Volumetric and Multidimensional Modeling using HyperFun

A. Pasko, V. Adzhiev, V. Savchenko

www.hyperfun.org

GraphiCon’2000
Content

- HyperFun team
- F-rep: surfaces, solids, volumes, ND
- Project motivation
- HyperFun language and interpreter
- HyperFun tools
- Applications
HyperFun Team

• Japan
  - *Hosei University*: Pasko, Savchenko
  - *Aizu University*: Goto, Hibi, Vilbrandt
  - *Credit Swiss*: Fausett

• Russia
  - *MEPI*: Adzhiev, Ossipov, Kartasheva
  - *MIPT*: Kazakov

• France
  - *LABRI*: Schmitt

• UK
  - *University of Warwick*: Cartwright
Implicit Surfaces ≠ Blobs

A set of points with

$$f(x, y, z) = 0$$

is an implicit surface or more precisely

iso-valued surface (isosurface) of a function of three variables.
3D Solids

A 3D solid is defined as

\[ f(x, y, z) \geq 0 \]

with the implicit surface as its boundary.

Sphere:
\[ R^2 - x^2 - y^2 - z^2 = 0 \]

Solid ball:
\[ R^2 - x^2 - y^2 - z^2 \geq 0 \]
Volumes

Volume is a 3D point set with a scalar field

- Voxel model: 3D discrete grid + node value
- Functional model:
  
  \[
  f_1(x, y, z) \geq 0 - \text{point set}
  \]
  
  \[
  f_2(x, y, z) \geq 0 - \text{scalar field}
  \]
F-rep: multidimensional model

\[ I + \bigcup_{q=4}^{5} A^q + I_3 \]

- Function evaluation procedure processing a general tree structure
- Leaves: **primitives** (algebraic, skeleton-based, voxel, parametric, procedural)
- Nodes: **operations** (set-theoretic, blending, metamorphosis, sweeping, Cartesian product, Minkowski sum, etc.) + **relations** (collision, inclusion, etc.)
Closure of operations on F-rep

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HyperFun project motivation

- Segmentation of implicit modeling
- Lack of exchange protocol
- Multidimensionality
- Cross-platform and Internet-based modeling
- Extendibility and openness
- Building applications
- Education
HyperFun language

• HyperFun is a minimalist language
• Supports all notions of F-rep
• Multiple coordinate variables support multidimensional modeling
• Functional expressions
• Built-in operators for set-theoretic operations: |, &, \, ~, @
• F-rep library of primitives and operations
HyperFun Project

Language and Software Tools for F-rep Geometric Modeling

HyperFun is a simple geometric modeling language. It is intended for modeling geometric objects described in the form:

\[ F(x_1, x_2, x_3, ..., x_n) = 0, \]

This language is applicable to modeling algebraic and skeleton-based "implicit" surfaces, convolution surfaces, distance-based models, voxel objects, and more general F-rep objects.

The model in HyperFun is interpreted by the modeling and visualization software tools.
This HyperFun program consists of one object:

--union of superellipsoid, torus and soft object

my_model(x[3], a[1])
{
  array x0[9], y0[9], z0[9], d[9], center[3];
  x1=x[1];
  x2=x[2];
  x3=x[3];

  -- superellipsoid by formula
  superEl = 1 (x1/6.8)^4 (x2/19)^4 (x3/0.8)^4;

  -- torus by library function
  center = [0, 9, 0];
  torus = hTorus(x, center, 3.5, 1);

  -- soft object
  x0 = [-2.1, 1.4, -1.4, -3, -3, 0, 2.5, 5, 6.5];
  y0 = [0, 0, 0, 6.5, 5, 4.5, 3, 2, 1];
  z0 = [0, -1.4, -1.4, 0, 3, 4, 2.5, 0, -1];
  d = [2.5, 2.5, 2.5, 2.5, 2.5, 2.5, 2.5, 2.7, 3];
  sum = 0.0;
  i = 1;
  while (i<10) loop
    xt = x[i] - x0[i];
    yt = x[i] - y0[i];
    zt = x[i] - z0[i];
    r = sqrt(xt^2+yt^2+zt^2);
    if (r <= d[i]) then
      r2 = r^2; d2 = d[i]^2; r6 = r^6 ;
      d2_d6 = d2^3 d6^2; d2_d4 = d2^4 d4;
      sum = sum + (1 - 22 r2 / (9 d2) + 17 r4 / (9 d4) - 4 r6 / (8 d6));
    endif;
    i = i + 1;
  endloop;
  soft = sum - 0.2;

  -- final model as set-theoretic union
  my_model = superEl | torus | soft;
}
HyperFun interpreter

API is a suite of functions in ANSI C:

**Parse** function:
- syntax analysis
- generates internal tree structure (*byte-code*)
- outputs a list of error messages
- is invoked just once for a model.

