# Function-based shape modeling using a specialized language

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In our talk, we describe the following different aspects of modeling multidimensional point sets (shapes) using real-valued functions of several variables:

- algebraic system as a formal framework
- representation of shapes, operations, and relations using real-valued functions
- internal representation and algorithms
- specialized language for function-based modeling
- extension to point sets with attributes (hypervolumes)
- some applications.

**Algebraic system.**

The concepts of the function representation FRep [1] can be presented as an algebraic system (Objects, Operations, Relations). A complex object is defined as $F(X) >= 0$, where F is a single continuous function of several variables (coordinates X of a point in a multidimensional space). Operations are unary, binary, and k-ary operations closed on the object representation. Relations as, for example, “interpenetration” are defined on the set of objects using predicates.

**Representation.**

A complex object can be constructed by applying different operations to primitive objects. A primitive is considered a "black box" with the defining function given by a known function evaluation procedure. There is a rich system of operations closed on the representation, i.e., resulting in a continuous real function: set-theoretic operations and Cartesian product defined using R-functions (exact $C^k$ continuous definitions for set operations on functionally defined arguments), blending and bounded blending, offsetting, sweeping, projection, deformation, metamorphosis, and extended space mapping, which combines spatial and functional transformations (mappings). FRep can be considered a combination and generalization of Constructive Solid Geometry (CSG), implicit surfaces, sweeping, and other known shape models.

**Internal representation**.

The real-valued function *F* defining the point set is associated with a tree structure that serves as its underlying representation. The function *F* is evaluated at the given point by a procedure traversing a tree structure with primitives in the leaves and operations in the nodes of the tree. In general, a k-ary tree should be supported. Specific details of processing different operations are discussed.

**Specialized language.**

HyperFun is a specialized high-level modeling language suitable for specifying FRep models [2]. While being minimalist, it supports all main notions of FRep. HyperFun is also intended to serve as a lightweight exchange protocol for FRep models to support platform independence and Internet-based collaborative modeling. A minimal API for interrogating HyperFun models includes the parsing and the function evaluation procedures. The applications developed for HyperFun include a polygonizer (surface mesh generator), plug-in to a ray-tracer, and a set of Web-based modeling tools such as translator to Java, polygonizer in Java, and interactive modeler based on empirical modeling principles and provided as an applet.

**Constructive hypervolume model.**

Multidimensional point sets with multiple attributes (hypervolumes) can be used to model heterogeneous objects with internal distribution of material, density, temperature, and other scalar attributes. FRep was recently applied to define a constructive hypervolume model [3]. The underlying representation can be defined in a similar way by introducing a set of tree structures. Along with the tree corresponding to a function $F$ defining the point set, there are constructive trees associated with functions $\{S_j\}$ defining attributes and reflecting the construction logic of the attribute definition. We describe an extension of HyperFun providing for using it to model hypervolumes.

**Applications.**

Main current application areas of FRep and HyperFun include education (geometry and geometric modeling, computer graphics, programming languages), animation and multimedia, and computer art. The constructive hypervolume models can be applied in multiple material rapid prototyping, geological and biological modeling, physics based simulations, and volume graphics. We are also planning to develop an advanced computer-aided design system based on several geometric representations including FRep and the constructive hypervolume model.

**References**

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