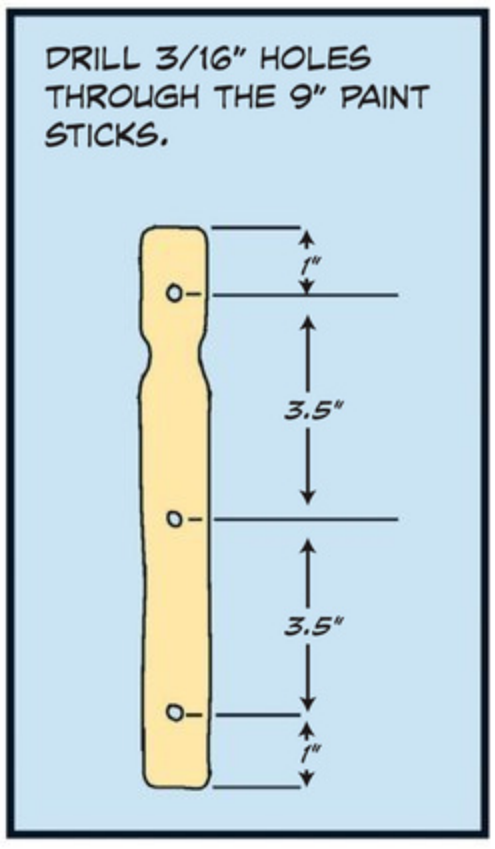
Peel off the battery casing and save the end panel with the 2 snap terminals. It's connected to the cells by riveted metal strips. Cut these free, leaving only short stubs at the terminals. Drill a ⅛" hole in the panel, to one side of the terminals.

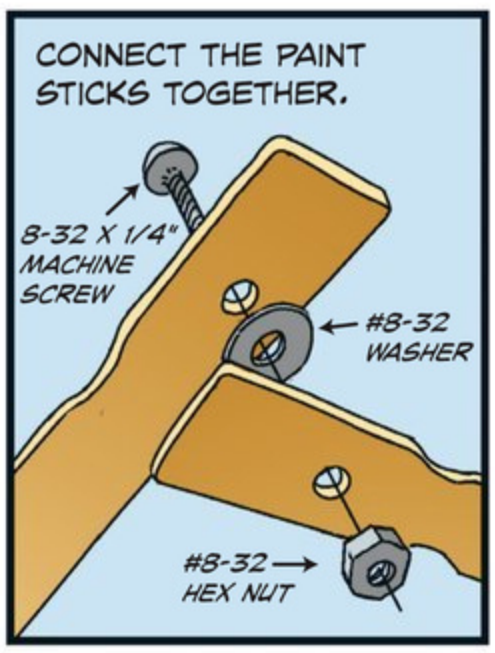
2. INSTALL DER SVITCH

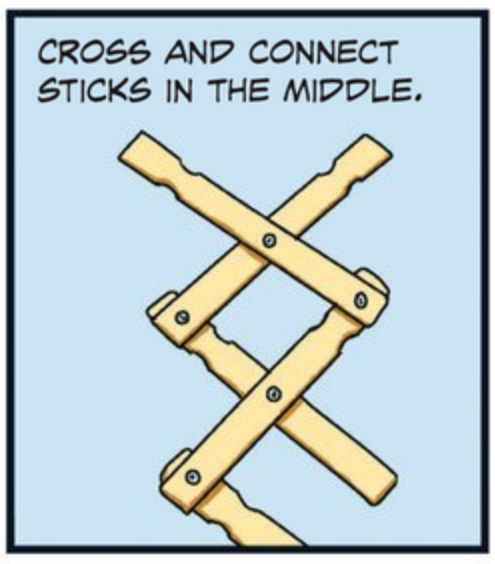
Solder a red wire to the switch's center pin and insulate with 2mm heat-shrink. Solder a black wire to an outer pin. Tie a strain-relief knot and route the wires through the ⅛" hole. Epoxy the switch to the panel, then solder the 2 outer pins to the metal terminal strips.

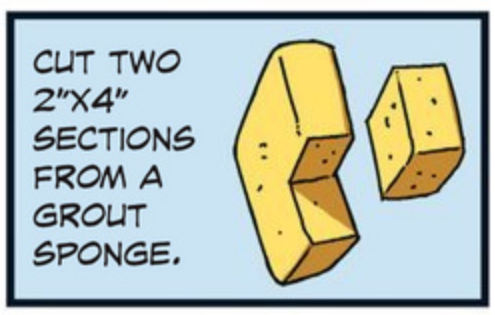
3. INSULATE UND TEST

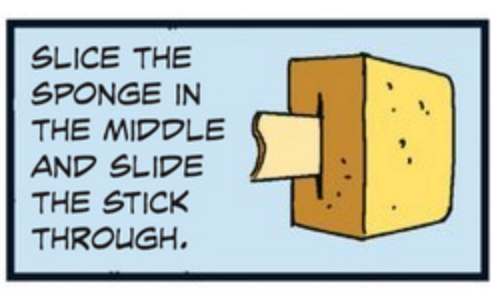
Cut 1" of 14mm heat-shrink tubing and slice a ¼" slit in the middle. Thread the wires into one end and out the slit. Slide the battery panel into the tubing, apply heat to shrink it, then cut openings for the switch and battery snaps. You've got a switchable battery clip!











FOR MORE 'TOONS VISIT US @ HOWTOONS.COM!

Measure the Altitude of Dust, Smog, Smoke, and Volcanic Aerosols

Written by Forrest M. Mims III

Part 2: How to collect and analyze your twilight data

NEXT TIME A PINATUBO-CLASS VOLCANO ERUPTS, AMATEUR SCIENTISTS WILL BE ABLE TO TRACK THE HEIGHT OF ITS AEROSOL CLOUD. In my previous column in *Make:* Volume 44 I showed how to make an ultra-sensitive DIY twilight photometer (see makezine.com/go/twilight-photometer). Now I'll show how to use a computer spreadsheet to manage and graph your photometer data so you can find the approximate altitude of layers of smoke, dust, smog, and volcanic aerosols in the atmosphere.

THE TWILIGHT GLOW

If you're looking toward the sun when it's just below the horizon, you are at the edge of Earth's shadow (Figure A). You can see Earth's shadow for 10 or so minutes after sunset or before sunrise by looking opposite the sun. If the sky is clear, a pink band will form a wide arc over the horizon. This is the *antitwilight glow*. The gray or purplish sky below the arc is in the shadow of the Earth.

After sunset the antitwilight arc rises higher in the sky; the opposite occurs during sunrise. Because the atmosphere becomes less dense with altitude, the sky you see when looking straight up during this time is brightest just above Earth's shadow. Therefore, the intensity measured with a twilight photometer is highest just above the top of Earth's shadow.

This means that the twilight intensity at any given time is approximately correlated with the height of Earth's shadow. If sufficiently dense aerosol layers are suspended in this region, the change they cause in the twilight signal can be detected and plotted (Figure B).

