Dancing Buddhas:
New Graphical Tools for Digital Cultural Heritage Preservation

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Abstract:

We will demonstrate and discuss the use of a mathematically based tool, Function Representation (FRep), for modeling complex 3D objects such as sculpture, and show the new capabilities that it provides for dynamically modifiable viewing and presentation. FRep uniquely allows smooth metamorphosis between structurally dissimilar objects, even with different mathematical connectivity. We intend to use FRep's modeling and metamorphosis capabilities for the multimedia presentation of a transformation of the kanji from a twelfth-century Japanese text of the Lotus sutra (one found in the Aizu region) into moving 3D buddha-images, accompanied by synchronous sounds of chanting. In our presentation, we will demonstrate some of the basic steps showing the concept and approach, but with a limited sample, and without sound. With our approach, an object at any point in its metamorphosis will be a verifiably closed, mathematically accurate representation of the object at that stage of the process. We achieve this by using HyperFun, a high level geometric modeling language for modeling based on FRep. Because of their mathematical basis, high level FRep and HyperFun data structures can survive centuries of hardware and software iterations, and form a useful tool for cultural preservation as well. We intend to make our methods, developed by an international multidisciplinary team and currently being refined and expanded for use in this field, freely available to the academic community, and welcome participation and suggestions.

1. Introduction: Modeling a Concept

In the field of virtual heritage preservation, computer modeling techniques have been used to reproduce existing artifacts and sites as well as to recreate them from archaeological and textual data. Although such objects are in themselves important components of a society's cultural heritage, they are also significant as representations of intellectual concepts, which may also be reproduced by electronic means. In this paper, we use modeling and metamorphosis techniques to illustrate a concept introduced to three of the authors by a monk at Ryuukouji temple in the

Aizu region of Japan, that each character (*kanji*) of the text of the Lotus sutra is in fact a buddha.

The Lotus sutra plays a central role in many schools of Japanese Buddhism, most importantly the Tendai school to which Ryuukouji belongs. One central principle of the sutra is the existence of the buddha-nature in all phenomena and the consequent equivalence of the phenomenal world and the world of enlightenment (buddhahood). This principle (*hongaku*) rejects the dualism implicit in symbolization [1] and thus justifies the equivalence of the signifier (kanji) with the signified (buddha).

The Ryuukouji text, copied in the twelfth century by a number of individuals, has been designated a national treasure. Each kanji in the text is shown atop a lotus-petal dais similar to the platforms on which buddha-images are traditionally seated. Thus the text itself illustrates the idea that each written word of the sutra is in fact a buddha, a concept that we intend to illustrate electronically by metamorphosis of the kanji into a three-dimensional buddha-image. With the addition of sound, the image can voice the character, creating an aural as well as a visual text. Using such techniques, whole passages or even the entire sutra may be reproduced.

Using a mathematical tool known as Function Representation (FRep, described below), we are creating digital data structures that can archive the sutra text. We plan to treat each two-dimensional kanji with its lotus-flower platform as a separate object that will make a smooth metamorphosis into a rotating virtual sculpture, also seated on a lotus platform. Differences between one kanji and another can be used to produce variations in the buddha-images.

2. Problems with Current Modeling and Metamorphosis Techniques

Generally speaking, current three-dimensional computer modeling techniques are adaptations of two-dimensional procedures originally designed for producing models on paper. Such methods produce inadequate results and are sometimes incompatible with one another. The most common methods use geometric models such as polygonal and parametric surfaces.

Polygons are decomposed into elements small enough to confuse the user visually. In this process the models are degraded, and it becomes difficult to transfer them to platforms other than the ones for which they were originally prepared. Parametric surfaces are decomposed into many straight surface elements, which are then linked together in a patchwork of inaccurate polygonal meshes. Using such methods compromises accuracy, reproducibility, and the ability to verify procedures, and also wastes memory and computation time. Inefficient and inaccurate even for computer-aided drafting, two-dimensional methods are unacceptable for computer-aided design (CAD) or for computer-aided manufacturing. In addition, while such methods may reproduce simple geometric shapes in a way that seems accurate to the eye, using them to produce images of more complex objects such as sculpture is time-consuming and labor-intensive, and may yield unsatisfactory results. Ordinary techniques are also inadequate for metamorphosis from one complex shape to another, in particular between shapes of differing connectivity (shapes with different numbers of holes).

