3D Printing Tutorial

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Dr. Denis Cormier

Dr. Ronald Aman
INTRODUCTION

3D printing, also referred to as “additive manufacturing,” converts a digital CAD (Computer Aided Design) file to a solid object. The technology has already come a long way and is continuing to rapidly expand and improve.

Today’s 3D printing can utilize a wide variety of materials beyond plastics, including metal, polymers, wax, glass, edible food and even human tissue.

This mechanical energy harvester was printed on a 3D printer. It works as the serpentine springs allow a magnet to move into and out of a coil of wire, changing the magnetic field and generating a voltage.
REAL WORLD APPLICATIONS

Additive manufacturing has been applied to an enormous variety of industries:
- Medicine: implants, prosthetics, bio-printing (printing tissues/organs made of cells suspended in a gel medium), dentistry
- Manufacturing: products and replacement parts
- Aviation/Aerospace: parts, models, aerodynamics testing
- Automotive: parts, models, air flow testing
- Art: models of sculptures, medium of artistic production, jewelry, fashion, clothing
- Construction/Architecture: building models, building materials
3D printing is already capable of printing objects in multiple colors and materials. With the potential to improve energy usage, the availability of products, waste reduction, and the customization of products, it appears as though 3D printing will be a staple of our future.

This car was printed by the binder jet printer by an RIT student.
INTRODUCTION

The three-dimensional modeling software used for 3D printing divides the CAD (Computer Aided Design) file into horizontal layers and prints each of those layers on top of one another one at a time. The method for creating these layers differs depending on which type of 3D printing is being used.

There are seven different generally accepted types of additive manufacturing, defined by the American Society for Testing and Materials (ASTM):

1) Material Extrusion  
2) Vat Polymerization  
3) Binder Jetting  
4) Powder Bed Fusion  
5) Material Jetting  
6) Sheet Lamination  
7) Directed Energy Deposition

This tutorial will focus on the first two methods and touch on the third.
THE FUTURE OF 3D PRINTING

Some believe that 3D printing will have a huge effect on economies throughout the world as people begin to manufacture their own products with personal printers rather than buying them from the market: a conversion from pre-fabrication to personal fabrication.

Already, the use of scanners allows for the replication of existing objects. Looking ahead, this may eventually allow consumers to make functional copies of household items, revolutionizing the manufacturing industry.

This is the MakerBot 3D scanner advertised http://store.makerbot.com/digitizer

We are coming closer and closer to the Star Trek replicator, once nothing more than pure science fiction.
Material extrusion, also referred to as Fused Deposition Modeling (FDM) and Fused Filament Fabrication (FFF), is the most common form of 3D printing and is openly available to RIT students in The Construct. In this type of printing, the material is supplied from a coil of plastic filament that is unwound and fed into a heated nozzle. The nozzle melts the plastic and controls the flow of material. It can move both horizontally and vertically depending on what the computer model instructs. The plastic cools and hardens as soon as it leaves the nozzle, allowing the printer to build layer-on-layer. The following two types of 3D printers utilize this type of printing.

Image at right from “What is 3D Printing?” shows nozzle depositing melted plastic in the process of material extrusion.
The MakerBot printer has two different printer heads that can print different materials. For example, this printer could print support structures in a soluble material and the designed structure in the designer’s choice of plastic. The support structure can then be dissolved away in a basic solution containing water and hydroxide. MakerBot printers are also capable of printing in plastic containing carbon fiber for a stronger material, as well as a flexible, rubber-like polymer that can produce a floppy membrane for applications such as an elastic spring or an O-ring to seal a connection.

At right is the mechanical energy harvester printed in a plastic reinforced with carbon fiber.
FLASH FORGE PRINTERS

Flash Forge printers are less expensive versions of the MakerBot printers. These printers are easily accessible in The Construct on the 4th floor of Institution Hall – the lab is open for RIT students and faculty. Visit the hack.rit.edu website and click on the LabCam link at the top of the page to see if the lab is open and somebody is present.

Image at right is a screen capture from The Construct LabCam.
Lab manager Michael Buffalin (left) and student David Donath work on a project in the Construct Lab at RIT
The current Flash Forge printers at RIT can successfully print basic shapes with no suspended areas. For any structure that is designed to be suspended above another layer, the printers must lay down a supporting material to fill the “empty space”. This fill is, however, the same plastic as the plastic that is used to create the structure because these printers only utilize one printer head. Therefore, the filler plastic cannot be dissolved and can be quite difficult to remove.

Serpentine springs suspended with support underneath.

