Deformable Materials 3

Adrien Treuille

Overview

- Last Week’s Question
- Elastic Collision Detection
- Collision Detection for Reduced Models
- Surface-Based Elastics
- New Question

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Question

- How could we reduce the cost of simulation for a very finely discretized surface?
- Are there cheap ways of getting volumetric behavior without a full tetrahedralization?
- How can collision constraints be integrated?
- How to simulate plasticity?

Solutions

- bounding volume tree w/ tetrahedra at leaves
    - simulate parent nodes instead of leaves (if stresses are close)
- simulate on a simplified mesh (make details into bump maps)
- adaptive tetrahedralization based on force magnitudes
- come up with tetrahedralization that best captures the simulation based on precomputed simulations
- springs connected to a "skeleton"
- plasticity based on sparse springs connecting the surface mesh to itself
- embed fine tetrahedral mesh as barycentric coordinates on a coarse tetrahedral mesh, solve on coarse mesh
- angular springs in a surface discretization of the dynamics
- nonuniform tetrahedral mesh based on the curvature of the surface mesh
- greater distance to the surface -- the larger the tetrahedron
- "shell" tetrahedralization with springs on the interior

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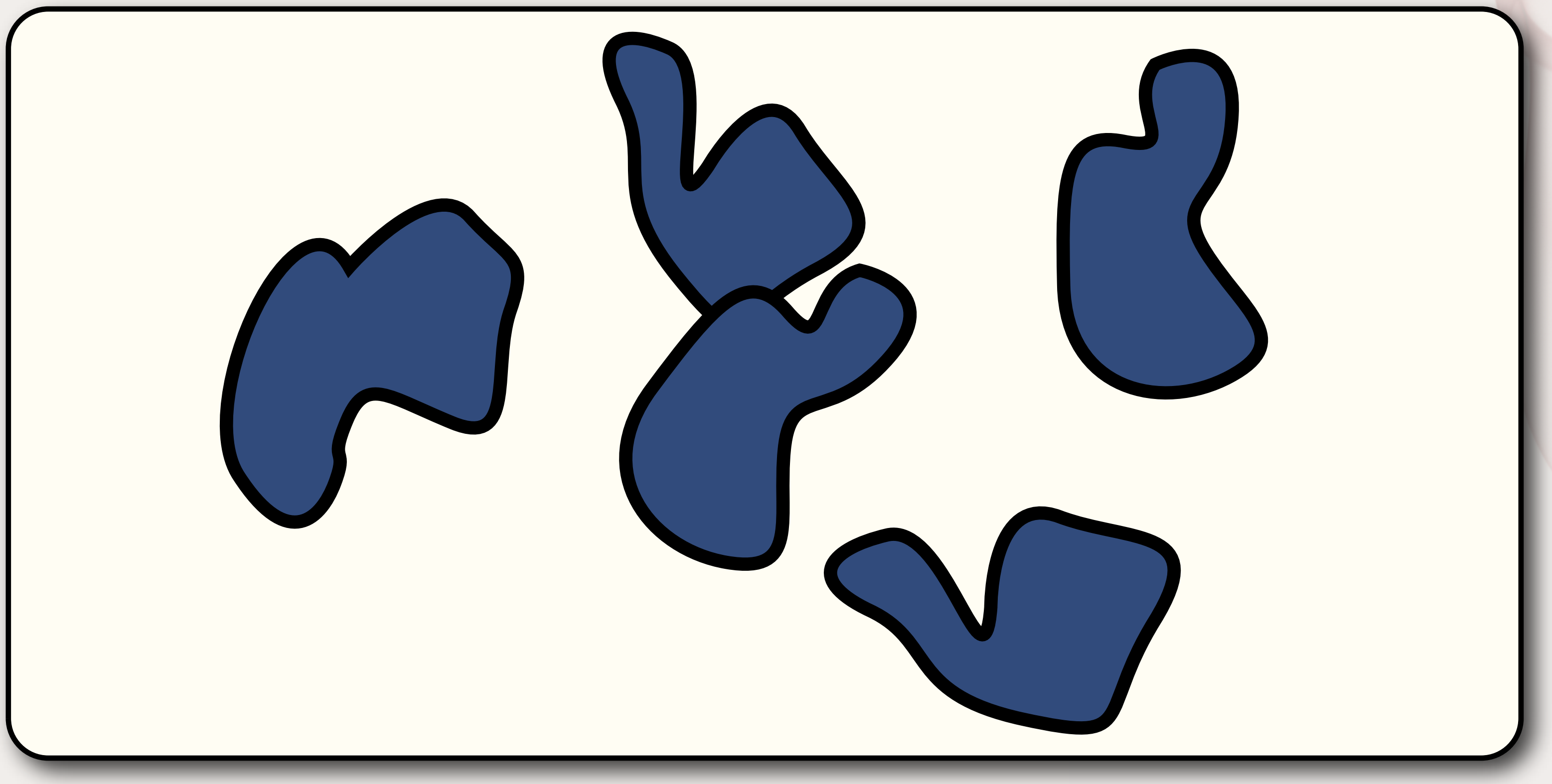
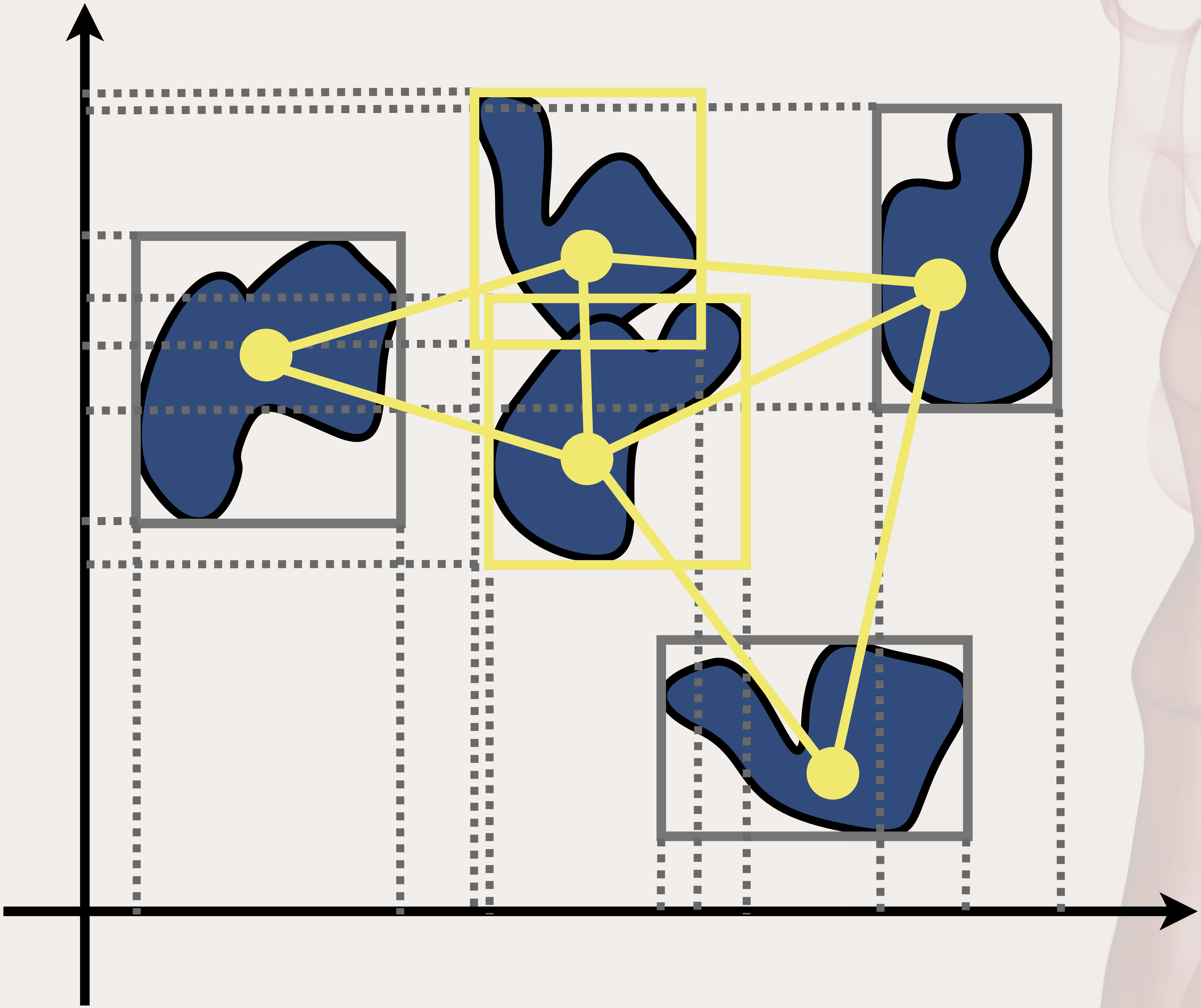
Collision Detection

