From Codes to Patterns: Designing Interactive Decoration for Tableware

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ABSTRACT

We explore the idea of making aesthetic decorative patterns that contain multiple visual codes. We chart an iterative collaboration with ceramic designers and a restaurant to refine a recognition technology to work reliably on ceramics, produce a pattern book of designs, and prototype sets of tableware and a mobile app to enhance a dining experience. We document how the designers learned to work with and creatively exploit the technology, enriching their patterns with embellishments and backgrounds and developing strategies for embedding codes into complex designs. We discuss the potential and challenges of interacting with such patterns. We argue for a transition from designing 'codes to patterns' that reflects the skills of designers alongside the development of new technologies.

Author Keywords

Barcodes; QR codes; patterns; vision; recognition; mobile applications; ceramics; food

ACM Classification Keywords

H.5.2 [Information Interfaces And Presentation]: User Interfaces - Interaction styles

INTRODUCTION

Decorative patterns are an ever-present feature of our everyday world. From motifs and borders, to swathes of colour and texture, almost every object that we value is embellished with a pattern that has been carefully designed to enhance its aesthetic, meaning and value. Such patterns are an essential feature of ceramics, textiles, wallpaper and all manner of home furnishings and fittings. They enhance the beauty of our environments, and we use them to adorn our bodies, enabling us to express our personalities and tastes by mixing and matching the objects that surround and cover us. Decorative patterns are a ubiquitous feature of the everyday world, literally 'part of the furniture'.

Our aim is to make such patterns interactive by associating them with digital materials so as to further enhance their value and meaning. Specifically, we aim to embed multiple visual codes that can be recognised by computers into wider decorative patterns that are attractive to people. While this will no doubt ultimately involve extending computer vision techniques to recognise various patterns in the everyday world, our core argument in this paper is that this is also a *design challenge*. We need to understand how designers can work with emerging vision technologies to create aesthetically rich and interactive patterns. How they can make creative use of these technologies, and in turn, how might the technologies better support their skills?

In response, we describe an iterative process of prototyping plates, placements and other tableware that are decorated with interactive patterns so as to enhance a dining experience. Specifically, we report the lessons learned from engaging a team of ceramic designers, with a restaurant chain and technologists to refine a vision technology, train designers to use it, commission them to produce a 'pattern book' of designs, and then explore how these could enhance the value of tableware at a restaurant.

Our contribution is to surface how designers can make creative use of the recognition technology, at times battling its rules and constraints, but also exploiting them to enrich patterns with embellishments and backgrounds. We articulate their strategies for placing recognisable visual codes within wider aesthetic patterns, identify the kinds of interactions that these might support, and finally discuss the challenges of interacting with them. As a result, we are able to argue for a shift in thinking from designing interactive 'codes to patterns', one that acknowledges the skills of designers alongside the role of vision technologies.

RELATED WORK ON VISUAL CODES

The idea of scanning visual codes to trigger digital interactions is well established. The use of specifically designed codes, containing many bits of information reaches back to the use of barcodes, initially patented in 1952 [22] and now almost universal on retail products. More recently, 2D codes that are readable by mobile applications (e.g., QR codes [15]), have become popular. In this paper, we refer to such images as *codes,* because each specific image maps onto a unique numeric identifier, distinguishing them from more general *patterns*.

Designed to be robustly identified, a key characteristic of these visual codes is that they are inherently recognizable for what they are – there is no mistaking a barcode or QR code once you have encountered one. Positively, this enables users to easily spot where they are and so interact

CHI 2013, April 27–May 2, 2013, Paris, France.

with them. On the other hand, it comes at the cost of a limited aesthetic [6]: they are designed to be robust, not to look good. Moreover their visual appearance remains fixed; it is not possible to redesign the code to some other visual aesthetic. Consequently, they are generally unsuitable for use within decorative patterns.

Recent work, both research and commercial, has attempted to address the limited aesthetic of visual codes in various ways. One approach is to retain the visual appearance of the code, but to reshape and embellish it so that it becomes part of a more meaningful picture, usually a logo. This can be seen in the work of specialist design companies such as Bar Code Revolution [1] and D-Barcode [9] who create clever and playful personalized barcodes. The various ways in which QR codes provide robustness lend themselves to this kind of manipulation, with online tools for embedding images in the padding bits [18], in the bits used for error correction [21], or by limiting contrast changes due to the overlaid design [19], while retaining the ability to recognize the code, leading to many creative QR code designs (e.g., [10]). Various artists have made creative and unusual uses of barcodes and QR codes to create interactive works that enhance or even celebrate their aesthetic. Yet other codes that are similar to, but distinct from, QR codes embed the code in the colour relationships between cells on a fixed grid [5]. This said, the 'ugly' aesthetic of such codes surely limits the extent to which they will ultimately populate the everyday world of design: it is difficult to envisage a world in which walls, clothing and furniture are covered with such codes, as they are with patterns.

