Title: Blueprints for colour mixing: Towards 2.5D textural printing

Introduction
As a result of current advances in inkjet colour management and halftoning (Lee, 2005; Morovik, 2012) a significant impact of inkjet printing has meant that the artist can now take for granted high-quality colour and resolution in their printed images. Now that the digital printing machine has reached a level where it is seemingly little more than a highly sophisticated image reproduction device, with little or no possibility for repair or modification, artists are beginning to question what next? What if inkjet printers can be modified or adapted to create something different? This research is motivated by painting and rendering programmes and the need to leverage meaningful interaction between the software, the colour printed output, viscous properties of the medium, that works towards the development of a digitally applied surface topology or as 2.5D Printing.

The machine and the maker
Now that digital technology fulfils many of the functions of art-making, an often repeated question is whether artists have lost their sensitivities for materials and process, or a hands on engagement with paints, inks or mixing colour. Moreover, if the artist has become reliant only on computer software, and the physical making process is removed, has the artist lost touch with the things that they make? (Sennet, 2009). Given the perceived deskilling of the modes of making and using colour in the digital realm, can a highly functional printing machine, such as inkjet, be re-employed as an innovative and creative colour mixing machine that moves beyond the grey-box printing device?

The line of enquiry is based on the author’s interest in the relationship between the ‘direct manipulated’ mark (Shneiderman, 2003) that is digitally generated (mouse, drawing tablets, iPads), compared to the analogue mark (produced by a brush, a charcoal smudge, an etched or hand-drawn line), compared to its surface tactility or gonio characteristics (Pauler, 2009; Ashbaugh, 2009, Höpe, 2006), compared to its printed reproduction (for example an inkjet, electrostatic, four-colour separation). From the perspective of material perception, there is a growing interest in accurate computer modelling, rendering of materials (Maloney 2012; Lehmann, 2012), and tangible displays (Ferwerda, 2012). The evolving question is whether images could be created with the benefit of printed texture. Could this texture be incorporated, for example, as a method for enhancing tactile interaction for the visually impaired, or to reproduce fine detail such as cracks, brush strokes or impasto to the surface of paintings to provide meaningful information to the conservator or that assists the artist in new ways for creativity?

Since the 15th century, the colour print has evolved through an incremental process of refining, comparison and redefining (Benson, 2008, Gascoigne, 1997). For the traditional printmaker the combination of paper and ink and the printing machine were (and still remain) important components of the creative art practice. The impact of the ‘technologies of reproduction’ (Tallman, 1996, p.15), such as photo-based screenprinting in the 1960s and ‘70s (Williams, 1986), enabled artists to combine a wide range of elements including colour, pattern and photo-based images to expand their creative vision. Now in the 21st century, computers and image manipulation software have significantly advanced colour mixing. Electrostatic and inkjet technologies enable colour, text and image to be printed in one pass. From its roots in 19th century photomechanical reproduction, the science and technology of the 21st century coloured print has become staggeringly sophisticated.

In the light of recent developments of post-digital printmaking processes (Catanese, 2012), artists’ adoption of CNC technologies has increased the range and diversity of image making, artefact
construction and a re-evaluation of old analogue processes, by hybridising old and new processes and hacking (earlier but now redundant) 20\textsuperscript{th} century technologies.

