Collision detection

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Overview

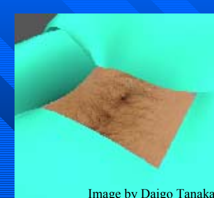
- Motivation
- Classification
- Query type
- Algorithms
- Examples
- Research directions

Motivation

- Surgical simulation involves a complex interaction between
  - Tool and tissue
  - Tissue and tissue
  - Tool and tool
- Interactions can mean
  - Physical contact
  - Penetration (piercing, cutting)
  - Proximity (thermal tool too close to sensitive tissue)

Brute force collision detection

- Check for collisions between everything and everything else!
- Includes
  - Self collision
  - Tool-tissue collision
  - tissue-tissue collision
- Too much, need to prune list of objects/polygons to test



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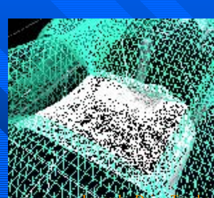
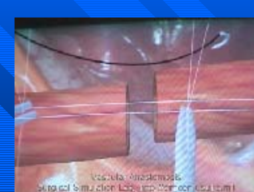


Collision detection

- Must be performed rapidly
  - For realistic visual and haptic responses
- Types of collisions
  - Tool/tool
  - Tool/tissue
  - Tissue/tissue
- Tissues can deform!



Detecting collision between polyhedra

- Feature-based algorithms
  - Features can be vertices, lines, or faces.
  - Examples
    - » Lin-Canny algorithm
    - » V-Clip
- Linear programming methods
  - Gilbert, Johnson and Kerrthi Algorithm
    - » GJK and enhanced GJK

Bounding volumes

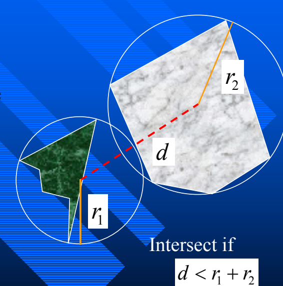
- Distant objects don't intersect
  - Ignore
- Need fast way to determine if objects are distant
- Use two level approach
  - Prune uninteresting objects
    - » Too far away
    - » No colliding for next "n" time steps
  - Check for collision between likely objects only
    - » Check between polytopes
    - » Check specific polygons between objects.

Popular pruning methods

- Bounding volumes
  - Spheres
  - Boxes
    - » Static partition
    - » Axis aligned bounding boxes
    - » Separating Axis Theorem
- Hierarchy of volumes
  - Octrees
  - Sphere trees
  - OBBTrees

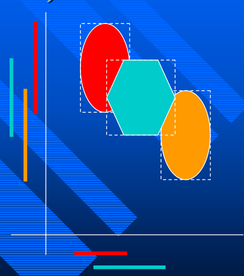
Spheres

- Bound objects by spheres
- Fast, easy to compute
- Can be too conservative
  - Too many false positives if object is long and thin/flat
  - But see [HUBBARD93] and [HUBBARD96]



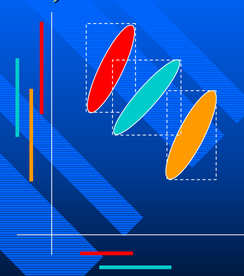
Axis Aligned Bounding Boxes (AABB)

- I-Collide algorithm [COHEN95]
  - Boxes intersect if and only if projections to coordinate axes intersect
  - Uses temporal coherence
    - » Detects all possible intersections in expected linear time



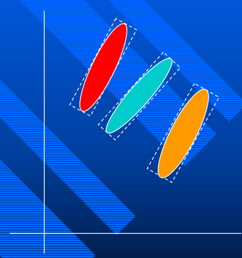
Axis Aligned Bounding Boxes (AABB)

- Inefficient for long thin objects at arbitrary orientations
- Need to keep recomputing bounding boxes for
  - rotating objects
  - deforming objects



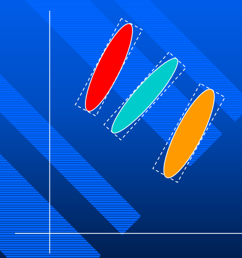
Oriented bounding boxes

- Oriented bounding boxes
- Bounding box is not necessarily aligned to coordinate axes
- Separating Axis Theorem [GOTTSCHALK96].
- Two polytopes are disjoint iff.
  - there exists an axis orthogonal to an edge in each polytope, or there exists an axis orthogonal to a face on one polytope



Oriented bounding boxes

- For boxes, need to test at most 15 axes
  - Each box has 3 unique face and 3 unique edge orientations
  - Thus, 3 faces (on one box) + 3 faces (on the other box) + 9 edge combinations



Static partition

- Partition space into fixed sized boxes
- Build hash table mapping space to polygons
- Advantages
  - Fast (expected constant time)
  - Deformations easily handled
- Disadvantages
  - Memory overhead
  - But memory is cheap

