A Hybrid Multiresolution Representation for Fast Tree Modeling and Rendering [1]

Ong Yongzhi

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Outline

Introduction and Background

Modeling Plants and Trees using L-Systems

Solution and Algorithm
   Trunk and Branch Modeling
   Leaves and Foliage
   Combined Execution

Results and Conclusion
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General Overview of Paper

- Object of discussion: Plants/Trees

- Individual techniques:
  - Multiresolution - Geometry-based simplification
  - Image-based - Billboards, textures, etc.

- General disadvantages:
  - Multiresolution - Fail to capture plant/tree nature
  - Image-based - Large storage requirements and close range artifacts

- Solution:
  - Use both techniques at procedural level: Hybrid Multiresolution
Texture-mapped Polygons / Billboards
Background - Plant/Tree Modeling - 2

- L-Systems [7]
- Components [2]
- Images of Real Plants/Trees [8]
Background - Level-of-Detail (LOD) - 1

- Degradation at Range and Pixel-based LODs [10]
- (Binary) Space Partitioning and Multiresolution [3]
- Cluster-based Hierarchical Polygon Decimation and Compression [11]
- Volumetric Textures [5]
- Bidirectional Textures [6]
Background - More about Multiresolution

- Representation of objects at various LODs

- 4 Characteristics of good multiresolution models:
  - Size of model does not increase with number of LODs
  - Extraction of LODs is fast enough for interactive rendering
  - No loss of information
  - Smooth transition between LODs
Model Type Choice and Justification

- Geometry-based simplification methods fail to maintain tree/plant structure
- Long hours required for designers to build tree representations
- Huge storage requirements

Selected Model Type: **L-Systems:**

- Quick model generation
- Low storage requirement
- View direction/position independent rendering quality
Problem Division

- Trunk and branches
- Leaves or foliage
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Example

Axiom:
A(length)

Rule 1:
A(l): itNum < maxIt -> B(l) [A(l/2) A(l/2)]

Rule 2:
A(l): itNum = maxIt -> B(l)
Example

Axiom : $A(1)$

$\text{itNum} = 0$

$\text{maxIt} = 2$

Output Chain:

$A(1)$
Example

Rule 1:
A(l): $\text{itNum} < \text{maxIt} \rightarrow B(l) [A(l/2) A(l/2)]$

$\text{itNum} = 1$
$\text{maxIt} = 3$

Output Chain (Before)
A(1)

Output Chain:
B(1) [A(0.5) A(0.5)]
Example

Rule 1:
A(l): \( \text{itNum} < \text{maxIt} \rightarrow B(l) \ [A(l/2) \ A(l/2)] \)

- itNum = 2
- maxIt = 3

Output Chain (Before)
B(1) \ [A(0.5) \ A(0.5)]

Output Chain:
B(1) \ [B(0.5) \ [A(0.25) \ A(0.25)]]
B(0.5) \ [A(0.25) \ A(0.25)]]
Example

Rule 2:
A(1): itNum = maxIt -> B(1)

Output Chain (Before)
B(1) [B(0.5) [A(0.25) A(0.25)]]
B(0.5) [A(0.25) A(0.25)]]

Output Chain:
B(1) [B(0.5) [B(0.25) B(0.25)]]
B(0.5) [B(0.25) B(0.25)]]
Example

Interpretation: F = Forward, R = Rotate
\[ F(1) \ [ R(90) \ F(1) ] \ F(2) \]
Example

$F(1) \ [ \ R(90) \ F(1) \ ] \ F(2)$
Turtle Interpretation - 3

Example

\[ F(1) \ [ \ R(90) \ F(1) ] \ F(2) \]
Example

\[ F(1) \ [ \ R(90) \ F(1) \] \ F(2) \]
Example

\[ F(1) \ [ \ R(90) \ F(1) \ ] \ F(2) \]
Example

\[ F(1) \ [ \ R(90) \ F(1) \ ] \ F(2) \]
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Results and Conclusion
Step 1 - Tree Abstract Data Type (tADT) - 1
L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

