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Measures of *Prägnanz?*

Prägnanz was suggested by Wertheimer (1922/23) as subsuming all "Laws of Gestalt" as they apply to visual awareness. He had already presented the idea at the Congress of Experimental Psychology in 1914. He mentioned "… a law of the tendency toward simple formation, according to which visible connection of the position, size, brightness and other qualities of components appears as a result of … Gestalt apprehensions …". Köhler (1920) extended the law from the phenomenological domain to the physiological domain and also the physical domain.

Although called "law", Wertheimer did not frame a formal definition. Thus the "law of Prägnanz" is like a theory in physics, ever in development (Feynman, 1967). The fact that the law is in common use identifies it as a vital concept. Indeed, it has let to many, mutually distinct, formalisations, a few of which are mentioned below. We do not feel that any of these may claim the exclusive right of the term, but rather that these mutually complement each other.

We are primarily interested in the scale issue here: can one *quantify* Prägnanz? Or, perhaps better, are there interpretations of the concept that allow for quantification? This implies that one perhaps has to deviate somewhat from Wertheimer's original ideas. We also deviate from the current literature, which predominantly seeks to define Prägnanz in terms of stimulus structure: we consider *biological factors* to be crucial to the issue. Our attempt is frankly an explorative one.

We use the original German word "Prägnanz" as an internationally accepted technical term, like "Gestalt" or "Umwelt" (mentioned later).

Experimental Phenomenology

Prägnanz is synonymous to "good Gestalt". What does it mean? The answer cannot be a straight definition, for, like pornography, "you know it when you see it" (as suggested by United States Supreme Court Justice Potter Stewart in 1964, see Gewirtz, 1996). A good Gestalt is both simple and unique. "Simple" means that a good Gestalt is fully seen at a glance. It is an "eye catcher". "Unique" means that nothing can be added or omitted without causing a qualitative change. Such conjunctions are remarkable because simple things tend to be mutually similar (think of eggs) and thus not particularly unique, whereas unique things tend to be complex (think of keys or passwords) and thus not particularly simple. Simplicity and uniqueness go badly together. One deals with a precarious tension, which is exactly what makes "good Gestalts" so remarkable.

Fine examples of high Prägnanz are visual designs such as Japanese family emblems that appear to strike the "perfect balance" between simplicity and uniqueness. We encounter similar balances in the visual arts and (especially) design of the West. Think of the art nouveau floral designs, for instance.

The simplicity/uniqueness conjunction is indeed a major aspect of good Gestalt, yet there are other aspects that have to be taken into account:

- Gestalts are not *singular*; they are experienced as instances of an enveloping taxonomy, a "style" (see later).
- Gestalts have *biological relevance*; thus, they exist relative to observer – agents.
- Gestalts have *physical causes*; thus, they exist as objects or processes of the natural environment of particular biological relevance.

The latter two points can be subsumed under a biological perspective (mentioned later) by taking the Gestalts as relative to the *Umwelt* of the agent. All these factors have obvious relevance to the definition of Prägnanz measures. In Wertheimer's experiments, the biological and physical aspects were downplayed, whereas the context was implicit and artificial: either that of simple line drawings or sequences of elementary sounds.

Biology

The most extreme instances of "good Gestalts" are the "releasers" of ethology. Here, certain specific optical structures trigger vital animal behaviors with the animals apparently having no choice in the matter (Riedl, 1984). In fact, it may even be to their occasional disadvantage, as when swans feed fishes instead of swan chicks or a small warbler parent feeds a cuckoo chicken measuring twice its size. The releaser is like a key that opens the lock of a behavior pattern. In case of human beings, we find similar, though rather less extreme, examples in the effects of patterns of facial cosmetics such as hairdo, outlining the eyes in black, or coloring lips or cheeks.

Releasers are special because of their dominating effect on behavior. Yet, as Tinbergen (1951) has shown in a number of remarkable cases of "supernormal stimuli", even the Prägnanz of releasers can often be augmented. They are only as good as required in life's context. When "good enough", further improvement hardly matters to biological fitness.

The releasers obviously promote biological fitness on the average, suggesting a relation between Gestalt and *affordance* (Gibson, 1979). Von Uexküll (1909) speaks of *functional tone*. The relation to the phenomenology is obvious. Affordance implies uniqueness and simplicity. It optimizes making the best choice in given settings. Releasers are key elements of a user interface whose design is honed through long periods of evolution.

The releasers exploit Herman von Helmholtz's principle (*we immediately perceive whatever could not happen by chance*, see Desolneux, Moisan, and Morel, 2008) by raising the likelihood of a given vital circumstance almost beyond all odds. This is done by exploiting uniqueness to raise the odds and simplicity to ensure automatic detection. An analysis along these lines was developed by Bod (2002). The famous example is the releaser "mammal" for the female tick (which is blind and deaf): *the conjunction of warmth and the smell of butyric acid*. Compared to any dictionary definition of "mammal", this is remarkably simple and unique.

Thus, the concept of biological fitness perhaps serves as a likely handle on the understanding of the phenomenological notion of Prägnanz. No doubt this applies to human beings too, although here the number of behavioral alternatives is usually too high to speak of "releasers".

Formal Structures

Simplicity and uniqueness can be *quantified* in formal systems. The prerequisite is existence of a well-defined universe of discourse. If "anything goes", neither simplicity nor uniqueness is defined, but when the universe is delimited, essentially all that is left to do is to count. A biological system is not like a clockwork whose mechanism was designed a priori by some clock maker. Animals have no predetermined function or use. Thus, for biological organisms, anything goes – in principle. However, organisms count on experienced regularities, accumulated over periods ranging from evolutionary time spans to the previous moment. They do okay for themselves by acting as "hypothetical realists" (Riedl, 1984; Vollmer, 1975). Contemporary thought would no doubt mention Bayesian judgment (Knill & Richards, 1996). Given time, organisms will adapt to any enduring structure, as they so often did in the past. Of course, this implies that simplicity and uniqueness are of the highest importance as abstractions from the structure of perception–action loops. Gestalts are objects of the "counter world" or "mirror world" in von Uexküll's "new loop".