**The hand of the artist**

The objective of the 2011 V&A and Crafts Council exhibition ‘The Power of Making’ was to showcase contemporary craft practitioners, to demonstrate the diversity of craft making and applaud the crossovers between the hand-made, digital fabrication and mechanical technologies. In the catalogue of the same name, the authors describe how craft skills are very much alive, despite the on-going negative and conflicting counter-arguments, ‘since the industrial revolution there has been a mourning for the loss of manual labour’ (Miller, 2011, p.16), and ‘we live in a world that constantly tempts us to be superficial and transient’ (p.22). Richard Sennet, in his book *The Craftsman*, echoes Miller et al., but also considers the notion of mechanisation in a different way, and proposes how ‘might we in our very comparative imperfection learn something positive about being human?’ (Sennet, 2009, p.81). He compares the craftsman’s desire to make by hand, incorporating variety and flaws, versus the anxiety of ‘the rigorous perfection of the machine’ (p.84). He describes two different types of machines, that of the replicant – that mimics human functions in order to best serve our needs (pacemakers, artificial limbs), or as a robot – a machine that is our-self but larger and stronger, that works faster but never tires (printing presses, paper mills, computers) ‘the replicant shows us as we are, the robot as we might be’ (p.84-5). Ben Shneiderman, in his book *Leonardo’s Laptop* (2003) describes the shift in technology over the last 20 years, ‘The old computing was about what computers could do; the new computing is about what users can do.’ This carefully considered book title and subsequent line of enquiry highlights the more recent problems, and split in communication and practice between the arts and sciences. Echoed in the 1959 Rede Lecture, C.P. Snow described how the arts and sciences were divided as ‘two cultures’ (Snow, 1959). Even in the 21st century, the arts and sciences’ engagement with colour is generally regarded as being practiced ‘in splendid isolation’ where the relevance of combining the sciences and the arts, is often called into question (Love, 2005), and which continues to be debated (Wilson et al. 2014) but promoted from a more positive perspective. For Leonardo da Vinci, embedding and demonstrating his knowledge of science and technology in the 15th century, through his drawings and art, the assumption was that ideas were explored through experience and the empirical process of *trial and error*. According to Venturi, one of Leonardo’s best students, ‘The rational intellect (l’esprit géometrique) guided him [Leonardo] in everything, whether in the art of analysing an object, in the stricture of his discourse, or in the care always to generalize his ideas’ (Turner, 1995, p.86).

**Towards the 2.5D surface**

In the 1980s, ‘direct manipulation\textsuperscript{1}’ was achieved through the revolutionary method of being able to point at the screen with a mouse. Software such as Mac Paint\textsuperscript{2} enabled artists to use a range of *tools* to paint, draw, spray and fill shapes with black and white patterns. In the 21st century there are many digital tools that artists can use to create images. Direct manipulation can be achieved through graphics tablets, touch screens, and Wi-Fi drawing pens, or working on touch-screen devices or drawing tablets, the user by *painting* on a touch-screen, can scroll their finger to select colours, modify brushes and manipulate paint. *Tangipaint* - a touch-screen paint mixing application that has been recently developed at Rochester Institute of Technology, USA (RIT) - creates the appearance of gloss and the texture of paint (Ferwerda, 2012; Blatner, 2011). Such an example highlights interesting opportunities for manipulating virtual paint, but does not indicate how images will appear when printed. The assumption is that images remain screen-based or are shared between

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\textsuperscript{1} Ben Shneiderman introduced the term ‘direct manipulation’ in the 1980s.

\textsuperscript{2} Mac Paint, developed by Bill Atkinson, was a novel software that was designed to interact with the user, interpret mouse and keyboard requests, and to decide what was to be drawn where.
As Margot Lovejoy describes in her chapter on the *Age of the Mechanical*, the ‘hand of the artist’ is considered as ‘doubly precious’ (Lovejoy, 2004, p.73). McCullough goes on to reflect that the ‘practiced digital hand’ humanises computer aided design, and in return, digital technologies has provided a currency for the tacit knowledge of craft skills (p.313).

The research into developing a 2.5D-printing machine has evolved as recent trends in digital printing and manufacture has moved from 2D inkjet printing to 3D additive layer deposition (Chua, 2003, Hoskins, 2013). Initial alternative methods into the development of a low-relief textured surface has been partially fulfilled by building layers through digital printing of UV curing materials to create a surface topography (Parraman, 2011).

A major component of colour reproduction is the accurate reproduction of the appearance of texture (Ashbaugh, 2009; Campisi, 2000). This is an emerging and significant area for accurate rendering and synthetic applications, for example surface rendering of 3D graphics in computer games. However, naturalistic rendering has proven to be difficult. Where the human visual system (HVS) is more forgiving in its perception of halftone images, texture is problematic, as the HVS is able to discriminate the difference between natural and patterned texture. A natural texture appears homogeneous, but remains random; each element is similar but unique. However a patterned texture, although homogeneous is composed of the same repeatable and recognisable elements. To create a natural-patterned texture would require unlimited variations of patterns for the HVS to not perceive the differences, therefore highly complex computational processing would be required.

As described in the introduction of this paper, the line of enquiry is based on the author’s interest in the relationship between the textured surface and its colour reproduction (Neugebauer, 1937, 2005). For example, when transcribing the fluid appearance of a brush stroke, there is a difference between a painted mark and a halftone printed mark. Figure 1 demonstrates the difference between a brush stroke (top right, top left, bottom right) and a mechanical halftone reproduction of a brush stroke (bottom left). The success of a halftone image is reliant on viewing distance, contrast and frequency
to ensure a meaningful engagement (Johnson, 2005). The issue of surface quality here is significant to its subjective qualities when studying the appearance of ink or paint on paper.

