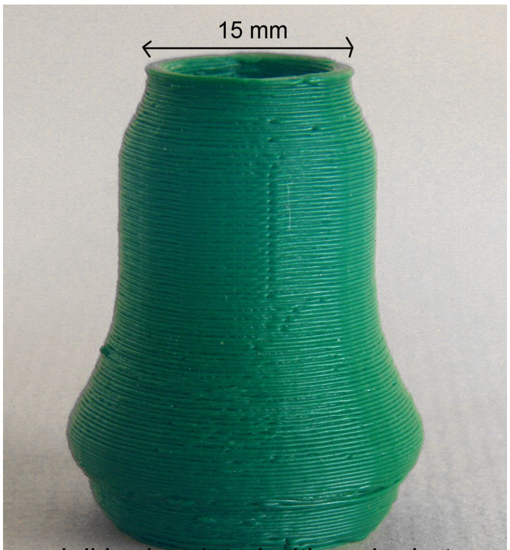
## 3D PRINTING MASTERCLASS AT FAB LAB ADELAIDE - SUE HARDING'S REPORT

3D printing isn't magic.  But it is a new way of making things, full of possibilities and suitable for small scale use.  There are several variations of the technology, but the thing they all have on common is that objects are built layer by thin layer.  All the many samples of 3D printing we were able to examine during the masterclass revealed some evidence of the layering process when looked at through a hand-lens, except a couple of metal ones that had been polished.

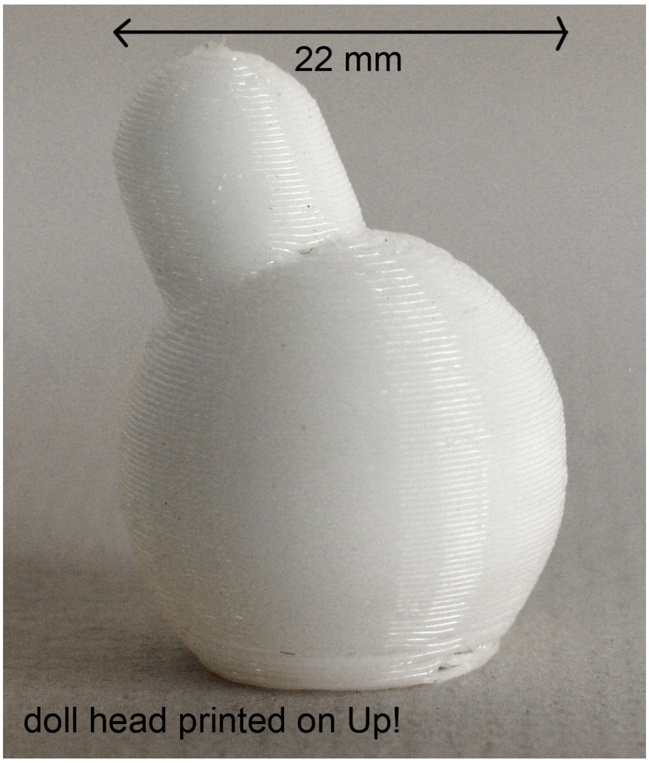
Most lower-cost 3D printers build things out of plastics which melt when heated ("thermoplastics").  Plastic filament is fed through a heated nozzle (extruder), comes out as a liquid, and is deposited in the desired shape, controlled by a computer.  The shape is traced out by the extruder moving relative to the build platform.  This process is known as FDM (fused deposition modelling), or FFF (fused filament fabrication).  There are practical limits to how fast it can be done.  The most common plastic used for 3D printing is ABS, a plastic used in a broad range of items, from LEGO to motorbike fairings.  Making things out plastic is a novelty in itself, it has previously been beyond the scope of most individual artists, craftspeople, hobbyists (except by cutting/bending sheets of perspex).  Many low-cost 3D printers prefer ABS, and it was the only type of plastic available when I tried out 3D printing at the Adelaide Fab Lab.  Luckily it was the one I wanted.  PLA, the other commonly-used 3D-printing plastic, is used for particular applications (especially printing models to make moulds for casting - it can be burned out), and some cheap printers use it exclusively because it does not need a heated build platform.  With 3D printers and printing it's very much horses for courses, but PLA does have a couple of significant negatives - it is not nearly as durable as ABS, and when it breaks it can form sharp, dangerous shards.