An alternative is to re-engineer the recognition technology to work with a much wider variety of images. Various augmented reality systems make use of general image recognition techniques ranging from free-form image processing, e.g., Google Goggles [14], to image recognition of a restricted set of images, e.g., Blippar [4] and String [17]. These recognize images at the pixel level, providing much greater freedom in terms of what can be recognized. Embedded Media Markers [16] is a pixel-based matching system that uses framed near-transparent images as markers to hide them somewhat from view. Alternatively, *topological markers* encode information in the structure of the image rather than its pixel-level content. Examples of this approach include reacTIVision [3], ARTag [12] and d-touch [7,8]. The latter represents codes through the relationship between nested contiguous black/white regions and is interesting here because it enables designers to draw their own codes. Subsequent work has begun to investigate the designability afforded by d-touch [6] and the use of d-touch codes in narratives [11].

Such techniques promise to transform the aesthetic of the visual code, and perhaps more to the point, place it under the direct control of the designer. They appear to open up the possibility of embedding codes into a wide variety of patterns that might cover all manner of surfaces. The question then becomes how might designers work with such approaches to create richer patterns? What creative possibilities do they open up? How can designers approach them and what support do they require? Answering these questions requires us to understand how the skills of designers will rub up against these emerging technologies, which is the core aim of our paper.

OUR APPROACH

Our approach has been to engage ceramic designers, a restaurant, and technologists in a practical exploration of how we might create and use interactive decorative patterns. This exploration unfolded in three broad phases:

- We worked with ceramic designers to *refine the drawing rules and recognition software* to work reliably with ceramics, implementing the results on a phone.
- We trained a team of designers to use the technology and then commissioned them to *produce a pattern book* of designs, enabling us to document how they conceived of the technology and learned to work with and exploit its constraints.
- We collaborated with a restaurant to *prototype a mobile phone app for diners*, enabling us to identify how to deploy patterns and associate them with digital services in a real-world setting.

Following this process involved three key choices.

Choice of recognition technology – technically, we opted to work with the d-touch approach. We felt this to be especially appropriate because it embodies a bottom-up, drawing-based approach that we felt would fit very well with the drawing skills of professional designers. Previous studies of d-touch suggested that, beginning with a blank page and following a small set of drawing rules, novice designers were quickly able to create aesthetic visual codes [6]. Intrigued by its potential, we saw d-touch as a useful probe for exploring how creative designers might engage with emerging recognition technologies to create wider patterns, anticipating that the lessons learned would be transferable to other recognition technologies.

Choice of design discipline – we decided to focus on the discipline of ceramic design, rather than say textile design, in the first instance. Ceramics are widespread and often highly patterned, but tend to be constrained in size and also rigid. This combination of factors leads to them being a realistic, but also technically viable, option for a first practical exploration when compared to the challenges presented by deformable and mobile fabrics.

Choice of application – in searching for a practical application of interactive ceramics, we decided to focus on a restaurant setting so that we could harness the creativity and knowledge of professional restauranteurs in helping us envision new interactions. We chose to work with the Busaba restaurant because of their creative approach to dining, including serving dishes on bespoke tableware.

PHASE 1: REFINING THE RECOGNITION SYSTEM

Our first challenge was to refine the recognition technology so that designers could create valid codes that would work

reliably on ceramics, implementing the results in software for Android phones. This involved a complex negotiation between our 6 technologists (4 developers of mobile apps and vision systems and 2 HCI researchers) and 3 designers (2 ceramics and 1 textile) to clarify the drawing rules and agree additional reliability constraints.

Clarifying the rules

We started with the pre-existing d-touch rules for drawing visual codes, which we briefly reproduce here for completeness. D-touch adopts a topological approach to visual codes. Its core drawing rule specifies how various black and white regions must be nested inside one another in order to form a valid visual marker:

"A valid marker can be composed of a black region containing 3 or more white regions, and at least half of these white regions must contain one or more black regions. This makes exactly 3 levels of nesting – it must be no more and no less. However, there is no limit in the number and shape of the regions." [1]

Each such marker maps onto a unique numerical identifier according to its topological structure. This is the comma-separated sequence of integers that counts the number of black regions inside each white region, written in ascending order. As a result, very different looking drawings can map to the same code providing they have a common topology.