The proprietary nature of much available modeling and metamorphosis software presents additional difficulties. The fact that there is no direct relationship between the commercial methods used today and the logic of three-dimensional object design leads to incompatible databases that cannot be shared across platforms and from one proprietary software package to another. Commercial software is often expensive, moreover, and requires costly upgrades for adaptations to new hardware and new operating systems. Perhaps most important in the field of cultural heritage preservation, commercial software eventually becomes obsolete. Unless the source code is made available, the models produced with such software--intended to preserve fragile cultural objects--may disappear in some cases even before the object itself.

3. FRep and HyperFun

To overcome the problems discussed above, we propose modeling with an open-source, mathematically based tool known as FRep, implemented by the language HyperFun [2,3]. FRep is a mathematical expression of a function of any number of variables that is used to represent (describe) any object, imaginary or real, with any number of dimensions (i.e. variables) such as shape, density, mixture of materials, or change over time. This representation can be used in different ways including visualization, animation, and rapid prototyping.

A generalization of traditional implicit surfaces [4] and constructive solid geometry (CSG), FRep represents the geometric structure of an object by a continuous function of three variables. A point belongs to the object if the function is positive at the point. The function is zero on the entire surface of the object and is negative at any point outside the object. The function can be easily parametrized to support modeling of a parametric family.

In FRep, the logical structure of an object is represented by a logical tree, in which leaves are arbitrary "black box" primitives and nodes are arbitrary operations. Function evaluation procedures traverse the tree and evaluate the function value in any given point. Algebraic surfaces, skeleton-based implicit surfaces, convolution surfaces, procedural objects (such as solid noise), swept objects, and volumetric (voxel) objects can be used as primitives (leaves of the construction tree).

Many modeling operations are closed on the representation, i.e., generate as a result of the operation another continuous function defining the transformed object. Closure allows the reuse of operation results as objects for building up more complex structures. Such modeling operations include set-theoretic operations, blending, offsetting, non-linear deformations, metamorphosis, and projection. A new operation can be included in the modeling system without changing its integrity by providing a corresponding function evaluation or space mapping procedure. Thus it can be seen that the FRep function describes an object using logical combinations of simpler FRep objects, also allowing intersection and subtraction operations for the removal of unwanted sections.

The FRep representation is not confined to the surface, but can describe the interior structure as well, by the use of the combinations discussed above. But it is also able to support parametrized description of properties of the material making up the object, and properties such as surface and volumetric textures [5].

Because it is capable of generating highly complex scenes and solid objects by economical descriptions needing only small file size, FRep is well suited for Internet applications which benefit from low bandwidth needs. As a basic mathematical representation of objects to be preserved in digital form, FRep has a number of advantages. It reflects the logic of the object's construction and supports the modeling of parametric families of shapes. It also supports specific modeling operations and offers the possibility to extend them. Using FRep, we may generate polygonal and other surface models, as well as voxelization for visualization, animation and virtual object presentation on the Web.

FRep permits direct control of rapid prototyping machines with arbitrarily high precision to reproduce the modeled objects. The graphical and command line interface utilized by FRep enables interactive real-time manipulation and visualization of 3D solids and their behavior in exact, non-polygonal geometry. FRep should be useful for anyone who wants to overcome the limitations of conventional proprietary software and to advance the digital world of "intelligent" shapes and matter.

In FRep, there are no differences in processing soft objects, CSG solids, or volumetric objects. This has allowed researchers to solve such long standing problems as sweeping by a moving solid, controlled blending for all types of set-theoretic operations, collision detection and hypertexturing for arbitrary solids, direct modeling of space-time and multidimensional objects, and metamorphosis between objects of different topology. It can be difficult to produce metamorphosis between objects with differing connectivity (such as a pretzel with two holes and a solid ball with no holes), particularly while in the midst of animation. But the parametrized representation used by FRep allows this problem to be handled well. FRep's visualization capabilities also allow smoothing and metamorphosis between structurally dissimilar objects such as a two-dimensional kanji and a three-dimensional solid object such as a sculpture.