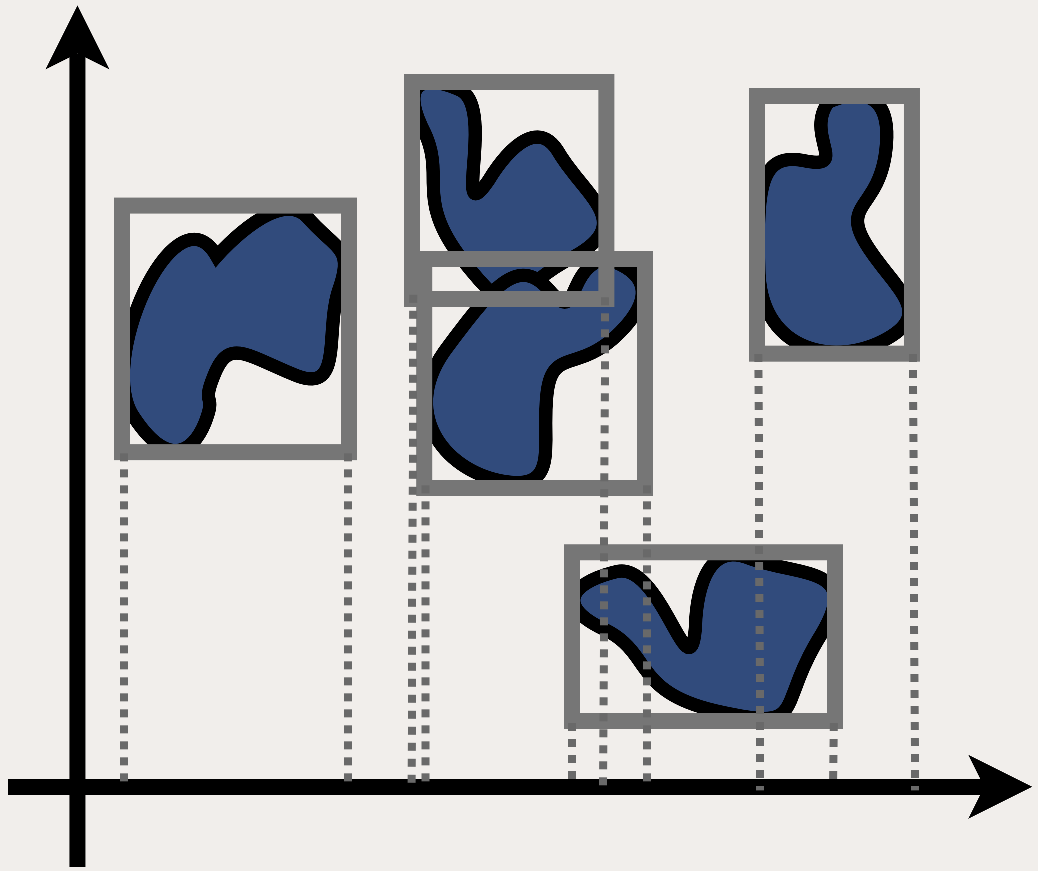


- **Broad Phase:**
  - **Guess collisions between objects.**
- **Narrow Phase:**
  - **Determine collision points.**

Broad Phase



Fast Interval Operations



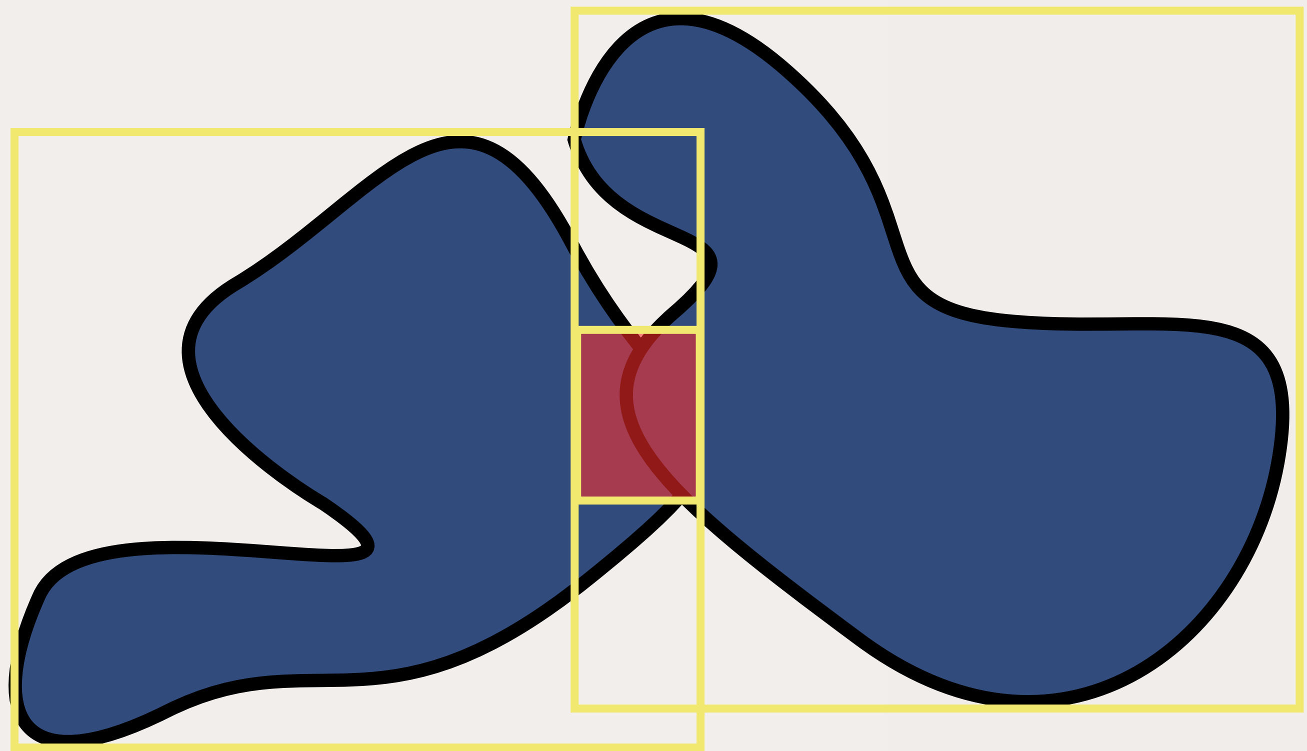
```
class BroadIntersection {

   int body_1_index;
   int body_2_index;
   bool x_overlap;
   bool y_overlap;
   bool z_overlap;

}
```

- **Temporal coherency: keep list between timesteps.**
- **Use insertion sort. Expected O(n) runtime.**
- **Update overlaps *during* insertion sort.**
- **Three cases:**
  - **A minimum and a maximum flip. Toggle overlap bit.**
  - **Two minima flip. Don't toggle.**
  - **Two maxima flip. Don't toggle.**

Narrow Phase



- Find exact collision point.
- Use a geometric partitioning algorithm.
- Two types:
  - Bounding Volume Hierarchies
  - Spatial Partitioning

