Kinetic Bounding Volume Hierarchies for Deformable Objects

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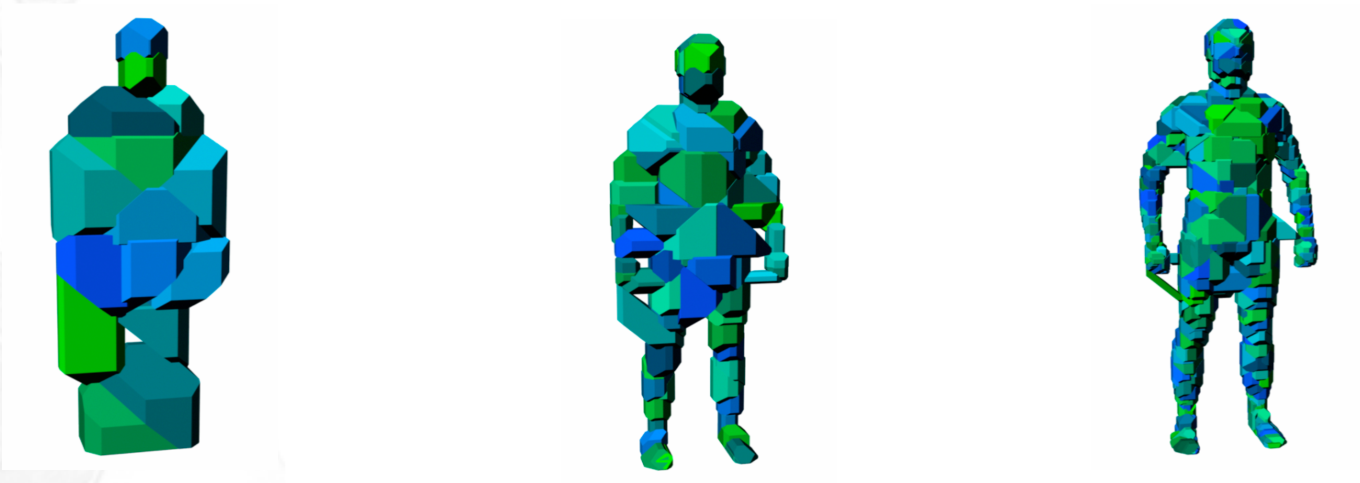
Motivation

- Bounding volume hierarchies (BVHs) are widely employed in many areas of computer science to accelerate geometric queries
  - ray-tracing
  - occlusion culling
  - collision detection

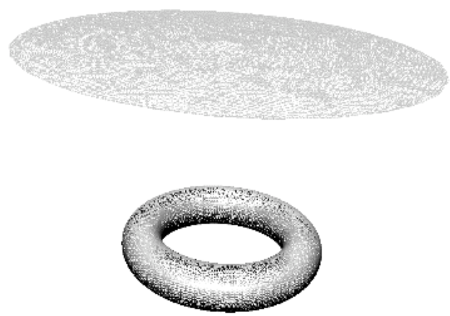


Courtesy GRIS, Tübingen

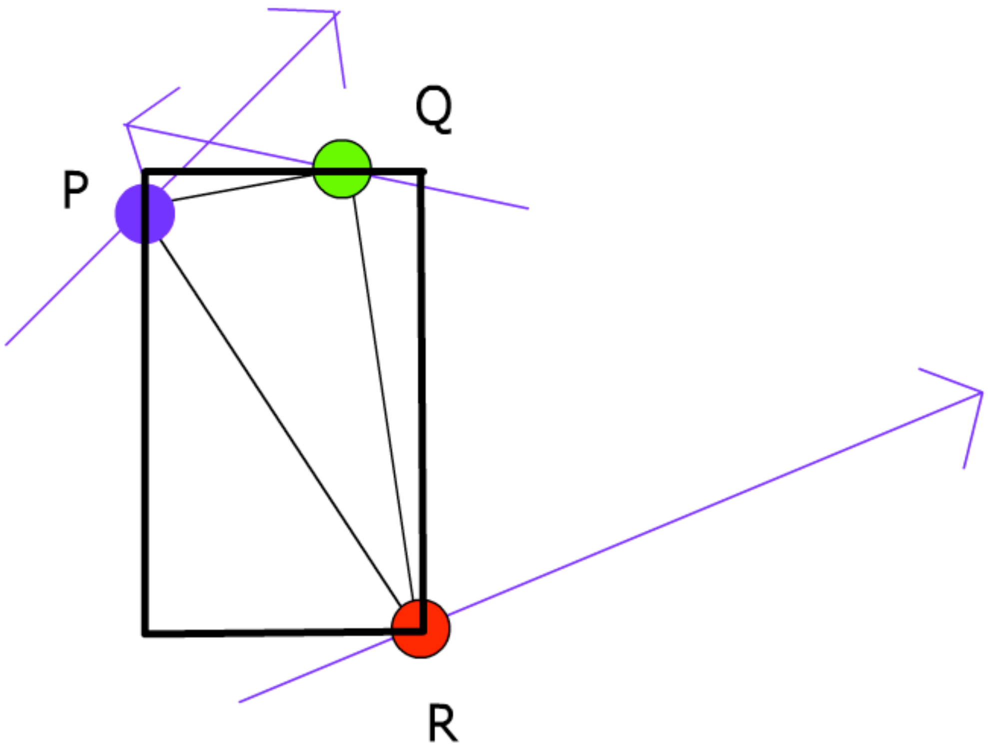
Deformable BVH

- BVHs are constructed in a pre-processing step
- The pre-processed hierarchy becomes invalid when the object deforms