Thus, regularities in the physics of the organism's *Umwelt* as noticeable by the organism are likely to structure its "inner world". This suggests that the formal structure of the physical world is likely to be mirrored in the mental makeup of organisms, at least to the extent that their inner worlds contain projections of such regularities. These "mirror worlds" are the organisms' *user interfaces* to the physical world at large (Hoffman, 2009). Whereas the physical world is meaningless structure, the interfaces are meaningful throughout. These meanings are necessarily idiosyncratic. Canine and feline interfaces are so different that cats and dogs live in distinct realities – even in the same physical environment. Again, human reality will be different from that of a pet animal.

Whether such regularities originate in the physical or the mental worlds becomes something of a chicken-and-egg problem. Causality becomes undefined in a circular process. It would seem that the phenomenology, biology (or ethology), and physics subtend a tight nexus that can hardly be pried apart. Too strict a distinction carries the cost of having to introduce some kind of "glue" like a psychophysical bridging hypothesis (Lewis, 1972). This insight is of major importance: for a measure of Prägnanz, one should not just consider the *stimulus* (the physics of the environment as limited to the Umwelt) but equally the *organism*, especially its affordance structure. The *same optical pattern* may trigger mating behavior in one species – thus implying infinite Prägnanz – and be irrelevant – perhaps implying zero Prägnanz ("noise" or irrelevant chaos) – to another.

Psychology proper appears too narrow a discipline to allow for a definition of Prägnanz, because it is entirely anthropocentrically oriented. One should widen the scope and consider *Homo* as just one member of the animal kingdom.

Algorithmics

As mentioned earlier, given a well-determined universe of discourse, simplicity and uniqueness become a matter of counting. However, "counting" can be done in numerous ways and is thus an art. For specificity, we introduce a simple example: 32×32 (1024 pixels) 1 bit (black or white) images. Figure 1 shows some examples. Although the example is specific, the principles discussed here have very general applicability.

These examples are not really *generic*. For instance, the kanji *mu* is the answer given by Jōshū Jūshin (778–897) to the question "does a dog have the Buddha nature?". Conventional translations of *mu* are "Yes!", or "No!", which are to be considered as mutually equivalent. Apparently, the 32×32 1 bit format allows for some serious messages.

Fig. 1 Some images in the 32×32-pixel image space. With some good will, one may be able to make out the *kanji* "Mu", a "smiley", the "Mona Lisa" and Kazimir Malevich's "Black Square". Each image would have only probability $2^{-32\times32}=5.6\ldots10^{-309}$ to occur by chance, so we made them up expressly for this example; we could hardly search or wait.

Suppose one takes one such message in mind, say the Mona Lisa. Can one guess it in a "twenty questions" game? Not in a simple way, say asking "is the pixel at 5 to the right and 7 to the top white or black?", because one would need to ask $32^2 = 1024$ questions in order to determine all pixels. These 1024 questions allow one to determine *any* 32×32 image, all 2^{1024}, that is approximately $1.8 \ldots \times 10^{308}$ of them.

One might be able to do better by not asking for *all* pixels. How many might do? From figure 2 one estimates that one may do with perhaps only three-quarters of the pixels. However, this hardly renders the problem tractable. This is the famous dactylographic monkey's theorem: given time, a randomly key hitting monkey is certain to type out the Book of Genesis. This idea is perhaps due to Borel (1913). The writer Jorge Luis Borges famously used the theorem in his story "The Library of Babel" (1941).

Apparently, one needs another technique. How about this – a record from the game of "20 questions":

Q1: Is it a work of the visual arts? A1: Yes, a work of the visual arts.

Q2: Western or Eastern tradition? A2: The Western tradition.

Q3: Before or after common era? A3: After common era.

Q4: Before or after the Middle Ages? A4: After the Middle ages.

Q5: Pre or post baroque? A5: Pre baroque.

Q6: Northern or Italian Renaissance? A6: Italian Renaissance.

Q7: Venetian or Florentine? A7: Florentine.

Q8: Artist a painter or sculptor–painter? A8: Mainly a painter.

Q9: Painting in the Louvre or Uffizi? A9: Currently at the Louvre.

Q10: Might it be *La Giaconda*? A10: You won; it is the Mona Lisa.

Fig. 2 From left to right, we randomly flipped 50%, 25%, 12.5%, 6.25%, and 3.125% pixels of the Mona Lisa image. Apparently, one does fine without 10% of the pixels. By squinting, one will find 25% hardly doable but 50% not at all. This defines the "fringe" of the Mona Lisa in the set of 32×32 1 bit images.

Here one proceeds in huge steps, often taking considerable risk, and in some cases, technically cheating. This is guessing or hallucinating, guided by a large body of cultural knowledge. However, notice that 20 binary questions will allow one to differentiate between 2^{20}, that is over a million alternatives. When one's questions are ternary (hoping that pre or post baroque might also reveal "baroque"), 20 questions get one in the thousands of millions range. Apparently, this works great. However, one has to be expert at the game. *One needs to be able to generate relevant questions*. It means one needs to be familiar with the territory – art in the example.

Consider figure 3. There is obviously no way to deal with these images; the 20 questions technique is powerless because one cannot draw on one's background knowledge bases. There are no experts in this case. The nice pictures of figure 1 are actually very *singular* images that one will hardly ever find in the 32×32-pixel image space. Yet, one will encounter millions of such "interesting" images given sufficient (nearly infinite) time to search. One may find one's initials in beautiful calligraphy. Millions count for nothing; this "nice" subset has almost measure zero (see later). No patience suffices because of the limited life spans of biological organisms.