BVH vs. Spatial Partitioning

BVH:

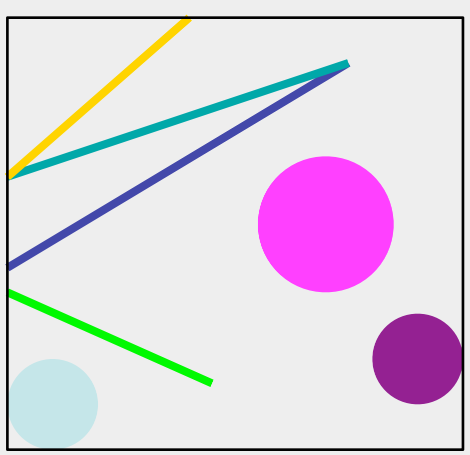
- Object centric

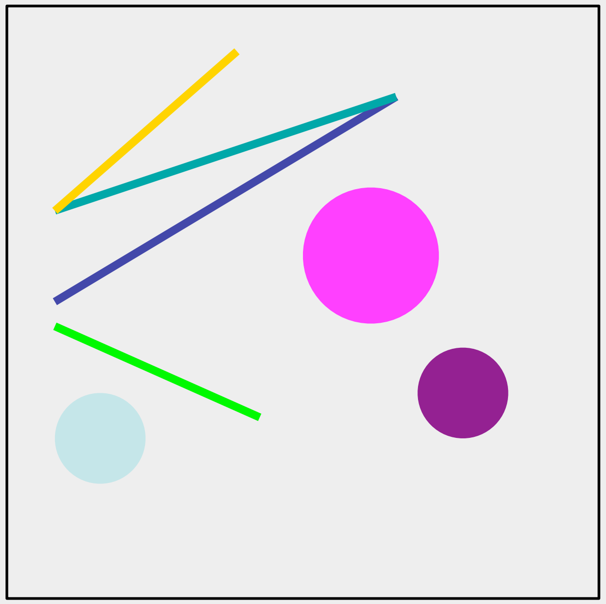
- Spatial redundancy

SP:

- Space centric

- Object redundancy





(From Doug James's Slides.)

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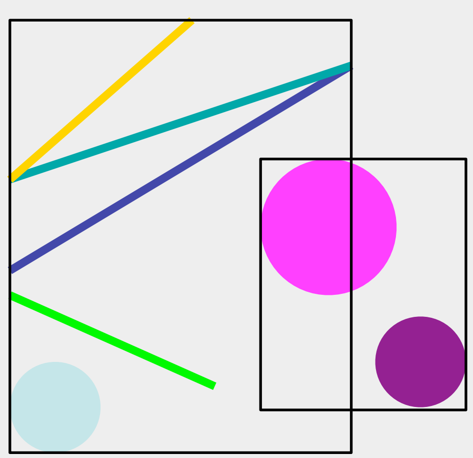

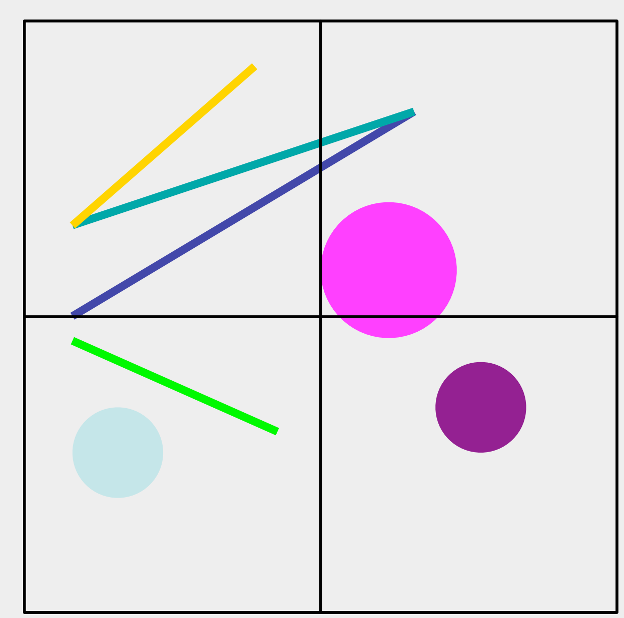

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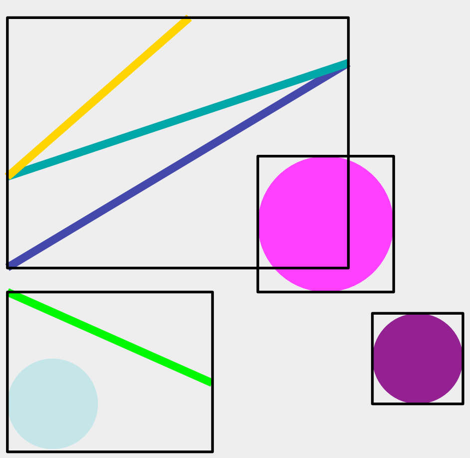

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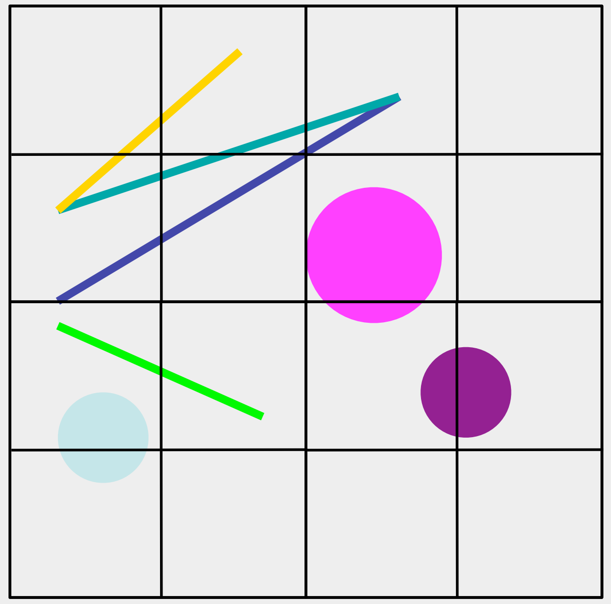

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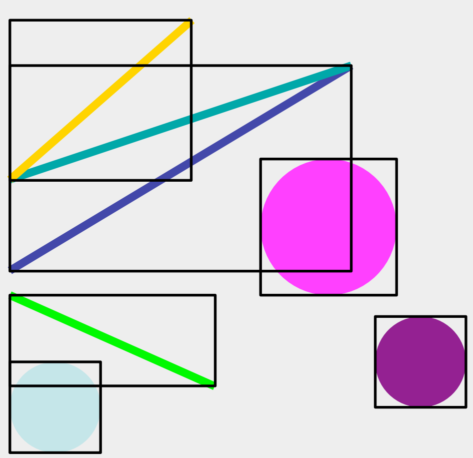
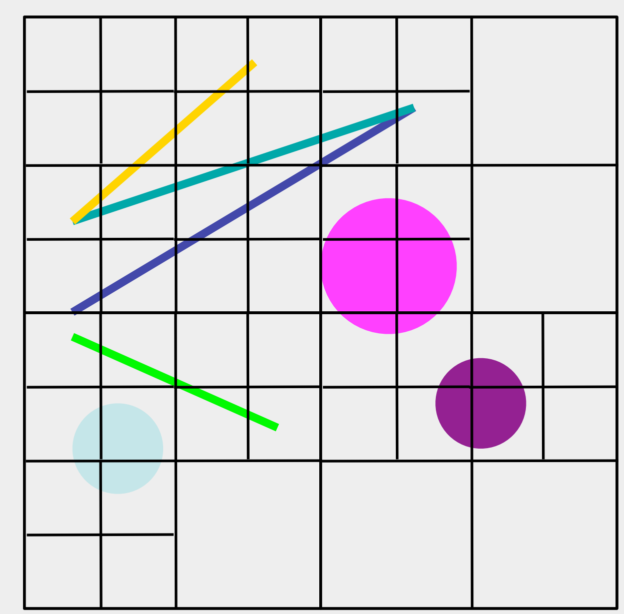
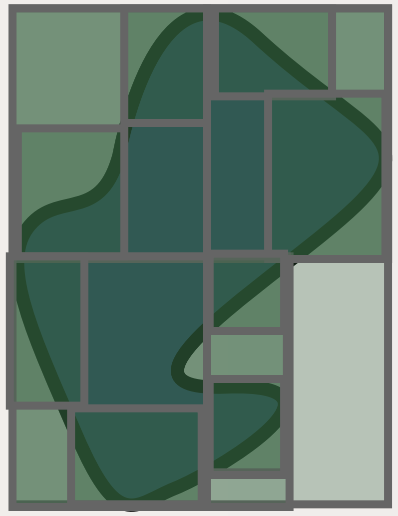




