Kinetic Separation Lists for Continuous Collision Detection of Deformable Objects

René Weller

Clausthal University, Germany

weller@in.tu-clausthal.de

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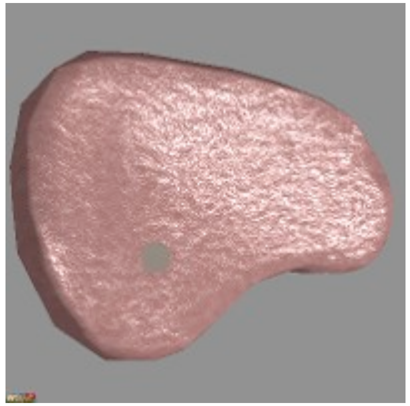
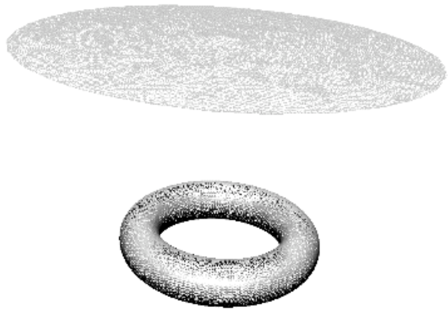
Motivation

- Environments with dynamically deforming objects play an important role in many applications
  - Medical simulation
  - Animations (Games/Movies)
  - Cloth simulation

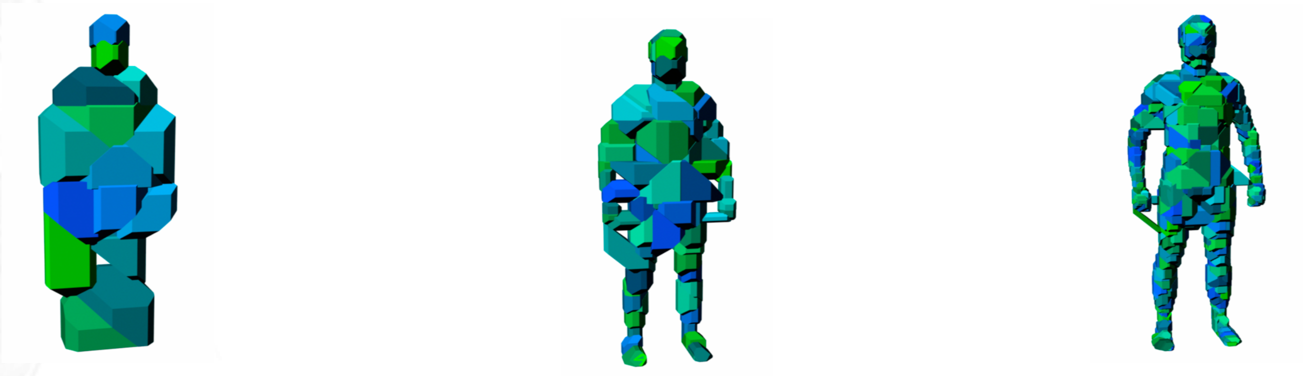




Courtesy GRIS, Tübingen

CD for Deformable Objects

- Most current techniques use BVHs
- The pre-processed hierarchy becomes invalid when the object deforms
- Problem of adjacency when using BVHs for self collision detection
- Swept volumes for continuous CD



Courtesy GRIS, Tübingen

Swept-Volume Continuous CD

Problems

- Discrete time sampling
  - Many update operations/ collision checks
- No adequate use of spatial and temporal coherence
- Other approaches:
  - Restriction of deformation schemes [James and Pai, 2004]
  - Chromatic decompositions [Govindaraju et al. 2005]
  - Kinetic sweep-and-prune-algorithm [Coming, Staadt, 2006]

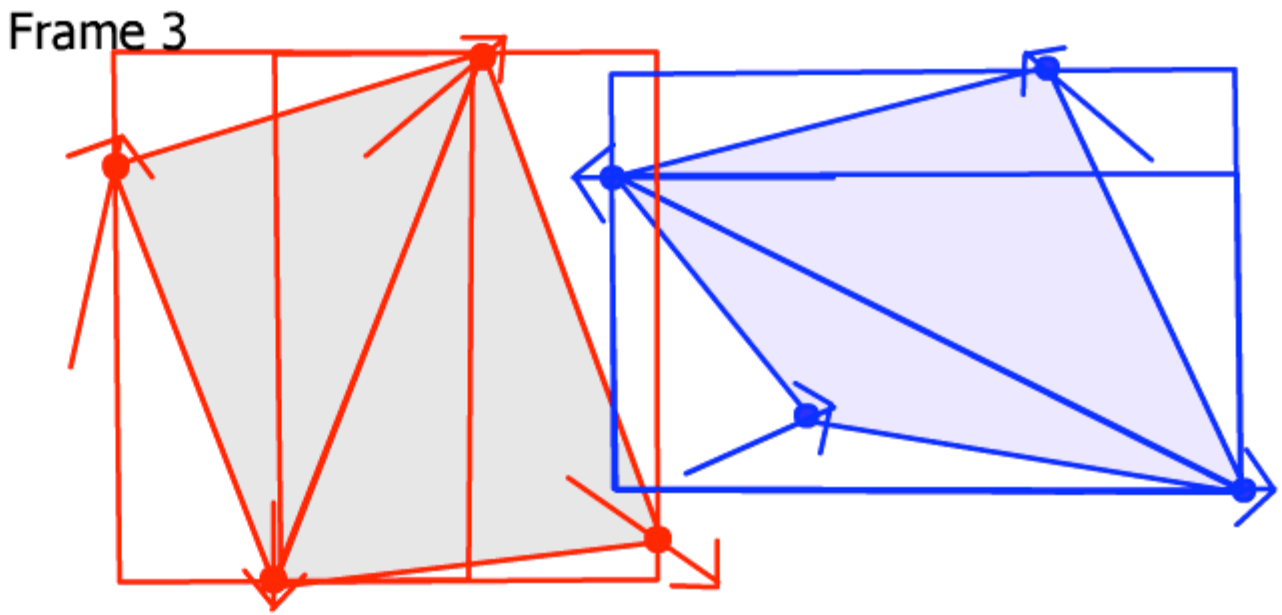
Our Approach

- Motion in the physical world is normally continuous
- Changes in the combinatorial structure of the BHVs and collisions occur only at discrete time points

