Information Amount Measurement in Generative Systems: An Objective Approach to Termination

Alexander Koutamanis
Delft University of Technology
Faculty of Architecture
Delft
The Netherlands

ABSTRACT

Termination in computational generative systems is linked increasingly to user intervention: the generative system concludes when the user chooses it to do so. The similarities between this approach to termination and the creative artistic process suggest that the products of generative systems are amenable to analysis in terms of well-formedness leading to a formal measure that acts as an automatic termination trigger. The paper proposes that such a measure can be derived from structural information theory. By applying the compression of structural information theory to meaningful principles of a design world we derive a consistent, universal description of the design result at any given state. This description expresses the correlation of the design with its formal constraints, as well as the general perception of the design's patterns.

1 GENERATION AND TERMINATION

One of the fundamental problems in computational generative systems is termination. This refers to the ability a system to determine when the generative process can conclude with a satisfactory result. The issue has been explored in the framework of formal systems such as shape grammars (Gips 1975; Stiny and Gips 1978; Stiny 1980). In such systems termination preferably occurs on the basis of cues produced by the generative process itself. Consequently, termination has been considered in relation to:

- the design process: the completeness of a sequence of design actions or steps)
- the design product: the fitness of the product with respect to a given framework

Recently the issue of termination is re-emerging as a result of renewed interest in automated and autonomous design generation (Kolarevic 2001; Walker 2001). In recent generative systems termination is a matter of user intervention: the generative system concludes when the user chooses it to do so, normally of the basis of intuitive criteria relating to the state of the process (usually appreciation of the appearance or structure of the design product).

What makes interactive termination interesting is that it provides a context for the formalized heuristics that characterize earlier approaches. Rather than attempt to extract and formalize incomplete cues, improvised strategies and local conditions, interactive termination re-establishes the human designer as the measure of his products and as guide of his own processes. This is essentially similar to the conventional creative artistic process, where the artist's work may be subject to external pragmatic constraints such as medium, time or money but ultimately remains a matter of personal (aesthetic) appreciation. Acceptance of the working hypothesis that this appreciation is the cornerstone of termination means that the products of a generative system can be analysed and evaluated in terms of *well-formedness*. Well-formedness can be defined in terms of a number of components:

1. A formal representation for describing a class of entities
2. A given context that provides constraints for the entities and their description
3. A matching system for correlating descriptions of entities to a formal framework of constraints

Well-formedness is not merely the product of the matching system. The derivation of a description is subject to formal rules that provide direct measures of consistency and coherence. An entity that is poorly described is by definition undefined and hence vague in terms of appreciation. Contextual constraints are similarly considered in terms of homogeneity and completeness. In the intuitive processes relating to the evaluation of well-formedness such evaluations relate to understanding the context of an artifact and their interrelationships.

In the framework of the visual arts and design disciplines perception plays a central role in all components. Acceptance of perception as the basis of well-formedness and by extension aesthetic appreciation, we adopt an inter-subjective model of aesthetic appreciation which stresses the cognitive similarities that exist between different persons and cultures (Scha and Bod 1993). Inter-subjectivity also allows us to correlate different aesthetic approaches. This is largely due to the reason for such cognitive similarities, the organization of perceptual information.

Gestalt psychologists have formulated a number of principles (or 'laws'), such as proximity, equality, closure and continuation, which underlie the derivation of a description from a percept by determining the grouping of its parts (Köhler 1929; Koffka 1935; Wertheimer 1938). Probably the most important and certainly the most mysterious of the Gestalt principles of perceptual organization is *Prägnanz* or *figural goodness* which refers to subjective feelings of simplicity, regularity, stability, balance, order, harmony and homogeneity that arise when a figure is perceived. Figural goodness ultimately determines the best possible organization of image parts under the prevailing conditions. As a result, it is normally equated to preference for the simplest structure. The principle is seen as the basis for preferring one out of several possible alternative descriptions of a percept.