"Nice" images can be guessed in the 20 questions game, whereas *most* images cannot. Thus, generic images have very low Prägnanz due to their lack of "structure", which is again due to the fact that they have "too much" structure. Having "structure" implies that the images belong to a small subset of the full space of images. It is a simple matter to construct examples of such sets. Images from a small set are easy to distinguish once one "knows" the set. However, observers can only somehow grasp the structure of the small set by its "style", that is to say *its physiognomic properties*. Here, we meet with the ideas of Rosch (1983) and Lakoff (1987).

This is important. A random subset of the full set of 32×32 1 bit images may be small – say just composed of the quintuple of figure 3 – but is no good without "style". Without a common style, the set can only be known through exhaustive

Fig. 3 A generic sample of five images from the 32×32 1 bit image space. The reader may have a hard time to keep them apart. The full set contains crude (32×32 black and white icons) renderings of every photograph ever made or yet to be made, all Chinese characters, a crude copy of the Mona Lisa, and so forth (see figure 1). There are lots (as many as one wants) of such "interesting" images, yet the probability to encounter one of these images by accident is practically nil. Indeed, the capacity of "God's Eye" that readily differentiates between all these images is way beyond human imagination.

description. The set of five images shown in figure 3 is such a set that lacks "style". Not just any prescription counts as a "style". The set of images shown in figure 3 may well be unique in God's Eye (Koenderink, 2014), whereas for human beings, it is just one of the 1.6 … 10^{1539} (binomial $2^{32\times32}$ over 5; essentially infinite!) subsets of cardinality five of the 32×32 1 bit images. Recognizing "style" implies that one can produce another instance of the same style on call. This again implies that doing so involves only a few degrees of freedom – *for this observer*.

This is superficially similar to the formal method of "minimum length description", which has been formally developed to great length (Leeuwenberg & van der Helm, 2013). Such methods dominate the technical literature. They essentially ignore the observer and concentrate on the stimulus, a practice Köhler would have welcomed. The minimum length description ("Kolmogorov complexity"; Kolmogorov, 1965; Zurek, 1989) attempts to exploit symmetries in the structure, the internal redundancy, that allow for short encoding.

The notion of "style" is psychological rather than algorithmic (figure 4). It is closely related to Rosch's understanding of psychological categories or von Goethe's (1790) understanding of empirical science, as exemplified in his account of the "primordial plant". Rosch's "typical" member becomes Goethe's transformational principle that generates members of a set that is properly "understood". This is what is meant by "one knows it when one sees it". A high Prägnanz implies being a perfect member of a well-recognized style.

Indeed, if the images of figure 3 can be said to have "style", it is something like "random texture of fifty/fifty white/black checks". This immediately renders the

```
long x=0x7fffffffffffffffL;void set
up(){size(100,100);frameRate(2);}vo
id draw(){stroke(0);background(255)
;for(int i=0;i<100;i++)for(int j=0;
j<100;j++){x^=(x<<21);x^=(x>>>35);x
^=(x<<4);if(x%2!=0)rect(i,j,1,1);}}
```

Fig. 4 This string of characters is a short Processing2+ program that will generate ten 100×100 Julesz patterns (Julesz, 1981) per second, for as long as one cares. The reader may go ahead and try. It is a linear sequence of 210 characters taken from a set of 46. The initial part of the string is only used at startup (less than a millisecond). The program then simply repeats the remaining part two times per second, essentially "forever" (actually it repeats (roughly) once every 1872 million years, if your computer holds out). It could do so much faster (that would shorten the string), but one would not be able to follow what happens. The impression is a sequence of "random Julesz patterns". God's Eye would not be fooled, whereas it would be powerless in case of a truly random sequence. To a human observer that makes no difference. The program yields upper bound on the Kolmogorov complexity of Julesz patterns, cutting down apparent complexity by an immense factor. The program achieves this only *given* a suitable platform (electronics, operating system, etc.) and JAVA software environment. It is not different in biology; DNA (the string) is not everything, the "proper" environment counts too.

set trivially simple. One effortlessly draws arbitrarily many instances with a single, short line of Mathematica code (even the short Processing2+ code in figure 4 is overkill). From the perspective of human visual awareness, this huge(!) set is rather uncomplicated or even boring. This illustrates that relevant measures of complexity cannot be merely stimulus-based.

The implication is that one has to become aware of the physiognomic "style", a ghostly cloud that envelopes the instance, perhaps only generated on the basis of a view of the single instance. We refer to such clouds as "eidolons". They contain shape-shifted doppelgänger of the original. Partitioning the world into eidolons was the task Adam and Eve were set to in the Garden of Eden, to generate the taxonomies of the animal and vegetable Kingdoms: "**19** And out of the ground the Lord God formed every beast of the field, and every fowl of the air; and brought them unto Adam to see what he would call them: and whatsoever Adam called every living creature, that was the name thereof. **20** And Adam gave names to all cattle, and to the fowl of the air, and to every beast of the field" (See Genesis 2, King James Version). Apparently, our forebears did well, for modern DNA-based cladistics had few occasions to put them right. Those human beings were able to do this points to a remarkable power of the human mind, although hardly anyone seems to have noticed: it just happened. Indeed, one recognizes feline or canine style in animals on the basis of just a few typical instances, without so much as thinking twice. There is no need to train as a zoologist either.

How Visual Awareness Arises

Psychogenesis of visual awareness is a legato-style, systolic process of "controlled imagery". It starts with dreamlike states that diversify and articulate into more specific "hallucinations" that can be checked against the current content of the sensorium. Fancies that apparently provide a bad fit are ruthlessly pruned (Brown, 2000). Psychogenesis is like the evolution of species in that much imagery is tried but few survivors remain. One's awareness is populated with these survivors. The moment they occur, they are replaced by the next wave, which is already on its way. Such a system can freewheel in the absence of any optical input and always yields the "best explanation" for the current optical structure. Here the measure of "best" is given by the lifestyle; it is different for the tiger or the lamb. The process is "top down", because optical structure has nothing to do with it – it is exactly the same for the tiger as for the lamb.

