About the Author

Lydia Sloan Cline teaches drafting, digital modeling, and 3D printing classes at Johnson County Community College in Overland Park, Kansas. She works for architecture firms, judges competitive technology events, and became a SketchUp fan after using its Push/Pull tool for the first time. Lydia is also the author of *3D Printing with Autodesk 123D, Tinkercad*, and *MakerBot* (published by McGraw-Hill Education) and other books.

3D Printing and CNC Fabrication with SketchUp

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To Makers all over the world and the companies that support their efforts.

And a big thanks to…

Roger, Amber, and Christie, who indulge and contribute to my own Maker efforts.

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Preface

THE PAST DECADE has seen tremendous interest and possibilities in 3D printing and CNC fabrication. Novices and professionals are using them to make their lives and jobs more rewarding and productiv When these technologies are combined with websites such as Quirky, Kickstarter, Prosper, Etsy, and Shapeways, and social media outlets such as Twitter and Facebook, people are empowered to turn hobbies into businesses. 3D printing, CNC fabrication, and those who do them are loudly ringing in the New Industrial Revolution.

3D printing in particular is becoming part of our nation's education, and to be competitive in school and work most people will eventually require knowledge of it. Electronics, toy, food, automotive, and construction companies are finding innovative ways to use this technology. The military is experimenting with it. 3D printing solutions are currently being utilized in everything fro housing to human body parts. But even so, current 3D printers are comparable to the dot-matrix printers of the early 1980s. Eventually they'll enable solutions we can barely imagine right now.

Creating, manufacturing, and advertising are becoming democratized because of affordable tools and low startup costs. No matter what your age or background, you can participate, because the barriers are low. The same way that software and laser printers let anyone publish from their kitchen table, and WordPress and a website let anyone have a nice storefront, free modeling software, cheap printers, and community Maker spaces enable anyone to put out a product. Mass manufacturing isn't going away, but micromanufacturing and justin-time manufacturing that cater to niche and customization markets also will find a bigger place (Figure 1). So will the Makers who learn these technologies.