→ The BVH must be rebuilt or updated after deformations



Brute Force Update of single BV



Max

x 1.0

y 0.9

Min

x 0.3

y 0.4

Frame 2

Problems

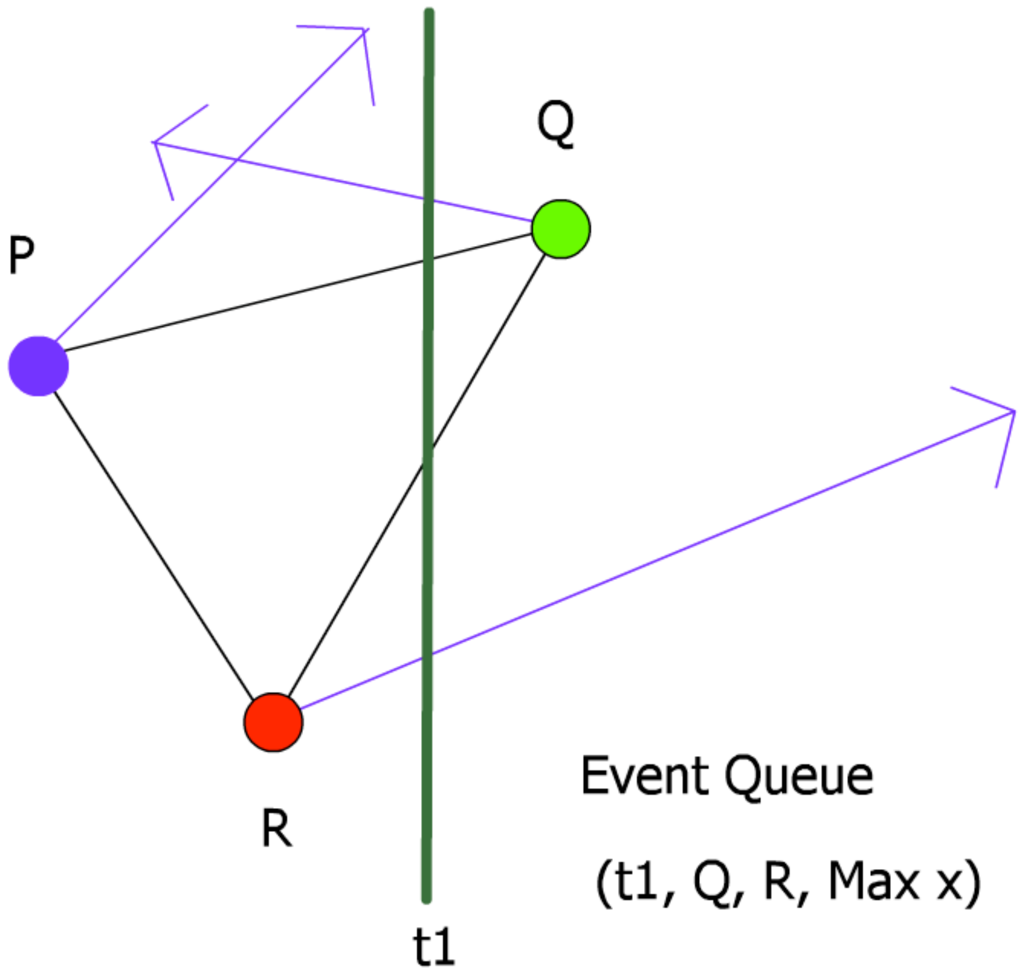
- Discrete time sampling
  - Many update operations
  - Missing changes between queries
- No adequate use of spatial and temporal coherence
- Other approaches:
  - Hybrid updates [van den Bergen, 1998]
  - Lazy updates [Mezger et al. 2003]
  - Restriction of deformation schemes [James and Pai, 2004]
  - Intrinsic collision test on the GPU [Wong and Baciu 2005]
  - Chromatic decompositions [Govindaraju et al. 2005]

Our Approach

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

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

Kinetic Updates



Max
x Q
y Q

Min
x P
y R

Event Queue

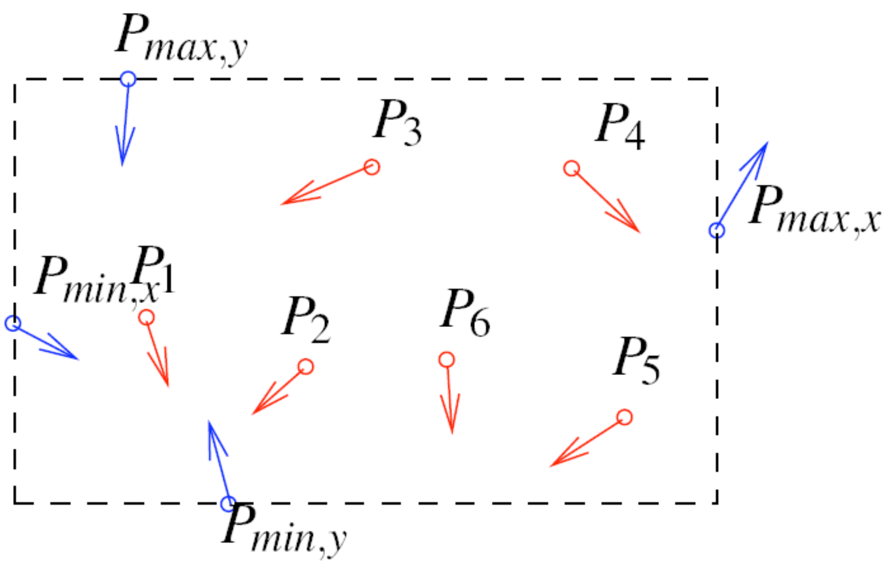
(t1, Q, R, Max x)

Advantages

- Fewer update operations
- Valid BVHs at every point in time
- Independent of query sampling frequency
- Can handle all kinds of objects
  - polygon soups, point clouds, and NURBS models
- Can handle insertions/deletions during run-time
- Can handle all kinds of deformations
  - Only a flightplan is required for every vertex
  - These flightplans may change during simulation

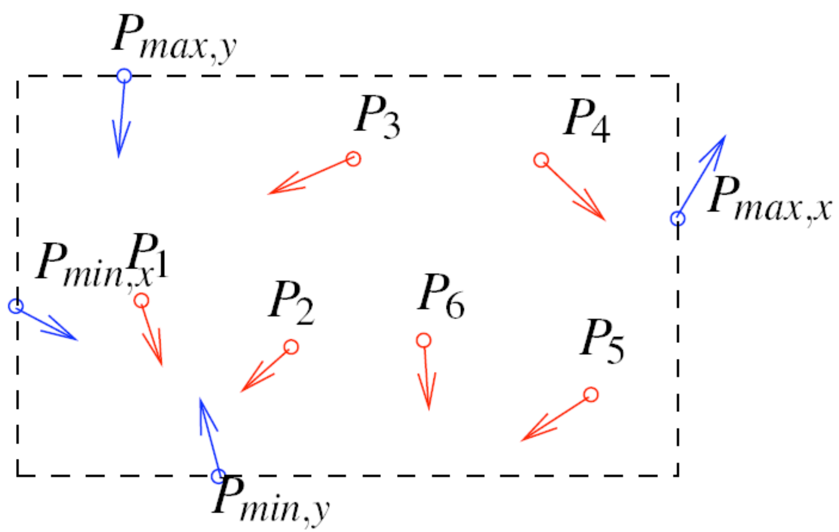
Recap: Kinetic Data Structures

- 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)