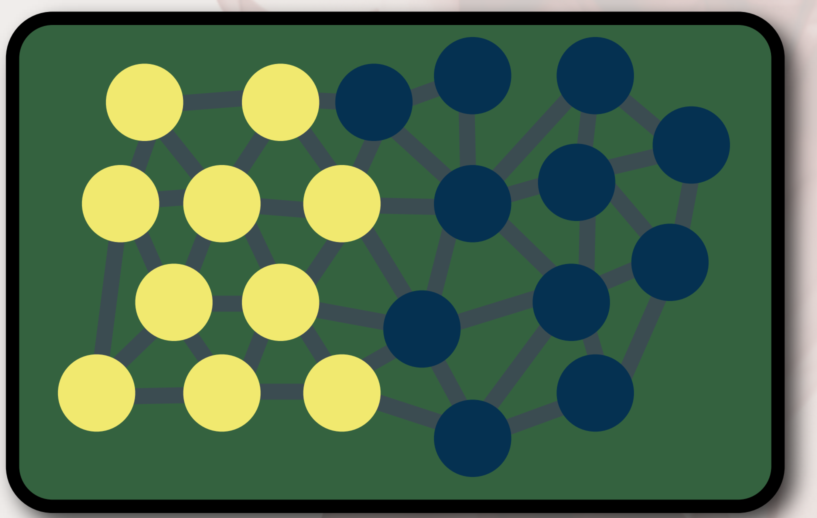
(From Doug James's Slides.)

Bounding Volume Hierarchies

- How to create a BVH:
  - Geometric Subdivision
  - Topological Subdivision
    - How implement?
  - Which is better?

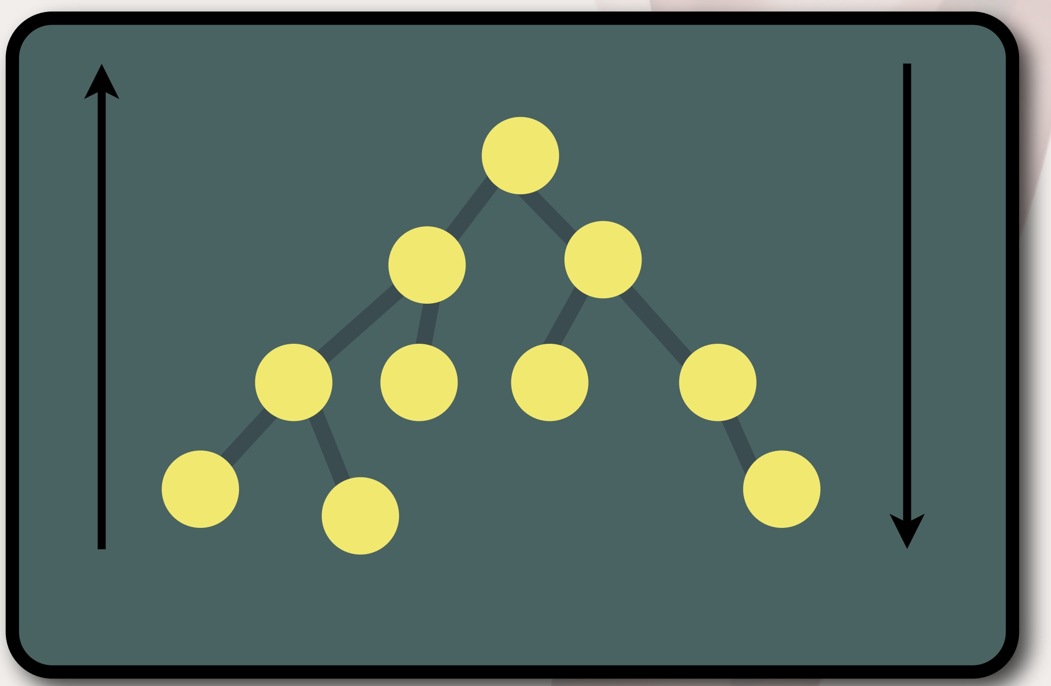


Geometric Subdivision



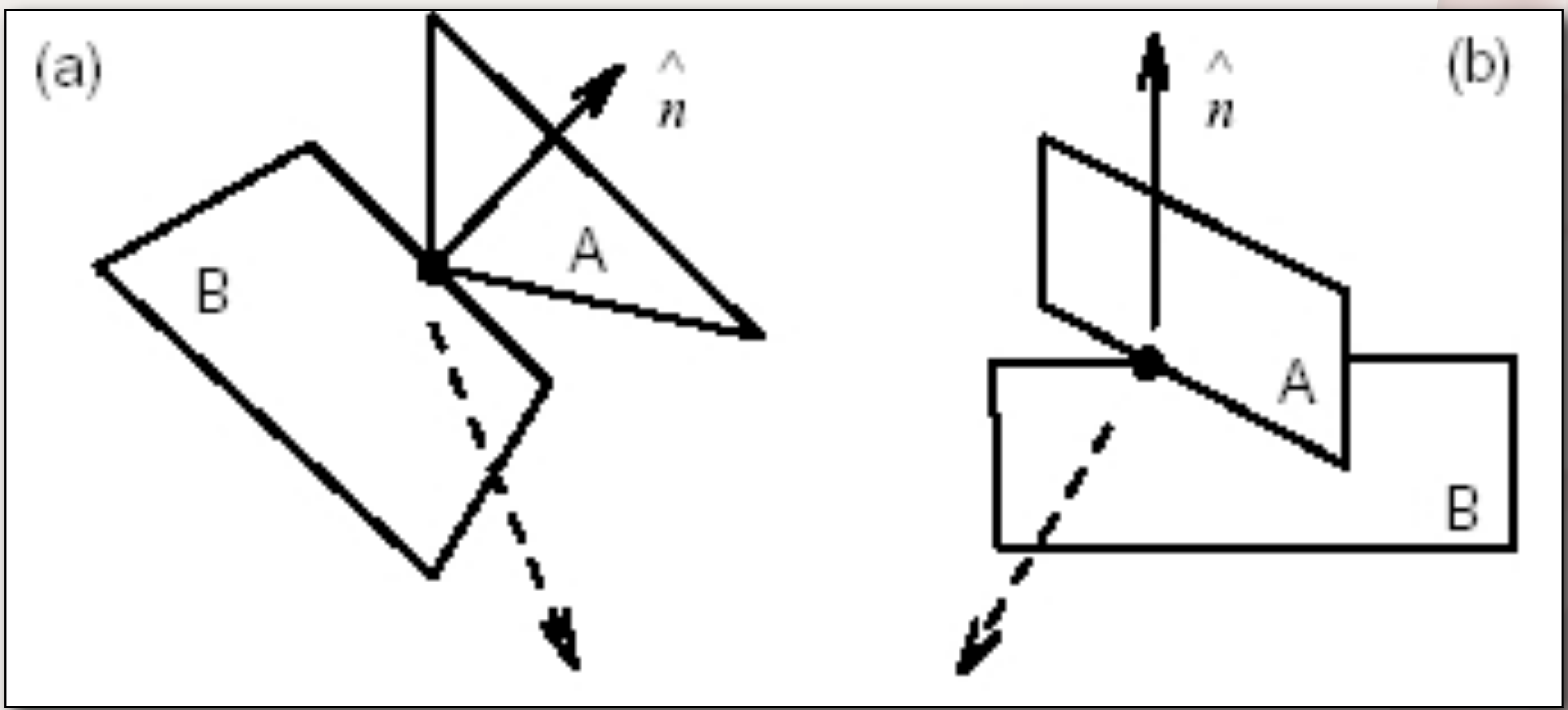
Topological Subdivision

- How to update a BVH:
  - Bottom Up (How?)
  - Directly (How?)
  - Which is faster?

