An overview of the past, present, and future of 3D printing technology with an emphasis on the present

Robin M Snyder
RobinSnyder.com
robin@robinsnyder.com
http://www.robinsnyder.com

Abstract

Just as the cost of high quality laser printing started in the tens of thousands of dollar and can now be purchased for under $100, so too has 3D printing technology started in the tens of thousands of dollars and is now in the thousand dollar range. Current 3D printing technology takes 2D printing into a third dimension. Many 3D printers are somewhat similar to ink jet printers in that that rolls flexible plastic is melted (instead of ink) and built up layer on layer to create a 3D artifact. A more expensive technology takes away from a black of material to so that the artifact produces is what remains. Each method has advantages and disadvantages. A related technology, laser cutting, is yet more expensive but, like the other technologies, is becoming less expensive each year. While information deals in intangible bits, 3D printing deals in tangible atoms. Soon the phrase "make it" may be as common as the phrase "print it". This paper/session will discuss the past, present, and future of 3D printing technology, concentrating on what can be done today with an actual demo of 3D printing in action. The general software language used to program 3D printers, CNC machines, for Computer Numerical Control, is g-code. One can do 3D printing, however, using available software packages, many Open Source. Software, hardware, and accessories necessary to get started will be covered.

Introduction

In 1985, Apple and Steve Jobs introduced the world to, among other things, low cost desktop publishing in the form of the Apple LaserWriter. This high quality laser printing (via PostScript, a language designed for high quality printing) started at over $5,000 but this technology can now be purchased for under $100. It is to the point that, like razer blades, film cameras, game consoles, and ink jet printers, one can in a short time spend more for the day-to-day usage supplies than for the original device.

Current 3D printing technology takes 2D printing into a third dimension. Many 3D printers are somewhat similar to ink jet printers in that that rolls of flexible plastic threads are melted (instead of ink in an ink jet printer) and built up layer on layer to create a 3D artifact.

The lower end 3D printing machines are additive devices that build up layer upon layer of material to create a 3D object. A more expensive technology uses a subtractive process takes away from a black of material to so that the artifact produced is what remains. Each method has advantages and disadvantages. A related technology, laser cutting, pretty much a 2D technology that cuts away from a thin material, is yet more expensive but, like the other technologies, is becoming less expensive each year.

While the field of information deals in intangible bits, 3D printing deals in tangible atoms. Soon the phrase "**make it**" may be as common as the phrase "**print it**". This paper/session will discuss the past,

present, and future of 3D printing technology, concentrating on what can be done today with an actual demo of 3D printing in action.

History

Humans have always made things - things that are sometimes called technology. For example, language is not a technology, but writing is a technology. Humans spoke languages long before they actually wrote things down using symbols in what we would call a language. Before the industrial revolution of the 18th Century, things were manually made one at a time, each one a custom instance of that thing. The industrial revolution facilitated the creation of things on a large scale, but things that were pretty much the same, such as guns with interchangeable parts, the Model-T Ford (any color as long as it was black), etc. Economies of scale allowed diversification of what was produced, but only to the extent that enough people wanted what was being produced in the form it was being produced.

An earlier revolution, the printing (information) revolution introduced by Gutenberg in the 15th Century, facilitated the mass production of information in the form of books of 2D paper containing information. Through the 20th Century, printing technologies developed on vast economies of scale. But yet, there needed to be enough demand for the book to be produced/published to justify printing it typical runs of 1,000 or more copies for each run. The information revolution of the Internet and the web has allow publishing to move to be on-demand. For example, the author has an interest in reading and understanding classical Greek (in the Greek language). an interest that is, by all accounts, not huge. But yet, on Amazon.com, there are a number of self-published authors of credible classical Greek texts with annotations, etc., that are quite interesting. These books are self-published and printed when ordered (thus, limited binding options, etc.). In a print-on-demand environment, custom books can be printed for an audience of one, a few, or many.

This same concept is approaching, and in some cases, here already, in the form of 3D printing. 2D printing prints information on paper. 3D printing makes things. Simple 3D printers use plastic, but more expensive 3D printers use metal, cake icing (e.g., customized cupcakes), body parts, etc. For example, a custom finger (for someone who has lost a finger) might have cost more than $10,000, once all the medical and domain experts are used. But, someone could put together a custom 3D printed finger replacement for much less. To find examples, use an Internet search such as "**3D printed finger**".

In 3D printing, the cost of a customized instance of one is no more costly than producing more than one. 3D printing may never replace the factory line dedicated to producing many of the same type of thing at lower cost, but the fewer and more customized the thing, the better suited is 3D printing to the task.