Flash Forge printer like those found in The Construct at RIT.
The Maker Lab has both ABS and PLA plastic as printing materials. PLA (Polylactic Acid) can span greater distances and tends to be more dimensionally accurate. PLA does not need as much support because the plastic hardens more quickly as it is printing. However, because it hardens faster, it is also more brittle. ABS (Acrylonitrile Butadiene Styrene) is a tougher, less brittle plastic, but it requires more support because it is slower to harden, which also makes it more susceptible to warping. ABS is also soluble in acetone making it weldable.
VAT POLYMERIZATION

Rather than building an object from the bottom layer up, SLA (Stereolithography Apparatus) 3D printing prints the top layer and then the next layer down, gradually pulling the object out of a vat of resin. The thin vat of resin costs about two hundred dollars. The resin hardens when exposed by light at a wavelength of ~405 nm. This is the wavelength of a green colored laser than shines from the bottom of the clear resin vat through the glass, hardening the resin. This process is also known as vat polymerization.

At right is the energy harvester printed using Vat Polymerization in RIT Mechanical Engineering lab. Image at right shows the SLA in the RIT Mechanical Engineering lab.
An additional type of 3D printing available for use in the mechanical engineering lab at RIT is Binder Jetting. In this type of printing, a liquid binder is applied to a powder bed through nozzles in the shape dictated by the computer program, in essence gluing the shape together. As the object prints, any powder that is not glued serves as supporting material, and then when the print is finished, any excess powder that remains in the printer can be used for the next print. This form of 3D printing allows objects to be printed in color.

Above: binder jet printer at RIT. Right: color 3D print made in the binder jet printer by an RIT student.
YOUR OWN 3D PRINTING

Students at RIT are lucky to have access to 3D printers, materials, and people who can help them create what they have imagined. Students and faculty members have up to 150 grams worth of free printing per semester and can pay for any additional material needed. If you are not familiar with 3D design software, there is a plethora of knowledge available to you, both through RIT and the web.

Above images from The Construct website: http://hack.rit.edu/
There are a few different kinds of 3D design software available for use by RIT students. The preferred software for compatibility with the 3D printers is Inventor. This software can be downloaded for free by students from the internet. SolidWorks is another software that can be found on some RIT computers. Both of these programs use similar vocabulary and functions, so after learning one software, it is not difficult to transition to another. The basic operations are either identical or very similar with only minor nuances between programs.
**USING 3D DESIGN SOFTWARE**

The basic premise behind the design software is that one first creates a two-dimensional drawing and then converts it into a three-dimensional shape using one of four main functions. Two-dimensional sketches are fairly straightforward. There are functions for drawing circles, rectangles and free form shapes.

The image at right shows a preliminary sketch as a circle is drawn and the designer specifies the radius.
There are four main functions for converting the two-dimensional sketch into a 3D object:

- Extrude: bring the profile up perpendicular (ex. circle -> cylinder, or square -> cube/rectangle)

- Sweep: draw a path and keep the profile normal to the path – can draw any path that the profile takes (unlike extrude which has to be a straight, perpendicular line) (we used to make spring)

- Loft: like sweep but possible to gradually change the geometry of the profile (ex. square into circle)

- Revolve: rotate the profile around an arbitrary axis that you set

Above image shows extrusion of circle to form a cylinder.

Sweep circle along curving line to produce shape at right.
There are two different types of files that are important when it comes to saving your design. Save the design as a Parts file (.prt) to allow you to continue editing the design. In order to print the file, save it as an STL file (.stl). You may have to export the file as an .stl if that option does not appear under the save menu. This type of file can be uploaded to the Maker software so the design can be printed. Before clicking save once you have selected .stl, click on settings and in the top left hand corner of the box that pops up; make sure that the units are the units that you designed the part with so that it has the correct dimensions when printed.

Screen capture shows exporting a file as .stl and below shows saving a file to .stl format.
THINGS TO KEEP IN MIND WHEN PRINTING

Although 3D printing can work for some parts, it may not always be the most effective way to produce the part that you need. The printers available are not industrial-grade manufacturing machines, and therefore the parts that they print may not always be accurate to your design or dimensions (The Construct website suggests a 0.25mm tolerance). Holes for example tend to lose their proper shape as the plastic cools and it may be better to machine these features (ex. use drill in the construct lab or ask for assistance). Larger prints are prone to warping, but at the same time, the printers have difficulty with fine detail. These factors make it important to consult the staff working in The Construct before printing your part, to make sure that the limited materials, printer space and time are not wasted printing a doomed part. Visit the construct website to read up on further guidelines that they set forth when it comes to printing.
When you are ready to print your design, save the file as an .stl file to a flash drive and bring that flash drive with you to The Construct. When you enter the room, there will be a computer and three printers along the wall to your left. Insert your flash drive into the computer on the left. Open up the Maker program and click on [Add File]. Find your flash drive and the file that you wish to print and open it. Your design will appear over the platform in the printer image on the computer. Using the controls on the left of the screen, rotate your part until it is in the correct orientation for how you want it to print. Keep in mind that the bottom side tends to be the roughest and the top the smoothest in the final printed object. Click on the [Lay Flat] control to ensure that your part is actually sitting on the platform.