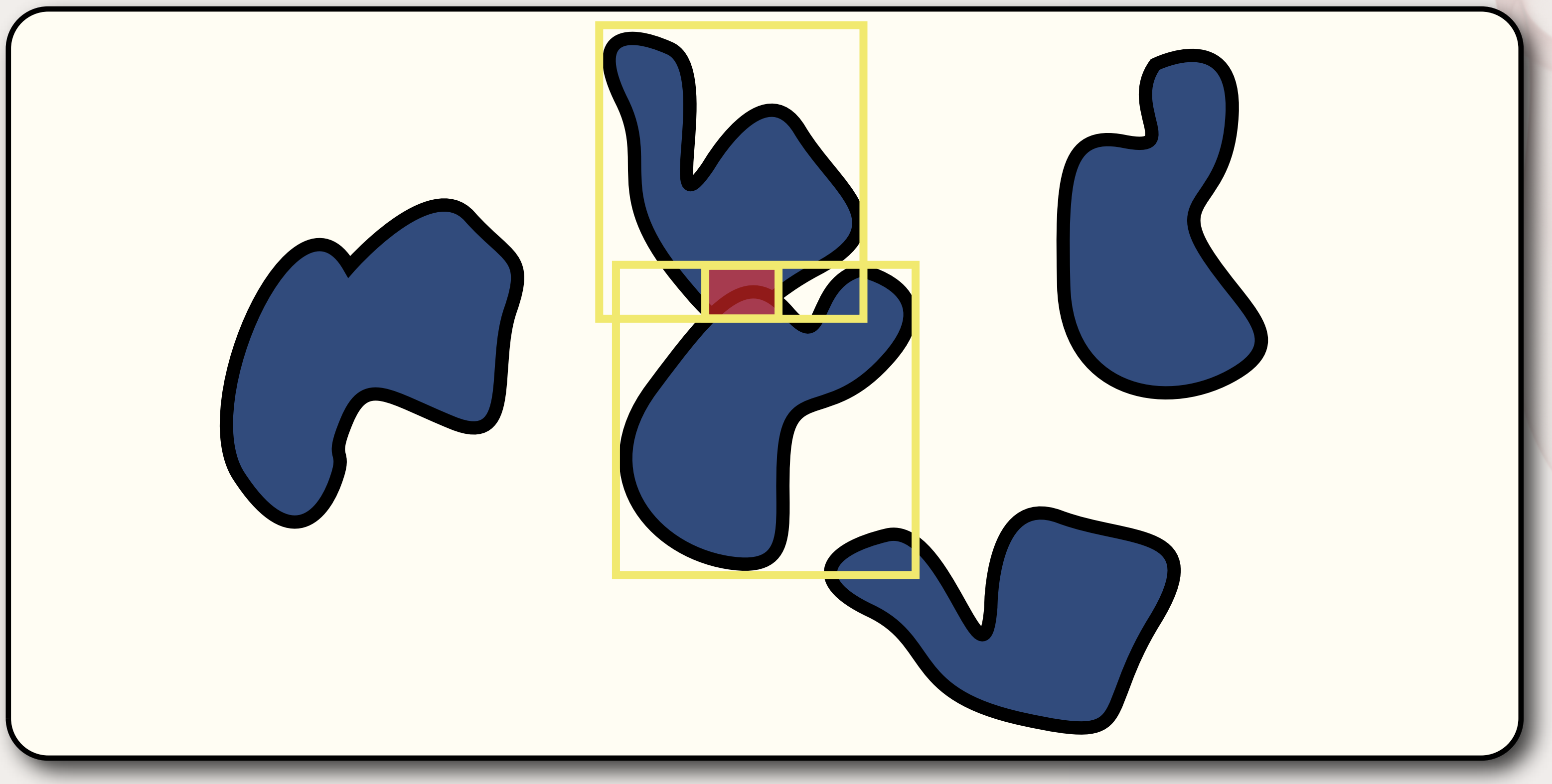


Triangle Intersection

- Edge-Edge
- Vertex-Face



Summary



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Collision Detection for

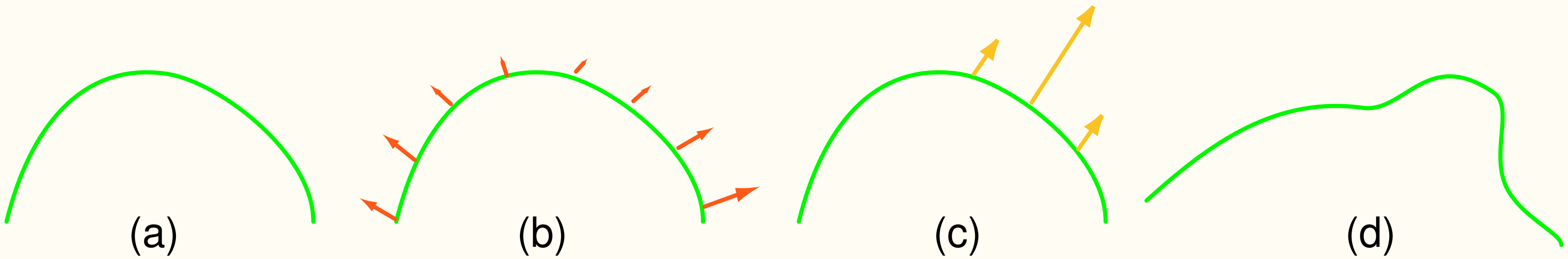
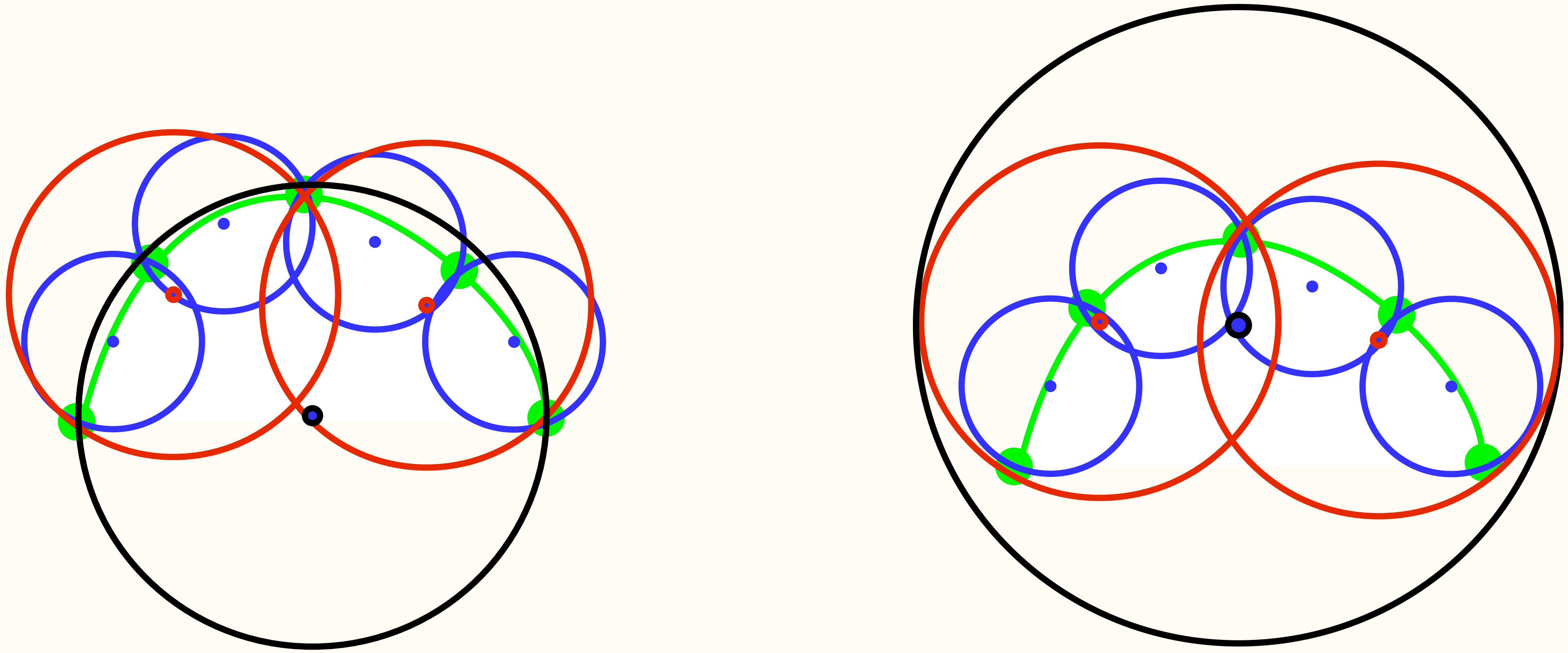


