Pseudoisochromatic plate design type is recoverable from delivered colour and dot geometry alone

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Abstract

Pseudoisochromatic plates fall into design types characterised by Hardy, Rand and Rittler. Demonstration plates are legible to every observer. Transformation plates show one figure to the normal observer and another to the deficient one. Vanishing plates show a figure that the deficient observer loses. Hidden digit plates invert the arrangement, presenting a figure that only the deficient observer resolves. The type governs what a plate measures, and it is ordinarily read from the test's own documentation. This note asks how much of it can be recovered from the delivered stimulus instead.

Eleven Ishihara-based plates from a currently deployed web-based screener were measured. Fills are declared in the delivered markup and dot geometry was recovered from the path data, giving 7,400 dots; the statistic below rests on the 420 to 694 figure/ground border pairs found on each plate. Figure and ground were separated by the spatial compactness of each colour class, which succeeds where assignment by dot count fails on six of the eleven plates. Neighbouring figure/ground dot pairs were then tested for alignment with the dichromatic confusion lines in CIE 1931 *xy*.

Three groups separate on that single quantity. The demonstration plate returns an aligned fraction of 0% on both red–green axes. The transformation and vanishing plates return 37–100% for protan and 50–85% for deutan, and they do not separate from one another — both types work by placing the figure/ground boundary along a confusion direction, so no separation between them is expected. The hidden digit plate returns 27% for protan and 5% for deutan, the inverted arrangement appearing directly in the measurement. Recovery of the figure/ground assignment itself by unsupervised community detection was also attempted and fails: recall reaches 100% on ten plates while precision falls to 38–63% on the vanishing plates, and the runner-up margin carries no signal distinguishing the successes from the failures.

Keywords: pseudoisochromatic plates, colour vision screening, confusion lines, colorimetry, plate taxonomy

1. Introduction

Colorimetric assessment of pseudoisochromatic plates has followed a stable procedure for four decades: measure the chromaticities of the figure and ground dots, and compare the direction in which they are separated against the confusion lines of the deficiency the plate claims to test. The National Research Council Committee on Vision applied this analysis to several plate tests. Danilova and Mollon measured the plates of the Yustova test and plotted the results against the protan copunctal point. Dain defined a deviation metric and applied it to four editions of the Hardy–Rand–Rittler test. The procedure has since moved to screens: Dain and AlMerdef measured the colours produced by five iPhone applications and assessed the visual task on the basis of colour differences and alignment to the dichromatic confusion lines, and Zhang and colleagues measured a commercial computerised test rendered across characterised displays.

Throughout that work the design type of each plate is taken from the test's documentation. This is reasonable — the documentation is available and the manufacturer knows what was built. It also means the type is treated as metadata rather than as a property of the stimulus.

There are circumstances in which the distinction matters. A plate served over the web may be delivered by a party that did not design it. Reproductions circulate without documentation. A plate may be re-rendered, rescaled or quantised by a display pipeline, and whether it still performs its original function is a separate question from what its documentation says it was built to do. In each case the stimulus is available and the design intent is not.

Computational work on Ishihara plates exists but addresses different problems. Recent machine-learning studies classify and recolour plate images to make them legible to deficient observers, and simulate deficient perception over plate datasets. We are aware of no study that recovers a plate's design type from its delivered colour and geometry.

This note asks how far the stimulus alone gets you. The answer is that it separates three groups of the classical taxonomy on a quantity the existing colorimetric literature already computes, and that it does not separate transformation from vanishing plates, for a reason that follows from how both types are built.

2. Methods

2.1 Corpus

The ZEISS Online Vision Screening colour check serves eleven Ishihara-based plates as SVG. Every dot's fill is declared in a stylesheet and the figure/ground assignment is carried by CSS class, so the colour values are read rather than estimated from a rendering.

Dot geometry was recovered by converting the endpoint arc parameterisation of the SVG path data to centre parameterisation, following SVG 1.1 §F.6.5. Recovered dot counts match the counts declared in the markup exactly on all eleven plates — 585, 708, 638, 746, 655, 750, 708, 700, 562, 746 and 602 dots, totalling 7,400 — and that exact agreement is what licenses using the recovered positions.

One further test was examined and excluded. The plates served by rgblind.com carry per-dot opacity values of 0.85, 0.9 and 0.95, and their dots overlap by up to 16 px. The declared fill of a dot is therefore not the colour delivered at that dot, and the extraction method used here does not apply to it.

2.2 Plate type

Plate type was taken from the site's own answer key, which functions as a classifier. A plate declaring both a digit and a confusion digit is a transformation plate. A plate declaring a digit alone is a vanishing plate. A plate declaring `correctAnswer: 'nothing'` together with a confusion digit is a hidden digit plate. The remaining plate, legible to all observers, is the demonstration plate.

