Game Technology

Lecture 10 – 09.01.2018
Large Game Worlds

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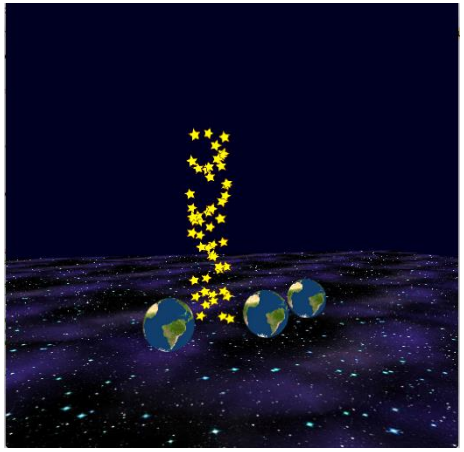
Best of …



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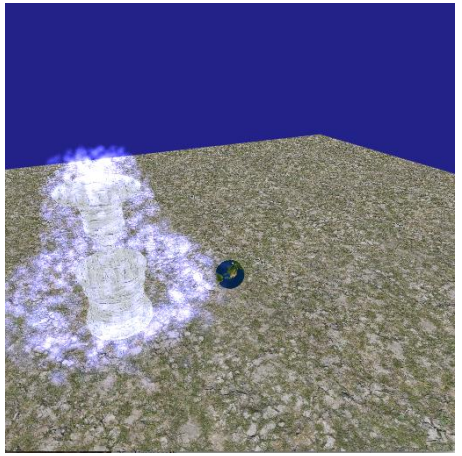
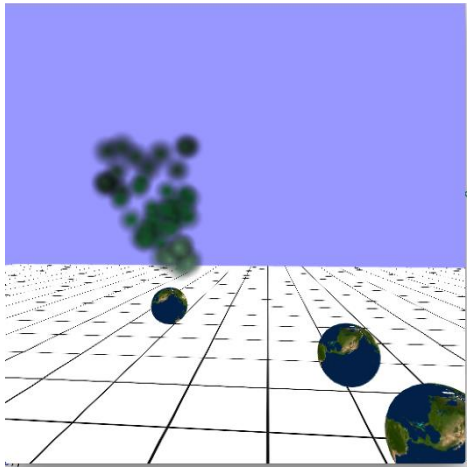


K^3

pathToExam



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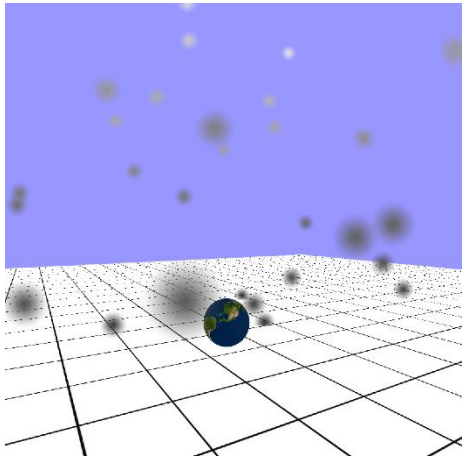


STEALTH-COM

Today‘s Games

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Typical hardware requirements

- 8 GiB RAM
- 2 GiB Video-RAM
- 50 GiB on disk

All SNES games ever (including all language versions)

- ~3000 games
- ~4.5 GiB

Today‘s Data

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One uncompressed texture

- 4096 x 4096 x 4 Bytes = 67108864 Bytes = 64 MiB
- 2 GiB / 64 MiB = 32
- Physically based rendering – typically 4 textures

Killzone 4 CPU data

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Sound	553 MB
Havok Scratch	350 MB
Game Heap	318 MB
Various Assets, Entities, etc.	143 MB
Animation	75 MB
Executable + Stack	74 MB
LUA Script	6 MB
Particle Buffer	6 MB
AI Data	6 MB
Physics Meshes	5 MB
Total	**1,536 MB**

Killzone 4 GPU data

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Non-Steaming Textures	1,321 MB
Render Targets	800 MB
Streaming Pool (1.6 GB of streaming data)	572 MB
Meshes	315 MB
CUE Heap (49x)	32 MB
ES-GS Buffer	16 MB
GS-VS Buffer	16 MB
Total	**3,072 MB**

PNG and JPEG

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PNG

- Lossless
- Compression highly dependent on image content

JPEG

- Lossy
- Generally strong compression

Both

- Slow decompression
  - Can slow down loading times
- Not possible to access a single pixel while compressed
  - Not usable for image computations aka not usable as a texture format

Texture Compression

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Many different formats

- S3TC, PVRTC, ASTC,…
- Has to be supported by GPU and Graphics API
- Of course much of it is patented and hard to standardize

Design goals

- High compression
- Low visual degradation
- Efficient single pixel access
  - → What we need during fragment shader execution
  - Constant size of a pixel or a pixel block

Strategies

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2K Texture

- Uncompressed: 4 byte * 2048 * 2048 = 16.77 MB
- DXT1: 2048 * 2048 / 16 * 8 bytes = 2.1 MB
- PNG: ~6 MB (Depends on content and compression details)
- JPEG: ~1 MB (Depends on content and compression details)

Save compressed for GPU (e.g. DXT)

- Quick file load direct into memory
- Fast, simple
- Requires much space

Save in complex format, convert to compressed while loading

- Smaller file sizes (e.g. mobile)
- Longer loading times

Advanced Strategies

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Save GPU format in lightly compressed format

- lz4, snappy,…
- Speeds up loading times (saved load time > decompression time)

Very advanced strategies

- Save in a compression format optimized for compressing gpu formats
  - crunch
- Uncompress on GPU
  - „GPU-decodable supercompressed textures“

Possible compression strategies

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Less than 8 bits per color might be ok

The eye‘s color resolution is less then its intensity resolution

Neighboring pixels likely have similar colors

S3TC

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Originally developed by S3 Graphics for the Savage 3D graphics accelerator

Also known as DXTn/DXTC (DirectX names)

De-facto standard for OpenGL implementations

Series of 5 algorithms that handle compression differently

- Mainly depending on the way alpha is treated

Block-based compression algorithm

- Input always 4x4 pixel block
- Output 64 or 128 bits

DXT1

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Input: 4x4 block

Output

- c0: Color encoded with r=5,g=6,b=5 bits (16 bits)
- c1: Color encoded with r=5,g=6,b=5 bits (16 bits)
- 4x4 lookup table with 2 bits per pixel (32 bits)

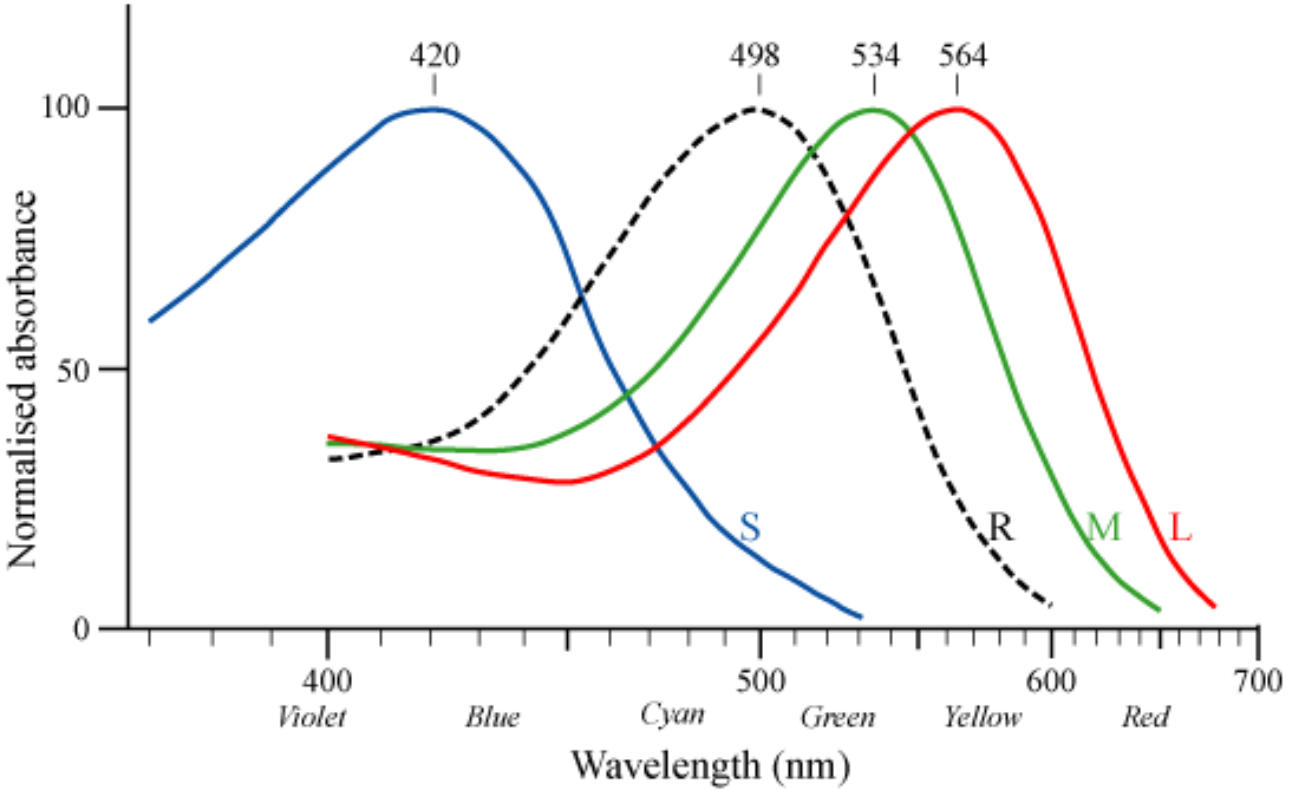
Intermediate values

- if (c0 > c1)
  - c2 = 2/3 c0 + 1/3 c1
  - c3 = 1/3 c0 + 2/3 c2
- if (c0 <= c1)
  - c2 = 1/2 c0 + 1/2 c1
  - c3 = transparent black

Why green?

Dotted line: Absorption of cones, Colored lines: Absorption of rods

Overlap in green area → human eyes can better differentiate variations of green than other colors (555/15bits would not align)



https://commons.wikimedia.org/wiki/File:Cone-response.png

DXT1 example

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Input block

4x4, 32 bits per pixel

DXT1 example

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Choose two colors

Here: Max distance

Encode using R5G6B5

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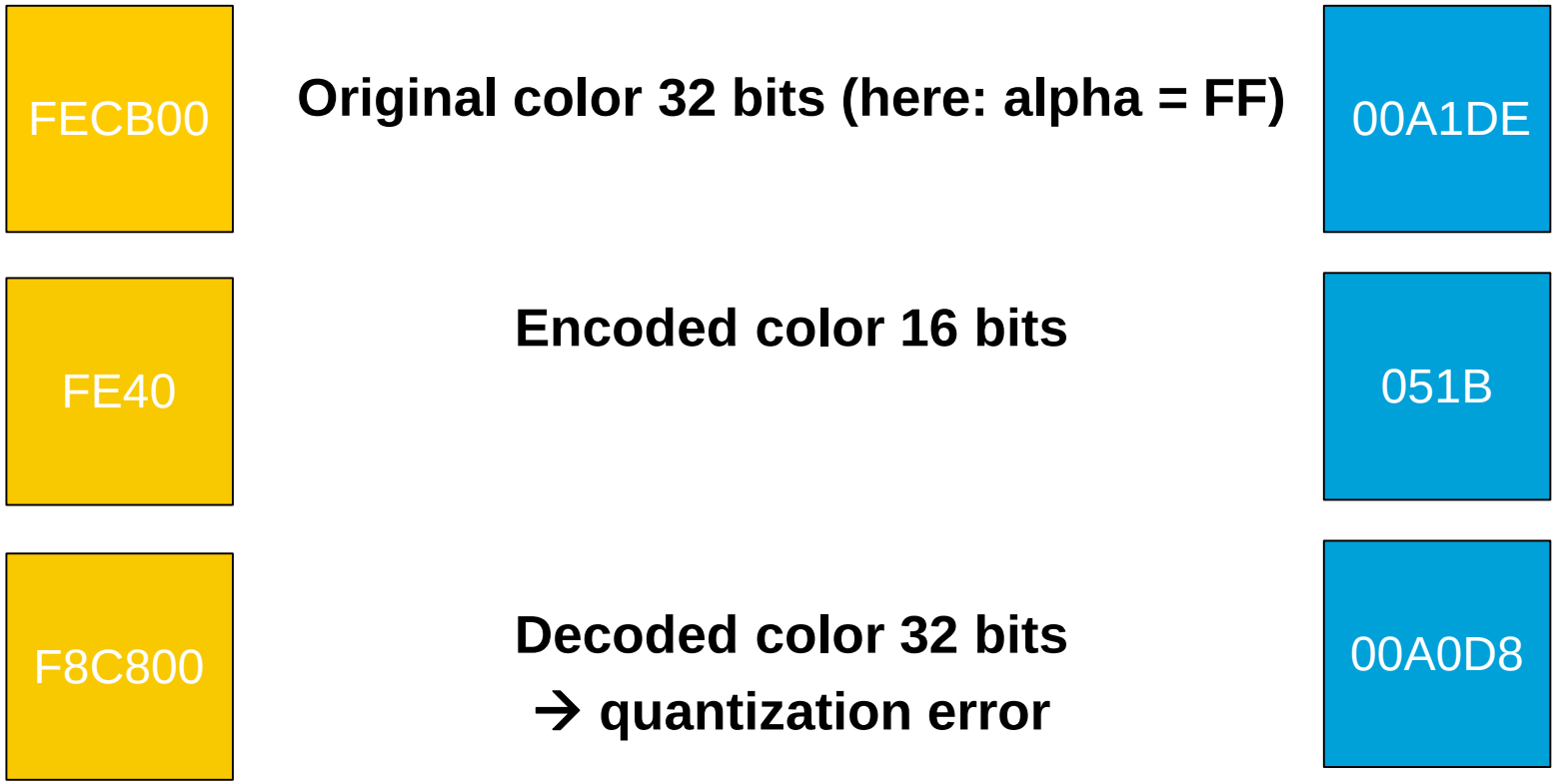