Figure 2: Example deformation: (a) Reference shape p (b) Displacement field U_{*1} (c) Field U_{*2} (d) Deformed shape p'.

$$\mathsf{p}' = \mathsf{p} + \mathsf{U}\mathsf{q} \qquad \text{or} \qquad \mathsf{p}'_i = \mathsf{p}_i + \sum_{j=1}^{M} \mathsf{U}_{ij}\mathsf{q}_j.$$

Source: Doug L. James and Dinesh K. Pai, *BD-Tree: Output-Sensitive Collision Detection for Collision Detection for Reduced Models*, ACM Transactions on Graphics (ACM SIGGRAPH 2004), 23(3), pp. 393-398.

Hierarchy Types

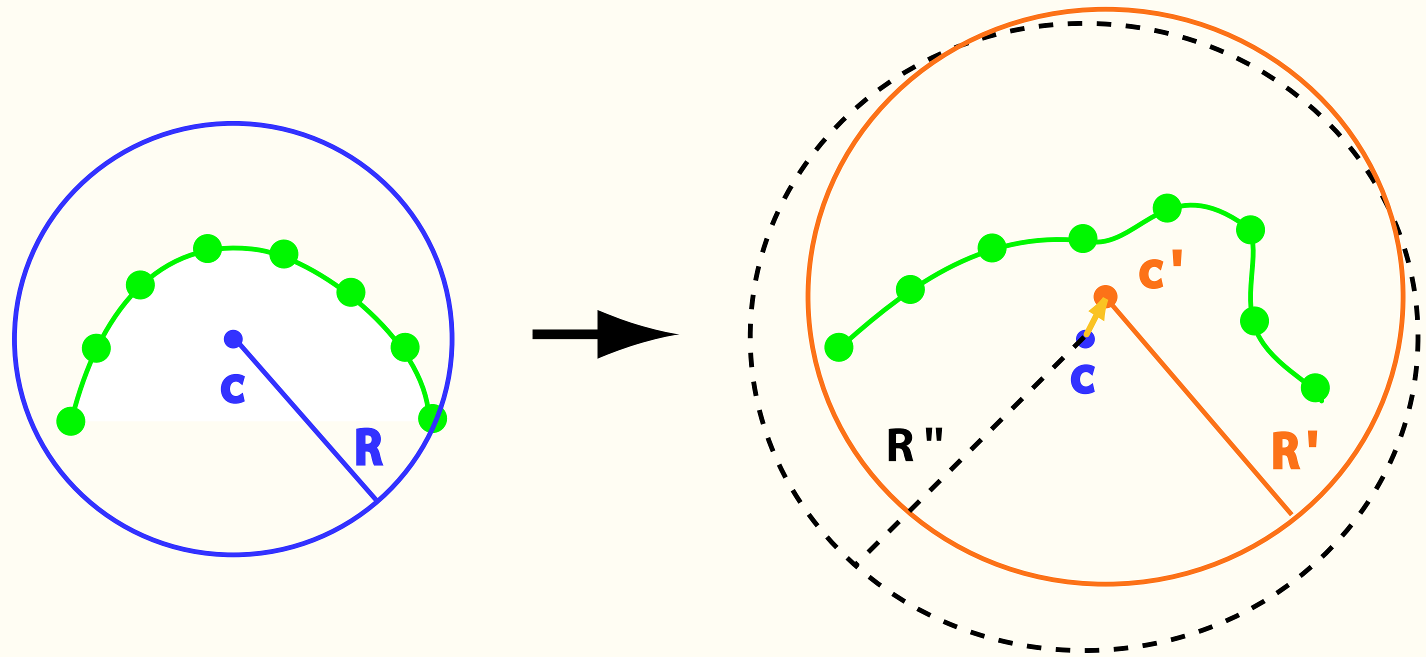


Wrapped Hierarchy

Layered Hierarchy

Source: Doug L. James and Dinesh K. Pai, *BD-Tree: Output-Sensitive Collision Detection for Collision Detection for Reduced Models*, ACM Transactions on Graphics (ACM SIGGRAPH 2004), 23(3), pp. 393-398.

Sphere Center Update



$$
\begin{aligned}
\mathrm{c}' &= \mathrm{c} + \sum_{i\in\Lambda} \beta_i \mathrm{u}_i = \mathrm{c} + \sum_{i\in\Lambda} \beta_i \left(\sum_{j=1}^{M} \mathrm{U}_{ij} \mathrm{q}_j \right) \\
&= \mathrm{c} + \sum_{j=1}^{M} \left(\sum_{i\in\Lambda} \beta_i \mathrm{U}_{ij} \right) \mathrm{q}_j \\
&\equiv \mathrm{c} + \sum_{j=1}^{M} \bar{\mathrm{U}}_j \mathrm{q}_j = \boxed{\mathrm{c} + \bar{\mathrm{U}}\mathrm{q} \equiv \mathrm{c}'}
\end{aligned}
$$

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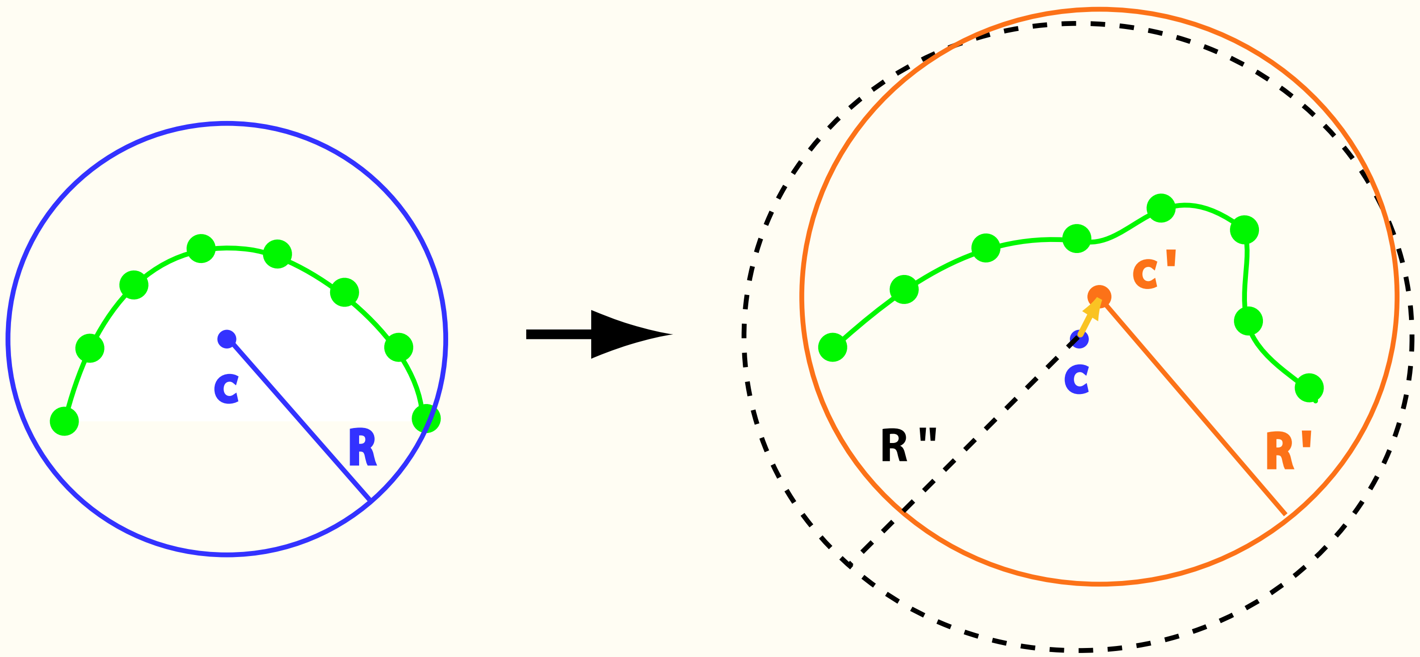


