ADB-Trees: Controlling the Error of Time-Critical Collision Detection

Jan Klein
University of Paderborn
Germany

Gabriel Zachmann
University of Bonn
Germany

Munich, Germany – 19. November 2003

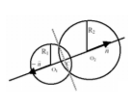
Motivation

- Collision detection is a fundamental operation in:
  - Games
  - Haptic rendering
  - Interaction in VR

- Important: responsive collision detection at all times.
- Time-critical: if algorithm cannot reach an exact answer during that time, return "best effort" result.
- "Best effort" result should be as good as possible.

Related Work

- Approximating Polyhedra with Spheres for Time-Critical Collision Detection [Hubbard, 1996]
- Graceful Degradation of Collision Handling in Physically Based Animation [Dingliana, O'Sullivan, 2000]



- No theoretical foundation concerning the error.
- No collision probability if time budget exhausted.

We concentrate on collision detection between rigid bodies.

Our Contribution

- New general framework for time-critical, hierarchical collision detection with error estimation.
- New probability-guided traversal of BV-hierarchies.
- Very small footprint of data structure (no polygons are needed).

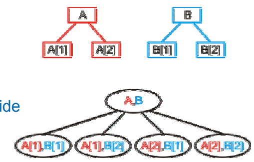
screenshot: two cars tested for collision

Average-Distribution (ADB) Trees

Collision Detection using ADB-Trees

ADB-tree: hierarchical, object partitioning tree where BVs are augmented by density attributes.

Given two ADB-trees for two objects



- traverse hierarchies simultaneously
- for each pair A,B: estimate Pr[A,B] that polygons in A and B collide
- give priority to pair with highest probability
- stop traversal, if Pr[A,B] $> p_{min}$

No polygon intersection tests are needed for “estimate Pr[A,B]”.

Main Idea

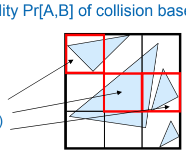
ADB-tree:

- Construct any hierarchical, object partitioning tree (e.g., AABB tree).
- For each BV *A* in the hierarchy:
  - partition *A* into grid
  - count number of cells that contain “large” polygon area → pc(*A*)
  - store *only* pc(*A*) with BV *A*
  - delete all polygons from tree

Given BVs *A* and *B* of different ADB-trees :

- estimate probability Pr[A,B] of collision based on pc(*A*), pc(*B*) and Vol ($A \cap B$)

possible collision cells (pc)

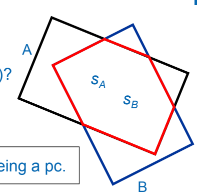


BV *A* , pc(*A*) = 3

ADB-Trees: Assumption

s_A : number of pc of *A* lying in Vol($A \cap B$)

Can we *quickly* estimate s_A and s_B by pc(*A*) and pc(*B*)?
→ Yes, under the following assumption!

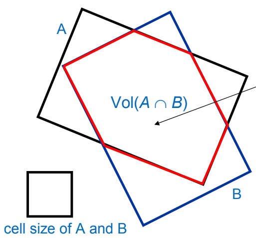


Assumption: each cell $\in A$ has same probability of being a pc.

If Vol(*A*) = Vol(*B*) ⇒ estimate s_A and s_B proportional to Vol($A \cap B$).
If Vol(*A*) ≠ Vol(*B*) ⇒ (please refer to our paper).

→ Average-case approach: it works well in the average case, where pc are evenly distributed.

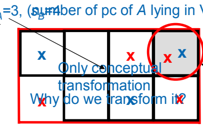
Our Average-Case Approach



cell size of A and B

s_A=3, (number of pc of A lying in Vol($A \cap B$))

s_B=4



s cells

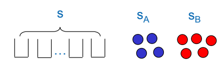
probability of being a pc is evenly distributed among all cells

Compute probability that ≥ *x* cells exist, which are pc with respect to *A* and *B* (called *collision cells (cc)*).

Probability Computations

HEINZ NIXDORF INSTITUTE
University of Paderborn
Algorithms and Complexity

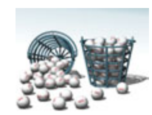
Given *s*, s_A, s_B, compute Pr[cc($A \cap B$) ≥ *x*] by *balls into bins model*.



