GPU Algorithms for NURBS Minimum Distance and Clearance Computations
Adarsh Krishnamurthy, Sara McMains
University of California, Berkeley

GPU Algorithm Development

Challenges
- GPU/CPU hybrid operations
- Distribution of work between CPU and GPU
- Some operations are inherently serial
- GPU restrictions
  - Restrictions on dynamic loops
  - Restrictions on texture memory usage
- GPU performance guidelines
  - Coherent memory reads
  - Branchless kernels
  - Reduced data read-back from GPU
- Multiple GPU vendors
  - Algorithms should run on any massively parallel architecture
  - Should be easy to port to many-core architecture

Strategies
- Separation of CPU/GPU operations
  - Example: NURBS evaluations
- Imposing artificial structure to the computations
  - Example: Surface minimum distance computations
- Separating problem into multiple stages
  - Example: Object clearance computations


NURBS Evaluation

- Two step operation
  - Evaluate basis function values in multiple passes
  - Multiply basis function values with control points to get surface coordinates
- Separation of CPU/GPU operations
  - Example: NURBS evaluations


NURBS Evaluation Results

- Graphs comparing NURBS evaluation times for different implementations on two different graphics cards
- Implementations tested
  - CUDA
  - CUDA with texture memory (CUDA Textures)
  - CUDA without ping-pong (CUDA NoPP)
  - GPGPU (OpenGL)
  - GPGPU with texture packing (OpenGL Packed)
  - GPGPU without ping-pong (OpenGL NoPP)

Bounding Boxes for NURBS Surfaces

- Build bounding-boxes for NURBS surfaces to accelerate geometric operations
- Use grid of points on surface already evaluated
- Find min, max, u, v, & w coordinates of four adjacent points and build the basic bounding-box
- Find the minimum possible deviation, δ of the actual surface from a piecewise-linear approximation
- Expand the size of the bounding-box by δ, which will guarantee that the bounding-box contains the surface

Surface Minimum Distance Computations

- GPU acceleration strategy
  - Construct bounding box hierarchies
  - Map sets of 4 boxes from each surface at each level of hierarchy to a minimum distance texture
  - Find set of potentially-close bounding-boxes at this level
  - Refine to the finer level
  - GPU acceleration effective when number of potentially-close bounding-boxes increase at lower levels
- Minimum distance computation
  - Linearize the surface patches inside the finest level of potentially-close bounding-boxes with triangles
  - Find the minimum distance between these triangles

Timing Results

- Interactive minimum distance computations
  - Using NVIDIA Quadro FX5800
  - One surface interactively rotated and translated with respect to a fixed surface
  - Average computation time: 0.11s
  - Tolerance bounds were < 0.01 for all computations

Object Clearance Computations

- Two-stage computations
  - Voxelize the object using the coarse tessellation used for display
  - Find list of potentially-close voxel pairs
- Surface-based second stage
  - Create a list of potentially-close surfaces that intersect the potentially-close voxel pairs
  - Compute minimum distance between the surfaces

Object Clearance Results

- Second step process
  - Voxelize the object using the coarse tessellation used for display
  - Find list of potentially-close voxel pairs
  - Use grid of points on surface already evaluated
  - Find min, max, u, v, & w coordinates of four adjacent points and build the basic bounding-box
  - Find the minimum possible deviation, δ of the actual surface from a piecewise-linear approximation
  - Expand the size of the bounding-box by δ, which will guarantee that the bounding-box contains the surface

Conclusions

- Dramatic performance gains
  - Frequent orders of magnitude improvement
  - But requires GPU optimized algorithms
- Hybrid CPU/GPU algorithms
  - Some parts of algorithms are inherently serial
  - Use GPU in such cases for better work-load balancing
- Guaranteed user-specified tolerances
  - Enables direct adoption of GPU algorithms in CAD
- GPU framework
  - Reduces development time for new algorithms
  - Helps in performance tuning and optimization

GPU Programming Insights

- Use grid of points on surface already evaluated
- Find min, max, u, v, & w coordinates of four adjacent points and build the basic bounding-box
- Find the minimum possible deviation, δ of the actual surface from a piecewise-linear approximation
- Expand the size of the bounding-box by δ, which will guarantee that the bounding-box contains the surface

Computer-Aided Design and Manufacturing Laboratory, Mechanical Engineering Department, University of California, Berkeley