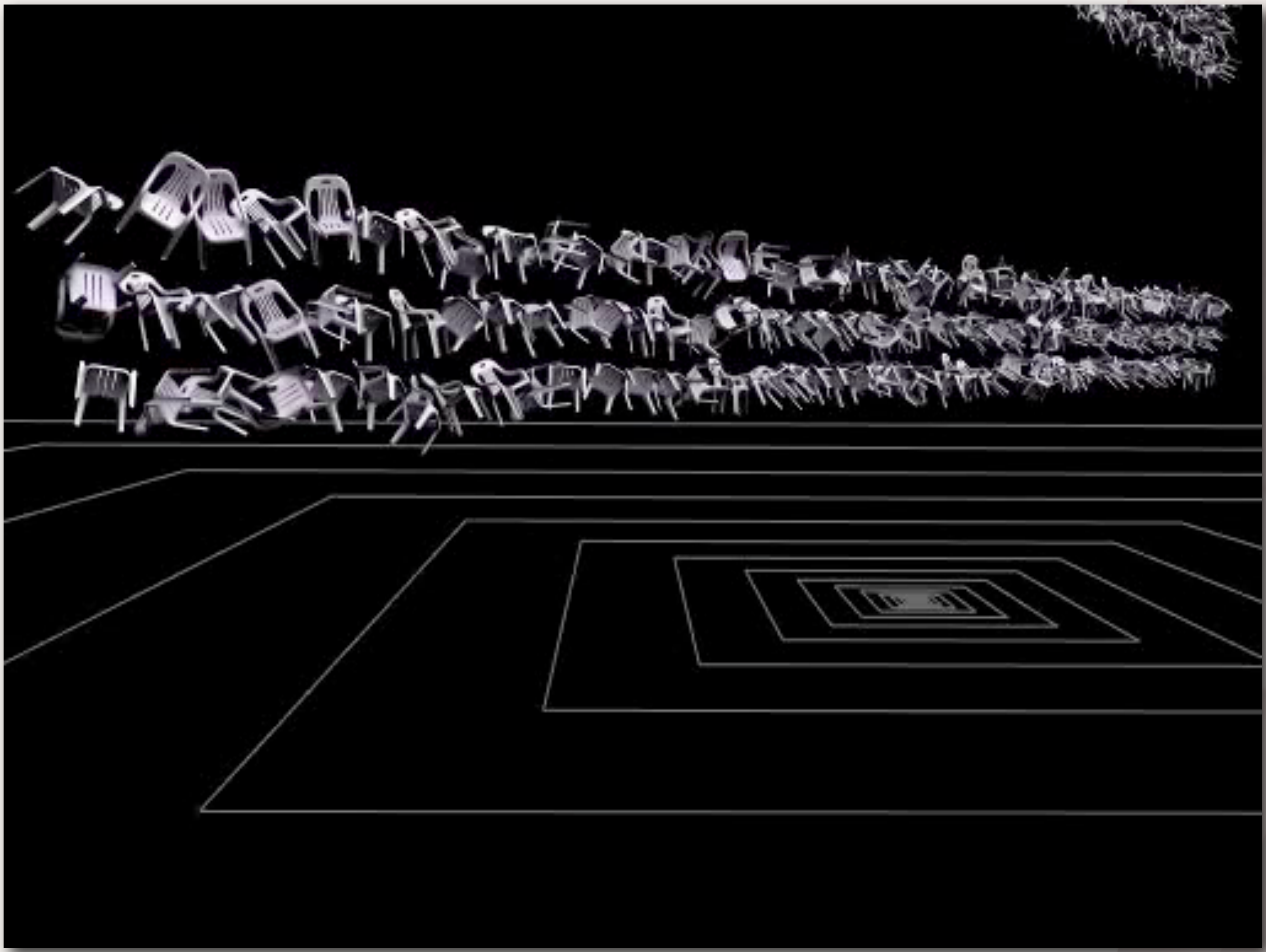
$$\max_{i\in\Lambda} \|\mathsf{p}'_i - \mathsf{c}'\|_2 = \max_{i\in\Lambda} \|(\mathsf{p}_i - \mathsf{c}) + \sum_{j=1}^{M} (\mathsf{U}_{ij} - \bar{\mathsf{U}}_j)\mathsf{q}_j\|_2 \quad (6)$$

$$\leq \max_{i\in\Lambda} \|\mathsf{p}_i - \mathsf{c}\|_2 + \sum_{j=1}^{M} \left(\max_{i\in\Lambda} \|\mathsf{U}_{ij} - \bar{\mathsf{U}}_j\|_2 \right) |\mathsf{q}_j|$$

$$\equiv R + \sum_{j=1}^{M} \Delta R_j |\mathsf{q}_j| = \boxed{R + \Delta R^T \mathsf{q}^{ABS} \equiv R'} \quad (7)$$

Source: Doug L. James and Dinesh K. Pai, *BD-Tree: Output-Sensitive Collision Detection for Collision Detection for Reduced Models*, ACM Transactions on Graphics (ACM SIGGRAPH 2004), 23(3), pp. 393-398.

Example



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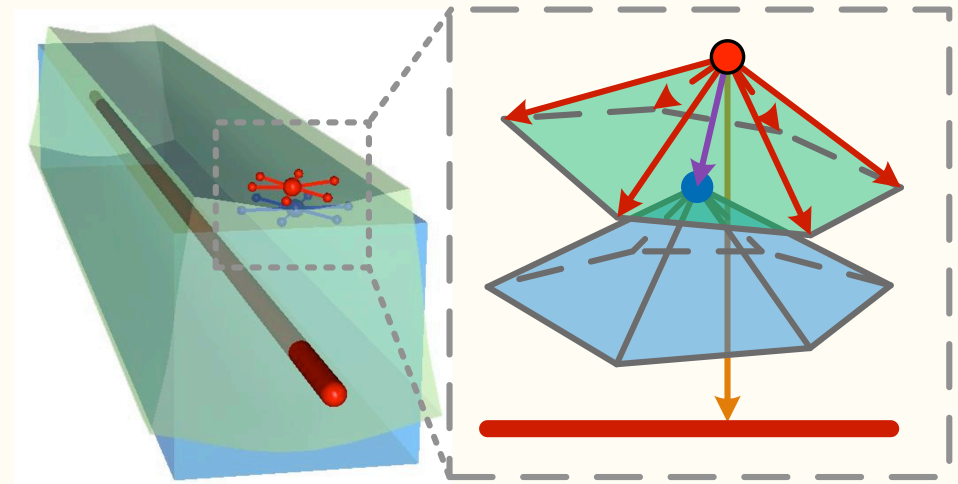
Surface-Based Elastics