Example
Output Chain from L-System:
C1 [ C2 [ C3 ] [ C4 ] ] [ C5 ]

Root
Step 1 - Tree Abstract Data Type (tADT) - 2

L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

Example

Output Chain from L-System:
C1 [ C2 [ C3 ] [ C4 ] ] [ C5 ]

C1-1
Example

Output Chain from L-System:
C1 [ C2 [ C3 ] [ C4 ] ] [ C5 ]
Step 1 - Tree Abstract Data Type (tADT) - 4

L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

Example

Output Chain from L-System:
C1 [ C2 [ C3 ] [ C4 ] ] [ C5 ]
Example

Output Chain from L-System:
C1 [ C2 [ C3 ] [ C4 ] ] [ C5 ]
Example

Output Chain from L-System:
C1 [ C2 [ C3 ] [ C4 ] ] [ C5 ]
Step 1 - Tree Abstract Data Type (tADT) - 7
L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

Example

Output Chain from L-System:
C1 [ C2 [ C3 ] [ C4 ] ] [ C5 ]
Step 1 - Tree Abstract Data Type (tADT) - 8
L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

Example

Output Chain from L-System:
C1 [ C2 [ C3 ] [ C4 ] ] [ C5 ]

```
C1-1
  /\  \
C2-2  |
  |  /\  |
C3-1  ?  
```
Example

Output Chain from L-System:
C1 [ C2 [ C3 ] [ C4 ] ] [ C5 ]
Step 1 - Tree Abstract Data Type (tADT) - 10
L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

Example

Output Chain from L-System:
C1 [ C2 [ C3 ] [ C4 ] ] [ C5 ]
Example

Output Chain from L-System:
C1 [ C2 [ C3 ] [ C4 ] ] [ C5 ]

Diagram:
- C1-4
- C2-3
- C3-1
- C4-1
Step 1 - Tree Abstract Data Type (tADT) - 12

L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

Example

Output Chain from L-System:
C1 [ C2 [ C3 ] [ C4 ] ] [ C5 ]
Example

Output Chain from L-System:
C1 [ C2 [ C3 ] [ C4 ] ] [ C5 ]
Example

Output Chain from L-System:
C1 [ C2 [ C3 ] [ C4 ] ] [ C5 ]
Step 2 - Metric Selection
L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

- Number of children
- Number of descendents
- Longest path to a leaf node
- **Branching length** (accumulated in each node in during tADT construction)
Example

tADT:

C1-5
   /\ 
  /   \ 
C2-3  C5-1
 |     |
V     V
C3-1  C4-1

C1 SAVE(C1)
Step 3 - Multiresolution Chain - 2
L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

Example

\[ tADT : \]

\[ C1-5 \]
\[ C2-3 \]
\[ C3-1 \]
\[ C4-1 \]
\[ C5-1 \]

C1 SAVE(C1) C2 SAVE(C2)
Example

tADT:

C1 SAVE(C1) C2 SAVE(C2) C3
Step 3 - Multiresolution Chain - 4
L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

Example

tADT:

```
C1-2
C2-1
C3-0
C4-1
C5-1
```

Branching length update
C1 SAVE(C1) C2 SAVE(C2) C3
Example

tADT:

C1 SAVE(C1) C2 SAVE(C2) C3 RESTORE(C2) C4
Example

$tADT:\n
```
C1-1
C2-0
C3-0
C4-0
C5-1
```

Branching length update

C1 SAVE(C1) C2 SAVE(C2) C3 RESTORE(C2) C4
Step 3 - Multiresolution Chain - 7
L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

Example

tADT:

C1 SAVE(C1) C2 SAVE(C2) C3 RESTORE(C2) C4 RESTORE(C1) C5
Step 3 - Multiresolution Chain - 8
L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

Example

tADT:

```
C1-0
```

Branching length update
C1 SAVE(C1) C2 SAVE(C2) C3 RESTORE(C2) C4 RESTORE(C1) C5
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Step 4 - Bounding Box Hierarchy - 1
L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

