Expert insight into current research

News & views

Engineering

How to print multi-material devices in one go

Johannes T. B. Overvelde

A multi-nozzle system has been devised that allows the 3D printing of objects using several viscous materials, thereby allowing control over the material properties of objects at the submillimetre scale. **See p.330**

Additive manufacturing, also known as 3D printing, is an invaluable platform for fabricating complex structures that would otherwise be time-consuming, or even impossible, to make using conventional techniques. The ultimate goal is to fully control the composition, geometry and properties of 3D-printed structures at a microscopic level. However, for objects made from multiple materials, the minimum size of features that can be printed is limited, because the rate at which printers can switch between materials is too slow. New technology is therefore needed to print fully functional, multi-material devices using a single printer. On page 330, Skylar-Scott *et al.*[1] report a micrometre-scale printing strategy that enables fast switching between viscous materials extruded through a single nozzle. The authors show that they can reduce the total printing time of certain structures by arranging up to 128 nozzles in parallel – a game changer for the field.

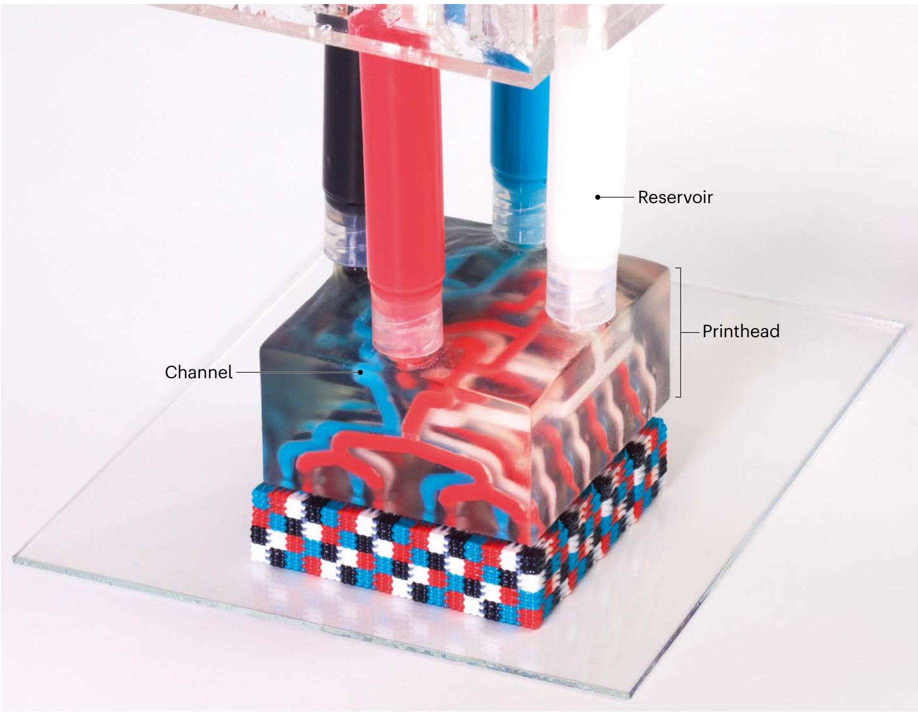
The 3D printing of soft or biological materials is often achieved through a process called direct ink writing, which involves the extrusion of a pressurized, viscous fluid through a single, moving nozzle. To print multiple materials using this method, the standard approach is to switch mechanically between nozzles, but this limits the minimum switching time. Another strategy is to sequentially push several materials through a single nozzle[2,3], but it has not been possible to produce sharp transitions between materials in this way, or to achieve switching rates above 1 hertz.

To solve these problems, Skylar-Scott *et al.* have developed a microfluidic nozzle that brings up to eight viscous fluids together as separate filaments just before the tip of the nozzle. They make smart use of the fact that their printing fluids flow only when the internal stresses are above a certain value. By sequentially pressurizing individual fluids, they can switch between materials at rates of up to 50 Hz, and produce features at a scale of approximately 250 micrometres.