This classifier places ZEISS plate 15 as a hidden digit plate. The composition commonly quoted for the Ishihara 38-plate edition places plates 10 to 17 among the vanishing plates. The conflict is recorded without resolution: the ZEISS set is a selection of eleven plates and its numbering need not follow the parent edition.

2.3 Colorimetry

Cone excitations were obtained from linear sRGB in a single step, using the Smith and Pokorny (1975) fundamentals composed with the Judd–Vos-corrected linear-sRGB-to-XYZ transform. The Smith and Pokorny transform is defined on Judd–Vos modified XYZ rather than on CIE 1931 XYZ. This was verified by composition: the product of the two published matrices reproduces the published one-step linear-sRGB-to-LMS matrix to 2.5×10^{-8}. Routing through a single matrix removes the intermediate space in which the two chromaticity systems could be mismatched.

Copunctal points were taken as protan (0.747, 0.253), deutan (1.400, −0.400) and tritan (0.1748, 0). Each was verified against its defining property: feeding the candidate chromaticity through the cone transform must return null excitation in the two cone classes other than the missing one. Residuals are 3×10^{-4} or less. This check requires no external source and settles any candidate value in one line.

Deviation of a figure/ground pair from the confusion line follows Dain. The confusion line is drawn through the pair's mean chromaticity in CIE 1931 *xy*, the angle between the pair's separation direction and that line is taken, and the result is folded onto [0°, 90°]. Zero indicates that the separation collapses for the deficiency;

ninety indicates that it remains fully available.

2.4 Figure and ground

Assignment was made by spatial compactness. For each colour class the radius of gyration of its dots was computed and expressed relative to the radius of gyration of all dots on the plate. Classes below 0.85 were taken as figure. Classes near 1.0, being spread across the whole plate, were taken as ground.

2.5 Local pairing

Figure and ground dots were paired locally. Two dots form a border pair when their centres are separated by less than 2.2 summed dot radii. Each border pair was scored aligned when its deviation fell at or below **25°**, and the reported statistic is the area-weighted share of border pairs meeting that criterion — the fraction of the figure/ground boundary that collapses for the deficiency in question. **The 25° criterion is illustrative. No standard threshold exists in this literature; Dain reports mean deviation without a cut.** The absolute fractions reported below are conditional on that value, and §3.3 examines their sensitivity to the border definition rather than to the alignment criterion.

3. Results

3.1 Figure and ground cannot be assigned by dot count

Radius of gyration separates the two populations cleanly. Assignment by taking the largest colour classes as ground mislabels six of the eleven plates, because several plates carry a plate-wide colour that is not among the two most numerous classes.

Plate 2 illustrates the failure. The classes #eb4825 and #f88c4f return relative radii of 0.66 and 0.63 and are figure. The class #928237 returns 1.03 and is spread across the plate, alongside grounds at 1.04 and 1.07. A count-based rule assigns #928237 to the figure and inverts the plate.

Compactness requires no knowledge of the plate's answer, and it is computed from geometry already recovered in the course of reading the dots.

3.2 Three groups separate; transformation and vanishing do not

Area-weighted share of border pairs collapsing, by deficiency. *n* is the number of border pairs, and *b* the number of figure dots on the boundary.

plate	type	n	b	protan	deutan
1	demonstration	465	100	**0%**	**0%**
2	transformation	482	100	100%	85%
6	transformation	668	141	94%	75%
8	vanishing	457	80	94%	57%
9	vanishing	539	100	93%	59%
10	vanishing	420	76	86%	68%
5	transformation	470	109	82%	54%
7	transformation	694	170	81%	50%
4	transformation	535	99	71%	53%
3	transformation	693	145	37%	58%
15	hidden digit	543	89	**27%**	**5%**

The demonstration plate returns 0% on both axes. Nothing along its figure/ground boundary collapses, which is the design: it is built to be legible to every vision type and carries no confusion-aligned separation to find.

The transformation and vanishing plates span 37–100% for protan and 50–85% for deutan. **They do not separate from one another**, and no separation is expected: both types place the figure/ground boundary along a confusion direction, and the measurement records that the boundary is so placed without distinguishing what is done with the second figure.

The hidden digit plate returns 27% for protan and 5% for deutan. Its boundary stays largely available to the deficient observer. The design is inverted and the measurement inverts with it. Miyahara showed by chromaticity measurement that Ishihara hidden digit plates carry a short-wavelength-sensitive cone signal that red–green deficient observers can exploit; the low aligned fraction reported here is that construction seen from the other direction, as the share of the boundary that fails to collapse.

Plate 3 stands apart from its siblings and does so asymmetrically: 37% for protan against 58% for deutan, the only plate in the set where the deutan fraction substantially exceeds the protan one. Its declared type is transformation.

