A Colour Alphabet and the Limits of Colour Coding

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Summary

This paper describes a series of studies designed to investigate the possible limits to the number of different colours that can be used in a colour code and the relative merits of colours and shapes for communicating information. The studies took their particular form in response to an observation by Rudolf Arnheim that an alphabet of 26 colours would be unusable. It was found that a text, with letters represented by coloured rectangles, can be read, first with the help of a key and then without. The colour alphabet, tested in competition with other alphabets made up of unfamiliar shapes and faces, was read more quickly than the others. Speed of reading was only matched with an alphabet made up of shapes that were familiar and nameable. Colours are most helpful for quick identification and for clarifying complex information, but where more than 26 distinctions must be made colours must be supplemented by shapes, typically in the form of letters and numbers.

Introduction

This paper is an elaboration, with some new material, of the paper presented at the 11th Congress of the International Colour Association (AIC) in Sydney, Australia [1]. The paper reflects an on-going interest in problems of colour coding and the ways in which colours and shapes can be used for communicating information. The main focus of the paper is on ways to determine the maximum number of different colours that can be used in a colour code without risk of confusion.

The number of different colours that can be used in a colour code will be greater for people with normal colour vision than for those without. While some reference will be made to the limitations experienced by people with defective colour vision, the discussion will be concerned mainly with problems of colour coding for people with normal colour vision.

In the first section, some of the problems associated with colour coding are illustrated by the colours used to identify the different routes on transport maps. There are different approaches to the problem of selecting colour sets for colour codes. One approach is to work within a chosen colour space and take a series of points within that space as far apart from each other as possible. Another approach is to use colour naming as a means of generating a suitable range of colours. A benchmark for colour coding is the set of 22 colours of maximum contrast proposed by Kenneth Kelly in 1965 [2].

Next, there is an account of the series of studies that were conducted to investigate the

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relative ease with which a text can be read when the letters are represented by colours or by unfamiliar shapes. A key to the colours and shapes was provided. The studies took their particular form as a response to a claim by Rudolf Arnheim that an alphabet of 26 colours rather than shapes would be unusable [3]. It turned out that letters can be represented by colours and combined in a text that can be read. A surprise finding was that the colours were read more quickly than the shapes. The studies were also concerned with the palette of colours that should be used and the way that colours should be assigned to letters.

The findings from these studies led to a further study, described in the third section, to test the influence of simultaneous contrast on the ease with which colours can be identified. Simultaneous contrast comes into play on geological maps where the appearance of colours is affected by surrounding colours. Correct identification of colours from the key is more difficult as a result. The findings from this study led to a modification of the palette of colours used for the colour alphabet and to re-assignment of colours to letters. This modified alphabet was learned and a series of short poems were read without reference to a key. Reading time improved with practice but one or two mistakes were made with each poem. This suggests that 26 colours could be taken as a provisional limit to the number of different colours that can be used in a code. The suitability of the alphabet colours for colour coding is supported by their striking similarity to Kelly's colours of maximum contrast.

The studies revealed the importance of simplicity and contrast where objects need to be identified quickly and easily. Provided the number of colours does not exceed 26, colours can be identified more quickly than shapes. Shapes also need to be simple and very different from each other if they are to be identified quickly. And there were two other factors, revealed by the studies, that contribute to speed and ease of identification. Shapes can be identified more quickly if they are familiar and can be named. Colours are already familiar and identification of colours is also made easier if the colours can be named.

The relative strengths and weaknesses of colours and shapes for communicating information are evident on geological maps. Without colour the maps would be almost impossible to read but colours alone are not enough. The colour patterns reveal the broad distribution of the rocks, but there are more than 26 kinds of rock to be identified. Slightly different colours may be used but the difference is too subtle. In order to establish the identity of every kind of rock each colour area is also marked by a letter-number code. Colours give quick access to the big picture; for the fine detail reliance must be placed on shapes.

Colour Sets for Colour Coding

The colours used to identify the different routes on transport maps are a familiar example of colour coding.

Transport map problem

What is the largest number of different colours that can be used to identify the different routes on a transport map without risk of confusion? Colour coding of different routes in a system of public transport can be very helpful. Consider this scenario: a traveller, arriving at Gothenburg Central Station in Sweden, has to meet a friend in suburban Kålltorp. The traveller asks how to get to Kålltorp and is told, 'Take tram no.3, going east, to the end of the line. It is the blue route – the vivid blue, not the light blue which is route no.9.' The Gothenburg trams have their route numbers and destinations shown on coloured panels above the drivers' front windows. The

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colour on an approaching tram can be identified well before it is possible to read the number or the name of the tram's destination. The same colours are used for the tram routes as shown on the Gothenburg transport map. Not only do the different colours identify the different routes, they also make the map easier to read.

The task of selecting colours for identifying the different routes of the Gothenburg trams was described by Lars Sivik during the 1983 meeting of the International Colour Association [4]. Sivik's account of that task led to consideration of the criteria that should be used when choosing colours for coding purposes. It also led to speculation about the limits, in terms of the number of different colours used in a coding system, beyond which colour coding would break down.

Colour codes for the Gothenburg trams and other transport systems

The 1995 edition of the Gothenburg transport map shows nine tram routes [5]. The coloured route lines are presented on a grey background. The colours can be named: white, yellow, vivid blue, green, red, orange, brown, purple and light blue.

Since 1995, the tram routes have been further modified. Two new routes are shown on the map that is available online [6] and further expansion of the system is planned. The new route 10 is identified by yellow–green and route 11 by black. Colour naming could be used as a means of extending the colour code. Pink could be used for a future route 12. Light green and light purple are distinct from vivid green and vivid purple and could be added for future routes 13 and 14. Blue–green could be added for route 15. To make room for even further expansion it would be possible to make slight modifications to the identifying colours of established routes. Orange, brown and purple could each be split into two separate colours. Existing routes 6, 7 and 8 could now be yellow–orange, yellow–brown and red–purple which would allow for new routes 16, 17 and 18 to be identified by red–orange, red–brown and blue–purple. The past, current and possible future route colours for the Gothenburg trams are shown on the left of Figure 1 as the 'Gothenburg Palette'.

Next to the Gothenburg Palette are the identifying colours used for other transport systems which have several established routes. The orders of the colours have been rearranged for easier comparison. The colours were matched visually to those on printed maps for the Tokyo Subway [7], the Paris Metro and RER [8,9], the London and the South East Rail Service [10] the London Underground [11] and the Oyster rail services in London [12]. The Paris RER routes are express services to the airports and outlying towns and are represented on the map by broader lines than those for the Metro. Travellers can transfer between the RER and the Metro. In London, the new Oyster card will allow travellers to transfer between the London Underground and mainline routes. The Underground routes are represented on the map by single lines, the mainline routes by double lines. The mainline routes are identified by the terminus stations which they serve and are colour coded accordingly.

The comparison in Figure 1 shows how the Tokyo route colours could be more clearly differentiated. Three routes are identified by similar reds which could be confused. Two of these could be modified to match the red–orange and red–purple of the Gothenburg Palette. Two blues that are similar are used on the Paris map for RER route B and Metro route 13. These could also be made more distinct if one were made a lighter blue, but the potential confusion is avoided because they are differentiated by shape – the route lines are shown in different widths. Shape differentiation also overcomes several potential confusions between the colours used for the routes on the London Oyster map where single lines are used for the London Underground routes and double lines for the routes serving the mainline termini.

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Figure 1 Colour codes for representing the different routes on transport maps

It might be possible to find alternative colours for the London termini so that shape differentiation were no longer necessary on the London Oyster map and all 24 routes were clearly differentiated by colour alone. The Paris Metro/RER system has some colours (for routes 3, 12 and 14) that have no clear equivalent in the Gothenburg Palette but which are still easily differentiated. This points to ways in which the range of colours could be extended in a solution to the transport map problem which might then be applied for London. A usable colour code with 24 colours might be possible. However, if the planners of the Oyster system had decided to identify the mainline routes as they are on the London and the South East Rail Services map they would have needed 19 colours for the mainline routes to be combined with the 13 well established route colours of the London Underground. Several of the Underground colours have confusable equivalents on the London and the South East Rail Services map as can be seen in Figure 1. A range of 32 colours would be needed. It seems unlikely that a solution to the transport map problem would be such a large number.