PREPARING THE TWILIGHT PHOTOMETER

It's important to adjust your twilight photometer to measure the widest possible range of twilight intensities. Ideally we'd do this by rotating a potentiometer shaft, but that's not feasible with our twilight photometer, because inserting a pot between the LED light sensor and the input to the op-amp might introduce noise. (And I'm unaware of inexpensive pots having a resistance of tens of gigohms.)

The photometer includes two gain resistors, R1 and R2, connected in series, and switch S2 connected across R2. Closing S2 cuts the gain in half. This provides an X1 and X2 gain control. You can alter the gain even more by using different resistances, but this can become expensive.

A simple way to fine-tune the sensitivity of a twilight photometer is to alter the length of the collimator tube installed over the LED. Start with a 5"–6" length of heat-shrink tubing for the collimator tube, then increase the photometer's sensitivity by clipping off short segments of the tube to allow more light to enter it, until the photometer output is slightly below the maximum voltage allowed by your data logger. This should be done a few minutes before sunset. You'll need at least one twilight session to find the optimum length of the collimator tube. You can then replace the heat-shrink with a permanent piece of tubing.

DATA LOGGER SELECTION

You can manually record your data at 15- to 30-second intervals, but automatic logging at 1-second intervals is much better. For this you'll need to connect

FORREST M. MIMS III (forrestmims.org), an amateur scientist and Rolex Award winner, was named by *Discover* magazine as one of the "50 Best Brains in Science." His books have sold more than 7 million copies.

the output of the twilight photometer to a 16-bit or higher resolution data logger. I've had good results with Onset's HOBO UX120, a 16-bit, 4-channel analog logger (onsetcomp.com/products/data-loggers/ux120-006m). I've also used the Unisource DM620, a 50,000-count data logging digital multimeter. Many other data loggers and 50,000-count logger DMMs are also available. Just be sure the software is compatible with your computer.

THE TWILIGHT PHOTOMETER SPREADSHEET

I've built a custom spreadsheet that manages and graphs your twilight data while saving you from having to solve many equations (Figure C). You can download it for free, and follow the detailed instructions for using it, at the project page online: makezine.com/go/twilight-photometer. The spreadsheet was developed in Microsoft Excel and converted to free LibreOffice (libreoffice.org). It has 6 pages:

1. ANALYSIS. This sheet calculates the times of sunset and sunrise, sun position, and height of Earth's shadow. It also calculates the derivative of the data (its change over time), averages it (to smooth it), and creates the charts shown on sheet 2. References are provided to acknowledge those who devised twilight photometry.

2. CHARTS. This sheet shows graphs of the altitude of Earth's shadow versus the raw data (linear and logarithmic) and the derivative (intensity gradient) of the data.

3. SATELLITE. Satellite and aerosol forecast images are pasted here. Satellite images show any clouds that might be present. The aerosol models predict the distribution of dust, smoke, and smog.

4. SOUNDINGS. This is an optional sheet for upper air soundings from weather balloons launched closest to your site.

5. DATA. Your raw data goes here.

6. README. Detailed photometer and data analysis instructions are here. Carefully read this sheet before your first twilight session.

SOME TWILIGHT EXAMPLES

Figure D shows the 3 graphs from 2 separate twilights superimposed, to demonstrate how the spreadsheet teases out the aerosol layers in the gradient graph. These graphs are from clear skies; irregular graphs are produced when clouds are present along the sun's azimuth.

GOING FURTHER

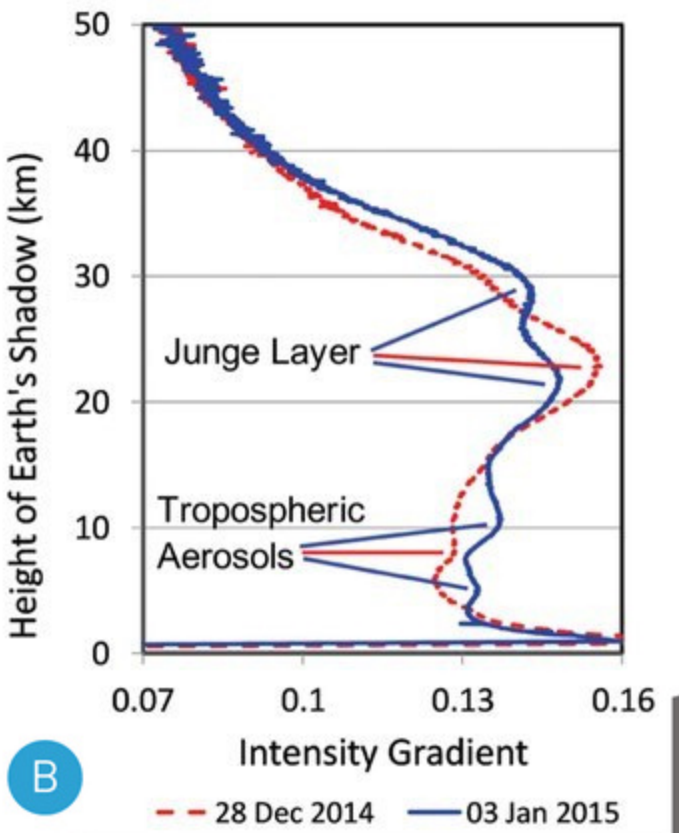
Twilight photometry is an ideal way to become better acquainted with the upper atmosphere. It's a useful tool for science fair projects, serious science, and curious sky watchers, especially if a major volcano eruption occurs. The spreadsheet also provides suggestions on how to expand the project and how to use a NASA aerosol model to identify aerosol layers you detect. When the next Pinatubo or Laki blows its top (or even a Villarica or Ontake or Eyjafjalla-jökull if you live nearby), you'll be ready.

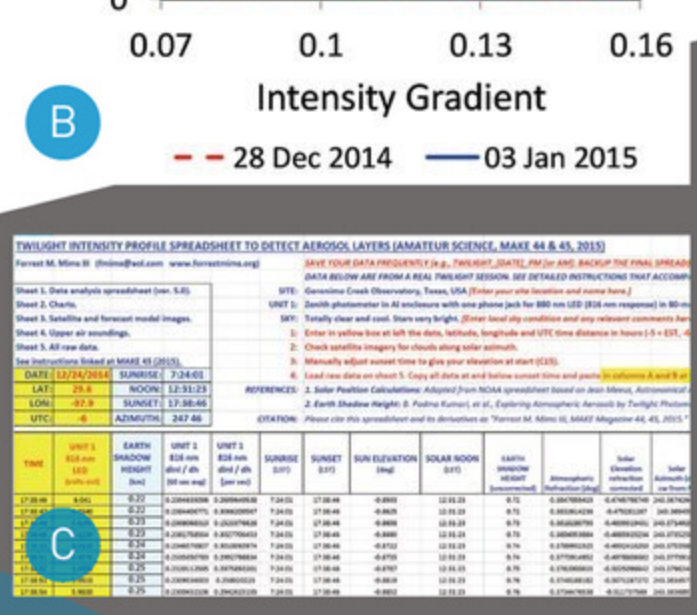
Build your photometer, get the Twilight Photometry Spreadsheet, and learn to use it at makezine.com/go/twilight-photometer.