The sensorium is a volatile buffer, continuously overwritten by the current optical structure impinging on the eye. This structure is variously sifted and packaged by the action of mechanisms such as Hubel and Wiesel's (1959) "line detectors" and so forth. Conceptually, it is much like the file of a forensic investigation in that it contains tons of potentially relevant but rather more probably irrelevant structure. Here the ideas of Brunswik and Kamiya (1953), Gibson (1979), and others pertain. The process is a "bottom up" one because it is purely *data driven*.

The combined machinery implements something like the 20 questions game. Psychogenesis asks questions – the hallucinations, or "seek images" (von Uexküll's *Suchbilder*) – and hunts for answers (or "fits") in the sensorium. This "blackboard" contains familiar summaries such as edge maps, color maps, and so forth. These are meaningless structures, any meaning deriving from a question. Only in the context of a question may meaningless *structure* become meaningful *data*. Here is the origin of mental objects to be found (Schrödinger, 1948).

The questioning, or probing, derives from the current emotional state, situational awareness, current goals, and so forth. The meanings are user interface objects, which are mental objects like qualities or affordances. A visual object is thus embedded in a meaningful context against which it individuates, a bit like Searle's (1983) "background". Here is where we have to look in order to construct a measure of Prägnanz.

Measures of Prägnanz

From a phenomenological perspective, some visual stimuli evidently "have more *Prägnanz*" than others, so Prägnanz appears to be an *intensive quality*. This calls up the question of *can one measure it*? That is to say, can Prägnanz be expressed in terms of a single number at all? Intuitively such a number should be positive and dimensionless, that is to say a pure quantity (Michell, 1999). Well, maybe not quite, for it is at least *conceivable* that some stimuli might so *confuse* the observer that the Prägnanz might even become negative. However, this is evidently not a mainstream conviction. For instance, Wertheimer would perhaps not have accepted it.

Consider what properties might characterize such a measure. First of all, it should be small not only for trivial patterns *but also for very complicated ones*.

For a simple, trivial pattern, there is "nothing to see". They "all look the same", because – in some sense – there *are* only few. The style of a very simple pattern is simple and leaves very little room for transformation. Thus, a uniform patch should probably receive measure zero as the single member of a one-member style.

On the other hand, Julesz patterns are equally trivial, for they all "look the same" too, although in this case, they are all really different. Thus, noise patterns should receive a very low rating, perhaps even measure zero when the observer chooses to ignore (or perhaps more likely willy-nilly ignores) their mutual differences. The style is trivial, and transformations are perceptually equivalent to the identity.

The measure of Prägnanz should peak for patterns that somehow "look interesting". We submit that "cowhide patterns", a minor subset of the Julesz patterns, fall into this general area (figures 5 and 6; see appendix for technical details). "Look interesting" means that the style is recognized prima facie, so that the productive imagination may come with countless instances due to the transformation of a few instances. "Interesting" also implies possibly high biological significance.

"Style" is implemented as a constraint on chaos here. In the case of the cowhide patterns the constraint is a very simple one. What is interesting is that it is almost immediately recognised. Even without knowledge of the actual algorithm, most people would be able to draw novel cowhide patterns on call, at least patterns that would be "close" (in the sense of the eidolon clouds) to "true" cowhide patterns. Observers tend to understand the constraints in terms of generative principles.

Evidently, a simple, entropy-like measure (Boltzmann, 1905) will fail to apply because a uniform pattern would have zero entropy (Shannon & Weaver, 1949), whereas a noise pattern would gain a very high one. This is an interesting observation because it implies that a Prägnanz measure is apparently not just a measure of

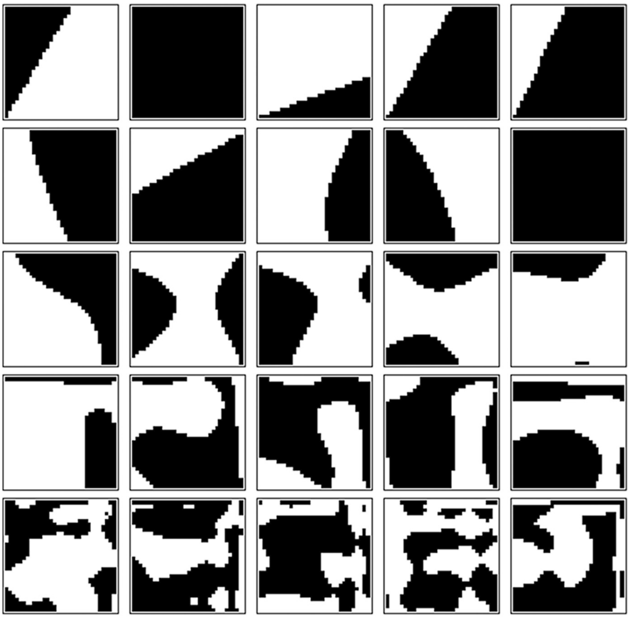

Fig. 5 "Cowhide patterns" like these are "individuals" who would easily be recognized again. They should receive a high *Prägnanz* rating (compare figures 1 and 2).These patterns were generated by a single stochastic algorithm. The degrees of freedom of the subsets are (rows from top to bottom) 2, 5, 14, 44, and 152. Notice that the top row patterns look trivial and the bottom row patterns perhaps confusing. "Good" cowhide patterns come in rows 3 or 4. One may design infinities of them, all different, yet they reside in a subset of measure zero in the space of 32×32 1 bit images.

stimulus structure. It also depends upon the *observer*. This is a crucial observation. One is dealing with *psychology*, not just structural complexity or information theory, which are independent of the observer. Indeed, in "God's Eye" (Koenderink, 2014), the noise patterns would all look different from each other and would deserve a high Prägnanz. On the other hand, to organisms with rather limited visual discrimination as compared to *Homo* (us!), patterns that look very Prägnant to us – say the cowhide patterns – would necessarily appear all the same, like noise patterns do to us.