Introducing additional drawing constraints

Early meetings explored these rules by sketching initial designs onto blank ceramics using pens. This was followed by the remote exchange and debugging of further designs that were applied to plates via transfers. Figure 1 shows early designs created by a technologist (left) and designer (right). Even this simplest of designer's sketches involved a fineness of detail that challenged the technology.

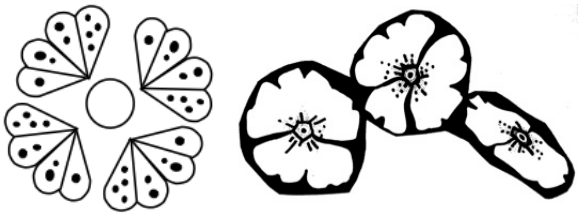

Figure 1. Early sketches from a technologist and designer

In response, the technical team conveyed to designers through a series of examples (Figure 2) how d-touch reconstructs images from pixels so that, given the limited resolution of a scanned image, fine visual detail can be lost. There is a complex relationship between line thickness, camera resolution and viewing distance. Following experimentation, the technical team proposed a 'rule of thumb' drawing constraint (over and above the basic rules) that they felt should render a design reliably recognisable when applied to a plate that is then framed in the viewfinder of a camera-phone: the designer should work to a recognition area of 40mm by 80mm, and lines should be at least 2mm wide, as should whitespace between them.

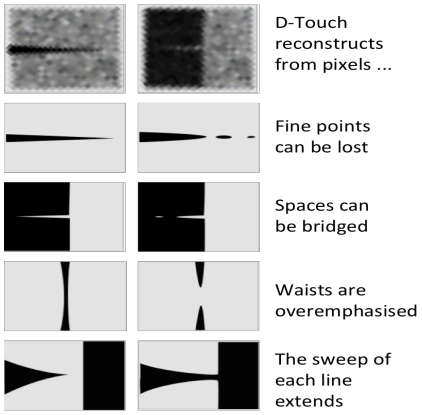

Figure 2. Common drawing problems due to pixilation

Ensuring reliability on ceramics

Early attempts to copy designs onto ceramics, along with a visit to a Busaba restaurant, revealed further challenges for reliable recognition under realistic conditions: specular reflections from lights would blot out areas of the image, especially on glazed surfaces; the mobile phone, objects such as chopsticks, and even the 3D structure of the ceramic object itself cast shadows; and plates get covered in food, obscuring areas of the pattern. The technical team introduced three robustness mechanisms in response:

Figure 3. Challenges of reflections, shadows and food

Checksum – the total count of all leaf regions (blobs) must be divisible by a checksum value (set to 6 in our software). This protects against the very common occurrence of miscounting the blobs, either missing existing ones (lighting conditions 'white out' a region or blobs merge in the recognition) or adding false ones (the recognition splits marks into two).

Validation regions – have a fixed known number of blobs. This detects disruptions severe enough to defeat the checksum (such as lighting conditions that induce noise). In our implementation, a valid code must contain two validation regions each with one blob (i.e. codes must start with the prefix 1,1).

Redundancy – replicating the code increases reliability if part of the pattern is obscured by food or specular reflections. We therefore extended our software to look for multiple versions of a code.

Based on their growing experience, our designers reflected on how these constraints impacted the aesthetic of their designs. They felt that the rectangular border had a very profound "emotional" effect in restricting the design from growing naturally in all directions to the point where it was

[1] https://d-touch.org/design/rules/

changed to be a square. The combination of a target number of regions and blobs, combined with the checksum and validation regions, defined the structure of a 'motif', a basic unit of the design that could be recognised. The challenge is to create a rich motif with a highly constrained structure. Redundancy, on the other hand, encourages repetition of the motif to make a pattern. Finally, line thickness and spacing were treated as a rough guide, often initially ignored, but then fixed later on during debugging.

By the end of this first stage, we had agreed the rules and constraints involved in designing valid visual codes for ceramics and implemented these as a library for Android phones. This uses OpenCV to read images and detect regions and allows us to define the constraints for the type of d-touch markers that should be recognized and set parameters for validation. Our code is open source and available on GitHub.[2] A sample application that scans codes can be downloaded from the Google play store.[3]

PHASE 2: PRODUCING A PATTERN BOOK

The next stage of our exploration involved engaging external designers to produce designs for the enhanced dining experience and understand how they would approach the challenge of creating interactive patterns.