Build the palette

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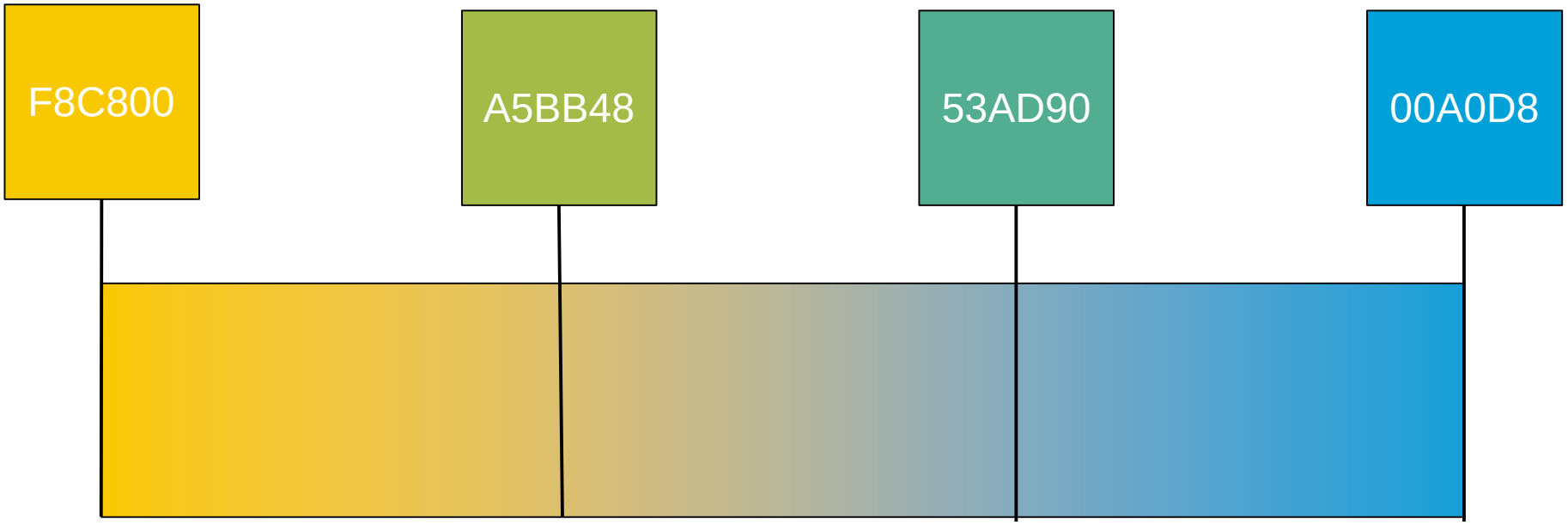
Choose c2 and c3 to lie at 1/3 and 2/3 between c0 and c1



Choosing endpoints

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Determines the quality of the result

Can apply several strategies

- Local: Only within our block
- Global: Optimize over the image

Principal Component Analysis

"Bounding Box", choose minimum and maximum values along 3 axes

Find the closest colors

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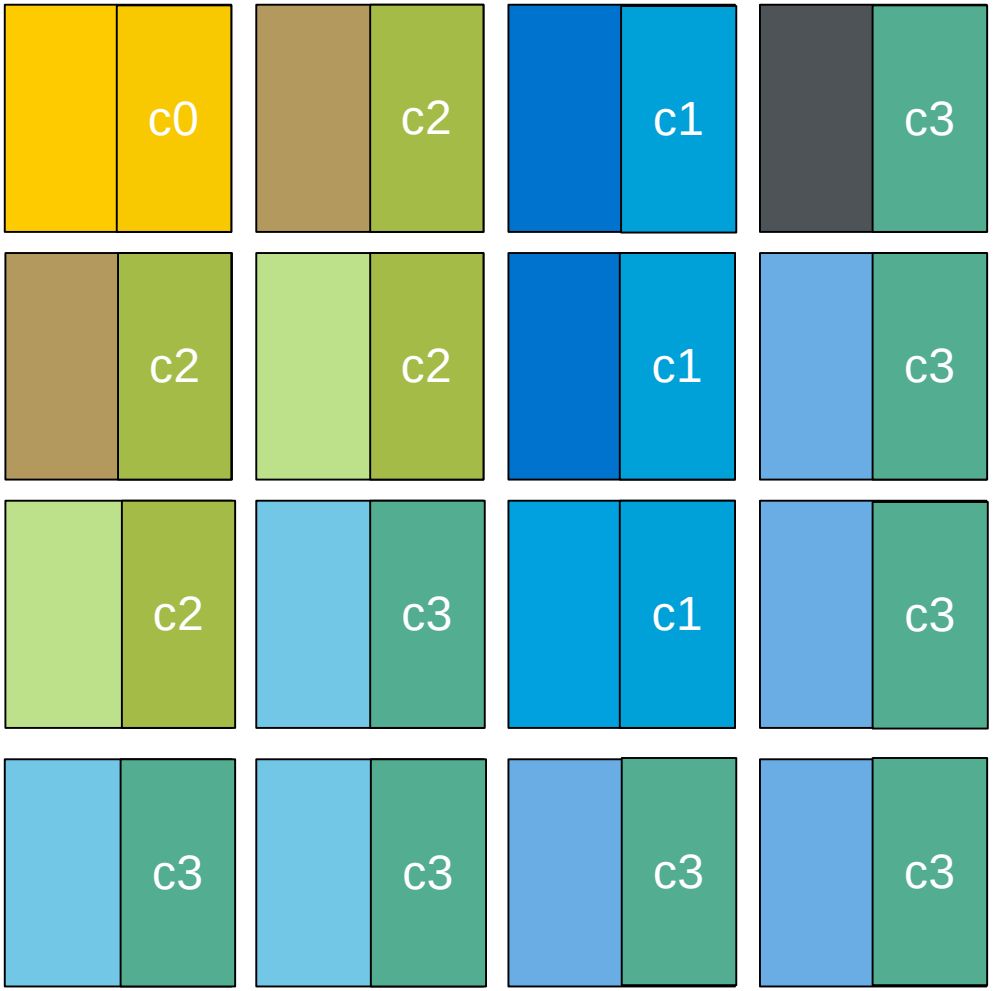
Compare to colors in the block to c0 to c3



Find the closest colors

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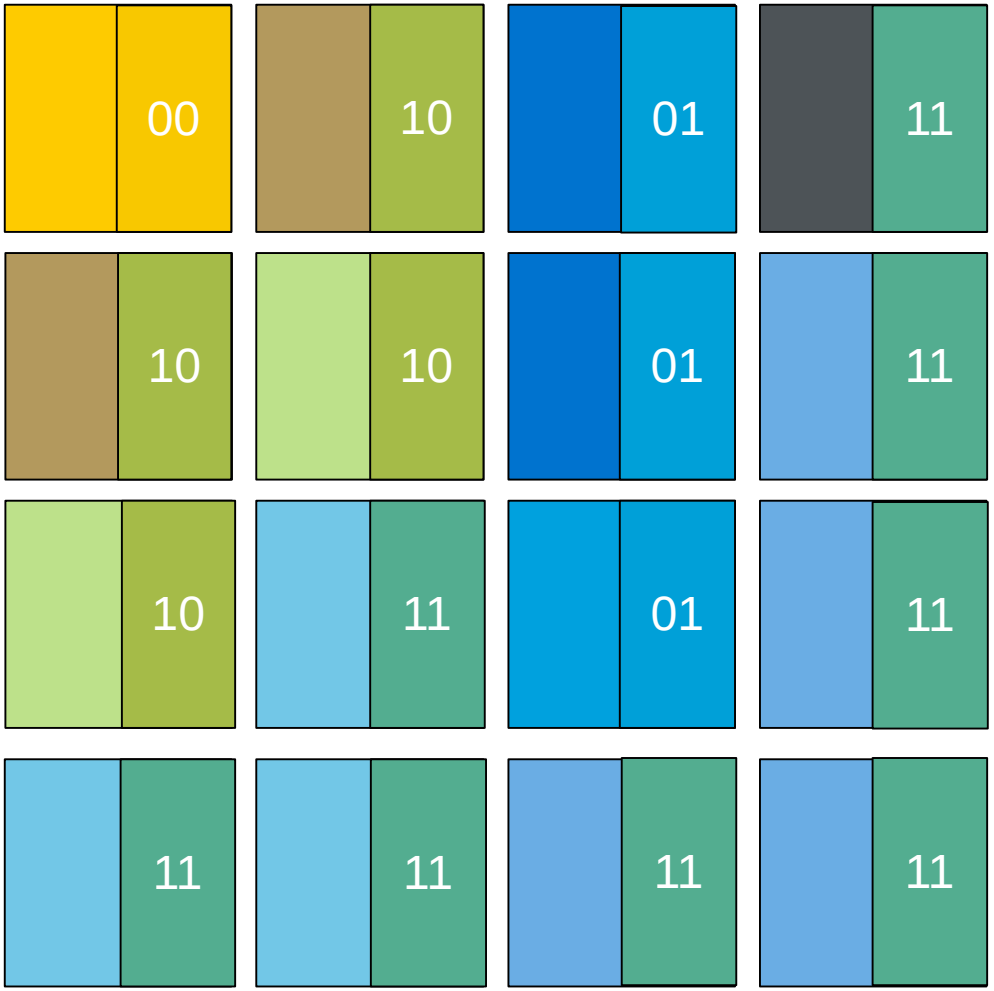
Color index can be encoded in 2 bits



Compressed block

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c0 = 0xFE40; // 565 – 16 bits

c1 = 0x051B; // 565 – 16 bits

LookupTable =

{00, 10, 01, 11, 10, 10, 01, 11, 10, 11, 01, 11}; // 16x2 bits = 32 bits

Comparison

DXT1 Examples

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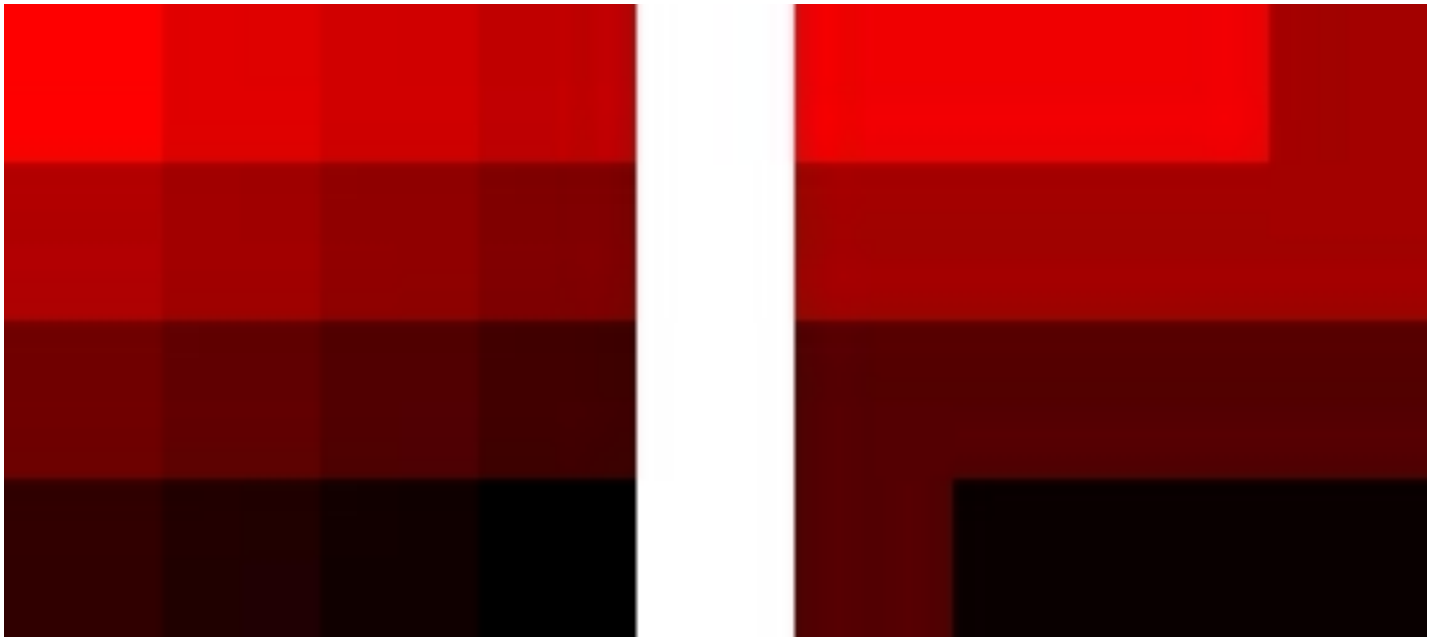
Well suited for similar gradients

→ We only lose accuracy due to quantization



DXT1 Examples

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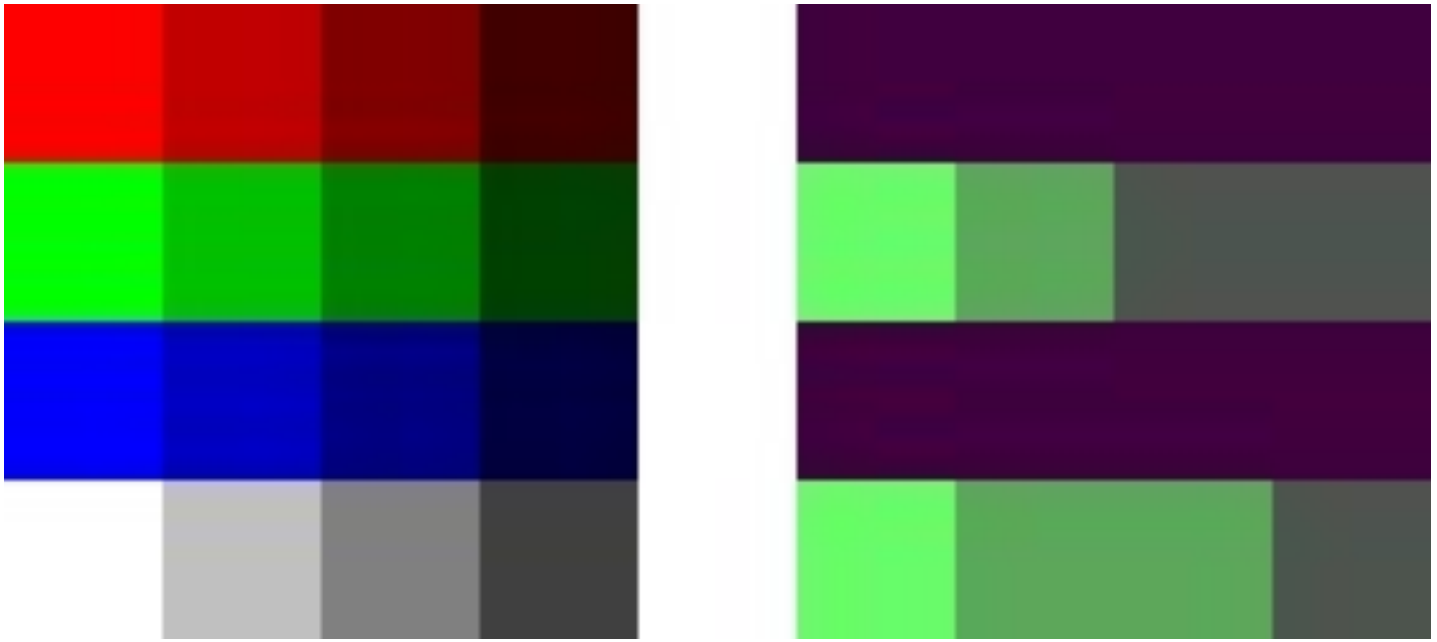
Worst case: Colors not on a gradient