  → We store only the combinatorial structure of the BVH and use an event based approach for updates

  → We maintain the combinatorial structure of the recursion tree
- Collision detection is reduced to the discrete problem of determining changes in our separation list

Event Based Continuous Collision Detection



Event-Queue

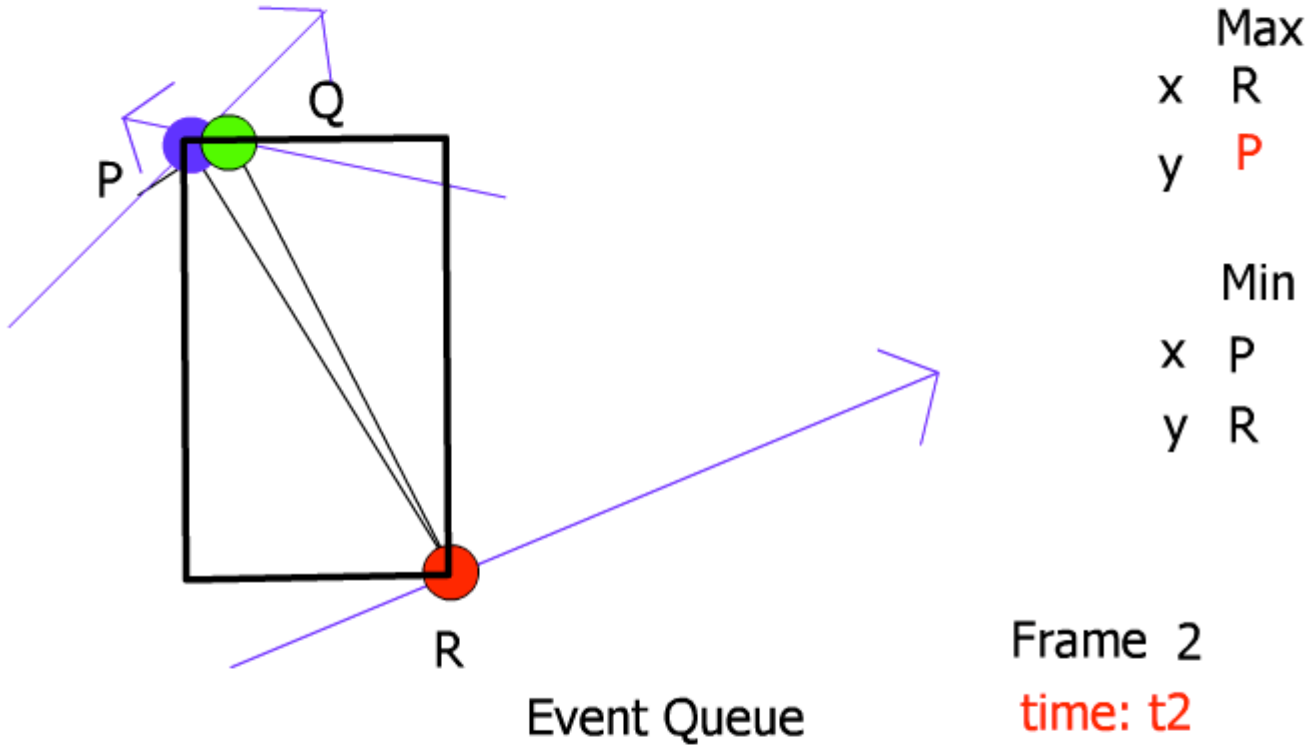
Advantages

- Valid BVHs and separation list at every point in time
- Independent of query sampling frequency
- Collisions are reported in the right order
- Can handle all kinds of objects
  - polygon soups, point clouds, and NURBS models
- Can handle insertions/deletions during run-time
- Inter-object and self-collision detection
- Can handle all kinds of deformations
  - Only a flightplan is required for every vertex
  - These flightplans may change during simulation

Recap: Kinetic AABB Tree

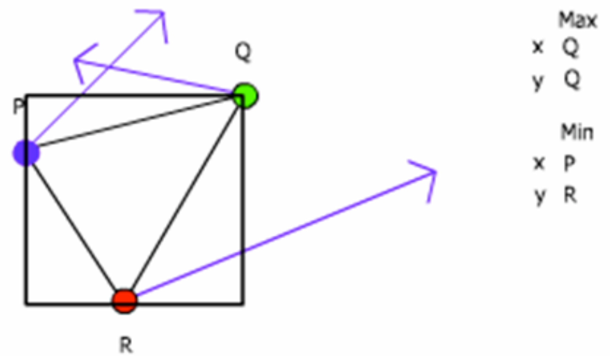
- Kinetization of the AABB tree
- Pre-processing: Build the tree by any algorithm suitable for static AABB trees
- Store with every node the indices of those points that determine the BV

