Procedural Generation

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What is procedural generation?
Procedural Generation

It is the algorithmic creation of data
Procedural Generation

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Almost anything can be created procedurally
Procedural generation vs manual creation

Depends on the objectives
Procedural generation vs manual creation

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When used in the right circumstances it can save

- Memory
Procedural generation vs manual creation

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When used in the right circumstances it can save

- Memory
- Disk space
Procedural generation vs manual creation

Depends on the objectives

When used in the right circumstances it can save

- Memory
- Disk space
- Design and development cost
Apparent randomness is a key ingredient in procedural generation
Noise

What is noise?
Noise

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Pseudorandom vs truly random
The issue with white noise

Nature is smooth
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Two points close to each other on the surface of an object will usually look similar. Points on the surface far from each other may look different.
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What we want is gradual local changes, but large global changes
The issue with white noise

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That's not how random number generators usually work
The issue with white noise
This is better
Value Noise

A simple type of noise which can be useful for a variety of applications, e.g. creating textures
Value noise 2D example

1. Generate random values in one dimension
Value noise 2D example

2. Generate random values in the other dimension as well
Value noise 2D example

3. Define a grid to use for interpolation
Value noise 2D example

4. Zoom in and interpolate (smoothstep function can give nice results)
Value noise 2D example

5. Stack multiple layers on top of each other with varying zoom levels and weights
Use case study: Generating the Milky Way galaxy in Elite Dangerous
History of Elite

4 Elite games have been released over the years
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Both the older and the newer games feature a significant amount of procedural generation, especially in terms of game world generation
Elite (1984)

Wireframe graphics with hidden line removal
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8 procedurally generated galaxies (developers wanted to go for $2^{48}$ galaxies, but publisher refused)
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256 star systems per galaxy
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One planet and space station per system
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Some issues with procedural star system and planet generation
Frontier: Elite II (1993)

Procedurally generated and varied star systems

Newtonian physics
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Procedurally generated and varied star systems

Newtonian physics

Seamless landing on planets

Procedural texturing (snow, plants, planet surfaces, etc.)

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Gouraud shading
Elite: Dangerous (2014)

Released 30 years after the original
Elite: Dangerous (2014)

Set in the 34th century when humanity has colonized other star systems in the galaxy
Setting of Elite: Dangerous

The entire 1:1 scale Milky Way galaxy
Setting of Elite: Dangerous

The entire 1:1 scale Milky Way galaxy

400 billion star systems spread across different structures in the galaxy
Setting of Elite: Dangerous

The entire 1:1 scale Milky Way galaxy

400 billion star systems spread across different structures in the galaxy

Nebulae, dust, all kinds of other objects
Mass distribution in the galaxy

Astronomers have constructed a top-down view of the galaxy’s luminosity
Mass distribution in the galaxy

Astronomers have constructed a top-down view of the galaxy’s luminosity

Mass distribution is based on luminosity distribution
Mass distribution in the galaxy

Astronomers have constructed a top-down (2D) view of the galaxy’s luminosity.

Mass distribution is derived from luminosity distribution.

That distribution is given a third dimension.
Sectors

Galaxy is divided into sectors (cubes) based on octrees (8 children per parent)
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8 layers of these cubes - linear dimensions from 10ly to 1280ly
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Sectors have attributes like mass, metallicity, type and age
Generating the primary star of a system

Lots of different attributes - e.g. metallicity, magnitude, position in the sector, radius, initial and final mass, existence of a planetary nebula, surface temperature, classification
Star color

Black body radiation

Temperatures

- O: > 30,000 K
- B: 10,000 - 30,000 K
- A: 7,500 - 10,000 K
- F: 6,000 - 7,500 K
- G: 5,200 - 6,000 K
- K: 3,700 - 5,200 K
- M: 2,400 - 3,700 K
Evolution of a star

Different stages of a star’s life are simulated - proto-star, main sequence, giant, death (stellar remnants)

Star evolution depends on the initial mass of the star
Star system generation

Generate a system

- Get the age of the system
- Get life cycle limits from mass

Calculate star's life stage

- Alter mass
- Calculate radius
- Calculate temperature
- Calculate absolute magnitude

Choose a name

Classify star

Calculate color
Creating the rest of the star system

Generate the main bodies (stars) by simulating collapse of gas
Creating the rest of the star system

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Generate a protoplanetary disk from the remaining mass (elemental distribution)
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Simulate clumping in stable orbits around the star
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Simulate clumping in stable orbits around the star

Step through time
Stepping through time

A lot of physics simulation going on:

- Gravitational clumping
Stepping through time

A lot of physics simulation going on:

- Gravitational clumping
- Gravitational heating
Stepping through time

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- Gravitational heating
- Moon / ring formation around clumps of mass
Stepping through time

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- Moon / ring formation around clumps of mass
- Mass erosion from radiation pressure
Stepping through time

A lot of physics simulation going on:

- Gravitational clumping
- Gravitational heating
- Moon / ring formation around clumps of mass
- Mass erosion from radiation pressure
- Special events
Stepping through time

Identifying the resulting clumps of mass:

- Gas giant vs brown dwarf vs star
Stepping through time

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- Chemical composition - icy, rocky, metallic planets
Stepping through time

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- Tidal heating, tidal locking
Stepping through time

Identifying the resulting clumps of mass:

- Gas giant vs brown dwarf vs star
- Chemical composition - icy, rocky, metallic planets
- Tidal heating, tidal locking
- Tectonics, volcanism, atmosphere
Unique ID of an astronomical object

64 bit number

00000000000000 00000000000000 00000000000000 000 0000000000 00000000000

14, 13 and 14 bits for the sector X, Y and Z coordinates respectively
3 bits for the layer of the cube (8 layers)
11 bits for the system ID within the sector (up to 2048 systems per sector)
9 bits for the body ID within the system (up to 512 bodies per system)
Nebulae

Based on 3D volume textures for density
Nebulae

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1D RGB texture to define density to light absorption relationship
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Based on 3D volume textures for density

1D RGB texture to define density to light absorption relationship

Step through while subtracting colors
Planet surfaces

Non-landable planets - perfect spheres with normal-mapped surfaces
Planet surfaces

Landable planets - start out as cubes, subdivision is used to enhance resolution the closer the player gets, terrain is based on layered noise
Planet surfaces
Combining procedurally generated with real

The galaxy in Elite: Dangerous also contains thousands of real stars, nebulae and other objects from stellar catalogs.
Galaxy map

When moving around in the in-game galaxy map, star system information is generated and displayed on the fly around the focused area.
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The radius of generation in the galaxy map is dependent on the star density of the focused area.
Thank you!