**Calc** function performs function evaluation at the given point.
HyperFun Tools and Applications

www.hyperfun.org
HyperFun Tools

• Available on-line:
  - HyperFun Polygonizer
  - HyperFun for POV-Ray

• Graphical User Interface:
  - Skeleton modeling (convolution surfaces)
  - Construction Tree
  - Special Interfaces (volume splines)

• HyperFun-to-Java compiler and Empirical Worlds

• GNU++ license
HyperFun Polygonizer

- Polygonization algorithm [Pasko et al. 1988] using hyperbolic arcs
- Command line interface
- VRML export
- MAM/VRS + Tcl/Tk
- Multi-Platform:
  - Windows
  - Unix
  - Linux
HyperFun for POVRay

- Uses Suzuki’s Isosurface Patch
- HyperFun Objects manipulated as POVRay Objects
- Object Parameters and Coordinate Mappings
- Animation Capabilities
- Multi-Platform:
  - Windows
  - Unix
  - Linux
Symbolic Windows Interface

- Input-Edit-Output
- HyperFun models
- Scene composing
- Coordinate mapping
- Modeling and viewing parameters control
- Polygonization and ray-tracing
Interactive Skeleton Modeling

- Interactive modeling of skeletons for convolution surfaces:
  - Points
  - Lines
  - Arcs
  - Triangles
- Export to HyperFun
- Extendable GUI
- To appear in EG’2000 (short papers)
Polygonization: fish bones and body

Skeleton lines

Skeleton triangles

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Ray-traced convolution fish
Construction Tree

- Graphical display of the F-rep construction tree:
  - root
  - leaves (primitives)
  - nodes (unary, binary, n-ary operations)
- Direct manipulation on the tree:
  - Create/Delete nodes
  - Connect nodes
  - Edit parameters of nodes
- Import and export to HyperFun
Construction Tree Import

```plaintext
-- head final
L1 = eye9 | eye7;
L2 = L1 | atama1;
L3 = L2 | head;
L4 = L3 | hana;
my_model = L4 \ xkuti;
}
```
Editing Construction Tree
Sculpting Using 4D Volume Splines

- Interactive control of 4D Bezier or B-splines
- Multiresolution
- Export to HyperFun
- B. Schmitt (U. Bordeaux), Implicit Surfaces ‘99

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Volume Spline Control Techniques

- Cross-section painting
- Multiresolution
- Colored 3D control points

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Volume spline primitives
HyperFun-to-Java compiler

- HyperFun $\rightarrow$ Java code $\rightarrow$ Bytecode $\rightarrow$ Application
- Alternative approach to fast processing HyperFun shapes
- Platform independent and easy distribution
- Uses polygonizer in Java
- R. Cartwright (U. of Warwick), *Implicit Surfaces* ‘99

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Empirical Worlds

- Spreadsheet-like environment
- Collaborative and concurrent interaction of agents
- Incremental development of shape models
- R. Cartwright (BBC Research)
GNU++ License

- GNU GPL + Human rights
  + Environmental rights

- Product is not during its making or application to promote the violation of Human Rights

- Product is not to be used to promote or support actions that impoverish the environment

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Applications

• Research tool
• Education:
  - geometry, CG, modeling, compilers
• Art and culture
• Animation
• CAD $\to$ B-rep + CSG + F-rep + Voxels
## HyperFun Gallery by Students

<table>
<thead>
<tr>
<th>Core</th>
<th>Prison</th>
<th>Faucet</th>
<th>Rabbit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flock</td>
<td>Earth</td>
<td>Spirit</td>
<td>Sand</td>
</tr>
<tr>
<td>Bunny</td>
<td>Babe</td>
<td>Doughnut</td>
<td>Child</td>
</tr>
<tr>
<td>Tank</td>
<td>Air Twist</td>
<td>Double Helix</td>
<td>Gundam</td>
</tr>
</tbody>
</table>

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Virtual Lacquer Ware
HyperFun Project

Space-Time and Higher Dimensional Modeling for Animation

E. Fausett, A. Pasko, V. Adzhieiev
Multidimensional F-Rep

Space-Time Modeling

\[ F(x, y, z, t) \geq 0 \]

Higher Dimensional Modeling

\[ F(x_1, x_2, x_3, x_4, x_5, \ldots) \geq 0 \]

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Coordinate Mapping

- F-Rep Object is Mapped to Normalized Coordinates
- Normalized Coordinates are then Mapped to Multimedia Coordinates
Multimedia Coordinates

- **World**
  - 2D (x, y) or 3D (x, y, z)

- **Dynamic**
  - single (t) or multiple (t₁, t₂)

- **Spreadsheet**
  - (u, v)

- **Transformation**

- **Audio/Video**

- **Other**
  - Haptic
Case: 3D Metamorphosis

- Basic Modeling
- Dimension Increase
- Mapping
- Rendering
Basic 3D Modeling

Cat

NiHon

Robot

Rob_let
Dimension Increase

Bi-linear Interpolation

\[ \text{Meta5D}(x_1, x_2, x_3, x_4, x_5) = \]
\[ \left( \text{Cat}(x_1, x_2, x_3) \cdot (1 - x_4) \right) \cdot (1 - x_5) + \left( \text{NiHon}(x_1, x_2, x_3) \cdot (1 - x_4) \right) \cdot x_5 \]
\[ + \text{Robot}(x_1, x_2, x_3) \cdot x_4 \]
Coordinate Mapping

\[ x_1 \rightarrow x \ (world \ x) \]
\[ x_2 \rightarrow y \ (world \ y) \]
\[ x_3 \rightarrow z \ (world \ z) \]
\[ x_4 \rightarrow u \ (spreadsheet \ u) \]
\[ x_5 \rightarrow v \ (spreadsheet \ v) \]
Spreadsheet Rendering
Coordinate Mapping

\[ x_1 \rightarrow x \ (world \ x) \]
\[ x_2 \rightarrow y \ (world \ y) \]
\[ x_3 \rightarrow z \ (world \ z) \]
\[ x_4 \rightarrow t_1 \ (dynamic) \]
\[ x_5 \rightarrow t_2 \ (dynamic) \]
Animation Path in $t_1t_2$ Plane
Show animation
“Homotopic Fun in 5D Space”
The End