A suitable Prägnanz measure thus *only nominally* applies to stimuli, which are observer-independent optical fields, but it must reflect the visual capacities and interests of the observer. One simply cannot skip psychology and biology. This becomes immediately evident if one considers the same patterns "as seen by" a set of mutually very different animals. The relevant concept to introduce here is von Uexküll's (1909, 1920) notion of "cue world" (*Merkwelt*). The organism only reacts to the aspects of the stimulus that fall into its cue world. The cue world cannot be simply measured in terms of visual acuity and contrast sensitivity, that is "optical channel capacity". It is not to be described in terms of "pixels", but in terms of cues, that are "proto-affordances" occurring in the sensorimotor loops that link the cue world to the "action world" through the physical environment. The organism "knows" the physical world only as its "counter world" or "mirror world" that plays a functional role as "optical user interface" (Hoffman, 2009; Koenderink, 2011) in its life.

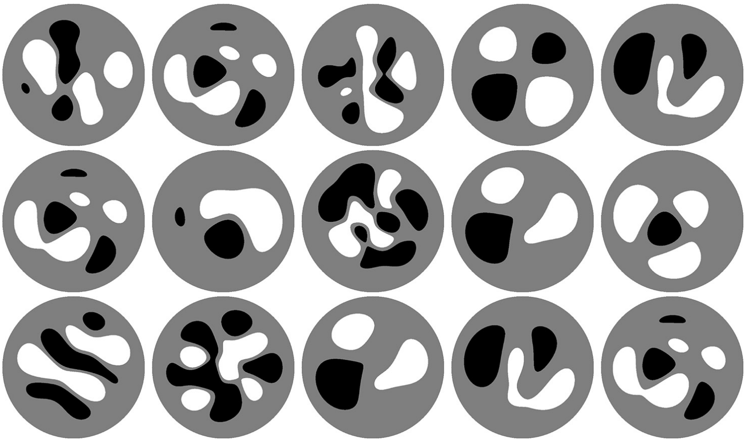

Fig. 6 The cowhide pictures shown in the previous figure were computed on a 32×32 grid. However, drawing them in arbitrary resolution does not increase their complexity. The ones in the present figure were generated with a very simple algorithm. They have only nine degrees of freedom. Notice that one needs to see several instances in order to be able to pick up the style; a single instance does not suffice.

Striking examples of alternative user interfaces in *Homo* are optical agnosias (Farah, 2004) known as *amblyopia* (Webber & Wood, 2005) or *tarachopia* (Hess, 1982). In cases of "scrambled vision", the physiological channel capacity is normal – as compared with the generic human observer – whereas the cue world is severely contracted. In the case of tarachopia, the physiological causes are unknown; thus, it has to be termed an agnosia (*Seelenblindheit*; see Munk, 1890). In animal ethology (Lorenz, 1970, 1973; Tinbergen, 1951), many "releasers" yield striking instances of such agnosias, although in the animal case; one should perhaps talk in terms of "template structures". However, there is accumulating evidence for the importance of template-like structures in human beings too.

For the "God's Eye" view, an appropriate measure of Prägnanz would perhaps be raw structural complexity, an entropy measure applied to the optical stimulus. Only uniqueness counts, since *everything is equally simple*. For images composed of N black or white pixels, the measure would be N bits. There are $W=2^N$ distinct images; thus, this equals to ld W (ld stands for the logarithm base 2), the entropy. This is the God's Eye limit (figure 3).

For the rest of us, who are strictly less than All Seeing, the patterns of high structural complexity would be hardly Prägnant because merely confusing. Only a few (figures 5 and 6) might draw our attention. Here we need a biological insight. For all sentient beings, a high Prägnanz implies a high potential relevance in terms of its life's challenges. This indeed involves at least *some* structural complexity and also a fit to its set of affordances (von Uexküll, 1920; Gibson, 1979), its *lifeworld*.

Prägnanz thus becomes a measure for the potential realm of actions suggested by the stimulus. It becomes a measure of "potential interest". We believe this to be the crux of the matter. The random dot patterns are largely irrelevant to any potential action, which explains why they are boring and lack Prägnanz.

This seems to fit the notion of "releasers" in animal ethology as mentioned earlier. Indeed, the pattern of chick beaks to the parent gull, the egg outside the nest to the greylag goose (Lorenz, 1970), and the red belly of the male to the female stickleback fish (Tinbergen, 1951), are striking examples of the highest possible levels of Prägnanz, since they actually trigger vital behavioral patterns, the feeding of the young and mating opportunities.

There are numerous examples of apparently dysfunctional, one might say "purely visual", examples too. Think of the empty beer bottles along the roadside humped to exhaustion by male Australian jewel beetles (Gwynne & Rentz, 1983). The extraordinarily high *Prägnanz* of the empty beer bottles almost led to the extinction of this species. They react to an optical structure that, by sheer coincidence, turns out to carry a super-pornographic affordance *for them*.

This illustrates that affordances belong to the animal's interaction with the world, but not to certain physical objects as such. Beer bottles carry no special pornographic affordances to human beings. This is an important point that was ignored by Gibson (1979), who placed the affordance of "throwability" in the stone. Von Uexküll (1920) got it right. His example of the toad attempting to eat match sticks yields a vivid insight in how affordances come to be (von Uexküll, 1934).

Thus, we find two, mutually quite distinct, aspects to the notion of Prägnanz. One has to do with the structural complexity bottleneck of visual systems. The other has to do with the relevance to the organism's biological fitness, one might say the affinity to its optical user interface. The Prägnanz measure we are looking for should necessarily cover both.