The view of perception as information processing has led to attempts to formulate figural goodness more precisely. Given the capacity limitations of the perceptual system and the consequent necessity of minimization, it has been assumed that the less information a figure contains (i.e. the more redundant it is), the more efficiently it could be processed by the perceptual system and stored in memory (Attneave 1954; Hochberg and McAlister 1954). Palmer's model of invariance under transformation is similarly motivated (Palmer 1983).

Concerning our subject such attempts promise formal structures and measures for evaluating the well-formedness of a design product throughout the design process. Such measures describe the design product by itself, as well as in relation to its context, in a similar way that an artist appreciates his work by its own merits and by fitness to its purpose or function. In the framework of generative systems this can be translated into descriptive, analytical structures that provide automatic triggers for the termination of the generative process in a transparent manner, i.e. together with an explanation of why termination is acceptable to the system and its user.

2 STRUCTURAL INFORMATION THEORY

Arguably the best model in this direction is Leeuwenberg's coding or *structural information theory* (Leeuwenberg 1967; Leeuwenberg 1971). According to Leeuwenberg a pattern is described in terms of an alphabet of atomic primitive types, such as straight-line segments and angles at which the segments meet. This description (the *primitive code*) carries an amount of structural information (I) that is equal to the number of elements (i.e., instances of the primitives) it contains. The structural information of the primitive code is subsequently minimized by repeatedly and progressively transforming the primitive code on the basis of a limited number of coding operations:

- *iteration*, by which the patterns

  $a\ a\ a\ a\ a\ a\ b\ b\ b\ b\ b\ b$ $(I = 12)$

  $a\ b\ a\ b\ a\ b\ a\ b\ a\ b\ a\ b$ $(I = 12)$

  become respectively

  $6 * [(a)\ (b)]$ $(I = 3)$

  $6 * [(a\ b)]$ $(I = 3)$

- *reversal*, denoted by r […]:

  $a\ b\ c = \mathrm{r}\ [c\ b\ a]$ $(I = 3)$

  Reversal allows the description of symmetrical patterns (Σ):

  $a\ b\ c\ c\ b\ a = a\ b\ c\ \mathrm{r}\ [a\ b\ c] = \Sigma\ [a\ b\ c]$ $(I = 4)$

  $a\ b\ c\ b\ a = a\ b\ c\ \mathrm{r}\ [\ a\ b] = \Sigma\ [a\ b\ (c)]$ $(I = 4)$

- *distribution*:

  $a\ b\ a\ c = \langle(a)\rangle\ \ \langle(b)\ (c)\rangle$ $(I = 3)$

- *continuation* (⊂…⊃), which halts if another element or an already encoded element is encountered:

$$a\ a\ a\ a\ a\ a\ a \ldots a = \subset a \supset \qquad (I = 1)$$

The coding process returns the *end code,* a code whose structural information cannot be further reduced. The structural information (*I*) of a pattern is that of its end code.

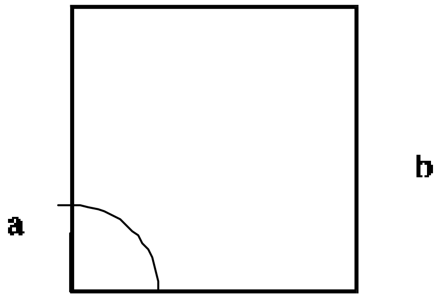

Figure 1: **Coding of square:** ***a b a b a b a b = Ì a b É*** ***(I = 2)***

The structural information of a pattern is a powerful measure of its figural goodness. By equating a figure's goodness with the parametric complexity of the code required to generate it we can both derive the different descriptions an image affords and choose the one(s) that contain the least information. Especially in situations where two or more descriptions are equally acceptable to the human perceiver, as in the Necker cube illusion, measurement of structural information clearly demonstrates that the preferred descriptions are normally equally compact. This suggests that structural information theory is particularly suited to untangling complex, overlapping or intertwined patterns, i.e. situations which are amenable to evaluations of figural goodness by e.g. invariance under geometric transformations only following an initial analysis which segments and disambiguates the image.