As shown in figure 1 (top left), a series of brush strokes are mechanically applied at regular intervals, at a relative even pressure and consistency of paint. Although the brush strokes are applied mechanically, there are still modulations in the stroke. The strokes appear uniform, and where more paint is applied, the brush strokes appear darker. In the magnified section of figure 1 (top-right) there is a significant difference in appearance between the area of the stroke that is heavily charged with paint, which appears darker and is more concentrated, compared to the area where less paint is applied, which appears lighter and more translucent. In the bottom-right section of figure 1, the paintbrush is loaded with less paint, and the lines of paint are discernable and more defined. The bottom-left image shows the brush stroke under magnification, the halftone dots are clearly visible, and the illusion of light and shade is lost.

The research is partially in response to the Royal Academy exhibition by David Hockney and inclusion of his iPad generated prints at the Royal Academy (London, 21 January - 9 April 2012) (Gayford, 2011). It is also motivated by painting and rendering programmes such as Corel® Painter™, Autodesk® Sketch Book Pro for iPad, Brushes by Taptrix Inc., which create the appearance of drawn marks, or oil or watercolour brush strokes on paper and canvas. These are more sophisticated versions of the 1980s MacPaint programme. The surface of the canvases on which Hockney has applied oil and acrylic paint in the exhibition has a multi-dimensional quality. The varying translucency and opacity of the brush strokes can be seen, as can the gloss and matte differential between oil on canvas and watercolour on paper.3 But as shown in the Hockney iPad drawings, and resulting prints, the attempt to create subtleties of layer and texture is lost by the use of limited patterns and tools.

Alternative methods for image construction and printing are available through vector and postscript formats that contain embedded information relating to spot colour, textures, special effects and vector paths (for example cut paths for laser etching or cutters), and images can be scaled without loss of information. This approach could also lead to opportunities for file transition between two-dimensional and three-dimensional formats. Kandinsky described the development of a point into a line, the line into a plane, and the plane into a spatial dimension, (Kandinsky, 1979). The evolving question is whether artworks can be reproduced with the benefit of texture that incorporates, for example, paint instead of ink, vector instead of dot? This approach could differ significantly from its pixel-cmyk based cousin.

As exampled by painter Paul Signac (figure 2), who used a highly repetitive method of painting that could be transcribed to a vector-based line. Signac used regular, short, horizontal strokes, which were used almost entirely throughout the painting. The strokes were applied in a highly controlled manner with no obvious flourish at the end of the stroke.

3 http://www.youtube.com/watch?v=0jabJKtqK0k
Creating a library of vectors towards a 2.5D print

In response to the richly textured paintings by Hockney and Signac, the project has reflected on the concept of developing a 2.5D deposition printer. The objective was to create a library of patterns that comprised a range of vector strokes, and to analyse the possible degrees of freedom using different application tools. These tools have included hand fabricated nibs and brushes, which were then used to test the application of different paints, inks, colours, the overlayering of colour, translucency, viscosity, fluid dynamics, force, and the investigation of texture and surface appearance.

Hardware setup

Originally designed as a plotter for cutting vinyl, the machine has an x and y-axis and solenoid to obtain z-axis. The cutting blade was replaced with a prototype fabricated brush holder that incorporated a screw-thread for accommodating brushes and nibs of different sizes (figure 3). A series of different shaped brushes and nibs were formed around a hollow 14-guage tip (more commonly used for dispensing glue) that has a Luer thread lock. Each brush could easily be removed and interchanged. The hollow centre meant that paint could be pumped through a rubber tube and the brush then applied the paint to the paper. The paint was dispensed from a syringe under vacuum and pumped through flexible rubber tubing to the paintbrush at the other end. In order to ensure a smooth continuous flow, the paint was pumped using a peristaltic variable flow pump. An artists’ acrylic pigment produced by Daler Rowney was used. In its original form, the pigment was too viscous to be pumped, and was diluted two-parts pigment to one-part water to obtain a viscosity of about 10,000-25,000 cps.
Setup of vector-based modules
As demonstrated in figures 4 and 5, a series of 20 x 20 cm modules were generated in Adobe Illustrator, each comprising a pattern of vector lines, where each component could be modified, enlarged, rotated or removed. Figure 5 is part of a library of hand-drawn and imported vector-based marks that could be copied, cut and pasted into any drawing. The 20 x 20 grid means that sampling could be undertaken by the overlaying of different patterns, colours or by experimenting with different scales, force or viscosity of ink.
Impact8 - Blueprints for colour mixing

(bottom right) Hog’s hair bristle, small; Scale and orientation: 100%, as original Acrylic – standard mix (2 parts paint: 1 part water); Flow rate: 2 x 10; Paint head force 100.