Time Required:
1-2 Evenings
Cost:
$35–$50 + optional data logger

Tools

- **Twilight photometer and bubble level** See *Make:* Volume 44, "Build a Twilight Photometer," makezine.com/go/build-a-twilight-photometer.
- **Digital voltmeter**
- **Data logger (optional)** recommended
- **Compass or compass rose**
- **Computer with internet access and LibreOffice spreadsheet software** free download at libreoffice.org





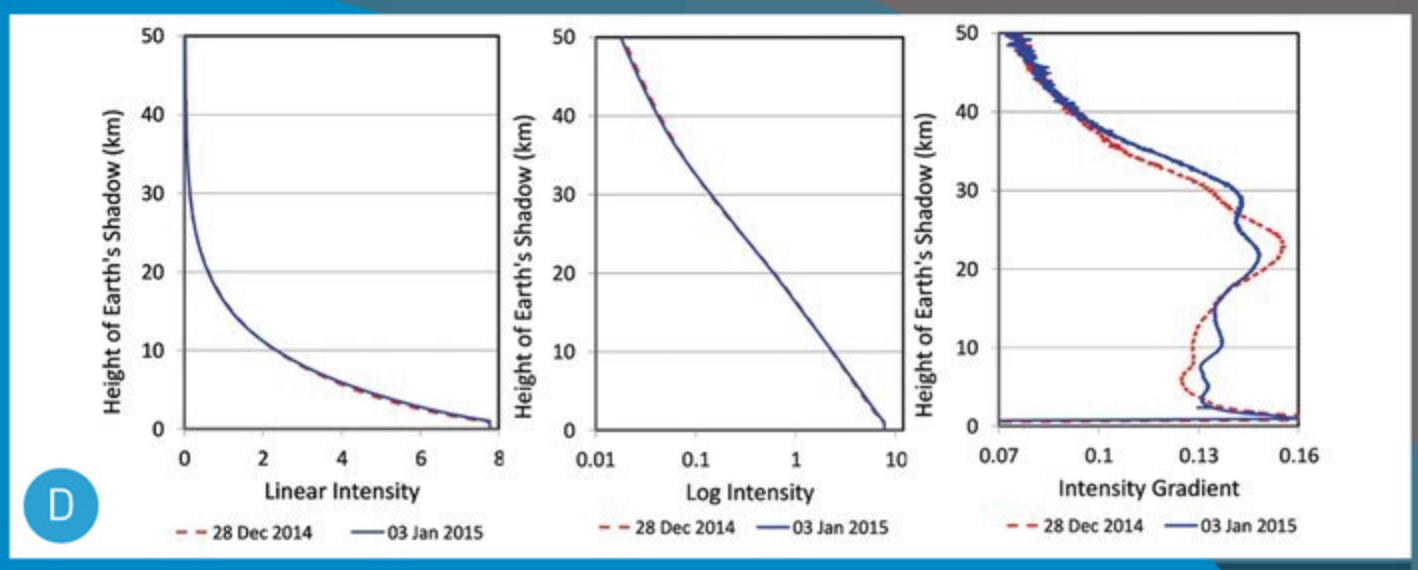
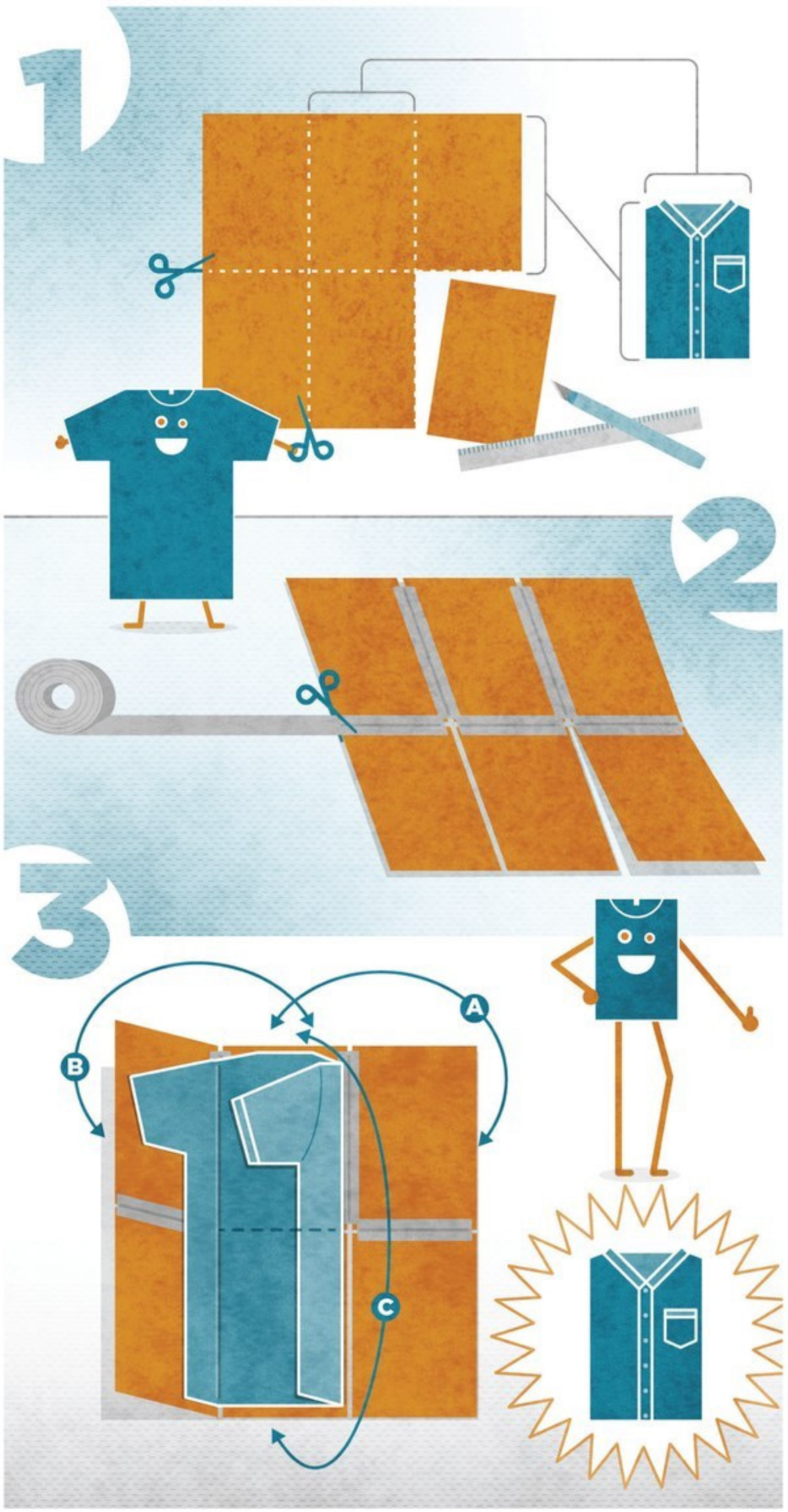


FIGURE A. After sunset, the sun is below the horizon and its rays illuminate the sky overhead. The sky between the ground and the sun's rays is in the Earth's shadow. A twilight photometer measures the reduction in sunlight at the top of the Earth's shadow as the sun continues to sink below the horizon. (The reverse occurs before sunrise.) Aerosols alter the amount of sunlight atop the Earth's shadow, which enables us to estimate their altitude.