There is plenty of information online about 3D printing, and I did some homework before going to Adelaide.  That helped, but there's no substitute for hands-on experience.  The first thing I noticed was the smell of hot plastic.  There seems to be no definitive evidence that it's bad for you, but it does smell like something you don't want to breathe.  Joris Peels' blog on the subject, is desktop 3D printing safe, goes into some detail.  The *Solidoodle* wiki includes a page about ABS safety which advises "Fumes produced during the melting processing, may cause eye, skin, and respiratory tract irritation, and if overexposed, could cause nausea and headache".  Personally I believe these sort of 3D printers need good ventilation, preferably with a fume hood or at least an exhaust fan.

Online research about 3D printing brings up a dizzying array of possibilities.  It is hard to sort them all out and make a logical decision about which 3D printer would do your job best., but gradually I gained a broader view.  There were three different makes of printers at the Masterclass: Makerbot Thing-o-matics, Up!s, and a Mojo.  The Makerbots (not the latest model) seemed to require frequent tinkering.  They don't make support structures for overhangs, and the small overhang on my first test piece came out with sagging.  The objects they produced were basically OK, but  a bit rough.

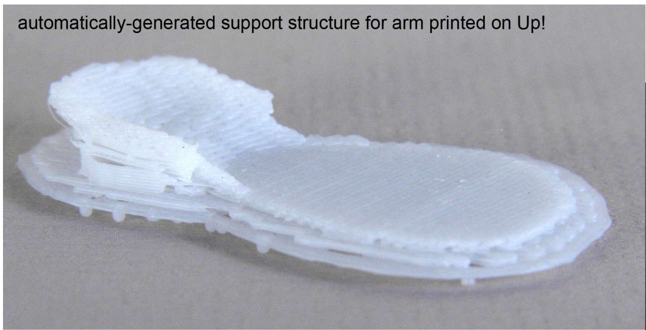


doll body printed with makerbot
note many flaws and sagging under overhang

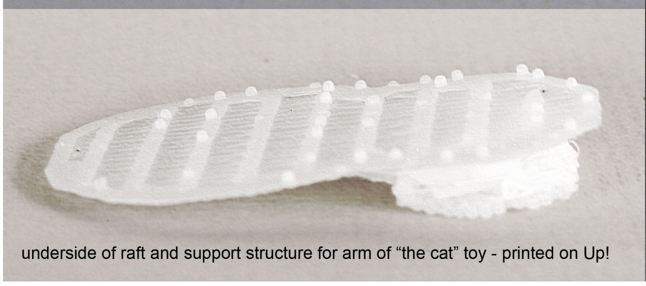



doll head printed on Up!

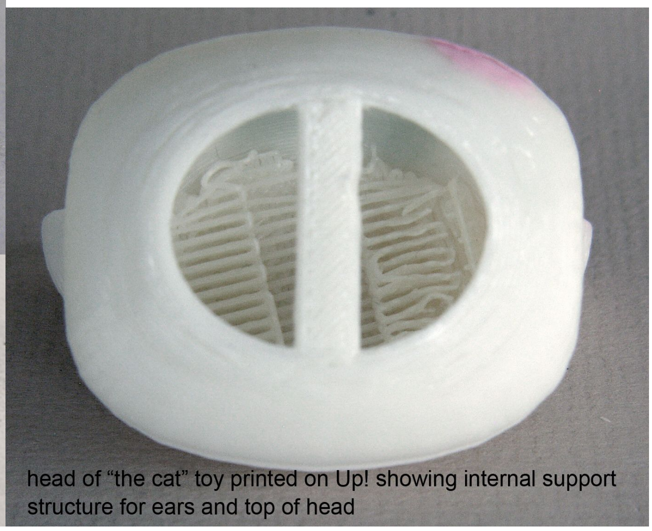
The Up! printers made prints that were smoother and more accurate. On the down side, though, they use slightly higher temperatures (producing stronger smells of hot plastic), and proprietary software. The first piece I printed on the Up! (small doll's head) did have a few flaws, but they were caused by problems in the 3D file, not errors made by the printer.
Up! printers start by constructing a raft on which to build the model. The raft is made from the same plastic as the model itself. They also make automatically-generated support structures for overhangs, so they can successfully print objects that many cheap printers cannot do (unless the designer includes support structures in the original design). The support structures have to be removed, by hand, after the print is completed (see this video)



automatically-generated support structure for arm printed on Up!



