The Microscope Sings

Robert Wilson, Simon StJohn-Green, Jack Dobinson and Gavin Bell

We have developed software which converts pictures into music: it is aimed principally at making natural-sounding music from partly-periodic images such as micrographs of crystalline materials.

The raw data of science come in many forms, but we think almost exclusively of "visualisation" when deciding how complicated information is best presented. Can other senses be used to represent or explore scientific data? In scanning probe microscopy (SPM) is it quite common practice to listen to the operation of the feedback loop during image acquisition, and even the sense of touch has been exploited in virtual reality SPM force-feedback [Guthold *et al.* (1999)]. Alternatively, arbitrary data could be mapped to other forms such as music, a process which we call "sonification". The use of pure algorithms in musical composition has a long history [Nierhaus (2009)], but in this project we have used the rich information content of microscopy images to generate natural-sounding music via user-specified transforms.

The work was mainly done during two successive vacation projects. During summer 2010, Jack Dobinson and Simon StJohn-Green created a framework called SAMI (standing for "SAMI Ain't a Musical Instrument") which facilitated the generation of music by allowing users to load images and manipulate them using selected scripts. In 2011, Robert Wilson expanded the functionality of the scripts, experimenting with different ways of mapping the information content of the images to music. The software is written using Python and accepts images in all common formats. The output is MIDI data, a standard representation of musical information which can be played on any computer or rendered in a synthesiser. There are no random elements in the process, so a particular image and set of parameters will always produce the same piece of music.

Broadly speaking, pleasing music is somewhat repetitive but also contains non-repeated "features". This sort of structure is often seen in images of real crystalline materials: at very high magnifications we might observe the crystal lattice structure directly, while on longer length scales the underlying crystal symmetry structure often produces periodic features. We have obtained good results with SPM images and electron micrographs of such samples. Here we show three images from Gavin Bell's research work, but many more are available at the Sonify web site www.warwick.ac.uk/go/sonify, together with the corresponding music and the SAMI software.

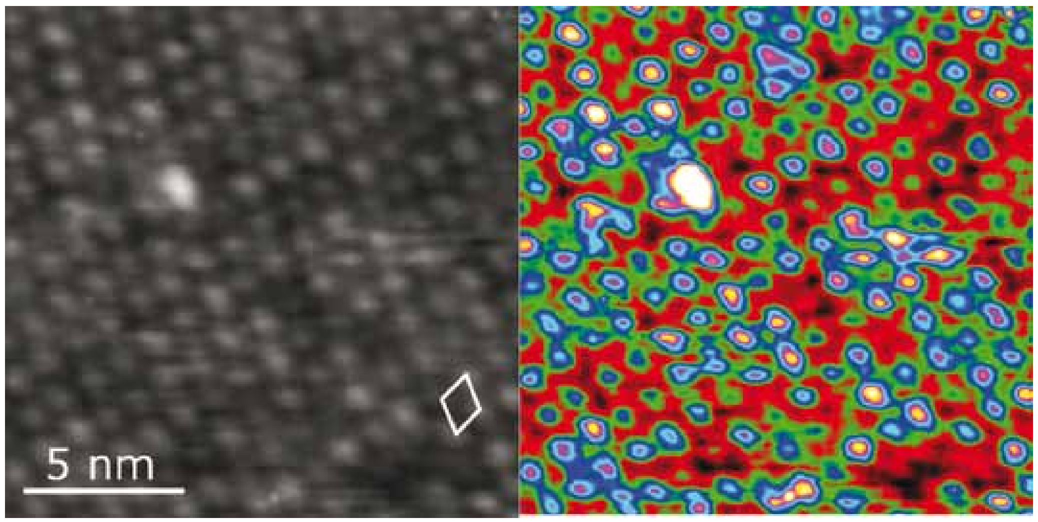

Figure 1: Scanning tunnelling micrograph of MnSb(0001)-(2×2) surface. A unit mesh is highlighted on the grayscale image.

It is not obvious how a two-dimensional image can be transformed to music, which is akin to a one-dimensional array of notes. Initially, we drew line profiles across images and rendered these to a string of notes, simultaneously generating other musical elements to accompany them. The scripts were extended to allow automatic detection of periodic regions in an image via Fourier transforms, and automatically generate profiles passing through those regions. We experimented with other methods such as polar coordinate transforms to create repeating patterns, use of colour histograms to shape the dynamics of the generated music, more complex methods of feature detection to influence the line profile position, and use of overall image symmetry to determine the music's time signature (4/4, 6/8, etc.).