3 WELL-FORMEDNESS AND VISUAL DESIGNS

The application of structural information measures to the evaluation of well-formedness in visual designs involves a number of fundamental conceptual problems:

- *Avoidance of aesthetic bias*: The compression rules employed for coding may derive from universal perceptual constraints but their strong relationships to formal aesthetic systems and hence to the interpretation of a pattern pose serious questions concerning the structure, production and evaluation of a representation. For example, the ability to compress a code based on reversal and distribution relates to certain types of symmetry. These in turn may or may not be preferred by an aesthetic system: Classicism encourages most if not all types of symmetry, while Modernism avoids bilateral symmetry but promotes translational symmetry. This does not suggest different coding systems for each aesthetic context but simply differences in the treatment of the resulting code (i.e. different matching priorities) and possibly in the order compression rules are applied. Changes in the order of application make one rule subservient to another in the description of a pattern.

- *Use of meaningful descriptive primitives:* The representation of designs has always been subject to misunderstandings and confusion concerning the description of an entity and the mechanisms employed for the implementation of this description in a given environment. The tentative relationship between geometry and architecture is strongly related to this confusion (Evans 1995). Computerization has made the confusion even deeper, partly because of fixation on the technology and partly because similar uncertainties are evident even in the most advanced areas of computer science (Marr 1982). In our case, we need to go beyond lines, surfaces and other primitives in computer graphics, i.e. implementation mechanisms. Domain theory and cognitive science (Biederman 1987; Biederman 1995; Nakayama, He et al. 1995) provide the means for identifying the components of a design, i.e. the symbols or primitives used by the generative system and its user (as opposed to its computer implementation).

- *Relations to mnemonic aspects*: Domain theory and cognitive science also relate to memory. Mnemonic processes and structures have a profound influence on recognition and representation, especially with respect to the descriptive primitives used in processing information (Scha and Bod 1993). A colonnade, for example, is normally described as a sequence of columns, even though columns can be complex configurations of basic primitives. This initial compression of these primitives into an objectively identifiable entity (a column) may occur in the way described previously, but obviously precedes the description of the whole scene (the colonnade). Moreover, the plasticity of memory means that the structure and complexity of identifiable complex configurations may change, e.g. through the diversification of a column into Ionic, Doric and Corinthian, or the correlation of a colonnade with a peripteral temple.

Such problems can be resolved within the constraints of concrete design worlds (formal systems) in a way that matches human recognition while attempting an explanation of how recognition works in the specific context (Koutamanis 1997). Even though resulting coding schemes are generally restricted to working hypotheses while the formal system becomes progressively explicit, the application of structural information theory compression to a design description results in a consistent, universal description. Such a description can be derived at any given state of the generative process, regardless of abstraction or completeness. This means that at any given state the well-formedness of a design can be evaluated with respect to the constraints of the particular design world using information load as the formal criterion. For example, Figure 2 depicts a design at an early state. The design contains a singe primitive (Figure 3) and can therefore be described as:

$$a \qquad (I = 1)$$

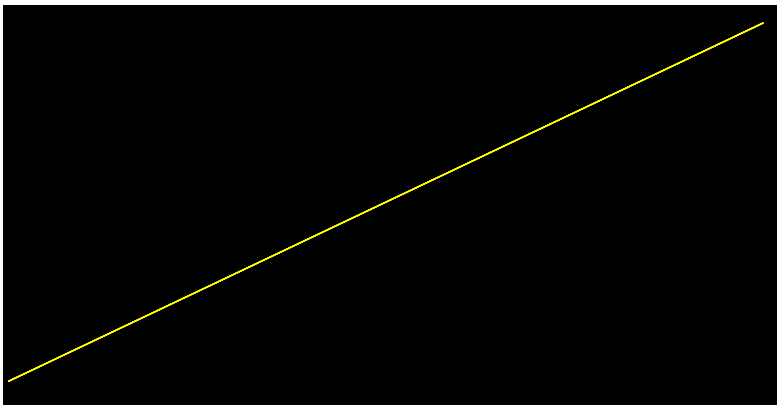

Figure 2: ***a*** ***I* = 1**

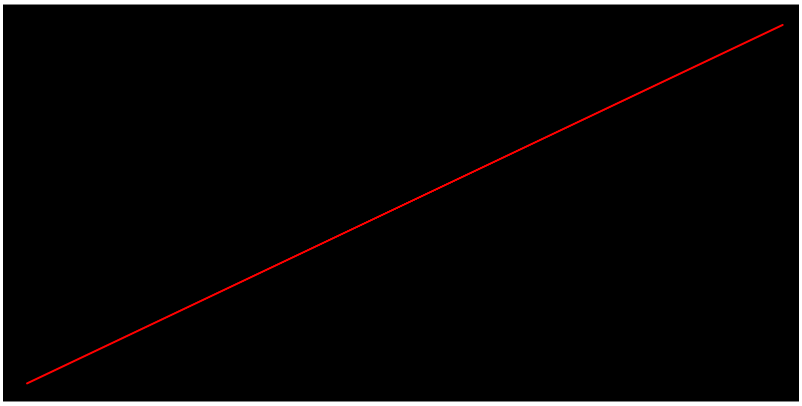

Figure 3: **Primitive *a* of Figure 2**

The addition of another instance of *a* in the design (Figure 4) poses a question: does the intersection of the two constitute a formal relationship and hen a second primitive? Such intersections often indicate partial occlusion, i.e. one entity behind another entity. This is obviously related to temporary or accidental aspects, such as the viewpoint of the perceiver or the layering of the scene. For this reason, it is preferable to ignore it initially as a possibly accidental condition, always bearing in mind that it might recur when spatial relationships in the overall scene are considered. Consequently, the design is described as a couple of disjointed elements:

a … a (*I* = 2)

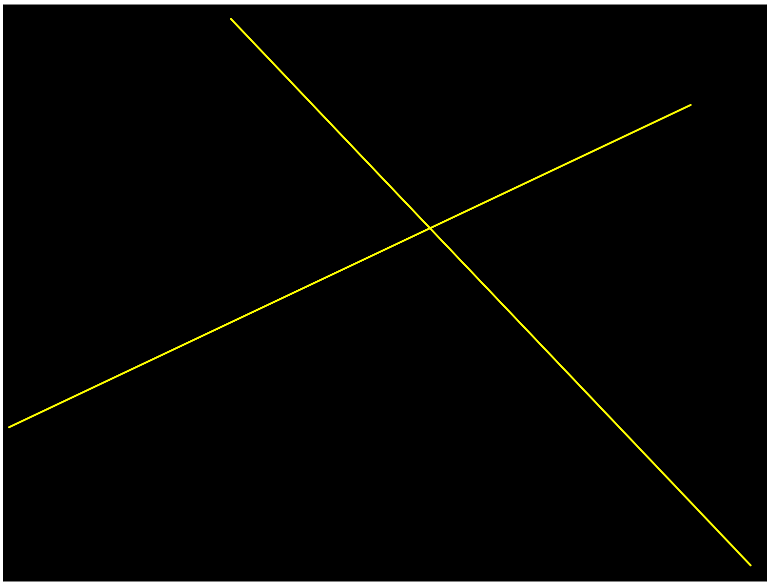

Figure 4: ***a … a*** **(*I* = 2)**

The addition of yet another instance of *a* in the design (Figure 5) also introduces angle *b* as a new primitive (Figure 6). This angle represents an unambiguous relationship between two connected instances of *a*. Consequently, the design is described as two disjointed groups:

a … a b a (*I* = 4)