In the case of *Homo*, the former aspect is likely to dominate, as the repertoire of possible actions is so large as to be noneffective in the computation. Possible exceptions include cases of exceptionally tasty dishes (pictures in *haute cuisine* magazines), high sexual interest (pornographic images), or potential lethal situations (iconic death head signs, etc.). However, such cases do not play a role in generic laboratory situations – we think of experimental situations that would typically be set up by a scientist like Wertheimer. A square has higher Prägnanz than a regular octagon, but where is the challenge to life's problems here? Here, the bottleneck dominates. Regular convex polygons with many vertices tend to be mutually confused since they all look like circles (figure 7; see Metzger, 1936).

The case of *Homo* is thus an instance in which the definition of a Prägnanz measure might be defined in some generality, because in this case, the cue world might be characterized to sufficient detail by a *structural complexity bottleneck*. Think of the "*magical number seven, plus or minus two*" (Miller, 1956) that most likely overestimates this bottleneck by a factor of two. For vision, the (soft) limit is perhaps more like three or four, close to the theoretical optimal chunk size (Dirlam, 1972). The actual pictorial content no doubt plays a role too, but *being recognized as a "picture"* – as distinct from being "featureless" or "just noise" – comes even before that.

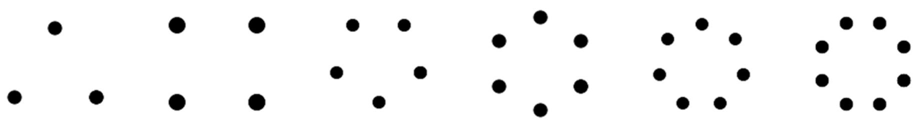

Fig. 7 Some regular polygons suggested by their vertices. The hexagon still looks like a polygon, although it has less Prägnanz than the triangle or the square. The octagon looks already like a circle to us; it has low Prägnanz *as a polygon* although it makes a reasonable circle. Recognition of "the" style crucially codetermines Prägnanz.

Suppose the stimulus is characterized by a certain structural complexity N, whereas the cue world extracts a maximum structural complexity M (both N and M measured in bits, as earlier). Then, when $N<M$, the system can use all structure in the stimulus, and we may take the measure of *Prägnanz* to be just N, the structural complexity of the stimulus. However, when $N>M$, the structural complexity of the extracted cues cannot exceed M and thus does not grow with N. Here, the limited structural complexity bottleneck becomes decisive. The measure of *Prägnanz* cannot possibly exceed M.

Notice that there are binomial N over M (say "Q") ways to extract M bits from N given ones. Thus, the stimulus is confusing, leading to a loss of ld Q bits. Hence, the measure of Prägnanz is only (M–ld Q) for $N>M$ and should possibly even be set to zero when the stimulus is more confusing than informative. In the latter case, the expression would become negative, which might apply when the observer is unable to ignore the stimulus. This measure of Prägnanz peaks at $N=M$.

Thus, one sets (maximum normalized at unity):

If $N<=M$ then $P=N/M$

If $N>M$ then $P = \max[0,M - \text{ld } B(N,M)]/M$

($B[i,j]$ is the binomial "i choose j")

Of course, the above reckoning is very abstract and general and does not take the specific nature of the cues into account. However, it is always possible to specialize to specific cases. The affordance may be used to weigh the structural complexity, and the nature of the cues will be different according the stimulus domain. For instance, for black and white checkerboard patterns, one may simply treat the squares as bits, whereas for a line drawing, one would perform an analysis similar to Attneave's (1954) well-known cat drawing before calculating the structural complexity of the stimulus, that is N. There are numerous possibilities, but they can all be treated in a similar way, since entropy yields a "common currency". Figure 8 applies to the patterns shown in figure 7 without further analysis.

Does this work? Well, such a measure as introduced here at least accounts for the most basic properties of Prägnanz. Of course, it is not that hard to think of a variety of possibly relevant qualities that one might like to cover in addition. However, this would likely turn out to be a self-defeating action.

Most embellishments will raise the dimension of the Prägnanz measure, as this will typically be the only way to increase its "resolution". However, this runs

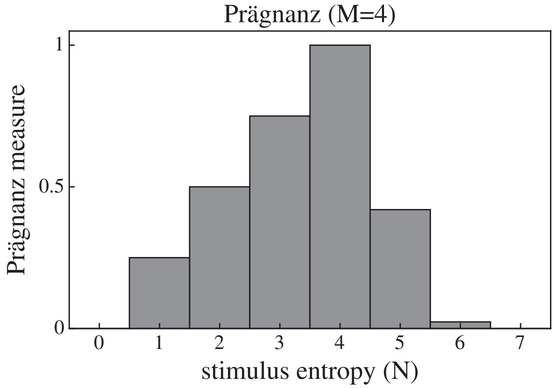

Fig. 8 The Prägnanz measure for $M=4$. The measure peaks at $N=M=4$ (value normalized to unity), is zero for $N=0$ (trivial stimulus), and drops precipitously for $N>M$. The Prägnanz measure is zero for $N>6$. Here, we assumed that the observer knows how to ignore abundant confusion, so we clipped negative values. Notice that this measure appears to describe the Prägnanz of the patterns in figure 7 quite well.

evidently against the grain of Wertheimer's intention, as it would decrease its simplicity. If Prägnanz is going to be a simple – thus scalar – measure, it has to admit of a simple definition and cannot account for a multitude of qualities.

We submit that a Prägnanz measure has to be either something like that proposed here or it can hardly be given a quantitative measure at all. Notice that our formalizations place the notion of Prägnanz squarely within the realm of ethology. The measure does not singularly refer to the stimulus but even more so to the *observer*. To look for Prägnanz in the stimulus implies a rigid God's Eye's view and in many instances an anthropocentric attitude, which is – at least in this context unfortunately – the rule in psychology. Without extending the universe of discourse to animal ethology, one arrives at a quandary.

An Experiment

We performed a simple experiment at the University of Sassari involving 101 naive participants of both genders (68% females), median age 21 years (interquartile range 19–23 years), using the patterns shown in figure 6. We asked to indicate the suitability of patterns as a logo on a 5-point scale. Remember that logos need to be both eye-catching and distinctive. The results are variable.