FRep is implemented through a programming language called HyperFun [6], developed for teaching and practical applications. This language is a universal tool for a space-efficient algorithmic description of three-dimensional geometrical shapes, volumes, surfaces, dynamics, materials, and any other practical number of multidimensional variables. HyperFun language is structured around a space information coding system which generates scenes, solid objects, materials, and dynamic behavior that are then decoded for realistic visualization. Based on an open data format, HyperFun enables the transmission of information in a robust digital structure that provides for infinite variables, uses mathematically proven and closed procedures, and includes a procedural history. The resulting data structures are complete enough for archival purposes.

Ordinary modeling techniques are inadequate for complex organic forms. But FRep and HyperFun allow the modeling of such organic shapes as though working with virtual clay, and support the automatic recovery of a mathematical function describing the finished virtual sculpture. It is also possible to deduce FRep descriptions of objects from point clouds obtained by 3D scans of their surfaces. Because of their mathematical basis, high level FRep and HyperFun data structures can survive centuries of hardware and software iterations, and thus form a useful tool for cultural heritage preservation.

4. The Dancing Buddhas Project

The copy of the Lotus sutra scroll at Ryuukouji has historical as well as religious significance. Because of this as well as its age and fragility, this artifact is not ordinarily available for viewing or appreciation. One goal of the “dancing Buddhas” project is to aid in preservation of the scroll, while at the same time making it available to the public. We hope that this can also serve as a “pilot project” for allowing artifacts, which are normally preserved only by storage and isolation, to be made more available.

We hope to create a mode of presentation which can convey some of the feeling as well as the meaning of the sutra scroll. Simply publishing the text does not do this. Digital scanning can show important details of the imagery. The metamorphosis of the kanji into 3D buddha-images, and the association of these images with the sound of the chanting of the characters can convey some of the emotional impact said to characterize this sutra. The creation of this virtual environment can thus simultaneously protect, preserve, and disseminate this artifact in ways not otherwise possible. And because of the compact representation of the 3D images, availability on the web becomes feasible.

There are many historically important books and scrolls that are rarely seen in their entirety (if at all), but are locked away for their protection. Many contain imagery which could benefit from animation and 3D representation, both realistic and fanciful. This project is designed as a start in that direction, although it is still work in progress. In the next section, we show examples of some of our approaches, including FRep descriptions of kanji and 3D images of sculptures, their visualization, and smooth parametric metamorphosis between radically dissimilar objects.

5. Metamorphosis with HyperFun and FRep: Examples

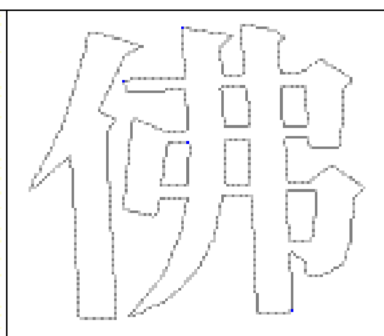
The HyperFun models can be viewed with the aid of a polygonizer, which creates a traditional polygon mesh on the surface of the object. This allows rudimentary rendering without detailed texture. However, other available tools allow the use of the freely available POV-Ray ray tracer for high quality rendering. At a later point we intend to texture map pictures of buddha-images and 3D textures onto the models, producing a variety of virtual images.

It is important to note that the polygonal mesh is used only for *visualization* of a mathematically valid model, and not for the construction of the 3D model itself. This avoids the difficulties of mismatch of mesh points which cause erroneous behavior in mesh based approaches.

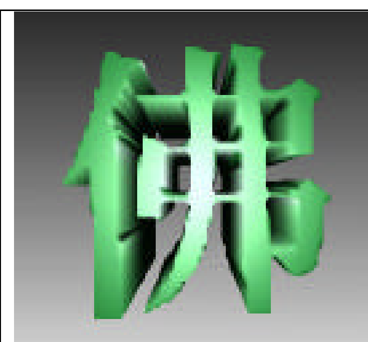
FRep also supports temporal changes in a natural way, by incorporating an additional parameter to describe the time behavior. Additional behaviors can be described by increasing model dimensionality [7].