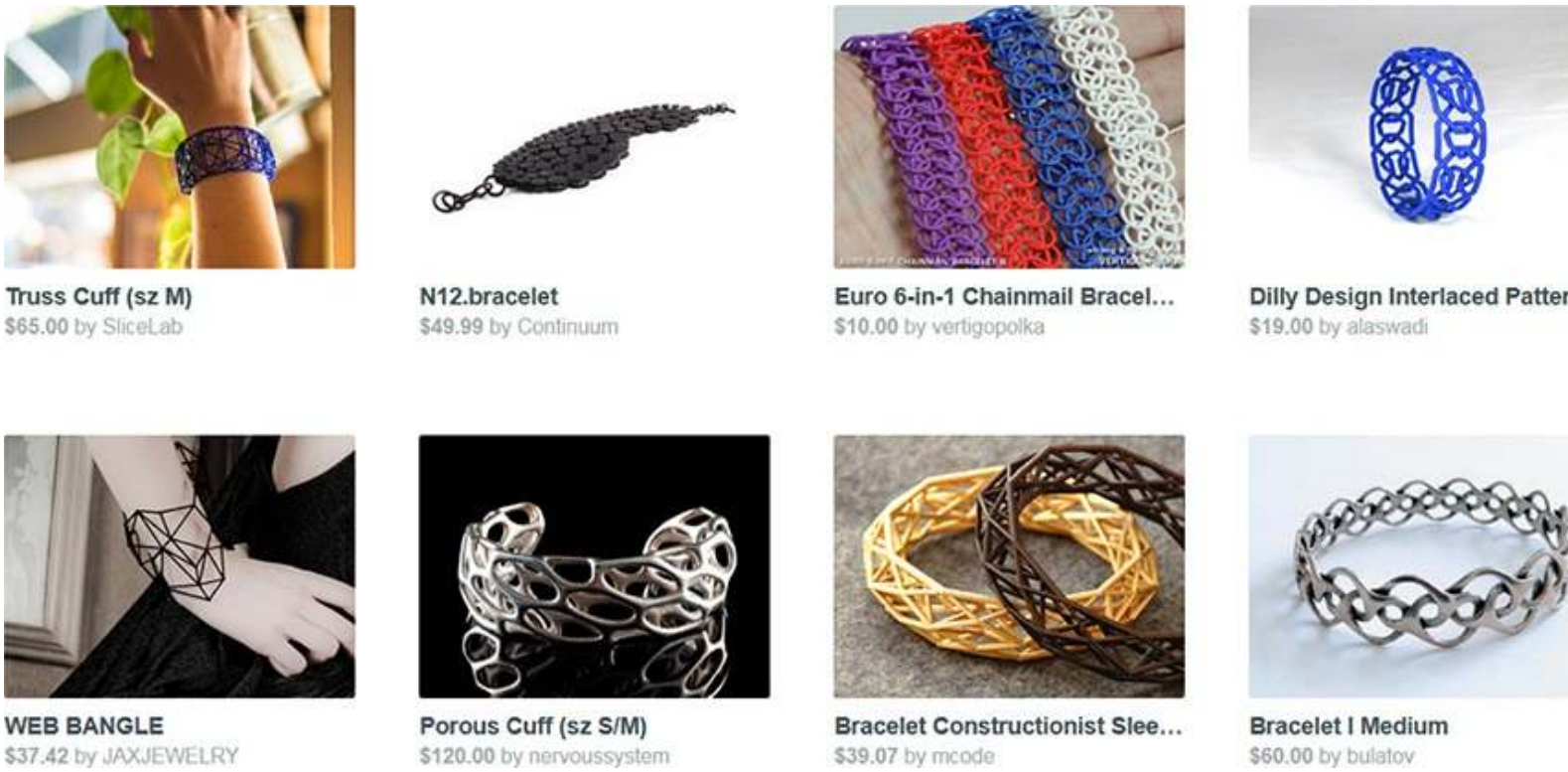

Figure 1 A page at shapeways.com, where Makers print and sell their creations.

Websites such as the Trimble 3D Warehouse, where designs are freely shared, let the world's citizens tinker with, customize, and improve each other's work in the spirit of open source. Maker Faires let them show off what they've done. The nascent Maker movement might counter cheap overseas labor and bring manufacturing back to the United States. Teachers, students, homeschoolers dreamers, entrepreneurs, and *you*, since you're holding this book, are making this happen! You may already have some concrete ideas about what you'd like to do.
So congratulations on finding your way here, because now you'll learn how to turn those ideas into a physical product.

Let's get started!

Lydia Sloan Cli

Resources to Check Out

- **Autodesk University 2013 video:** *The New Industrial Revolution*, available at: http://au.autodesk.com/au-online/classes-on-demand/class-catalog/2013/class-detail/3604
- **Information about Maker Faires:** http://www.makerfaire.com
- **Kickstarter, Indiegogo, and Prosper, sites where entrepreneurs can solicit crowdfunding, market research, and feedback from a large participant community:** http://www.kickstarter.com http://www.indiegogo.com http://www.prosper.com
- **Quirky, a large community that gives feedback on the product development and manufacturing process:** http://www.quirky.com
- **Etsy, an online marketplace for handmade products:** www.etsy.com
- **Shapeways, Ponoko, and Imaterialise, online service bureaus where you can send files for 3D printing or CNC cutting and sell copies via their storefronts:** http://www.shapeways.com http://www.ponoko.com http://i.materialise.com/
- **Trimble 3D Warehouse, a website from which to download all kinds of things to tinker with and 3D print:** https://3dwarehouse.sketchup.com/
- **Instructables, a website from which to get instructions to make all kinds of things:** http://www.instructables.com
- Cline, Lydia Sloan. *3D Printing with Autodesk 123D, Tinkercad, and MakerBot*, 2015 (New York: TAB/McGraw-Hill)
- Cline, Lydia Sloan. *SketchUp for Interior Design: 3D Visualizing, Designing, and Space Planning* 2014 (Hoboken, NJ: Wiley)

We  Creating!

HELLO! SINCE YOU FOUND your way here, I'm betting you're a creator, someone who sews, cooks, crafts, woodworks, builds, machines, programs, repurposes, fixes, invents, and tinkers. Perhaps you have or want a small business and are always thinking up new wares to make. Maybe you make cosplay items. You might be on a quest for the Next Best Thing or a way to improve an existing thing. Or maybe you just want to decorate your life with tangible outputs of your ideas (Figures 1-1 and 1-2). You probably look at items in your field of interest and consider how to create similar or better ones. You discuss your ideas with the similar-minded and attend gatherings where ideas and wares are shown off (Figure 1-3). There's actually a word for this—*Maker*. Makers are part of the new industrial revolution, and you've come to the right place!