→ We can‘t preserve all colors



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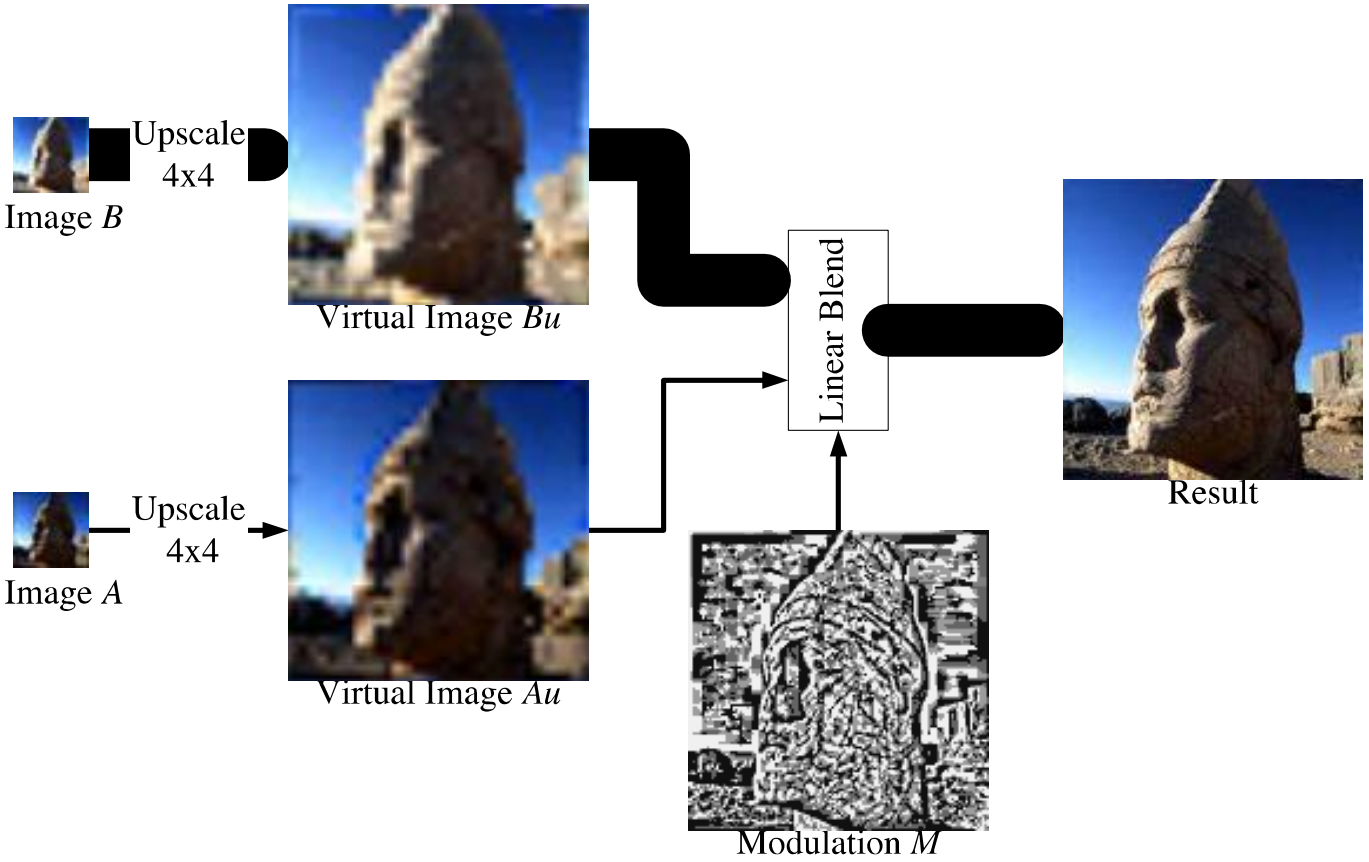
PVRTC

- PowerVR Texture Compression



Normal Maps, Masks, ...

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Compression for images might not be optimal for other textures

- But it might just work
- Swizzling channels can help
- No Alpha used for normal maps
- Some algorithms encode alpha better than other values
  - Move one channel to alpha

3Dc

- $x^2+y^2+z^2=1$
  - $z^2=1-x^2-y^2$
  - One value can be omitted
- Can save normals unnormalized, recover later
- Plus block compression

Manual Compression

Let the artists do the job

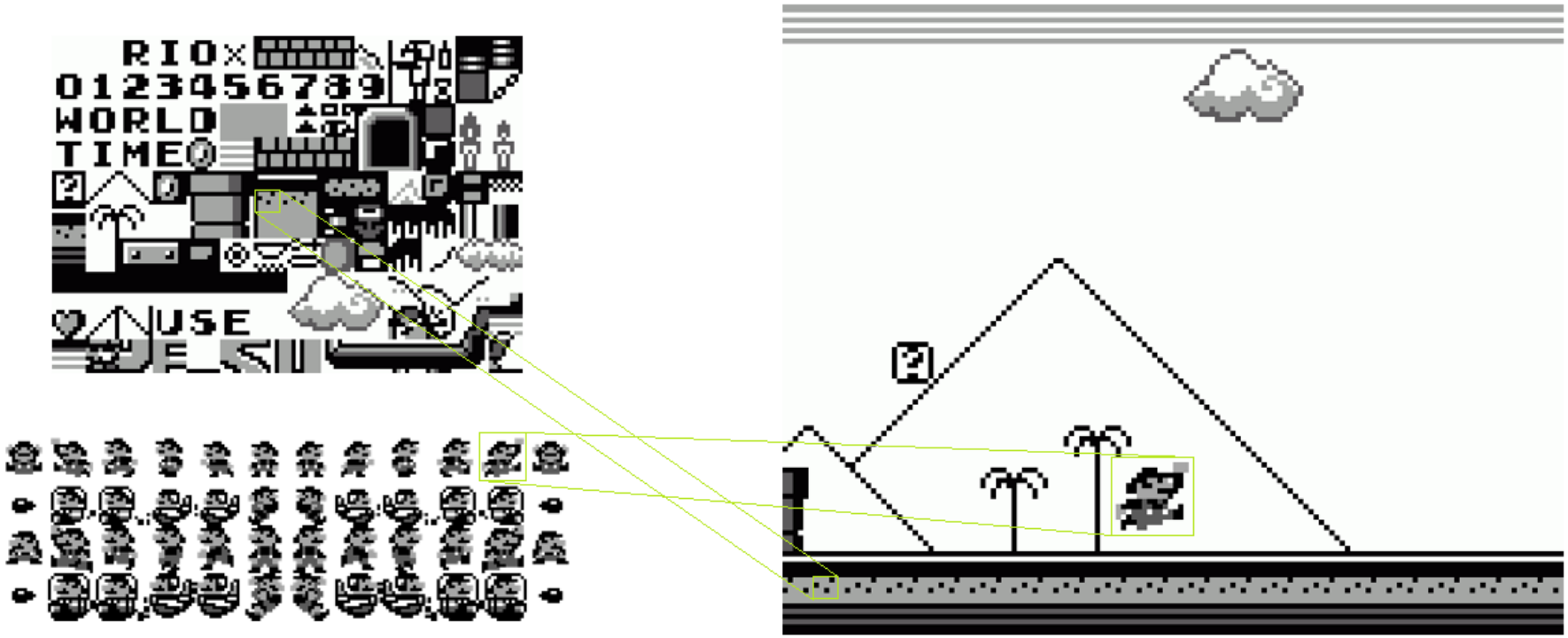
Repeat images over and over

- Nobody might notice it when you do it cleverly

Manual Compression

Uncharted 3, 2011

Tilemaps/Tilesets



Tile Editors

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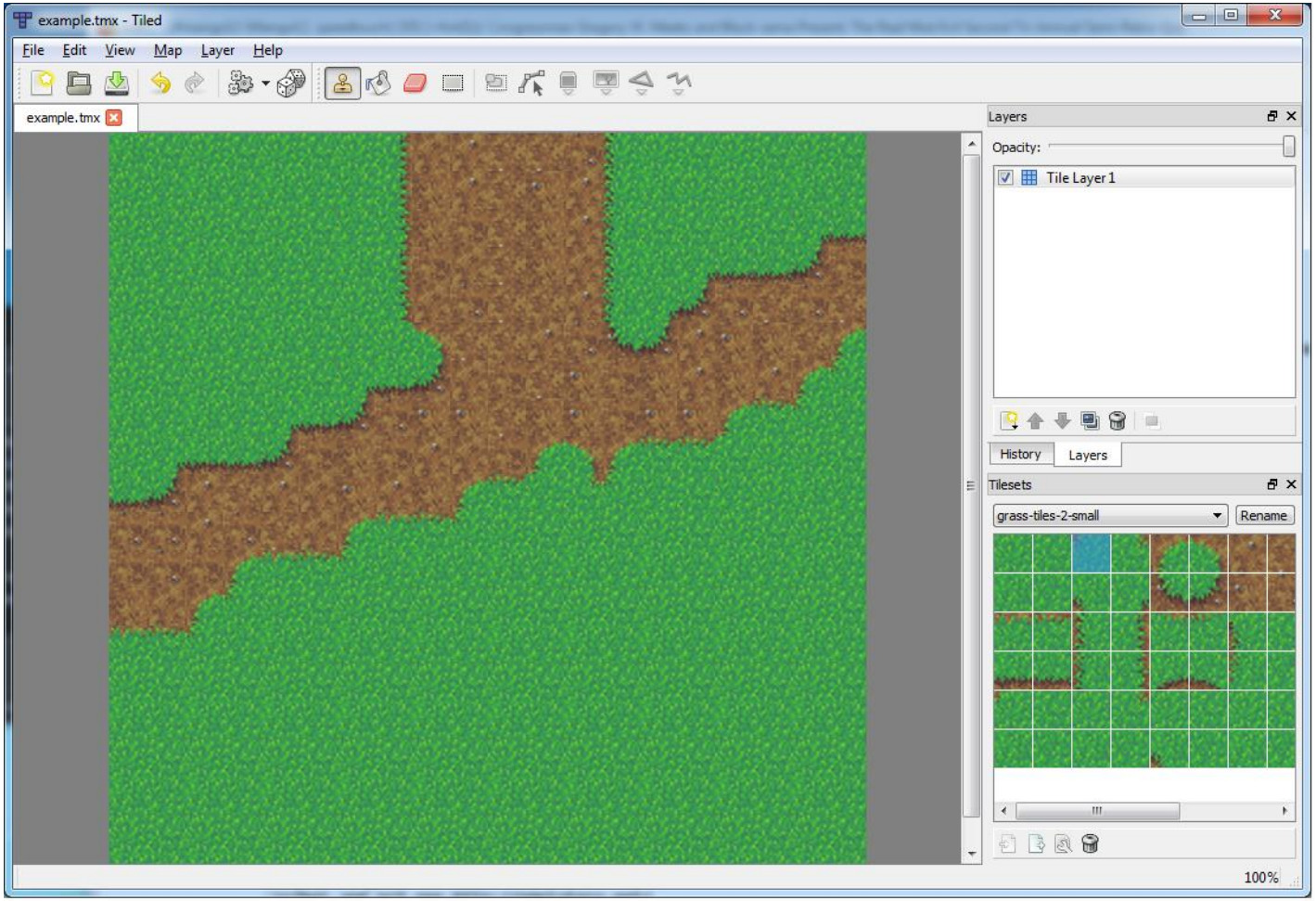

http://www.mapeditor.org/

Pitfall: The Mayan Adventure (1994)

Warcraft 3 (2002)

Tile textures in 3D

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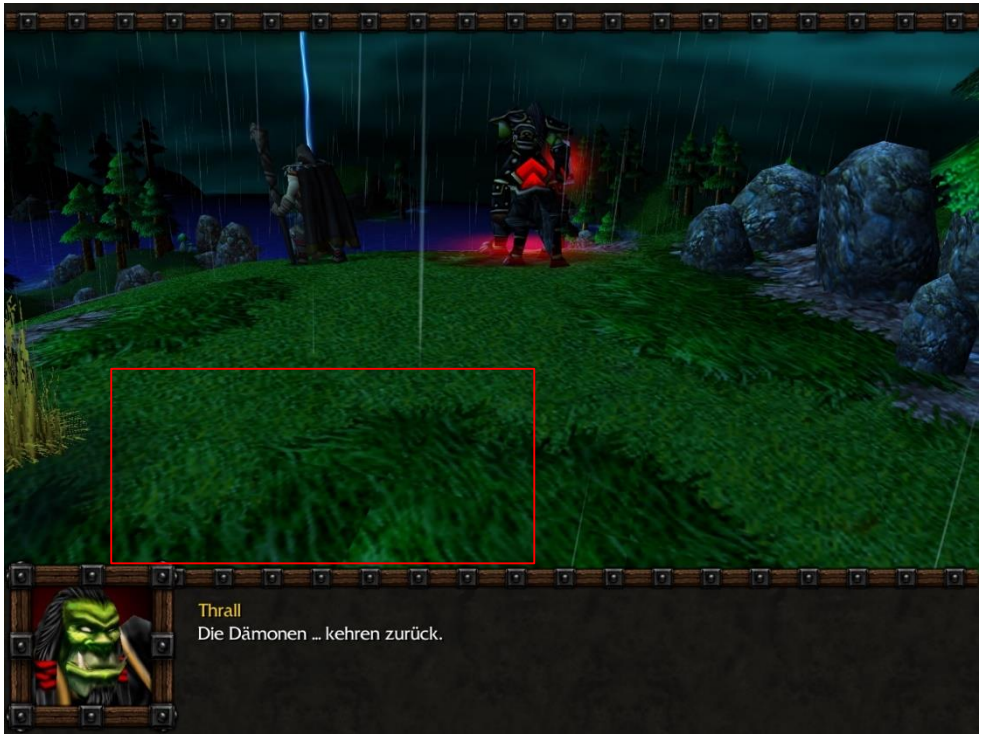
Bilinear Filtering

- Would have to use texels from two tiles at tile boundaries
- Complicated
- Expensive, Rarely used



Multitexturing

Multitexturing

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Multitexturing

Problems

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Performance

- More textures, less performance
- Precalculating which polys actually use more textures can help

Needs good tool support

- Scary communication with artists

Streaming

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Coarse Streaming

- Load and replace complete assets

Fine Grained Streaming

- Load and show/play a single asset bit by bit

Coarse Streaming

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Similar to level of detail systems

- Load big textures for near objects
- Kick out big textures for far away objects
- Maybe blend texture changes in and out

http://www.opensg.org/htdocs/doc-1.8/lod.png

Problems

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Disks are slow and unreliable

- No timing guarantees at all
- Load textures in a second thread, always have an emergency strategy ready (keep super low resolution textures of everything in RAM)

Changing textures at runtime from a helper thread is problematic

- Driver might decide to convert the texture
- Easier on consoles
- Easier with Direct3D 11/12, Vulkan,…

Fine grained texture streaming

Rage (2011)