It is noteworthy that as *b* connects two endpoints of different entities (cotermination) it forms a strong and unambiguous condition in the scene. Its significance apparently justifies the dismissal of the intersection of the two instances of *a* in Figure 4 as accidental and non-structural. Nevertheless, the intersection now occurs in two different places in Figure 5. This suggests that distinction between significant and accidental conditions relates more strongly to general perceptual principles than to the frequency of occurrence in a scene. A powerful example of this is small perturbations or missing parts in entities: these are generally ignored on the basis of principles of continuation and completion.

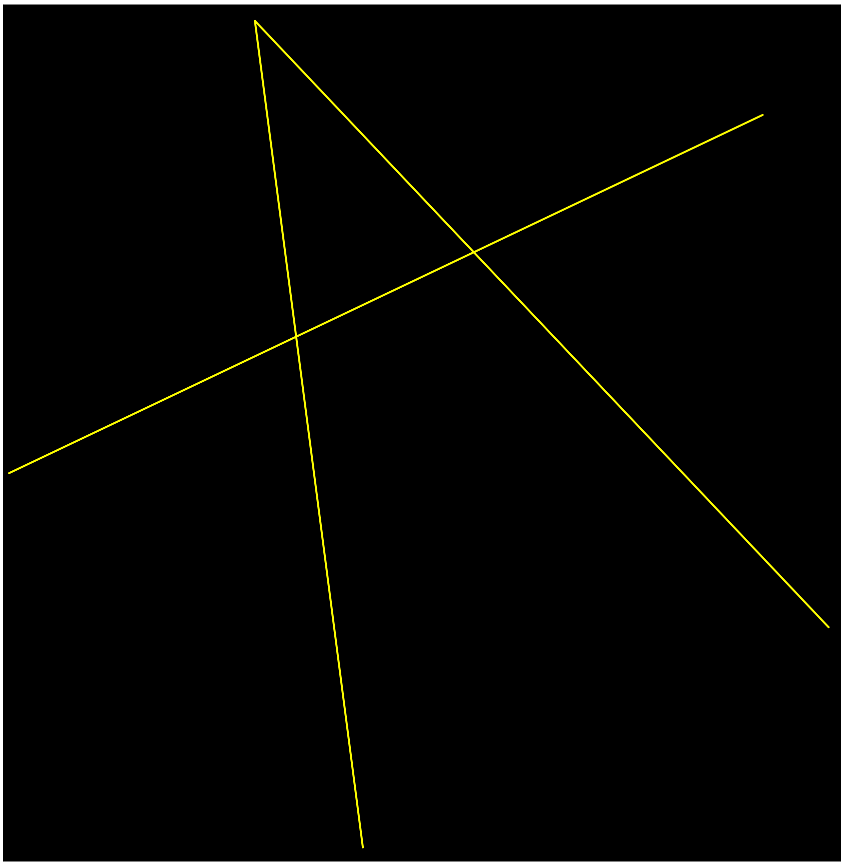

Figure 5: ***a … a b a*** **(*I* = 4)**