What is the probability that at least *x* bins get a red and a blue ball?

$$Pr[cc(A \cap B) \geq x] \approx 1 - \sum_{t=0}^{x-1} \frac{\binom{s_B}{t}\binom{s-s_B}{s_A-t}}{\binom{s}{s_A}}$$

s_A and s_B can only be estimated!



balls into bins

Estimating Probability of Collision

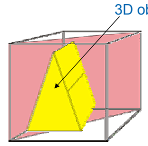
HEINZ NIXDORF INSTITUTE
University of Paderborn
Algorithms and Complexity

What can we do with Pr[cc(A ∩ B) ≥ x]?

- This probability depends on the definition of a pc (“large” polygon area).
- cc contain “large” polygon area from both objects, but the polygons do not have to collide.

→ LB($A \cap B$): lower bound for the probability that a collision really takes place in a cc (detail → VRST’03 paper).

3D object



possible collision cell

Estimate Pr[A,B]:

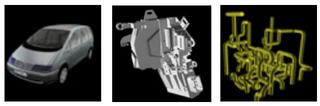
$$\max_{valid\ x} \{Pr[cc(A \cap B) \geq x] \cdot (1-(1-LB(A \cap B))^x)\}$$

HEINZ NIXDORF INSTITUTE
University of Paderborn
Algorithms and Complexity

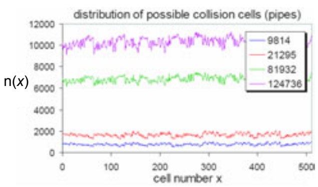
Results

Possible Collision Cell Distribution

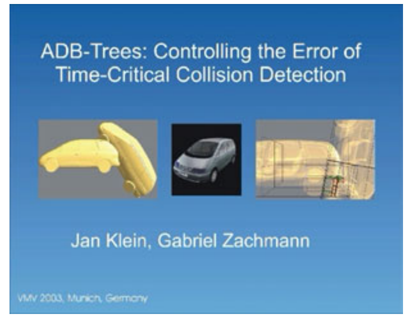
- Given all BVs of an ADB tree + information which cell is a pc.
- Each node is partitioned into *c* cells.
- Identify corresponding cells of all nodes by *x*.



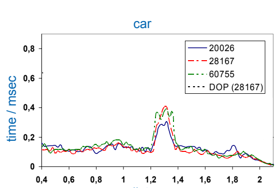
- Count over all nodes how often cells with the identifier *x* are pc → n(*x*).

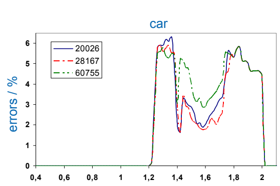


Video



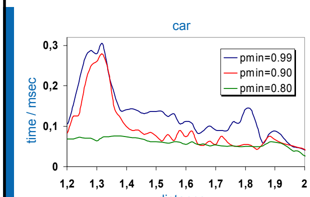
Time and Quality vs Complexity

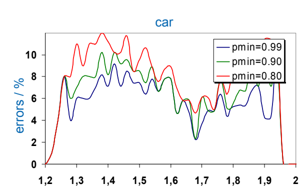




(Pentium-IV, 2.4GHz, 1 GB main memory)

Time vs Quality





Runtime increases if p_{min} increases.

Error rate decreases if p_{min} increases.

Remember: if p_{min} is reached, our algorithm claims it has found a collision.
(Pr[cc(A + B) ≥ x] ≥ pmin? → stop traversal)

Conclusion & Future Work

HEINZ NIXDORF INSTITUTE
University of Paderborn
Algorithms and Complexity

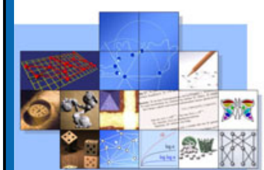
Conclusion

- General framework for time-critical hierarchical collision detection.
- It uses probability estimations to balance speed and quality.
- Results show speedup of about a factor 3 to 6 with only about 4 % errors.

Future Work

- Non-polygonal geometry
- Broad phase of collision detection
- Deformable objects
- Other BV hierarchies (DOP tree, restricted boxtree)

Thank you!



Jan Klein

Heinz Nixdorf Institute and
Institute of Computer Science
University of Paderborn, Germany

E-Mail: janklein@uni-paderborn.de

Dr. Gabriel Zachmann

Dept. of Computer Graphics and
Virtual Reality
University of Bonn, Germany

E-Mail: zach@cs.uni-bonn.de