1 2 3 Clothes Folding Board

Written by Jason Poel Smith ■ Illustrated by Andrew J. Nilsen



FOLDING CLOTHES IS A BORING AND LABORIOUS CHORE. So I tried to figure out a way to speed up the process using materials that I had lying around. My solution was to make a folding board out of cardboard and duct tape, like the ones used to fold shirts at retail stores.

1. CUT OUT THE PANELS

To make a folding board, you'll need 6 cardboard panels. Each panel should have the dimensions of a folded shirt. » So fold one shirt by hand and measure its dimensions. Then cut out 6 pieces of cardboard this size.

2. ASSEMBLE THE BOARD

Lay the cardboard panels on the floor in 2 rows of 3. Space them out so that there's a ¼" gap between each piece. » Next, tape the 3 panels in the top row together. » Then *individually* tape each panel in the top row to the panel below it. » Turn the whole assembly over and apply tape to the back of all these same gaps. » Press the 2 sides of tape together to seal them.

3. USE THE FOLDING BOARD

Place the folding board on your work surface. » Then lay a shirt face down on top of it. » Fold one side panel over and back. » Then fold the other side over and back. » Lastly, fold up the bottom center panel. You should now have a perfectly folded shirt. This tool can drastically speed up the folding process, and every shirt will be uniformly folded.

See the how-to video and more photos at makezine.com/go/diy-clothes-folding-board

JASON POEL SMITH makes the "DIY Hacks and How Tos" project video series on *Make:*. He is a lifelong student of all forms of making, and his projects range from electronics to crafts and everything in between.

You will need:

- **Cardboard**
- **Duct tape**
- **Ruler or measuring tape**
- **Sharp knife or scissors**

Toy Inventor's Notebook

FAUX ENAMEL TRINKET MAKER

Invented and drawn by Bob Knetzger

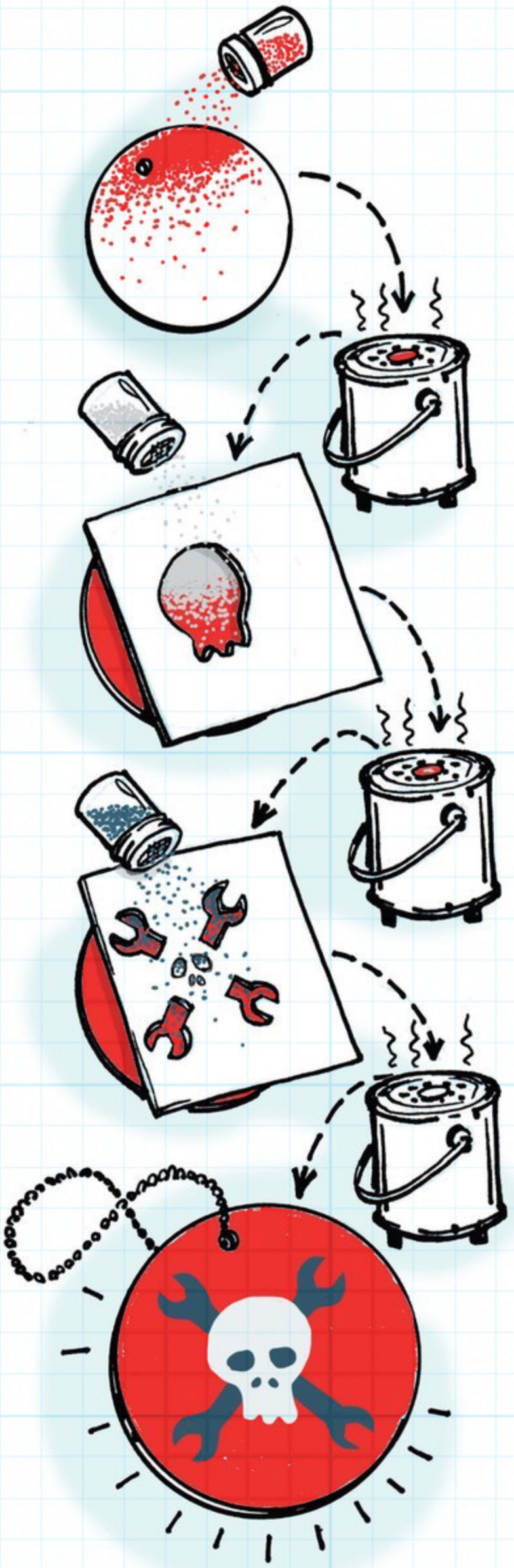
Time Required:
1–2 Hours
Cost:
$5–$10

Materials

- **Small brass discs** cut from sheet brass. Thin is easier to cut, thicker gives a nice "heft."
- **Low-temperature polymer enamel powder** Sold at craft stores as embossing powder.
- **Cardstock** for stencils

Tools

- **Oven** You can build the EZ-Make Oven at makezine.com/projects/ez-make-oven or use your kitchen oven, or even a heat gun.
- **Hobby knife**



Here's a fun toy project that uses another DIY project from a past issue of *Make:* — the "EZ Make Oven" from Volume 35. It featured an incandescent bulb as a heat source built into a paint can, for baking plastisol creatures, aka Creepy Crawlers! Here's how you can make something else with the EZ Make Oven: colorful enameled jewelry and trinkets.

This faux enamel technique uses colored polymer powders that melt and fuse at low temperature to give a bright, shiny finish. They look like glass enamel or cloisonné but you can bake them with just a light bulb. Find the fusing powders in crafts store or online. They're sold as embossing powders for stamping and scrapbooking.

I cut a small disc out of brass, deburred the edges, and cleaned it with vinegar and water to remove any finger oil so that the powders will adhere uniformly. Keep it clean: handle the trinket by the edges only.

Sprinkle on some low-temp powder and build up an even layer about 1/32" thick. Then carefully place the trinket on the warmed EZ Make Oven. After a few minutes when the powder melts and gets shiny, remove and let cool.

You can add more powders in different colors to create a design. I made this "Jolly Hacker" medallion with hand-cut stencils of thin cardstock. You could also make super-intricate, laser-cut stencils!

When all your colors have been added, return the trinket to the oven for a 20-minute final bake for maximum hardness (about 300°F in a kitchen oven). Add a chain to finish your medallion, or glue on a pin back to make a brooch or badge.

Go online at makezine.com/go/faux-enamel-trinket-maker to see more trinket examples and share your own.