Figure 1-1 A dinosaur showerhead from the Thingiverse.

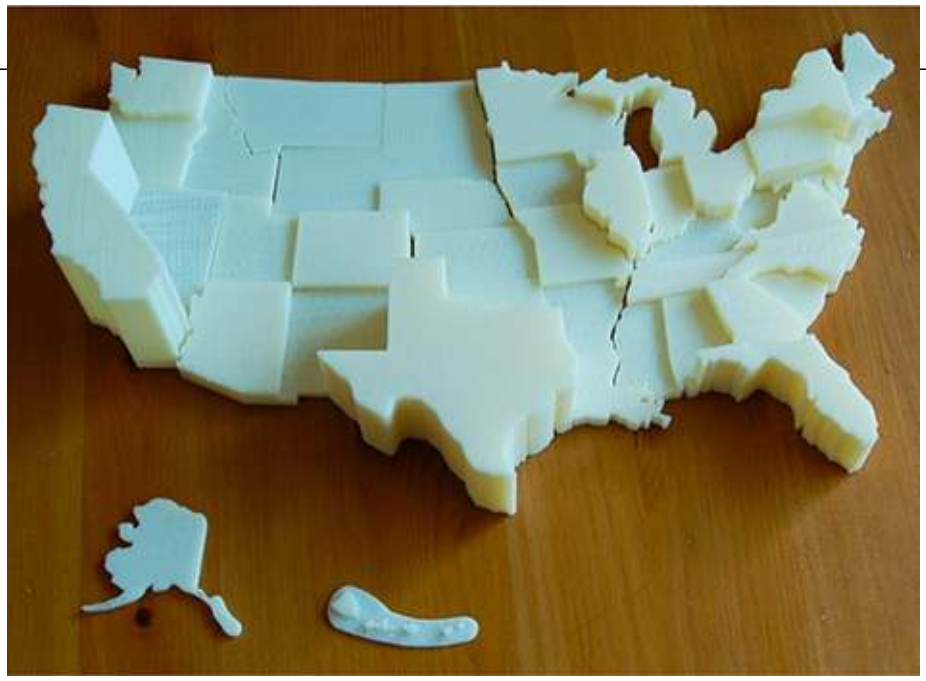

Figure 1-2 A puzzle made with SketchUp. (*Courtesy of Chris Krueger, http://thenewhobbyist.com/.*)

Figure 1-3 A display at the Kansas City Maker Faire.

What Is This Book About?

This book shows how to digitally model your ideas, make those models printable, and then bring the

to physical life. It's for those who want to design, iterate, customize, and prototype their ideas—jewelry, shoes, eyeglasses, phone accessories, toys, promotional materials, furniture, whatever—relatively easily and cheaply. To do so, we'll make some fun, easy projects with a popular program called *SketchUp*, pairing it up with other programs as needed. We'll also physically make some of ou projects on a 3D printer and on a CNC (computer numerical control) router. We'll discuss how to operate, maintain and troubleshoot a 3D printer, and software that runs printers and routers. If you don't personally own such machines, no worries, we'll also discuss places you can go to get your creations made.

No prior knowledge of any drafting or modeling programs is assumed or needed. My assumption i that you have no modeling or 3D printing experience and are using SketchUp for the first time. Henc everything is explained in a project-based, step-by-step manner. So if you're a beginner, you've com to the right place! This book is arranged chronologically, and the content builds from the first chapte to the last. Make sure to check out my YouTube channel, where videos of some of this book's projec are posted. Its URL is at the end of this chapter.

My goal is to get you get up and running fast in the 3D modeling, printing, and fabrication world. Hence, our use of SketchUp's tools and functions will be limited to those relevant to 3D printing projects. So know that while SketchUp has the capability to do such things as create construction documents and animations, we won't be doing that.

What Is a Modeling Program?

A *modeling program* is graphics software in which you create three-dimensional (3D) drawings calle *models*. You can spin these drawings around on the screen to view from any angle. Modeling is different from traditional computer-aided drafting (CAD) software in that the latter is basically an electronic pencil with which you draw two-dimensional (2D) pictures. With modeling, your picture i always 3D.

