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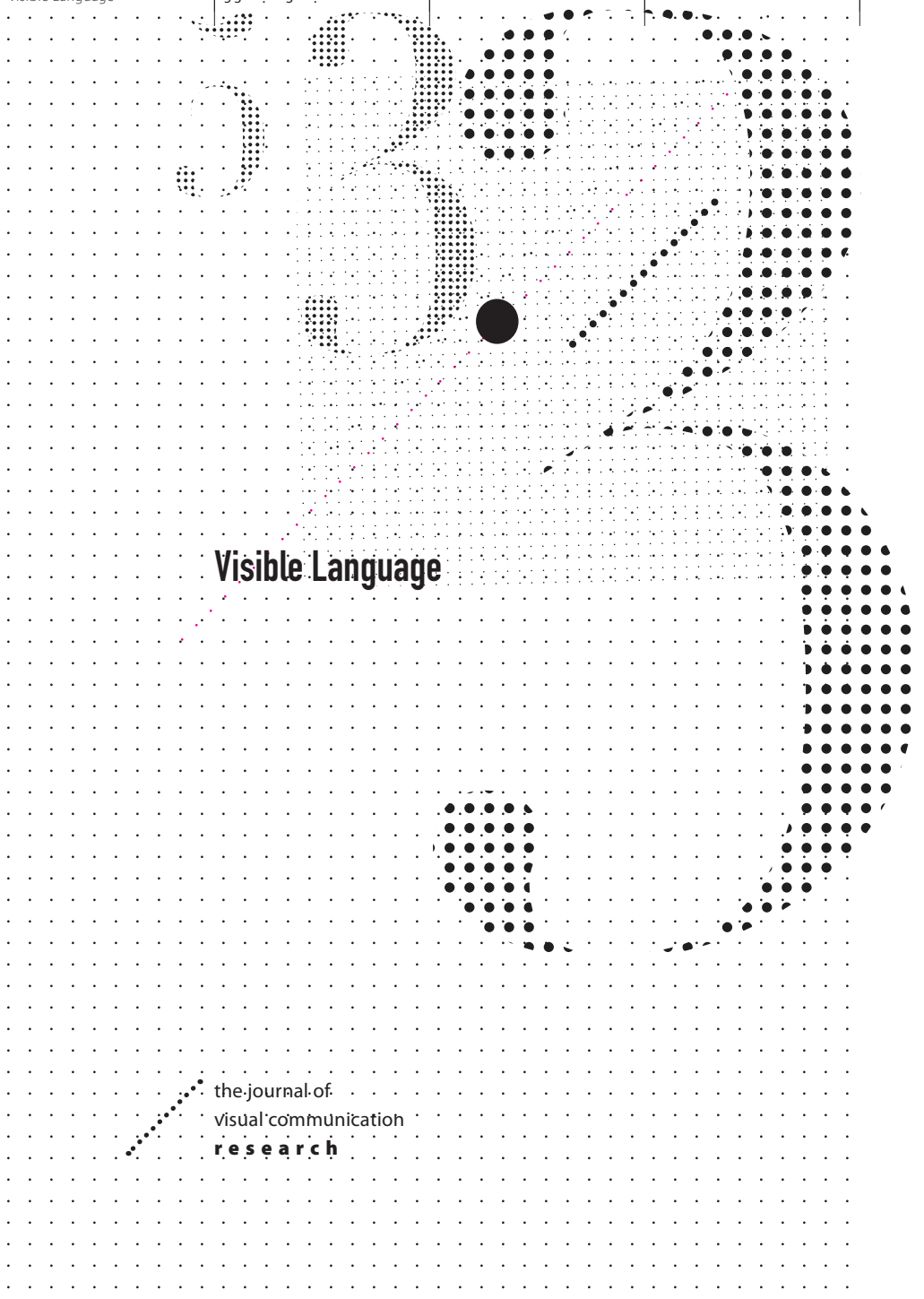

Visible Language

the journal of visual communication **research**

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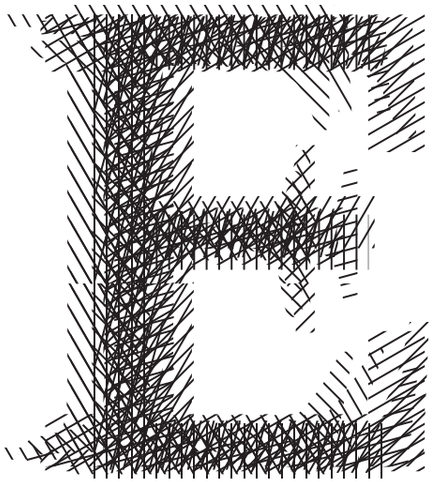
LETTERFORMS

Helvetica Garamond 3 Frutiger Times Roman Univers Futura Bodoni Rockwell Bembo Franklin Gothic

10 popular typefaces overlapped, to reveal the cap "E" letterform skeleton.



