Shape Specification in Design Using Fuzzy Logic

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This is the author's version of this work.

Details of full proceedings:

Pham, B (1999) Shape Specification in Design Using Fuzzy Logic . In *Proceedings of KES'99 Third International Conference on Knowledge-based Intelligent Information Engineering Systems*, Adelaide, Australia.

Key words: fuzzy logic, conceptual design, shape specification, aesthetics.

Abstract

A shape specification system based on fuzzy logic is proposed, which aims to facilitate designers in conceptual design stage by allowing them to specify and work with rough models in a more intuitive fashion. The system uses a 3D object representation called 'parametric geons' which provide both qualitative and quantitative descriptions, in addition to global shape constraints, via eight shape parameters. Geometric descriptors and aesthetic descriptors are introduced and their fuzzy membership functions are constructed. Inference rules are obtained to link these descriptors with shape parameters. The system which models after designers' behaviour, allows designers' own aesthetic terms and interpretation of shapes to be added, and a library of successful designs with appropriate fuzzy descriptions to be constructed for later use.

1. Introduction

Elaborate styling has been made an integral part of marketing for some products, noticeably cars, household and office products, because there is an increasing demand to produce objects that are more artistically pleasing. People are not merely satisfied with the effects of photographic exactness, but demand the style and expressiveness produced by the artistic flair. This is even more paramount for artistic applications such as sculpting. One major problem that hinders artistic design is that geometric modelling capabilities provided by current CAD systems do not allow design aesthetic intents to be realised satisfactorily. These systems require designers to specify object shape in *exact* geometric representations such as edges and vertices, CSG (Constructive Solid Geometry) primitives, or control vertices for parametric surfaces. Such representations cannot adequately reflect design intents for a rough initial model. An intuitive and flexible way to automate the specification of a rough model is also essential during conceptual design stage to avoid the need for designers to manually sketch many alternative designs before a final design is chosen and a detailed CAD model is constructed from it.

What needed is a scheme that enable a designer to specify an initial shape in terms of fuzzy global shape characteristics and to explore its variations. Once desired shapes have been obtained, it would also be advantageous if they can be labelled with a designer's aesthetic descriptions and stored in a library for later use. This paper proposes such a scheme based on fuzzy logic.

Although fuzzy logic has been used extensively in many areas, especially in social sciences and engineering (e.g. [2,3,8,11]), very few attempts have been made to apply fuzzy logic to geometric modelling. In previous papers [6-9], we discussed relevant issues concerning design for aesthetics. In particular, the needs for fuzziness in CAD was analysed and a systematic scheme was proposed to represent and realise aesthetic intents of designers using fuzzy logic [6]. We also explored the interactions of design variables and aesthetic properties [8]. We investigate how fuzzy logic may be used for shape specification to satisfy aesthetic requirements. The intention is to bridge the gap between the impreciseness of artistic interpretation and the preciseness of mathematical representations of shapes. Although the scheme illustrated here is based on the use of a geometric representation for 3D objects called parametric geons [10], its essence is independent of the geometric model and hence the method can be directly applied to other geometric models using appropriate parameters or parametric functions.

Geometric modelling systems may be viewed as consisting of two major components: *geometric models* and *design methods*. These components, in turn, determine the types of system. Underlying geometric models may be first chosen and a system is then constructed using design techniques that are most appropriate for these geometric models. Alternatively, a system may be built based on some specified design techniques which would limit the choice of available geometric models used for representing objects. Both approaches suffer some drawbacks. Ideally, designers wish to be relieved of the need to specify a geometric representation at exact low-level details, and to have access to a number of flexible and intuitive design tools. In particular, they wish to have an initial model by specifying some fuzzy criteria which are more in tune with the fuzziness in human thought process and subjective perception. This need for fuzziness also arises from our inability to acquire and process adequate information about a complex system. For example, it is difficult to extract exact relationships between what humans have in mind for objects' shape and what geometric techniques can offer due to the complexity of rules and underlying principles, viewed from both perceptual and technical perspectives.

For some applications, fuzzy systems often perform better than traditional systems because of their capability to deal with non-linearity and uncertainty. One reason is that while traditional systems make precise decisions at every stage, fuzzy systems retain the information about uncertainty as long as possible and only draw a crisp decision at the last stage. Another advantage for design is that linguistic rules, when used in fuzzy systems, would not only make designing tools more intuitive, but also provide better understanding and appreciation of the characteristics of each design. Section 2 discusses how parametric geons can be used as an underlying shape representation for a fuzzy shape specification system. Section 3 describes in detail the components of the system and their operations.