Many free, ready-made models are available for download, but knowing how to operate modeling software enables you to create your own designs. Maybe you'd like to experiment with some Fitbit and GoPro accessories or customized Lego blocks. Or you need to tweak some premade content to make it printable. This must be done inside modeling software.

There are many modeling programs on the market; besides SketchUp, popular ones include the Autodesk 123D apps, Inventor, 3dsMax, Maya, Rhinoceros, Solidworks, Blender, Modo, Sculptris, an Zbrush. However, most of those have steep learning curves or high prices. The advantages of SketchUp are that it has a free version and you can start modeling your ideas with it pretty fast.

What Is SketchUp?

SketchUp, formerly owned by Google and now owned by Trimble, is a program used to electronicall sketch ideas three-dimensionally, or "get your doodle on." It's the closest you can get to pencil and tracing paper for thinking out ideas. You can "sketch" loosely (meaning without imputing numbers) or sketch precisely. You also can start out sketching loosely and then scale the model precisely.

Specifically, it's a polygonal surface-modeling program. *Polygonal* means that the model is made of mesh, that is, a bunch of polygons (flat surfaces). *Surface* means that the model is hollow (Figure 4). Some programs create solid models, which are forms completely filled inside. Both model types

have their strengths and weaknesses. Generally, mesh models are best for organic, free-form subjects and solid models are best for mechanical pieces. That said, SketchUp in particular was designed originally for architects and interior designers to model houses; hence its native (built-in) tools creat rectangular items best. Curved items can be made, but within limits; for instance, you can't model facial features very easily. However, the fact that it's used by people in such diverse fields such as game development, animation, logo design, woodworking, catalog illustration, and landscaping mean that you'll probably be able to do what you want with it, too. SketchUp is a not a parametric program that lets you model the object and change all its individual dimensions later. Nor is it a building information modeling (BIM) program, where you can extract volumetric data from it. That said, third party developers are constantly coming up with downloadable tools that give it some parametric and BIM capabilities.