This concept has been labeled the long tail versus short tail. The short tail consists of common items in high demand that are worth being produced - but every item is the same. This could be the blockbuster movie, the book everyone wants to read, the most common size clothing in the some colors and styles, etc. The long tail are the unique items that have a very small demand - the specialized movie, book, piece of clothing, etc. In the case of DVD rentals, NetFlix took the long tail of sales (and some of the short tail) while Redbox took the short tail (common high demand DVD's), and Blockbuster, with expensive brick and mortar stores disappeared. 3D printers create a new market for specialized good in

the long tail of things - customized and individualized doll house parts, customized and individualized Lego parts, customized and individualized war gaming parts, etc.

Makers

At one time, a computer was a term to describe a person whose job was doing computations - typically on an adding machine. Many human computers were used to do calculations during the Second World War. As electronic digital computers developed (as contrasted, for example, with mechanical analog computers), and prices decreased, jobs for human computers disappeared and the term computer now refers to an electronic digital computer. So too, a printer did, and still does to some extent, refer to a company and/or a person whose job it is to facilitate printing - which has changed slowly since the time of Gutenberg. However, many people today use the term printer to refer to a device on the desk next to the computer that produces hard copy output. A maker is someone who makes things. Terms often start out describing what they do in terms of what already exists, and then changes to another term. Examples are horseless carriage (automobile), iron horse (locomotive), lift or vertical railway (elevator), cellular phone (cell phone), talking telegraph (telephone), talking pictures (movies), etc. Today, a maker is someone who makes something, and what better way to make something than by using a 3D printer. Might a 3D printer eventually be called a maker? And whereas today we may say "**print it**", we may soon say "**make it**".

PrintrBot Simple

The cost of getting into 3D printing has been dropping over time. The author started using the PrintrBot simple, which costs about $300 as a kit (with wooden parts) or $700 pre-assembled (with metal parts). Since the field of 3D printing is in a state of fast change, the prices and many of the details will change over time but the concepts will remain about the same. And the cutting edge can be the bleeding edge. The author's first attempt at a 3D printer resulted in some shipping damage and a delay in actually getting 3D printed objects realized.

The PrintrBot simple web site is at http://printrbot.com and the instructions, videos, software links, etc., for the PrintrBot Simple are at http://printrbot.com/simple.

As with a traditional 2D printer, the following are needed.

- printer hardware (which changes over time)
- printer firmware (hardware-embedded software which can be updated)
- host software drivers (Windows, Mac, etc.)
- host application software (Windows, Mac, etc.)
- printer filament (the consumable that can eventually have a total cost more than the printer)

Printer filiment

The most common printer material used by the PrintrBot Simple is PLA filament with a thickness of 1.75 mm. A 1 kg roll of PLA filament costs about $30. This filament is melted to spread and then dries to a solid plastic, in analogy to an ink jet printer spraying ink that then dries on the paper. Feeding the

filament corresponds to the 4th dimension in 3D printing, which is in addition to the three spatial dimensions.

The filament needs to be heated to the correct temperature, and then applied in a consistent manner. Typically, the firmware running the 3D printer controls this with a user interface on the host computer to set and monitor such aspects of the 3D printer.

Drivers

As is typical, Windows requires an extra step to install the required drivers. It is reported that Microsoft may soon host and ship drivers that would then be automatically recognized by Windows when the printer is connected to a USB port.

Repetier

The Repetier 3D printing software can be downloaded at http://www.repetier.com. It includes Slic3r, Skeinforge, Python and Pypy and requires the .NET 4 framework. There are versions for Linux and Mac although the Linux version requires WINE which is a Windows emulator, so it appears to be more Windows-based than Linux-based.

Once started, one must configure the printer via the "**Printer Settings**" icon in the upper right of the Repetier program window. The "**Port:**" setting needs to be set to the port assigned by Windows when the USB cable is attached, and after installing the Windows serial drivers.

Following the installation instructions, the PrinterBot simple web site has a recommended G-Code file with which to start.

SketchUp

SketchUp is 3D software for designing and creating 3D objects. The web site is at http://www.sketchup.com/products/sketchup-make. From their web site:

> *Hobbyists, kids and backyard spaceship builders all agree that SketchUp Make is the easiest, most fun, entirely free 3D drawing tool in the world. We think you will, too.*

They offer a free version and a SketchUp Pro version - $590 as of May, 2014. It is available for Windows and Mac. The author primarily worked with Repetier in getting started with 3D printing.

CNC Machines

A CNC (Computer Numerical Control) machine uses a computer program to control a "**machine**". In 3D printing terms, a CNC machine can be used to "**take awake**" from what is there - a subtractive technology. Common examples of CNC machines are lathes, laser cutters, routers, mills, etc. Obviously anything more than the most simple CNC machine can get expensive, although, like most technologies, the cost decreases over time as demand spurs the automation and creation of more supply.