Learning the rules

We invited six external designers to a daylong training workshop. All were working as professional designers, either freelance and/or with their own galleries and shops. Three were focused on ceramic design and three on textile or print design. The workshop followed a hands-on approach, gradually introducing the principles, rules and constraints during the course of four drawing exercises, two involving copying existing designs followed by two more to quickly sketch their own designs corresponding to specified codes. Useful lessons were learned during these initial training exercises, specifically:

- We agreed the terminology of regions and blobs (within regions) to refer to the key visual elements in codes.
- The designers appreciated seeing examples of common mistakes such as blobs being too close to regions and regions not being properly joined up.
- They used the debug mode in the mobile software to check their designs and then fixed them by drawing new elements or removing current ones with Tippex. At their request, we later extended debug mode to highlight where the codes are found in an image as well as show the numeric value of the code.
- Their most immediate frustration was working with the thick pens that we had provided to ensure reliability ("*I'm not used to drawing with such a soft felt tip*").

Preliminary sketches

We then asked our designers to create more sophisticated designs. They were invited to browse a selection of design books and catalogues as a source of inspiration and to spend twenty minutes thinking and sketching, but without worrying about creating valid visual codes. We then asked them to refine their ideas to create three valid visual codes (1:1:2:2:6, 1:1:2:3:5, 1:1:3:3:4), testing them with the software as they went. This exercise lasted about an hour and a half and on completion we recorded a short video interview with each designer asking them to comment on their inspiration and approach.

The designer of Figure 4 noted her inspiration as: *"Like a Morrison picture but with loads of background detail that had nothing to do with [it?] ... so it was camouflaged ... I'd have loads of foliage or background imagery and then just have the code hidden inside"*. She explained her approach was to *"establish the regions first in a motif ... then afterwards that you can add the blobs."*

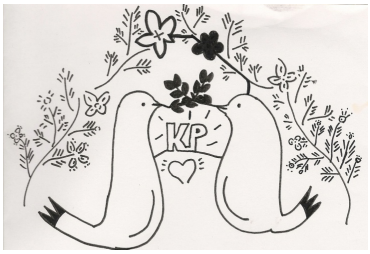

Figure 4. Morrison design

The designer of Figure 5 reported her inspiration to be *"traditional patterns on plates like fleur-de-lis"* and described how she began with a valid code before adding embellishments that would be invisible to the system: *"I'm just trying to make them blend in ... so at first I put the ones [dots] that were in the code and then I just added some more around the edge"*. She also designed the motif to be easily manipulated and repeated: *"I think that's why I started with this one ... and then you could turn it over ... so it's like a sort of mirror image ... then maybe joining them ... having a different amount of dots in each"*.

Figure 5. Fleur-de-Lis

A third designer noted her inspiration as *"very simplified Japanese drawings which is a good resource to work from because they work from those outlines"* explaining how she *"did the five zones first and then planted in them the amount of blobs that need to be in each section."* She reflected on how she embellished her fish with scales: *"Initially you think 'I can only put one mark in that region' but then you realize you can put as many as you want as long as you connect them to the outside line"*.

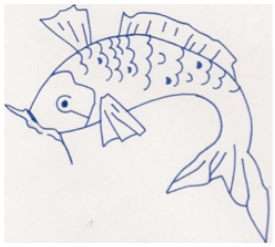

Figure 6. Fish

A fourth designer confirmed this 'structure first' approach of beginning with the code *("I find it easier to start developing an idea based on I know how many regions and I know how many blobs"*) before then adding to the basic design to create a richer pattern *("so adding these little bits*

[2] http://horizon-institute.github.com/tableware/

[3] https://play.google.com/store/search?q=aestheticodes

it becomes more of a pattern") that disguised the presence of the code (*"I think if the eye is not just drawn to a specific area but is just drawn to the whole design"*).

Figure 7. Bird

However, our other two designers adopted a different strategy, preferring to create a general sketch of an idea first, before incrementally amending this to reach the correct topology of regions and blobs. The designer of the bird in Figure 7 noted: *"Actually I started just drawing it out how I naturally just draw like this with like lots of little lines. So I just started drawing it out and then started kinda thinking which bits should I join so as to make them into regions*", although she did have a sense of where the regions would appear from the start: *"I kind of had an idea in my head that I would do the tail feathers as regions"*. Our final designer also described how she adopted a sketch-first strategy (*"I took this picture and I thought ... I started to draw it as I saw but not joined up*") before refining her initial drawing to make it *"more simple like this"*. A key feature of her 'leaves' design was the use of large solid shaded regions that would appear significant to a human, but just appear as a thick line to the recognition system.

Figure 8. Leaves

In short, even at this early training stage, it was becoming clear that our designers had a distinctive way of approaching visually rich aesthetic codes by camouflaging them with embellishments and backgrounds that would appear significant to people, but would be invisible to the system. We were also seeing two emerging approaches – 'structure first' and 'sketch first'.

