Computer Graphics
MTAT.03.015

Raimond Tunnel

Study IT in .ee
The Road So Far...

```
mtllib triangle.mtl
o Plane
v 1.007839 0.000000 -1.000000
v 1.000000 0.000000 0.978599
v -1.000000 0.000000 -0.588960
usemtl None
s off
f 3 2 1
```
Procedural Generation

- Generating objects algorithmically

```cpp
for(y = 0; y <= heightSegments; y++) {
    for(x = 0; x <= widthSegments; x++) {
        u = (float)x / widthSegments;
        v = (float)y / heightSegments;

        glm::vec3 vertex = glm::vec3(
            -radius * glm::cos(phiStart + u * phiLength) * glm::sin(thetaStart + v * thetaLength),
            radius * glm::cos(thetaStart + v * thetaLength),
            radius * glm::sin(phiStart + u * phiLength) * glm::sin(thetaStart + v * thetaLength)
        );

        vertices.push_back(vertex);
        normals.push_back(glm::normalize(vertex));
        colors.push_back(color);
    }
}
```
Procedural Generation

- Generating objects algorithmically
  - Mesh (geometry)
Procedural Generation

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  - Mesh (geometry)
  - Material (texture)
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  - Mesh (geometry)
  - Material (texture)
  - Effects (particles)

Custom B. Chopper solution by Siim Raudsepp
Procedural Generation

- Generating objects algorithmically
  - Mesh (geometry)
  - Material (texture)
  - Effects (particles)
  - Animation

Inverse kinematics
Procedural Generation

• Generating objects algorithmically
  • Mesh (geometry)
  • Material (texture)
  • Effects (particles)
  • Animation
  • Worlds
Procedural Generation

- Generating objects algorithmically
  - Mesh (geometry)
  - Material (texture)
  - Effects (particles)
  - Animation
  - Worlds

Infinite Procedural Infrastructured World Generation (MSc thesis) by Andreas Sepp
Procedural Generation

- Generating objects algorithmically
  - Mesh (geometry)
  - Material (texture)
  - Effects (particles)
  - Animation
  - Worlds
  - Characters, weapons, space ships, ...

NPC Generator by Jaanus Jaggo
Procedural Generation

- Generating objects algorithmically
  - Mesh (geometry)
  - Material (texture)
  - Effects (particles)
  - Animation
  - Worlds
  - Characters, weapons, space ships, ...

- More content, less repetative work for artists
Tree

- Let's try to generate a tree branch structure.
Tree

- Let's try to generate a tree branch structure.
- We start with a trunk.
Tree

- From the trunk, we create two branches for either side.
- We also continue on the forward path.
Tree

- We repeat the process for the new segments.
Tree

- We repeat the same process for all of the new segments.
Tree

- Decrease the length of the segments each time.
Tree

- Repeat again the same process.
Tree

• Introduce randomness.
Tree

• What if we want to store the generated structure?
Tree

- What if we want to store the generated structure?
- For example, this smaller tree:
Tree

- What if we want to store the generated structure?
- For example, this smaller tree:
- We should specify the structure and the parameters (length, angle).
Formal Grammar (Chomsky)

• Formal grammar consists of:
  • Set of nonterminal symbols $N$.  

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Nonterminals can be changed by production rules.
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They do not „terminate“ the derivation.
Formal Grammar (Chomsky)

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  - Set of nonterminal symbols $\mathcal{N}$.
  - Set of terminal symbols $\Sigma$. 
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Formal Grammar (Chomsky)

• Formal grammar consists of:
  • Set of nonterminal symbols \( \mathcal{N} \).
  • Set of terminal symbols \( \Sigma \).
  • Set of production rules.
Formal Grammar (Chomsky)

- Formal grammar consists of:
  - Set of nonterminal symbols $N$.
  - Set of terminal symbols $\Sigma$.
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Rules tell you what nonterminals can be replaced with other nonterminals or terminals.
Formal Grammar (Chomsky)

- Formal grammar consists of:
  - Set of nonterminal symbols $N$.
  - Set of terminal symbols $\Sigma$.
  - Set of production rules.
  - Starting axiom.
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The initial „word“ of symbols / system state.
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- Example:
  $$N = \{ A \}$$
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  $\Sigma = \{ a \}$
  $R = \{ A \rightarrow AA \, \, A \rightarrow a \}$
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• Example:

\[
N = \{ A \} \quad Axiom = A \\
\Sigma = \{ a \} \\
R = \{ A \rightarrow AA, A \rightarrow a \}
\]
Formal Grammar (Chomsky)