PERCEPTUAL FEATURES

diagonal curve vertical horizontal

Four basic perceptual features:
diagonal, curve, vertical, horizontal.

Letterform Legibility and Visual Perception: a speculation

Mike Zender

"Roman capital letters first achieved the forms we know today about AD 100. ... At their most formal they are based on very simple geometric shapes, symbols for the sounds in a language. And each letter is successful as a symbol because its shape is hard to confuse with the others and is easy to memorize."
(Sutton & Bartram, 1968, p. 6)

This short paper explores a straightforward insight: that the basic features of visual perception map instructively onto the letterform skeletons of the Latin alphabet. Linking findings from visual perception with knowledge about typography and reading might advance our knowledge of how letterforms function visually. This knowledge could be used to develop a formal measure of letterform legibility, to provide means to distinguish between a text and a display typeface, and to provide guidance for typeface design.

Keywords

letterform
visual perception
letterform skeleton
legibility

1. Typography

I am typing this paper on a keyboard. How trivial. It is easy to forget how remarkable an achievement it is to be able to construct every word in a language by pressing just 26 keys.

Alphabets' definition and origin

Some of the most significant human achievements are shrouded in the fog of historical uncertainty. The alphabet, a small set of abstract visual symbols to represent all human language, is such an achievement. As significant an invention as an alphabet is, no one living knows what person or persons first imagined it. For eons ancient cultures as disparate as Mayans in Central America and the Egyptians in Northern Africa effectively used picture-based language systems, hieroglyphs, to communicate. While pictures of physical objects worked well to represent things, hieroglyphic writers had to invent strategies to communicate actions and proper names. Egyptian hieroglyphs used some pictures to represent words, some pictures to represent sounds, some pictures to represent ideas with graphic marks to serve as conceptual modifiers to indicate whether a particular picture was a word or a sound (Stone & Zender, 2011). Picture-based systems have not disappeared. Even today, the Chinese reading system is picture-based rather than alphabetic. But about 4,000 years ago someone somewhere took a different approach. The Phoenicians and Hebrews broke from a hieroglyphic approach and began to use a non-pictorial system of roughly 20-30 abstract glyphs, each glyph to visualize a spoken sound. An alphabet, the first of many, was born.

Alphabet's benefits

A non-pictorial alphabet of 20-30 abstract glyphs to visually embody language has significant benefits. A language may consist of 10's of thousands of words. As a result, picture-based systems such as hieroglyphs must have 10's of thousands of distinct pictorial representations to remember, whereas an alphabetic system that visualizes sounds has just a couple of dozen visual forms to learn. For example, the BBC reported that there are about 50,000 Chinese picture-based characters but that the average literate Chinese person recognizes only about 8,000 of these (BBC, 2014). On the other hand, every English word is represented by just 26 letterforms. Command of the English language is less restricted by the system used to represent it than by an individual's vocabulary and the availability of a dictionary. The keyboard noted above is one example of the efficiency of an alphabet for graphically producing words. The ease with which a typographic system with a limited number of glyphs can be reproduced is another example.

Multiple possible alphabets

An alphabet is a simple and adaptable graphic system that can take many possible visual forms. Arabic, Cyrillic, Greek, and Latin alphabets are contemporary examples of different kinds of alphabets, each with a different graphic form language ranging from curvilinear to square. While one might assume that alphabets are equally effective even though they use different visual forms, it is also possible that some graphic systems more effectively facilitate reading than others.

Legibility and reading

Various models are used to explain how we read from an alphabet. The model described in Sofie Beier's 2012 book *Reading Letters* indicated that both bottom-up letterform recognition and top-down language and content flow work together when reading (Beier, 2012, p. 29). An overview by Jonathan Grainger concluded that readers of sentences draw upon both orthographic codes – neurological patterns linked to letter identities and their locations – and semantic knowledge – the meanings of words and their associations with other meanings ("orange pumpkin" is an example of two words whose meanings would be associated by those familiar with pumpkins) (Grainger, 2016). While researchers continue to explore the exact role letterform recognition plays, experts generally agree that it is a critical part of reading.

Legibility

Legibility is the informal measure of the ability to distinguish one letterform shape from another. An ideal alphabetic system would have excellent legibility. It would help people to quickly and accurately distinguish one letterform from others. A good alphabet would also do this while maintaining unity so that letterforms visually combine to form words. Conversely, an ineffective alphabet would have letterforms that are easily confused with others, causing readers to slowly and carefully identify letters.