As an example, we show the stages in the development of a 3D kanji model from a 2D image. First we select the relevant points for the part of the image we want to model. Note that the character naturally appears as two sections, which are modeled independently. It is simplest to model each piece as a composition of simpler components, for example, treating the two strokes of the left part separately. The pieces are then connected using HyperFun logical operators. The depth is then captured as though extruding the 2D x-y model into the z-direction. Finally, the HyperFun file (source code using simple ASCII characters) is passed to the polygonizer, which computes the surface and does a basic rendering.

Base image



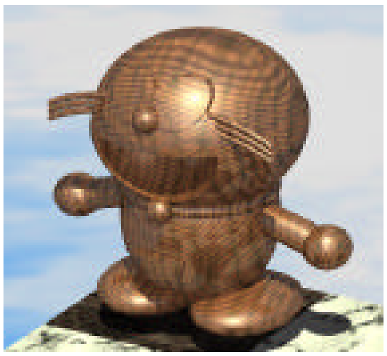
2D HyperFun model



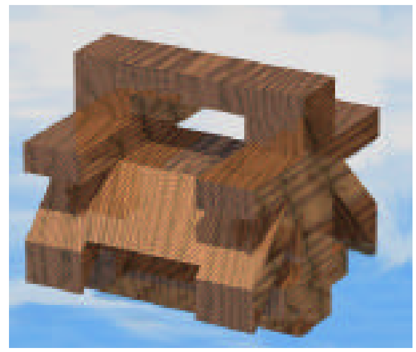
3D HyperFun model

The final object is true 3D, and can be rotated and displayed in any orientation, in real time. A HyperFun file is small, typically about 5 KB, thus well suited for web access.

Next we show a metamorphosis between a toy cat and a character (here the word “Nihon”) constructed as a sort of 3D pun. It is made by joining the kanji for “nichi” (ni) with the one for “hon” at right angles, to make a stylized “Nihon” which appears as hon from one direction, but as nichi from a direction at right angles to the previous one. First we show the two 3D models.

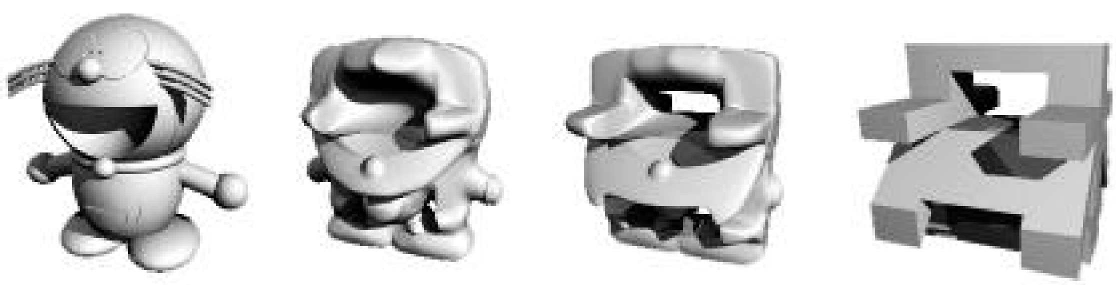


HyperFun toy cat



Nichi + Hon → Nihon

Next we show the stages in the metamorphosis between the two 3D objects, formed by interpolating the initial and final parameter sets.



Metamorphosis between the models

We next present a brief view of the initial stage of the transition between a kanji and a buddha image, using 2D HyperFun models. The metamorphosis is defined by a function F(x,y,time) as a time-dependent HyperFun model of a 2D object, and not as a blend of the images..

2D metamorphosis from kanji model to buddha model

For our example, we chose an old version of the character for buddha, which was shown in previous figures.

The examples above demonstrate some of the basic steps showing our concept and approach. With our approach, an object at any point in its metamorphosis will be a verifiably closed, mathematically accurate representation of the object at that stage of the metamorphosis, produced by using some of the forty currently available operations in HyperFun. For further information, refer to the website: http://www.hyperfun.org.