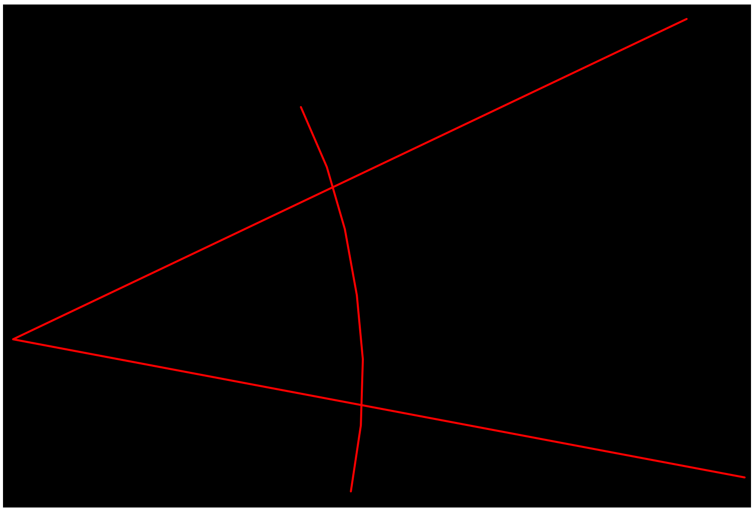

Figure 6: **Primitive *b* of Figure 5**

An interesting change in the end code takes place when yet another instance of *a* and *b* are added to the design (Figure 7). The unification of the two groups by these two elements also reveals repetition and symmetry in the design pattern. Consequently, the design can be described by either of two end codes, which start showing the benefits of compression, as the amount of structural information remains unchanged in the repetitive code:

$$a\ b\ a\ b\ a\ b\ a = \Sigma\ [a\ b\ a\ (b)] \qquad (I = 5)$$

$$a\ b\ a\ b\ a\ b\ a = a\ 3^*\ [(a\ b)] \qquad (I = 4)$$

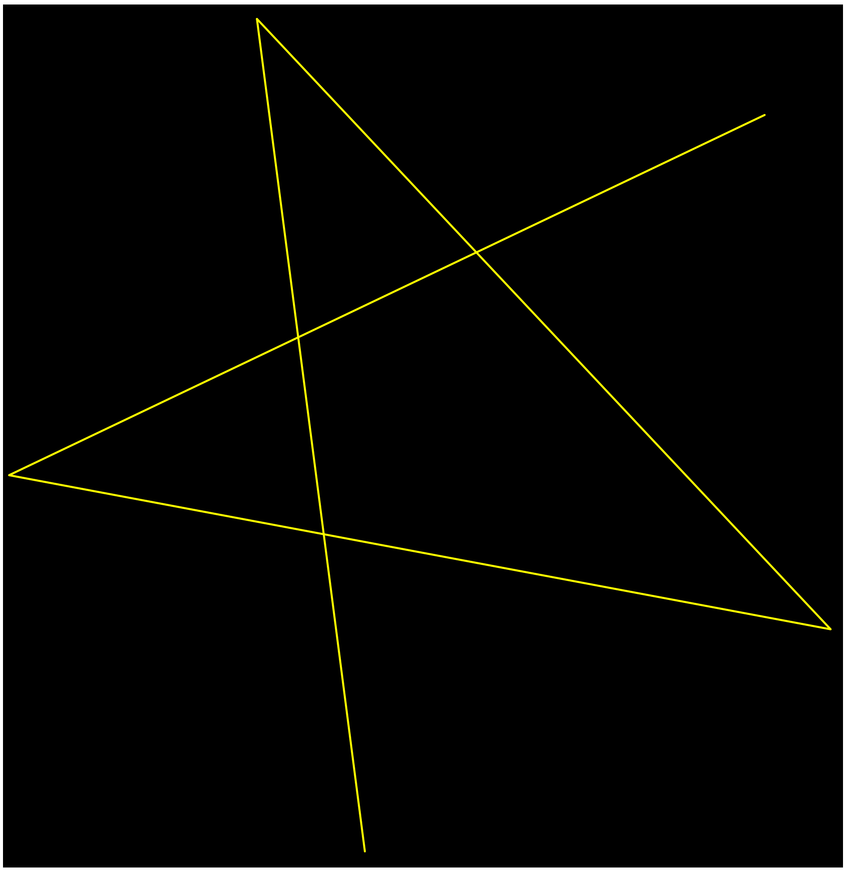

Figure 7: ***a b a b a b a* = S [*a b a* (*b*)]** ***I* = 5**
or *a* 3* [(*a b)*] ***I* = 4**