Recap: Kinetic AABB Updates



Recap: KDS terminology

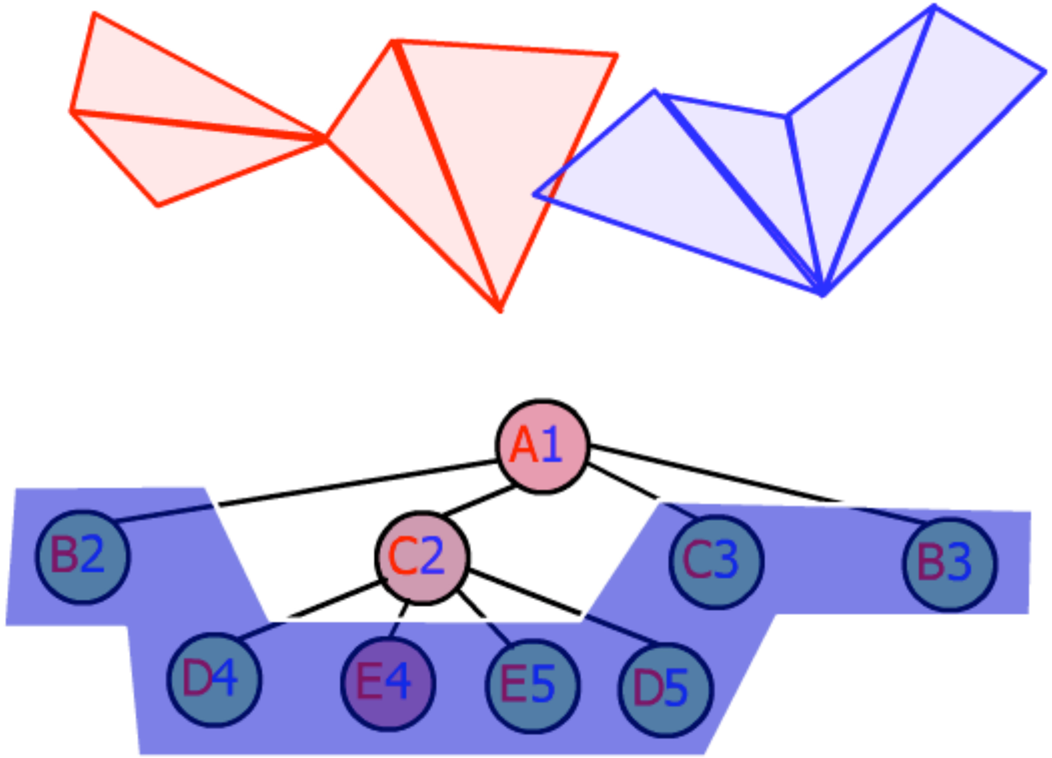
- KDS are a framework for designing and analyzing algorithms for objects in motion [Basch et al. 1997]
- KDS framework leads to event-based algorithms that samples the state of parts of a system only as often as necessary for a special task (e.g. a bounding box)
- The task is called the attribute
- A KDS consists of certificates
- Certificate failures are called events
- If the attribute changes at the time of an event, the event is called external, otherwise internal



Kinetic Separation List

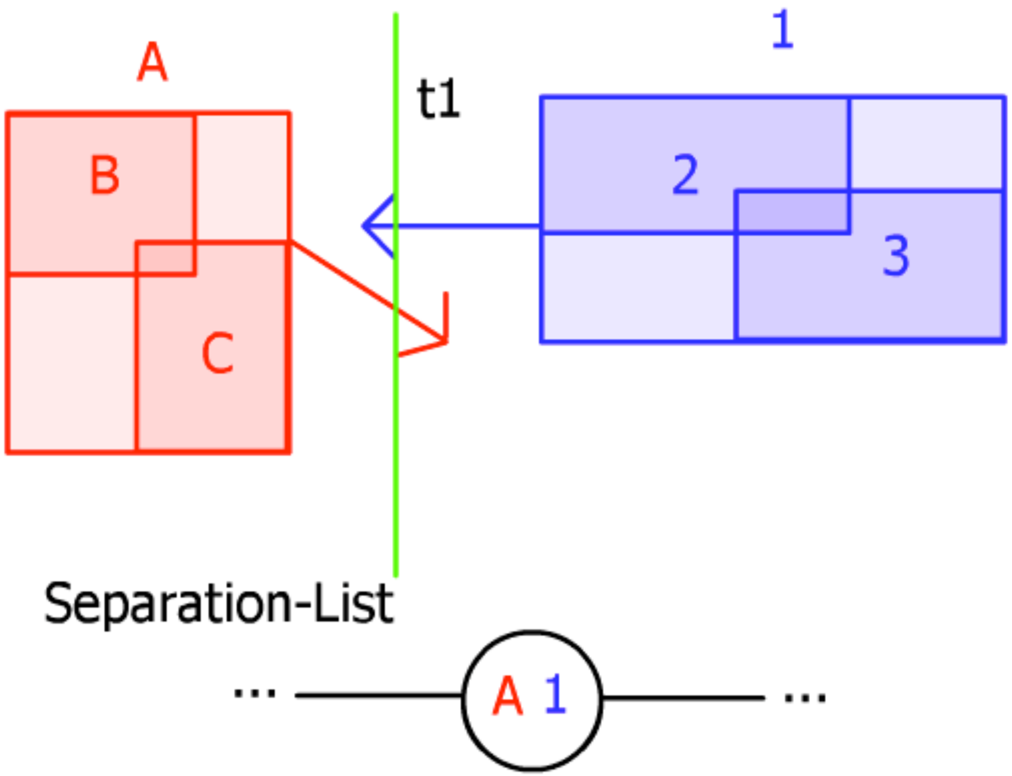
- Kinetic AABB tree utilizes coherence only for updates
- Kinetic separation list uses event-based approach also for collision detection
  - Between pairs of objects
  - Self-collision detection
- Kinetization of the „moving front" algorithm