3.3 Sensitivity to the border definition

The border threshold was swept from 1.15 to 3.0 summed dot radii. Absolute fractions move by up to **0.146** across that range, on plate 4.

The rank ordering of the eleven plates is highly stable but not identical across the sweep. Spearman correlation between the 1.15 setting and the 1.5, 2.2 and 3.0 settings is **+0.964, +0.936 and +0.936** respectively. Adjacent plates exchange positions — plates 6 and 8 swap between the 1.15 and 2.2 settings — while the three groups identified in §3.2 do not change membership at any setting. The demonstration plate returns 0.000 at every setting, and the hidden digit plate returns 0.205 to 0.271.

3.4 A bounded negative result

Recovery of the figure/ground assignment without an answer key was attempted, by maximising Newman modularity over every partition of a plate's colour classes. The attempt reaches 100% recall on plates 1 to 10. Precision falls to between 38% and 63% on the three vanishing plates, and the method fails outright on the hidden digit plate.

The runner-up margin was examined as a possible confidence signal and does not serve. Plate 6 succeeds at a margin of 0.011; plate 8 fails at a margin of 0.001. The margins overlap the boundary between success and failure, so a practitioner holding only a partition and its score cannot tell which case they are in.

This closes the route for unlabelled raster reproductions. Where the figure/ground assignment is not carried in the delivered markup, the result in §3.2 cannot presently be reached.

4. Discussion

Part of a plate's design type is a property of its delivered colour and geometry. The eleven plates measured here separate into three groups on a single quantity that the plate colorimetry literature already computes, and the measurement adds one step to an established procedure: dots are paired locally rather than pooled across the plate, and the statistic reported is the share of the figure/ground boundary that collapses.

Local pairing is what makes the statistic interpretable. A plate-wide average over all figure and ground chromaticities returns a single number for a boundary that is not uniform, and on the plates measured here that pooled number differs from the mean over local pairs by up to 9.8°. The share of border pairs that collapse describes what an observer encounters at the edge of the figure, which is where the plate's task is performed.

Two consequences follow for practice.

The first concerns provenance. A plate served without documentation can be characterised on its own terms, and a claim about what a plate tests can be checked against what the plate delivers. This applies to reproductions, to re-renderings, and to any deployment in which the party serving the plate is not the party that designed it.

The second concerns plate 3. Its protan fraction sits at 37% while the other transformation plates in the set range from 71% to 100%, and its deutan fraction at 58% exceeds its protan fraction — the reverse of every other plate here. A discrepancy of that size and shape between declared type and measured behaviour is the kind of signal this measurement exists to surface. Its cause is unresolved. It may reflect the plate's construction, its selection into this eleven-plate set, or the alignment criterion. Each is checkable and none is checked here.

The negative result in §3.4 bounds the method. The taxonomy is recoverable when figure and ground are separable, and the separation used here depends on structure carried in the delivered markup. Unsupervised recovery of that structure was attempted, did not reach usable precision, and offered no confidence signal that would let a practitioner distinguish a good partition from a bad one. Raster reproductions therefore remain outside the method's reach.

5. Limitations

One test, one manufacturer, eleven plates. The sample is a selection made by the party deploying it, and generalisation to other editions or other manufacturers is not supported by these data.

Colours were measured as declared in the delivered markup rather than as emitted by a display. Nothing reported here bears on the reproduction chain, on browser rendering, or on panel characteristics.

No angular uncertainty is established for this measurement. The colour values are read exactly from markup, and the recovered geometry is validated by reproducing the declared dot counts exactly on all eleven plates, but neither of those bounds the deviation angle. A ±3.5° figure obtained elsewhere for a raster extraction pipeline does not transfer to this measurement, which never rasterises, and is not claimed here.

The 25° alignment criterion is illustrative and the absolute fractions in §3.2 are conditional on it. Stability was demonstrated against the border definition, not against the alignment criterion.

No observers were tested. The taxonomy was validated against declared design intent, and behavioural validation is required before any claim is made about what a deficient observer sees on these plates.

The conflict noted in §2.2, between the classifier's placement of plate 15 and the composition commonly quoted for the parent edition, is recorded and unresolved.

Three of the works cited in §1 are characterised from their abstracts and from secondary descriptions rather than from their full texts, which were not accessible to the author: the National Research Council Working Group 41 report, Danilova and Mollon, and Dain (2004). Their methods are described here only to the extent those sources state them.

6. Data and code availability

The extracted plate colours, the recovered dot geometry, and the analysis code are available under an MIT licence at https://github.com/zengineco/opticquiz.com and **will be archived with a DOI on acceptance**. Each tool carries a self-test that must pass before the tool will run, and each self-test includes a positive control: a colour group known to be off axis is required to be reported off axis, so that a check unable to detect the defect it exists to catch fails rather than passes.

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