Hebrew, perhaps the most ancient alphabet still in use today, illustrates some interesting legibility challenges (Van Pelt & Pratico, 2007). Among its 22 letters, H – He and CH – Het each have two vertical lines with a horizontal line resting across the top of them. Figure 1 shows that the H is distinguished from CH by a very small separation between the top and left side. The letter Th – Taw is very similar to H and CH being distinguished from them by a small protrusion at the bottom of the left vertical. Otherwise, it is just like H. Hebrew Z – Zayin and W – Waw (or V – Vav in modern usage) also share great similarity. Figure 1 shows the small horizontal line at the top of Z extends a little farther to the right than it does with V. Hebrew's letterform

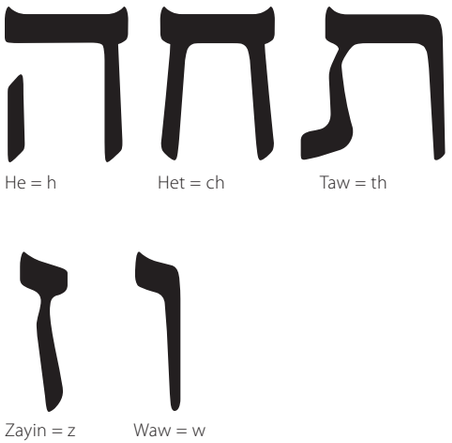


FIGURE 1.

Comparison of Hebrew letters H, CH, and TH. Also shown, Z and W/V.

similarities are used here to illustrate that the ease with which one letterform is distinguished from another is not a given property of an alphabet but must be designed-in. Hebrew is relevant because the Latin alphabet, which is the focus of study here, evolved from Phoenician and Hebrew alphabets through the Greeks and the Romans.

Letterform evolution

While history does not record how ancient Hebrew or other ancient alphabetic systems come to be as they are, with the exception of contemporary Korean, our best guess is that a single person did not consciously design the visual forms of contemporary alphabets but that alphabets evolved, through use, over time. Though we cannot identify a designer who guided early letterform evolution, various historians have traced the influence that technology had on the shapes of letterforms. Cultures whose writing technology involved making cuts on clay tablets with a stylus developed an alphabet consisting of triangular dots and lines such as Cuneiform. Those using a pen developed more rectilinear forms such as Hebrew. Those with brushes more fluid forms such as Arabic. Those carving words onto stone monuments used hammers and chisels resulting in serifs. In addition to technology, historians have observed how hand-copying manuscripts by Medieval scribes led them to streamline the shapes of many letters resulting in new cursive shapes and ligatures. Commercial interests such as advertising influenced the development of both very bold condensed and sans serif letterforms.

In the 1450's Johannes Gutenberg's casting of the alphabet in modular metal blocks greatly impacted letterform evolution. His movable, reusable letterforms and related inventions popularized letterform manufacturing and invented typography.[1] Gutenberg's first substantial book, a Bible, was set in letterforms popularly called blackletter. The graphic language of blackletter resulted from the use of a thick nib calligraphic

1 Gerrit Noordzij, on page 49 of the 2019 English edition, defines typography as "writing with prefabricated letters."

pen. Gutenberg's first typeface demonstrably imitated the irregularities of handwritten calligraphy, as Emil Ruder noted in his book *Typographie* (Ruder, 1967, pp. 24-25). Gutenberg's work had dramatic and widespread influence, so it was not long before others began mass-producing metal types of their own designs and the printing and typographic industries came into being. The mechanical production of letterforms, typography, spawned many new letterform variations as rival type manufacturers competed for business. At the same time, the idiosyncrasies of handwritten forms were overwhelmed by mass production as typography served to codify the elemental shapes of Latin letters. Since many early typographers were in Italy where a renaissance of interest in ancient Greek and Roman sources had occurred, many of the early typographic shapes were influenced by letterforms from the Greek and Roman empires. Sutton & Bartram and multiple other histories, the sources of the forgoing historic narrative, have cited the Trajan Column in Rome as a prime model for the uppercase letters of the Latin alphabet (Sutton & Bartram, 1968, pp. 6-9). Type classification systems have codified the historical evolution of typography.