These switching rates are high enough to print 'voxelated' structures – in which each point (voxel) in a 3D grid that represents the structure can have different material properties (Fig. 1). The printing of voxelated structures has so far been demonstrated only for low-viscosity fluids using inkjet-based methods[4] (which involve the propulsion of droplets rather than the extrusion of filaments). Skylar-Scott and colleagues' work expands the potential range of materials that can be printed at these small feature sizes, and thereby opens up a range of applications for 3D printing that require precise control of local material properties.

The authors demonstrated the effectiveness of their approach by printing two functional objects that have periodic layouts of voxels. The first was a Miura origami pattern[5]: a sheet consisting of tessellating parallelograms. Skylar-Scott and colleagues printed this from a stiff epoxy material, connected by folds made from a second epoxy that was approximately 1,000 times softer. The object can be reversibly transformed from a flat shape to a folded, compact state by manually applying a force (see Fig. 4f of the paper[1]).

The second object was a soft robot[6] made from two forms of silicone rubber of different



REF. 1

Figure 1 | A multi-nozzle head for 3D printing. Skylar-Scott *et al.*[1] report printheads that enable the fabrication of objects consisting of submillimetre-scale features known as voxels, using several materials. Here, four types of printable fluid are fed from reservoirs fixed into the transparent printhead. Channels carry all four fluids to each nozzle (not visible) at the base of the printhead, and the flow is controlled so that the type of fluid extruded by each nozzle can be switched rapidly and programmably to produce voxels. This printhead contains a 4 × 4 array of nozzles. The voxels are picked out in different colours in the object taking shape beneath the printhead.

stiffnesses (see Fig. 5 of the paper[1]). The robot's legs consist of chambers that deform in a predefined direction when deflated and inflated; sequential inflation and deflation therefore results in a walking motion. For both objects, the use of multiple parallel nozzles was instrumental in reducing the printing time. This was important because the printing fluids start to harden continuously once made, limiting the window for using them.

Skylar-Scott and colleagues' multi-material, multi-nozzle technique could have major implications for the development of 'architected' materials[7] – those that exhibit exotic properties arising from their engineered, periodic substructures rather than their chemistry. Examples include materials that are extremely light yet strong[8], and materials whose mechanical, optical or acoustic properties can be tuned by reconfiguring their internal structures[9]. Most architected materials so far have been made from a single non-architected compound. The ability to control the make-up of objects at a microscopic level (by printing combinations of voxels of different substances) opens up a new playing field, in which more and innovative functionalities can be programmed into the same architected material. This might lead to the production of architected materials that exhibit more machine-like behaviour than is currently possible[10].

But we are not there yet. The available library of printable materials, and the range of properties represented, needs to be extended – for example, to include materials that have a variety of electrical and thermal conductivities, or that swell when they absorb a solvent. Moreover, at present, the spacing between the nozzles in the multi-nozzle printheads is unchangeable, and all the nozzles eject fluid simultaneously and at the same rate. This means that Skylar-Scott and colleagues' system speeds up printing only for periodic structures in which the spacing between the nozzles determines the size of the periodic components. A different multi-nozzle printhead will be needed to produce structures that have other periodicities.

If the spacing between the nozzles was increased, then an alternative application of the multi-nozzle system could be to print exact copies of the same object in parallel. Work will also be needed to increase the flexibility of the technology, by making it possible to independently program the flow through each nozzle in a printhead, as is the case for inkjet-based methods.

Skylar-Scott *et al.* have pushed the boundaries of achievable speed and materials in additive manufacturing technologies. The work brings us closer than ever to being able to control the composition, geometry and properties of structures so small that they cannot be seen by the naked eye. This breakthrough is not merely a practical advance: it will change the way we design, build and think about functional devices.