Creating patterns

Following the training workshop, five of the designers accepted a commission to create a series of designs over a period of a month. Each was given the same three codes for which they had to produce three distinct patterns. The resulting 15 designs are shown in figure 9. They vary widely from classical, to natural, to abstract designs, and from repeated patterns to iconic images. In this section we will refer to them using the numbering in this figure. Again, we asked them about their inspirations and process.

Figure 9. The fifteen patterns grouped by designer

These designs were inspired by existing artwork and structures that fit well with the concepts of regions and blobs, such as Delft blue and white china (2.3), simple motifs of birds and florals (3.3), old photographs of ink in water (4.1, 4.3) and the dividing cells in mould (2.2). Designers also took inspiration from images with simple lines such as simplified graphic line illustrations (group 5), architectural lines (2.1), mark making (3.1, 3.2) and fabric stitch patterns (4.2). One of the designers continued her explorations of classic William Morris designs from the workshop and reiterated her desire to camouflage the code in something that looks traditional (group 1). Our designers remained split between the structure-first and sketch-first approaches that we had first seen at the training workshop.

Figure 10. A code revealed

Figure 10 shows an example of how adept the designers became at hiding codes within patterns (the code is highlighted in red).

The challenge of creating three different versions of each design for three distinct codes revealed how designers set about adapting a pattern. They found that simple changes could create a different code in some designs while in others, whole regions had to be rethought and modified in order for the designs to work. Some introduced subtle changes that were intended to be invisible to the viewer so that the three codes looked alike. Figure 11 shows three patterns each of which maps to a different code according to the number of blobs within the bodies of the penguins, and where these are disguised by being small but also being seen as part of the wider splatter of larger blobs which serve to distract the eye.

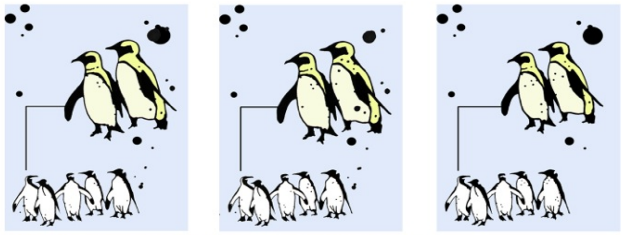

Figure 11. Invisible change in design for 3 different codes

In contrast, Figure 12 shows how a series of codes can be created by adding distinct new visual elements (two different birds) to the basic design resulting in a series of designs that visibly tell a story to the viewer. Designers also reflected on their strategies to accommodate redundancy – some selected sections of the design to repeat as a motif (e.g., 1.3) opening up the possibility for large area of repeated pattern that would contain many redundant codes, while others explored the repetition of the same code, but without actually repeating the same visual elements (e.g., the three birds in 5.2 each map to the same code).

Figure 12. Visible change in design for 3 different codes

The designers also expanded on their use of embellishments and backgrounds from the training workshop, while also experimenting with new ones. Notably, they realised that light colours become thresholded to white and so would be indistinguishable by the technology. This enabled them to create interesting effects such as coloured regions (group 1 and 5) and layers (3.3) that embellished and reinforced the aesthetic of the pattern without affecting its recognition.

Finally, our designers reported various challenges and requests for additional capabilities. As designs became more complex, so it became very challenging to create large-scale patterns that retained an aesthetic richness through fine detail. Designers would either draw physically larger images so the phone had to be held further away to capture them, or they would scale parts down to fit many elements into one pattern. In either case, this led to problems with the software recognising codes, as blobs and lines were seen to merge. In response, designers needed to take care to enlarge regions to provide more space for the blobs, not put blobs too close to region lines, and avoid too much detail in small regions. Once again, some noted issues with lines being too thin or close together to be recognized correctly. A solution for one was to recreate the artwork in Illustrator once it had been hand drawn, so that these problems could be easily solved without distorting the original pattern. There was a request to be able to further expand the use of colour: "*At present the designs and patterns can only be read if they are produced in one solid strong colour. If it was possible that more colour variation and tonal difference could be read I think it would potentially add more depth to the designs"* and one designer also wanted to be able to read and verify the pattern by gradually scanning over it rather than having to see it all at once.

In spite of these challenges, designers were positive about the approach, observing that the drawing rules provide plenty of scope for creating interesting designs. As one said: *"I found though that the more you played with the codes the more versatile you realised the formula is – and really a huge scope of imagery can already be created within the existing structures".*

By the end of this second phase we had 15 varied patterns. The next challenge was to put them to practical use.