Painting and Weathering for Props and Replicas

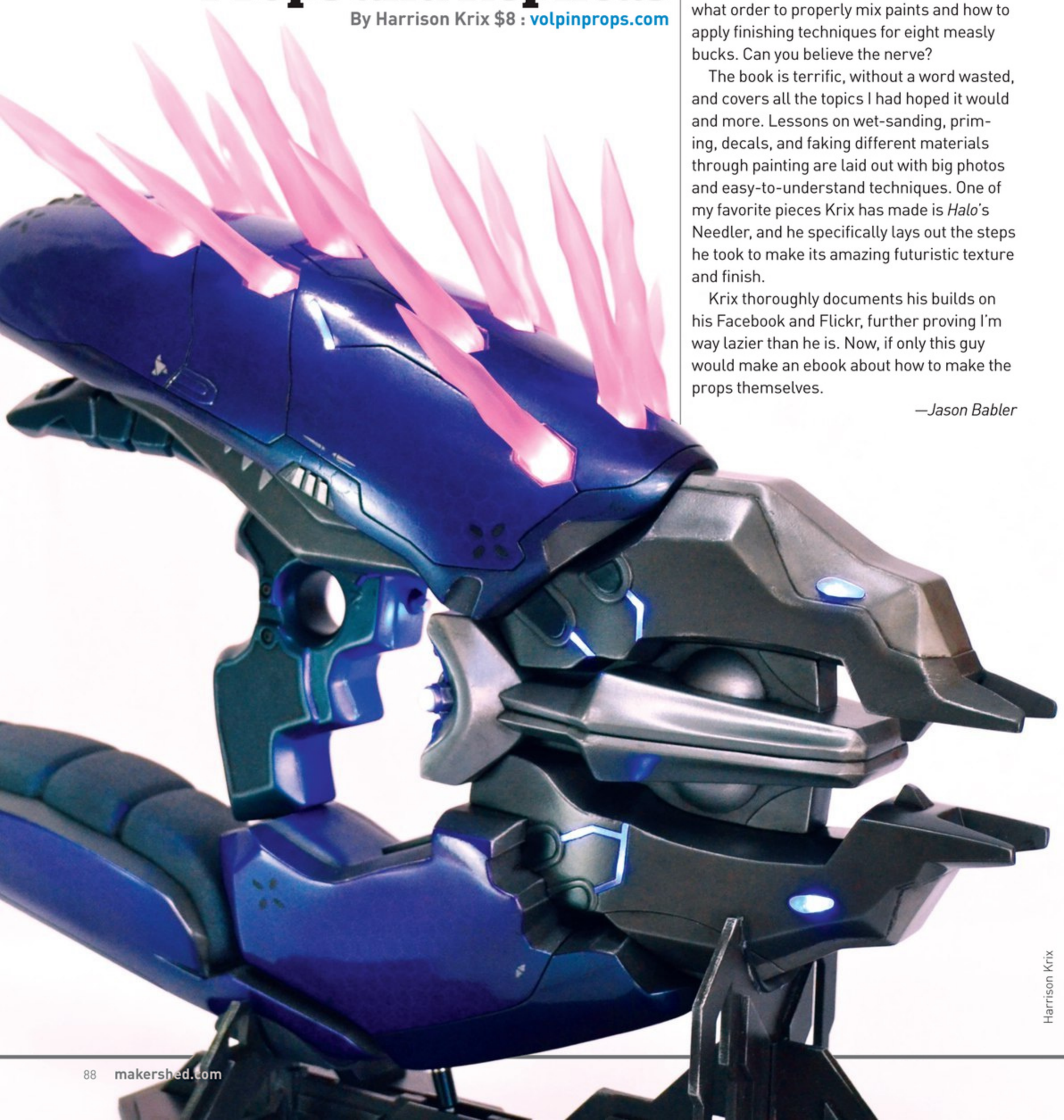
By Harrison Krix $8 : volpinprops.com

I felt a little guilty (at first) about buying and reading Harrison Krix's excellent ebook, *Painting and Weathering for Props and Replicas*. Part of being a maker is discovery by making, and this guy decided to take all his years of success (or rather, failures) and teach us all what order to properly mix paints and how to apply finishing techniques for eight measly bucks. Can you believe the nerve?

The book is terrific, without a word wasted, and covers all the topics I had hoped it would and more. Lessons on wet-sanding, priming, decals, and faking different materials through painting are laid out with big photos and easy-to-understand techniques. One of my favorite pieces Krix has made is *Halo*'s Needler, and he specifically lays out the steps he took to make its amazing futuristic texture and finish.

Krix thoroughly documents his builds on his Facebook and Flickr, further proving I'm way lazier than he is. Now, if only this guy would make an ebook about how to make the props themselves.

—Jason Babler



Harrison Krix

6" DIAL CALIPERS BY CEN-TECH

$20 : harborfreight.com

Calipers are precision instruments that can make three types of measurements: inner diameter, outer diameter, and depth. They make measuring small parts a breeze.

Most makers I've met — myself included — use calipers to measure round objects, such as PVC fittings, to tens-of-thousandths of an inch. They can, of course, also be used to measure rectangular objects and other such shapes.

I have a trusty pair of 6" dial calipers from Cen-Tech, and they've been great for 99.9% of my work. While a digital pair gives you a choice of units and can be quicker to use, I prefer the dial because they never need a new battery. 6" might not seem like much, but keep in mind a 12" set might not fit in your toolbox.

For CADing up a 3D-printed accessory to an existing part, a reliable pair of calipers in one hand beats any 3D scanner you're likely to get. More than 10 years (four of them in college) later, my set feels just as tough as when I opened the box. And I haven't had to change a single battery.

—Sam Freeman

[Bonus Tip: If you have a higher budget, consider upgrading to Mitutoyo — their measurement tools are absolutely superb. —Stuart Deutsch]

Skill Builder

Here's a tip: Calipers can be locked in and used to transfer measurements to a workpiece that has a straight edge. If you drag one jaw along the edge of the workpiece, the other jaw can scribe a shallow line into the surface a set distance away from the edge. This is best done with calipers that have carbide jaws, but ultimately the points will still wear down.

WERA TOOL-CHECK PLUS

$115 : www-us.wera.de

The Tool-Check Plus is a highly versatile set that offers bit and driver combinations for most common applications. It's surprising to me that I'm so effusive about Wera's tool design. I just wanted to fix my bike! But when I grabbed this toolkit, I fell in love.

The set contains 28 bits, 7 sockets, a bit-holding screwdriver, ratchet, socket adaptor, and a Rapidaptor bit holder/extension. But unlike the budget toolkits I own, the Tool-Check Plus exudes serious, solid quality. I never thought I cared enough to be a toolkit connoisseur, but Wera amazes me. This is clearly a well thought-out product, from the way the screw bits lock-snap into place to the satisfying ratchet clicks. Somebody meticulously developed this from beginning to end.