2. Fuzzy shape representation based on parametric geons

A few attempts have been made to explore the use of qualitative shape models for object recognition. Biederman [1] proposed that an object can be represented as a hierarchy of geometrical ions, called *geons*. This model gives a qualitative description of the whole object and its topology, is based on the fact that our visual system uses co-linearity, curvature, symmetry and co-termination to discriminate and recognise shapes. Geons form a restricted class of generalised cylinders whose cross-sections, axes and sweep properties are arbitrary functions. As the geon representation describes larger structures of the object, it avoids some restrictions imposed by other models that are based on local information. However, this model suffers a drawback in not being able to provide sufficient quantitative information about the object. Such information is required at later stages for object refinement and manipulation.

This drawback was addressed later by Wu and Levine [10], who proposed a set of parametric geons which is based on simple, regular and symmetric shapes represented by super-ellipsoids and their deformations. The seven basic parametric geons are: ellipsoid, cylinder, cuboid, tapered cylinder, tapered cuboid, curved cylinder and curved cuboid. These parametric geons have distinct volumetric characteristics such as roundness, squareness, ellipsoidness, tapering and bending, which can be controlled by manipulating a set of parameters.

While the geons are described in strictly qualitative and local attributes, the parametric geons provide both *qualitative* and *quantitative* characteristics, as well as *global shape constraints*. There are 8 *shape parameters* that govern the shape of parametric geons: 3 for size, 2 for shape type, and 4 for controlling global shape deformation (tapering and bending). Fig. 1 shows three sample shapes that may be created using this representation.

However, to use such parametric geons for specification and representation of initial rough shapes is still a tedious task because mathematical insights and trial-and error experiments are needed to obtain appropriate values for these parameters in order to generate a desired shape. The main reason is that the variation of these parameters has non-linear and sometimes unpredictable effects on the shape. In addition, designers often have some fuzzy global geometric or aesthetic characteristics about the shape in mind and wish to obtain such a shape quickly. They might also wish to re-use some designs of similar global characteristics.

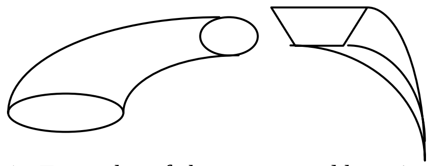

Fig.1. Examples of shapes created by using parametric geons.

We distinguish two types of global shape descriptors: *geometric* and *aesthetic descriptors*.
We start with six main fuzzy geometric descriptors: *roundish, squarish, ellipsoidish, cylinderish, tapered* and *bent*; and 4 aesthetic descriptors - *sensual, fragile, sleek* and *dynamic*. But we also allow a designer to add other geometric descriptors and his / her own subjective aesthetic descriptors.

The fuzzy membership functions for parametric geons will be constructed by the following steps:

- allowing 5 fuzzy linguistic partitions for each geometric descriptors: roundness, oblongness, squareness, bendiness, and taperness. For example, extremely round - very round - moderately round - slightly round - very slightly round.
- carrying out experiments to obtain human responses in terms of these shape characteristics by varying appropriate geometric parameters of a shape.
- designing fuzzy membership functions based on the results of these experiments.
- determining rules for combining single fuzzy membership functions.

Once these fuzzy membership functions are designed, experiments will then be carried out to obtained fuzzy membership functions for customised preferences for each designer by the following steps:

- generating and identifying those sets of shape desired by a designer and the range of parametric values required to generate these shapes.
- naming these sets using a fuzzy natural language. For example, extremely sensual – very sensual – moderately sensual – slightly sensual – very slightly sensual.

3. A Fuzzy Shape Specification System

Underlying the construction of a fuzzy system for shape specification for design is the need to address the following questions:

- What shape charateristics (in terms of both geometric and aesthetic) that designers normally require?
- What geometric parameters or functions can be used to achieve these characteristics?
- Can we use this knowledge to construct a set of rules to represent the heuristic strategies of designers?
- Can we incorporate designers' needs for having customised models that satisfy certain subjective aesthetic constraints?
- Can we devise rules to generate promising output, given certain fuzzy geometric specifications or fuzzy subjective aesthetic constraints?

- Can we evaluate the degree of fulfilment of these rules for a generated output, given certain fuzzy geometric specifications or fuzzy subjective aesthetic constraints?