Colours of maximum contrast

Identifying the different routes on a transport map is one of many possible applications for a colour code. In a more general discussion of colour coding Robert Carter and Ellen Carter

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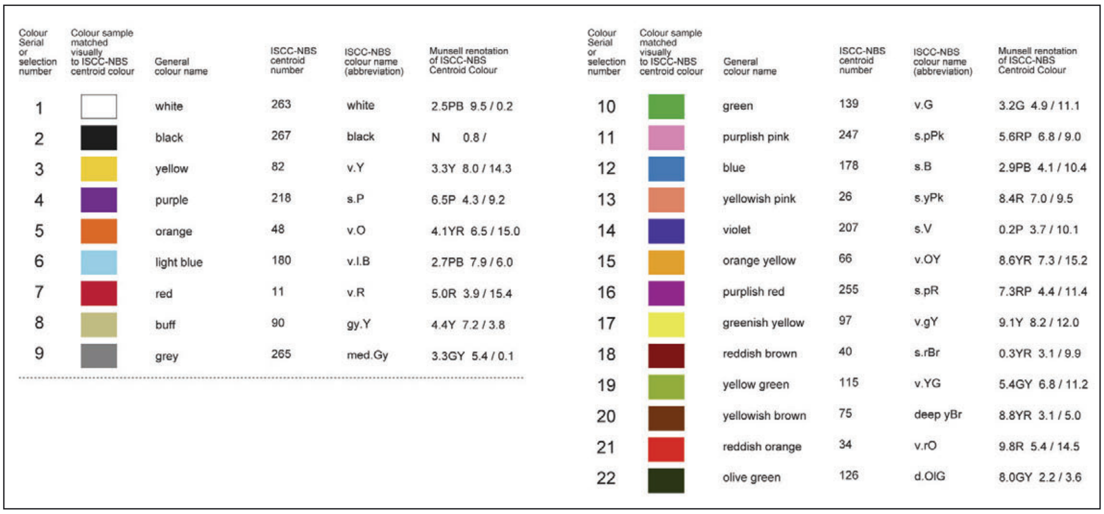
discuss problems of choosing colour sets that will be most effective for communicating information in a given situation [13]. They also pose the question, 'What is the maximum number of colours that can be used?'

In response to requests for sets of colours that would be as different from each other as possible for purposes of colour coding, Kenneth Kelly proposed a sequence of colours from which it would be possible to select up to 22 colours of maximum contrast [2]. Kelly made use of the Inter-Society Color Council and National Bureau of Standards (ISCC-NBS) method of designating colours [14] and selected his colours from the ISCC-NBS Centroid Color Charts [15]. The colours are listed in a table together with general colour names, their ISCC-NBS Centroid numbers, their ISCC-NBS colour name abbreviations and Munsell notations. Kelly's list, with colour samples matched visually to the ISCC-NBS centroid colours, is shown in Figure 2.



Colour Serial or selection number	Colour sample matched visually to ISCC-NBS centroid colour	General colour name	ISCC-NBS centroid number	ISCC-NBS colour name (abbreviation)	Munsell renotation of ISCC-NBS Centroid Colour
1		white	263	white	2.5PB 9.5 / 0.2
2		black	267	black	N 0.8 /
3		yellow	82	v.Y	3.3Y 8.0 / 14.3
4		purple	218	s.P	6.5P 4.3 / 9.2
5		orange	48	v.O	4.1YR 6.5 / 15.0
6		light blue	180	v.l.B	2.7PB 7.9 / 6.0
7		red	11	v.R	5.0R 3.9 / 15.4
8		buff	90	gy.Y	4.4Y 7.2 / 3.8
9		grey	265	med.Gy	3.3GY 5.4 / 0.1
10		green	139	v.G	3.2G 4.9 / 11.1
11		purplish pink	247	s.pPk	5.6RP 6.8 / 9.0
12		blue	178	s.B	2.9PB 4.1 / 10.4
13		yellowish pink	26	s.yPk	8.4R 7.0 / 9.5
14		violet	207	s.V	0.2P 3.7 / 10.1
15		orange yellow	66	v.OY	8.6YR 7.3 / 15.2
16		purplish red	255	s.pR	7.3RP 4.4 / 11.4
17		greenish yellow	97	v.gY	9.1Y 8.2 / 12.0
18		reddish brown	40	s.rBr	0.3YR 3.1 / 9.9
19		yellow green	115	v.YG	5.4GY 6.8 / 11.2
20		yellowish brown	75	deep yBr	8.8YR 3.1 / 5.0
21		reddish orange	34	v.rO	9.8R 5.4 / 14.5
22		olive green	126	d.OlG	8.0GY 2.2 / 3.6

Figure 2 Kelly's 22 colours of maximum contrast

The order of colours in Kelly's list was planned so that there would be maximum contrast between colours in a set if the required number of colours were always selected in order from the top. So a set of five colours should be white, black, yellow, purple and orange. And if seven colours were required, light blue and red should be added. Kelly took care of the needs of people with defective colour vision. The first nine colours would be maximally different for such people as well as for people with normal vision. These nine colours are also readily distinguishable by colour name. The dotted line in Figure 2 separates these from the other colours on the list.

Carter and Carter [13] make reference to Kelly's work and verify his assumption that the ease with which two colours can be discriminated depends on how far apart the colours are in colour space. From the colour spaces available at the time they chose CIE $L^*u^*v^*$ as most appropriate for their study. They recognised that the key to their problem was to establish the smallest degree of difference between two colours that would still allow people to discriminate the colours with acceptable ease. They found that people's ability to identify colours correctly diminished rapidly when the distance between colours was less than 40 CIE $L^*u^*v^*$ units. They provide a rough answer to their own question about the maximum number of usable colours: their Table 1 shows that colours in a set of 25 could all be separated by at least 51.6 CIE $L^*u^*v^*$ units.

In a later study, Carter and Carter investigated the role of colour coding for rapid location of small symbols on electronic displays [16]. They show how ease and speed of location are influenced, in part, by the degree of difference between colours, but also by the size and

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luminance of the symbols in relation to the surround. In their earlier study [13], Carter and Carter propose an algorithm for establishing colour sets within CIE $L^*u^*v^*$ space. Building on the work of Carter and Carter, others have proposed algorithms for generating colour sets [17,18]. The ISCC set up Project Committee 54 with the intention of bringing Kelly's work up to date [19]. However, the committee decided that, for what they were trying to do, they could not improve on Kelly's set of colours [20]. Robert Carter and Rafael Huertas have investigated the use of other colour spaces and colour difference metrics for generating colour sets [21]. They also refer to an alternative approach, investigated by Smallman and Boynton, whereby a colour code could be based on colour name concepts.

Colour naming and basic colour terms

The concept of 'basic colour terms' was introduced by Brent Berlin and Paul Kay in their landmark study which was published in 1969 [22]. Berlin and Kay mapped the basic terms of 20 languages on an array of 329 colours from the Munsell colour order system. They claim that 'a total universal inventory of exactly eleven basic colour categories exists from which the eleven or fewer basic colour terms of any given language are always drawn.' They list the basic colour terms for English as: white, black, red, green, yellow, blue, brown, purple, pink, orange and grey. Participants in their study had indicated the range of colours which they would describe by each name and also pinpointed the best, most typical example of each.

Some colour names are mapped onto a much larger range of different colours than other colour names. This means that it is possible to make additional distinctions such as that between light and vivid blue as for the Gothenburg tram colours. Further distinctions can be made by using composite names such as yellow–green and blue–green. While the difference in appearance between the colours may be the key to a successful colour code, the naming structure, as mapped by Berlin and Kay, could be used as a starting point. This was the approach used for the Gothenburg Palette and it is surely an advantage if the colours in a code can also be named. This is clear from the example given above of a traveller arriving in Gothenburg and needing to get to Kålltorp.