underside of raft and support structure for arm of “the cat” toy - printed on Up!



head of “the cat” toy printed on Up! showing internal support structure for ears and top of head

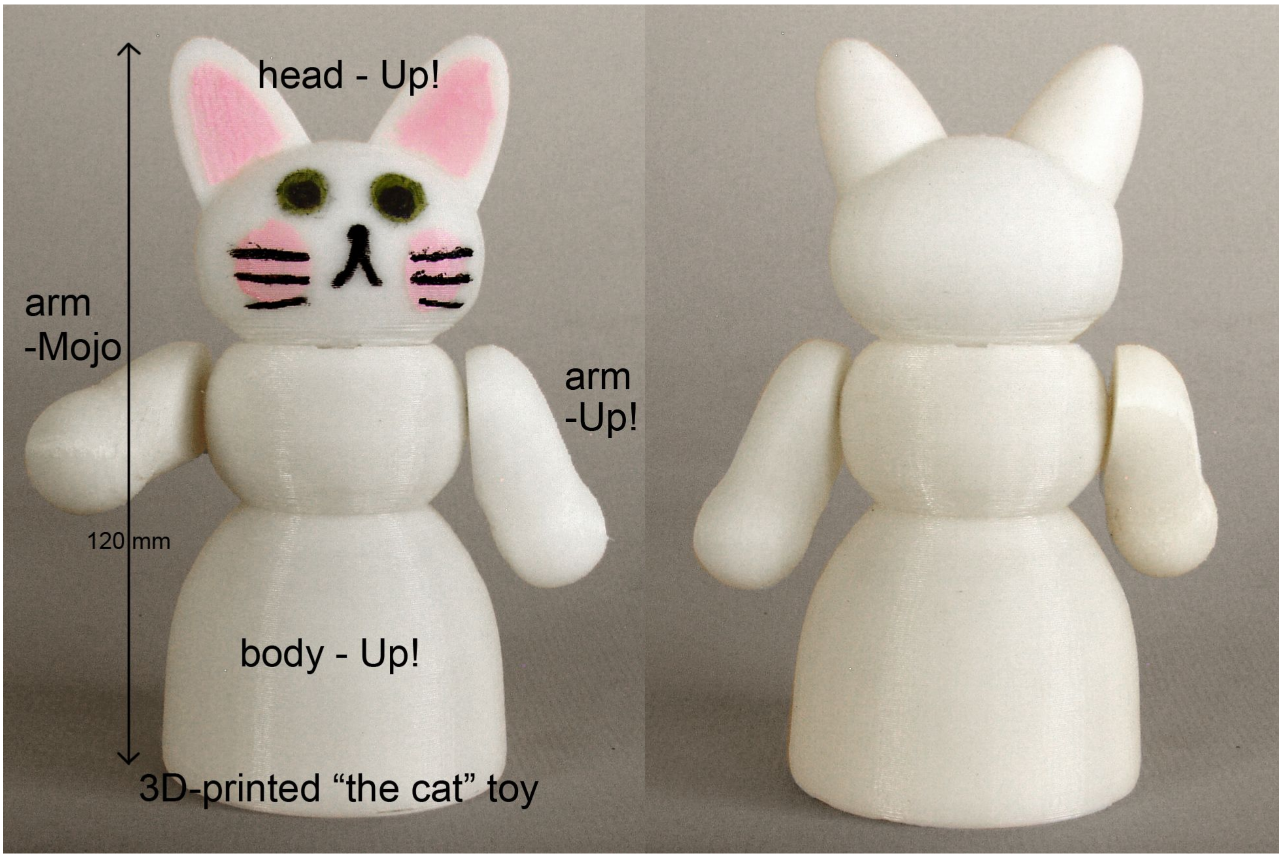
Up!s are a similar price to Makerbots ($2-2½K), and come fully-assembled, ready to print.

The $10K Mojo also comes ready to print, and it, too, builds support structures, but with a different material, which can be dissolved away once printing is completed (the printer has two extrusion heads, one for the ABS and the other for the support material). The Mojo uses proprietary cartridges of filament instead of the open reels used by the cheaper machines, and printing takes place inside a closed build chamber - there's a window on the front but you can't see much. (Online videos don't really show the process either - the whole ethos of the Mojo is convenience and the machine is presented more or less as a "black box").