MegaTextures

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Really huge textures

- Rage supports textures of up to 128000×128000
  - That‘s ~60 GiB

Compression

- Texture is highly compressed on disk
  - Using lossy JPEG like compression

One texture for everything

- Complete world in one texture
- No restrictions for artists
  - But toolsets provide classical multitexturing tricks
  - Artists don‘t manually paint 128000x128000 pixels

MegaTextures Implementation

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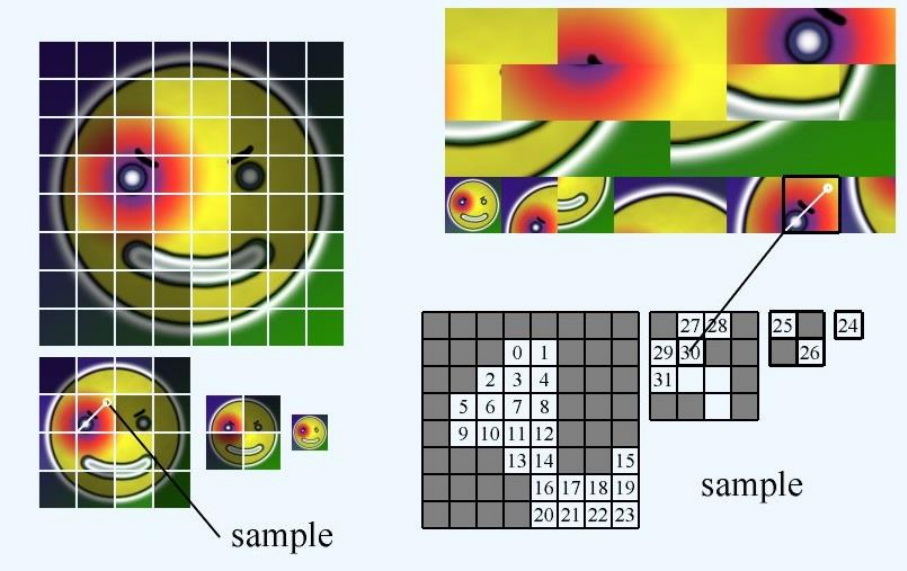
Similar to virtual memory

- Application (= pixel shader) believes that there is a huge, continuous area of memory (= texture) it can work on
- Operating system (= texture manager) provides required memory pages by mapping them



For details, see GDC Talk by Sean Barret: https://www.youtube.com/watch?v=MejJL87yNgI

Level of Detail

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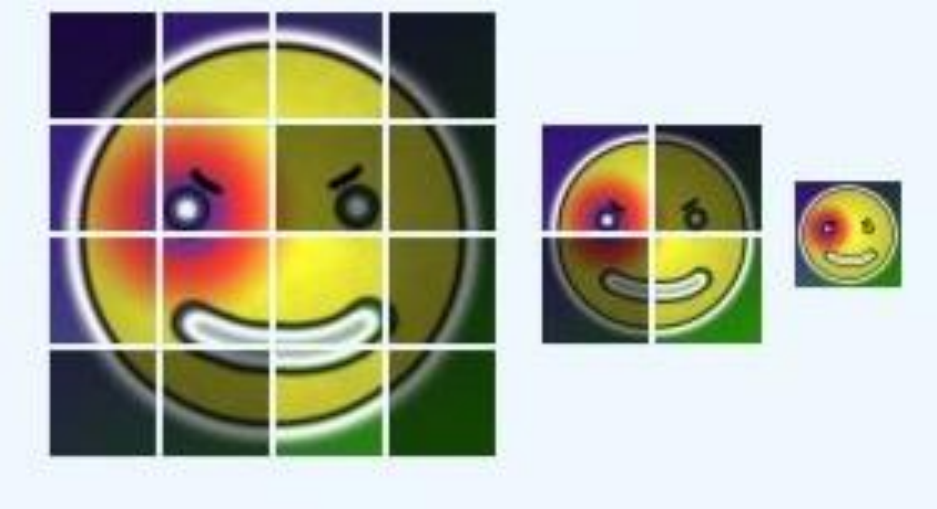
- Similar to mip maps
- We provide different resolutions of the MegaTexture
- Smaller resolution version should encompass everything we need to sample



MegaTextures

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Geometry is split up in tiles

- Engine determines screen size of visible tiles
- Loads texture parts in varying sizes to optimize current view

MegaTextures

https://www.youtube.com/watch?v=YNilHiBpVic

Geometry

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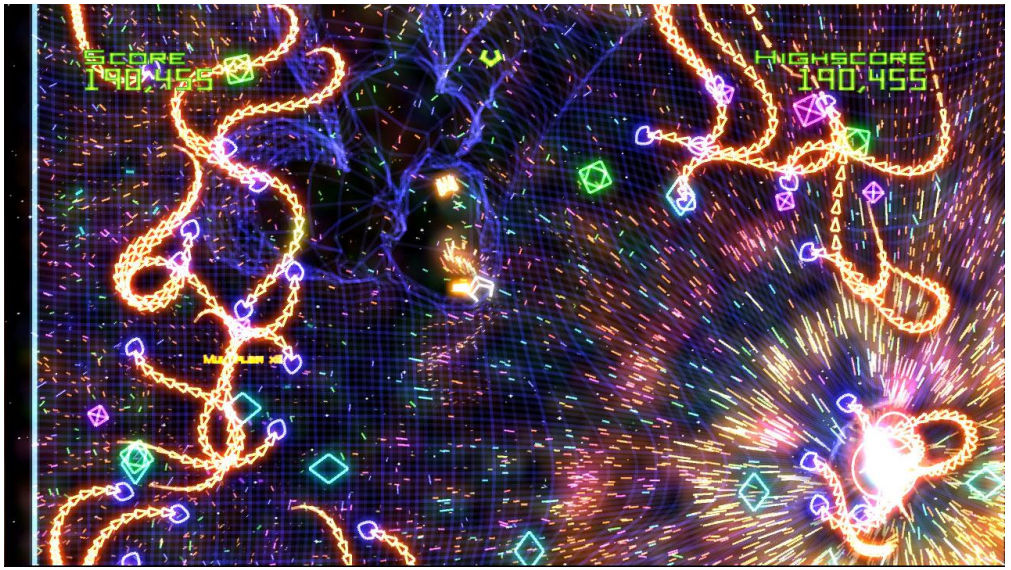
Geometry compression

- Not widely used
- No hardware support
- Animation data mostly small (thanks to skeletal animations)



Geometry Wars, 2003

Normal Maps

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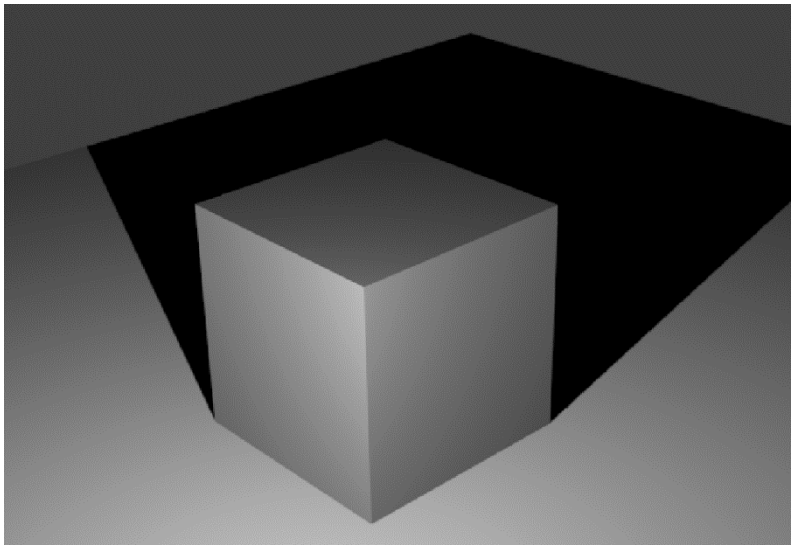
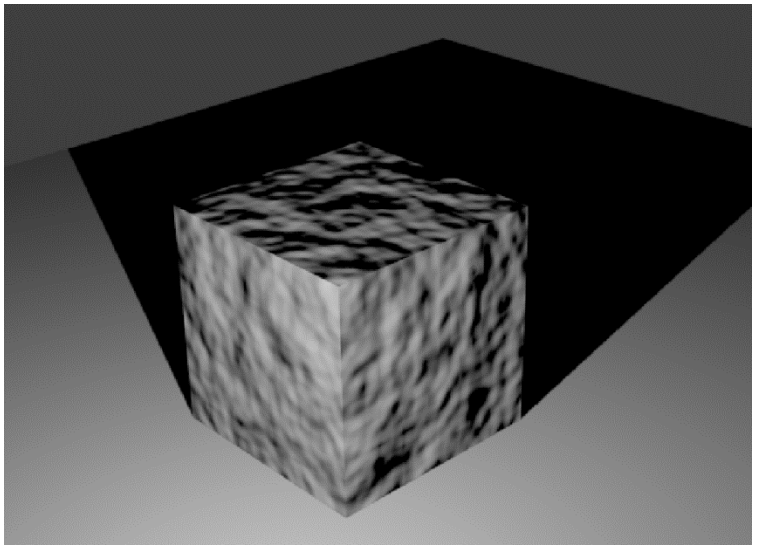
Remove super detailed geometry

Replace with normal maps

- Which is a form of compression by itself
- Plus normals can be compressed further





Coarse Geometry Streaming

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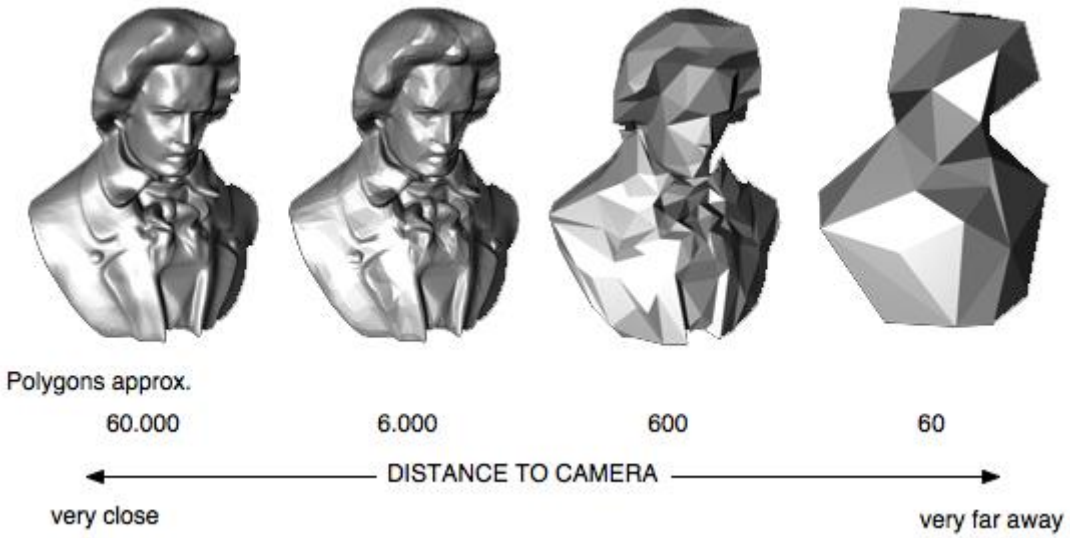
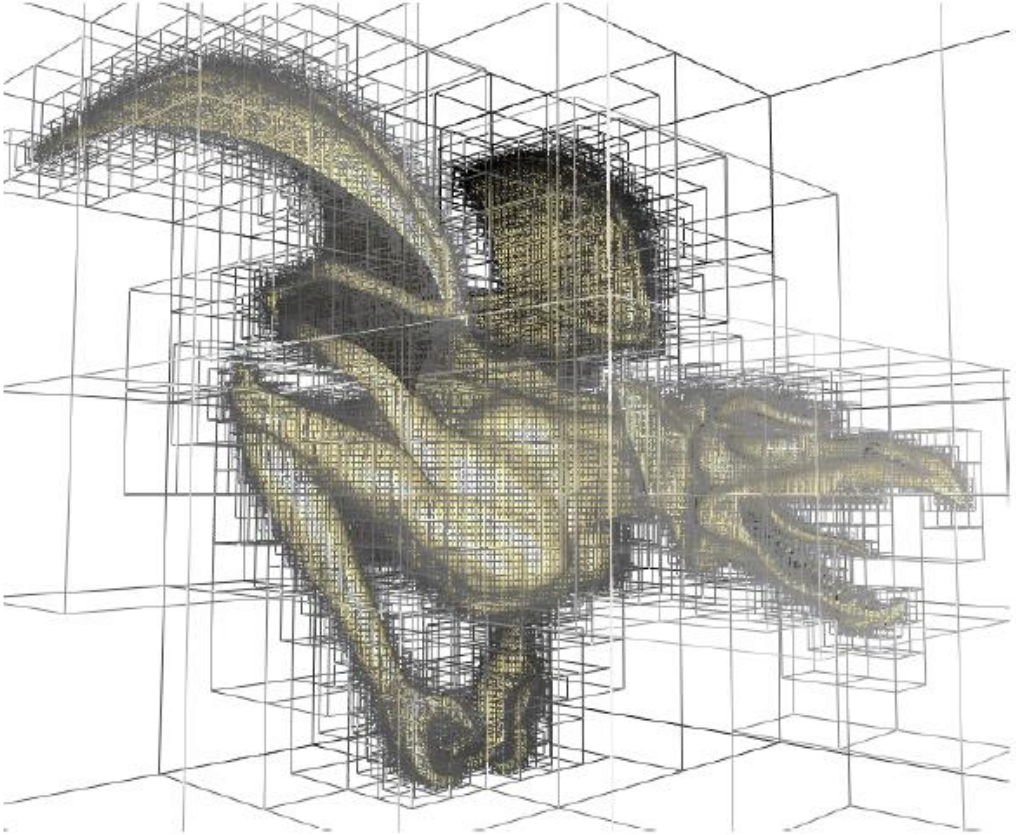
Same strategies as for textures