Relating colour names to colour space

The number of colours that can be named by the ISCC-NBS method of designating colours, as used by Kelly, is 267. This is level three of the 'Universal Color Language' (UCL), with its six levels of increasing precision. The UCL is published by the US Department of Commerce [14]. Munsell colour space [23] is subdivided into smaller and smaller blocks, each block containing a range of colours that are identified by the same name. The ISCC-NBS centroid colours represent the focal colours for the 267 blocks at level three. At level one, with 13 colours, the blocks are much larger and the naming of the range of colours within each block is much less precise. There are 29 colours at level two. At level four are the thousand or more colours in a colour order system such as Munsell. Interpolation between colour standards, and then the use of measuring instruments, increases the number of colours to about 500 000 at level five and 5000 000 at level six. A Munsell notation is provided for each colour in the ISCC-NBS Centroid Color Charts. The focal colours for levels one and two of the UCL, matched visually to the designated ISCC-NBS centroid colours, are shown in Figure 3. The level one colours are represented by circles, the colours added at level two are represented by diamonds. The colours are arranged approximately according to their Munsell hues and lightness values on the gird used by Berlin and Kay to record the way that colour names were mapped. The shaded

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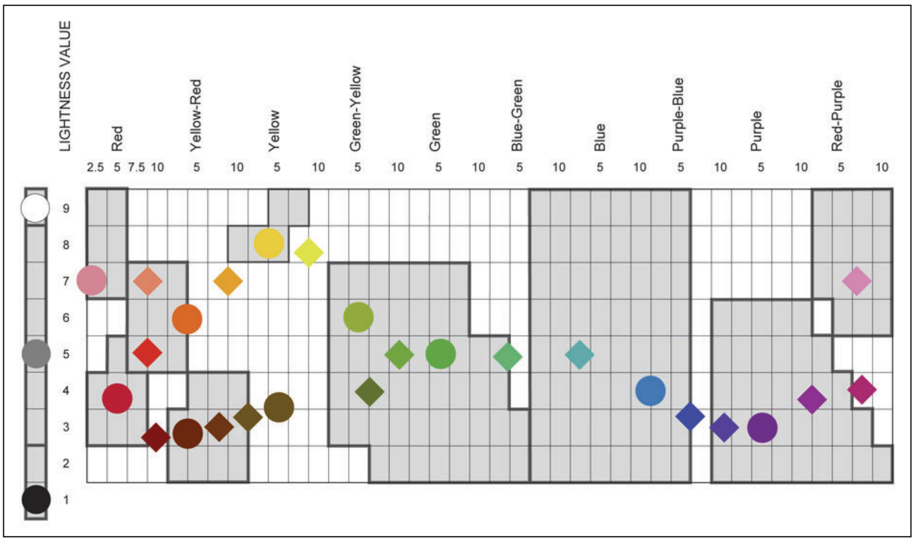

Figure 3 Focal colours for levels one and two of the Universal Color Language arranged according to Munsell hue and lightness value; the shaded areas indicate the range of colours that would be named by the basic colour terms: white, grey, black, pink, red, orange, brown, yellow, green, blue, purple

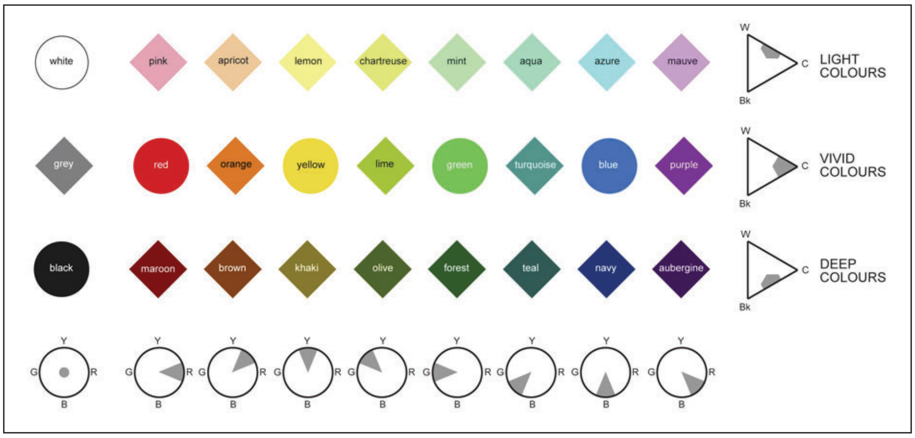

Figure 4 Focal colours for levels one and two of the Colour Zones system arranged according to hue and nuance

areas in Figure 3 represent the range of colours that would be described by each colour name as recorded by English speaking participants in the Berlin and Kay study: white, grey, black, pink, red, orange, brown, yellow, green, blue and purple.

The 29 colours at level two of the UCL could be considered as a basis for a colour code. However, some of the colours might be too similar for confident identification and there are also areas of colour space that are not well represented.

A simpler alternative to the first three levels of the UCL is the three-level system of Colour Zones [24,25]. The structural framework for the zones is that of the Natural Color System (NCS) [26]. The reference points for the NCS, and for the Colour Zones, are the Elementary Colours (ürfarben) proposed by Ewald Hering: Yellow, Red, Blue, Green, White and Black [27]. These are not physical samples but ideas such as a yellow that is neither reddish, greenish, blackish nor whitish. The appearance of any colour can be described in terms of its relative resemblance to these conceptual reference points. So the ISCC-NBS centroid colour 'Vivid Yellow Green' would be described as 50% yellowish, 50% greenish, 10% whitish and 10% blackish. Colour Zones are subdivisions of the NCS colour space. Each zone contains a range of similar colours with a focal colour as a reference point at the centre of the zone. Hering's

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Elementary Colours are the focal points for the six zones at level one. Further subdivisions provide 27 zones at level two and 165 zones at level three.

The colours from levels one and two of the Colour Zones system are shown in Figure 4. The Elementary Colours, at level one, are represented by circles and the colours added at level two by diamonds. The colour names, selected after extensive research, should be generally acceptable and can be defended. The symbols below each column of colours indicate the hue zone to which the colours belong. The symbols to the right of each row of colours indicate the nuance zone.

The 27 colours at level two of the Colour Zones system could also be used as a basis for a colour code. They were tested as part of the colour alphabet project which is described in the next section.

Colour Alphabet Project

A palette of colours that represented a solution to the transport map problem would be of practical value for a number of situations which call for colour coding. This was one of the motivating considerations for a workshop which was conducted for members of the Colour Society of Australia in 2007. The workshop followed a morning of lectures on the topic 'colour as information'. The plan of the workshop was to investigate the transport map problem and also to test the relative merits of colours and shapes for communicating information. The activity took its particular form as a response to an observation by Rudolf Arnheim. In his book, *Art and Visual Perception* [3], Arnheim compares shape and colour for their power of discrimination:

> '... we acknowledge that shape lets us distinguish an almost infinite number of different individual objects. This is especially true for the thousands of human faces we can identify with considerable certainty on the basis of minute differences in shape. By objective measurement we can identify the fingerprints of one specific person among millions of others. But if we tried to construct an alphabet of 26 colours rather than shapes, we would find the system unusable. ... we are quite sensitive in distinguishing subtly different shades from one another, but when it comes to identifying a particular colour by memory or at some spatial distance from another, our power of discrimination is severely limited.'

In this argument in favour of shape, Arnheim could be accused of 'moving the goal posts'; shape and colour need to be compared on equal terms. If 'objective measurement' is allowed, the number of colours that could be discriminated by a spectrophotometer would also be in the millions as they are at level six of the UCL. But if things are to be identified 'by memory or at some spatial distance' the number would fall dramatically, whether it were colours, faces or fingerprints.

Rudolf Arnheim challenge

Participants in the workshop took up the 'Rudolf Arnheim challenge'. The aim was to see if it is possible to construct a usable alphabet of 26 colours. While it could not be claimed that a usable colour alphabet would represent a definitive answer to the transport map problem, such a palette of 26 colours could show how the Gothenburg Palette could be extended. It could also

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provide colours for identifying the mainline routes on the London Oyster map which would be distinct from the Underground route colours.