Johannes T. B. Overvelde is in the Soft Robotic Matter Group, Designer Matter Department, AMOLF, Amsterdam 1098 XG, the Netherlands.
e-mail: overvelde@amolf.nl

1. Skylar-Scott, M. A., Mueller, J., Visser, C. W. & Lewis, J. A. *Nature* **575**, 330–335 (2019).
2. Hardin, J. O., Ober, T. J., Valentine, A. D. & Lewis, J. A. *Adv. Mater.* **27**, 3279–3284 (2015).
3. Liu, W. *et al. Adv. Mater.* **29**, 1604630 (2017).
4. Hosny, A. *et al. 3D Print. Addit. Manuf.* **5**, 103–113 (2018).
5. Miura, K. *Inst. Space Astronaut. Sci. Rep.* **618**, 1–9 (1985).
6. Rus, D. & Tolley, M. T. *Nature* **521**, 467–475 (2015).
7. Schaedler, T. A. & Carter, W. B. *Annu. Rev. Mater. Res.* **46**, 187–210 (2016).
8. Greer, J. R. & Park, J. *Nano Lett.* **18**, 2187–2188 (2018).
9. Bertoldi, K., Vitelli, V., Christensen, J. & Van Hecke, M. *Nature Rev. Mater.* **2**, 17066 (2017).
10. Coulais, C., Teomy, E., De Reus, K., Shokef, Y. & Van Hecke, M. *Nature* **535**, 529–532 (2016). ,

Learning

A genetically tailored education for birds

Ofer Tchernichovski & Dalton Conley

The ability of birds to learn a song depends not on their genes alone, but also on whether their genetic make-up is well matched to that of their singing teacher. This discovery sheds light on how gene–environment interactions affect learning.

The belief that some people are born gifted and others are fated to be mediocre is deeply rooted in our culture. But the influence of genes on learning is not straightforward. Writing in *eLife*, Mets and Brainard[1] describe how learning can be enhanced in songbirds by tailoring tutoring strategies to match the genetic biases of individuals. The authors' study suggests that there are not necessarily 'high-quality' or 'low-quality' gene sets when it comes to learning – instead, certain sets of genes are better or worse fits for particular learning environments.

A polygenic score is an estimate of an individual's propensity to display a given trait, taking into account all of his or her genes. These scores have been viewed by some as a way to assess a baby's genetic potential to develop complex disorders such as schizophrenia[2]. They have also been used to assess educational success, and can currently explain about 13% of the variation in the number of years of schooling that individuals in a population will complete[3]. But we are a long way from a genomic analysis that could direct specific educational investments or predict which children would benefit the most. Working this out in humans is dauntingly hard, because we cannot experimentally control genes and environments simultaneously.

However, interactions between genetics and learning are not unique to humans. Young songbirds acquire their vocal repertoire by imitating songs produced by adults. For birds, as for humans, learning is a social and cultural process – as in spoken language, vocal learning across generations produces local cultures of song dialects. Accurate learning is crucial for birds because those that do not acquire the local dialect are less likely to attract mates[4].

Experimental systems have been established that allow researchers to control both the genetics and the learning environment of songbirds from an early age, yielding insights into how the two interact. These systems have revealed, for example, that when birds are raised away from their parents and 'tutored' by song playbacks, the tempo of their songs is strongly influenced by their genetics[5]. By contrast, the influence of genetics on tempo is much weaker when a bird is raised by an adult tutor that actively guides the youngster[6]. Thus, a picture has emerged of an interplay between genetics and learning experience.

Mets and Brainard set out to pin down this relationship in more detail, using a population of Bengalese finches (*Lonchura striata domestica*) that had varied song-learning abilities. First, they compared how well finches tutored by their own parents learnt a song, compared with birds whose eggs had been moved into that nest before hatching. When birds were tutored by their own fathers, they generally learnt better than did fostered birds, suggesting that a match in genetic propensity for learning is key to how well birds learn songs.

The authors found that cross-fostered birds learnt well if their adoptive tutor had a song that was similar in tempo to their own. This result indicates that an interaction between