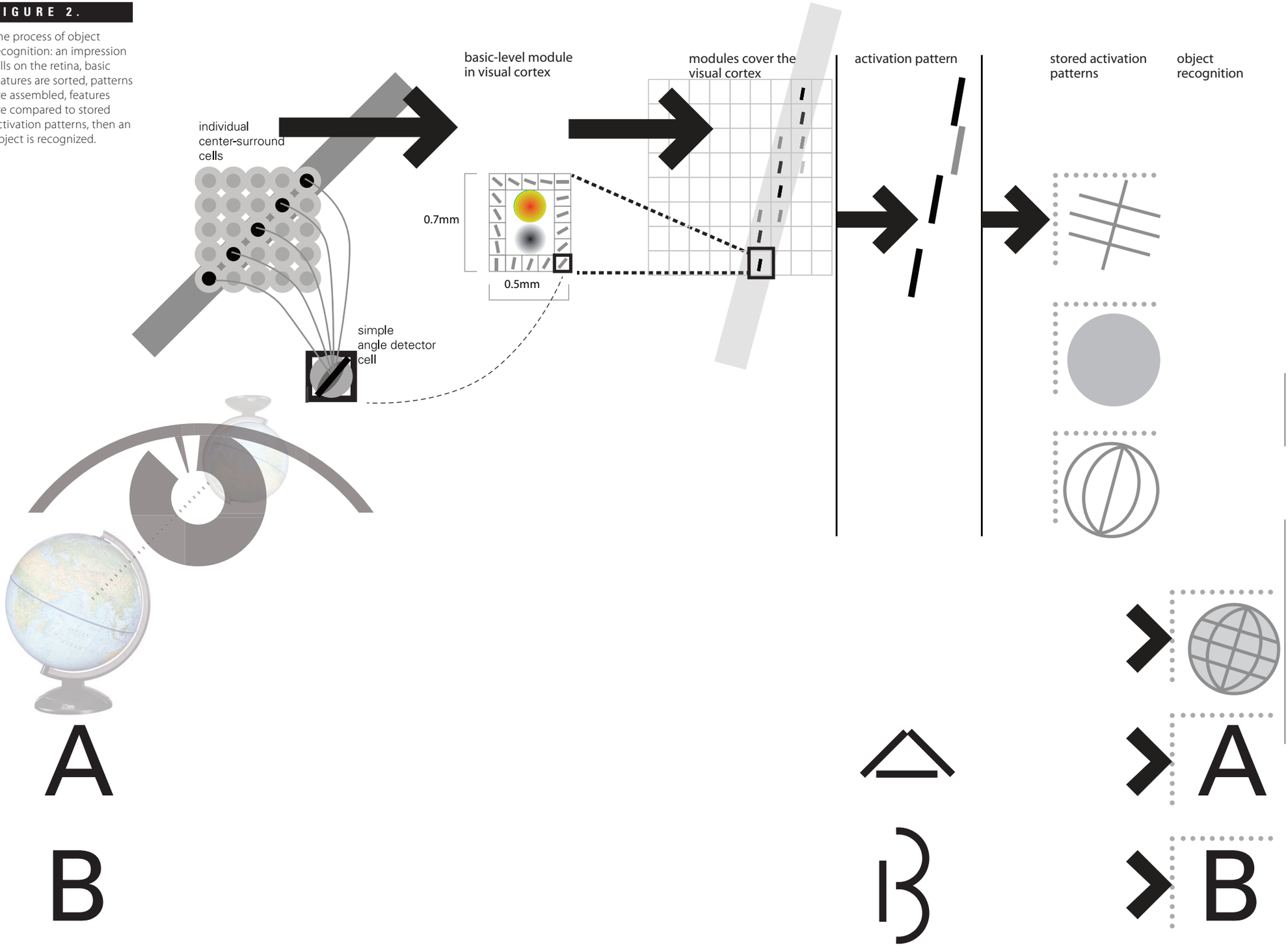
As letterform variety increased in the 18th and 19th centuries, driven by the pace of technological change, literacy became more widespread. Literacy growth, both as a percent of a given culture and in the number of cultures achieving literacy around the globe, made novel departures from alphabetic letterforms less desirable because novel forms would require a rapidly growing population of readers to re-learn reading. Gerrit Noordzij observed that it is "Not that drawing unconventional shapes should be difficult or forbidden, but shapes that do not conform to convention are just not writing (Noordzij, 1985 (2019 English version), p. 9)." Adrian Frutiger cited the historic rise in global literacy as the causal factor of an "international basic form" (Frutiger, Besset, Ruder, & Schneebeli, 1980). He wrote that "printing types are a cultural heritage from our ancestors which should neither be neglected nor violently altered" (p. 13). Frutiger went on to say, "the letters of our alphabet have been assimilated to one another and balanced against one another through centuries of use" (p.64). Centuries of typeface design have resulted in thousands of variations on stable letterform themes. What is the essence of these letterform themes, why unconventional forms are "just not writing," and what exactly is the character of this "cultural heritage" that we should resist changing are the subjects of this paper.

2. Visual Perception

The rapid, widespread growth of global literacy driven by the development of modern typography demonstrates that the Latin alphabet is a highly functional system. The foundation of letterforms' functional success is likely

FIGURE 2.