(a) (b)

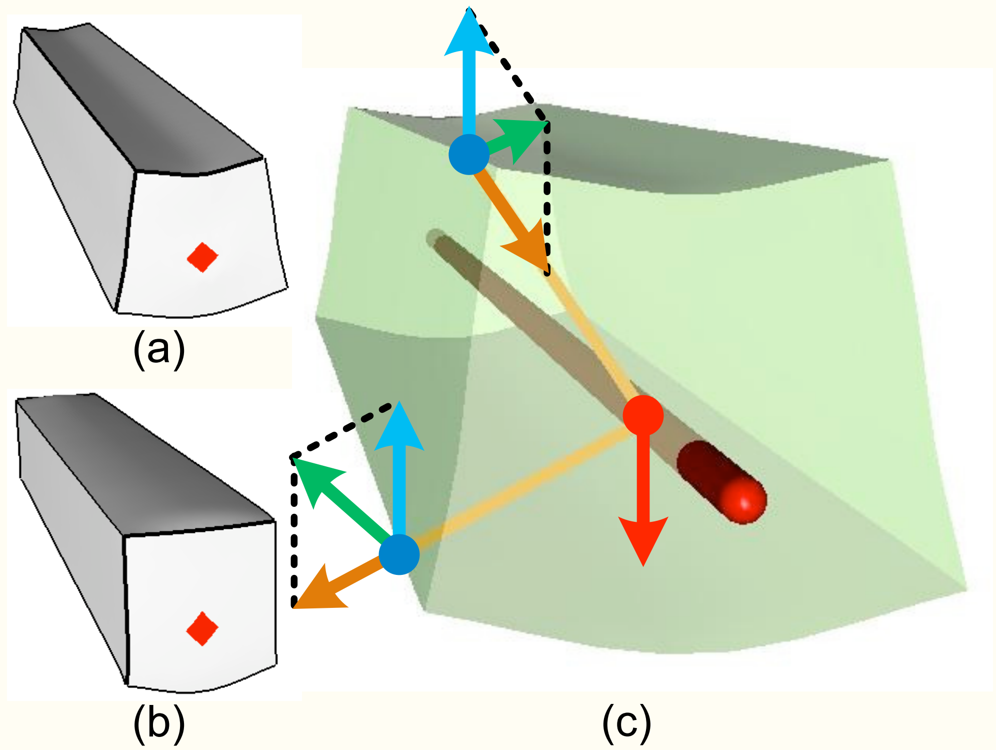
$$\mathbf{A} = \sum_{j \in nbr(i)} \left(\mathbf{x}_j(t) - \mathbf{x}_i(t)\right)\left(\mathbf{x}_j^0 - \mathbf{x}_i^0\right)^T.$$

$$\mathbf{c}_i(t) = \frac{1}{|nbr(i)|} \sum_{j \in nbr(i)} \left(\mathbf{R}(\mathbf{x}_i^0 - \mathbf{x}_j^0) + \mathbf{x}_j(t)\right).$$

$$\mathbf{L}_i(t) = \frac{\mathbf{c}_i(t) - \mathbf{x}_i(t)}{h^2}.$$

Source: Xiaohan Shi, Kun Zhou, Yiying Tong, Mathieu Desbrun, Hujun Bao, Baining Guo.
Example-Based Dynamic Skinning in Real Time. ACM TOG (SIGGRAPH 2008)

Volumetric Behavior



$$\mathbf{B}_i(t) = \frac{\left(|\mathbf{x}_{ib}^0|/|\mathbf{x}_{ib}(t)| - 1\right)\mathbf{x}_{ib}(t)}{h^2},$$

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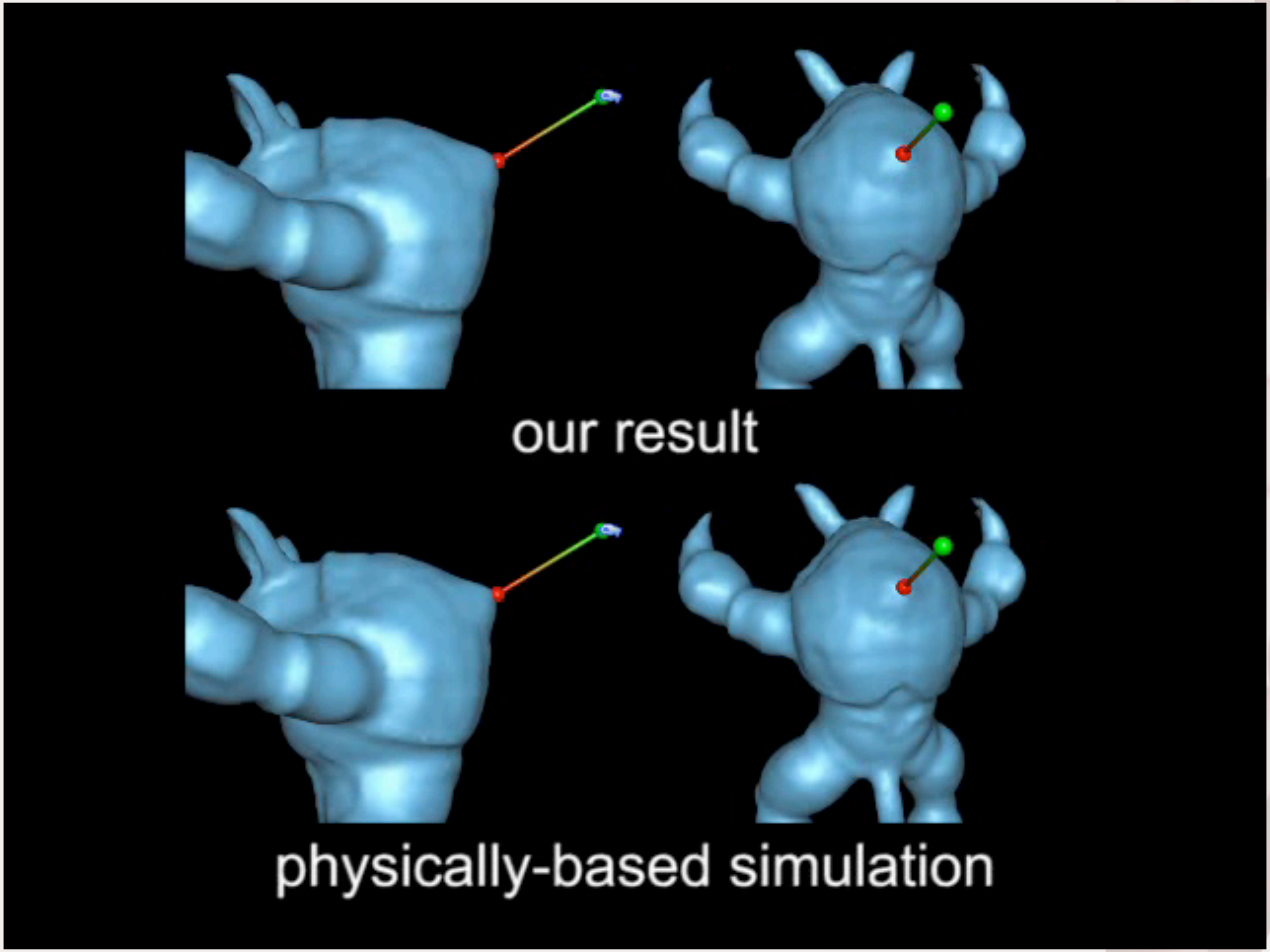
Example



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Questions

- How could we represent a human body on a computer with few dimensions.
- What kind of optical technology could we use to capture a human body?
- How can we convert the captured data into the human body representation.
- In animation, what do you think are the most important aspects of human motion to capture / model?
  - Physically / Stylistically?