Definition/Initialization of the Separation List

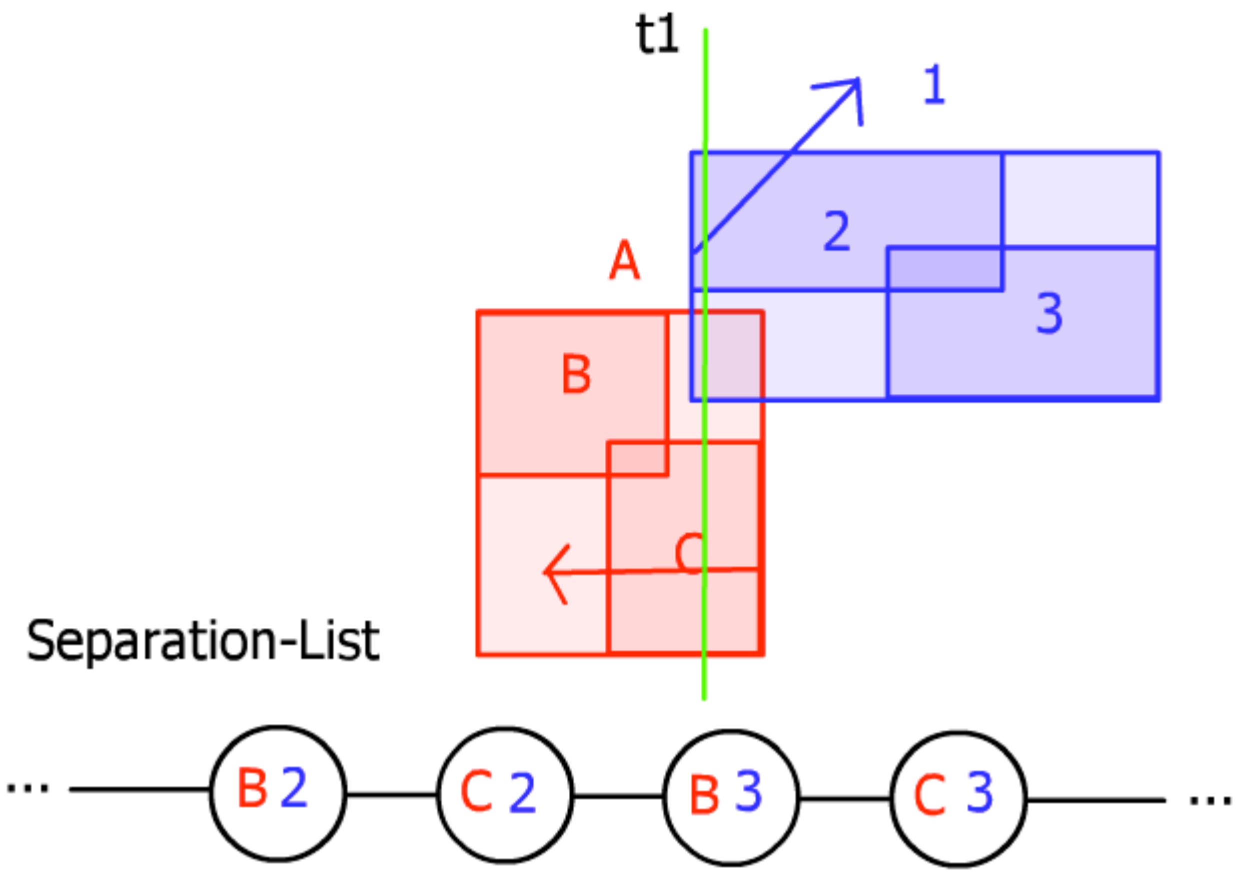


- Separation list contains highest non-overlapping BVs and overlapping leaves

Initializing events: BVs overlap



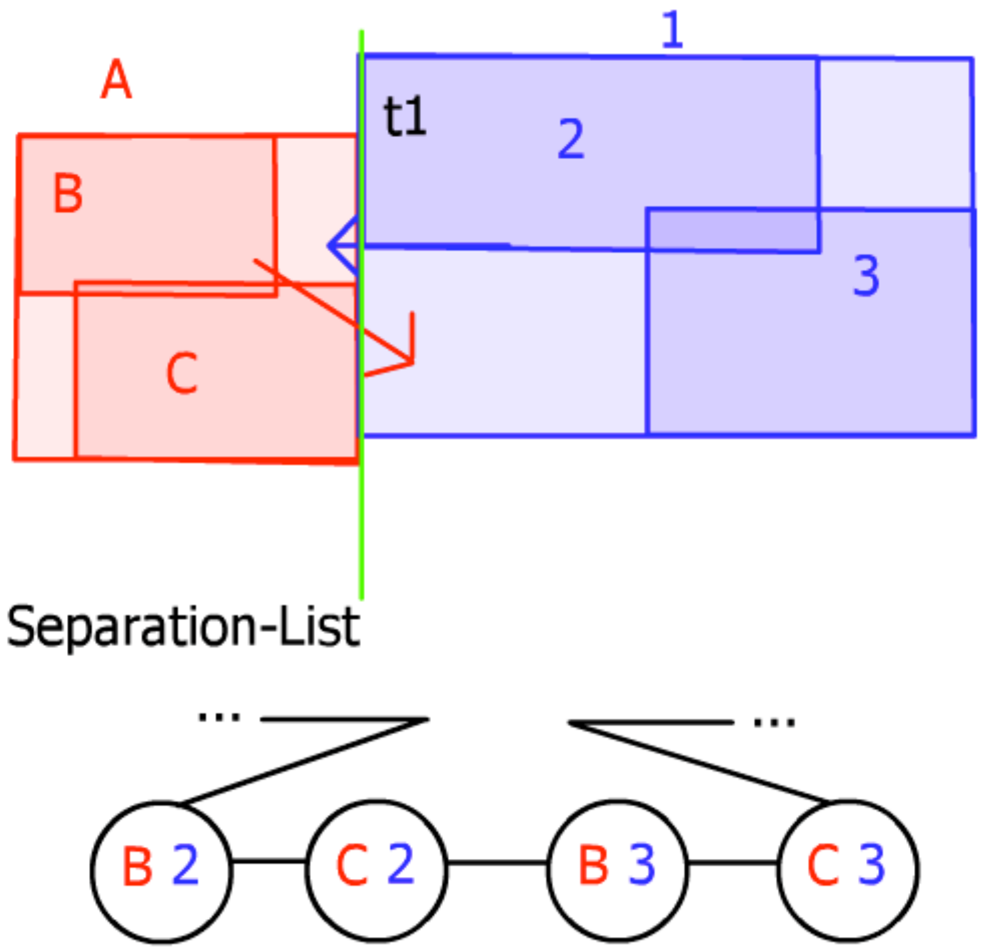
Initializing events: Fathers do not overlap