The process of object recognition: an impression falls on the retina, basic features are sorted, patterns are assembled, features are compared to stored activation patterns, then an object is recognized.



not found in the letterforms themselves but in the fundamental principles of human perception and cognition. The simple observation of this paper is that basic features of visual perception and cognition described in the late 20th century help explain both the functionality of the wide variety of typographic expression and the stability of its elemental forms.

David Hubel – basic features

In the 1950s, David Hubel's lab produced groundbreaking work in the function of neurobiological processes behind human visual perception (D. H. Hubel & Wiesel, 2009).[2] By monitoring the responses of individual neurons in the cat brain, Hubel and his colleagues found the occipital lobe's visual cortex to be organized according to small neuron modules. As they studied, they learned that within each of these modules specific neurons were bundled together that respond to different visual features: horizontal, diagonal, vertical, curve. These modules formed, in effect, a massively parallel processing mechanism for visual input from the eyes. Subsequent study observed that the organization of these modules was topographic such that objects close together in the outside world were close together on the visual cortex. Researchers such as Dr. Eyal Seidemann have dramatically illustrated that what the eye sees can literally be observed on the surface of the visual cortex of the brain (NIH & Health, 2012). Over time we have learned that the modules in the visual cortex are the building blocks in the early stages of visual processing in what has come to be called the "bottom-up" model of object recognition and meaning-making. In the bottom-up model, we first process basic visual features in the retina and immediately after in the visual cortex, then assemble patterns of these basic visual features, then match feature patterns with activation patterns remembered from past experiences. We then recognize an object. Figure 2 illustrates this process.

Anne Treisman – pop-out

Around the time of Hubel & Wiesel's ground-breaking work, Anne Treisman and her colleagues were exploring visual perception from a psychological knowledge base. Treisman's key contribution was to observe that some visual forms pop-out; that is, they compel attention, while other visual forms take time and effort to decode (Treisman, 1985). At first, these were called "pre-attentive" features because they seemed to compel visual attention before a person even had a chance to look for them, though this terminology was later dropped in favor of the more descriptive term "pop-out" because these features pop-out from so quickly other visual stimuli. Treisman and those who built upon her work identified some of these features: value, hue, horizontal, diagonal, vertical, curved, blurred, and found that they share a basic simplicity compared to more complex forms. Whatever the observation is called, scientists quickly noted that pop-out features correlated well with findings on basic neurological features and their place in the bottom-up process of seeing and recognizing objects. Pop-out and neuron organization both shared the same basic forms: horizontal, diagonal, vertical, curved, and blurred.

2 This citation is the 50th anniversary re-publishing of Hubel & Wiesel's seminal work. Its republication demonstrates its lasting influence.

Letterform as object recognition

Letterforms are visual objects that, like all seen objects, are processed according to the bottom-up model. The visual processing of letterforms is hardly a novel observation. In the Introduction to Frutiger's 1979 book, Hans Rudolf Schneebeli observed that the foundation of Frutiger's work was

> "what was optically acceptable to man. That which the human eye can accept, which is comfortable to it, is his first concern, above all human concern. This is an obligation which cannot be overemphasized in a period when there is a frequent tendency to subordinate man to technical progress." (Frutiger, p.7)

As I will elaborate below, Frutiger said that letterform "silhouettes have engraved themselves in the subconscious of the reader as a kind of elemental form. (p.64)" Frutiger's intuitive insight, written just when Hubel and Treisman's findings in neurobiology or psychology were published, is evidence of awareness of strong ties between the process of visual perception and letterform design. Years later, In a 2008 review, Jonathan Grainger confirmed the earlier work of Oliver Selfridge that people recognize letterforms by their component visual features (Grainger, Rey, & Dufau, 2008). He illustrated the proposed process showing how a letterform first activates simple cells, then composite feature cells, finally stimulating letter-specific cells (see Grainger, Figure 4, p.385). Support for Selfrige's theory and Grainger's later contribution is found in David Hubel's neuroscience work on feature detection (David H. Hubel, 1988; D. H. Hubel & Wiesel, 2009), though contemporary perceptual researchers might argue against the idea of "letter-specific cells" in favor of "activation patterns." Though the mechanisms are different, the stage in processing and the result are the same, letters are recognized.

3. Latin Letterform Skeletons

Reading certainly draws upon the process of visual perception described above. Though reading is complex and incompletely understood, nearly everyone recognizes that at some level, reading involves distinguishing

one letterform from another. As Sofie Beijer has noted, a popular subject of early reading research was the study of confusion of individual letterforms such as that done by pioneer Miles A. Tinker in the 1920s (Beijer, 2012, p.70). These early studies identified several pairs of easily confused letterforms, ones that would be considered to impede legibility.