PHASE 3: PLACING PATTERNS IN CONTEXT

We engaged with the Busaba restaurant to reveal additional issues that would arise when deploying patterns in a real-world setting. This took the form of a series of workshops to iteratively prototype a set of 'trackable tableware' and an associated mobile app. The first meeting held at a Busaba

restaurant, acquainted us with the broad setting. We learned that Busaba serves authentic Thai food in a modern casual setting and has created a series of bespoke dishes, each with a specific history and provenance that it is keen to communicate to customers. Individual dishes are served in their own distinctive tableware. We had initially anticipated using a fixed camera mounted above each table to scan patterns on tableware. To our surprise, however, Busaba had no objections to customers using phones in their restaurants and were keen to develop a mobile app.

A subsequent daylong participative design workshop involving 11 Busaba staff (operations managers and waiting staff) and our technologists and ceramic designers explored how patterns might be used around the restaurant to trigger various services. It became clear that Busaba was keen to enhance the dining experience rather than replace the functions of the waiting staff. Proposals generally fell into two broad categories. First was sharing the Busaba culture, giving customers additional information about the restaurant, its approach and food, including recipe cards to take away. The second focused on enhancing the ten stages of the Busaba service process (arrival, seating, greeting, food and drink ordering, suggest and educate, drink and food service, check back on satisfaction and second drink, clearing, payment, and farewell).

Significantly, the workshop revealed the potential to pattern a variety of objects at the table and beyond. While ceramic dishes were seen as important, participants also suggested decorating menus, paper placemats given to each customer, and signage near the restaurant entrance. A key element of the discussion involved creating an appropriate mapping between the location of a pattern and the service that was subsequently triggered. Specifically, it was proposed that:

- Scanning patterns on the menu would give information about dishes and prices, including specials. A specific proposal that we subsequently implemented was that of a zoomable pattern, in which scanning the part of a pattern near a menu item would give information about this specific dish, whereas scanning the entire menu would give information about daily specials.
- Scanning patterns on plates would reveal information about associated dishes such as inspiration, ingredients and giving recipe cards. The casual style of dining at Busaba means that groups of friends, and often strangers too, sit at a common table with dishes around them. It was hoped that diners would learn about their own dishes, but also those of others at the table.
- Scanning the placemat triggers services related to this customer's order, including calling for the waiter or the bill, or launching a "Look in the kitchen" video view.
- Finally, scanning a sign near the entrance would inform potential customers of likely waiting times, including at other nearby Busaba restaurants.

We implemented these ideas in a prototype (meaning that scanning patterns triggered interactions but the app was not integrated with Busaba' systems) for a public demonstration at one of their restaurants. We further refined the patterns in Figure 9 and manufactured fifteen place settings, each comprising two different plates (the pattern is applied as a glaze), a placemat and a menu. We chose one of the designs to be printed on a sign to be displayed near the entrance. Figure 13 shows two example place settings, while Figure 14 shows screenshots from the prototype app.

Figure 13. Two place settings – plate, placemat, and menu

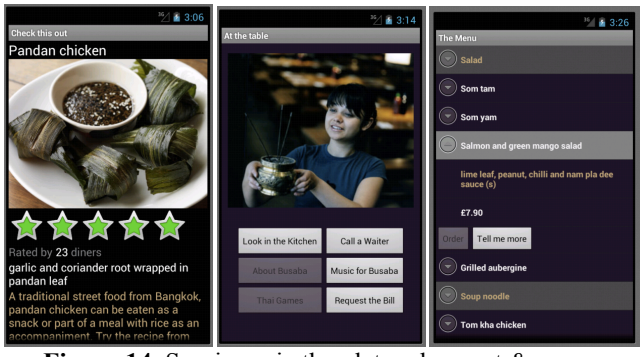

Figure 14. Services via the plate, placemat & menu

In summary, prototyping with Busaba highlighted the potential for deploying patterns across a range of tableware, not just on the ceramics themselves, as well as out into the

wider restaurant. It also revealed the challenge of making appropriate associations between digital services and the locations of patterns, as well as the potential of interacting by zooming into and out of a pattern.

DISCUSSION: FROM CODES TO PATTERNS

We first articulate the key lessons learned so far by considering how can we support designers in creating valid codes and creating rich patterns that contain many such codes. We then discuss the opportunities and challenges for future work on enabling the transition from codes to patterns, focusing on sketching potential applications of our approach and how people might interact with such patterns.

Key lessons for supporting designers

Rules, constraints and tools for creating valid codes

Our first key lesson is that designers quickly learn how to create workable designs from a small set of topological drawing rules. The approach of drawing patterns from scratch appears to fit their existing skills and enables them to take inspiration from variety of existing designs. However, setting the rules is only the first step; it is then necessary to introduce additional constraints to ensure reliability for a given application in a given setting.