Fig. 1 shows a scanning tunnelling micrograph of a (2×2) reconstructed surface of MnSb [Hatfield & Bell (2007)]. Each bright feature in the grayscale (left) is associated with a single unit mesh of the surface, while the colourised version (right) brings out the longer-scale variation of contrast superimposed on the (2×2) atomic periodicity. Music based on both images is available on the Sonify web site.

The scanning tunnelling micrograph shown in Fig. 2 was obtained inside a molecular beam epitaxy growth chamber using a unique microscope developed by Professor Shiro Tsukamoto in Japan, with whom Gavin Bell has a long-standing collaboration. It shows the early stages of the growth of MnAs, a magnetic material, on GaAs, a semiconductor. Two different nanocluster morphologies can be seen: small rectangular platelets and larger islands [Hirayama *et al.* (2000)]. We created some music based on different Japanese pentatonic scales using this image and others from the same growth series, so that the growing nano-clusters affect the musical patterns achieved.

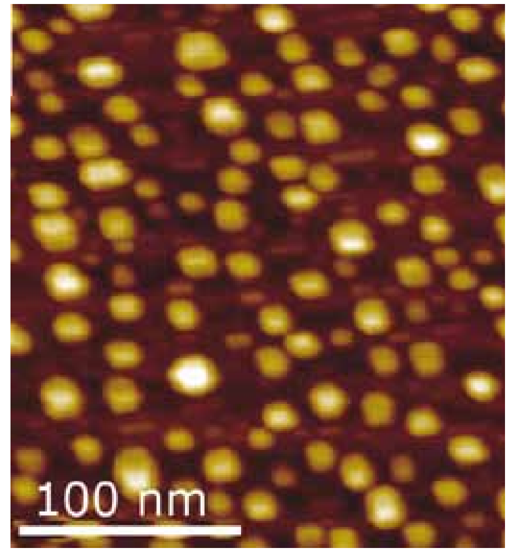

Figure 2: Scanning tunnelling micrograph obtained in situ of MnAs growing on GaAs.

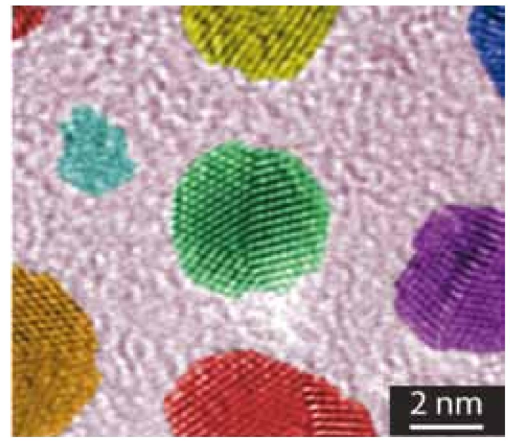

Figure 3: False-colour high resolution transmission electron micrograph of gold nanoparticles grown on a single sheet of graphene oxide.

The image in Fig. 3 was obtained by transmission electron microscopy. It shows Au nanoparticles grown directly on suspended graphene oxide (GO) by physical vapour deposition. The ultra-high transparency of the single sheet of GO makes it an ideal substrate for imaging nano-structured materials [Pandey *et al*. (2011)]. A short musical piece was constructed by processing this image using SAMI.

It would be impossible to codify every kind of music in the SAMI framework and we did not try to make human intervention totally unnecessary in the production of the music. SAMI explicitly allows experimentation in how the scripts are parameterised and applied. Furthermore, the choice of instruments on which the MIDI output is rendered is the user's. The music can even be printed as a score. These options allow musicians to generate phrases or ideas and use them as they see fit. Nonetheless, SAMI can be used with fixed data processing to "hear" the differences between images, and some further examples are given on the web site.

To conclude, sonification allows us to experience scientific data in a new way. The often striking visual impact of microscopy can be translated to musical forms. We would welcome the submission of images to our web site from infocus readers interested in hearing them sonified!

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References

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Rob Wilson is a final year Physics student at Warwick, while Simon StJohn-Green and Jack Dobinson graduated from Warwick in 2011 with M.Math. and M.Phys. degrees respectively. They are pictured with transmission electron microscope, accordion (Simon) and guitar (Jack). Both are now studying for Ph.D. degrees, at the Universities of Southampton and Bristol. Gavin Bell is an Associate Professor in Warwick. He studied at the Universities of Cambridge and Warwick and held research fellowships at Imperial College London before returning to Warwick as a Royal Society University Research Fellow, specialising in crystal and nanostructure growth on surfaces. Rob and Gavin (with bass guitar) are pictured next to an ultra-high vacuum scanning tunnelling microscope which is part of a new oxide thin film growth system funded by the Birmingham Science City initiative.

Jack Dobinson (left) and Simon StJohn-Green (right)

Robert Wilson (left) and Gavin Bell (right)