There were 28 participants in the workshop and two exercises. Participants were first given a sheet on which a palette of 76 colours had been printed in a square grid and a sheet with blank boxes next to the letters of the alphabet. The task for the participants was to choose, from this palette, a colour for each letter. They were to cut out coloured squares for the letters, and stick them down in the appropriate boxes.

The second task was to translate a poem which had been rendered in one of three new 'alphabets', which had been prepared before the workshop. One alphabet was made of colours, one of unfamiliar shapes, and the third of unfamiliar faces. In later studies, further tests were carried out with alphabets made up of different colours, shapes and faces.

Strategies for choosing colours for an alphabet

When the participants had completed the exercises, the colour alphabets they had proposed were displayed and the various strategies for selection were discussed. Some participants started with the colours and selected 26 that made a satisfying visual sequence. The colour order came first and the letters followed. However, most participants worked in the opposite direction. While it may be desirable that a colour alphabet be beautiful, it is more important that it be legible. There were two aspects to the task: what colours should be selected and how should the colours be assigned to particular letters.

For several participants, a key requirement was that the colours be as different from each other as possible. Colours that are maximally different from each other are most helpful in systems of coding. Participants in the workshop were not in a position to apply the kind of method used by Carter and Carter [13] and had to rely on their own judgements when choosing, from the printed squares, those colours that they considered to be maximally different from one another. One participant, Tony Marrion, made a point of sticking down colours next to the selected colours with which they might be confused.

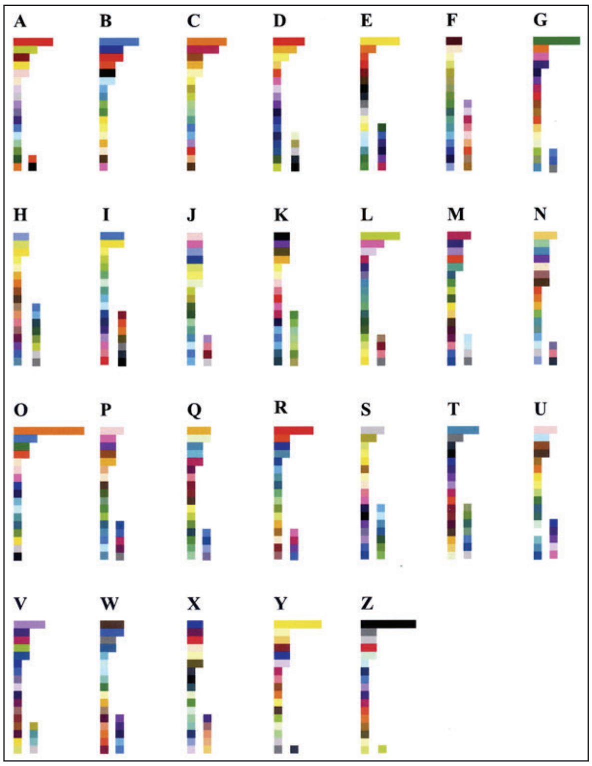

Figure 5 Colours to represent the letters of the alphabet chosen by participants in a workshop conducted for the Colour Society of Australia in 2007

There were many approaches to the problem of assigning colours to letters. Some participants looked for ways of grouping the letters as a basis for linking them to groups of colours. Many participants considered ways of distinguishing vowels and consonants such as using achromatic colours for the vowels. The colour choices were studied to see if there were any cases where a significant number of people had chosen the same colours for the same letters. The colours chosen for the letters are shown in Figure 5.

The association of particular colours with particular letters is known to be an experience of people with synaesthesia. Such people have cross-

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sensory experiences; they might ‘taste’ sounds or ‘hear’ smells. The experience of synaesthesia might be a good basis for the choice of colours for an alphabet if the associations of colours with letters were consistent for all letters, from person to person, but this does not always seem to be the case [28,29]. However, there is data to support some colour-letter connections. In a large-scale study of synaesthesia, Rich *et al*. showed how people with synaesthesia, and people without, link the eleven basic colour terms with letters of the alphabet [30]. People with and without synaesthesia share some strong associations: I is white; X is grey or black; Z is black; A and R are red; G is green; Y is yellow; B is blue; D is brown; V is purple; and P is pink. There are no strong associations shared by the two groups for orange. For those with synaesthesia it is J, for those without it is O.

Colour names

A striking feature of the data collected by Rich *et al*. is the link between colours and the initial letters of colour names, i.e. B for blue, R for red, etc. These colour–letter associations also feature in the choices made by participants in the workshop and there were other colour name associations: several chose lime green for L and turquoise for T. Some participants wrote down their colour names; one used the names of fruit and vegetables – apple, banana, carrot, etc. – and another, Joan Hodsdon, managed to find a name for every letter.

Being able to name the colours would surely be an advantage where colours need to be distinguished from one another and remembered. M D Vernon points out that ‘One of the obstacles to remembering colours, especially the intermediate shades, is the paucity of generally accepted colour names’ [31], and Ammon Shea argues for the value of a large vocabulary. Shea is a collector of words and has completed the eccentric task of reading all 20 volumes of the Oxford English Dictionary. He explains how his knowledge of words has increased his sensitivity to his surroundings, ‘If I know there is a word for something...I will stop and pay more attention to it’ [32].

Many of these strategies were used for the prototype alphabet which had been designed before the workshop: colours of maximum contrast; vowels separated from consonants by colour nuance; colours linked to names, etc. Pale colours were used for vowels so that words might have clearer colour patterns, much as the heraldic ‘rule of tincture’ leads to highly legible designs by ensuring that there is strong contrast of lightness values between elements [33]. In a coat of arms, a shape – such as a cross – can be a colour (red, blue, black, green, purple) or a metal (silver/white, gold/yellow) but the background must be from the other group. Colour can never be used on colour or metal on metal. In practice it turned out that the juxtapositions of letters in words is too varied for that particular strategy to be helpful.

Testing alphabets made of colours, unfamiliar shapes and unfamiliar faces

For the second task at the workshop, the participants were given a poem which had been rendered in one of three new ‘alphabets’. The poem was a nonsense poem containing all the letters of the alphabet. It was provided with a key to the alphabet and a sheet with blank spaces for writing down the words of the poem. For each alphabet there was a prize for the person who wrote out the poem first. The poem is shown in each of the alphabets, together with the key, in Figures 6, 7 and 8. The unfamiliar shapes used for the alphabet in Figure 7 are the ‘capital letters’ for ‘Dingbats’ which are available as a font on many computers. The faces for the alphabet in Figure 8 were isolated from a group photograph of staff and students at the Western Australian Institute of Technology taken in 1973.

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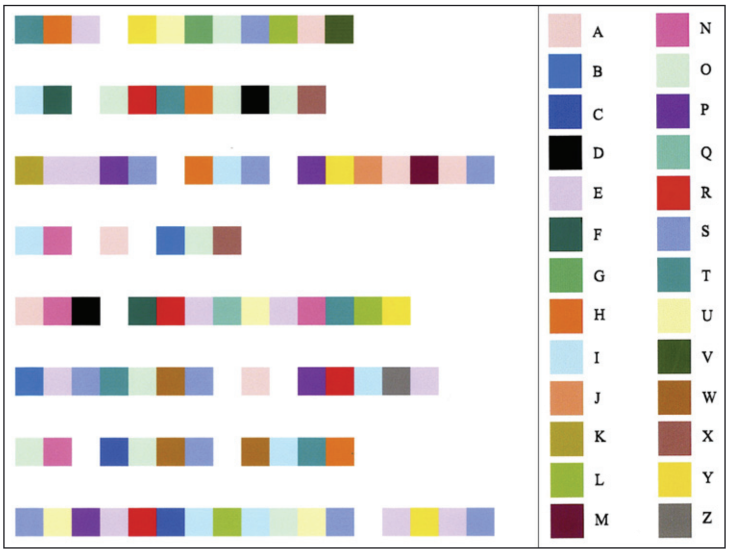

