CHAPTER 14

Futures

It is always very dangerous to predict the future of a rapidly moving field because it is very easy to be far too conservative or too aggressive. That said, this chapter picks out a few technologies, applications, and business issues that might shape the field in the longer term. There are many other possible futures out there; if you are reading this book, it is likely you, too, will have an influence!

A great deal of experimentation is going on right now in the 3D-printing space, and in the near term you are likely to see various approaches to increasing speed, and perhaps mixing subtractive and additive manufacturing methods. Just the fact that 3D printing brings together computer scientists and people who like to make things renders it a likely spawning ground for innovative ideas.

The story of any technology is the story of how and when different users adopt it. Desktop 3D printing is a classic *disruptive technology*. The term (usually credited to Harvard's Clayton Christenson) refers to any technology that is created to be a less-capable, cheaper version of an existing, expensive capability. Over time, the cheap technology gets better and starts to take over the market from the entrenched one. In the case of 3D printing, though, what is the desktop printer displacing? One could argue that commercial-grade 3D printing and conventional machining and molding all are at some risk of being displaced or at least changed. When objects can be transmitted digitally into your home, that disrupts retail and supply chains, too.

This chapter explores possible extensions of existing technology trends as well as some of the economic, social, and business issues that arise when anyone can share designs.

Technology Trends

The last few years have seen desktop 3D printers mature from purely hobbyist endeavors, requiring a significant learning curve, to far more user-friendly machines. As the desktop machines have stabilized, more aggressive users have moved off into the realm of 3D printing the very big and very small.

We explore one of the more spectacular, very large 3D printing projects first. Then we look at how the desktop environment itself is evolving in several parallel directions—some that give users more control, and some that automate the process away from the user. The realm of the micron-or-less resolution print—sometimes called *microfabrication*—remains rather exotic but will be an area to watch once it emerges from the lab.

Extreme Users

Usually we think of 3D printing as printing very delicate, small parts. Behrokh Khoshnevis is a professor of Industrial and Systems Engineering at the University of Southern California. He has developed a process he calls *contour crafting* to 3D print concrete at scales appropriate for building houses. The Contour Crafting group has even been looking into using the technique to build structures for colonies on other planets.

Figure 14-1 shows a test concrete wall created with the Contour Crafting process. Videos of it in action are available on the project's website (`http://contourcrafting.org`).

Figure 14-1. *A section of 3D printed concrete wall. Courtesy of Contour Crafting*

The Contour Crafting printer in some ways looks like a giant version of the desktop 3D printers shown in the photos throughout this book, particularly the one back in Figure 2-1. An extruder head (which puts out a special concrete mix) runs back and forth on a gantry, building up a wall in the *x-z* plane, with the thickness of the wall in the *y* direction. The whole giant gantry is on rails that increment along in the front and back (*y*) direction, building up the side walls.

Concrete can be laid down without any forms (except for the print head that shapes the concrete as it emerges from the extruder). Rebar and other supporting material can be dropped in during fabrication. Figure 14-2 is an artist's conception of the process being used to fabricate a house. Although this is an experimental process right now, the Contour Crafting team hopes to use the technology to rapidly construct housing in areas of great need—such as after natural disasters or in areas that currently lack adequate shelter.

Figure 14-2. *Artist's concept of the process of 3D printing a house. Courtesy of Contour Crafting*

Improving the User Experience

Consumer 3D printers have been evolving very rapidly, and competition on features and price is becoming fierce. If you have read this whole book to this point, you are now very aware that 3D printing is not a simple process (yet). Some manufacturers have developed simplified user interfaces, but these interfaces limit the types of objects users can print.

In other words, both the good thing and the bad thing about open source 3D printers is that a large number of parameters need to be set by the user. Over time, ways of automatically analyzing input files and optimizing a print will likely start to find their way down into the consumer space. But until that happens, you need to understand most of the parameters discussed in Chapters 5 and 6.

There has also been a lot of interest in finding ways for 3D printers to calibrate and align themselves. That is challenging to do within the cost and complexity constraints of a consumer printer, but nevertheless, various solutions are likely to emerge over the coming years.

Faster Printing

3D printing is still very slow. Prints can take hours, or even days. Some of the limitations are just physics—that a layer needs to cool before another one can be laid up on top of it. Current filament-based machines are starting to push against some of these physical limits.