Figure 5. A test sheet of hand drawn vector lines in Adobe Illustrator and dialogue box for exporting the modules (left) to computer numerically drive the vector paths to the plotter. The examples (centre and right) show a cork nib, which unlike as in figure 4 that is rotated, here the test sheet is rotated by 90° to achieve a different printed appearance. Scale and orientation: 100%, as original Acrylic – standard mix (2 parts paint: 1 part water); Flow rate: 2 x 10; Paint head force 100.

Printing the modules
A series of modules were generated that comprised evenly placed vector marks to form a grid (figure 4 and 5). Different tests were undertaken to compare the character and behaviour of paint, stylus and mark at different flow rates. The speed and pressure of the brush remained constant, but for each test the flow rate was incrementally increased. In some tests, depending on the size of brush or stylus, the lines overlapped or where different colours were overlaid, secondary colour mixing occurred (figure 6). Tests included the application of wet upon wet strokes, wet upon partially dry, or allowed to dry before adding further layers. In some tests the consistency of the paint was reduced to flow like a watercolour. As demonstrated in these examples, by changing the orientation of the nib or by using a different brush, resulted in quite different appearances. Extra layers could be added to build up paint to create a textured 2.5D surface as shown in figure 6.

Figure 6. Detail of the surface, captured at an angle, showing the application of two layers of ink and working towards a 2.5D surface.
Conclusion
This project has developed in response to recent trends in digital printing and manufacture, as it has moved from 2D inkjet printing to 3D additive layer deposition. This paper has introduced ideas around 2.5D deposition printing, perception of texture, and the fluid dynamics of paint on paper by adjusting the topological surface of the substrate by layering inks or pigments to achieve the desired change in tone, viscosity, gloss and texture.

In response to the question that given the deskilling of the modes of making and using colour in the digital realm, could a painting machine be employed as an innovative and creative colour mixing and plotting device? ‘The desire to do something well is a personal litmus test … in the light of our own limits rather than the machine’s potential… a machine like any model, ought to propose rather than command.’ (Sennet, 2009, p.97-106). The suggestion is that a deeper understanding of the relationship between methods for colour mixing and vector-based methods of application, that move between analogue and digital, could have significance in developing alternative approaches for digital printing systems.

In 1979 Lyotard described our future where ‘anything in the constituted body of knowledge that is not translatable into digital language will be abandoned’ (Lyotard, 1979, p.4). Although Lyotard was partially correct, digital and analogue do co-exist, and knowledge of traditional fabrication methods and manipulation of materials is not lost, but celebrated. As McCulloch suggests ‘histories of technology reveal the increasing abstraction of work… each level forms a layer over the old, rather than casting it aside, as in the stages of a natural growth. This means that even if new abstractions eventually become the most prominent methods, they do not replace existing activities so much as transform or complement them.’ (McCullough, 2010, p.315).

References
FERWERDA, J. A. Tangible display systems: bringing virtual objects into the real world. Electronic Imaging: Science & Technology 2012. IS&T/SPIE


LYOTARD, J. 1979. The Postmodern Condition: A Report on Knowledge, Manchester


Figure Captions

Figure 1. Cadmium red (TL) uniform brush strokes, (TR) brush overloaded with paint, (BR) dry brush, (BL) halftone (TR, BR and BL) at 40x magnification.

Figure 2. (left) Paul Signac, *The Papal Palace, Avignon*, 1900, Oil on Canvas, 735mm x 925mm, Musée d'Orsay; (centre) showing vector drawn marks using the image as a guide; (right) showing the resulting brush marks made with a small hog’s hair brush on the painting machine.

Figure 3. A modified plotter with brush head.

Figure 4. A test sheet of hand drawn vector lines in Adobe Illustrator (top left) and demonstrating an exploration of different methods of application; (top right) Double cork. At -45° angle (clockwise from vertical); (bottom left) Double cork. At 45° angle (anti-clockwise from vertical); (bottom right) Hog’s hair bristle, small; Scale and orientation: 100%, as original Acrylic – standard mix (2 parts paint: 1 part water); Flow rate: 2 x 10; Paint head force 100.

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