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

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1 ALGORITHMS FOR TIME INTEGRATION

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

Algorithm 1 Work Queue Generation Algorithm used for Pipelined SpMV

```
sw: index of the switch
offset: offset for sub-vector index
lvl: level in the binary tree, 0 for leaf nodes
GetGPURange:
Returns the indices of the GPU that the given switch interconnects. For a leaf switch, returns exact 2 GPU indices.
GetChildSwitches:
Return the indices of 2 child switches of a given switch.

// Call GenerateWorkQueues(0, 0, log_2 n) for the overall
// work queues.
procedure GenerateWorkQueues(sw, offset, lvl)
    // step (1):
    // Recursively generate optimal work queues for
    // its children.
    if lvl != 0 then
        sw0, sw1 ← GetChildSwitches(sw)
        GenerateWorkQueues(sw0, offset, lvl - 1)
        GenerateWorkQueues(sw1, offset, lvl - 1)
    else
        // Each leaf switch interconnects exact 2 GPUs.
        G0, G1 ← GetGPURange(sw)
        node0 ← (G1, G0 + offset)
        node1 ← (G0, G1 + offset)
        Push node0 to Q(G0)
        Push node1 to Q(G1)
    end if

    // step (2):
    // Transfer minimized amount of data between
    // its children.
    range0 ← GetGPURange(sw0)
    range1 ← GetGPURange(sw1)
    for G0, G1 ∈ range0, range1 do
        node0 ← (G1, G0 + offset)
        node1 ← (G0, G1 + offset)
        Push node0 to Q(G0)
        Push node1 to Q(G1)
    end for

    // step (3):
    // Delegate rest of the work queue generation
    // tasks to its children.
    offset0 ← offset + 2^lvl
    offset1 ← offset - 2^lvl
    // An offset is applied so that the work queue is
    // generated for the delegated sub-vectors.
    GenerateWorkQueues(sw0, offset0, lvl - 1)
    GenerateWorkQueues(sw1, offset1, lvl - 1)
end procedure
```

Algorithm 2 Sparse Matrix Filling Algorithm

```
// Index Table Allocating:
for each GPU_i do in parallel
    IndexTable_i ← AllocateIndexTable(i)
end for

// Index Filling:
```

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for each GPU_i **do in parallel**
  for $Element \in AssemblyElements$ **do**
    $rowIdx \leftarrow$ GetElementRowIdx($Element$)
    $colIdx \leftarrow$ GetElementColIdx($Element$)
    Push $colIdx$ to $IndexTable_i[rowIdx]$ // atomic operator
  end for
end for

// Index Compacting:
for each GPU_i **do in parallel**
  for $row \in IndexTable_i$ **do**
    RemoveDuplication(row)
  end for
end for

// Value Table Allocating:
for each GPU_i **do in parallel**
  $ValueTable_i \leftarrow$ AllocateValueTable(i)
end for

// Value Filling:
for each GPU_i **do in parallel**
  for $Element \in AssemblyElements$ **do**
    $entry \leftarrow$ FindElementEntry($Element$)
    $value \leftarrow$ GetElementValue($Element$)
    $ValueTable_i[entry]$ += $value$ // atomic operator
  end for
end for

2 STITCHING ALGORITHM

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

Algorithm 3 Stitching Algorithm

Input: Stitching node pairs NP.
Output: Stitched and refined cloth mesh .

// Stitching cloth pieces with linking constraints
// for all the NP.
StitchingCoarsePieces(NP)

// Merge the pieces together by merging
// all the node pairs NP
MergePieces(NP)

// Refine the merged cloth mesh to higher resolution
// by subdividing.
RefinePieces()

3 ADDITIONAL BENCHMARKS

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

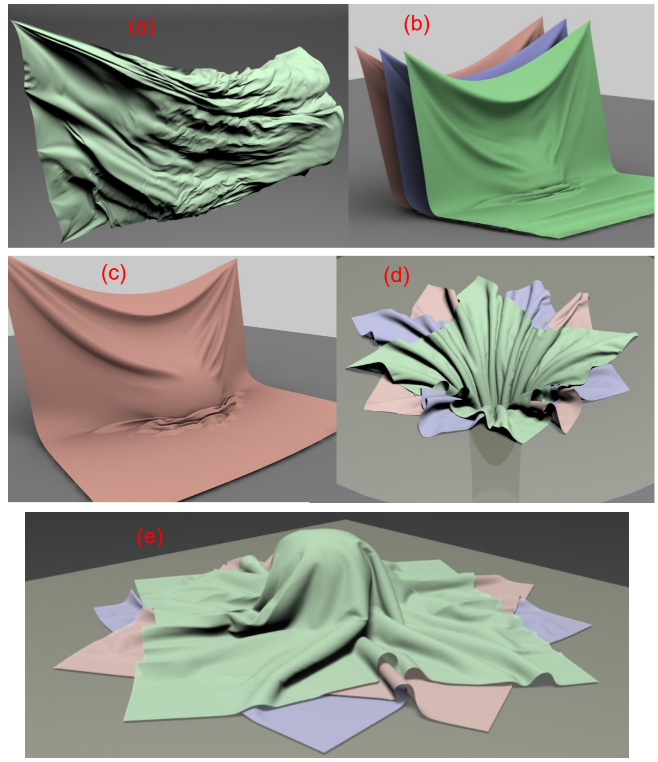

Fig. 1. **Benchmarks:** We use different multi-layered cloth simulation benchmarks ((a)Flag, (b) Sphere, (c) Sphere-1M, (d) Funnel, and (e) Twisting) for evaluation. The mesh complexity varies between $0.5 - 1.65$M triangles. P-Cloth can perform cloth simulation at $2 - 5$ fps on the 4-GPU workstation.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