Some projects (such as the prosthetic hand project described later in this chapter) are using "farms" of low-cost printers to produce significant numbers of custom products in parallel. Using many printers at a time like this may be one way to get past the inherent slow speed of filament-based prints.

Filament

As noted in Chapter 7, new filament materials are appearing on a regular basis. Filament variety will likely continue to expand as the market does, and as new users start looking for materials with particular characteristics, like higher strength, greater elasticity, good adhesion with glues, and so on.

Current 3D printers need filament with very precisely controlled diameters. This inflexibility makes it challenging to recycle filament, particularly at home. There are some efforts to design machines to recycle filament, notably the Kickstarter-funded Filastruder (`www.filastruder.com`), a machine that takes in pellets and puts out filament.

Recycled filament is a bit further away still. Right now, filament costs are a very significant part of the overall cost of owning a 3D printer, and if that can be lowered (particularly for volume users), then the cost of 3D prints will fall by a lot, too.

Emerging 3D-Printing Applications

The early days of consumer-level 3D printing were dominated by hobbyist applications of the technology. Now, however, the use of 3D printers (though not necessarily consumer-level ones) has rapidly expanded into many industries, and this expansion is likely to continue. This section highlights two applications—printing food and medical applications—that have captured public attention. The phenomenal growth in applications of 3D printing is likely to continue for some time.

Printing Food

Printing food is a little challenging, both because most foods do not lend themselves into being made into prefabricated filaments, and because the whole food-extrusion chain (everything that touches whatever you are extruding) has to be food-safe. Some foods (such as chocolate) can behave similarly to thermoplastics, others can be extruded as a paste or gel, and others can be sprayed or drizzled as a liquid or powder, or deposited using a "sprinkling" or pick-and-place type of system as large solids (which may then be melted, as with topping a pizza). Many foods are already made by squirting out some of their constituents, so it depends on whether you consider a pastry chef to be "additively manufacturing" wedding cake icing.

One concept machine was developed by the Dovetailed design studio (www.dovetailed.co) in Cambridge, England as part of a food hackathon. It develops a raspberry (Figure 14-3) with a machine (Figure 14-4) that builds up the food piece droplet by droplet.

Figure 14-3. *A 3D-printed "raspberry." Photo courtesy of Dovetailed*

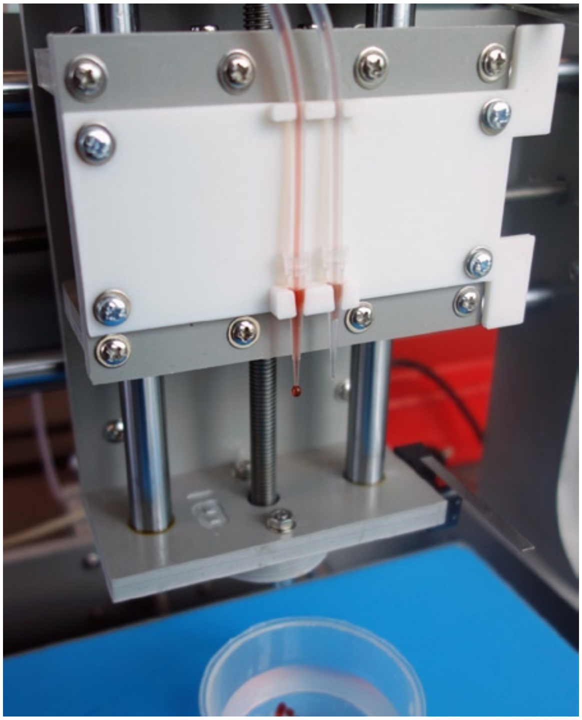

Figure 14-4. *The "fruit" 3D printer. Photo courtesy of Dovetailed*

The printer in Figure 14-4 takes tiny drops of a fruit juice mixed with a gelling solution like sodium alginate. This mix is dripped into a liquid solution to make thin-skinned droplets using a molecular gastronomy technique called *spherification.* (*Molecular gastronomy* is the use of relatively advanced chemistry and biochemistry to create novel foods, particularly identified with Nathan Myhrvold and his *Modernist Cuisine* books.)

Whether 3D printing food remains a specialty process for wedding cake toppers with mere novelty value or moves into the mainstream as a manufacturing process is something that will evolve over the coming years. Despite the challenges, there has been a lot of interest in printing pancakes, chocolate and various other foods made of sugar, and, strangely, pizza. Consumer producer Hershey's and 3D Systems announced in early 2014 that they were planning to co-develop a chocolate printer.