I printed one of my toy's arms on an Up! and the other on the Mojo for comparison.  The end results were very similar.  The arms have small U-shaped channels for threading elastic, which, in my haste, I had designed smaller than intended.  The channels came out only about a millimetre in diameter, and both printers did them successfully - the difficult part was threading the elastic through such small channels!

arm printed on Mojo
with support material partly dissolved away

Of the three printers I tried, I would definitely choose the Up! (in spite of the fumes) - I'd rather get on and print things than fiddle about adjusting the




3D-printed “the cat” toy

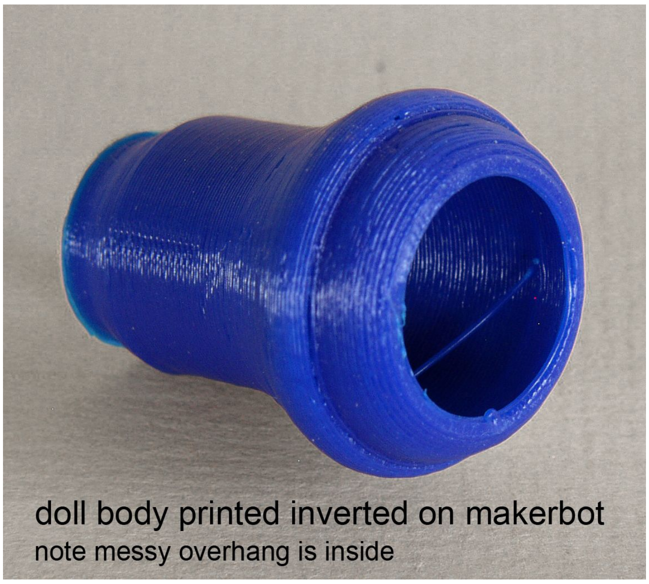
machine, but the slick professional one didn't seem to produce results that made it worth several times the price.   In the Mojo's favour, however,  is the fact it can be left printing without human supervision - the others can't - a significant advantage, given that 3D printing is a slow process (e.g. the body for my toy took just over an hour).  The Mojo can print multiple objects in one batch - whatever will fit on the build platform - so it can be set going to do a print job overnight, for instance.

With 3D printing, the best printer to use depends on the nature of the job.

Overhangs

Small strings of melted plastic tend to sag down under gravity until they've cooled a bit - 3D printers can only lay down accurately-placed molten plastic if there is something underneath for it to sit on.  However if the angle of the overhang is steep enough (more than 45 degrees) it is usually OK.  Choosing the orientation of the piece is very important, to minimize overhangs, and also for structural strength (because of the layered structure, strength is not the same in all directions).  My first test piece on the Makerbot Thing-o-matic showed overhang problems, so then I tried printing it upside down.  The model still had a shallow-angled overhang, but it was on the inside instead of the outside.  The overhang still produced a bit of a mess, but it was out of sight.


doll body printed upside down on makerbot


doll body printed inverted on makerbot
note messy overhang is inside

The design of support structures may be simplified if using a printer with two extruders - one of them can print the model using ABS, and the other can fill voids with another kind of plastic which can be dissolved away.  This is what happens automatically with the Mojo, but the same principle can be used to print with soluble support using other two-extruder machines, for example see 3D printing parts with overhangs using new soluble support material.

Surface finish

The surface of 3D prints always has ridges, an inevitable result of the layer-by-layer construction.  Each layer begins with the extruder going around the outside of the shape, then following around that first row of plastic, progressively inwards, a specified number of times (depending how tough/thick the 'skin' of the final object needs to be).  Inside that outer, dense shell, the rest is printed as  an internal lattice (whose density can be specified) - this minimizes plastic usage and printing time.  If the 'skin' is made thick enough, the ridges on the surface can be sanded away, but for complex shapes that is difficult and slow.  The ridges are finer if the layers are thinner, but the time for printing takes longer, because to make every layer the extruder has to move over the whole area where plastic needs to be laid down, and there will be more layers - if the layers are made half as thick, there will have to be twice as many of them, so it will take about twice as long to print.  ABS plastic can be made smooth and shiny by putting it in an acetone 'vapour bath' for a while (recommendations vary from a few minutes to about an hour) - this wasn't covered at the masterclass and I have not tried it, but there are online demonstrations of how some people have done it e.g. here and here. Fine details may be lost, and the smoothing effect continues for some time after the item is removed from the vapour bath (until the acetone has evaporated from the surface).