- Could be directly plugged into a level of detail system



Fine-grained geometry streaming



Height Maps

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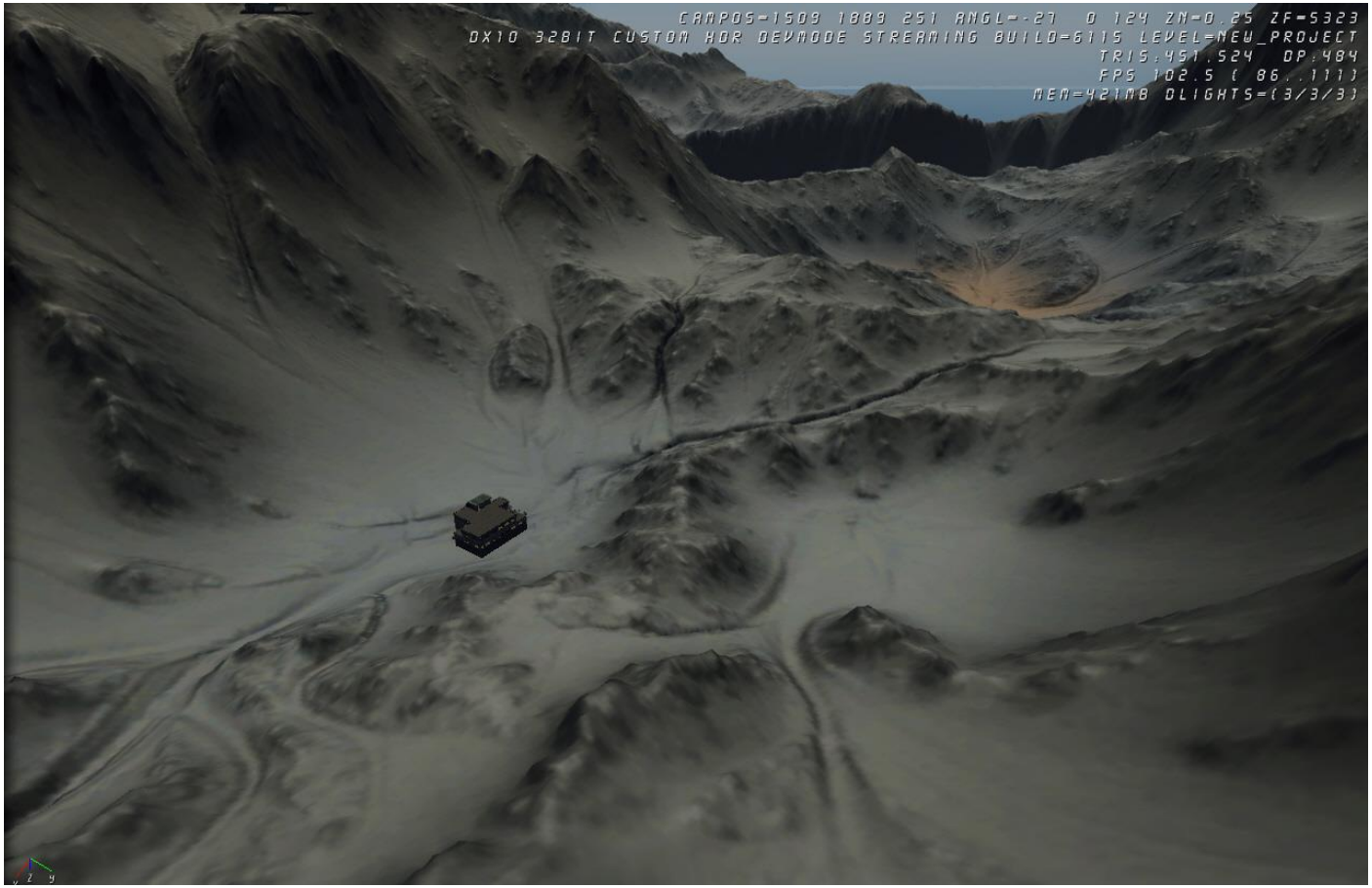
Just Y instead of X/Y/Z



Level Streaming

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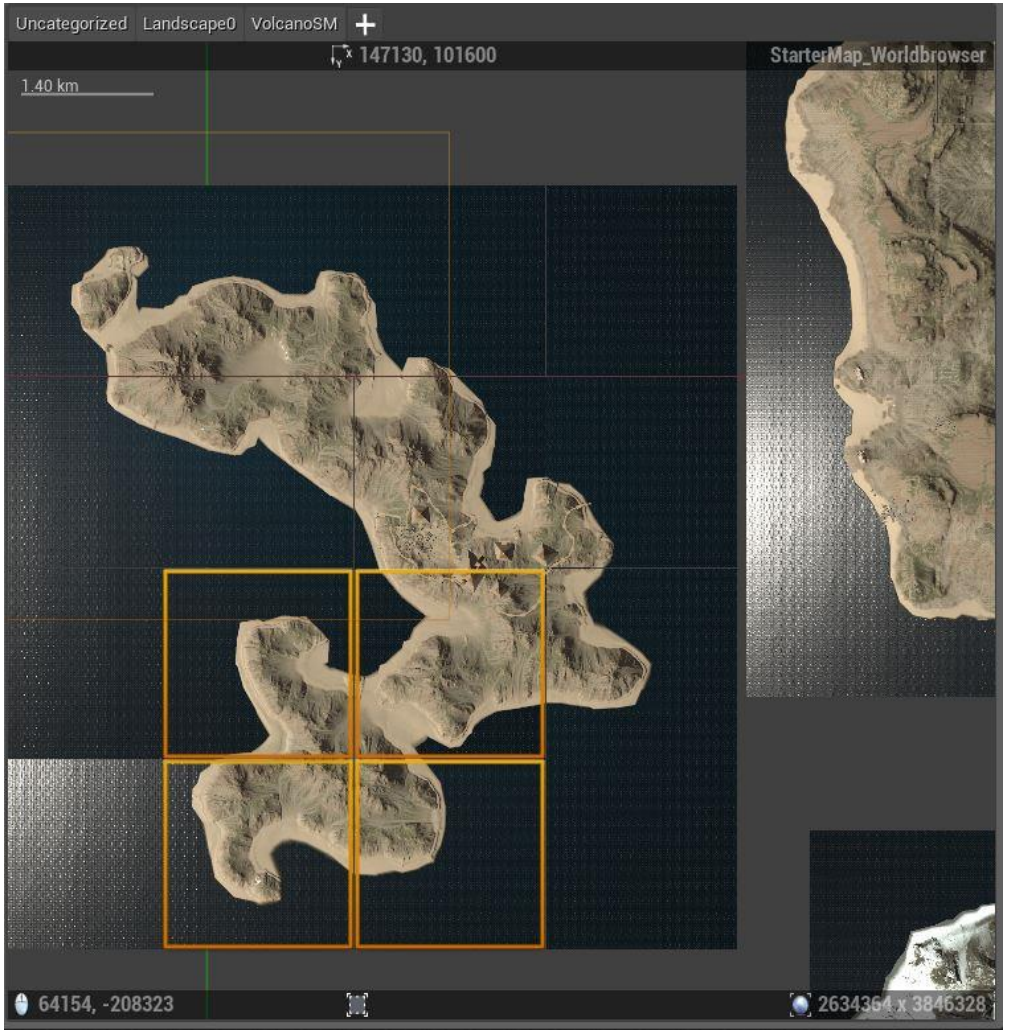
Included in current game engines

Very coarse geometry streaming

Need to watch out for objects and data

- Pathfinding
- AIs
- …



Sound

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mp3 and similar compressed formats

- Nothing special – at least not anymore

Coarse streaming for sound effects

- Easy
  - Sound effects are short
  - Sound effects don’t stay on screen
  - Sound effects can stay in CPU RAM

Fine grained streaming for music and maybe speech

- Even mp3 players do it

Really Big Worlds

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32 bit floats

- "total precision is 24 bits (equivalent to $\log_{10}(2^{24}) \approx 7.225$ decimal digits)"
  - Can be a little tight for big worlds

Use 64 bit floats for positions

- Hard to integrate 32 bit physics engines

Split and Shift the world

- Split the world
- Shift the closest parts to a position nearer at the camera
  - Physics work better with smaller coordinates

Procedural Worlds

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Elite

- 1984
- 8 galaxies with 256 planets each
- Generated galaxies, planets including names and properties
- BBC Micro: max. 128 KB Memory, Elite was 52 KB of disk space

Minecraft

- Official Release 2011
- Generates terrain including placement of settlements, resources, ... Procedurally
- Sold for 2.5 billion USD to Microsoft in 2014

Vegetation

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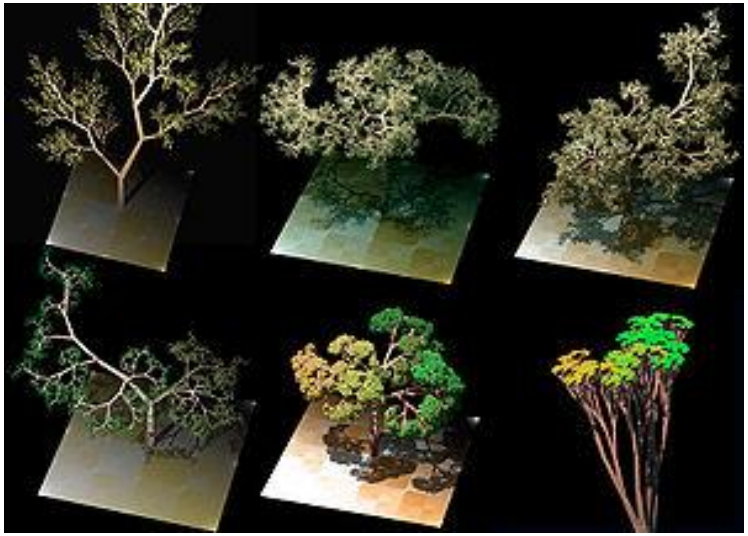
One of the oldest fields of procedural content generation in computer graphics

Lots of info available at:
http://algorithmicbotany.org

Well suited for generation

- Based on natural processes
- Complexity makes the shapes look realistic
- Can be found by examining how nature handles growth



Principles

Structure

- Many PCG algorithms can create instances of classes of objects
- One type of house, tree, clothing, ...
- Recognizable structure in each instance
- Structured way of deriving an instance

Randomness

- Not a defining characteristic of PCG
- But often a central component

Texture Generation

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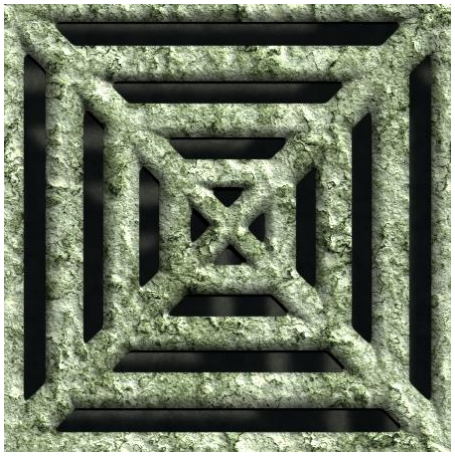
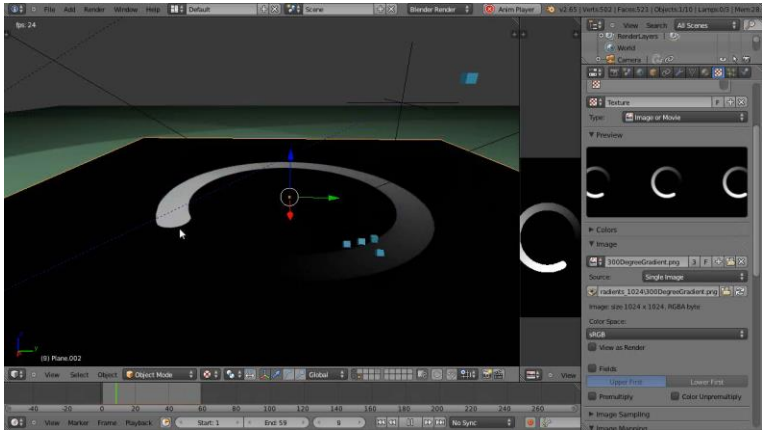
Generate

- Texture
- Normal Map
- Specular Map
- ...



Can be used in different systems

- Textures for objects
- Height maps
- Controlling flow or emission of particles



https://www.youtube.com/watch?v=UZGoht2vkzU

Texture Generation

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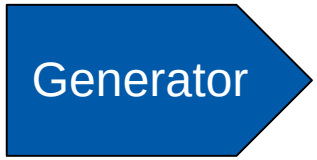
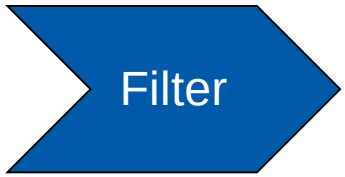
Basic Generators & Image inputs

- Provide basic shapes and patterns
- Can insert randomness into the process
- Also image inputs to use in further steps



Filters

- Change the look of the input texture
- Enhance, blur, filter, ...
- Carry out mathematical operations



Combinations

- Combine different textures

Texture Generation Node Networks

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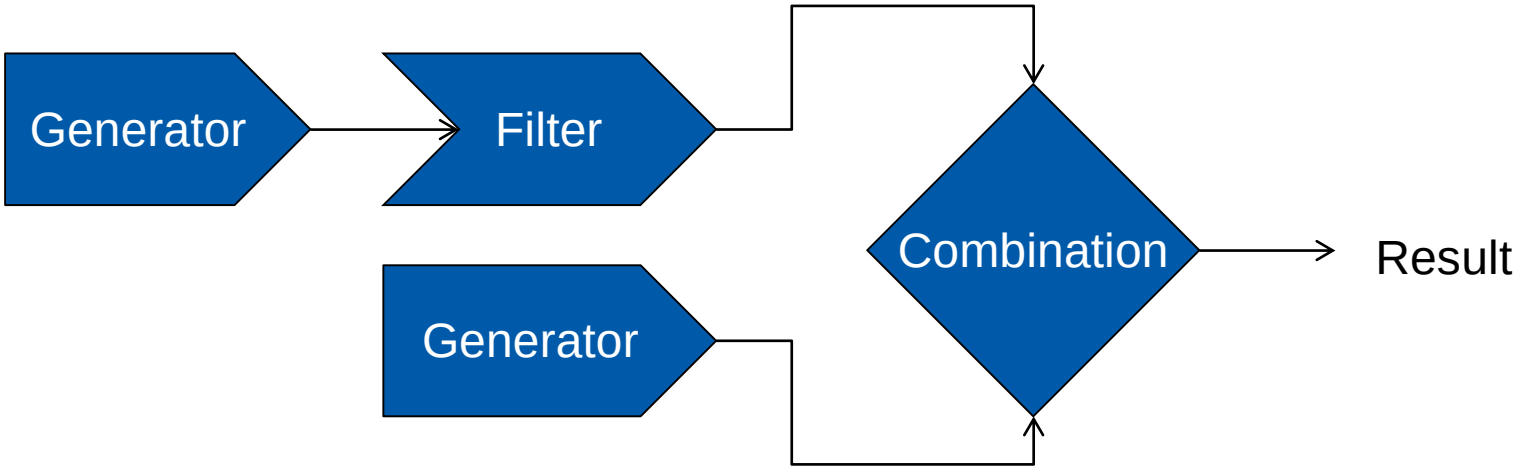
Combine different algorithms