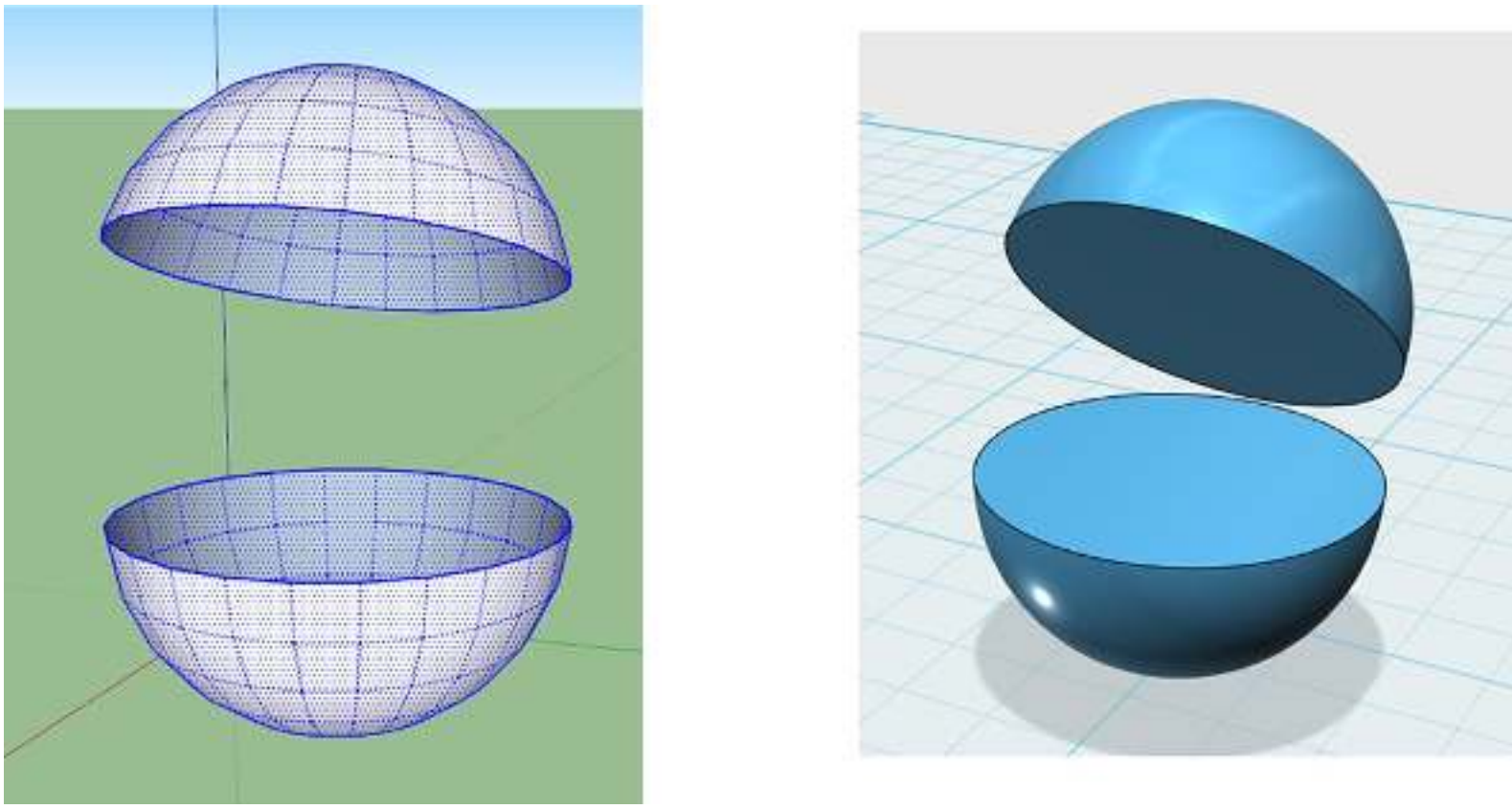

Figure 1-4 SketchUp (*left*) creates hollow polygonal forms. Circles and spheres are actually made of multiple polygons. A solid-modeling program (*right*) creates true forms that are filled inside.

SketchUp is a *vector* program, meaning that it creates vector files. A *vector file* is a collection of lines and curves that scale up or down without loss of quality. Examples are .pdfs (Adobe documents) and .dwgs (AutoCAD documents). This is as opposed to a *raster file*, which is made with pixels and loses resolution quality when enlarged. Examples are .jpgs and .gifs. SketchUp is strictly a desktop program, not a Web-based one.

There are two versions: a free one called *Make* and a pay one called *Pro*. Both look and work identically; Pro simply has additional features, some of which we'll discuss in this book. Pro also allows commercial use.

SketchUp works on PC, Mac, and Android platforms and works similarly on all three. Files transf seamlessly between all platforms. The projects in this book are done on a PC. Mac screenshots are shown in the rare instance when things look or work differently.

SketchUp works well with other programs as part of a larger workflow. We'll use it with Autodesk's AutoCAD (which has a free trial version), 123D Meshmixer (free), and 123D Make (free) You'll learn how to import an AutoCAD file into the Pro version, evaluate a file for printability with 123D Meshmixer, and turn a model into a pattern file for a CNC router with 123D Make. We'll also download and install extensions, which are downloadable tools that let you do things SketchUp's native (built-in) tools don't. Some are free; some have a cost. We'll discuss where to find them, how to install and use them, and any costs and licensing restrictions as we get to them.

What Is 3D Printing?

3D printing is the process of making a physical model from a digital one. A 3D printer is the machin that builds it. It does this by applying successive layers of material onto a flat surface called a *build plate* and melting that material into the shape of the model. You can assemble a printer yourself or buy one preassembled. Consumer model prices range from around $300 for unassembled parts to around $6,000 for a higher-end assembled machine. 3D printers plug into a USB port on your computer just like any other peripheral (Figure 1-5). They're run with software that either comes wit them or that can be downloaded for free or cost from various sites.