KDS terminology

- 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



Quality of a KDS

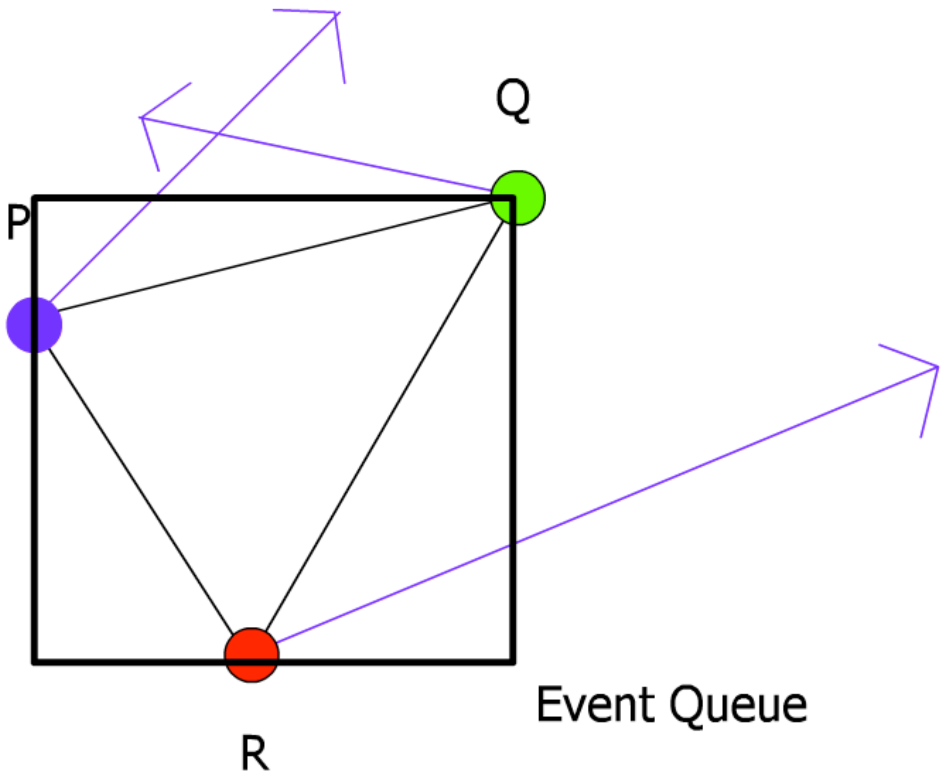
- A KDS is compact, if it requires only little space
- A KDS is responsive if we can update it quickly in case of a certificate failure
- A KDS is local, if one object is involved in not too many events
- A KDS is efficient, if the overhead of internal events with respect to external events is reasonable

Kinetic AABB Tree

- Kinetization of the AABB tree
- Pre-processing: Build the tree by any algorithm suitable for static AABB trees
  - It is only required that the height of the BVH is logarithmic
- Store with every node the indices of those points that determine the BV
- Initialize the event queue

Kinetic AABB Tree Events

- Leaf Event



Event Queue

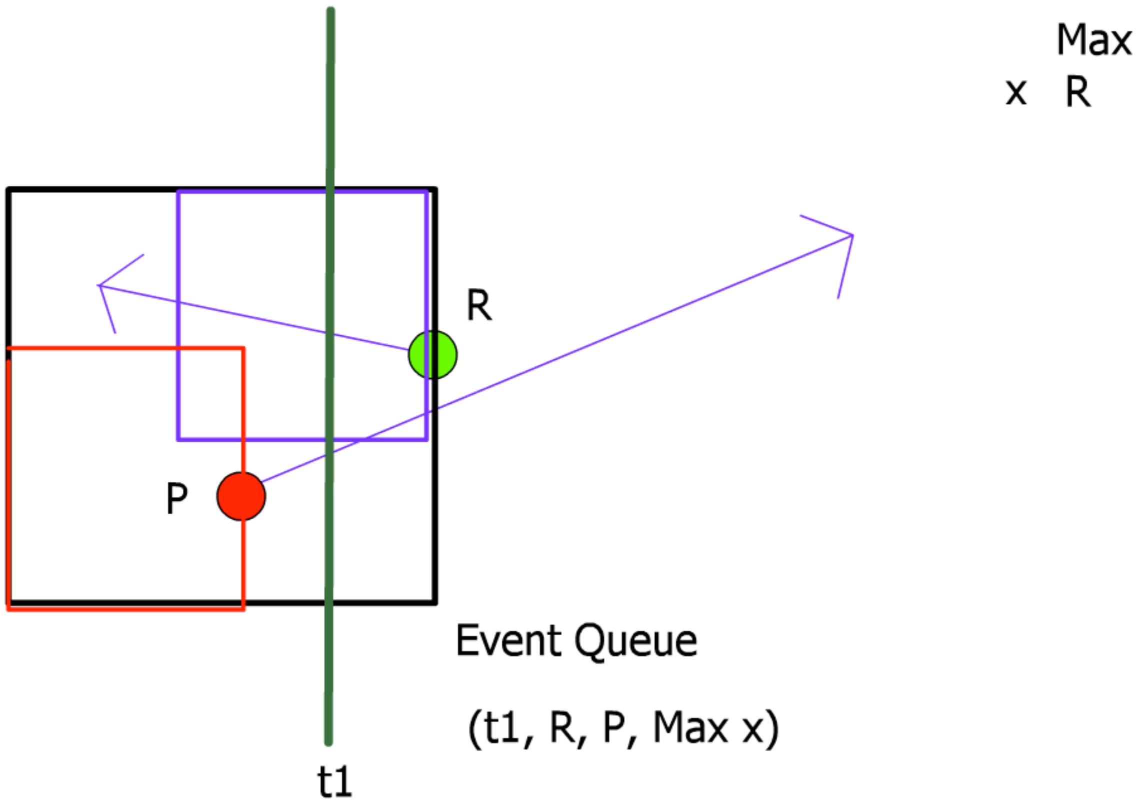
(t1, Q, R, Max x)

