

# P-Cloth: Interactive Complex Cloth Simulation on Multi-GPU Systems using Dynamic Matrix Assembly and Pipelined Implicit Integrators

## Supplementary Material

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<https://min-tang.github.io/home/PCloth/>

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## 1 ALGORITHMS FOR TIME INTEGRATION

Some algorithms used for parallel time integration is described in the following pseudo-code.

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**Algorithm 1** Work Queue Generation Algorithm used for Pipelined SpMV

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```
1: sw: index of the switch
2: offset: offset for sub-vector index
3: lvl: level in the binary tree, 0 for leaf nodes
4: GetGPURange:
5: Returns the indices of the GPU that the given switch intercon-
   connects. For a leaf switch, returns exact 2 GPU indices.
6: GetChildSwitches:
7: Return the indices of 2 child switches of a given switch.
8:
9: // Call GenerateWorkQueues(0, 0, log2n) for the overall
10: // work queues.
11: procedure GENERATEWORKQUEUES(sw, offset, lvl)
12:   // step (1):
13:   // Recursively generate optimal work queues for
14:   // its children.
```

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```
15: if lvl != 0 then
16:   sw0, sw1 ← GetChildSwitches(sw)
17:   GenerateWorkQueues(sw0, offset, lvl - 1)
18:   GenerateWorkQueues(sw1, offset, lvl - 1)
19: else
20:   // Each leaf switch interconnects exact 2 GPUs.
21:   G0, G1 ← GetGPURange(sw)
22:   node0 ← (G1, G0 + offset)
23:   node1 ← (G0, G1 + offset)
24:   Push node0 to Q(G0)
25:   Push node1 to Q(G1)
26: end if
27:
28: // step (2):
29: // Transfer minimized amount of data between
30: // its children.
31: range0 ← GetGPURange(sw0)
32: range1 ← GetGPURange(sw1)
33: for G0, G1 ∈ range0, range1 do
34:   node0 ← (G1, G0 + offset)
35:   node1 ← (G0, G1 + offset)
36:   Push node0 to Q(G0)
37:   Push node1 to Q(G1)
38: end for
39:
40: // step (3):
41: // Delegate rest of the work queue generation
42: // tasks to its children.
43: offset0 ← offset + 2lvl
44: offset1 ← offset - 2lvl
45: // An offset is applied so that the work queue is
46: // generated for the delegated sub-vectors.
47: GenerateWorkQueues(sw0, offset0, lvl - 1)
48: GenerateWorkQueues(sw1, offset1, lvl - 1)
49: end procedure
```

---

**Algorithm 2** Sparse Matrix Filling Algorithm

---

```
1: // Index Table Allocating:
2: for each GPUi do in parallel
3:   IndexTablei ← AllocateIndexTable(i)
```

```

4: end for
5:
6: // Index Filling:
7: for each GPUi do in parallel
8:   for Element ∈ AssemblyElements do
9:     rowIdx ← GetElementRowIdx(Element)
10:    colIdx ← GetElementColIdx(Element)
11:    Push colIdx to IndexTablei[rowIdx] // atomic operator
12:   end for
13: end for
14:
15: // Index Compacting:
16: for each GPUi do in parallel
17:   for row ∈ IndexTablei do
18:     RemoveDuplication(row)
19:   end for
20: end for
21:
22: // Value Table Allocating:
23: for each GPUi do in parallel
24:   ValueTablei ← AllocateValueTable(i)
25: end for
26:
27: // Value Filling:
28: for each GPUi do in parallel
29:   for Element ∈ AssemblyElements do
30:     entry ← FindElementEntry(Element)
31:     value ← GetElementValue(Element)
32:     ValueTablei[entry] += value // atomic operator
33:   end for
34: end for

```

## 2 STITCHING ALGORITHM

The stitching algorithm is described in the following pseudo-code.

### Algorithm 3 Stitching Algorithm

```

1: Input: Stitching node pairs  $NP$ .
2: Output: Stitched and refined cloth mesh .
3:
4: // Stitching cloth pieces with linking constraints
5: // for all the  $NP$ .
6: StitchingCoarsePieces( $NP$ )
7:
8: // Merge the pieces together by merging
9: // all the node pairs  $NP$ 
10: MergePieces( $NP$ )
11:
12: // Refine the merged cloth mesh to higher resolution
13: // by subdividing.
14: RefinePieces()

```

## 3 ADDITIONAL BENCHMARKS

We use some complex cloth simulation benchmarks for regular/irregular-shaped cloth simulation (Fig. 1 and Fig. 2).

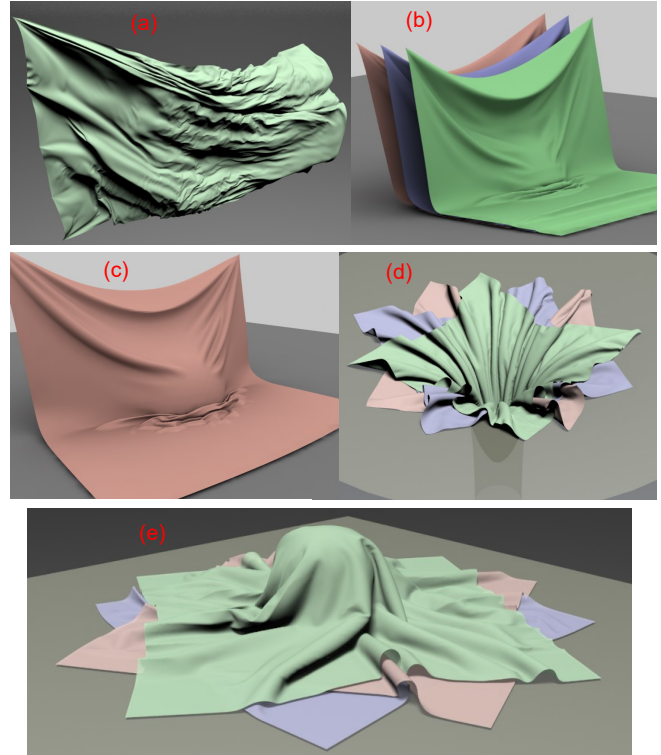


Fig. 1. **Benchmarks:** We use different multi-layered cloth simulation benchmarks ((a)Flag, (b) Sphere, (c) Sphere-1M, (d) Funnel, and (e) Twisting) for evaluation. The mesh complexity varies between 0.5 – 1.65M triangles. P-Cloth can perform cloth simulation at 2 – 5 fps on the 4-GPU workstation. The memory overhead on each GPU is between 4 – 8 GB.



Fig. 2. **Multi-layer Garment Benchmarks:** We used these benchmarks: (a) Miku with 1.33M triangles, (b) Zoey with 569K triangles, (c) Andy with 538K triangles, and (d) Kimono with 1M triangles, for multi-layer garment simulation.