Figure 6 Nonsense poem with letters represented by colours

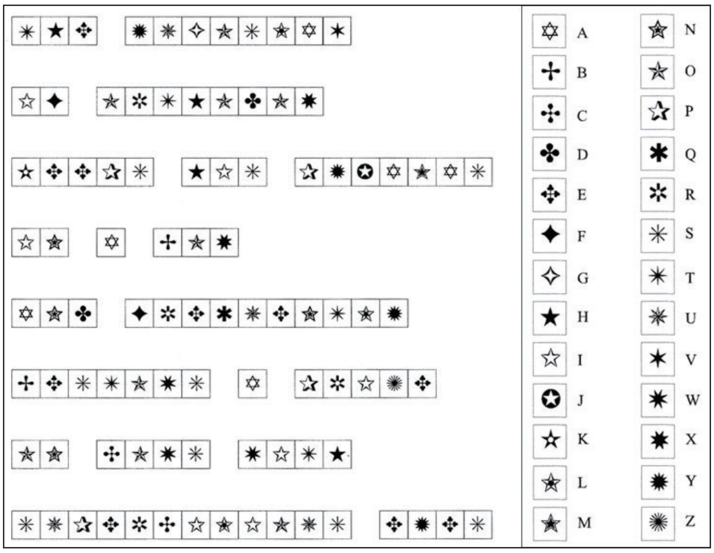

Figure 7 Nonsense poem with letters represented by shapes (Dingbats)

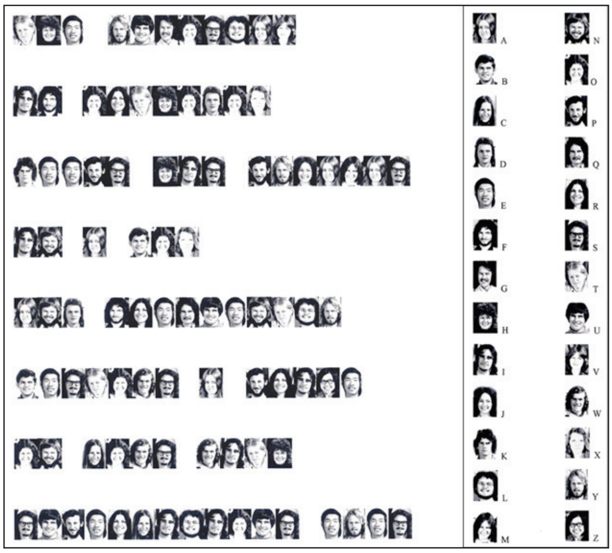

Figure 8 Nonsense poem with letters represented by faces isolated from a group photograph

This is the poem:

'THE YUGOSLAV
IF ORTHODOX
KEEPS HIS PYJAMAS
IN A BOX
AND FREQUENTLY
BESTOWS A PRIZE
ON COWS WITH
SUPERCILIOUS EYES'.

The participants at the workshop found it quite easy to read the poem printed in colours (Figure 6). So there was an answer for Arnheim – it does seem to be possible to construct an alphabet of 26 colours that is usable, if only in this limited sense. But there was a surprise: the colours were read more quickly than the shapes or the faces. All those who had been given the poem printed in colours had completed the task before any of those who were trying to read the faces.

During the discussion, people complained that the shapes (the Dingbats) (Figure 7) were too similar and that the faces were too small (Figure 8). So the next step was to find out whether these results were due to a natural superiority of colours for this kind of task or to the choice of those particular shapes and faces which might have given the colours an advantage. There was an opportunity for follow-up studies with two groups of first year students of Design at Curtin University of Technology. It was possible to test new alphabets of colours, shapes and faces.

Alphabets for follow-up studies

It was a striking coincidence that there are 27 colours in the Colour Zones system at level two, one of which is white. With 26 colours for the 26 letters on a white background, it was possible to test the potential usefulness of the Colour Zones palette for a colour code. The follow-up studies also made it possible to see if an arbitrary assignment of colours to letters would make any difference to ease of legibility. The colour alphabet used for the follow-up studies is shown in Figure 9.

For the follow-up studies four new sentences were composed, each containing all the letters of the alphabet. This made it possible for each student to try reading all three kinds of alphabet and it would be possible to compare an individual's performance in each task. The new sentences, with 61 or 62 letters, were shorter than the poem used at the workshop. This meant that the faces could be larger on the sheet of A4 paper. For the first group of students it was also decided to use a real but unfamiliar alphabet instead of the Dingbats. The Georgians, in Eastern Europe, use an alphabet that is quite unlike the more familiar Greek or Cyrillic alphabets. Georgian fonts can be downloaded from the Internet.

There were 43 students in the first group. The results were similar to those from the workshop, with colours being read most quickly. The potential usefulness of the Colour Zones palette for colour coding was supported by this result. It also appeared that, in this situation where reference could be made to a key, the arbitrary assignment of colours to letters had not affected ease of legibility.

Figure 9 Colours from the Colour Zones palette assigned to letters for the follow-up studies

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A more accurate record was kept of the times taken to read the sentence and write it down. The average times were: colours, 3 minutes 8 seconds; shapes (Georgian), 4 min 50 s; faces, 5 min 30 s. When these times were discussed, it was suggested that familiarity might have been a factor. It was pointed out that, while the shapes and faces were new to people, 'they already knew the colours'.

The project took on a new dimension: a challenge to create alphabets of shapes or faces that could be read as quickly as the colours. For the second group, of 55 students, two new alphabets were created. Movie stars were chosen for the alphabet of faces. Their faces are familiar and available for downloading from the Internet. A survey was conducted to find out which movie stars the students would recognise most easily. Two alphabets of movie stars were used. For one, the movie stars were assigned to letters which corresponded with the first letters of their surnames (Rowan Atkinson, Halle Berry, Tom Cruise, etc.). For the other, the most familiar movie stars were assigned to letters in an arbitrary way. (Copyright prevents publication of these alphabets.) For the shapes, reference was made to the results of an old study to find nameable shapes. This time it was also important for the shapes to be familiar; 26 shapes were needed that were simple and familiar with names beginning with each letter of the alphabet – arrow, bottle, cross, etc.

One of the new sentences, rendered in four different alphabets, is shown in Figure 10. The original alphabet of faces was used for the first group, but with the faces larger and separated by small gaps. The sentence is shown in Georgian at bottom left and in the new alphabet of shapes at bottom right.

Figure 10 Sentence with letters represented by colours, letters of the Georgian alphabet, faces and nameable shapes

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This is the sentence:

'WE NEVER
EXPECTED
TO QUIT
SMOKING
JUST BECAUSE
OF A HOLE
IN THE
OZONE LAYER'.

With the second group, the familiarity of shapes and faces did make a difference. The average time for reading the colours was similar to that for the first group but the shapes and faces were read much more quickly. The average times were: colours, 3 min 20 s (twelve seconds slower than the first group); shapes, 2 min 55 s (nearly two minutes quicker than the first group); faces, 4 min 39 s (nearly one minute quicker than the first group). In spite of the familiarity of the movie stars, that alphabet of faces still took significantly longer to read. One student made the telling comment, 'Too much information'.

With the new alphabet of shapes, it was finally possible to match the colours. The shapes were simple, clearly differentiated and familiar. Some students also realised that the initial letters of the shapes' names were the corresponding letters in the sentence. Since most shapes were easily named it was not necessary to spend time checking the key. One student took just 61 seconds to read the sentence. The correspondence between letters for the alphabet and the first letters of the movie-stars' surnames did not seem to help, perhaps because the connection was not immediately obvious. Nevertheless, the value of nameability was established with the shapes and this could be extended to colours. An alphabet of colours that had names, such as those proposed by some participants at the workshop, should be quicker to learn and easier to read.

The conclusion from the workshop and follow-up studies, therefore, was that there are four factors that contribute to quicker and easier reading: simplicity, contrast, familiarity and nameability.

Further Tests and Modifications to the Colour Alphabet

It was evident from the workshop and follow-up studies that the Colour Zones palette can be used to represent letters of the alphabet and that these colours can be put together to form words and sentences that can be read. However, there was no certainty that this was the optimum palette. It is an advantage to be able to name the colours but some colours in the palette appear quite similar. With colours juxtaposed to form words it seemed possible that the appearance of colours could be affected by the influence of neighbouring colours to such an extent that a colour forming part of a word might be mistaken for another colour from the palette with the result that the word would be misinterpreted.