Many of the rules and constraints affect the structure of motifs in a pattern, and while this can affect the aesthetic, our study suggests that designers can be very creative at working around them. Others, such as a rectangular boundary area, appeared to have a strong 'emotional' affect on the design. Minimum line thickness and spacing proved to be an on-going battleground, often being fixed during debugging and clearly frustrating some designers. This may be because we were asking them to work on relatively small-scale designs – their responses may have been different if designing for large surfaces. Equally, coarse lines could be part of a strong aesthetic in some cases. This said, minimum line thickness in relation to the scale of the image feels like a significant constraint and mitigating it should be priority for future technology development.

We also leaned many other small but useful practical lessons in how to support our designers: it is important to define a shared language (blobs and regions); a library of example problems helps learning; and good debugging tools on mobile phones are essential. While we asked our designers to work with traditional pen and paper, there is clear potential for computer-based drawing tools. A particular challenge here would be to support the sketch-first approach to design, taking a sketch and automatically suggesting ways in which it may be adapted to create a valid motif or pattern.

Creating aesthetically rich patterns

Being able to design valid visual codes is a necessary but not sufficient condition for making interesting patterns. The second key lesson from our study therefore lies in understanding how designers set about creating aesthetically rich patterns once they have mastered the underlying rules and constraints. Our study revealed how designers adopted various strategies for enriching designs:

- They **embellished** designs by extending their lines to introduce complexity but without adding new regions or blobs. They realised that solid shaded regions would appear only as lines in the topology read by the system.
- They introduced **additional elements** into the pattern that appeared to be significant to the human eye, but were actually invisible to the recognition system due to being disconnected from other recognisable structures.
- They exploited the (partial) colour-blindness of the technology by **colouring the pattern** in ways that were meaningful to a human, but invisible to the system.

In creatively exploiting the d-touch rules in these ways, designers are applying a much deeper principle, one that we believe is fundamental to designing aesthetically rich interactive patterns. Our designers are naturally exploiting fundamental differences in the ways in which humans and computers perceive patterns in images. Designers are skilled – indeed trained – in the art of designing patterns to be seen by humans. One of their fundamental principles is the separation of *figure* (the essential form that is seen in an image) from *ground* (the rest) [23].

There are many techniques for separating the two. Of particular relevance here (and to HCI in general) is Gestalt psychology, which explains the interpretation of figure in terms of principles such as proximity, similarity, symmetry, continuity and closure of the visual elements in an image [23]. The designs shown in Figure 9 exploit these principles in various ways to make us see a particular pattern from a series of marks on a page. The recognition technology also separates figure from ground, but in a very different way, by strictly applying the d-touch rules. This difference between the human and system perception of what is figure provides the 'creative wiggle room' for hiding visual codes within patterns. For example, the Gestalt principle of closure tells us that a human may perceive shapes whose boundaries are broken as figure, whereas our system will not unless their lines are completely joined.

These differences between human and machine vision can be a source of creative opportunity as we have noted, but can also be a problem. Shadows are a persistent challenge for our recognition technology, often appearing as large solid back regions to the computer, while humans learn to push them into the ground rather than seeing them as figure. Thus, designers may find it naturally difficult to reason about their impact unless they are explicitly made noticeable.

The significant implication of this discussion is that designers need to appreciate how both humans and computers perceive patterns if they are to creatively enrich them. The designer needs to bridge between the two worlds, creating designs that exploit the differences between them while also being reliable. We suggest that this is easily possible in the case of d-touch because the operation of the vision system can be expressed through a simple set of drawing rules that can be communicated to

designers. By implication, other vision approaches that might replace d-touch will need to be similarly explainable in terms of a set of rules that designers can understand in order to creatively bend. While it may sometimes be good for computer systems to work transparently 'as if by magic' for end users, designers must know how the magic works. A further implication is the need for debugging tools to directly reveal to designers how the vision system 'sees' the pattern, e.g., by highlighting shadows.

Finally, we have seen how designers created motifs that could be easily modified to create different codes and then repeated within larger patterns, either for reasons of redundancy or to support interaction by panning and zooming (e.g., the Busaba menu). The computer design tools that we proposed earlier should also support the adaption and repetition of motifs to create patterns.

Future research directions

Our approach enables a range of exciting applications from enhancing the dining experience and customer loyalty in restaurants such as Busaba, to associating personal memories and stories with valuable ceramics (e.g., a family dining set that is handed down between generations), to being able to interrogate wallpapers, textiles and decorated surfaces to find out about their designers, histories and sources. At the same time it raises opportunities and challenges

New kinds of interactions

An interesting avenue to explore is what kinds of new interactions will become possible with the transition from codes to patterns. While we had initially placed multiple visual codes into patterns for reasons of reliability through redundancy, our study suggests other possibilities. The Busaba menu incorporated a simple example of a zooming interaction, while designs such as those shown in Figure 12 point towards patterns that tell stories, much like the traditional Willow Pattern. We can generalise from these to imagine how extended patterns might contain many codes, enabling users to interact by panning and zooming.