6. Obtaining FRep Models from 3D Scans

FRep models may be obtained by scanning three-dimensional objects. The input is a cloud of points $\{(x_i,y_i,z_i), i=1,N\}$ on or near the surface of the object. The problem is to construct a continuous real-valued function F(x,y,z) such that the points belong to the zero value isosurface F(x,y,z) = 0. We use the method proposed in [8] and developed further in [9].

The reconstruction method is based on the volume spline S(x,y,z) interpolating given scalar values in the scattered points. The 2D version of this spline is called "thin-plate spline" and is widely used in image warping. We introduce a carrier solid defined by an inequality $C(x,y,z) >= 0$, which can be a 3D ball or more close approximation of the initial object. Then, the function C(x,y,z) is evaluated at each point of the given cloud and these scalar values are interpolated by the volume spline S(x,y,z). Finally, the wanted function is constructed as $F(x,y,z) = S(x,y,z) - C(x,y,z)$.

Although there was no strong dependence found between the quality of the reconstruction and the shape of the carrier solid, intuitively a solid defined by C(x,y,z), which more closely approximates the initial object shape, should provide smaller deviations of the reconstructed surface from the initial one. This aspect requires further theoretical and experimental work. Such a carrier solid approximating the initial object shape can be constructed using the function representation technique as discussed in [3].

7. Conclusion

The work above demonstrates the use of mathematically-based modeling tools for cultural heritage preservation. As we have shown, FRep and HyperFun are particularly useful for cultural heritage projects because of their ability to handle complex shapes and to adapt them for virtual-reality animation. The fact that these tools are open-source rather than proprietary software is a crucial advantage in terms of portability and durability, both important requirements for preservation projects. Models produced with open-source tools such as HyperFun and FRep, moreover, can easily be adapted for educational use. Some of the authors have taught HyperFun to first-year university, high school, and junior high school students with considerable success, suggesting that students may use these tools to study the structure of cultural heritage objects and sites by making their own models.

8. Acknowledgements

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9. References

[1] William R. LaFleur, *The Karma of Words: Buddhism and the Literary Arts in Medieval Japan,* University of California Press, Berkeley, Los Angeles & London, 1983, p. 23.

[2] A. Pasko, V. Adzhiev, A. Sourin, and V. Savchenko, "Function representation in geometric modeling: concepts, implementation and applications", *The Visual Computer* 11:9 (1995), pp. 429-446.

[3] James M. Goodwin, Janet R. Goodwin, Alexander Pasko, Galina Pasko, and Carl Vilbrandt, "Digital Preservation of Cultural Heritage through Constructive Modeling", Proceedings of International Cultural Heritage Informatics Meeting (ICHIM 2001), Milan, Italy (to appear).

[4] Jules Bloomenthal, ed., *Introduction to Implicit Surfaces*, San Francisco: Morgan Kaufmann, 1997.

[5] A. Pasko, V. Adzhiev, and B. Schmitt, "Constructive hypervolume modelling", Technical Report TR-NCCA-2001-01, National Centre for Computer Animation, Bournemouth University, UK, 2001, ISBN 1-85899-123-4.

[6] V. Adzhiev, R. Cartwright, E. Fausett, A. Ossipov, A. Pasko, and V. Savchenko, "Hyperfun project: a framework for collaborative multidimensional FRep modeling", in J. Hughes and C. Schlick, eds., *Implicit Surfaces '99*, Eurographics/ACM SIGGRAPH Workshop, Bordeaux 1999; HyperFun Project: Language and Software for FRep Modeling, http://www.hyperfun.org.

[7] E. Fausett, A. Pasko, and V. Adzhiev, "Space-time and higher dimensional modeling for animation", Proceedings of Computer Animation 2000, IEEE Computer Society, 2000, pp.140-145.

[8] V. Savchenko, A. Pasko, O. Okunev, and T. Kunii, "Function representation of solids reconstructed from scattered surface points and contours", *Computer Graphics Forum* 14:4 (1995), pp.181-188.

[9] G. Turk, H. Dinh, J. O'Brien, and G. Yngve, "Implicit surfaces that interpolate", Proceedings of Shape Modeling and Applications (SMI 2001), IEEE Computer Society, 2001, pp. 62-71.