Geological map problem

Colour coding is stretched beyond its limit on geological maps. The geology of an area can be very complex. To record the varied age and nature of the rocks, the Geological Survey of

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Western Australia required 97 different ways to mark the map [34]. These are shown in the key. Different colours are used but in some cases a textured pattern is superimposed on the colour and in all cases there is also an identifying letter–number code.

Without colour it would be extremely difficult to follow the intricate contours which separate areas of different rock, such as dolerite and granite. But there are five different greens for dolerite and five different pinks or pinkish reds for granite. To identify rocks of different age the greens and pinks are marked d1, d2, g1, g2, etc. Without this letter–number code it would not be possible to check from the map to the key and be confident that a particular area of pink represented granite that was over 3 billion years old (g1) or granite that was just over 2 billion years old (g3). The situation is aggravated by the phenomenon of simultaneous contrast: the g3 pink for 2 billion-year-old granite, when surrounded by the blue for siltstone, looks different from that g3 pink surrounded by the yellow for limestone and different again when surrounded by the white background of the key. A detail of the geological map of Western Australia, and part of the key, are shown in Figure 11.

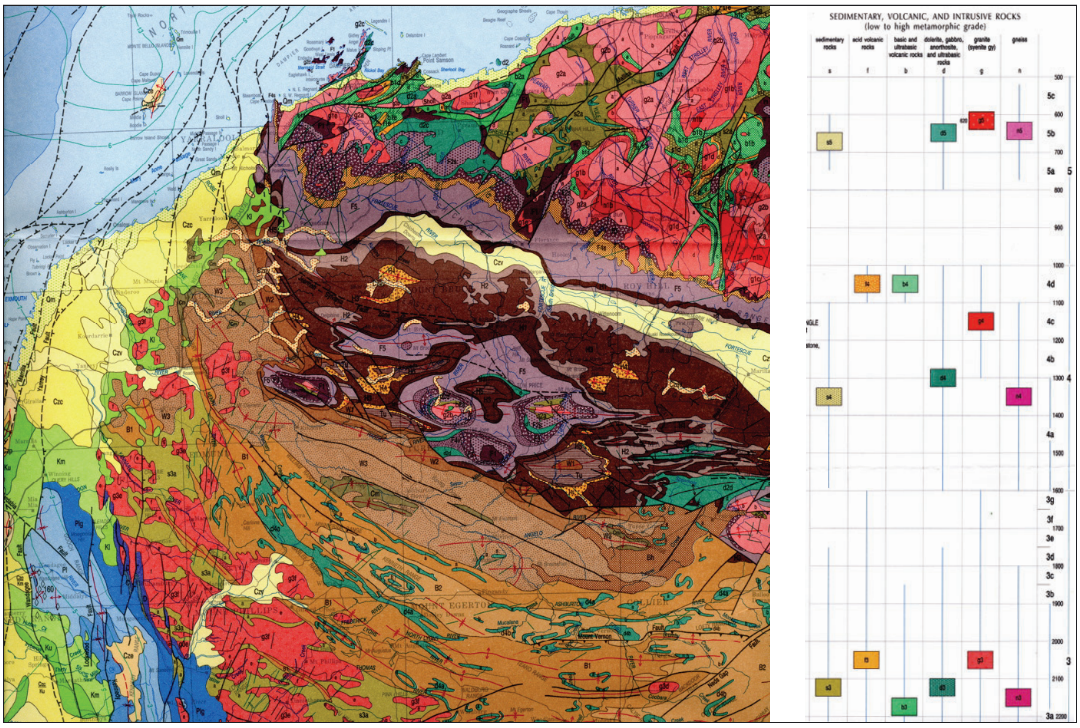

Figure 11 Detail of the geological map of Western Australia with part of the key (image courtesy of the Geological Survey of Western Australia, Department of Mines and Petroleum © State of Western Australia and reproduced with permission)

The geological map problem is more challenging than the transport map problem. On a transport map the background colour is generally uniform. On a geological map the background colours are constantly changing. Simultaneous contrast comes into play so that areas printed with the same ink formula (in that sense being the 'same colour') can appear different on different areas of the map and different again against the white background of the key.

Testing the colour zones palette as a potential colour key for a geological map

A new study was carried out, with 12 participants, to test the colours of the Colour Zones palette in a context that was similar to that of a geological map. There were 40 different

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colours, which included the Colour Zones colours, assigned by a random process to the squares in a 5 × 8 grid. The colours were given names as for girls and boys: Anne, Brad, Cora, Dick, etc. The names were put in a bowl and drawn out, one after the other, to determine the colours of the squares. Small rectangles of these colours were arranged, with their identifying names, as a key beside the grid. On each coloured square there was a figure – a letter, number or other symbol – in one of the Colour Zones colours. The same random process of drawing names out of a bowl was used to determine the colours of the figures. Since there were 40 squares but only 26 colours in the Colour Zones palette (excluding white) this meant that some colours were used for more than one figure. If the process led to the colour for the figure being the same as that for the square background a new name was drawn from the bowl. The task for the participants was to identify the colours of the figures and the square backgrounds by referring to the key. Three sheets were prepared which had the same sequence of background colours but different colours for the figures. One of these sheets is shown in Figure 12. The colours marked with a star in the key are the colours from the Colour Zones palette.

Figure 12 Sheet used to test people's ability to recognise colours under the influence of simultaneous contrast

Most people were able to identify the colours of the background squares. Eight of the twelve participants identified all the background colours correctly. Where confusions occurred, the colours involved were of the same or immediately neighbouring hues. The white background of the colours in the key makes them appear slightly darker than the 'same colours' in the squares, so Dora as the colour of the background to K could be confused with Dick in the key and Owen as the background to Q could be confused with Tara in the key. Where colours of neighbouring hues were confused they were of the same nuance and, typically, in the range of hues from blue to green. So, Faye was confused with Greg and Nora with Owen. These results can be seen in relation to the law of simultaneous contrast as formulated by M E Chevreul, 'In the case where the eye sees at the same time two contiguous colours, they will appear as dissimilar as possible, both in their optical composition and in the height of their tone' [35].

The influence of simultaneous contrast was much stronger for the figures. The participants

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studied all three sheets for a total of 120 coloured figures. The average number of errors was 13. Two participants identified all but three colours correctly; the least successful participant made 31 errors. In most cases the errors could be predicted from the laws of simultaneous contrast. Fred is the colour of the letter D, but four people saw it as Emma and one as Evan. In each case the lime green surround makes the D appear more bluish. Ivan is the colour of the letter G but four people saw it as Adam. The dark brown surround makes the G appear lighter. The letter X, which is Gina, is almost invisible against its background. The background colour, Fred, is more bluish and makes the X appear more yellowish. Ten people saw the X as Hugo. In a later section of his book, Chevreul explains how a grey figure, surrounded by a given colour, will appear tinged with the complementary of that colour. The colour of the number 9 is Sara but three people saw it as Dora.

Modifications to the colours for the alphabet

This study showed that the colours in the Colour Zones palette (see Figure 4) that were most commonly confused were those in the range of hues between Blue and Green. The study also showed that vivid colours are more easily identified than light or deep colours. The percentage averages for correct identification were: 93.5% for vivid colours, 90.3% for light colours and 85.0% for deep colours. This implies that the legibility of the colour alphabet could be improved by departing from strict adherence to the Colour Zones structure, with its eight focal colours in each of the vivid, light and deep nuance zones.

The Colour Zones palette can be compared with the colour codes illustrated in Figure 1 which all feature predominantly vivid colours, typically in ten different hues. However, it is not necessary to abandon the Colour Zones structure as a point of reference. A claimed advantage of the Colour Zones system is that it is imprecise and flexible – a colour does not have to be the focal colour of a zone in order to represent that zone. Each zone contains a range of colours. A yellow–orange and a red–orange would be at the edges of the Orange zone but still within that zone. In the same way, a red–purple and a blue–purple would each be within the Purple zone. Furthermore, where a colour is the sole representative of a zone it can be moved a short way from the focal point of that zone in order to differentiate it more clearly from a colour in a neighbouring zone.