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- Example:

  $N = \{ A \}$
  $\Sigma = \{ a \}$

  $R = \begin{cases} 
  A \rightarrow AA \\ 
  A \rightarrow a 
  \end{cases}$

  Axiom $= A$

  Generates words $A \rightarrow a$
Formal Grammar (Chomsky)

• Formal grammar consists of:
  • Set of nonterminal symbols \( N \).
  • Set of terminal symbols \( \Sigma \).
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  • Starting axiom.

• Example:

\[
\begin{align*}
N &= \{ A \} \\
\Sigma &= \{ a \} \\
R &= \left\{ \begin{array}{l}
A \rightarrow AA \\
A \rightarrow a 
\end{array} \right\}
\end{align*}
\]

\( A \rightarrow a \)
\( A \rightarrow AA \rightarrow aA \rightarrow aa \)

Generates words
Formal Grammar (Chomsky)

- Formal grammar consists of:
  - Set of nonterminal symbols $N$.
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  - Set of production rules.
  - Starting axiom.

- Example:

  $N = \{A\}$  \hspace{1cm} Axiom = $A$

  $\Sigma = \{a\}$

  $R = \{ A \rightarrow AA \}$ \hspace{1cm} Generates words

  $A \rightarrow a$

  $A \rightarrow AA \rightarrow aA \rightarrow aa$

  $A \rightarrow AA \rightarrow AAA \rightarrow aAA \rightarrow aaA \rightarrow aaa$
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  $$\Sigma = \{ a \}$$
  $$R = \begin{cases} 
  A \rightarrow AA \\
  A \rightarrow a 
  \end{cases}$$

  Generates words
  $$A \rightarrow a$$
  $$A \rightarrow AA \rightarrow aA \rightarrow aa$$
  $$A \rightarrow AA \rightarrow AAA \rightarrow aAA \rightarrow aaA \rightarrow aaa$$
  $$\ldots$$
Formal Grammar (Chomsky)

- Used for:
Formal Grammar (Chomsky)

- Used for:
  - Natural language processing
Formal Grammar (Chomsky)

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  - Program code processing (compiler, interpreter)
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  • **Type 0: Unrestricted** – $N = \Sigma$
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  • **Type 2: Context free** – left side contains only a single non-terminal symbol
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  - **Type 0: Unrestricted** – $N = \Sigma$
  - **Type 1: Context sensitive** – non-terminal symbol on the left side, can be surrounded by a context
  - **Type 2: Context free** – left side contains only a single non-terminal symbol
  - **Type 3: Regular** – right side is empty, single terminal, or single terminal follower by non-terminal
Lindenmayer System

• Variant of a formal grammar.
Lindenmayer System

- Variant of a formal grammar.
- Parallel rewriting system.
Lindenmayer System

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Because of that, does not fall directly under Chomsky's hierarchy
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  • Bracketed system.

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  - Context free (0L-system).

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Lindenmayer System

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- Parallel rewriting system.
- We will look at one, that is:
  - Bracketed system.
  - Stochastic system.
  - Context free (0L-system).
  - Parametric system.

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Lindenmayer System

- **Bracketed system** – we use brackets to indicate branches.
Lindenmayer System

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- **Using following symbols:**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Segment</td>
</tr>
<tr>
<td>+</td>
<td>Rotate left 45°</td>
</tr>
<tr>
<td>-</td>
<td>Rotate right 45°</td>
</tr>
<tr>
<td>[</td>
<td>Start of a branch</td>
</tr>
<tr>
<td>]</td>
<td>End of a branch</td>
</tr>
</tbody>
</table>

Can we write our tree using those?
Lindenmayer System

- Parallel rewriting system – all the rules will be applied in parallel to rewrite the entire word.
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What would be the rules to create the following?

Axiom: F
Lindenmayer System

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What would be the rules to create the following?

Axiom: F  
1. iteration: F[+F][-F]F
Lindenmayer System

- Parallel rewriting system – all the rules will be applied in parallel to rewrite the entire word.

What would be the rules to create the following?

Axiom: F
1. iteration: F[+F][-F]F
2. iteration:
   F[+F[+F][-F]F]
   [-F[+F][-F]F]
   F[+F][-F]F
Lindenmayer System

- Parallel rewriting system – all the rules will be applied in parallel to rewrite the entire word.