3D Printing in Medicine

The medical community has been very interested in 3D printing. Medicine has many problems that play to 3D printing's strengths: a need for custom devices, a lack of good, reasonably priced fabrication techniques in some cases, and a drive for lower cost everywhere. One issue, though, is whether 3D-printed parts are actually safe for medical uses.

The following Note offers details on finding further information as the rules for 3D-printed medical devices are made and commented upon by the medical community. Some issues, according to the FDA's initial workshop call, include how repeatable the manufacturing process is (repeatability is important for testing), the biocompatibility of the materials, and whether and how the materials can be sterilized adequately.

■ **Note** The U.S. Food and Drug Administration (FDA), which has jurisdiction over medical devices sold in the United States, is starting to consider rules for 3D-printed medical devices. As of the writing of this book, the FDA had scheduled a workshop for October 2014 (the formal Notice is dated 5/19/2014), called Additive Manufacturing of Medical Devices: An Interactive Discussion on the Technical Considerations of 3-D Printing; Public Workshop; Request for Comments. You can read more about it here: `www.federalregister.gov/articles/2014/05/19/2014-11513/additive-manufacturing-of-medical-devices-an-interactive-discussion-on-the-technical-considerations`.

Bioprinting

Culturing body tissues to replace diseased or damaged body parts is not new. However, 3D printing might make the process more efficient and capable of reproducing more complex systems than has been possible before. *Bioprinting,* as the process is often called, often relies on printing some sort of scaffolding material, similar to consumer 3D printing (or squirting out some gel, like the food printer in the preceding section). The company Organovo, for example (`www.organovo.com`) is exploring bioprinting tissues for research, including an attempt to test the printing of liver tissue.

The bioprinting arena is expanding so rapidly that any attempt to be inclusive here will be woefully out of date within months. The open source journals *PLoSONE* (`www.plosone.org`) and *PLoSBiology* (`www.plosbiology.org`) are readily available resources to explore the state of the field beyond what you might find in a general web search; search on the keyword *bioprinting.*

■ **Tip** A good survey reference about bioprinting is a 2014 article by Jordan Miller in *PLoSBiology*, called "The Billion Cell Construct: Will Three-Dimensional Printing Get Us There?" The article is freely available at `www.plosbiology.org/article/info%3Adoi%2F10.1371%2Fjournal.pbio.1001882`). As Miller points out in his article, U.S. National Institutes of Health (NIH) has started a website for sharing bioprints and related models (`http://3dprint.nih.gov`) and has begun developing standards for the things that an STL file just cannot capture about something created partially of living cells.

The Low-Resource Health Worker

Later on in this chapter, we discuss low-cost, homebuilt prosthetics both for the developing world and for generally making lower-cost medical devices. The ability to make a medical device without training creates some interesting regulatory, ethical, and philanthropic challenges. Several organizations are looking at DIY medicine, both for resource-poor communities and to solve gaps in the day-to-day healthcare space.

The Little Devices lab at MIT has several websites, notably its main one (`http://littledevices.org`) and its MakerNurse site (`http://makernurse.org`). 3D printing is involved only as a potential part of the lab's solutions, but its sites feature some interesting early projects that you may find to be a rich source of ideas.

Low-Cost Prosthetic Hands

The 3D-printing community has developed 3D-printed prosthetic hands. Some designs have arisen from people helping out someone they know who has lost a hand but who cannot afford a conventional first-world prosthesis.

One collaboration between Richard Van As of Johannesburg, South Africa—who lost his hand in a shop accident—and special-effects professional Ivan Owen resulted in a design that was then converted to a 3D-printable version for a 5-year-old boy, Liam, and subsequently posted to Thingiverse. Robohand, as it has come to be known, is a mix of 3D-printed and CNC machine parts, as well as some conventional off-the-shelf hardware.

Robohand (www.robohand.net) has continued evolving to become simpler to put together, and, according to its website, the group maintains a "print farm" of consumer 3D printers to create hands. The organization has worked with Los Angeles-based Not Impossible Labs to take the concept to Sudan to provide hands for people who lost them due to ongoing wars. Robohand has inspired others to take the plans and create their own versions. For example, e-Nable, an organization that creates 3D-printed prosthetic hands for those in need and shares its designs for free (http://enablingthefuture.org), credits the Robohand group as inspiration.