These considerations led to a revision of the palette for the colour alphabet. The light and deep blue–greens were removed and the vivid orange and vivid purple were each sub-divided. There are now seven light colours, seven deep colours, ten vivid colours, grey and black.

Assigning colours to letters and naming the colours

The value of names had been established so the colour chosen for each letter should have a name beginning with that letter. However, there was another consideration that could lead to conflict. During discussions about how best to assign colours to letters, it was suggested that the colours that were easiest to identify should be assigned to the letters that occur most frequently. In some cases there was no credible name for a given colour that might be the best choice for a given letter.

An indication of how frequently letters occur can be derived from the numbers on the letter tiles for the board game Scrabble [36]. Letters that occur very frequently, such as E, R and T, have the number ‘1’ while the least common letters, Q and Z, have the number ‘10’. Another source of information is the website *AskOxford* produced by Oxford University Press [37]. An answer to the question about letter frequency is provided in the form of a table. This shows how

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often each letter appears in a list of all the words in the *Concise Oxford Dictionary*. 11.16% of the letters are the letter E while only 0.196% are the letter Q. In order of frequency the letters are: E, A, R, I, O, T, N, S, L, C, U, D, P, M, H, G, B, F, Y, W, K, V, X, Z, J, Q.

An advantage of the Colour Zones system is that the colours can be considered to be ‘naturally nameable’ in that they are clearly related to shared concepts of yellowness, redness, blueness, greenness, whiteness and blackness. A colour either corresponds to one of the elementary colours, such as Yellow, or it bears equal resemblance to such colours. So Orange is equally yellowish and reddish and Pink is equally reddish and whitish. Also, the Colour Zones already have names that can be justified by the research. It was decided that these names should be used as far as possible, but alternative names were needed where more than one name had the same initial letter. It was also decided that use should be made of the findings of Rich *et al*. So B should be blue rather than brown or black, G should be green rather than grey, R should be red and Y should be yellow. A number of alternatives were tested.

‘A’ is the initial letter for four of the Colour Zones names: apricot, azure, aqua and aubergine. ‘A’ is the second most commonly occurring letter, so it needed to be represented by a colour that would be easily identified. Aqua, as a light blue–green, is no longer included in the palette. Apricot and aubergine are names for colours that were not well identified in the study described above. Azure is the name for light blue in the Colour Zones system and light blue was identified by all participants in the study. However, an alternative name for that colour is sky and S is another commonly occurring letter. Light blue has been assigned to the letter S. Light purple (mauve) was another colour that was identified by all participants in the study and there is a suitable name for that colour beginning with the letter A: amethyst.

Black was another colour that was correctly identified by all participants in the study, but from the findings of Rich *et al.* black is most commonly associated with the letter Z. A quarter of all the participants in the original workshop had chosen black for the letter Z, while only one had chosen black for the letter E. Nevertheless, the letter E is now black. Ease of legibility was the overriding criterion and there is a suitable name for black which begins with the letter E: ebony.

A consequence of having two colours in the orange zone and two in the purple zone was that neither colour name should be used. Two new names were needed for orange and two for purple. The letter P might have been purple but is now pink. With one exception all the colour names can be found among the 7500 names listed in the *Color Names Dictionary* published by the US Department of Commerce [14]. The exception is ‘quagmire’ which is defined in the *Concise Oxford Dictionary* as ‘a soft boggy or marshy area that gives way underfoot’ [38]. This seems to be a suitable name for a colour that is greenish, yellowish and blackish. The revised palette, with colour names and RGB values, is shown in Figure 13. No reference was made to

Amethyst	**A**	240 - 163 - 255	Jade	**J**	148 - 255 - 181	Sky	**S**	94 - 241 - 242
Blue	**B**	0 - 117 - 220	Khaki	**K**	143 - 124 - 0	Turquoise	**T**	0 - 153 - 143
Caramel	**C**	153 - 63 - 0	Lime	**L**	157 - 204 - 0	Uranium	**U**	224 - 255 - 102
Damson	**D**	76 - 0 - 92	Mallow	**M**	194 - 0 - 136	Violet	**V**	116 - 10 - 255
Ebony	**E**	25 - 25 - 25	Navy	**N**	0 - 51 - 128	Wine	**W**	153 - 0 - 0
Forest	**F**	0 - 92 - 49	Orpiment	**O**	255 - 164 - 5	Xanthin	**X**	255 - 255 - 128
Green	**G**	43 - 206 - 72	Pink	**P**	255 - 168 - 187	Yellow	**Y**	255 - 225 - 0
Honeydew	**H**	255 - 204 - 153	Quagmire	**Q**	66 - 102 - 0	Zinnia	**Z**	255 - 80 - 5
Iron	**I**	128 - 128 - 128	Red	**R**	255 - 0 - 16			

Figure 13 Alphabet colours with names and RGB values as revised following the study of the influence of simultaneous contrast

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the names chosen for alphabet colours by Joan Hodsdon at the original workshop, but it was interesting to see, after the event, that ten of her names feature among those selected for the final version of the colour alphabet: blue, damson, green, jade, khaki, pink, red, violet, wine and yellow.

Chromacons

The next step was to learn the colour alphabet and see if it would be possible to read a text without the help of a key. Peter Kovesi, a participant in the original workshop, suggested that the coloured rectangles representing the letters should have a name. They are now called 'chromacons'. Kovesi wrote a simple computer program which enables him to convert ordinary text into chromacons. The RGB values for the chromacons had to be fine-tuned so that they would be sufficiently distinct to be read on computer screens as well as in print.

The words in chromacons are like medal ribbons. The experience of reading a text in chromacons was similar to that of reading words in Russian after first learning the Cyrillic alphabet. At first, each letter had to be identified one by one but it began to be possible to recognise complete words by their medal-ribbon patterns. In the first trial, using the earlier colour alphabet, Kovesi chose a sonnet by Shakespeare, rendered it in chromacons and sent it as an attachment to an email. It took 13 min and 45 s to read and write down the 14 lines of *Sonnet LIX*. The revised colour alphabet was easier to read. Kovesi sent six more sonnets and these were read one after the other. Times improved from 9 min 53 s for the first of these sonnets to 7 min 31 s for the last. No doubt reading times would improve even further with more practice. In the reading of each sonnet, one or two mistakes were made. The confusions were confusions of memory rather than perception in all cases but one. The blackish red (wine) for W was confused with the brown (caramel) for C. *Sonnet CXI*, that was read in 7 min 31 s, is shown in Figure 14.

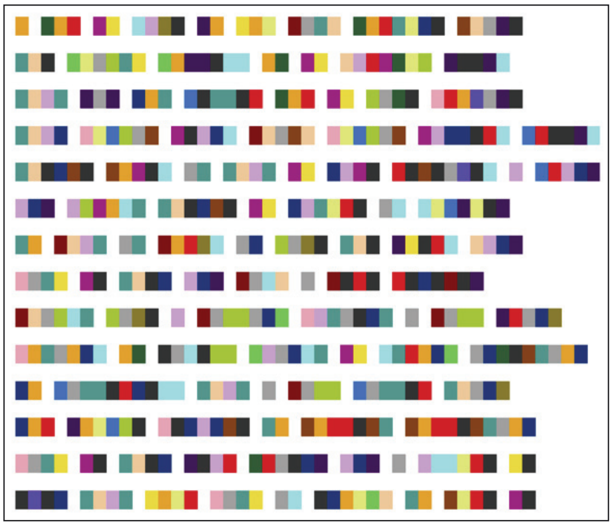

Figure 14 Shakespeare's *Sonnet CXI* as rendered in 'chromacons' and sent as an email attachment to test ease of reading

There are 467 letters in this sonnet which took 451 seconds to read and record at just under one second per letter. This can be compared with the fastest time achieved by a student working with the help of the key. The 61 letters were read and recorded in 99 seconds at 1.62 seconds per letter.