The completion of the design with one more instance of *a* and two of *b* (Figure 8) brings compression even further, as the pattern and its code become continuous, with great benefits in terms of amount of structural information:

$$a\ b\ a\ b\ a\ b\ a\ b\ a\ b = \subset a\ b \supset \qquad (I = 2)$$

The compactness of the end code corresponds with the ease by which we recognize and remember the pattern. Accordingly, it can be argued that such changes in the amount of structural code form triggers for termination. This holds generally for everyday circumstances, as in making a diagram, a doodle or a simple sketch like Figure 8. The artistic process may rely more on the presence of specific patterns in the code. For example, the symmetric code of Figure 7 is longer than the repetitive one, but symmetry may be an explicit constraint of the particular design world.

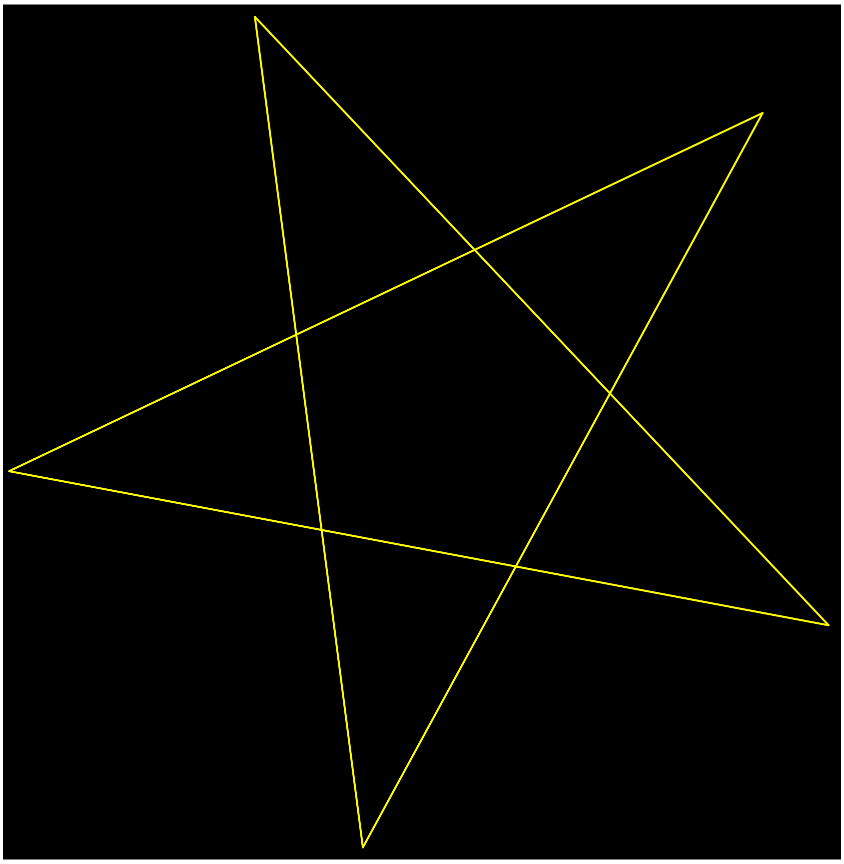

Figure 8: ***a b a b a b a b a b* = Ì *a b* É (*I* = 2)**

Another consideration is whether striving for the least amount of structural information fits the design world. Figure 8 is obviously superior to Figure 7 in terms of compactness of end code, but the lack of termination and continuity in Figure 7 may bear significant advantages for artistic creativity in certain contexts. Complexity, irregularity and other devices for stimulating curiosity and uncertainty in interpretation or for contradicting established aesthetic views are common to many schools, tendencies and styles.