Legibility and Readability

While studies of legibility continue, reading experts recognize legibility as just one aspect of readability. Readability, the ease with which one can read a text, is a function of not only how easily letterforms are distinguished from each other but also on how large the letterforms are, the amount of space between letters, how long the lines of letterforms are, how much space is between each line in relation to line length, and other factors such the uneven distribution of vertical space in a typeface as found in Sofie Beir and Chiron Oderkerk's acticle in this issue (Beier & Oderkirk, 2019). These factors interact to form a complex and delicate relationship that supports or impedes reading: hence read-ability.

Although legibility may only be just one factor in readability, it is a key factor. The measure of success of any glyph-based typographic system, any alphabet, is its ability to enable readers to distinguish one letterform from another quickly. Legibility is the informal measure of this ability. To date, there are no formal, specific measures of legibility, no predictable guides to pre-identify which letterform characteristics which will produce the most legible letterforms. There are only general letterform guides, rules of thumb based on observed experience.

Skeletons

One of these observed features is the concept of a distinct, essential path undergirding each letterform: a letterform skeleton. While hardly new, the concept of a letterform skeleton has recently gained popularity.

Edward Johnston, in his 1906 book *Writing & Illuminating & Lettering* in the section "Simplicity," described a letterform "skeleton or structural plan" as one of the "essential forms" of letters (Johnston, 1948). He illustrated the skeletons in figure 142 of that book by showing "single pencil strokes, (as a child does when it "learns its letters")" and writing that through these simple lines, "we get a rough representation of their Essential Forms." (p.240).

Seventy or so years later, Adrian Frutiger reported an experiment that he conducted to define the most elemental shapes of letterforms. In his 1979 book *Type Sign Symbol* he showed overlapping screen versions of the "most widely used text faces of the world" to expose their shared "letterform skeletons."

> "The experiment makes it clear that the dark areas covering all the figures form a kind of basic skeleton for the type tool of today. These silhouettes have engraved themselves in the subconscious of the reader as a kind of elemental form." (Frutiger, 1979, p.64)

Frutiger went on to use this "elemental form," Johnston's "essential form," to guide his design for typefaces Meridien, Iridium, Egyptienne F., Serifa, Glypha, Univers, and Frutiger.

Both Frutiger (pg.60) and Johnston before him were careful to distinguish the letterform skeleton from a letterform grid. A system of related but different visual forms, such as alphabetic letterforms, is frequently based on a grid. Indeed, Frutiger's analysis of the Latin alphabet (Frutiger p. 60-61), as reinforced in multiple sources, showed that both upper case and lowercase Latin letters were based on a grid consisting of a square, divided horizontally and vertically into half squares. Compared to a grid, the letterform skeleton is the essential, the most basic linear gesture of the letterform whereas letterform grids, such as the one behind the 17th century Romaine du Roi, proscribed more detailed proportions of letterforms such as the ratio of ascenders to x-heights. Letterform skeletons are proportion free. Rather than defining proportions, they describe just the letterform's most basic formal gestures.

More recently, letterform skeletons gained recognition through the popularity of Gerrit Noordzij's book *The Stroke* (Noordzij, 1985 (2019 English version)). Like Edward Johnston and others before him, Noordzij studied handwriting/calligraphy as the elemental basis of letterform shapes. Noordzij defined the stroke through its multiple dimensions, the core of which was the midpoint, which he called the *heartline* of the stroke. This heartline, which is the physical center of the hand-drawn stroke, is very similar to the more conceptual letterform skeleton of typography. A student of Noordzij, Frank E. Blokland, wrote in 2012, "Commonly letters are treated as skeleton forms on which a certain contrast-flow is applied." He went on to quote Sumner Stone "It seems doubtful that Renaissance scribes thought of their letterforms as anything but organic units, but the abstractions to a skeleton form do capture the essence of the letters […]." Current type designer Filip Zajac defines the skeleton as "the fundamental constructional prerequisite of any letterform. Technically, it is a notional line that leads a nib. By the form of a skeleton, we distinguish letters from each other." https://medium.com/letterink/skeleton-type-design-explained-d443f146de97 Feb 26, 2017.

In 'skeleton-based type design,' a virtual pen 'nib' follows the letterform skeleton. Zajac believes this is the next great thing in typeface design, "Yes, I believe it is the next typo gig." In March 2018, Mohnish Tejan wrote: "Skeletons form the base for any structure, be it a human body or a letter form." https://www.behance.net/gallery/63430267/Letter-form-design

The letterform skeleton offers us an enduring concept that

FIGURE 3.

Perceptual features mapped onto Latin alphabet letterform skeletons.

Upper case top, lower case botttom.

describes the core visual structure of each letterform and, as a consequence, gives us the key to our ability to distinguish one letterform from another. It would be beneficial to understand the perceptual mechanism people use to discern the letterform skeleton.