The Developing World

If 3D printers can make life more convenient and prototyping more cost-effective in the First World, what might they do in developing countries? Running a 3D printer in a region without infrastructure presents several challenges: you need to power it and you have to somehow find a way to buy or make filament. In the long run, it will be essential to find a way to recycle filament or otherwise create it locally for these markets.

The open source appropriate technology movement (notably the Michigan Tech Lab in Open Sustainability Technology, at www.mse.mtu.edu/~pearce/) has been trying to find ways to link up open source 3D printing, solar power, and ways of locally creating filament to enable manufacturing anywhere.

Cellphones and online banking took hold in Africa quickly because of the lack of other infrastructure. Time will tell whether 3D printing can become an enabling technology there in the same way. Kodjo Afate Gnikou from the West African country of Togo received a lot of press in 2013 when he built a 3D printer at the WoeLab, a hackerspace in the capital city of Lome.

The printer, built mostly out of e-waste, was one of the true *RepStrap* printers. A RepRap printer, as you learned in Chapter 1, is a printer built to replicate itself. A Rep*Strap* printer, on the other hand, is built out of whatever is lying around, just to enable 3D printing somehow (not necessarily with the intent to build more printers, per se).

Gnikou built the printer for the most part out of things he found in a dump, spending about $100 on other parts that he could not find lying around. Subsequently, WoeLab has used a crowdfunding site to build more printers based on Gnidou's design.

■ **Note** To read more about this RepStrap printer, see its crowdfunding page at www.ulule.com/wafate/.

The Business of 3D Printing

At the moment, the 3D-printing industry is split into 3D printer manufacturers and *service bureaus*—organizations that will, for a fee, 3D print an object for you. The content part of the industry—models available for printing by third parties—is still maturing. Whether the sale of 3D models becomes a significant business in its own right remains to be seen and depends to a degree on how easy to use consumer 3D printers become. Meanwhile, some basic intellectual property issues need to be sorted through.

Printer Patent Issues

Business models using 3D printing are evolving rapidly. What does the future hold for the printer industry itself? There are some crosscurrents out there right now in the business environment that will likely have a big effect on the industry going forward.

As discussed in Chapter 1's section "The RepRap Movement," consumer 3D printers largely arose because of the open availability of most of the 3D-printing technology when key patents expired. The RepRap printers evolved quickly as open source designs, and as long as it was mostly a hobbyist enterprise, there was not a lot of incentive to invest in any further patent protection.

However, the tone of the discussion changed when Stratasys (the parent company of consumer 3D-printer manufacturer Makerbot) sued 3D printer maker Afinia for patent infringement of some of the remaining unexpired patents in the field. Afinia's response was to declare that the patents in question were invalid on a variety of grounds and to claim that Stratasys was attempting to create a monopoly.

As of the writing of this book, the case was still pending. There has been further distress in the open source community over patents held by some manufacturers that the community considers to be inventions that were in fact developed as open source. Sorting all this out is going to take time.

■ **Note** Afinia's response to Stratasys in its entirety is available at `www.afinia.com/3d-printers-and-printing/afinia-answer-to-stratasys-claims`.

Hardware as a Service

The current trend for businesses is to think of *software as a service*. That is, instead of buying software, a user subscribes to it and never actually owns it. Is 3D printing creating an era of *hardware as a service*? This might mean purchasing a design and printing it yourself, or purchasing a print created by a service bureau.

Some knotty problems arise with this business model, though. The previous section talked about patents for the printers. What about the ownership of the items being printed? At the moment, scanning a part is still a fairly painful and time-consuming process, but presumably this, too, will start to improve. The issues about who can make a copy of what (and who can sell those copies) is likely to make the digital distribution disruption in the music and publishing industries pale in comparison.

STL or G-code file sharing has some similarities with music sharing, but it takes more skill to print an object than to open an e-book or play an MP3 file. Will users (and printers) evolve so that most people print their own copies, or will they use networks of custom print shops? An explosion of business models and services seems inevitable in the coming years as people explore different routes to mass-customized products.

No matter how the business models turn out, that there will be a lot of different ones seems inevitable. We hope that you learned enough from this book to be able to come up with your own and change the world!

Summary

This chapter reviewed some usability and technology challenges that the industry is working to overcome in order to enable more broad-based use of 3D printers. This chapter also took a look at some of the many possible growth avenues of 3D printing, notably food and medical printing. Finally, it reviewed some of the difficult business issues that will need to be considered as the industry grows.