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Discussion

While it is possible to read a text in chromacons, the colour alphabet was never expected to be a serious alternative to alphabets made up of shapes. Whether or not there is a practical use for a colour alphabet, as an alphabet, is an open question. It has been suggested that people who have extreme difficulty discriminating the shapes of letters might not have the same kind of difficulty with colours, but this would need further investigation. Meanwhile there remain problems of punctuation, accents and how to deal with numerals and other symbols. The range of readily distinguishable colours seems at the limit with the 26 letters; the system would surely break down much beyond that number. Differentiation by shape would have to be introduced as it is on the London Oyster map.

The use of colour names might make the colours easier to learn for speakers of English but not for speakers of other languages. More seriously, and another topic for further studies, is the difficulty that would be faced by people with defective colour vision who would confuse many of the 'letters'. It seems unlikely that a usable colour alphabet could be devised for such people. Perhaps the format used for testing the influence of simultaneous contrast, illustrated in Figure 12, might be developed for investigating vision deficiencies.

Of more practical value: the colour alphabet could help people to establish a basic frame of reference for colours, well distributed in colour space. That was the aim when the system of Colour Zones was first proposed and the alphabet colours are still related to the Colour Zones structure.

For people with normal vision, the colour alphabet offers a playful and decorative way to present a text. A sonnet rendered in chromacons could even be regarded as a work of visual art, just as Shakespeare's words are works of literary art. Such an approach is reminiscent of the work of Ellsworth Kelly, Gerhard Richter and Damien Hirst as shown in the exhibition 'Color Chart: Reinventing Color, 1950 to Today' presented at the Museum of Modern Art in New York in 2008 [39].

This project has not provided a definitive answer to the transport map problem and it seems unlikely that the answer would be a single number. The number of different colours that can be discriminated with confidence will vary from one situation to another as was found by Carter and Carter [16]. The varied success of those who participated in the most recent study, reported above, suggests that the number of different colours that can be identified correctly in a code will also depend on the person who is trying to read the code. However, it does seem that the limit to the number of colours that can be used successfully in a colour code is close to 26. Carter and Carter arrived at a similar number by different means [13] and Kelly may have felt that his proposal of 22 colours of maximum contrast was also about the maximum number of colours that could be used in a code although he does not explain how he arrived at that number [2].

A final surprise has come from comparing the colours from the colour alphabet with Kelly's colours of maximum contrast. The two sets of colours are shown side by side in Figure 15. The extra five alphabet colours have been added following Kelly's principle of maximum contrast. Although not perfect, the degree of correspondence between the two sets is striking and shows how different approaches to a similar problem have led to similar conclusions. It could be claimed that each result validates the other.

For purposes of communication, colours are superior to shapes in some respects and inferior in others. Colour is often the first distinguishing feature used for identification and may override differences in shape. In a game of cards a player is more likely to mistake a heart for a diamond than a diamond for a spade. Colour is likely to be the first point of recognition

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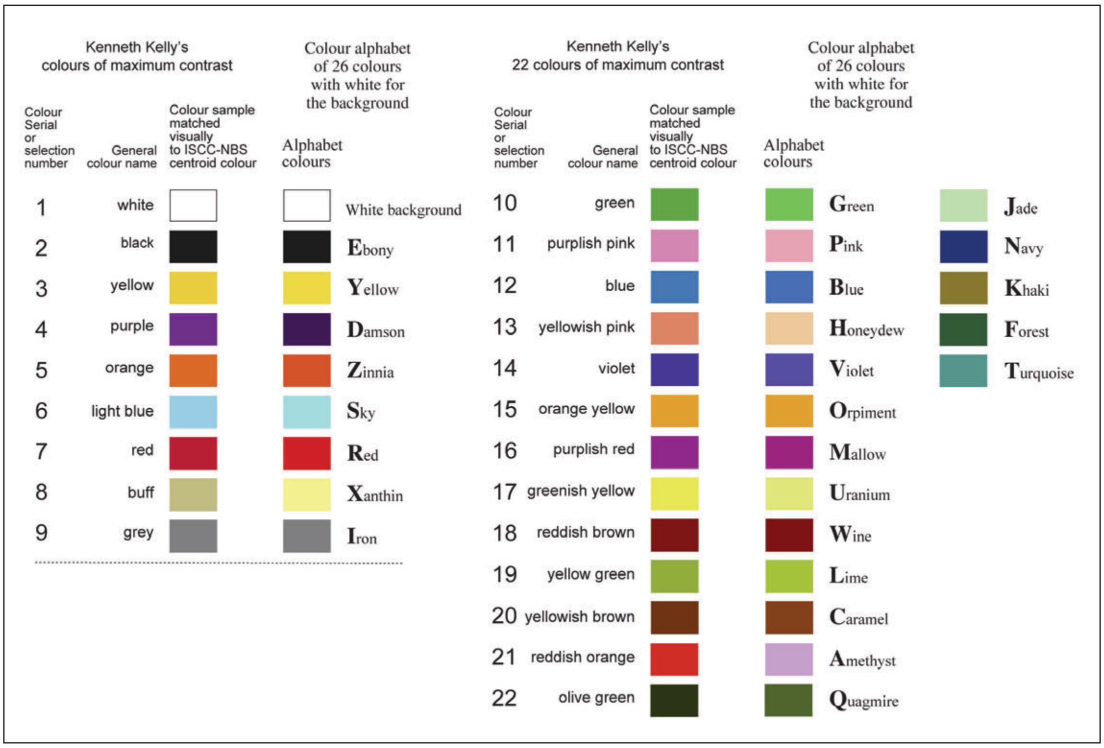

Figure 15 Kelly's 22 colours of maximum contrast set beside similar colours from the colour alphabet

for travellers when looking for their bags to appear on the carousel in the arrivals area of an airport. A traveller whose bag has gone missing is shown a card and asked to point to the illustration that corresponds most closely to the missing bag [40]. The traveller is also asked to point to one from a range of 12 appearance characteristics which are shown at the top of the card. These are white/clear, black, grey, blue, red, yellow, beige, brown, green, two or more solid colours excluding trim, tweed and pattern. These are illustrated with examples. There are three 'blues', three 'reds', three 'yellows' and three 'greens'. There is a turquoise among the blues, a purple among the reds, an orange among the yellows and an olive among the greens.

The relative strengths of colours and shapes for communicating information are well demonstrated on geological maps. The world's first geological map was produce by William Smith and published in 1799. Simon Winchester records how Smith considered various ways to represent the complexities of the 'unseen underworld' and concluded that colour was essential despite the cost [41]. Colour provides broad information about the geological structure and makes it possible to read the map. However, the number of different kinds of rock that need to be recorded exceeds the number that can be represented unambiguously in a colour code. Different pinks may be used to identify granite of various ages, but the pinks are too similar for certain identification without the additional letter–number code. For communicating these fine distinctions colours alone are no longer adequate. This was Arnheim's essential point when he compared the relative merits of colours and shapes and claimed that 'shape lets us distinguish an almost infinite number of different individual objects' [3].

Conclusion

The colour alphabet project was an investigation of the limits of colour coding and the relative merits of colours and shapes for communicating information. The workshop and follow-up studies led to the identification of four main factors that contribute to speed and ease of

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reading: simplicity, familiarity, nameability and contrast. Colours are simpler than shapes, they are familiar and they can be named, but the degree of contrast depends on how many different colours are used. The colour alphabet can be used for text that can be read, but only just. Given the different contexts in which colour coding is used there may be no definitive answer but, for practical purposes, the 26 colours of the alphabet can be regarded as a provisional limit – the largest number of different colours that can be used before colour coding breaks down. These 26 colours can be set beside the 25 colours that would be separated by at least 51.6 CIE $L^*u^*v^*$ units as shown by Carter and Carter [13] and the 22 colours of maximum contrast listed by Kelly [2]. Within these limits, colours offer the most efficient means of differentiation and identification. Beyond these limits colours can still help to differentiate and clarify information, as on a geological map, and they can be used in partnership with shapes in the way that the single lines representing the London Underground routes are distinguished from the double lines for the mainline routes on the London Oyster map, but shapes in some form will be needed. Geological maps, with colour coding supplemented by a shape code in the form of letters and numbers, illustrate what colours and shapes each do best.

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