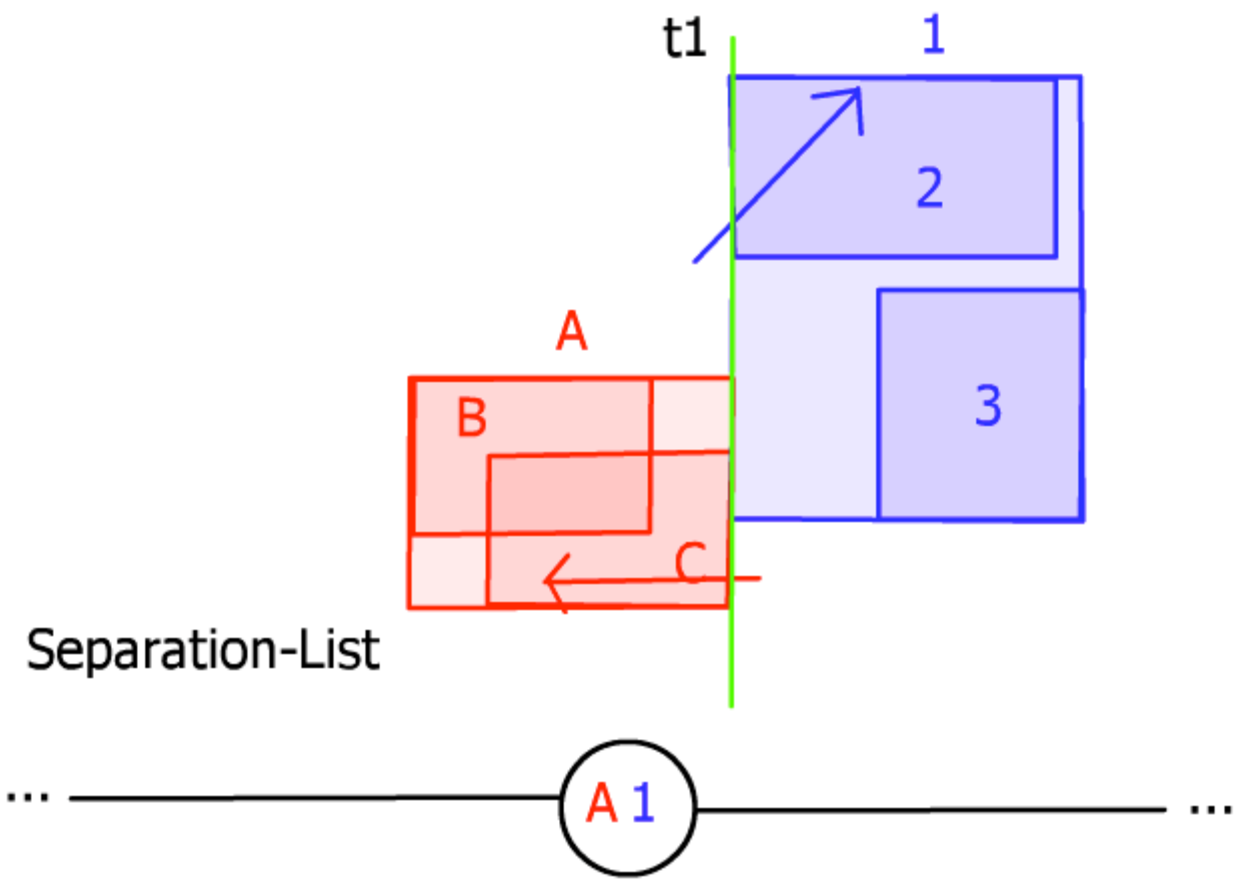
Simulation Loop

```
while simulation runs
        determine time t of next rendering
        e ← min event in event queue
        while e.timestamp < t
                processEvent(e)
                e ← min event in event queue
        render scene
```