A cluster analysis reveals four main clusters. One cluster (18%) shows no preferences at all; we ignore it as noise. There remain three major clusters. These clusters clearly exemplify the major tendencies that compete in the Prägnanz measure.

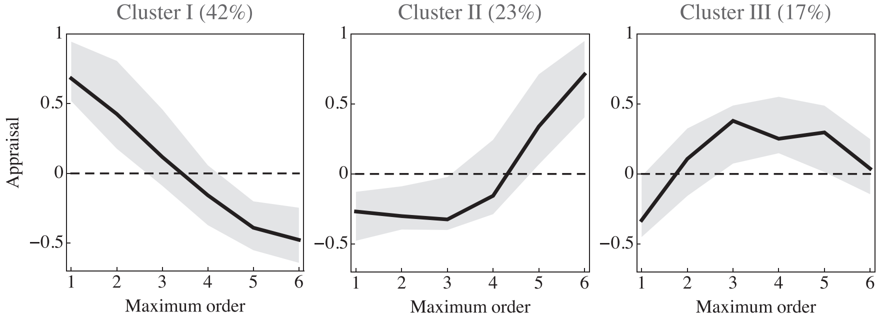

Fig. 9 The preference for patterns as shown in figure 6 rated by suitability for a logo. We show the main clusters for an experiment involving a hundred naive participants. The first cluster essentially values simplicity, the second cluster distinctiveness, and the third cluster the attempt to arrive at a balance, which represents the Prägnanz of a pattern *as a logo*. The gray ribbon indicates the interquartile range and the black curve the median. The appraisal is in terms of the 5-point scale; "0" denotes the midpoint. The maximum order serves as a convenient complexity measure. Notice that individual curves are often much more pronounced and may use the full scale.

The largest cluster is a preference for simplicity and the next larger cluster a preference for complexity. The third cluster clearly involves a balance, which makes sense, because logos should be "eye-catching" (thus simple) but distinctive (thus complex) (See figure 9).

Especially, when one looks longer, the complicated patterns often start to "make sense", looking like faces and so forth. This makes them suddenly appear much less complex and may well be one reason for the trend in cluster II. Such experiments as this illustrate the elusiveness of a measure. This hardly detracts from the importance of the concept though.

Such an experiment is in many respects similar to what may be found in the literature (Checkosky & Whitlock, 1973; Chipman, 1977; Markovic & Gvozdenovic, 2001) except that the instructions differ.

Conclusion

Wertheimer's notion of Prägnanz has remained enigmatic, despite the fact that it is intuitively exactly what is called for. In our view, this unsatisfactory situation derives from the fact that the literature often fails to recognize the importance of factors different from mere stimulus structure. What is missing is the biological perspective, which includes the relevant psychological perspective. Indeed, psychology without reference to biology cannot avoid the anthropocentric fallacy. Inputs from mathematics (structural information theory), psychology (the physiognomic bottleneck, affordances), and biology (ethology, the notion of biological fitness) all have to be considered.

Birkhoff's (1933) "Aesthetic Measure" (order over complexity) is as good as any; it sums up the formal mathematics involved. However, the problem then is how to quantify "order" (or "simplicity") and "complexity". The latter measures cannot be drawn from structural information theory, which only considers the stimulus. These measures must involve biological considerations, including (in the case of *Homo*), though not replacing, psychological considerations.

Some relevant issues derive from physiology and experimental phenomenology. Physical structure that cannot lead to changes in the state of the sensorium should be ignored. That is to say, optical structure can only be considered a "stimulus" to the extent that it fits the agent's cue world. However, there is more. A "stimulus" is only worth taking into account if it plays a role in the agent's action world, as well as its lifeworld. The red belly of the male stickleback fish is hardly more remarkable than a rosebud or a reddish pebble to a human observer, but it triggers vital behavior in stickleback females. The female fish has an extreme physiognomic perception of the red belly or indeed any red blob of about the right size. It primarily experiences a strong affordance, relative to the structure of her lifeworld. On the other hand, the extreme complexity of the immediate environment (pebbles on the stream bed, ripples in the water surface above, random patches of sunlight filtering through the trees near the stream) counts for little and is largely ignored. Thus, the challenge is due to ethological factors, rather than the mathematics of structural complexity.

The above ethological discussion still fails to consider many relevant facts. For instance, many plants generate flowers that appear as highly Prägnant patterns to many species of animals. This is evidently no accidental feature, although the plants can hardly be understood as intentional agents. Here, Prägnanz appears as a property of an ecosystem, that is of nature at large. The present theory still applies though, when "ecosystem" is substituted for "animal".

In conclusion, we propose that Prägnanz is not a property of physical structures but has to be understood in the context of specific lifeworlds. In relatively isolated parts of the world, like Wertheimer's laboratory, it may well be possible to come up with simple and useful Prägnanz measures (figures 7 and 8). But a "general theory" appears not so much (currently) out of reach, as a *non-issue*. There are as many measures of Prägnanz as there are distinct lifeworlds.

Appendix. The Examples

All examples are essentially trivial to generate. However, they tend to be computationally intensive, so it is best to use a computer. Virtually, any computer language will do, although some are more convenient than others.

Examples of figures 1, 2 and 3

Basic ingredients are the "Julesz patterns" shown in figure 3. These are generated by filling a 32×32 array of squares with white or black using a coin-flip (fifty-fifty fair coin) random generator.

The examples in figure 1 are generated by starting with an image, downsampling it to 32×32 pixels, and thresholding it to black or white. The result will depend upon the threshold. This might be set so as to arrive at a certain fraction of black pixels, but we set it by eye so as to achieve a "nice" result.

The examples of figure 2 are computed by combining these methods. Given some "nice" images, we use an unfair coin to invert any pixel with some arbitrary probability p. Thus, $p=0$ will simply leave the image as it is, but $p=0.5$ will transform it into a Julesz pattern.