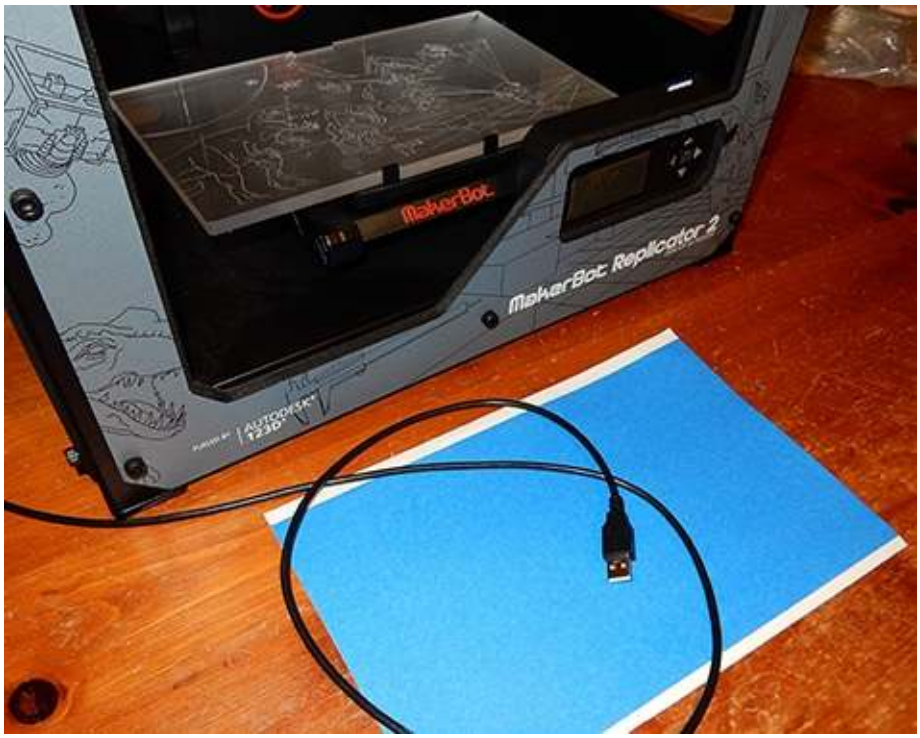

Figure 1-5 A 3D printer plugs into a computer USB port.

Printers use *filament*, a string of material wrapped around a spool (Figure 1-6). Consumer machin primarily use thermoplastic, the main types being PLA (plant-based) and ABS (oil-based). Both com in all colors. Other filament types, such as flexible, dissolvable, conductive, and wood, are also available. Commercial machines use a wide range of filaments, such as ceramic, food paste, silver,

gold, and steel. There are even biomedical filaments for making human body parts (Figure 1-7).

Figure 1-6 Plastic filament spools.