You know what it feels like? It's like I've been perfectly happy driving an economy car all my life, and I stumble into the driver's seat of a luxury car: Whoa. I had no idea driving could feel this smooth. Everything about the Tool-Check feels polished, durable, and purposeful. Heck, there's even a belt clip to hold the entire toolkit hands-free.

—Frank Teng

SPYDER HOLE SAWS

From $10 : spyderproducts.com

Manufacturers have come up with all kinds of hole saw and arbor designs with the intent of making the cores easier to remove, but nothing works as well as Spyder's Rapid Core Eject System.

It's almost funny that it can take longer to remove the core from inside a hole saw than it takes to make the cut itself, but that's usually the way it is. Thankfully, Spyder has made the process simple, and all it requires is their new arbor. After each cut, simply pushing a button on the arbor allows the hole saw to slide back and expose the core for easy removal by hand. The arbor works with Spyder's own hole saws, and it can also be used with many other brands' as well.

—Chris Rodenius

MILWAUKEE FASTBACK II UTILITY KNIFE

$15 : milwaukeetool.com

One-handed opening makes the Milwaukee Fastback II faster than necessary and stupidly cool. The all-metal body fits nicely in the hand and looks like it came off the set of an action movie.

It's so well balanced when it swings out smoothly and locks into place. It's comfortable too, not because of slapped-on rubber grips, but because it's well thought out; the curves just fit.

It also features a built-in blade storage mechanism. True to the design, the backup blade flips out as well. The magnetic holder carries one spare blade. Swapping blades is fast, tool-less, and secure.

Though the cheaper original Fastback is slimmer and might fit better in smaller hands, you'll be giving up the built-in blade storage. If you can live without that, it's a trusty tool, but for a badass knife that will serve you for years, go for the II. *—SF*

HUB-EE ALL-IN-ONE WHEELS

$35 : creative-robotics.com

Creative Robotics makes a special wheel that has a built-in motor within the hub, meaning that you could get your rover or mobile robot rolling right away, rather than worrying about making sure your hubs match your axles and motors. Instead, you just attach the wheel to your robot through the clever mounting holes, which are threaded for #4-40 or M3 machine screws. These wheels are also Lego-compatible and work with standard cross-axles, making for some multiplatform possibilities. HUB-ee wheels come in 120:1 or 180:1 gear ratios and have an encoder built in so they can be rotated precisely. Creative Robotics also sells breakout boards and an Arduino shield for managing the wheels. *—John Baichtal*

PORTER CABLE 20V MAX BLUETOOTH RADIO

$100 : portercable.com

Small Bluetooth-connected radios and music players are "in" right now, but a lot of these consumer models are designed for more delicate environments. This new model from Porter Cable isn't the first portable Bluetooth radio designed for rough and tough environments, but it's one of the best workshop-friendly models I've seen.

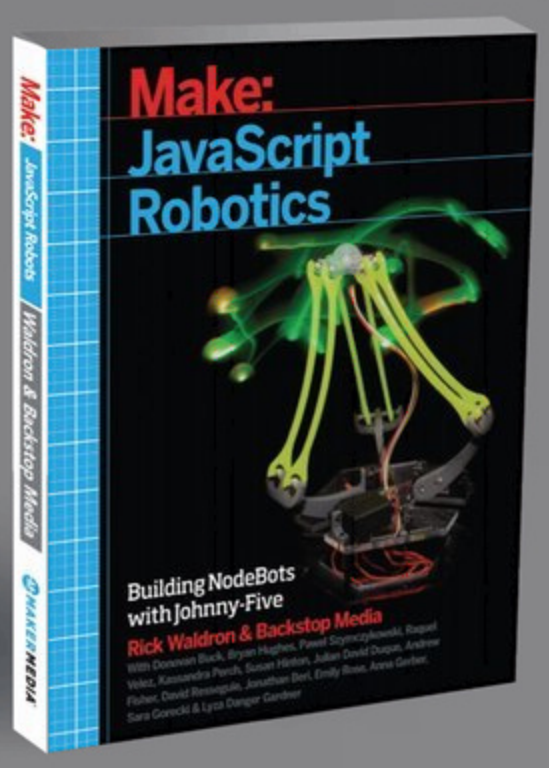
The radio sounds great for its size (13" x 6" x 6"), and although it's not well suited for huge outdoor settings, it's perfect for your garage, workshop, and smaller areas such as decks or yards.

You can connect to music players via Bluetooth or with the aux jack and a headphone cable, and there's also a digital AM/FM radio. There are also two ways to power the device: using one of Porter Cable's 20V Max Li-ion batteries for full wireless operation, or with the included AC adapter for unlimited runtime.

This radio feels just like it looks — sturdy and rugged. I also particularly like the stereo speaker setup. It might not seem like much, but to my ears the two speakers sound better than a lot of the single-speaker units out there. *—SD*

PRINT

NEW FROM MAKER MEDIA



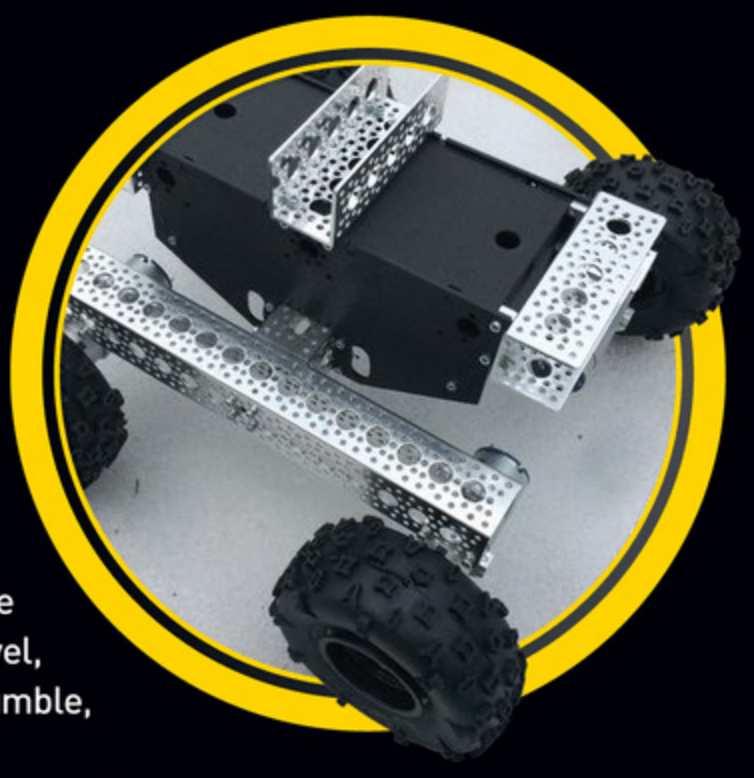
MAKE: JAVASCRIPT ROBOTICS

By Rick Waldron and Backstop Media
$29.99 : makershed.com

JavaScript Robotics is on the rise, and Rick Waldron, the lead author of this book and creator of the Johnny-Five platform, is at the forefront of this movement. Johnny-Five is an open-source JavaScript Arduino programming framework for robotics. This book brings together 15 innovative programmers, each creating a unique Johnny-Five robot step-by-step, and offering tips and tricks along the way. Experience with JavaScript is a prerequisite.