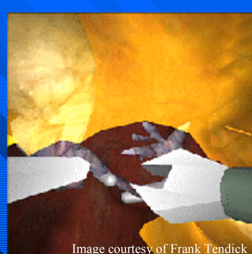


Image courtesy of Frank Tendick

Hierarchy of bounding volumes

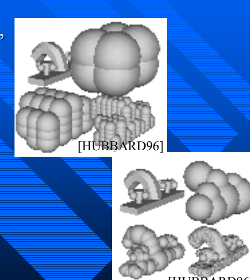
- Need tighter fit with object
- Collision detection reduced to tree search
  - Typically O(lg N) time
- Types of bounding volume hierarchies
  - Octrees [SAMMET98]
  - Sphere trees [HUBBARD93]
  - AABB Trees [BERGEN97]
  - OBB Trees [GOTTSCHALK96]

Octrees
[SAMMET98]

- Start with AABB encompassing entire object
  - Recursively subdivide box into four sub-boxes until a lower limit is reached
  - Relatively easy to construct
  - Updates are non-trivial
    - » Movement
    - » Deformation

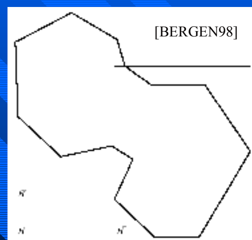
Sphere trees
[HUBBARD93]

- Instead of using boxes, use spheres
- Methods for building hierarchy
  - Octree subdivision [HUBBARD93]
  - Medial axis based [HUBBARD96]



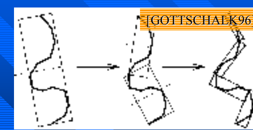
AABB Trees
[BERGEN98]

- Recursively subdivide AABB by partitioning along longest axis
- Refit boxes after deformation
  - AABB of child AABBs is smallest AABB enclosing all primitives.
  - Refitted boxes have more overlap than rebuilt boxes
- Software available (SOLID)
  - See resources slide at end



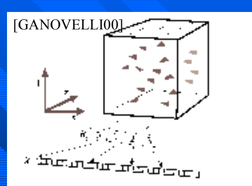
OBBTrees
[GOTTSCHALK96]

- Recursively subdivide OBBs
  - Divide along longest/2nd longest/shortest axis
  - Repeat division until not possible to divide on any axis
  - Use Separating Axis Theorem to determine intersection



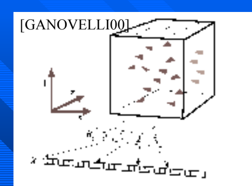
Bucket trees
[GANOVELLI00]

- For each axis, maintain sorted list of polygon coordinates
- Use octree to partition space
- Leaves point to polygon with lowest coordinate value in each array
  - Each leaf contains a “bucket” of polygons



Bucket trees

- When object deforms, polygons move to different bucket
  - Change pointer at leaves



Sphere trees	AABB Tree	OBB Tree	Bucket Trees
• Rotationally invariant • Intersection test is very simple • Approximation to underlying object may be poor	• No need to rebuilt tree for deformable objects • Easy to build • Relatively easy to test for intersections • Needs more intersection tests compared to OBB Tree (object dependent)	• Tight fit with underlying object • Faster • Relatively easy to test for intersections • Needs fewer intersection tests compared to AABB Tree (object dependent)	• Updating tree for deformable objects requires little effort • Tree can get unbalanced
Efficient for rejection tests, less efficient for cases where multiple intersections exists			

Hardware based collision detection
[LOMBARDO99]

- Hardware implementation for a specific collision detection task
- No additional data structures
- Uses commonly available graphics hardware
  - OpenGL based
- Detects multiple contact points in one pass
- Runs at interactive frame rates
  - Depending on hardware

Hardware based collision detection [LOMBARDO99]

- Laparoscopic instrument moves about a pivot point
- At each time step, instrument moves in (nearly) a straight line.
- Volume swept out by instrument approximates a viewing frustum
- Use OpenGL define that frustum, then render
- Anything visible must be due to objects intersecting path of instrument

Hardware based collision detection [LOMBARDO99]

Using the Author's method:

processor / graphic	R10000 195 MHz Onyx2 IR	DEC alpha 500 MHz 4D60	Pentium2 333Mhz software (Linux Mesa)	Pentium2 333Mhz 3Dfx Voodoo2 (Linux Mesa)
static	0.13 ms	0.09 ms	2.2 ms	1.7 ms
dynamic	0,16 ms	0,11 ms	3.0 ms	2.3 ms

Using the Obb tree method:

processor	R10000 195 MHz	DEC alpha 500 MHz	Pentium2 333Mhz
Precomputations	24.1 ms	15.7 ms	35.6 ms
static	0.63 ms	0.44 ms	1.0 ms
dynamic	0.76 ms	0.48 ms	1.2 ms

NB: *static* means considering a single position for the tool
dynamic means considering the tool positions during a time interval

Open questions

- Many, many points of contact
  - Organ/organ, Suturing, Palpation
  - Many current algorithms not efficient at solving this problem
- Deformation, change in topology
- Self collision
  - Knot tying
- Collision detection using a volumetric representation
- Need to do everything in real-time

Collision detection code

- Lin-Canny algorithm
  - http://www.cs.berkeley.edu/~mirtich/collDet.html
- I-COLLIDE,V-COLLIDE and many others
  - http://www.cs.unc.edu/~geom/
- SOLID (AABB Trees)
  - http://www.win.tue.nl/~gino/solid/
- Enhanced GJK
  - http://web.comlab.ox.ac.uk/oucl/work/stephen.cameron /distances/index.html

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