Figure 14. Tiling a pattern of codes

By way of a simple example, Figure 14 shows a set of ceramic tiles decorated with a floral design. Each flower corresponds to a particular visual code, labelled A or B. In this example, each tile is decorated by two flowers with the same code for redundancy. However, the flowers on different tiles can yield different codes. Our current mobile app can read this pattern on up to four tiles at a time, enabling the user to read combinations of codes by both panning and zooming across a tiled surface.

Interacting with the invisible

The possibility of richer interactions with ever-more complex patterns, each of which may contain many codes, raises the question of how users will know what to do. The challenge of interacting with invisible sensing systems has been discussed previously in HCI [2], raising questions such as how does a user address the system? How do they know it is attending to them? How do they effect meaningful action, be sure that it has done the right thing, or avoid mistakes? In the case of interactive patterns, how will they know which patterns are interactive? Where in the pattern they should be pointing a camera? How should they move the camera, and what might they expect as a result? Addressing such questions in detail is beyond our scope. However, we briefly outline some possible approaches.

First, we might use the context of the pattern to guide interaction. The function or meaning of the patterned object, in its local environment, might simply suggest appropriate interactions. This is the approach attempted in our Busaba prototype, where menu patterns are associated with menu information and so forth.

Second, we can add cues into the pattern itself while trying to retain its overall aesthetic. This might range from accentuating regions with borders or colours to more figurative patterns such as those by designer 5 in Figure 9, which suggest interactional stories. In other words, we can ask the designer to walk the line between sufficiently camouflaging the codes so as to create an aesthetic design, while subtly revealing cues so as to guide users.

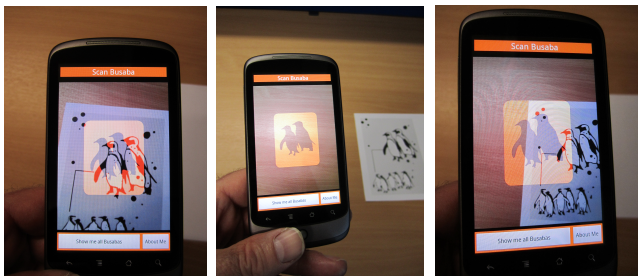

Figure 15. Use of cue on phone to suggest shape of code

Third, we can provide additional cues on the interaction device, in our case the mobile phone. Figure 15 shows a simple example of overlaying the scan window on the phone with a template that shows the user the shape of the motif they are searching for. A local environment might provide downloadable templates for current patterns in use. This strategy has the benefit of preserving the integrity of the pattern while being able to vary levels of support, for example scaffolding users while they learn to interact.

This last point raises the further question – to whom is a code visible? We have argued that designers require a different understanding of patterns and codes from users. The issue of whether to place interactional cues within the

pattern or on the mobile device raises the question of whether we should further separate users into 'participants' who interact with the code and 'unwitting bystanders' who experience the code in an everyday sense, but who may be ignorant of interactions [20]. The question of visibility then requires us to systematically consider the viewpoints of the various entities that might see it: participants, bystanders, designers and of course, the system itself.

CONCLUSION

We have explored the idea of moving away from designing individual visual codes towards creating complex interactive patterns that embed multiple codes within them and that might potentially decorate a wide variety of surfaces. Through an iterative prototyping process involving ceramic designers, a restaurant and technologists, we have been able to explore how such patterns can be created in practice. In particular, we have documented the ways in which designers set about creating patterns, by first learning the various rules and constraints of the technology, and then creatively exploiting them to extend and embellish patterns and hide them within backgrounds. We have argued that in so doing, designers are exploiting the differences in how humans and the system construct patterns from images, carefully managing which parts of the pattern are figure and which are ground, to both parties.

Our study also shows that recognising how designers work with such a technology enables us to extend it to better meet their needs. One possibility is to build drawing tools that enable designers to create such patterns, using structure-first or sketch-first approaches and including features for adapting, repeating, and debugging patterns. More theoretically, we would argue a case for opening up the rules in computer vision technologies so that designers can develop creative strategies that bridge between the two worlds of human and system perception.

ACKNOWLEDGEMENTS

This work was funded by RCUK through the Horizon Digital Economy Research grant (EP/G065802/1) and by EPSRC through Dream Fellowship award EP/J005215/1.

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