Branching Support Structures for 3D Printing

Ryan Schmidt Nobuyuki Umetani
Autodesk Research

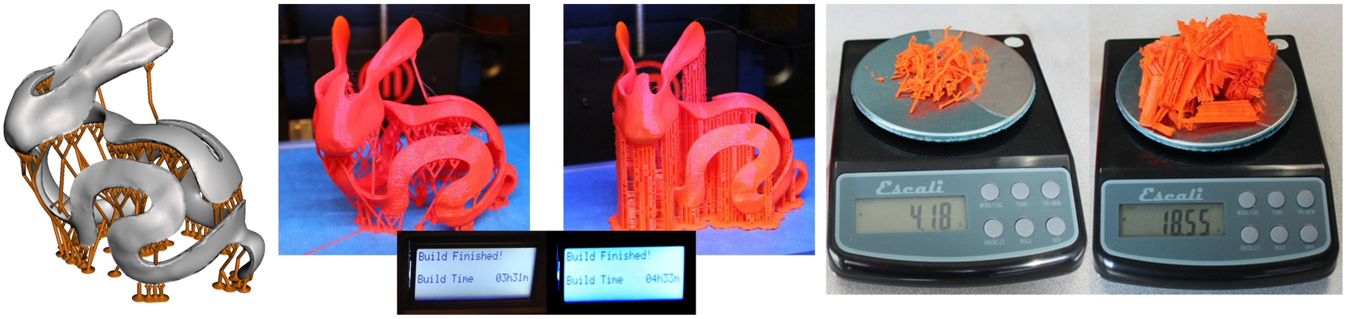

Figure 1: *We reduce wasted time and material in fused-filament 3D printing by generating space-efficient branching support structures. In this example our support uses* 75% *less plastic than the manufacturer-provided supports, which also reduces print time by one hour.*

1 The Problem

Most 3D printing processes can be modeled by an incremental stacking of thin, flexible layers. In this case, it is apparent that for complex shapes, some stacks will be ”floating” in mid-air unless they are supported from below by additional material. Similarly if a slice is much larger than the one below it, it will droop unless supported. These areas are called *overhangs* [Evans 2012], and most 3D printing software provides automated generation of some kind of support structure. However, the support is waste, of both time and material, and this waste should be minimized.

2 Branching Support Structures

The support generation techniques in widespread use today are limited to producing strictly vertical structures, which are not space-efficient, particularly when there are many regions to be supported high above the print bed. However, most 3D printers are capable of printing at some minimum *draft angle* relative to the print bed. If we wish to support a given point with a *support post*, this draft angle provides us with a cone constraint which the post axis must satisfy. This capability was used by Wang et al [2013] to generate individual support posts. However, given a set of support posts, we can incrementally join two support posts into one, and replace two cone constraints with a new one.

The above observation leads us to a strategy for top-down procedural generation of support structures, starting from a set of support points. We define support points using a combination of Watershed and Poisson surface sampling strategies. From these points we then grow support posts downward, iteratively joining them wherever the cone constraints can be satisfied, while also preventing intersections with the 3D surface. Posts terminate when they reach the ground or a sufficiently flat point on the surface. The resulting tree-like structure is highly space efficient but may be too weak to hold up the surface during printing, so we add *struts* to increase print strength. We call the resulting network of support posts a *support graph*. Currently our generative process uses a greedy strategy without backtracking, so some posts get stuck, and others may be non-optimal. We handle these cases with post-processing optimization passes. We have also developed interactive tools for manipulating the support graph.

Although we initially focused only on the geometry of the problem, our generated structures were vastly improved by taking the printing process into account. For example, a post represented by a smooth 3D tube becomes a set of stacked discs when printed. As a result, for a given vertical delta, the same number of discs - and hence roughly the same print time and material - are required regardless of the post angle relative to the bed. Long posts through free-space may catch on the print head and break, while posts which grow ”around” the surface are more reliable. Posts near the surface also reduce travel time of the print head, which is a significant factor in print time. By taking these observations into account, our techniques generate paths which do not minimize 3D Euclidean distance, but use a similar amount of material to those which do, and print both more quickly and more robustly.

Figure 1 shows an example support structure created with our techniques. Our support weighs 75% less than the structure generated by Makerbot Makerware, and due to this material and structural optimization, the model prints one hour faster. The benefits of this sparsity increase as the model size increases, and for larger prints we can observe speedups of 50% or more. Not visible in the images is that our support is much easier to snap off, and leaves fewer artifacts on the final surface. These findings have been confirmed by widespread use of an early implementation of our technique, which is available in the free software tool Autodesk meshmixer.

References

EVANS, B. 2012. *Practical 3D Printers: The Science and Art of 3D Printing*, 1st ed. Apress, Berkely, CA, USA.

WANG, W., WANG, T. Y., YANG, Z., LIU, L., TONG, X., TONG, W., DENG, J., CHEN, F., AND LIU, X. 2013. Cost-effective printing of 3d objects with skin-frame structures. *ACM Trans. Graph. 32*, 6.