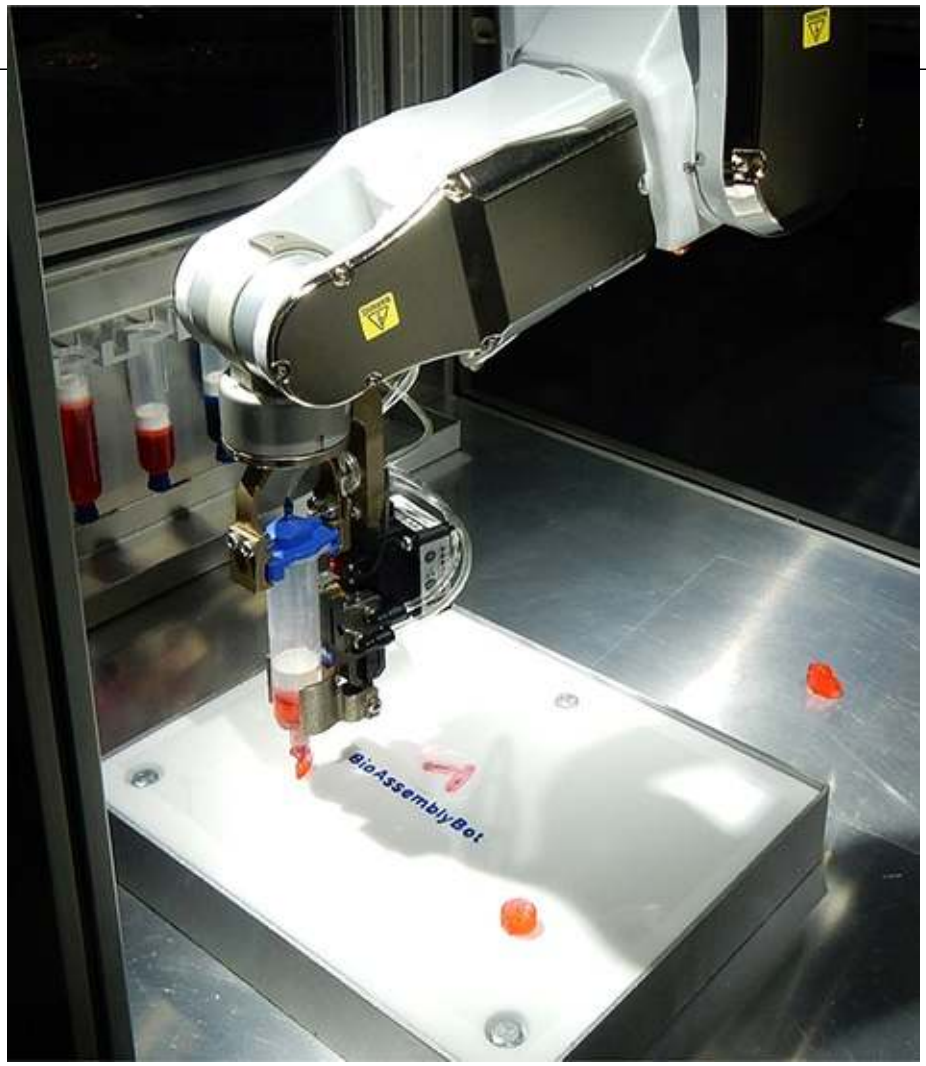

Figure 1-7 A printer making arteries with biomedical filament.

Is 3D Printing Cheap?

It depends on what you mean by “cheap”! If you’re iterating or prototyping an idea, it’s certainly cheaper than having to commission parts made with an injection-mold process. You can have a copy of your idea in the time it takes to print it. However, there’s no economy of scale, time- or material-wise. You cannot print multiple copies in the same time as one (Figure 1-8). If you use a third-party printer, you’ll be charged for the amount of material the model requires, the time it takes in the printers, and any post-production labor involved. When you print something on your own machine, the software that interfaces with it will tell you the printing time and amount of material required.

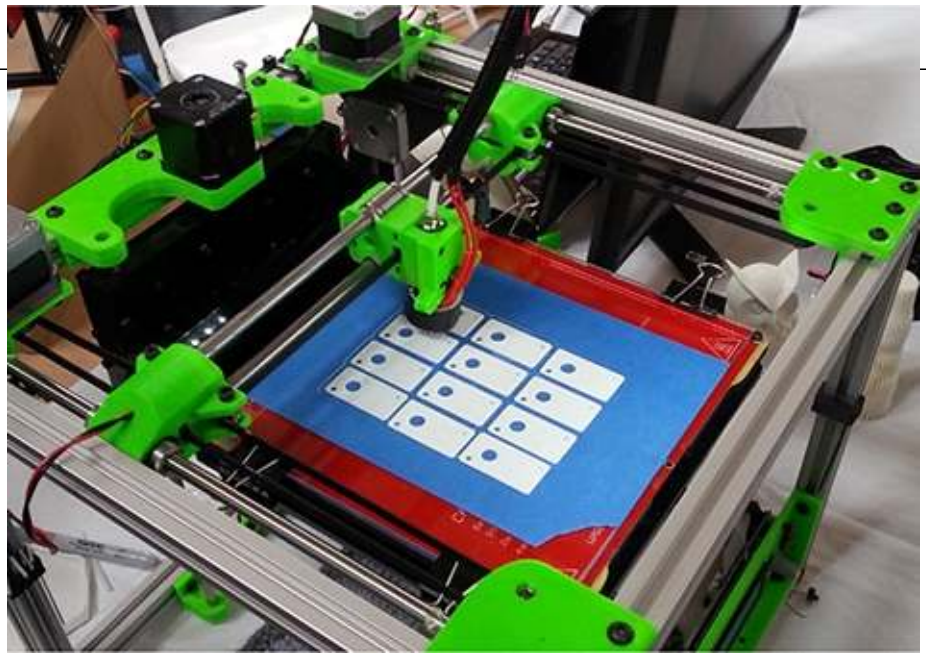

Figure 1-8 3D printing doesn’t offer economies of scale in time or material. It takes 12 times as long to print 12 items as it does to print one.

What Is CNC Fabrication?