In some home improvement stores, keys such as traditional house keys (e.g., to open pin cylinder locks), traditionally replicated by following an analog pattern and replicating the key, are now made as follows using a CNC machine.

- The key is place and lined up on a small dedicated scanner bed.
- A photo (or scan) of the key is made.
- A CNC machine then removes the part of the key metal not needed from a blank key.

Yes, photos and scans can be used to create the G-Code necessary to run a CNC machine dedicated to creating keys. The company Diebold, which creates many of the touch screen voting machines used in the United States, became infamous for publishing an innocuous photo of the voting machine machine and key on their website. For some reason, each voting machine used the same key. Replicas of the keys were made from the published photos that then compromised the asserted security of the vowing machines.

Steps

The basic steps in creating and realizing a 3D model are as follows.

- Create the 3D model using some software system.
- Use software (e.g., Slic3r) to slice the model into slices for the 3D printer.
- Convert the slices, and associated control, into a low level code for the 3D printer (e.g., G-Code).
- Use software to send the G-Code to the 3D printer while monitoring the progress of the print.

Creation

Creating a 3D model can be a tedious and time-consuming task.

A 3D scanner is a device to help automate the process. Such scanners can be quite expensive. Some projects use the Microsoft XBox Kinect, with associated software and the Microsoft Kinect SDK (Software Development Kit) to obtain a 3D model of an object.

STL

A common 3D printer model file format is STL (Standard Tessellation Language). Here is an example ASCII (i.e., text, human friendly) STL segment from the **`FirstCube.stl`** file that is recommended for the PrintrBot Simple.

```
solid model
facet normal 1.0 0.0 0.0
outer loop
vertex 19.0726873012066 20.1520966447257 0.0
vertex 19.0726873012066 0.152096644725744 10.0
vertex 19.0726873012066 0.152096644725744 0.0
endloop
endfacet
...
endsolid model
```

In practice, for compactness, the binary STL format (i.e., not human friendly) is used rather than the larger text file format. There are extensions and additions to the format to support color, etc.

G-code

The low level NC (Numerical Control) code used by 3D printers is G-Code. A program such as Slic3r, built into Repetier, can be used to slice the 3D model into thin slices that can then be printed by the 3D printer. These slices can be expressed in G-Code. Here is an example G-Code segment from the **`FirstCube.g`** file that is recommended for the PrintrBot Simple.

```
G21 ; set units to millimeters
M104 S200 ; set temperature
G28 X0 Y0 ; home
G29
M109 S200 ; wait for temperature to be reached
G90 ; use absolute coordinates
G92 E0
M82 ; use absolute distances for extrusion
G1 F1800.000 E-1.00000
G92 E0
G1 Z0.300 F7800.000
G1 X59.580 Y59.580 F7800.000
G1 E1.00000 F1800.000
```

The semicolon is used as a comment symbol whereby the text to the end of the line is ignored.

- The "**G**" command is used to provide some value, such as motion, etc.
- The "**M**" command is used to provide miscellaneous commands.

Typically one would not write G-Code but would, instead, generate from some higher level model.

Thingiverse

Since 3D printer models can be tedious and time-consuming to create, it would be nice if there were a web site where people could share their 3D designs. There is, Thingiverse at http://www.thingiverse.com. Need a case for your Raspberry Pi? There are so many available, one does not need to make it. Need a case for your Intel Galileo? This is more uncommon. Once can download and make such a case. Need custom Lego parts? Need custom and inexpensive doll furniture for your daughter - furniture that matches the furniture in your house? Welcome to 3D printing.

Got an idea? Someone may have already done work on it and published it on Thingiverse. In that case, perhaps you can build on that idea without starting from scratch.

Maker spaces

Many cities have started maker spaces, sometimes called hacker spaces, to allow makers to come together, brainstorm, create, and make things. Such "**things**" can become tomorrows inventions and create jobs making and using them. It all starts with ideas and ideas are stimulated by communication and working together of like-minded individuals.

Future

The future of 3D printing is that it will become less expensive, better quality, and more purposive and ubiquities. Soon the phrase "make it" may be as common as the phrase "print it".

Karl Marx said, "*Each country has its own ruling class. In capitalist countries, the rulers own the means of production and employ workers. The capitalist class is also called the bourgeoisie. Means of production are what it takes to produce goods. Raw materials, satellite networks, machinery, ships and factories are examples. Workers own nothing but their ability to sell their labor for a wage.*". What happens when the means of production is lowered, as is the case with the declining price of 3D printers, such that almost anyone can own the "**means of production**".

Summary

This paper/session has discussed and/or demonstrated 3D printing, past, present, and future, with an emphasis on the present.

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