What would be the rules to create the following?

Axiom: F

1. iteration: F[+F][-F]F


This is a trick question.
Lindenmayer System

• **Parametric system** – we can specify parameters for some of the symbols.
Lindenmayer System

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  - The length, the angle etc
Lindenmayer System

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  - The length, the angle etc

F[+(45)F[+(45)F][-(45)F]F]
[(-(45)F[+(45)F][-(45)F]F]
F[+(45)F][-(45)F]F

Every + or - is followed by the angle of rotation.
Lindenmayer System

• We can generate angles with some variance.

F[+(31.24)F][--(47.89)F]F
Lindenmayer System

- We can generate angles with some variance.
- Also specify the lengths of the segments.

\[ F(1)[+(31.24)F(0.75)][-(47.89)F(0.75)]F(0.75) \]
Lindenmayer System

• We can generate angles with some variance.

• Also specify the lengths of the segments.

\[ F(1)[+(31.24)F(0.75)][-(47.89)F(0.75)]F(0.75) \]

If the decrease of lengths is deterministic, we could consider it only, when drawing the tree...
Lindenmayer System

- **Stochastic system** – we can have many rules, with the same left-hand side.

\[
\begin{align*}
A & \rightarrow F[+A]A \\
A & \rightarrow F[-A]A \\
A & \rightarrow F[+A][-A]
\end{align*}
\]
Lindenmayer System

- **Stochastic system** – we can have many rules, with the same left-hand side.

- Each rule has a probability.

\[
\begin{align*}
A & \rightarrow \frac{1}{3} F[+A] A \\
A & \rightarrow \frac{1}{3} F[-A] A \\
A & \rightarrow \frac{1}{3} F[+A][-A]
\end{align*}
\]
Lindenmayer System

- **Stochastic system** – we can have many rules, with the same left-hand side.
- Each rule has a probability.
- The sum of the probabilities of all the rules, with the same left-hand side, **has to be 1**.

\[
\begin{align*}
A & \rightarrow \frac{1}{3} F[+A]A \\
A & \rightarrow \frac{1}{3} F[-A]A \\
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\end{align*}
\]
Lindenmayer System

- Rigorous way to specify a mechanism for a **self-similar** structure generation.
Lindenmayer System

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recursive
Lindenmayer System

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- Rigorous way to specify a mechanism for a self-similar structure generation.
- Lot of research and different possibilities.
Lindenmayer System

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- Lot of research and different possibilities.
  http://algorithmicbotany.org/papers/abop/abop.pdf
Lindenmayer System

- Rigorous way to specify a mechanism for a **self-similar** structure generation.
- Lot of research and different possibilities.
- Try out 2D online:  
  [http://www.kevs3d.co.uk/dev/lsystems/](http://www.kevs3d.co.uk/dev/lsystems/)
Lindenmayer System

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- Questions?
Particle System

- Used for different effects
  - Fire, fluid, wind, smoke
  - Precipitation (rain, snow)
  - Groups of objects with behaviour (birds, NPC-s)

This you did in the Soft Particle Chopper.
Particle System

- Particles can have a transparency that varies over time.
Particle System

- Particles can have a transparency that varies over time.
- Particles can be generated from an object pool.
  - If a particle dies, return it to the object pool.
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- Particle can be 1 pixel in size, or have an image.
Particle System

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- Particles can be generated from an object pool.
  - If a particle dies, return it to the object pool.
- Particle can be 1 pixel in size, or have an image.
- Particle system has an emitter of particles.

Emitter can also be a line, a surface, a volume etc.
Boids Algorithm

• Used to model flocking (eg of birds).
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- Each particle follows a set of rules:
  - **Cohesion** – Move towards the center of mass.
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- Each particle follows a set of rules:
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  - **Separation** – Keep distance from other particles.
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Boids Algorithm

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- Each particle follows a set of rules:
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  - **Separation** – Keep distance from other particles.
  - **Alignment** – Follow the average direction.
- There can be other rules.
Particle Systems

- Blender has particle systems

- Example of scar generation via particles: https://www.youtube.com/watch?v=e3FpG3CFIfQ
What was new for you today?

What more would you like to know?

Next time: Ray Casting, Ray Tracing, Space Partitioning, BVH