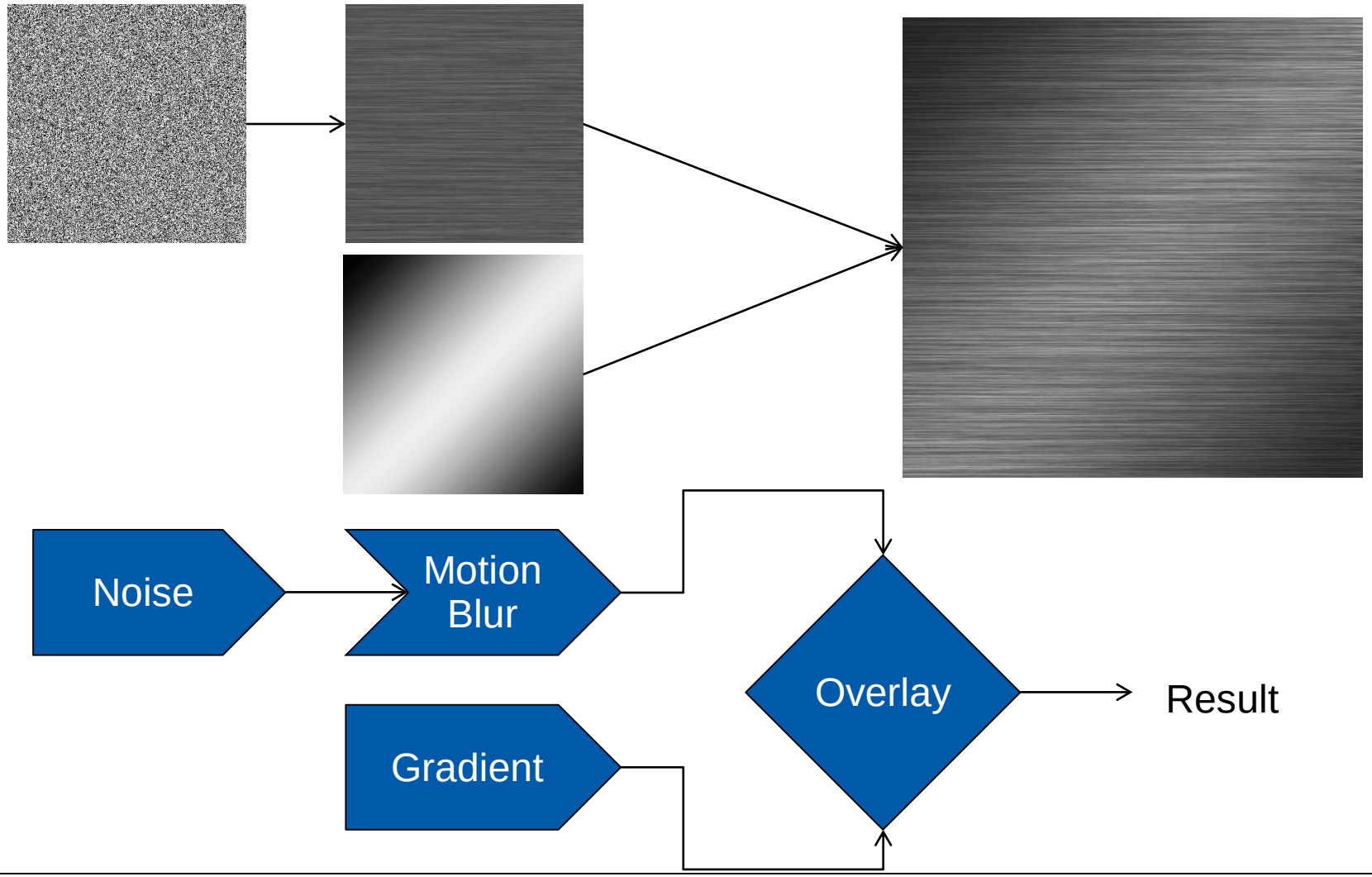
Basic Generators have only texture output(s)

Filters and Combiners have

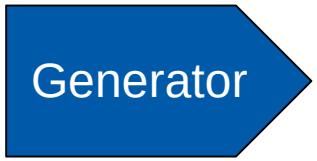
- One or more texture inputs
- One or more texture outputs



Example of networks - Metal



Basic Generators



TECHNISCHE UNIVERSITÄT DARMSTADT

Random

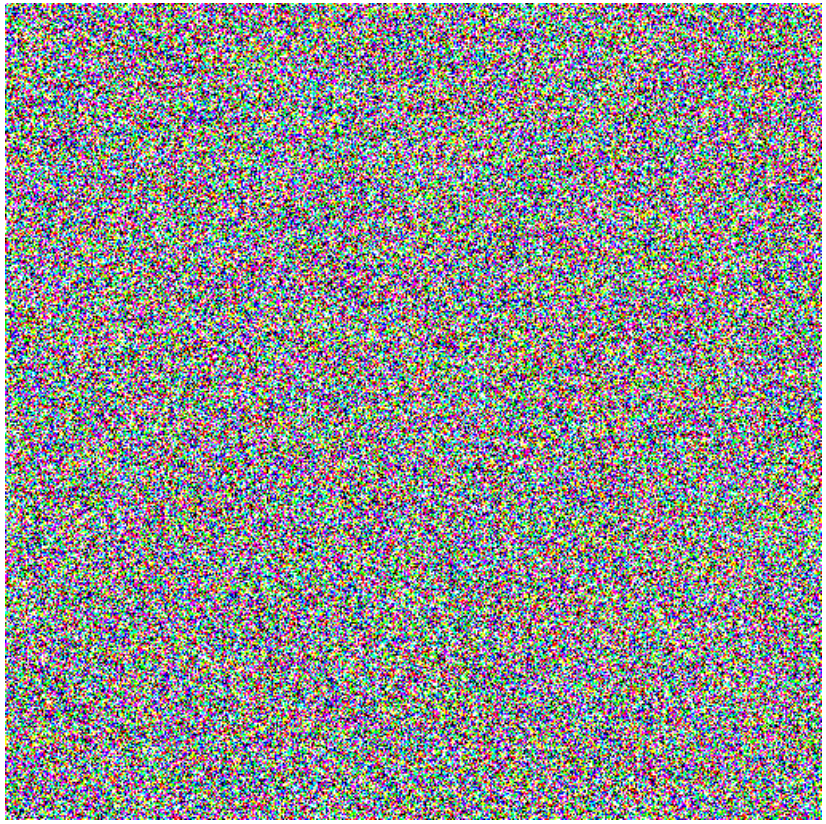
- **All colors**
- Grayscale

Patterns

- Grids
- Dots/Spheres
- Jittered patterns
- Voronoi Diagram

Random Noise

- Perlin Noise



Basic Generators

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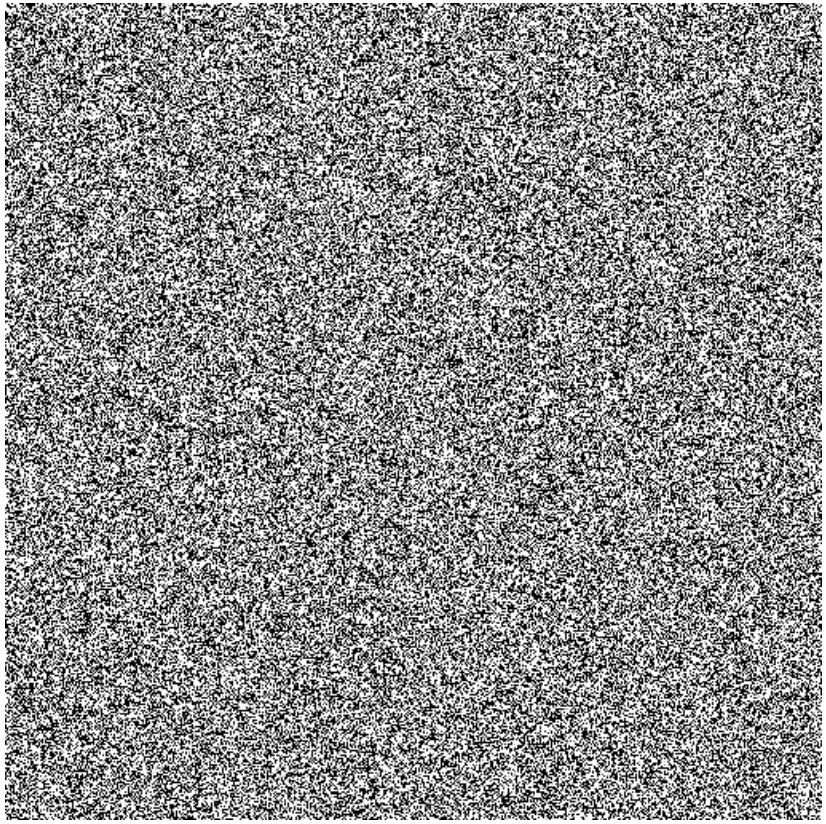

Basic Generators

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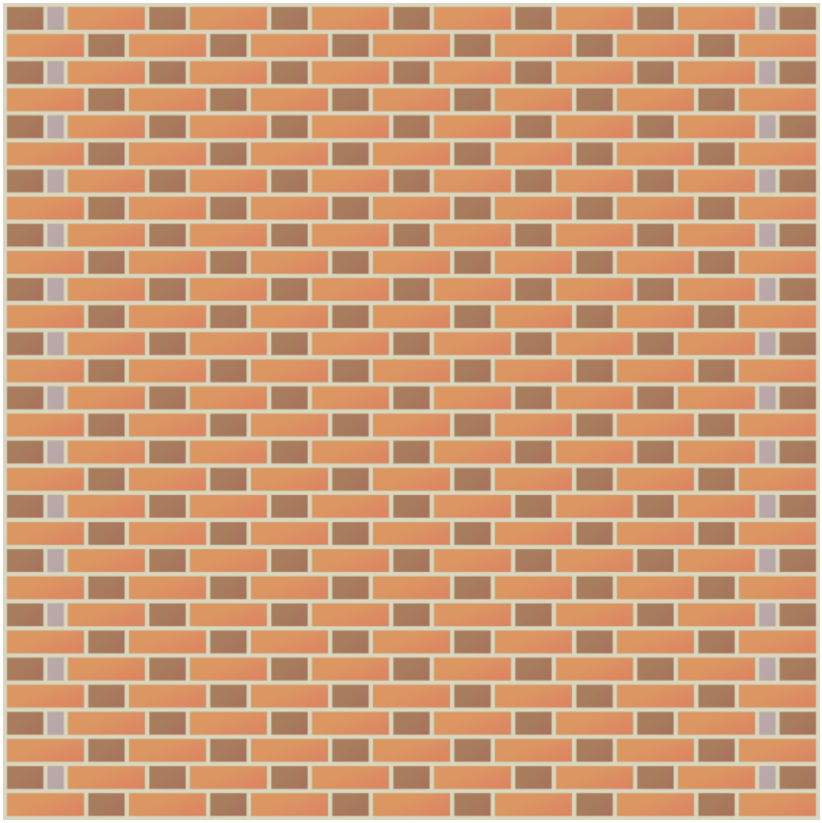
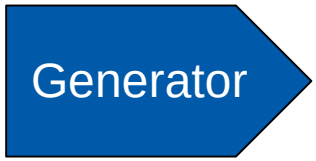


Basic Generators



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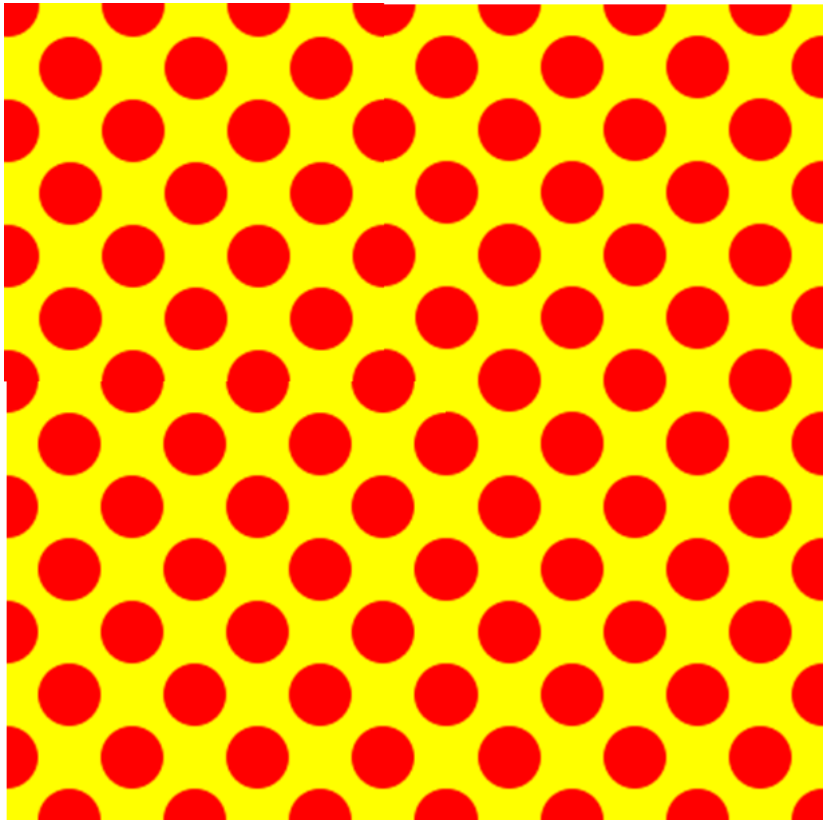

Basic Generators

Generator

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- All colors
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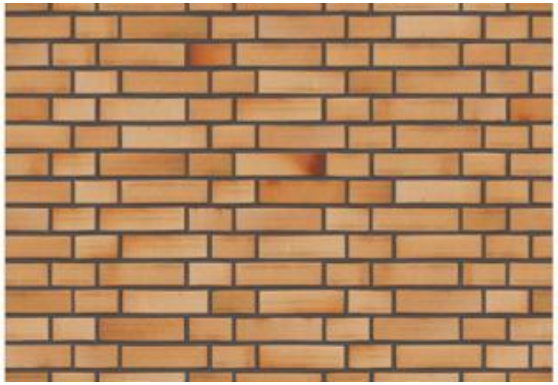
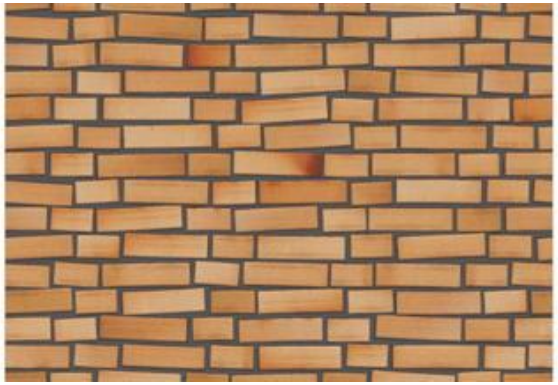