	Max
x	Q
y	Q

	Min
x	P
y	R

Kinetic AABB Tree Events

- Tree Event



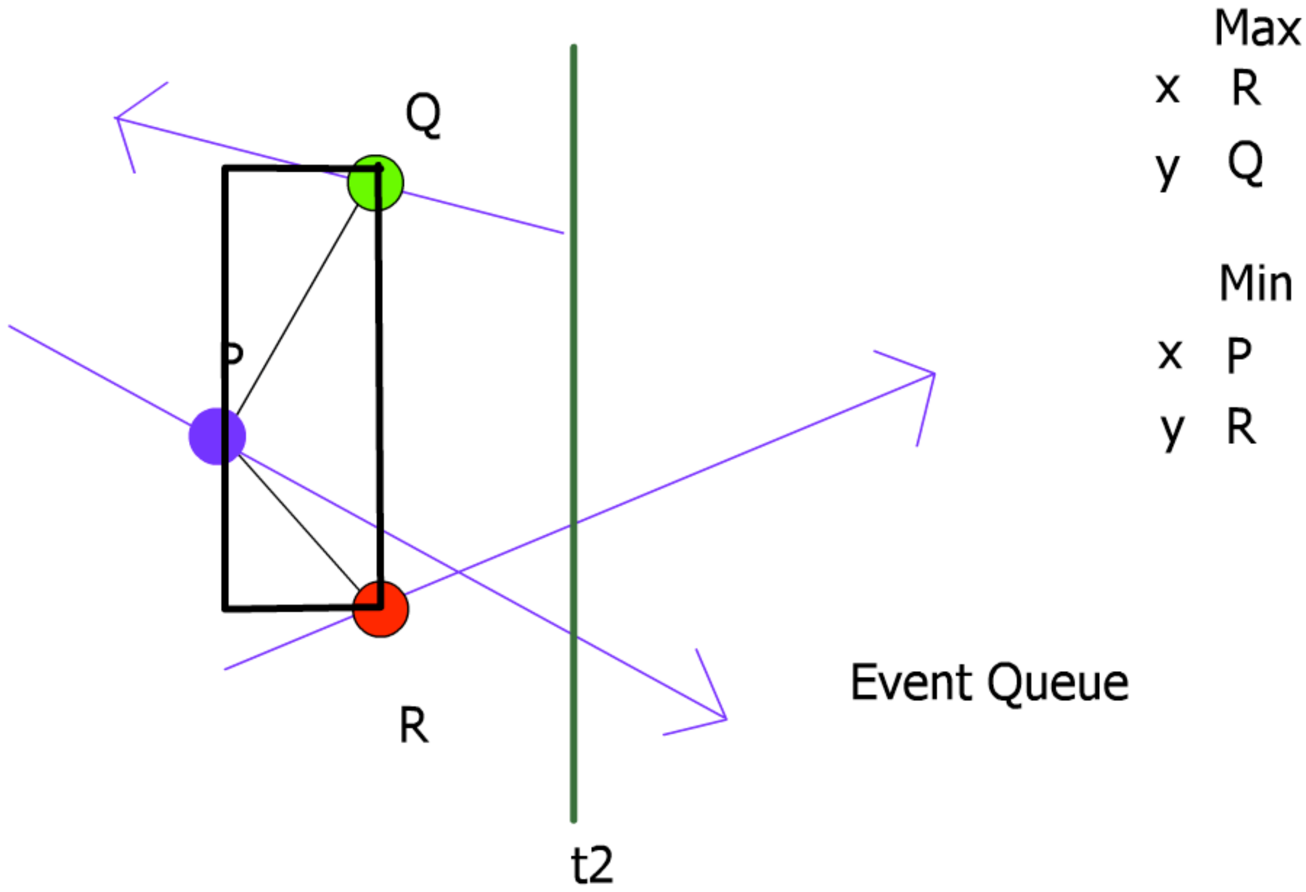
- Flightplan Update Event

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
    check for collisions (or cast ray, or …)
    render scene
```

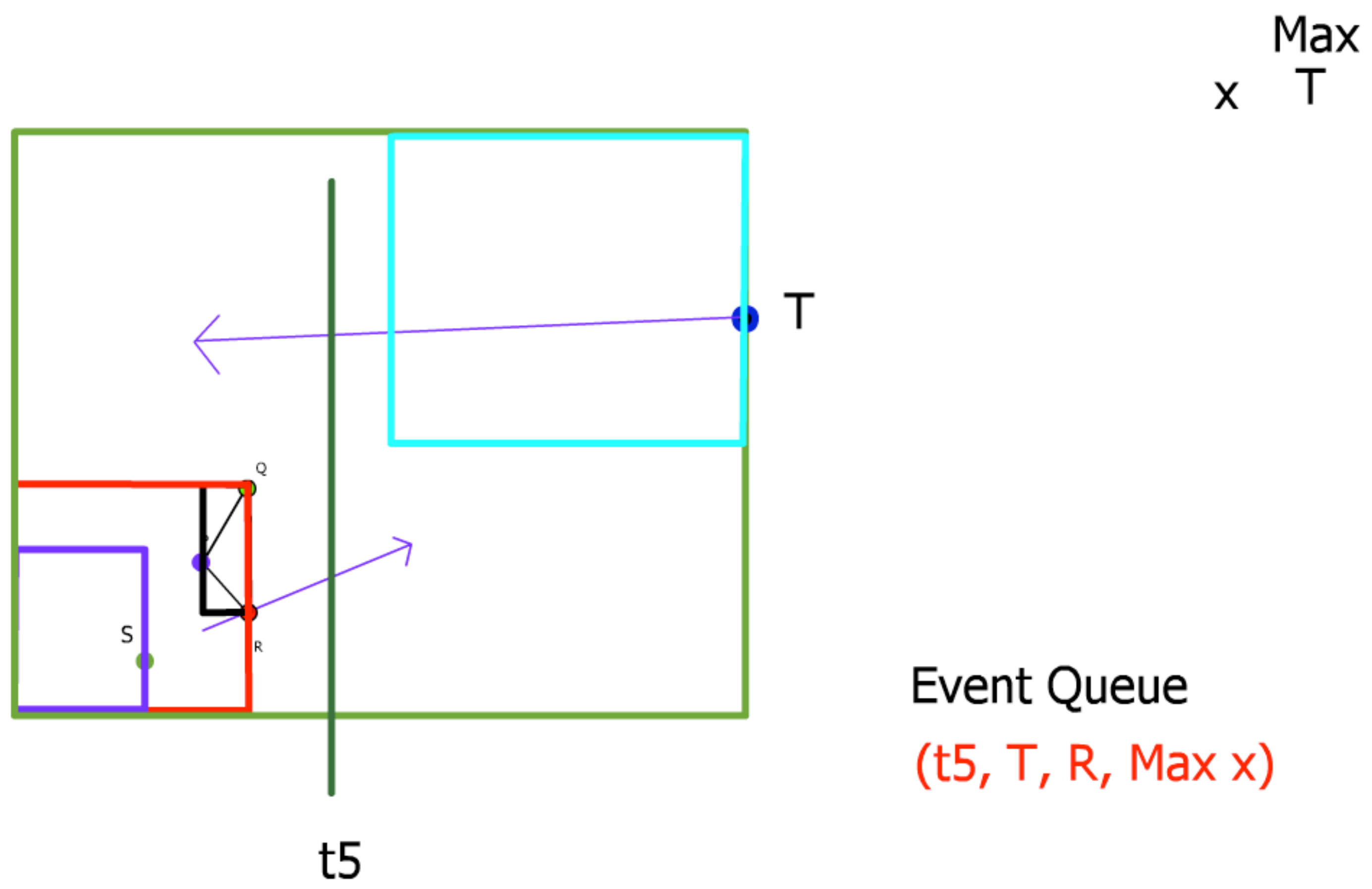
Event Handling

- Leaf Event



Event Handling

- Leaf Event cont

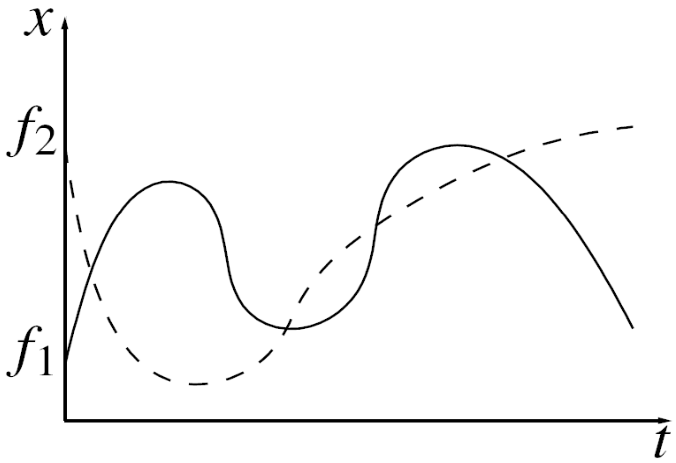


Event Queue

(t5, T, R, Max x)

Analysis

- Theorem 1: The kinetic AABB tree is compact (O(n)), local (O(log n)), responsive (O(log n)) and efficient. Furthermore, the kinetic AABB tree is a valid BVH at every point of time.



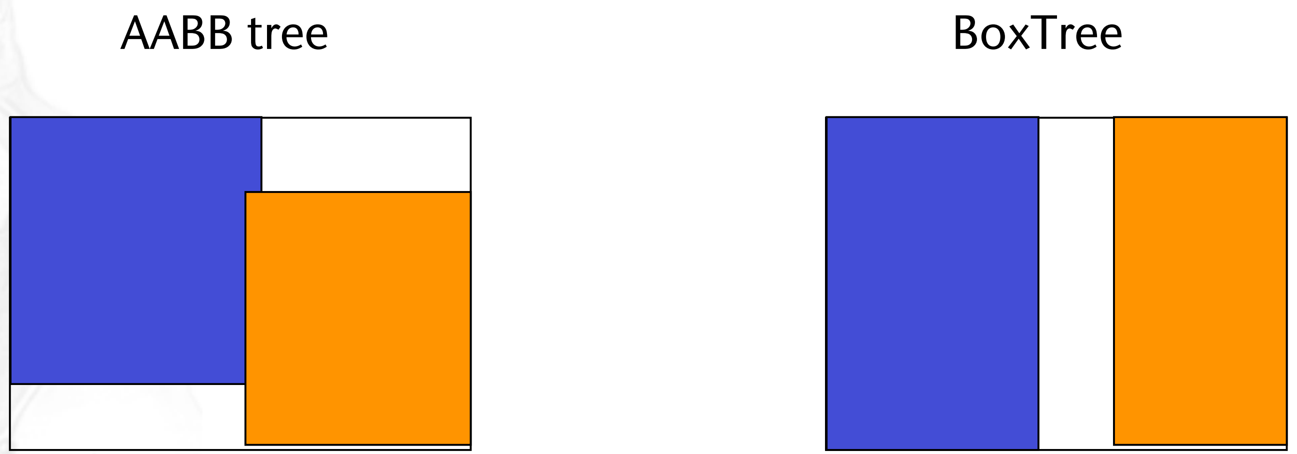
- Theorem 2: Given n vertices, we assume that each pair of flightplans intersect at most s times.
  Then, the total number of events is in nearly O(n log n).

Kinetic Boxtree

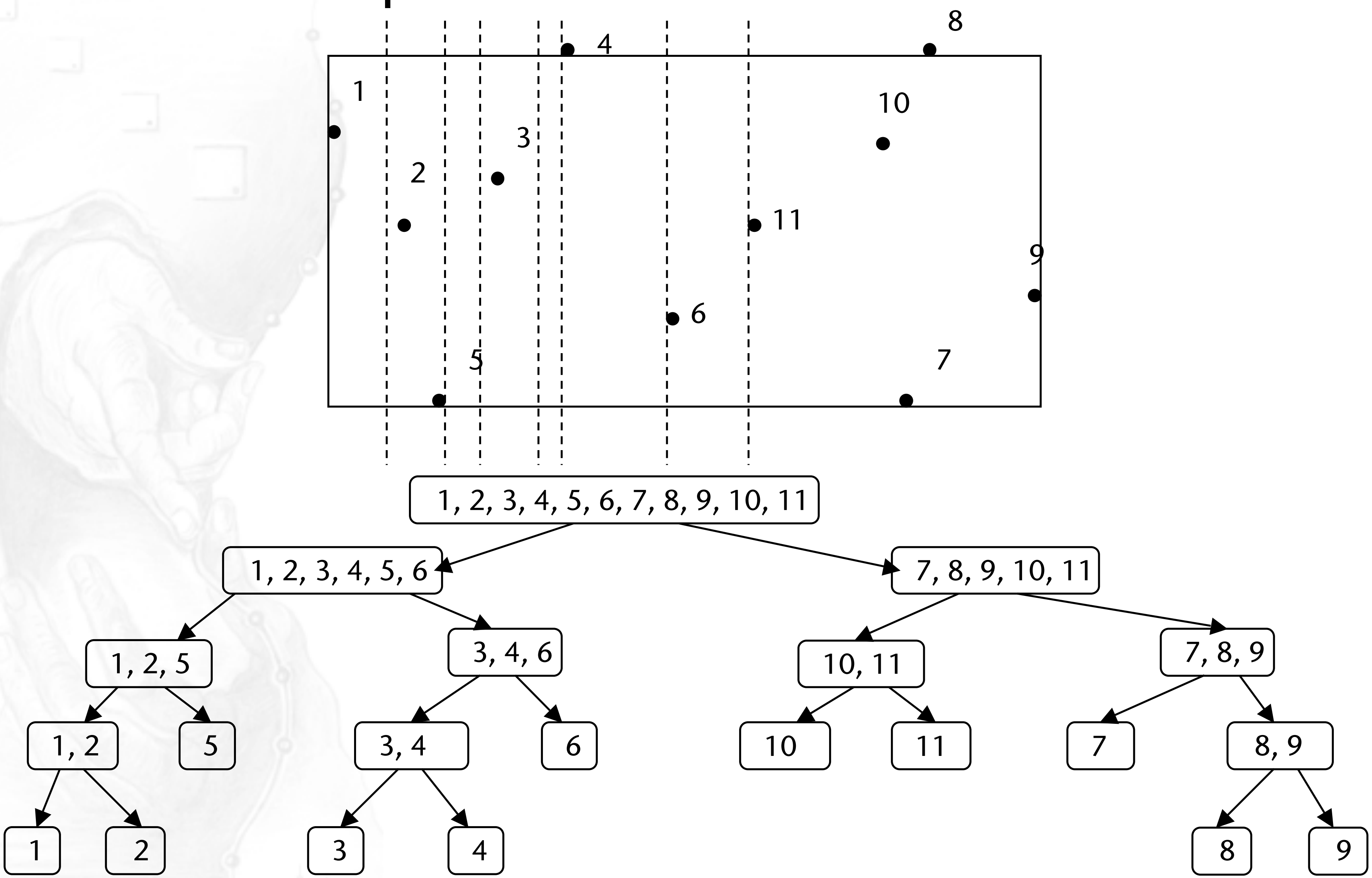
- Kinetic AABB tree needs up to six events for every BV

=> The kinetic BoxTree which uses less memory than the kinetic AABB tree

- Combination of k-d tree and AABB