NEW MAKER TECH

ACTOBOTICS NOMAD



$280 : servocity.com

This isn't a rover for navigating cushions in your living room. If you want to build a rover that can traverse everything from snow to gravel, and tough enough to take a tumble, you'll want the Nomad.

The Nomad is available only as a kit, and consists of a chassis made with aluminum Actobotics beams. These are peppered with mounting holes, and there's a whole system of additional beams, shafts, bearings, and mounts you can buy, meaning that you could easily modify your Nomad to make it work better for you simply by finding more Actobotics parts.

The Nomad also comes with an ABS enclosure big enough to accommodate a microcontroller, as well as some big ol' LiPos for the four full-metal planetary gearmotors that come with the kit. This is a great start to a rover — just add wiring, battery, sensors, and microcontroller.

—JB

IFIXIT JIMMY

$8 : ifixit.com

There are many ways to pry open electronics devices. You could use a slotted screwdriver or a knife, although in a lot of cases you'll damage the sides wherever you do some prying.

Then there's the iFixit Jimmy, which is specially made for separating snap-fit parts of an enclosure. It features an ultra-thin stainless steel blade and rubbery grip. Even though the steel blade is extremely flexible, it is also strong enough to be used for prying into tough plastic housings.

The Jimmy doesn't work perfectly on all devices — I had to use it with a small screwdriver to pry open a remote for repair — but it still does a respectable job and is useful for widening small gaps.

—SD

LITTLEBITS SMART HOME KIT

$280 : makershed.com

Whether you're totally new to littleBits or already have a library of modules, the Smart Home Kit is an essential collection for creating connected home projects. The kit includes many of the basic Bits for sensing your home environment, such as light, temperature, and sound sensor modules. The included cloudBit connects your projects to the internet for remote sensing and control through their API or IFTTT. The kit also sports a few new Bits such as the AC switch for controlling power to appliances and the MP3 player for playing music or sound effects.

—Matt Richardson

LULZBOT MINI

WRITTEN AND PHOTOGRAPHED BY MATT STULTZ

Great engineering in a compact desktop configuration

LulzBot Mini
lulzbot.com

- **Price** $1,350
- **Build Volume** 152mm×152mm×158mm
- **Bed Style** Heated bed with PEI-coated glass build plate
- **Temperature Control?** Yes
- **Materials** ABS, PLA, HIIP, nylon, many others
- **Print Untethered?** No (But AstroPrint, OctoPrint, or other control interfaces will work)
- **Onboard controls?** No
- **Host Software** LulzBot version of Cura suggested
- **Slicer** LulzBot version of Cura suggested
- **OS** Windows, OSX, Linux
- **Firmware** Marlin
- **Open Software?** Yes
- **Open Hardware?** Yes, GPLv3 and/or CC BY SA 4.0

LULZBOT IS KNOWN FOR THEIR EXCEPTIONAL ENGINEERING, UPGRADABILITY, AND COMMITMENT TO OPEN SOURCE — but not for portability, nor for having a space-saving footprint.

Now, the team has released the LulzBot Mini to help those who don't have the desk space required for their larger Taz, but are looking for many of the same features.

The Mini features an all-metal frame, making a rigid and stable base that contains the majority of the mechanical parts of the printer. Like other LulzBot machines, the Mini uses Igus polymer bearings that don't require added lubrication, resulting in a long lasting, maintenance-free operation. The Mini has a 6"×6" build area and uses a PEI (polyethylenimine)-coated borosilicate glass plate that's heated for maximum material compatibility. All cables are neatly routed through cable chains, which help protect the wires from accidental snags. A fantastic spool holder swings out from the side of the machine and solidly locks in place when in use.

TWO BIG IMPROVEMENTS

The Mini also features two major upgrades from previous models. First is LulzBot's new Hexagon all-metal hot end. Unlike plastic-lined hot ends, this one's capable of reaching temperatures up to 300°C (572°F) — so you can print in materials like nylon and polycarbonate. And while most metal hot ends can't print reliably with PLA and PLA-composite filaments, the Hexagon does not suffer from this issue, printing extremely well in my tests.

The second significant addition is LulzBot's first implementation of an auto bed leveling system. The Mini not only levels the bed, it ensures that the nozzle is at the right height by touching the tip to four conductive points in each corner. To guaranty that the nozzle can properly conduct, the machine first goes through a cleaning phase — heating the nozzle and rubbing it repeatedly against a pad mounted behind the build plate. After this process is complete, the print starts, but the Z-height is adjusted constantly to keep the nozzle at a consistent distance from the build plate.

LulzBot has created their own version of Cura printing software to power the new Mini. Ultimaker originally developed Cura, but since both Ultimaker and LulzBot use open-source firmware and standard G-code files to power their printers, it was possible for LulzBot to create their own version. Cura is easily the most user-friendly slicing software on the market.

Interestingly LulzBot's filament of choice for the Mini is HIPS (high-impact polystyrene). The usage of HIPS as a primary print material is fairly uncommon. HIPS has more often been used as a dissolvable support material after my research in 2012 revealed this possibility. But as a primary print material, HIPS offers a great surface quality, with a matte finish and a soft hand feel. This material, combined with very good print quality from the Mini, made impressive test prints.

SOME SHORTCOMINGS

I did find a few things disappointing about the Mini. While the machine is definitely more portable than the Taz, and even includes a comfortable handgrip for carrying, the all-metal case adds enough weight to make this not a truly portable machine. The 3mm Wade's-type extruder provides an extremely reliable flow but also takes up a lot of space within the machine. A smaller 1.75mm direct-drive extruder might give the printer a few extra inches of print space or decrease its footprint. LulzBot is committed to 3mm filament, however, as they believe it can be printed more reliably across a range of materials.

I was also surprised by the lack of onboard controls, memory, and LCD. To me the ability to print untethered from a computer is crucial for portability, and is pretty high on my must-haves for any printer. Removing these components does keep the cost down though, and with the growing popularity of add-on controllers like AstroPrint/AstroBox and the Matter Control Touch, onboard controls may not be as crucial.

CONCLUSION

The Mini continues to show that LulzBot is committed to creating extremely well-engineered machines, and to sharing those designs with the community. The Mini gives you everything you want from a LulzBot printer, and a little more of your desk back.

PRINT SCORE: 29

Accuracy	1	2	3	**4**	5	
Backlash	1	2	**3**	4	5	
Bridging	1	2	**3**	4	5	
Overhangs	1	2	**3**	4	5	
Fine Features	1	2	3	**4**	5	
Surface Curved	1	2	3	**4**	5	
Surface General	1	2	3	**4**	5	
Tolerance	1	**2**	3	4	5	
XY Resonance	FAIL	**PASS (2)**				
Z Resonance	**FAIL**	PASS	**(0)**			

PRO TIPS

If you are already a Cura user, you can download material profiles from the LulzBot support site without the need to install Cura LulzBot Edition.