4. Basic perceptual features mapped to letterform skeletons

Letterform skeletons are the core descriptor of letterforms. Basic perceptual features are an early and elemental step in visual perception. Conceptually, it makes sense that elemental letterform skeletons would have some relationship to basic visual features. It occurred to the author that an alphabet with effective legibility might be one that effectively utilizes different visual features. Adrian Frutiger anticipated this line of thinking in his design of OCR B when he sought a design in which "One letter may never be completely contained within another. Each must be different by certain additional elements" (Frutiger, 1989, p. 54). Similarly, in an effective alphabet, each letterform skeleton would likely activate different basic visual features. Remember, these basic perceptual features pop-out very quickly, making distinctions based on them advantageous to reading. Given the functional success of the Latin alphabet, I explored it through visual study. I hypothesized that each letter of the Latin alphabet would activate different perceptual features.

Demonstration

The first step was to identify the letterform skeletons. Following Frutiger's method for identifying skeletons, I superimposed the uppercase letters of the 10 most popular typefaces, adjusting to match x-heights. Of course, any top 10 list is debatable. For this study the list from the Creative Beacon was used because it reflected both my own impression of what should be in a top 10 list and because Creative Beacon's list had good diversity of styles: 5 sans serif and 5 serif; a geometric sans serif; two standard sans serifs; a humanist sans serif; a Didone with thin strokes; and a slab serif with even strokes. The typefaces used were: Helvetica, Garamond 3, Frutiger, Univers, Times New Roman, Futura, Bodoni, Franklin Gothic, Bembo, and Rockwell. Each letter of each typeface was given a linear fill at a different angle and superimposed. The resulting letterform superimpositions of the letter E are shown on the title page. These superimpositions became the letterform skeletons for my study.

Four basic perceptual features drawn from the findings of perceptual science: diagonal, curve; vertical, horizontal; are also illustrated on

the title page. The symbols represent neurobiological modules that respond very quickly (pop-out) to a specific visual feature perceived in the world.

I mapped four basic perceptual features onto the Latin alphabet letterform skeletons. Figure 3 illustrates which perceptual feature or combination of features are activated by each letterform skeleton. The mapping in Figure 3 does NOT attempt to trace the letterform skeletons but is instead a symbolic representation of the basic visual features each skeleton activates. This distinction is essential to understanding the power of this observation. Perceptual features define essential skeletal differences independent of any particular letterform proportion, length, or width. The mapped results are shown in Figure 3, uppercase on top, lowercase beneath.

Figure 3 demonstrates that most letterforms activate a different set of basic perceptual features. Cap A combines two angles and a horizontal; B a vertical and two curves; C a single curve; D a vertical and a curve; and so forth. Vowels are some of the most frequently used letterforms, and these each activate primarily one of the different visual features: A activates angles; E primarily activates horizontals; I activates only a vertical; O only a circle; U two verticals and a curve. Bolder forms in Figure 3 illustrate the vowels.

Test a less legible alphabet

It is not enough to prove the hypothesis by one successful mapping. It may be that basic perceptual features map equally well to all alphabets. In order to test this possibility, I mapped the same four perceptual features to the Hebrew alphabet. As already noted, the Hebrew alphabet is one of the earliest alphabets, is an ancient precursor of the Latin alphabet, and has known legibility issues (see *Figure 1*). If my hypothesis is valid it should identify and explain these problems. Using a similar process, I mapped the four basic perceptual features to Hebrew. This is shown in Figure 4. The previously noted similarities of T, H, and CH are obvious. Each of these activates two verticals and a horizontal at the top. For comparison, the Latin alphabet is shown below. I scrambled the orientation of each Latin letterform to limit the effects of similarity. Even given English readers' greater familiarity with the Latin alphabet, the lower diversity of combinations of four perceptual features in the Hebrew alphabet is obvious.

Test against easily misread Latin letterforms

Another test of the validity of this observation would be to apply it to Latin letterforms than have proven to be easily confused. If the observation is valid, easily confused letterforms will draw upon the same basic visual features with only slight non-basic feature modifications.

Using Sofie Beier's summary of the work of Tinker and others

FIGURE 4.

Perceptual features mapped onto Hebrew alphabet letterform skeletons. Hebrew skeletons based on: Ariel Hebrew, Ezra SIL, Myraid Hebrew, and David Hadash Formal Bold..