Random Noise

- Perlin Noise

Image Source: http://www.tri-nitro.com/project_mt_1_key_features.php

Basic Generators

Generator

TECHNISCHE UNIVERSITÄT DARMSTADT

Random

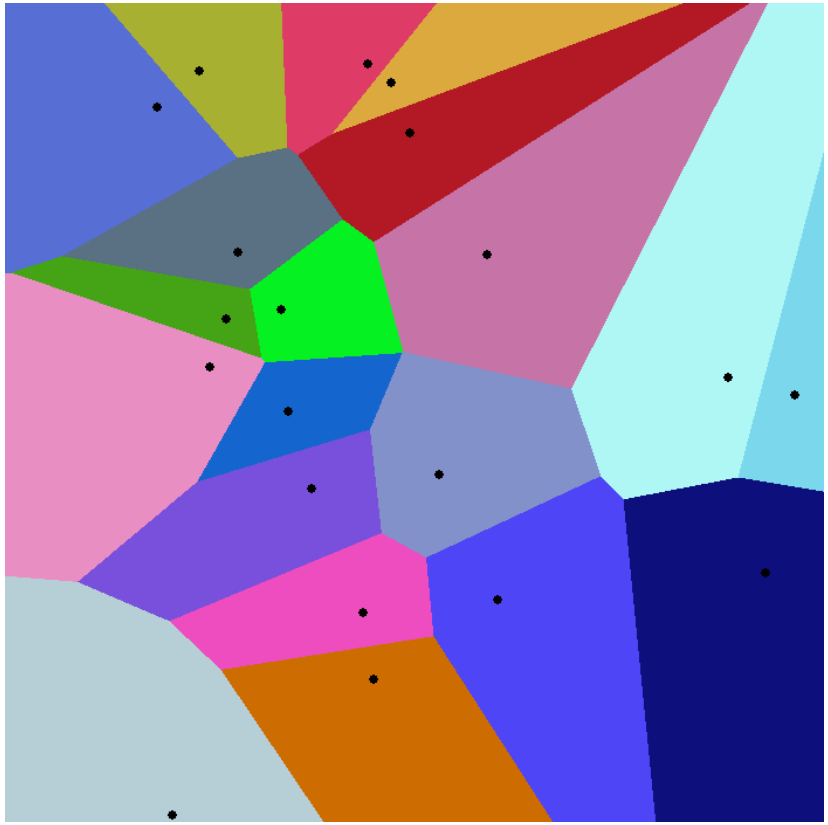
- All colors
- Grayscale

Patterns

- Grids
- Dots/Spheres
- Jittered patterns
- **Voronoi Diagram**

Random Noise

- Perlin Noise



Voronoi Diagram

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Take a set of points C1 to Cn, „sites“

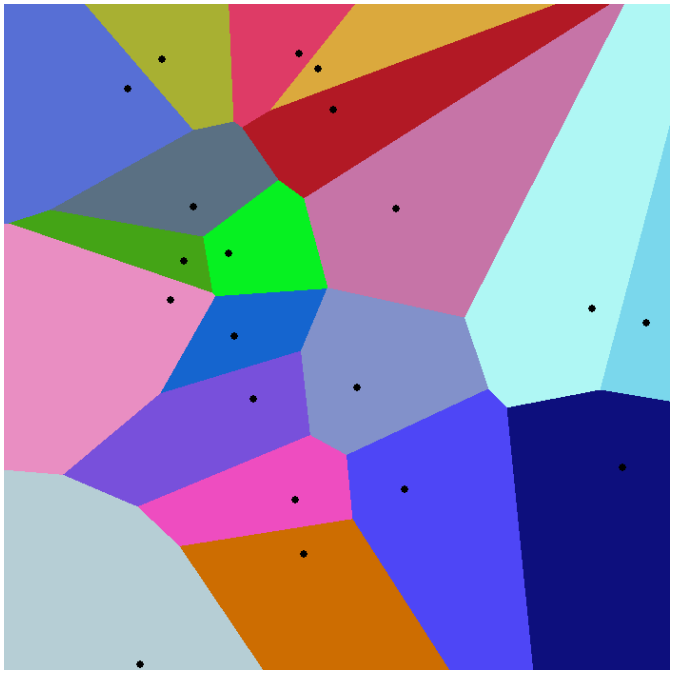
Every point Ci defines a cell such that for each point P in the cell, no other point in C lies closer to P than Ci

Regular points lead to regular patterns

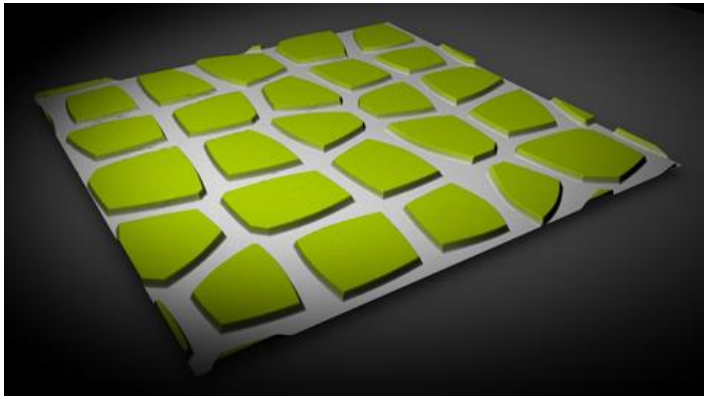
Random points lead to irregular patterns

- Reptile skin
- Parcels of land
- ...

(Dual to Delaunay Triangulation)

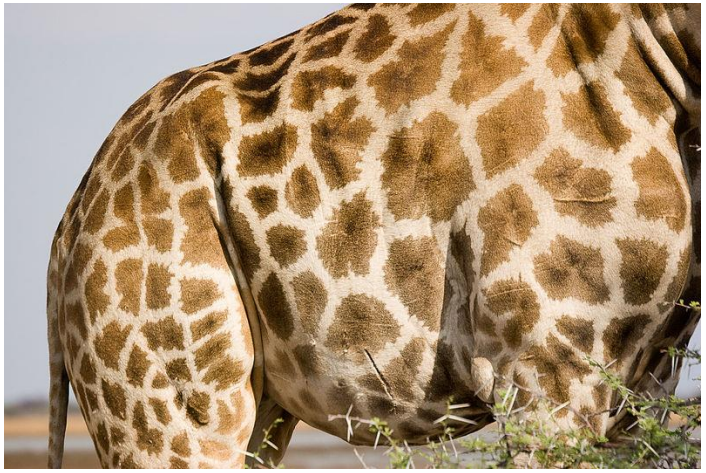


Voronoi Diagram – Texture examples

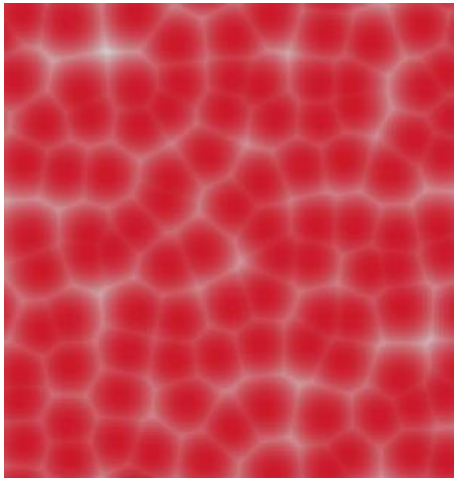


Cobblestone

Dry dirt



Giraffe skin



Blood cells

Basic Generators

Generator

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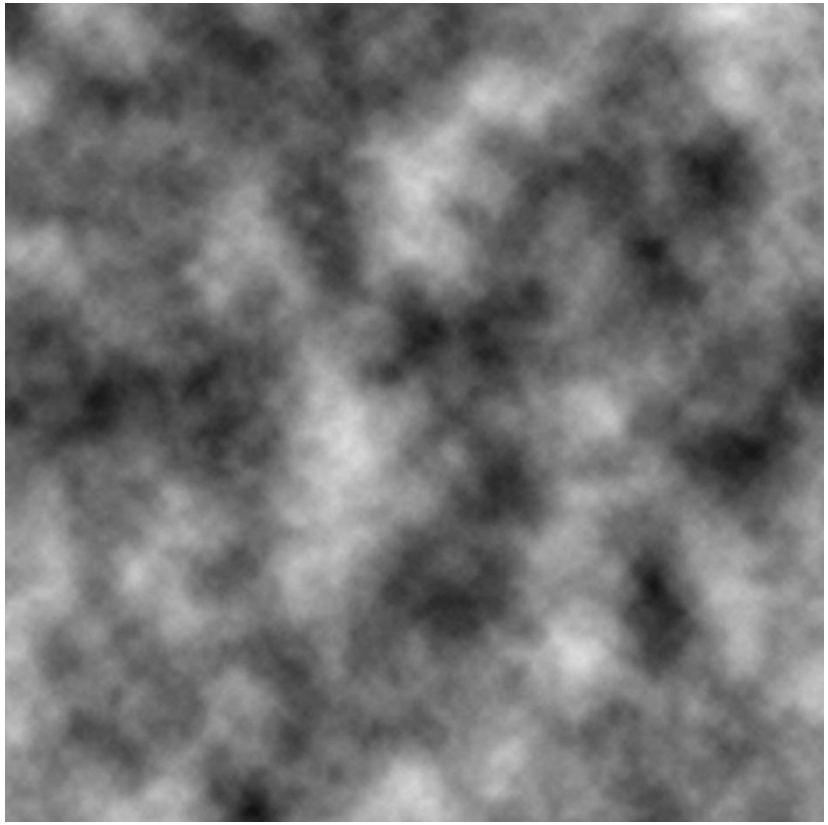
Random Noise

- **Perlin Noise**



Perlin Noise / Simplex Noise

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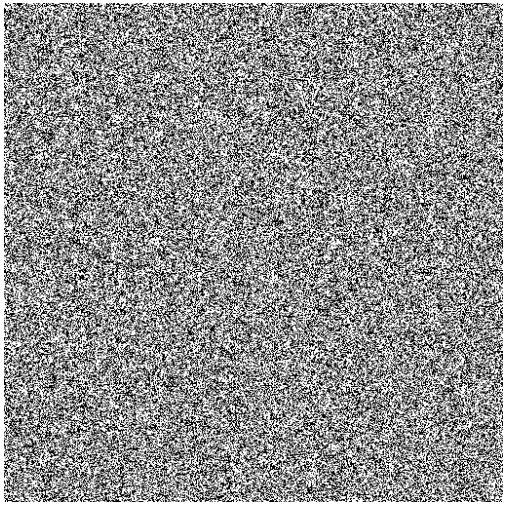
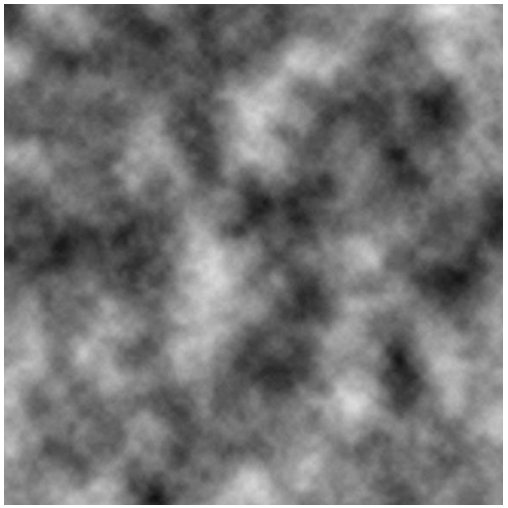
Random pixels

- No continuity
- If we interpreted it as a 2-dimensional function (heightmap), it would not work

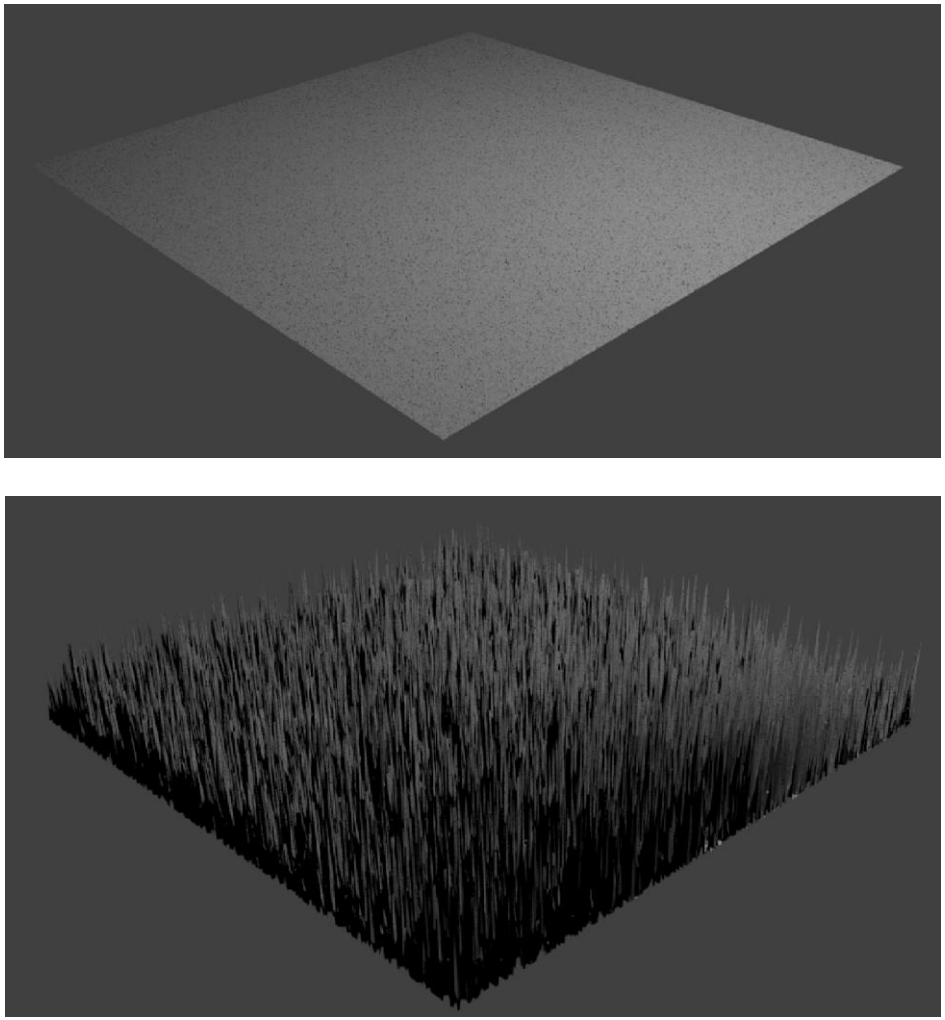


Semi-Random Noise

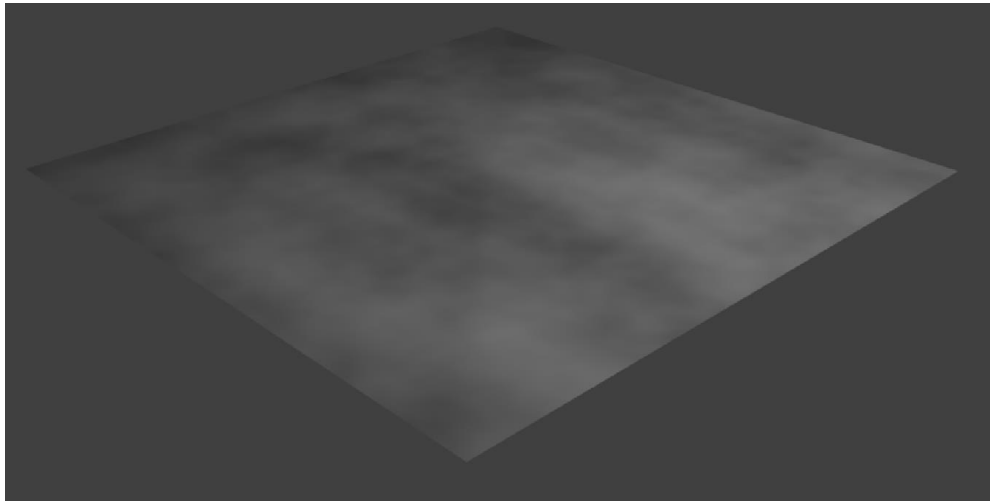
- Cloud-like look
- Continuous
- Works well as a heightmap