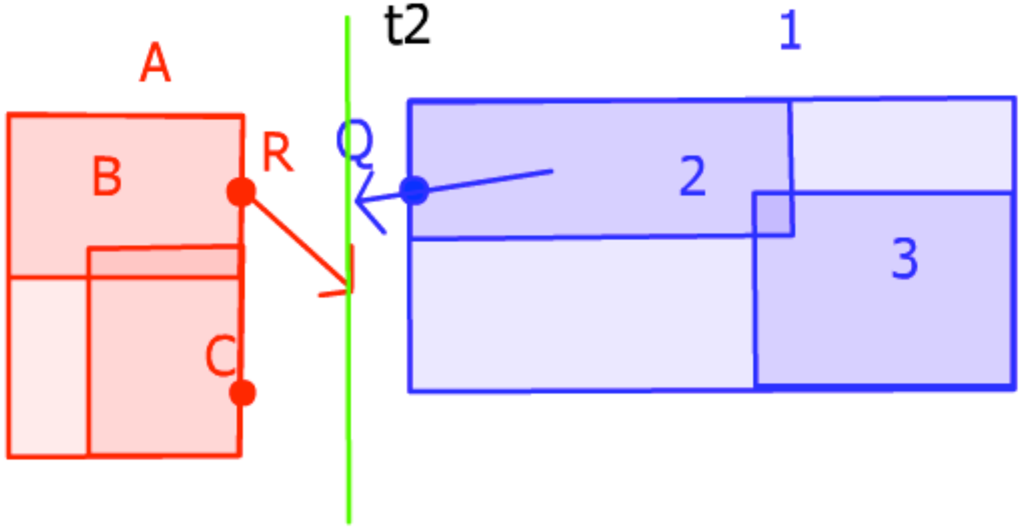
Event-Handling: BVs overlap

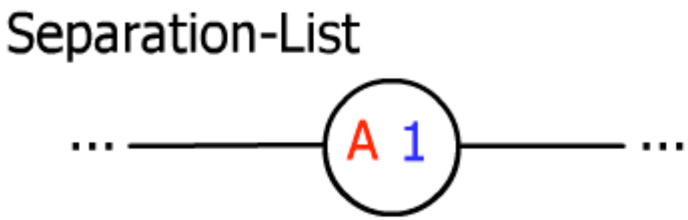


Event-Handling: Fathers do not overlap



Event-Handling: Topology of BVs change





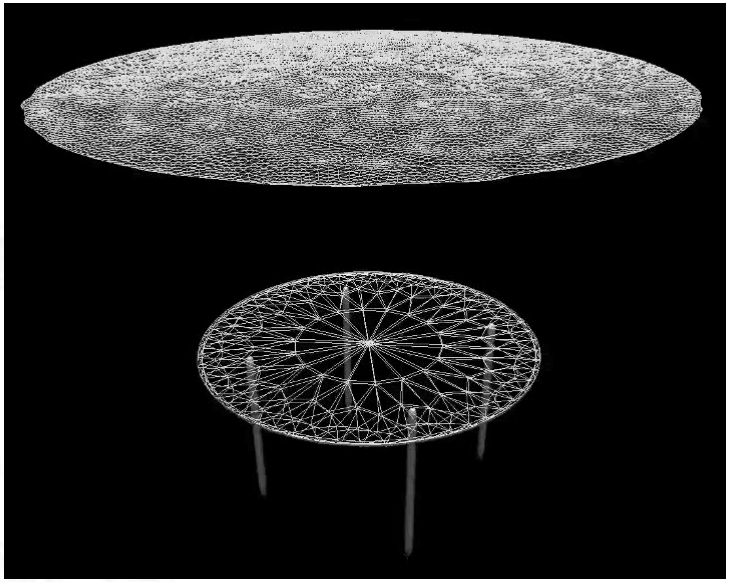
Quality of a KDS

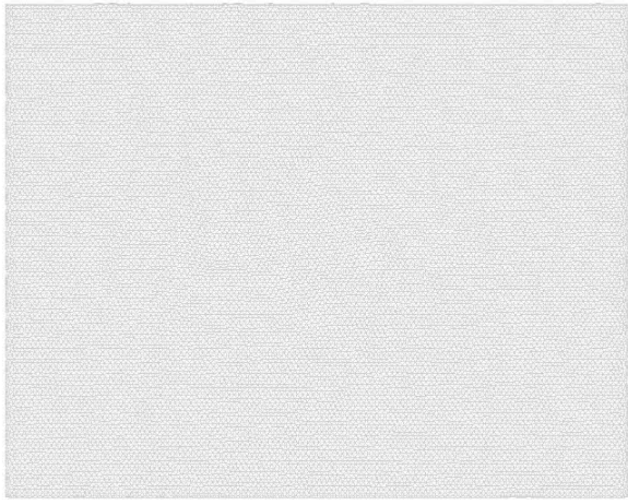
- A KDS is compact, if it requires only little space
- A KDS is responsive if we can update it quickly in case of a certificate failure
- A KDS is local, if one object is involved in not too many events
- A KDS is efficient, if the overhead of internal events with respect to external events is reasonable

Analysis

- Worst case:
  - Theorem 1: Our kinetic separation list is compact ($O(n^2)$), local ($O(n)$), responsive ($O(1)$) and efficient.
    Furthermore, the kinetic separation list is valid at every point of time.
- Average Case:
  - Theorem 2: Our kinetic separation list is compact ($O(n)$), local ($O(1)$), responsive ($O(1)$) and efficient.

