What is procedural generation?

**Procedural generation** is a method of creating data (content) algorithmically as opposed to manually.

**Deterministic**: same inputs → same output.
Early games

Pitfall 1982 - initially released for Atari 2600

128 Bytes of RAM
4K Byte ROM cartridge

More info: https://www.youtube.com/watch?v=tfAnxaWiSeE
Early games

Pitfall 1982

More info: https://www.youtube.com/watch?v=tfAnxaWiSeE
Early games

Rogue 1980
What can be generated procedurally?

1. Game map
2. ...
We will cover following things:

1. Content (items, weapons, characters, animals).
2. Maps and puzzles
3. Procedural geometry
4. Noises
Procedural game content

Typical procedural generation system is made of:
1. **Randomizer** - modifies values using some random input
2. **Constraint system** - sets constraints to the randomizer to make the output logically correct or visually appealing.

Procedural items

Usually combinations of pre-made objects

Borderlands and Fallout 4 both create weapons procedurally

https://borderlands.fandom.com/wiki/Gun_Component_Charts
Procedural characters

Combining objects and textures in Dwarf Block
Procedural characters

Creatures (Spore and No Man Sky)
Procedural characters

**Metaball** - an n-dimensional distance function. Thresholding this value defines a solid volume.

\[ \sum_{i=0}^{m} \text{metaball}_i(x, y, z) \leq \text{threshold} \]

The Marching cubes algorithm allows to turn a scalar field into geometry.
Procedural characters

Many RPG games allow character customizations.
Procedural characters

My implementation of character creation / customization:
https://drive.google.com/open?id=0B232TQYJs91cbTFSOE1WYk56Qzw
Procedural characters

How it was done

Each slider has painted UV texture:

- Green - vertex is moved along normal
- Blue - vertex is moved in y-direction.
The Sims 4 character generation

Technical talk: https://www.youtube.com/watch?v=s7R_HHxCokU
Procedural level design

Level generation:

- Map
- Puzzle
Procedural level layout

Procedural mazes:
http://www.nullpointer.co.uk/content/research-info-in-ruins/
Drunkard walk algorithm

http://www.youtube.com/watch?v=I74I_MhZlK8&t=1m0s
Procedural level layout

**Carcassonne** a city building board game where players are placing map tiles.
Waveform Collapse

Bad North

Townscaper
Waveform Collapse

Generator example: [http://oskarstalberg.com/game/wave/wave.html](http://oskarstalberg.com/game/wave/wave.html)
Procedural level layout

Spelunky platformer game → http://tinysubversions.com/spelunkyGen/
Procedural level layout

World Remade (a game I was making) → Connect the dots puzzle
Procedural level layout

*World Remade* (a game I was making) → *Connect the dots puzzle*
Procedural map generation

https://watabou.itch.io/medieval-fantasy-city-generator
Procedural map generation

https://azgaar.github.io/Fantasy-Map-Generator/
Procedural map generation

Voronoi diagram - a partition of a plane into regions.
- Generate seed points (black dots).
- For each seed there is a corresponding region.
- Each point in the plane belongs to the region which seed point is the closest.

http://www-cs-students.stanford.edu/~amitp/game-programming/polygon-map-generation/
Procedural Galaxies

Procedural star systems

Layer-Based Procedural Generation

https://www.youtube.com/watch?v=GJWuVwZO98s
Procedural level structure

Generating puzzles

Grammar based approach

Pros:
- Can be used in real time

Cons:
- Some puzzles can be too easy / hard
Generating puzzles

Generate and solve approach:
- **Generator** - generates random rooms
- **Solver** - evaluates the puzzle

<table>
<thead>
<tr>
<th></th>
<th>9 moves</th>
<th>11 moves</th>
<th>12 moves</th>
<th>21 moves</th>
<th>10 moves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room</td>
<td></td>
<td></td>
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**Cons:**
- Doesn’t work in real time
- Needs manual verification in the end

**Pros:**
- Can be applied to any kind of puzzle
- Can generate puzzles with brilliant ideas

https://www.youtube.com/watch?v=RLcMvCS4-gY
Procedural geometry

Making or altering a 3D model.
Procedural geometry

1. Generative functions like Superformula (Patented)
Procedural geometry

2. Lindenmayer system (L-system)
Procedural geometry

3. **Voronoi diagram** - cut 3D meshes or create artistic structures
Noise

4. Noise - mathematical function → noise(coordinate) = value
Noises

1. White Noise
Noises

1. Value noise
Noises

1. Perlin noise

Simplex noise produces similar results, but it is a little bit faster to calculate.
Noises

1. **Voronoï noise** - uses voronoï pattern, cell points are scattered uniformly
Working with noises

Example of heightmap generated in GPU using noises:
Working with noises

Another example:
Working with noises

This is how it’s done

\[ \text{simplex}(p) \rightarrow \text{abs(simplex}(p)) \]

billow
Working with noises

This is how it’s done

$$\text{abs} (\text{simplex}(p))$$ → $$1 - (\text{abs} (\text{simplex}(p)))$$

billow → ridged
Working with noises

This is how it’s done
Working with noises

This is how it’s done

Use simplex noise to distort the coordinates
Working with noises

This is how it’s done

Use ridged noise for distortion
Working with noises

This is how it’s done

Based on rigged noise

Based on billow noise
Working with noises

What about Voronoi?
Advanced landscapes

For more realistic terrains you also have to simulate:

thermal / hydraulic / wind erosion

Example: [https://experiments.withgoogle.com/craftscape](https://experiments.withgoogle.com/craftscape)
Procedural textures

Which one of these textures is procedurally generated?

A

B
Procedural textures

Many steps forward

https://i.pinimg.com/originals/09/b7/01/09b701daa24f5193086da0ecd52c7a0a.jpg
Procedural tools

Substance-designer: https://www.allegorithmic.com/products/substance-designer
Blastronaut procedural generation

World is divided into chunks, each chunk is processed twice.

Layer 1:
- Calculates solid blocks
- Calculates filled background blocks

Layer 2:
- Adds resources
- Selects block variation
- Selects background block variation

https://store.steampowered.com/app/1392650/BLASTRONAUT/
Lecture task

Find an example of procedural generation in game:

- Add a picture
- Describe how it is done
- Add a link where you found the explanation (if possible)