CNC fabrication is the process of manufacturing objects on a computer-controlled cutting machine. Such machines are typically routers or lasers, and they carve and cut shapes out of sheets of cardboard, plastic, wood, wax, and foam, and blocks of aluminum (Figure 1-9). This is popular for creating furniture, crafts, puzzles, and toys (Figure 1-10). Examples are the Cricut, which is a person CNC machine that cuts card stock and paper, and the Carvey, which is a personal CNC machine that cuts wood. ShopBot and Tormach make personal machines, and Haas makes mills, which are large, commercial machines. Figure 1-11 shows a Carvey and a Haas.

Figure 1-9 CNC routers cut flat shapes out of sheets of material. On the left are plastic and paper sheets; on the right are aluminum blocks.

Figure 1-10 Toys are common CNC-milled items.

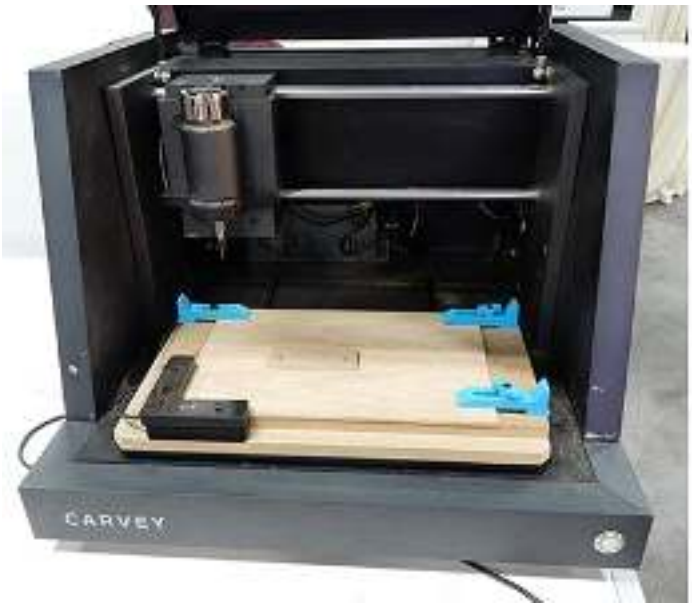

Figure 1-11 Carvey CNC router (*left*) and Haas CNC mill (*right*).

What Is a Maker Space?

3D printers and CNC machines are too expensive for many Makers, but fortunately, they can be foun in *Maker spaces*, also called *hacker spaces*. These are physical locations that contains computers and fabrication tools for member or public use (Figure 1-12). Many libraries and museums have set up these spaces, too. There are TechShops in some states; a monthly membership fee accesses their equipment. Then there's 100Kgarages.com, a matching service that connects people who own shop equipment with people who want to use it. Google "Maker space" or "hacker space" and the name of

your city to find what's available near you. There are also service bureaus to which you can upload your files and get them printed for a cost.

Figure 1-12 HammerSpace, a Maker space in Kansas City, MO.

What You Need, Computer-wise

SketchUp is a graphics-intensive program, so the stronger the video card, the better. Intel cards aren' recommended; NVidia cards work well. You also need a three-button scroll-wheel mouse. A one-button mouse or laptop track pad is usable but difficult. The scroll wheel performs zoom and pan functions, saving you from having to click on those icons all the time. Mac users, your one-button mouse can be swapped with any manufacturer's two-button scroll-wheel mouse. There's also a mous specifically designed for the 3D environment called a *Space Navigator*. It combines the zoom, pan, and orbit navigation tools, plus it tilts, spins, and rolls (Figure 1-13).

Figure 1-13 The Space Navigator mouse by Logitech is designed for the 3D environment. It can b used along with a traditional mouse.

Some Makers use a drawing tablet (not the same as a computer tablet) and digital pen. The tablet' buttons can be programmed to perform multistep functions that otherwise take multiple keystrokes t perform, and the pen offers more control than a mouse. Wacom's Graphire, Intuous, Cintiq, and Bamboo are popular tablets.

Here's the recommended hardware for SketchUp 2015:

PC

- Microsoft Internet Explorer browser 9.0 or higher
- SketchUp Pro requires .NET Framework version 4.0.
- 2-GHz or greater processor
- 8 GB or more of RAM
- 500 MB of available hard-disk space
- 3D class video card with 1 GB or more of memory (The video card driver must support OpenGL 2.0 or higher and be up to date.)
- Both the 32- and 64-bit versions of Windows are okay.