Examples of figure 5

The cowhide pictures shown in figure 5 were generated as follows. Let $i, j=1 \ldots 32$ denote the pixel coordinates. Consider a function $F(i,j)$ and render pixel $\{i,j\}$ black if $F(i,j)<0$ and otherwise white.

The cowhide pixels are generated by the random binary polynomials:

$$F(u,v)=\sum_{n=1}{}^{k}\sum_{m=0}{}^{n} N(s)\,T_{m}(u)\,T_{n-m}(v),$$

where $k=1, 2, 3, \ldots$ is the "order" and $N(s)$ a random normal deviate with mean zero and standard deviation s. We let the standard deviation depend upon the order, setting $s=e^{-k/2}$.

The function $T_p(x)$ denotes the Chebyshev polynomials of the first kind and order p in the variable x. The Chebyshev polynomials have their zero crossings in the interval $(-1,+1)$, whereas their extremal values on this interval are ± 1. This renders them particularly suitable for pictures on the canvas $((-1,+1),(-1,+1))$. One useful definition of the Chebyshev polynomials is $T_n(\cos\theta)=\cos(n\theta)$. For example, $T_{10}(x)=-1+50x^2-400x^4+1120x^6-1280x^8+512x^{10}$.

The highest power of x in $F(u,v)$ is k. Owing to the random normal deviates, each instance of $F(u,v)$ will be unique.

The rows in figure 5 show the orders, $k=1, 2, 4, 8, 16$. The corresponding numbers of degrees of freedom (the numbers of random normal deviates) are 2, 5, 14, 44, and 152. Order 4 yields nice "cowhide" patterns; lower orders tend to look trivial, and higher orders tend to look complicated and confusing.

Figure 6

For the pictures in figure 6, we use a function $G(x,y)$ and a threshold value t. We define the gray tone at location (x,y) to be 0 (black) when $G(x,y) < t$, 1 (white) when $G(x,y) > t$, and 0.5 (gray) otherwise. The function $G(x,y)$ is defined as

$$G(x,y) = \sum_{n=1}^{k} \sum_{m=0}^{n} R\Psi_m(x)\Psi_{n-m}(y),$$

where R is a random normal unit variance deviate and $\Psi_n(x)$ designates the Hermite function $\Psi_n(x)$, which is defined as

$$\Psi_n(x) = H_n(x)\ \exp(-x^2/2)/(2^n n!\sqrt{\pi})^{1/2},$$

where $H_n(x)$ are the Hermite polynomials. The Hermite polynomials are orthogonal under the weight function $\exp(-x^2)$ in the interval $(-\infty,+\infty)$. They are most conveniently defined recursively. One uses the relation $H_n(x) = 2xH_{n-1}(x) - (n-1)/2H_{n-2}(x)$, starting from $H_0(x)=1$ and $H_1(x)=2x$. For example, $H_{10}(x) = -30{,}240 + 302{,}400x^2 - 403{,}200x^4 + 161{,}280x^6 - 23{,}040x^8 + 1024x^{10}$.

Since the $\Psi_n(x)$ are wave functions of the quantum-mechanical harmonic oscillator (that is how we picked them), they are not polarized by the Cartesian coordinate system and they peter out away from the origin, rendering them particularly useful (in combination with the finite threshold) to generate icon-like patterns of finite size.

This is a very general method that can be used to generate "icon-like" images of various kinds (one may vary the order and the variance of the normal deviates as a function of order – here taken as constant). Owing to the random normal deviates, each instance is bound to be a unique "icon".

The order k determines the complexity. It is the parameter we varied in the experiment.

Summary

Prägnanz was suggested by Max Wertheimer in the 1920s as subsuming all "Laws of Gestalt" as they apply to visual awareness. Thus, it assumes a prominent position in any account of Gestalt phenomena. From a phenomenological perspective, some visual stimuli evidently "have more *Prägnanz*" than others, so *Prägnanz* seems to be an *intensive quality*. Here, we investigate the intricacies that need to be faced on the way to a definition of formal scales. Such measures naturally depend both upon the stimulus and upon the observer. Structural complexity bottlenecks of visual systems play a role, as well as the relevance to biological fitness, that is the affinity to the optical user interface. This positions the notion of *Prägnanz* squarely within the realm of biology. Indeed, the familiar "releasers" of ethology are singular cases of extremely high *Prägnanz*.

Keywords: Prägnanz, structural complexity, affordance, good Gestalt, simplicity.

Messungen von *Prägnanz?*

Zusammenfassung

Der Begriff *Prägnanz* wurde von Max Wertheimer in den zwanziger Jahren des vorigen Jahrhunderts eingeführt, um damit alle "Gestaltgesetze", die für das visuelle Bewusstsein gelten, zusammenzufassen. Damit nimmt der Begriff eine in jeder Hinsicht herausragende Stellung innerhalb der Gestalt-Phänomene ein. Aus phänomenologischer Sicht haben einige visuelle Reize offenbar mehr *"Prägnanz"* als andere, daher scheint *Prägnanz* eine *intensive Qualität* zu sein. Hier untersuchen wir die Feinheiten, die auf dem Weg zu einer Definition formaler Skalen in Betracht gezogen werden müssen. Solche Messungen hängen natürlich sowohl vom Reiz als auch vom Beobachter ab. Strukturelle Komplexitätsengpässe visueller Systeme spielen ebenso eine Rolle wie die Bedeutung für die biologische Fitness, also die Gemeinsamkeit zur optischen Benutzerschnittstelle. Damit ist der Begriff der *Prägnanz* eindeutig im Bereich der Biologie angesiedelt. Tatsächlich sind die bekannten "Auslöser" der Verhaltensforschung singuläre Fälle extrem hoher Prägnanz.

Schlüsselwörter: Prägnanz, strukturelle Komplexität, Angebotscharakter, gute Gestalt, Einfachheit.

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