WHY TO BUY

All the great engineering you expect from LulzBot but in a footprint that most people will have desk space for.

How'd it print?

MATT STULTZ is a community organizer and founder of both 3D Printing Providence and HackPittsburgh. He's a professional software developer, which helps fuel his passion for being a Maker. 3DPPVD.org

Tradinno the Gargantuan

Written by James Burke

AFTER CROSSING YET ANOTHER FORMIDABLE RIVER, YOUR PARTY CONVERGES AT THE EDGE OF A DENSE FOREST. The shroud of thick fog does not dissuade you, and you begin the descent into the emerald detritus. Scattered about are the broken vestiges of trunks — their crushed remains offer hints of tremendous impact that fill your party with a sense of foreboding.

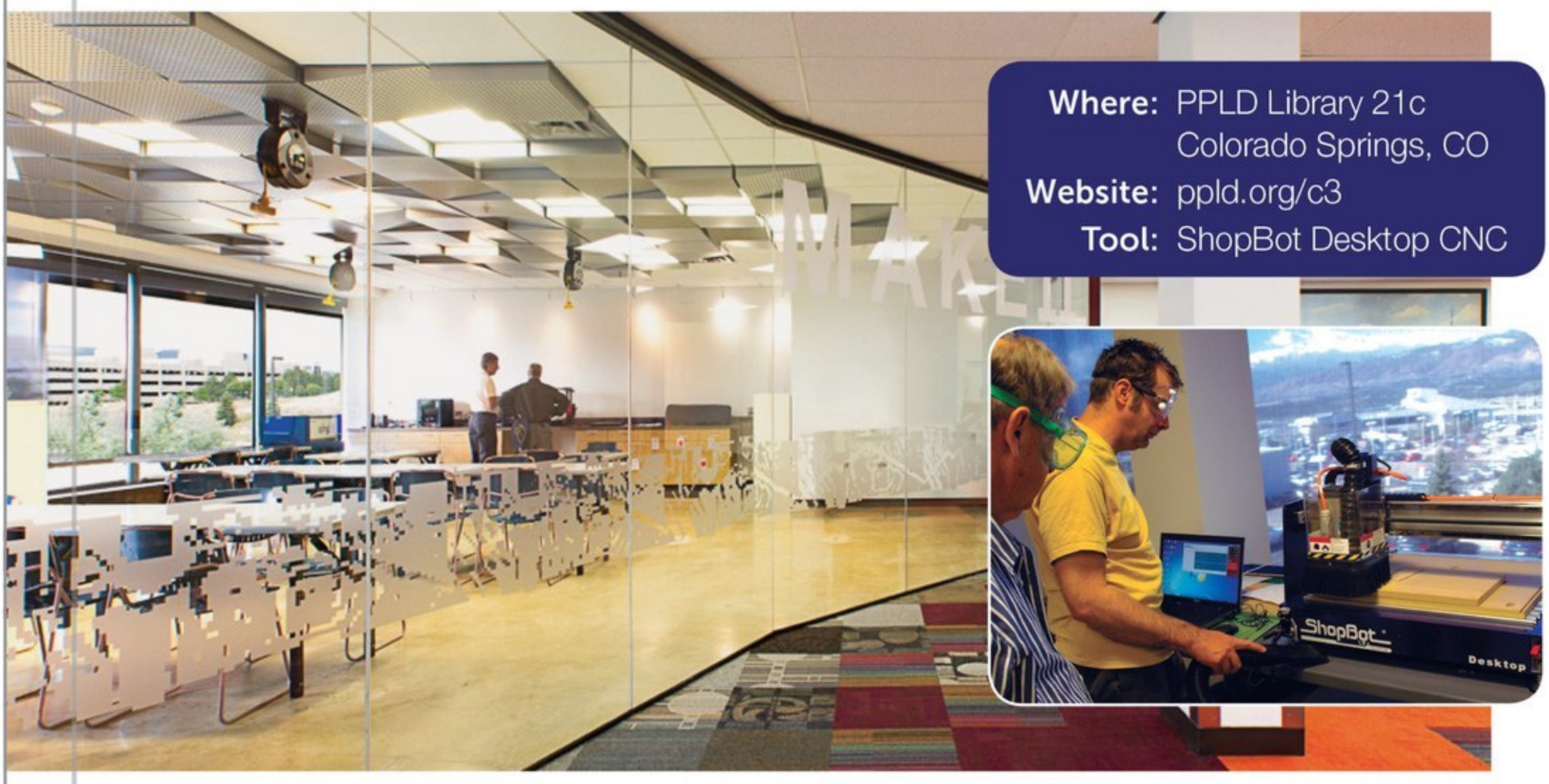
Your march is interrupted by a weathered wooden sign at eye level. Written in an ancient script is the name *Furth im Wald*, and 300 paces ahead rests the small German village bearing said name. A pathway leads toward a castle with a dark, daunting silhouette at its entrance. As you approach, your legs buckle as the form is revealed to be Tradinno, a Gargantuan Dragon who has called this village home since 2010.

At nearly 11 tons and well over 50 feet long, the beast stands 15 feet high, which is record shattering for a mechanization of its kind. Though Tradinno has more than 80 liters of (stage) blood in his veins, he is entirely mechanical. Born from the mechatronic genius of Zollner Electronik, the dragon stands on hydraulic feet and is powered by a 2.0-liter diesel motor. The enchanted creature's walk, head, neck, and eyes are controlled wirelessly. Be wary of his reach, for Tradinno breathes fire and operates as the main set piece for the town's 500-year-old annual theater performance, *Drachenstich*.

Your party leader produces a number-covered plastic gem. You roll for initiative. You cast mage armor and attack the beast.

Zollner Elektronik AG

This library invites you to check out **a ShopBot.**



Where: PPLD Library 21c
Colorado Springs, CO
Website: ppld.org/c3
Tool: ShopBot Desktop CNC

No, you can't take it home. But you're free to use one right here! Pikes Peak Library District's makerspace is humming with making of all kinds: filmmaking, art, product prototyping, and much more.

The Library's Travis Duncan said, "We want to be on the forefront of making public libraries useful for patrons in the tech age. We need to be more than a repository of information. We want to be a community lab where new content of all kinds can be created."

To that end, the makerspace is outfitted with a variety of digital fabrication tools including the ShopBot Desktop CNC. Duncan says, "The ShopBot Desktop is perfect for our space — it's powerful, professional CNC equipment in a small footprint. We're excited to see patrons of all ages have access to these 21st century tools. And we're gaining support from the local business community, which sees the potential of this space as a learning ground for a tech age workforce."

Special Offer
Purchase a ShopBot Desktop and receive an Onsrud Bit Kit ($195 value) for **FREE**!
Call and mention promo code: *MAKE515*
Offer ends September 1, 2015.

Learn more about the ShopBot Desktop at shopbottools.com Then give us a call. We'll help you choose the right tool for your interests.

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