Event Computation



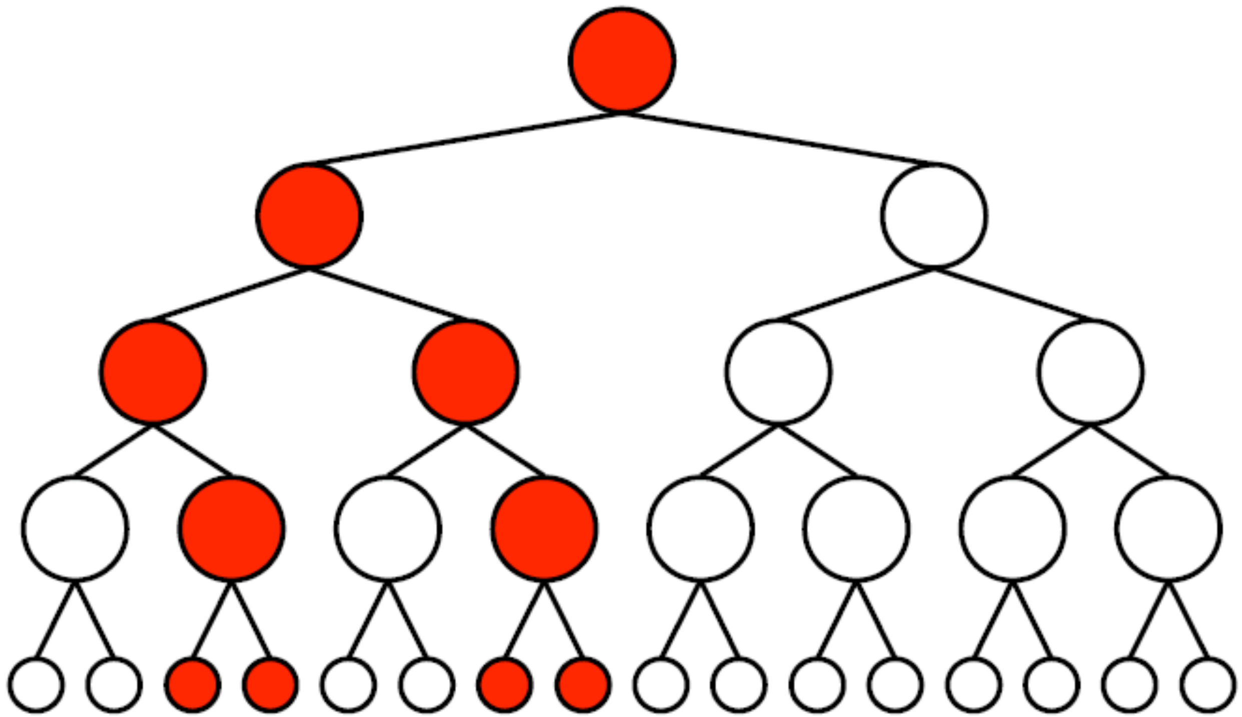
BoxTree Events

$split_x$

$split_y$

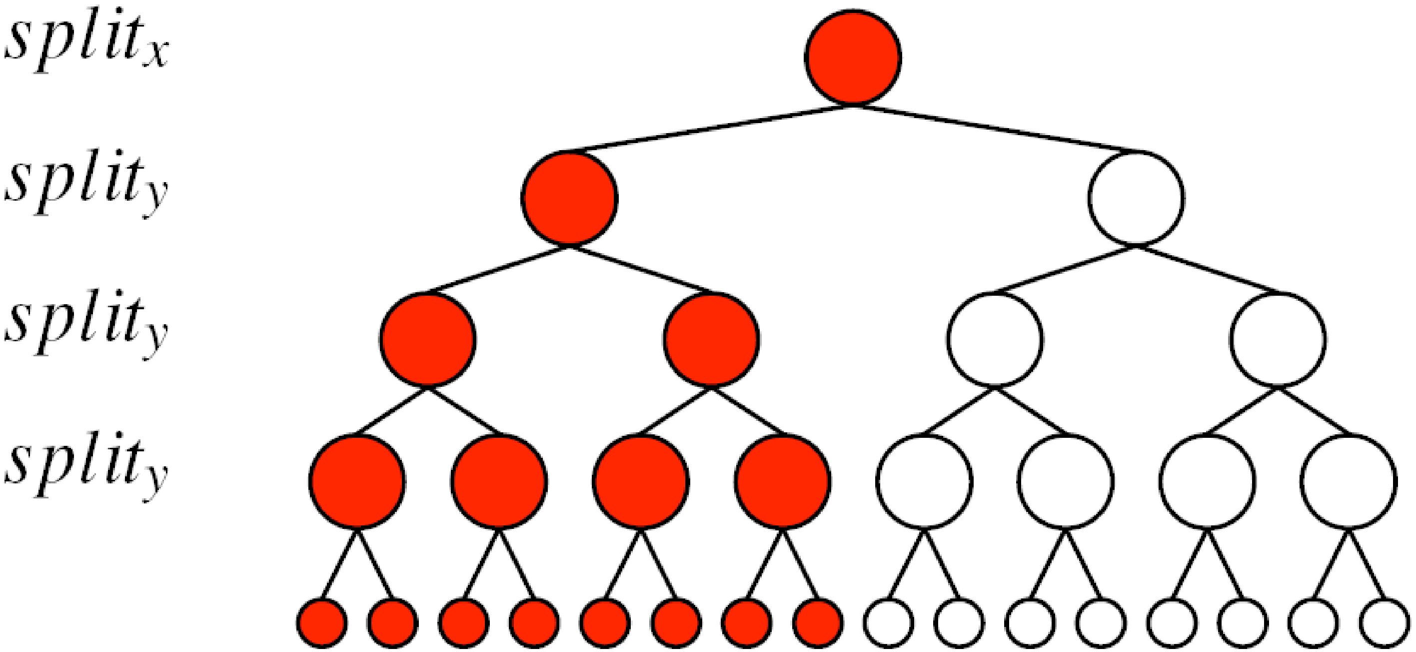
$split_x$

$split_y$

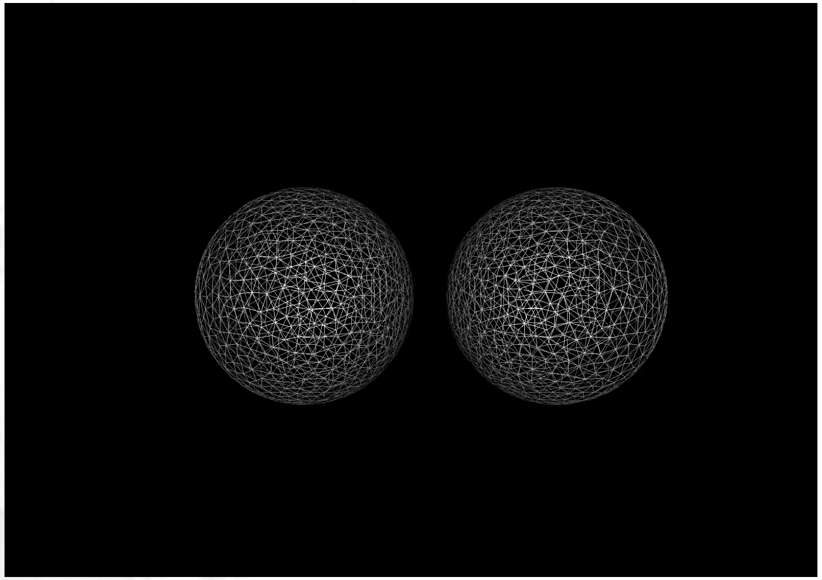


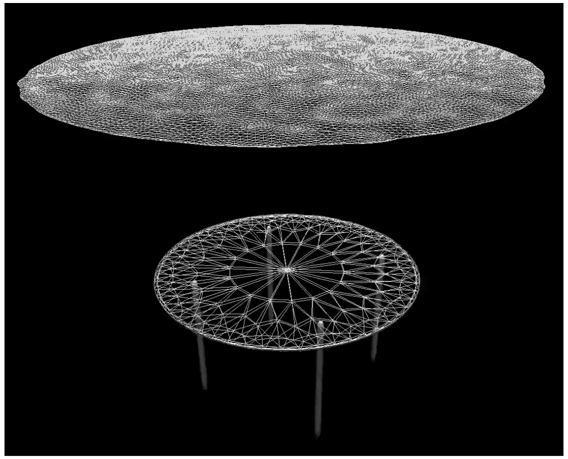
Analysis

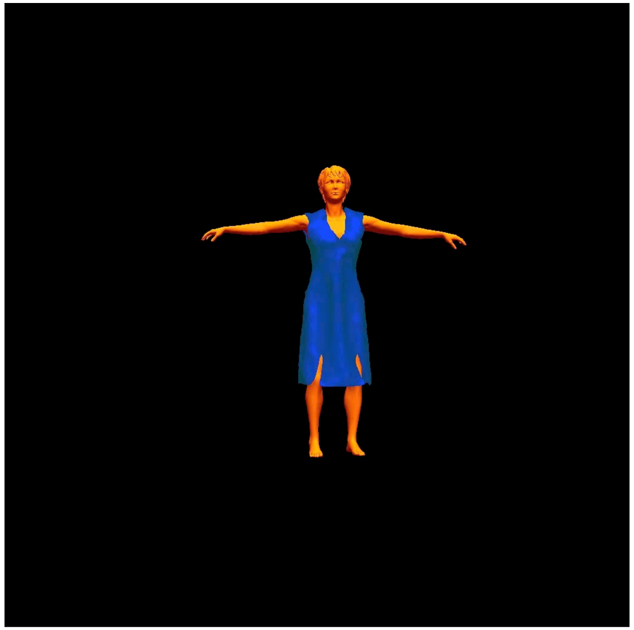
- Theorem: The kinetic BoxTree is compact, local and efficient. The responsiveness holds only in the one-dimensional case. Furthermore, the kinetic BoxTree builds a valid BVH at every point of time.



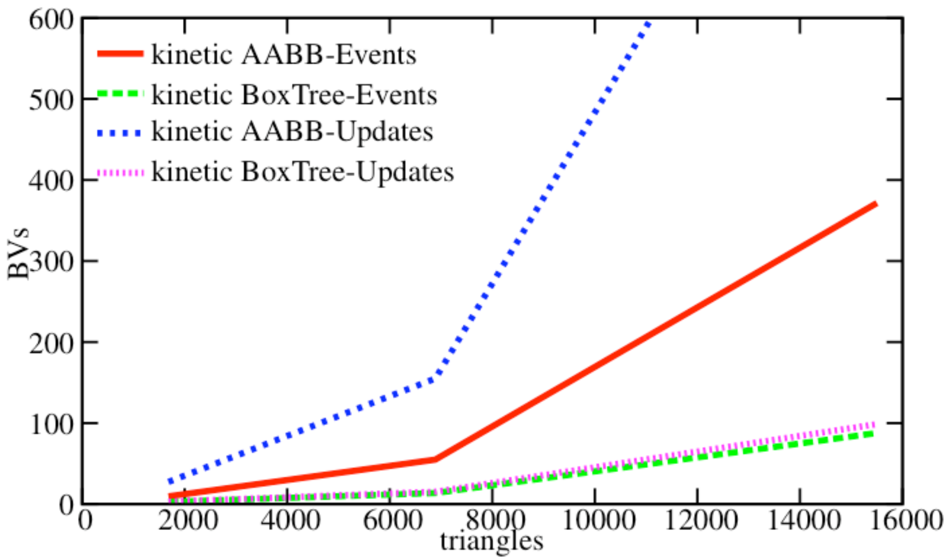