The Construct @ RIT

Screen capture at right from MakerBot website showing software program.
Now the file is almost ready to export. Remove the SD card from the printer that you are going to use. Make sure you choose a printer that prints in the type of plastic that you want to produce your part in. Also check to make sure that the printer has a complete tape layer down over the platform. If there is a hole in the area you are printing in, the raft material can curl up and your part will not print completely flat. Put the SD card in the F Drive external SD reader plugged into the computer. If a message pops up asking you to reconfigure Drive F, simply cancel the message and unplug the entire F Drive (not just the SD card) and plug it back in. The message should not reappear.
3D PRINTING YOUR DESIGN

Ensure that before you export a print file to the flash forge printers, you check the settings to ensure that they match the type of plastic that you plan to print in (either ABS or PLA). If person who printed before you changed the setting to the other type of plastic, the printer will still follow the recipe for that plastic which involves a different temperature. If the wrong recipe is used, you will most likely have to use tweezers and pliers to peel melted plastic off of a very hot (200°) printer head.

If your print is doing this, it was exported on the wrong setting!
Click on [Export File] at the top right hand corner of the page and a small window should open. DO NOT CLICK EXPORT YET. Go to The Construct website, [http://hack.rit.edu/3d-printer-policies-and-logging/](http://hack.rit.edu/3d-printer-policies-and-logging/) and click on the [3d Printing Form] in the middle of the page. Fill out the online survey about your print. When it asks for how much plastic you are using for your print, pull up the Maker program and look at the small window that popped up when you hit [Export File] – it will contain that information.

Image at right is a screen capture from The Construct website showing the 3d Printing Form link. At left is the pop-up window containing mass of filament to be used.
Once you have successfully completed and submitted the form, return to the maker program. Click on [Print Preview] and adjust the angle and zoom of the image to see how the plastic layers will be laid down to create your part. This will alert you if, for example, a section of your part is too small to print with clarity. If this is your first or second print, ask a staff member in the lab to take a look at your print to check if it looks good. With their go-ahead, you can click on the [Export] button in the bottom right-hand corner of the small window. Remove the SD card from the reader and replace it in the printer.

Screen capture at right shows print preview from MakerBot software.
Look at the small screen on the front of the printer. Next to it is a small keypad with four arrows and an [OK] button in the middle. Scroll over [Main Menu] on the screen using the up and down arrows and hit [OK]. Scroll to [Print from SD] and hit [OK]. Then scroll until you find the name of your file and hit [OK]. The printer should begin to warm up and will begin printing within five to ten minutes.

Image at left shows small screen on the front of the Flash Forge printers.
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3D PRINTING YOUR DESIGN

Stick around for a few minutes after you initiate the print to ensure that the first layer of your print is laid down successfully. Remember that the first layers the printer puts down are raft material, not your actual part. Also check to make sure that there is a sufficient supply of the plastic cord raw material at the back of the machine to print your part. If the printer runs out of plastic partway through your print, your print will not be completed and you will have to reprint your design.

If the printer runs out of filament, it will abort your print and you will wind up with something like this.
When your part has finished printing, carefully remove your part from the platform. The raft material should come off as well. The raft material is printed to ensure that the printer is printing on a level surface. It should have a larger footprint than your part itself. Gently pull the raft material off of the bottom of your part – it should detach without too much trouble and there should be no raft material left behind. If some remains stuck to the bottom of your part, you can use pliers, a file, or some sandpaper to remove the excess.

Image at right, from Phuc, shows removal of raft material from bottom of print.
The object below is a gas flow chamber designed and 3D printed for a gas flow sensor. The width, height and shape of the channel through which the gas will flow could be designed and printed to the exact proportions desired using 3D design software. These dimensions will determine the rate at which the gas will pass over the circuitry that will detect it, which is vital to the proper functioning of the sensor. If the gas does not move quickly enough across the sensor, it will be much more difficult to detect.

The first version, on the left, did not allow the circuitry close enough access to the flow of gas. The part was redesigned to fix the problem, creating the model to the right.
REFERENCES