CDDC: Collision Detection Based on Fuzzy Clustering for Deformable Objects on GPUs

David Mainzer$^1$ and Gabriel Zachmann$^2$

$^1$Clausthal University, Germany, dm@tu-clausthal.de and $^2$University of Bremen, Germany, zach@cs-bremen.de

Our Contributions
- Reports intersections and self-intersections
- Works for arbitrary polygon soups
- Works for arbitrary & unknown motions of the primitives
- No need do distinguish between broad and narrow phase

Sweep-Plane Approach via PCA
- Compute covariance matrix over all centroid points of all primitives
- Left: Initial scene and result of PCA
- Right: Scene in the local coordinate system of the PCA
- Overlap between clusters in close proximity $\geq \max_{k=1,2,...,n} \left( \max_{o=1,2}\left( \|C_i - \text{vertex}_k\|_2 \right) \right) - m\|C_i - \text{vertex}_k\|_2$
  where $m$ = hard clustering border,
  $m_c$ = fuzzy clustering border, $C_i$ = centroid of primitive $i$, $\text{vertex}_k$ = vertex $k$ of primitive $i$
- Membership value $\in [0,1]$ in the clustering step controls size of cluster overlap $\rightarrow$ trade-off between cluster overlap and performance

Segmentation Process
- Problem: sweeping essentially projects boxes down to intervals $\rightarrow$ primitives are potentially colliding, even if there is a large distance in-between
- Solution: subdivide scene into connected components using fuzzy C-Means
- Condition on clusters: Clusters in close proximity have to be connected, otherwise collisions across border of clusters would be missed

Sweep-Plane Technique using PCA
- All primitives in a scene $\rightarrow$ huge amount of false positives if using a fixed world coordinate axis as sweep direction
- Best sweep direction separates the primitives as much as possible
- Principle component analysis (PCA): direction of first principal component maximizes variance

Results
- NVIDIA GeForce GTX 480 & CUDA Toolkit 5.0
- External and self-collision detection

<table>
<thead>
<tr>
<th>Benchmark</th>
<th>Our</th>
<th>CSL $^3$</th>
<th>Pab $^3$</th>
<th>HP</th>
<th>MC $^4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cloth on Ball</td>
<td>6.33ms</td>
<td>4.4ms</td>
<td>6.7ms</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cloth on Ball</td>
<td>20.24ms</td>
<td>18.6ms</td>
<td>36.6ms</td>
<td>25.2ms</td>
<td>13.2ms</td>
</tr>
<tr>
<td>Funnel</td>
<td>6.53ms</td>
<td>4.4ms</td>
<td>6.7ms</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Funnel</td>
<td>5.34ms</td>
<td>4.4ms</td>
<td>6.7ms</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

References