The system has 5 main modules: Input Module, Rules Module, Inference Engine, Graphics Engine and Library. The Input Module caters for both specification and processing of input data. There will be two types of input: generic and customised. Generic inputs include the geometric descriptors of geons, and their generic aesthetic descriptors supplied by the system, while customised inputs include subjective aesthetic terms described by a designer. One thing to note is that the inputs for the shape specification system are mainly fuzzy variables because they are more intuitive to designers. However, it is possible to add crisp variables such as specific values for shape parameters, if designers already have some numerical data about the desired shape (e.g. an existing design).

The Rules Module contains two types of rules. The first type links geometric descriptors with shape parameters, while the second type links aesthetic descriptors with geometric descriptors, and with shape parameters. The Inference Engine computes the combination of rules and the degree of fulfilment of specifications using logic operations. It also computes implication results using fuzzy implication operators. The Graphics Engine uses the values of shape parameters produced by the Inference Engine to generate alternative shapes with required degree of fulfilment. Finally, the Library contains shapes that satisfy a designer's requirements, in terms of geometric specifications or generic aesthetic specifications, or their own expression and interpretation of aesthetic characteristics. Fuzzy membership functions for such descriptors of these shapes will also be stored for later use.

The work flow of the system is as follows:

1. An user specifies fuzzy geometric descriptors and / or fuzzy aesthetic descriptors of the desired shapes, and a threshold for the overall degree of fulfilment of his/her intents.
2. For each shape parameter, at equally-spaced values, the system computes the degree of fulfilment of the user's intents, using logic operations.
3. Sets of shape whose degree of fulfilment exceeds the threshold are generated.
4. The user examines these shapes and proceed with one of the following actions:
   - Modifying a shape further by returning to step 1 and adding more fuzzy specifications, e.g. 'making this shape a slightly rounder'.
   - Exploring the evolution of shapes by manipulating the weights for each fuzzy descriptors.
   - Once the user is satisfied with a specific shape, s/he can classify it using fuzzy generic aesthetic descriptors supplied by the system, or using personal aesthetic descriptors. This shape is then stored in a library for later use.

4. Conclusion

A framework for a fuzzy shape specification system has been presented, with the aim to facilitate designers' task at early stage of design. The system enables designers to express their intents concerning shape global characteristics in terms of either fuzzy geometric descriptors or fuzzy aesthetic descriptors. It also provides a method for generating promising alternative designs, from which designers can compare, manipulate further, and select according to personal preferences. The system designed this way can also model designers' behaviour by incorporating subjective knowledge and needs, and is continually adapted by updating a library of successful designs chosen by each user. We are also exploring the possibility of combining the evolutionary programming approach with the fuzzy logic approach in order to extend the capability of searching for optimal designs.

Acknowledgement: The author acknowledges the support of ARC Grant A49802801.

References

1. Bierdman I., Human image understanding and: Recent research and a theory, *Computer Vision, Graphics and Image Processing,* 32, 1985, 29-73.
2. Berkan R.C. and Trubatch S.L., Fuzzy System Design Principles, IEEE Press,NY, 1997.
3. Farwowski W. and Mital A. (Eds.), *Applications of fuzzy set theory in human factors,* 1986.

4. McNeill D., Freioberger P., *Fuzzy Logic*, Simon & Scuster, NY, 1993.
5. Negotia C.V., Ralescu D., *Simulation Knowledge-based Computing and Fuzzy Statistics*, Van Nostrand Reinhold, NY, 1987.
6. Pham B., Fuzzy Logic Applications in CAD, in *Fuzzy System Design: Social and Engineering*, Eds. Reznik L., Dimitrov V., Kacprzyk J., 1998, 73-85.
7. Pham B., A hybrid representation for aesthetic factors in design, *International Jour. On Machine Graphics & Vision 6 (2)*, 1997, 237-246.
8. Pham B., Design for aesthetics: Interactions of design variables and aesthetic properties, *Proceedings of IS&T / SPIE 11th Annual Symposium - Electronic Imaging '99*, Feb 1999, San Jose, USA, in print.
9. Pham B., Integration of Aesthetic Intents to CAD systems, *Proceedings of ASME 1996 International Design Engineering Technical Conferences and Computers In Engineering Conference*, Sep 1996, Irvine, CA, 16-20.
10. Wu K., and Levine M.D., Parametric Geons: A Discrete Set of Shapes with Parameterised Attributes, Proceed. SPIE Inter. Symposium on Optical Engineering and Photonics in Aerospace Sensing: Visual Info. Process. V2239, 14-26, Orlando Fl., 1994.
11. Zadeh L., Fuzzy Sets, *Information and Control* 8(3), 1965, 338-353.