ABS can be painted with acrylic paint, and also nail polish (which is acetone-based, so should stick really well). There are different levels of toxicity for different nail polishes, see this blog or look up and compare nail polishes on Environmental Working Group's Skin Deep database.

What to print

With melted plastic, nothing very big. Build platforms are mostly about 10-15 cm square, the process is slow, and larger pieces are more prone to distortion and problems with de-laminating. However larger items may be made in smaller sections which are then joined together.

The basic requirement before one can print is to have a 3D digital computer model of the item to be printed. Files for 3D printing are in the .stl format. Models can be created, starting from simple geometry, in many different 3D modelling programs, some easier to learn than others. One of the simplest is *Google Sketchup*, which has a free version (note that it requires a plug-in to be able to export .stl files). Another free one is *Blender* (which is open source), but it requires more concentration and practice to learn (however there are active forums, and many free online tutorials). In recent years I managed to teach myself to use *Blender* (for 3D animation), but I already had a pretty good idea of the general approach to take, because I had previously used several other 3D programs. At the masterclass there was a session about modelling with *Blender*. It was helpful for me, but it seemed most other participants found the pace a bit too fast, because they were not familiar with *Blender*'s user interface.

I already had digital 3D models of my animation characters - my idea was to make toys of them. My computer-animation models needed to be modified to become printable functional toys (e.g. by adding holes and extra structures to attach elastic to hold the toy together). There are online repositories of digital models suitable for 3D printing (e.g. thingiverse) for those who wish to use them.

There are other kinds of 3D printing which do not involve laying down layers of plastic (or wax, chocolate, or anything else that can be melted and extruded through a nozzle). In general terms they involve solidifying selected parts of successive thin layers of liquid (e.g. UV-setting plastic resins), or powder (e.g. plaster, metals). In the case of powder, the non-solidified portion can function as support for overhangs during the build, then be brushed away later. These methods were broadly covered in the theory part of the masterclass, but we had no hands-on experience. There is plenty of information about them online.

Because it is so slow, 3D printing is generally unsuitable for making large quantities of the same thing, however it can be good for prototypes, one-offs (e.g. customised items) and very small batches (e.g. artworks). In some cases it can be used to make fully-functional items (like my toys), but in others it is mainly good for partly-functional models (e.g. to test the way designed parts fit together) or making models to look at (e.g. architectural visualisations). Clearly it is easiest to try out in fields where making 3D digital models is part of the design process. And 3D printing can be used to make some items that are impossible to make any other way, especially when there are complex internal channels or parts inside other parts (but removing support material from inside nooks and crannies may sometimes be difficult).

The Fab Lab in Adelaide, where the masterclass took place, is part of a worldwide network of Fab Labs, which originated at MIT. At the moment it is the only one up and running in Australia, although a few others are planned. The idea is to provide community access to this technology. Like many other artists, hobbyists and inventors I would like to use a 3D printer from time to time, but don't want to own one - at this stage of development it is best for many people to get the use out of such machines before they are inevitably superceded. Inspired by the Adelaide Fab Lab and the great staff there, I am keen to help create a similar facility in the Wagga area. It may be best to wait a little longer before deciding which printers would be most useful as patents expiring in 2014 will probably make 3D printing by methods other than extruded plastic more affordable. I invite anyone who would like to be involved to contact me (suedotmatrix at hotmail dot com).

3ders.org is a website which stays up to date with lots of info about 3D printers, and forums. It includes pages devoted to 3D Printing Basics, price comparisons for printers, and top 3D printing websites.

Wikipedia and also the *Protoparadigm* blog have useful information too.

There is a simple online artlicle about the mechanics of how FFF 3D printers work.

My attendance at the 3D printing masterclass was assisted by the Australian Government Regional Arts Fund through a Regional Arts NSW Quick Response grant. The Regional Arts Fund is an Australian Government initiative supporting the arts in regional, remote and very remote/isolated Australia.

Sue Harding
December 2013