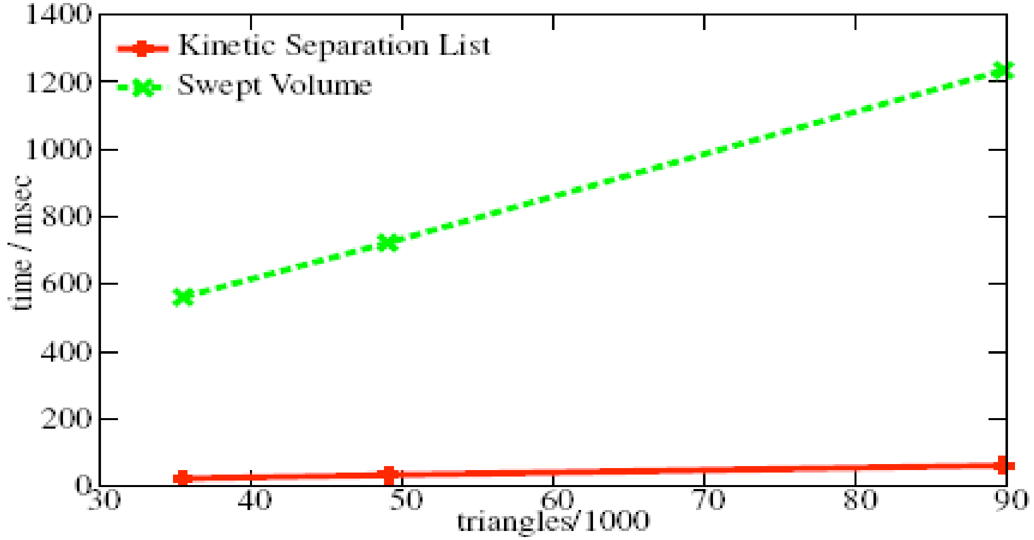
Test Scenes

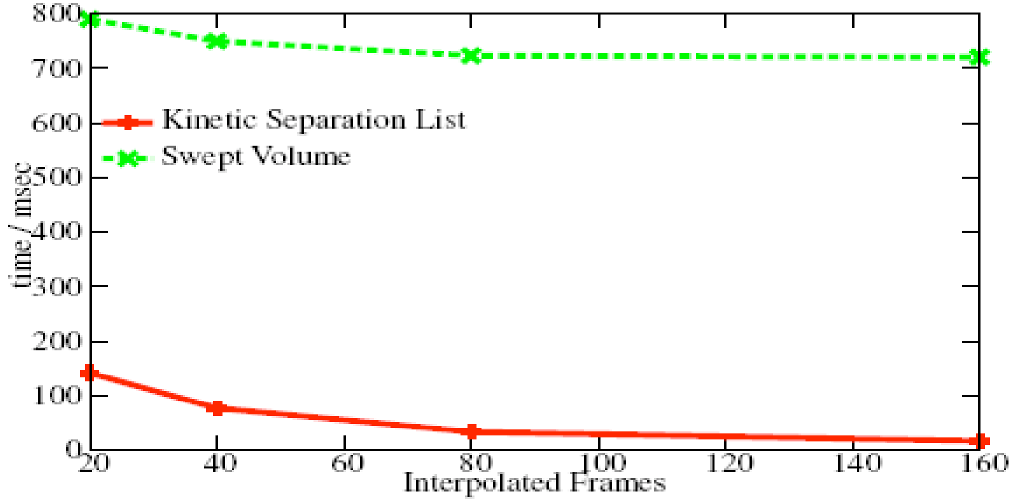


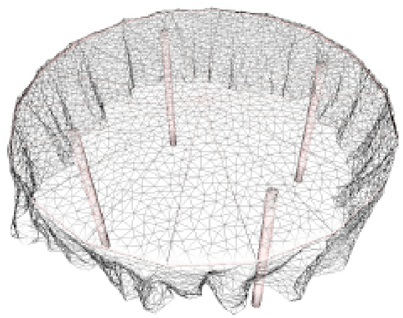


Results

- Time for updates and collision check

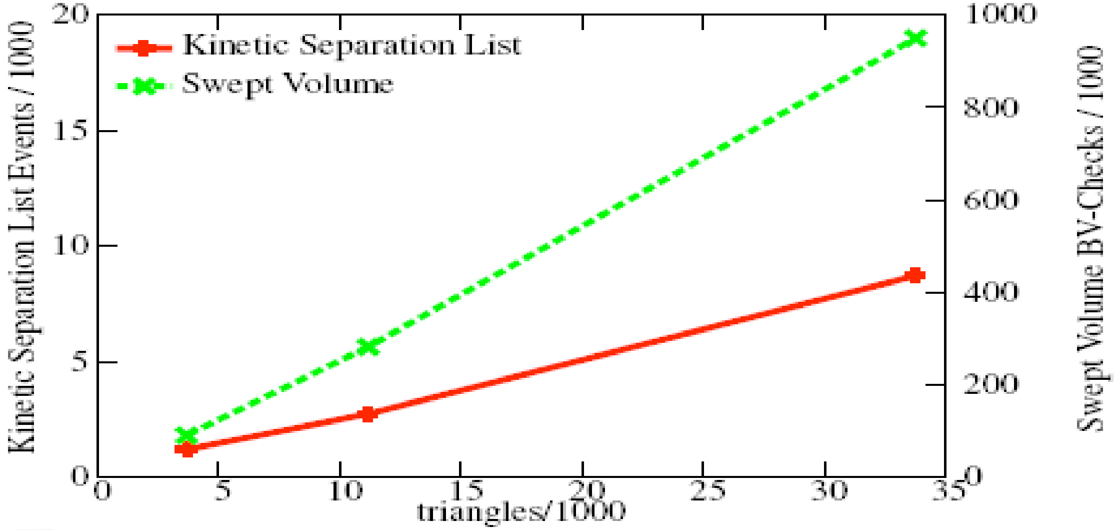


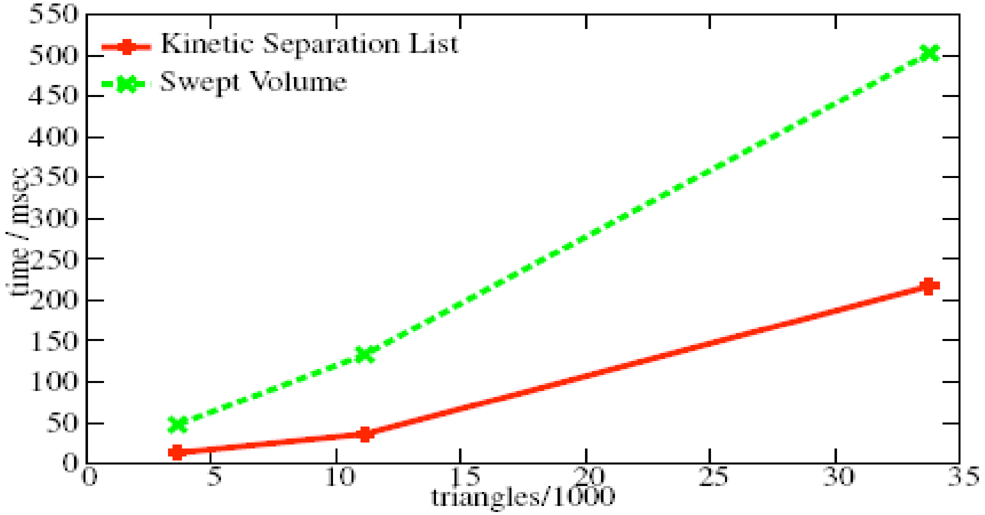




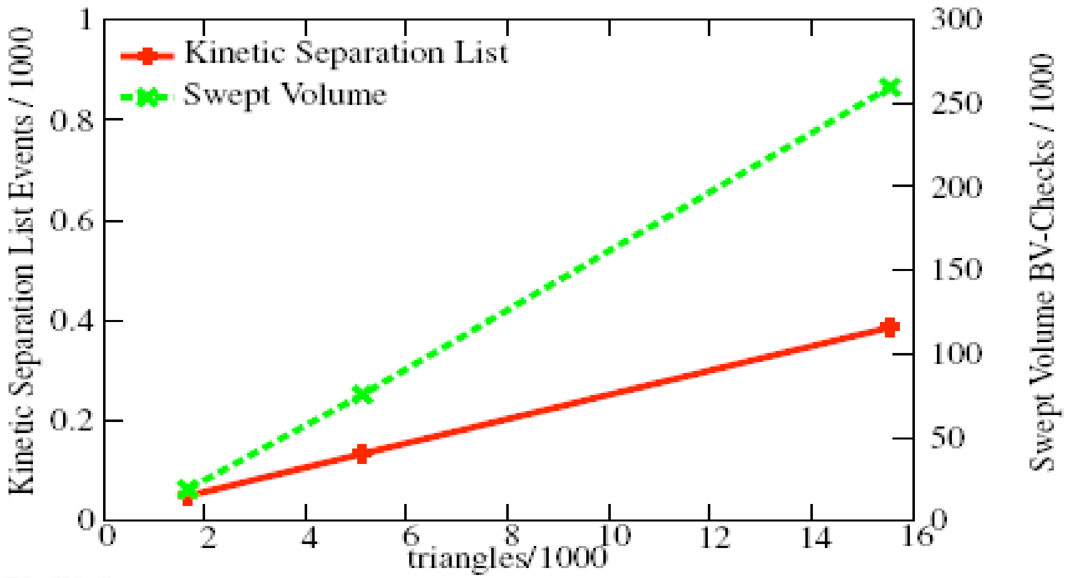
Results

- Self Collision

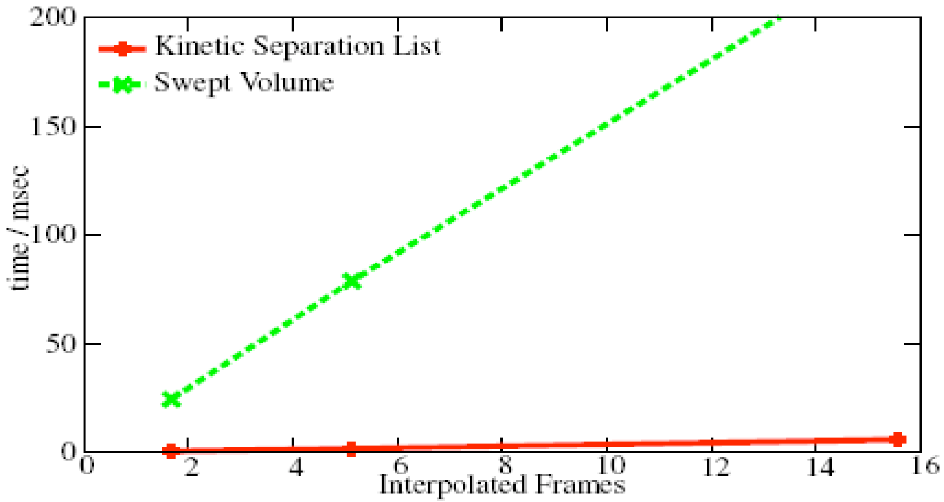




Results



Kinetic Separation List
Swept Volume
Kinetic Separation List Events / 1000
Swept Volume BV-Checks / 1000
triangles/1000
0
0.2
0.4
0.6
0.8
1
0
50
100
150
200
250
300
0
2
4
6
8
10
12
14
16



Kinetic Separation List
Swept Volume
time / msec
Interpolated Frames
0
50
100
150
200
0
2
4
6
8
10
12
14
16

Conclusions

- A novel data structures for inter- and intra-collision detection between deformable object
- Efficiency due to event based approach
- Well suited for collision response
- Up to 50 times faster than swept volume approach in practically relevant scenarios

Future Work

- Use our kinetic data structures also for other kinds of primitives like NURBS
- Utilize our data structures for other kinds of motion
  - physically-based simulations
  - other animation schemes

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