Test Scenes

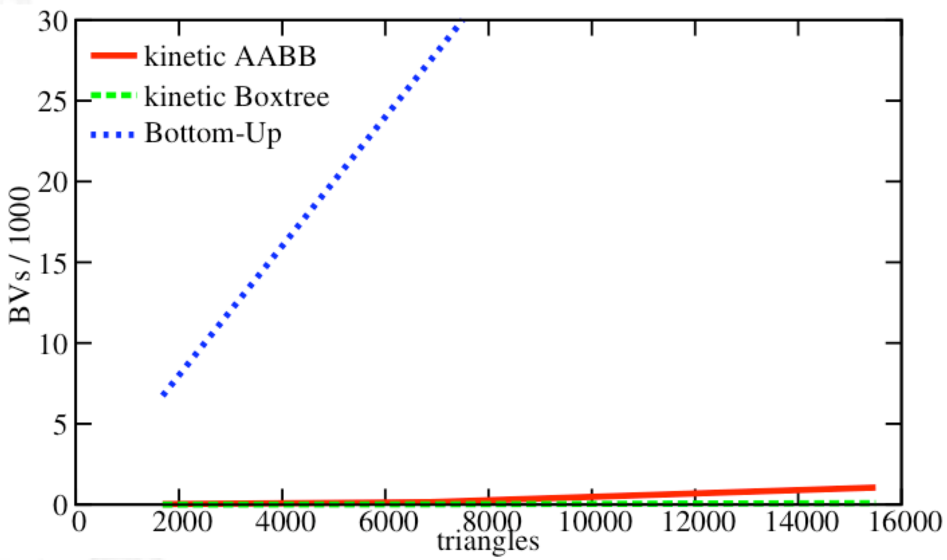




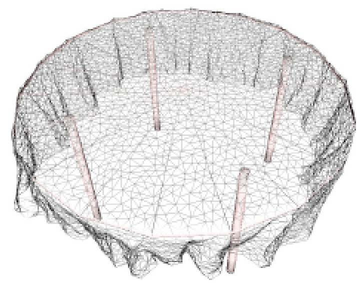


Results

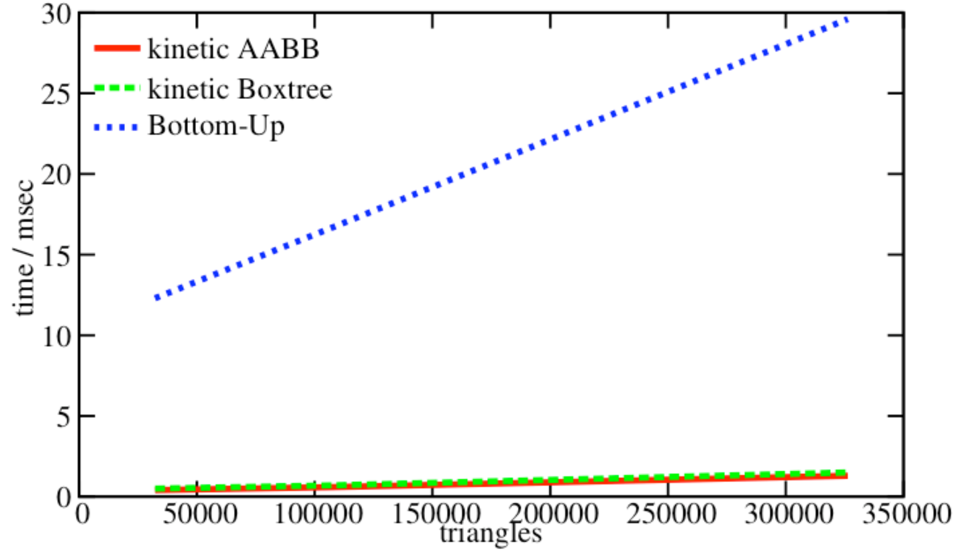


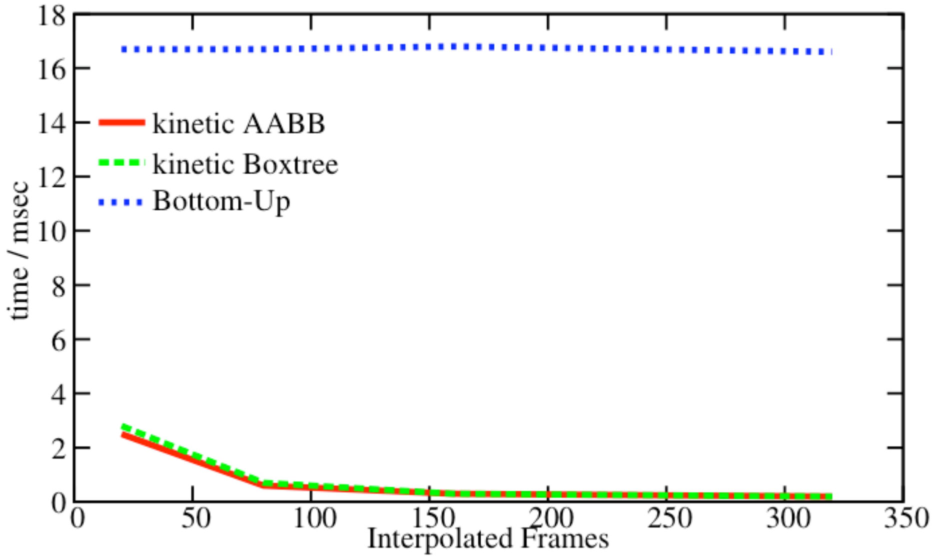


#Events and #Updates

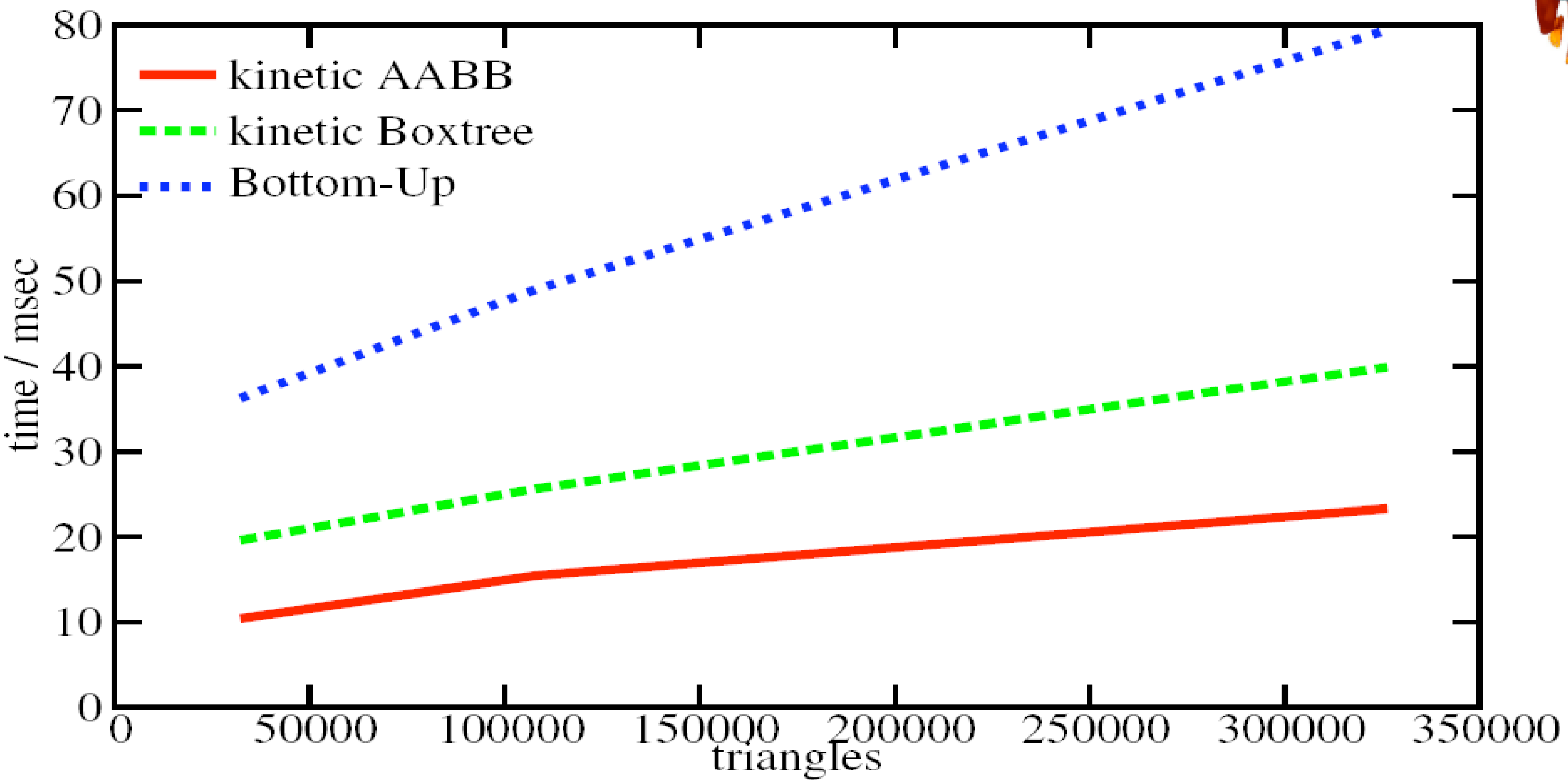


Updating time





Total time (= Update + Collision Check)



Conclusions

- Two novel data structures for updating a BVH over deformable objects fast and efficient
- Efficiency due to event based approach
- Theoretic Analysis:
  - Upper bound of nearly O(n log n) for the updates that are required to keep a BVH valid
  - Our kinetic AABB tree and kinetic BoxTree are optimal in number of updates
- Up to 20 times faster than bottom-up updates in practically relevant scenarios

Future Work

- Use our kinetic Data Structures also for continuous collision detection
- Utilize our data structures for other kinds of motion
  - physically-based simulations
  - other animation schemes
- Use our KDS for other applications like ray-tracing or occlusion culling

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