(Beier, 2012, p.71-73, Figures 6.1 and 6.4), the reader can compare the basic features of i – j – l; t – f; e – c – o; s– a; – n – u; w – v and see for themselves how each troublesome pair activates the same perceptual features with less impactful non-basic perceptual feature variations such as length (i – l), or flipped (n – u), or quantity (v – w). Length, flipping orientation change, and quantity are not basic perceptual features. Figure 3 shows that flipping alone has little impact on perceptual feature activation: a diagonal is still diagonal, a curve still a curve. Both n – u are two verticals and a curve. The fact that "n" has the curve on top and "u" has the curve in the bottom does not distinguish them as powerfully as a change in basic perceptual feature. Because flipping is not a basic perceptual feature, flipping does not pop-out. The basic premise stated above is that the feature is key: a curve is still a curve; a vertical is still vertical, so differences in length or flipping don't impact legibility as much as a perceptual feature.

Comparing upper and lower case perceptual features reveals that uppercase skeletons utilize more variations of horizontal, vertical, and diagonal and fewer instances of curve than lowercase letters which rely more on curve forms: 11 of 26 uppercase letters activate curve perceptual feature; 17 of 26 lowercase letterforms activate the curve. This uneven activation of curve makes sense given lowercase's roots in script writing.

5. Limitations

This paper reports not a formal research study but the exploration and verification of an observation: that letterform skeletons might correspond to basic perceptual features. As such it is filled with procedural assumptions such as the top 10 list of typefaces and the method of forming letterform skeletons by overlapping letterforms of different typefaces. While those typefaces were all "regular" weight, no allowance was made for outlier letterforms such as Snell Roundhand or Univers 39 Ultra Condensed, no attempt was made to find other ways to define letterform skeletons, neither readers nor typographers were consulted. The list of limitations is so long as to be hard to discuss.

I understand a theory to be a general explanation founded on several well-established observations of fact. A theory is different from a speculation in that a speculation has less evidence. This paper presents a speculation based on an observation which has been briefly tested. The speculation is offered as an invitation for others to explore and elaborate upon rather than as a procedural or methodological roadmap for others to follow. The observation may be sound even though the methods are flawed.

6. Conclusions

From this study, it appears that each letterform skeleton of the Latin alphabet activates a different basic visual feature or combination of basic visual features of perception plus non-basic features of reflection and duplication, and, in particular, that high-frequency vowel letters each activate a distinctly different visual feature set.

Let me unpack that a bit. These findings support the idea of letterform evolution, not in a Darwinian sense of random variation, but in the sense of human-guided change over time. The difference between the legibility of Hebrew and Latin alphabets demonstrated here supports, or at least hints at, the idea that some people in different places across time made changes to letterforms to make them work better in their eyes. Literally "in their eyes" since it would seem likely they made changes that made it easier for them to distinguish one letter shape from another. This observation is hardly novel. Daniel Berkeley Updike subtitled his 1937 history of printing types A Study in Survival (Updike, 1927). D. G. Pelli wrote in 2006, "It occurred to us that, through centuries of use, traditional alphabets might have been optimized to match the human visual system, making it difficult to design a new alphabet that would yield as high an efficiency (Pelli, Burns, Farell, & Moore-Page, 2006)." I quoted Frutiger earlier on the possible role of the "subconscious of the reader." What is novel here, I believe, is the suggestion that innate human perceptual feature differences are what drove those ancient, intuitive letterform design changes.

These findings revealed that high-frequency vowel letterforms activate different basic visual features. Having the most frequently used letters each activate a different visual feature would seem to produce maximum legibility. Even if it is proven ineffective, at least knowing that letterforms activate basic visual features gives researchers a tool to explore how frequently used letterforms relate to one another at a perceptual level.

These findings also support the notion that alphabets can be crafted based on the basic features of visual perception; that is, we can consciously design alphabets to leverage what we now know about basic perceptual features. One can imagine combining knowledge of basic features with knowledge of common letterform combinations in different languages to optimize the design of an alphabet for a specific language. The optimization would tweak common letterform pairs so that they accentuate different basic features.

These findings also suggest that, through research, letterforms correspondence to perceptual features might be used to develop measures of legibility, and that a legibility scale might be used to score the legibility of both individual letterforms in a typeface and a composite score for a complete typeface. Such a scale might be used to distinguish a text from a display typeface, or even to identify typefaces more suitable for long texts than short ones.

These findings support Gerrit Noordzij's observation that quickly written cursive letterforms impede legibility (Noordzij, 1985 (2019 English version), p. 39). The continuous stroke of cursive continuously changes direction and thus creates a skeleton of continuously changing orientation. The speculation here would predict that such variety would impede legibility.

The findings presented here, if accurate, suggest that

letterform skeletons have evolved to activate basic perceptual features, that Noordzij's "unconventional shapes" are those that deviate from letterform skeletons, and that the letterform characteristics, Frutiger's "cultural heritage" that we should resist changing, are those that violate the unchangeable neurobiological nature of visual perception.

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