Example
C1 and C2 are turtle commands (orientated bounding boxes)
C3, C4 and C5 are geometry modules

Output Chain from L-System:
C1[C2[C3(leaf)][C4(leaf)]][C5(leaf)]
Step 4 - Bounding Box Hierarchy - 2
L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

Example

Output Chain from L-System:
C1[C2[C3(leaf)][C4(leaf)]][C5(leaf)]
Step 4 - Bounding Box Hierarchy - 3
L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

Example

Output Chain from L-System:
C1[C2[C3(leaf)][C4(leaf)]][C5(leaf)]
Example

Output Chain from L-System:
C1[C2 [C3(leaf)] [C4(leaf)]] [C5(leaf)]
Example

Output Chain from L-System:
$C_1[C_2[C_3(leaf)][C_4(leaf)]][C_5(leaf)]$
Example

Output Chain from L-System:
C1[C2[C3(leaf)][C4(leaf)]][C5(leaf)]
Step 4 - Bounding Box Hierarchy - 7

L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

Example

Output Chain from L-System:
C1[C2[C3(leaf)][C4(leaf)]][C5(leaf)]
Step 4 - Bounding Box Hierarchy - 8
L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

Example

Output Chain from L-System:
C1[C2[C3(leaf)][C4(leaf)]]C5(leaf)
Step 4 - Bounding Box Hierarchy - 9
L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

Example

Output Chain from L-System:
C1[C2[C3(leaf)][C4(leaf)]][C5(leaf)]]
Step 4 - Bounding Box Hierarchy - 10
L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

Example

Output Chain from L-System:
C1[C2[C3(leaf)]][C4(leaf)][C5(leaf)]
Step 4 - Bounding Box Hierarchy - 11
L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

Example

Output Chain from L-System:
C1[C2[C3(leaf) ][C4(leaf) ]][C5(leaf) ]
Step 4 - Bounding Box Hierarchy - 12
L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

Example

Output Chain from L-System:
C1[C2[C3(leaf)][C4(leaf)]][C5(leaf)]
Step 4 - Bounding Box Hierarchy
L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

Example

Output Chain from L-System:
C1 [C2 [C3 (leaf)] [C4 (leaf)]] [C5 (leaf)]
Step 5 - Pre-computed Textures

L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures

- Textures of 6 diagonal planes for each bounding box
- Size: 128x128 pixels (constant for all levels of detail)
- If ratio(current bbox volume:root bbox volume) < threshold, stop computing textures
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Results and Conclusion
Each **RESTORE** point on the Multiresolution Chain is the next LOD.

Each **Level** of the Bounding Box Hierarchy **is the next LOD**.

Progressively traverse down Multiresolution Chain and Bounding Box Hierarchy **until desired LOD and render**.

A Multiresolution Chain **is interpreted as in turtle interpretation**. Geometry-representing modules are rendered.
Visual Results - Branches
Visual Results - Branches and Leaves
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Results and Comparison

▶ 100 Trees:
  ▶ Geometric Model: 3 fps (min)
  ▶ Hybrid Multiresolution Model: 69 fps (min)

▶ 2000 Trees:
  ▶ Geometric Model: 0.1 fps (min)
  ▶ Hybrid Multiresolution Model: 6 fps (min)
Potential Improvements

- Smooth transitions between LODs
- Reduce memory required for textures
- Wind movements
Thank you!


Hierarchical rendering of trees from precomputed multi-layer z-buffers.

Interactive Volumetric Textures.
Bibliography III


An Evaluative Review of Simulated Dynamic Smart 3D Objects. 

Creation and Rendering of Realistic Trees. 
**Tree Abstract Data Type (tADT) - Problem?**

**L-System Chain -> tADT -> Multiresolution Chain -> BBox -> Textures**

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**Example**

*Output Chain from L-System:*

\[ C_1 \ [ \ C_2 \ [ \ C_3 \ ] \ [ \ C_4 \ ] \ ] \ [ \ C_5 \ ] \ C_6 \]