What is Kizamu?

• A computer-based sculpting system for creating digital characters

• Incorporates
  – New algorithms
  – Technical advances
  – Novel interaction paradigms

• Focus
  – High-end digital character design for the entertainment industry
Requirements for Digital Character Design

• Digital clay
  – Clay-like: intuitive to sculpt, represents both fine detail and organic shapes
  – Digital: can undo, script, duplicate, store permanently, etc.

• Responsive
  – Interactive on standard hardware

• Fits into the animation production pipeline
  – Accept scanned data as well as other standard representations
  – Produce standard representations as output

Kizamu System

• Objects represented as Adaptively Sampled Distance Fields (ADFs)
  – ADFs can be directly and intuitively edited
  – ADFs represent fine detail and smooth organic surfaces
  – ADFs support fast processing with a reasonable memory footprint

• Volumetric sculpting interface that exploits the distance field to provide intuitive interaction

• Accepts range data, triangle models, Bezier patches, and implicit functions as input

• Produces LOD triangle models as output
A Brief Overview of ADFs

- **Distance fields**
  - A distance field is a scalar field that specifies the distance to the surface of a shape.
  - The distance may be signed to distinguish between the inside and outside of the shape.

2D shape with sampled distances to the surface

Regularly sampled distance values

2D distance field
Regularly Sampled Distance Fields

- Distance fields must be sampled at high enough rates to avoid aliasing (jagged edges)
- Very dense sampling is required when fine detail is present
- Regularly sampled distance fields require excessive memory when any fine detail is present

Adaptively Sampled Distance Fields (ADFs)

- Detail-directed sampling of a distance field
  - High sampling rates only where needed
- Spatial data structure (e.g., an octree)
  - Fast localization for efficient processing
- Reconstruction method (e.g., trilinear interpolation)
  - For reconstructing the distance field and gradient from sampled distance values
Adaptively Sampled Distance Fields

A 2D crescent ADF and its quadtree data structure

Advantages of ADFs for Editing

- Represent both smooth surfaces and sharp corners without excessive memory
- Sculpting is direct, intuitive, and fast using simple Boolean operations
- Does not require control point manipulation or trimming
- The distance field can be used to enhance the user interface
  - Guide the position and orientation of the sculpting tool
  - Enable distance-based constraints for carving
What was Required to Build Kizamu

- Innovations in the sculpting interface
- Advances in ADF generation and ADF editing
- New approaches for ADF rendering
- Methods for generating ADFs directly from range data and converting ADFs to triangle models

Sculpting Interface

- Surface following
- Distance-based constraints
- Control-point editing
Sculpting Interface

- Surface following
- Distance-based constraints
- Control-point editing
Bottom-up ADF Generation

- Requires too many distance computations, too much memory, pre-set resolution

Top-down ADF Generation

- Requires expensive neighbor searches and redundant distance computation
Tiled Generation

- Reduced memory requirements, better memory coherency and reduced computation

- Significantly faster (20x)
  - 2 seconds vs 40 seconds for a level 9 ADF
  - 7.6 seconds for a level 12 ADF

- More detail ((8x)^3 higher resolution)
  - level 12 and level 13 ADFs vs level 9 ADFs

Tiled Generation – Method

Outline

- Recursively subdivide root cell to a level $L$

- Cells at level $L$ requiring further subdivision are appended to a list of candidate cells, $C$-list

- These candidate cells are recursively subdivided between levels $L$ and $2L$, where new candidate cells are produced and appended to $C$-list

- Repeat layered production of candidate cells ($2L$ to $3L$, etc.) until $C$-list is empty
Tiled Generation – Tiling

- For each candidate cell, computed and reconstructed distances are produced only as needed during subdivision.
- These distances are stored in a tile, a regularly sampled volume.
- Avoids recomputing distance values shared by neighboring cells. A corresponding volume of bit flags keeps track of valid distances in the tile.
- The tile resides in cache memory and its size determines $L$.

Sculpting

- Sculpting is localized regeneration
  - The ADF is regenerated inside cells that overlap the tool’s bounding volume.
  - Regeneration combines the distance fields of the ADF and the tool using CSG operations.
Local Rendering

• Ray casting method

• Problems
  – Too slow for local updates on low-end systems
  – Woefully inadequate for global view changes

Adaptive Ray Casting

• Adaptive ray casting method
  – Image divided into a hierarchy of tiles
  – Tiles are subdivided according to perceptually based predicates
  – Pixels in tiles greater than 1x1 are bilinearly interpolated

• Achieve 6x speedup (10x for supersampling)
Adaptive Ray Casting

Adaptively ray cast ADF

Rays cast to render part of the left image

Global Rendering of Point Models

- Method for generating point models from ADFs
  - Seed each boundary leaf cell with randomly placed points, with number of points proportional to surface area within the cell
  - Relax the points onto the ADF surface using the distance field and its gradient
  - Optionally shade each point using the distance gradient

- Can generate 800,000 Phong illuminated points in 0.2 seconds

- Point models are sufficient for positioning
Point-based Rendering

An ADF rendered as points at two different scales

Global Rendering using Triangles

- Convert ADFs to triangle models and render interactively with hardware

- Fast new triangulation algorithm creates triangle models from ADFs on-the-fly
  - Watertight and oriented
  - Good-quality triangles
  - 200,000 triangles in 0.37 seconds
  - Can create LOD models
Converting to Triangle Models

- **Seed**
  - Assign a vertex to each boundary leaf cell of the ADF, initially placing vertices at cell centers

- **Join**
  - Join vertices of neighboring cells to form triangles

- **Relax**
  - Move vertices to the surface using the distance field

- **Improve**
  - Move vertices over the surface towards their average neighbors’ position to improve triangle quality

Creating LOD Triangle Models

- **Adapt triangulation to generate LOD models**
  - Traverse octree from root to leaf cells
  - Seed vertices in (possibly) non-leaf boundary cells that satisfy a minimum error criterion
  - Ignore cells below these in the hierarchy
Converting Range Data to ADFs

• Capture 2D range images from multiple views

Range images collected from several viewpoints

• Combine distances from multiple range images to estimate ADF distance values

Combine distances from multiple range images

ADF generated from 14 synthetic range images
Results – Detail

“Boston road map” sculpted with 2000 random chisel strokes

Results – Detail

ADF cow procedurally sculpted with 21,063 chisel strokes
Results – And More Detail

Flowers carved from a photograph using conversion from range images to ADFs

Kizamu Demonstration
New Directions

- ADFs provide a single representation for both surface and volume models
- Extend Kizamu to support the creation of detailed volumetric digital characters

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