4 DISCUSSION

The application of structural information theory coding and compression provides means for considering the well-formedness of a design in absolute and relative terms, i.e. with respect to universal perceptual aspects, as well as in relation to the specific cultural context of a design. Using such a measure of well-formedness relates directly to informational and descriptive aspects, such as the amount of information, the presence of structures corresponding to design constraints and the global and local articulation of the design with respect to both information amount and structure / constraints. Appreciation of a design at any state or stage depends on such aspects and their combinations. The transfer of this appreciation to (semi-)automatic design generation means that the design representation contains autonomous mechanisms that react either to single aspects or to combinations of aspects. Activation of these mechanisms implies that the design has reached a level that makes it fit for its formal context and purpose and therefore allows the generative process to terminate with satisfactory results. The prevailing conceptual (as well as applicability) problem is the meaning of such mechanisms and the significance of termination. Resolution of this problem presupposes an explicit representation of each design world, with unambiguous relations to perception and aesthetics. This is a huge task which thankfully can be implemented through the application of the proposed approach in an exploratory, evolutionary manner.

5 REFERENCES

Attneave, F. (1954). "Some informational aspects of visual perception." *Psychological Review* **61**: 183-193.

Biederman, I. (1987). "Recognition-by-components: A theory of human image understanding." *Psychological Review* **94**(2): 115–147.

Biederman, I. (1995). Visual object recognition. *Visual cognition. An invitation to cognitive science. 2nd ed.* S. M. Kosslyn and D. N. Osherson. Cambridge, Massachusetts.

Evans, R. (1995). *The projective cast. Architecture and its three geometries.* Cambridge, Massachusetts, MIT Press.

Gips, J. (1975). *Shape grammars and their uses.* Basel, Birkhäuser.

Hochberg, J. E. and E. McAlister (1954). "A quantitative approach to figural 'goodness'." *Journal of Experimental Psychology* **46**: 361-364.

Koffka, K. (1935). *Principles of Gestalt psychology.* New York, Harcourt Brace.

Köhler, W. (1929). *Gestalt psychology.* New York, Liveright.

Kolarevic, B. (2001). Designing and manufacturing architecture in the digital age. *Architectural information management*. H. Penttilä. Espoo, eCAADe & Helsinki University of Technology.

Koutamanis, A. (1997). On the evaluation of figural architectural goodness: A foundation for computational architectural aesthetics. *CAAD Futures 1997*. R. Junge. Dordrecht, Kluwer.

Leeuwenberg, E. L. J. (1967). *Structural information of visual patterns. An efficient coding system in perception. Doctoral dissertation, Catholic University of Nijmegen.* The Hague, Mouton.

Leeuwenberg, E. L. J. (1971). "A perceptual coding language for visual and auditory patterns." *American Journal of Psychology* **84**: 307-350.

Marr, D. (1982). *Computer vision.* San Francisco, W.H. Freeman.

Nakayama, K., Z. J. He, et al. (1995). Visual surface representation: a critical link between lower-level and higher-level vision. *Visual cognition. An invitation to cognitive science. 2nd ed.* S. M. Kosslyn and D. N. Osherson. Cambridge, Massachusetts.

Palmer, S. E. (1983). The psychology of perceptual organization: a transformational approach. *Human and machine vision.* J. Beck, B. Hope and A. Rosenfeld. New York, Academic Press.

Scha, R. and R. Bod (1993). "Computationele esthetica." *Informatie en Informatiebeleid* **11**: 54-63.

Stiny, G. (1980). "Introduction to shape and shape grammars." *Environment and planning B* **7**: 343-351.

Stiny, G. and J. Gips (1978). *Algorithmic aesthetics. Computer models for criticism and design in the arts.* Berkeley, California, University of California Press.

Walker, C. (2001). Digital techniques in architecture. *AVOCAAD: Third International Conference.* K. Nys, T. Provoost, J. Verbeke and J. Verleye. Brussels, Hogeschool voor Wetenschap en Kunst, Departement Architecture Sint-Lucas.

Wertheimer, M. (1938). Laws of organization in perceptual forms. *A source book of Gestalt psychology.* W. D. Ellis. London, Routledge & Kegan Paul.