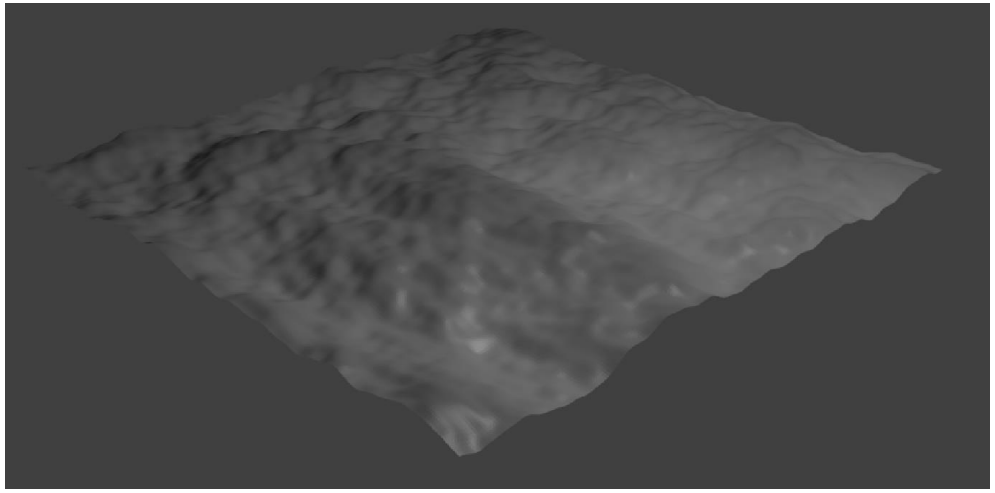


Purely random noise



Continuous noise





Perlin Noise, Simplex Noise

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Perlin Noise

- Developed by Ken Perlin
  - Invented while working on „Tron“ in 1982
  - Won an Oscar in 1997
- Omnipresent noise generation function

Simplex Noise

- Suggested by Perlin in 2001 as a succesor to the previous noise function
- Better properties
- Scales better to higher dimensions

Perlin Noise

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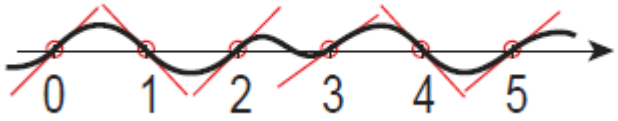
Gradient-based noise

- Determine for each integer value
  - Function value 0
  - Pseudo-random gradient



Perlin Noise

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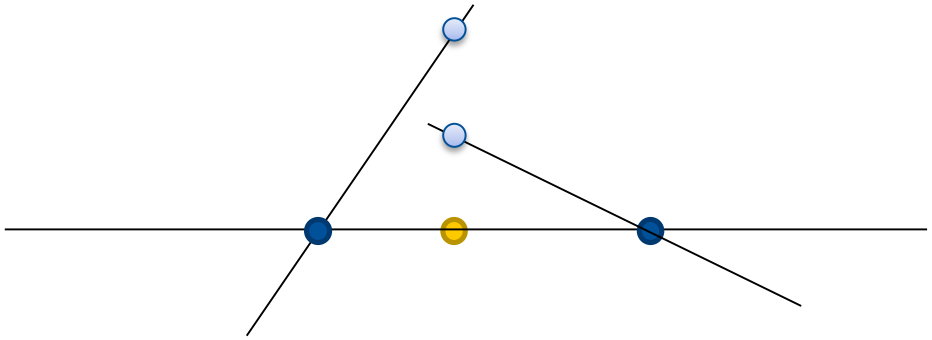
For a given point x (2D), the result is computed by blending

- The value of the previous gradient extrapolated to point x
- The value of the next gradient extrapolated to point x



Perlin Noise

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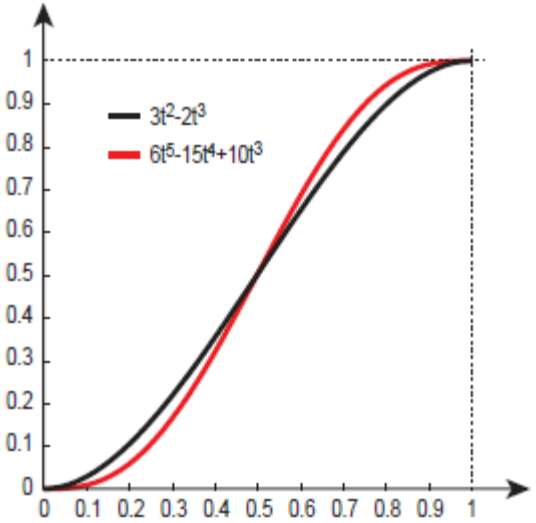
Blending function

- Originally f(t) = 3t^2 – 2t^3
- Later f(t) = 6t^5 – 15t^4 + 10t^3



Purpose

- This way, the noise is also continuous at the integer positions

Gradients, Computation

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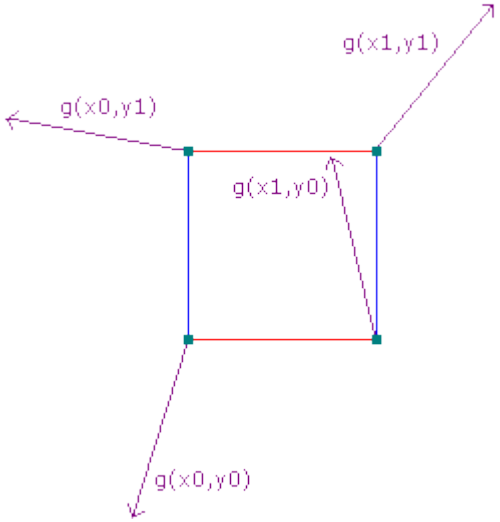
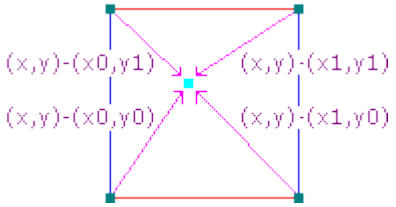
Use the dot product to calculate the contribution of a gradient to the sample

- Gradients are defined at the grid points
- Use vectors from grid points pointing to (x, y)





Interpolate in x-direction (2 rows)

Interpolate in y-direction

Perlin Noise – Dot product

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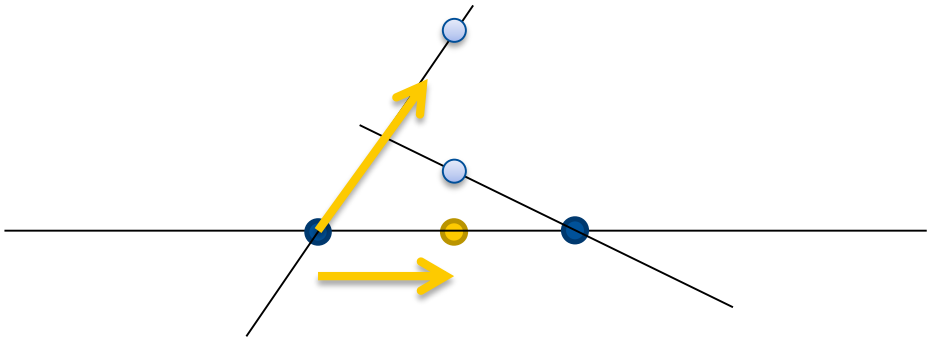
Can be seen better in 1D

Gradient is the slope of the function

Vector towards the evaluated point is the x-Value

In this case, the dot product becomes slope * x



Using Perlin Noise

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Normalize the noise

- Divide x by width and y by height

Frequency

- Noise = perlin(xnormalized * frequency, ynormalized * frequency)

Amplitude

- Noise = perlin(x, y) * amplitude

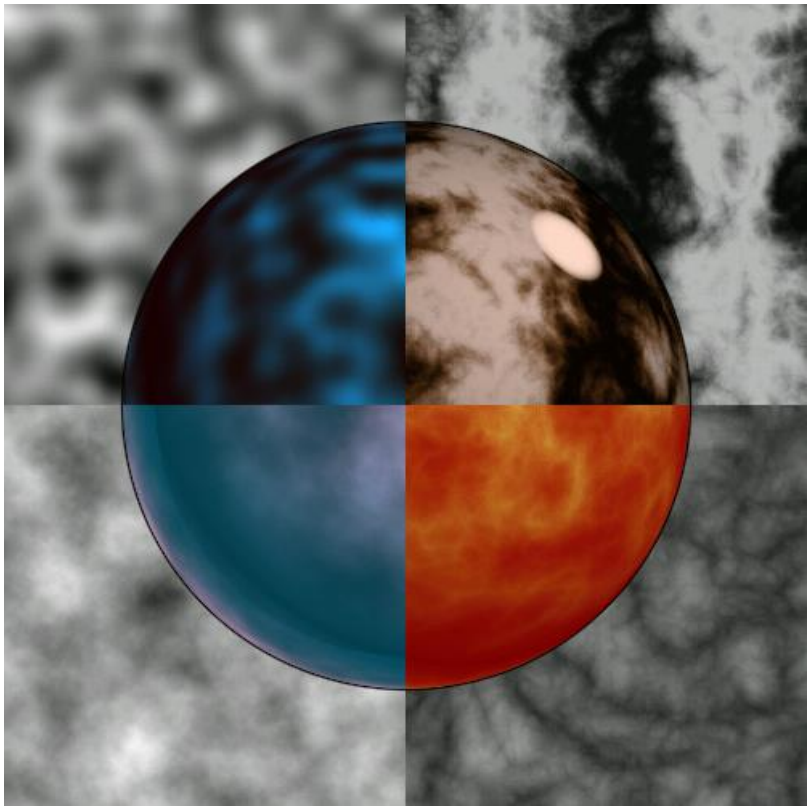
Bring into range [0, 1]

- Noise is in [-1, 1]
- → Add 1, Divide by 2

Using Perlin Noise

noise

sin(x + |noise(**p**)| + ½ |noise(2**p**)| + ...)



noise(**p**) + ½ noise(2**p**) + ¼ noise(4**p**) ...

|noise(**p**)| + ½ |noise(2**p**)| + ¼ |noise(4**p**)| ...

Filters - Basics

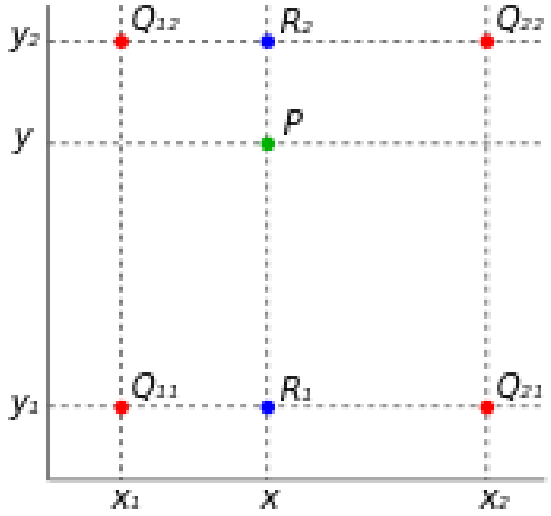
Each pixel of the resulting image is based on one or more pixels of the input image

Remember bilinear filtering for texture lookups

- We looked up the values of 2x2 pixels to get a value for the final pixel

Filter kernel

- Specifies the pixels we need to sample and the weights we sample them with



Box filter

Filter

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Move a box over the image

- New pixel = Sum of original pixels * weights
- Iterate over the image and calculate new pixels

Minimal Kernel size: 3x3

- Sizes schould be odd numbers (→ central pixel)

In the following slides

- Divide by the sum of the values of the kernel → Normalization
- Alternatively, floating point numbers could be used

How to handle edges?

- Similar to texture lookup
- Extend the image, fill with constant color, …

Image source for next slides: http://tech-algorithm.com/articles/boxfiltering/

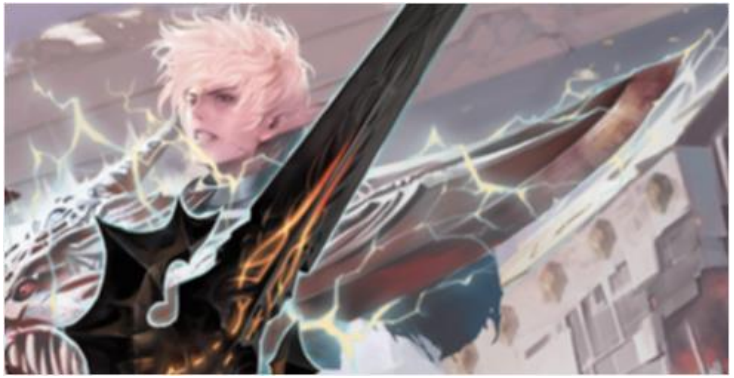
Box filter results

Unfiltered image

$$\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

Smoothing

$$\begin{bmatrix} 1 & 1 & 1 \\ 1 & 2 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$



Box filter results

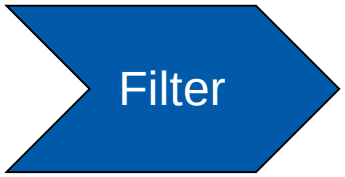
Sharpening

$$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 9 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

Raised

$$\begin{bmatrix} 0 & 0 & -2 \\ 0 & 2 & 0 \\ 1 & 0 & 0 \end{bmatrix}$$

Box filter results



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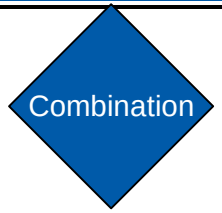
Motion Blur

$$\begin{bmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix}$$

Edge Detection

$$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

Combinations



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Remember the lecture on Alpha Blending → Combination of source and destination pixels

Modes

- Normal blend mode
- Dissolve
- Multiply
- Screen
- Overlay
- Hard Light
- Soft Light
- Dodge and burn
- Divide
- Addition
- Subtract
- Difference
- Darken Only
- Lighten Only

Examples: http://docs.gimp.org/en/gimp-concepts-layer-modes.html

Combine PCG and Streaming

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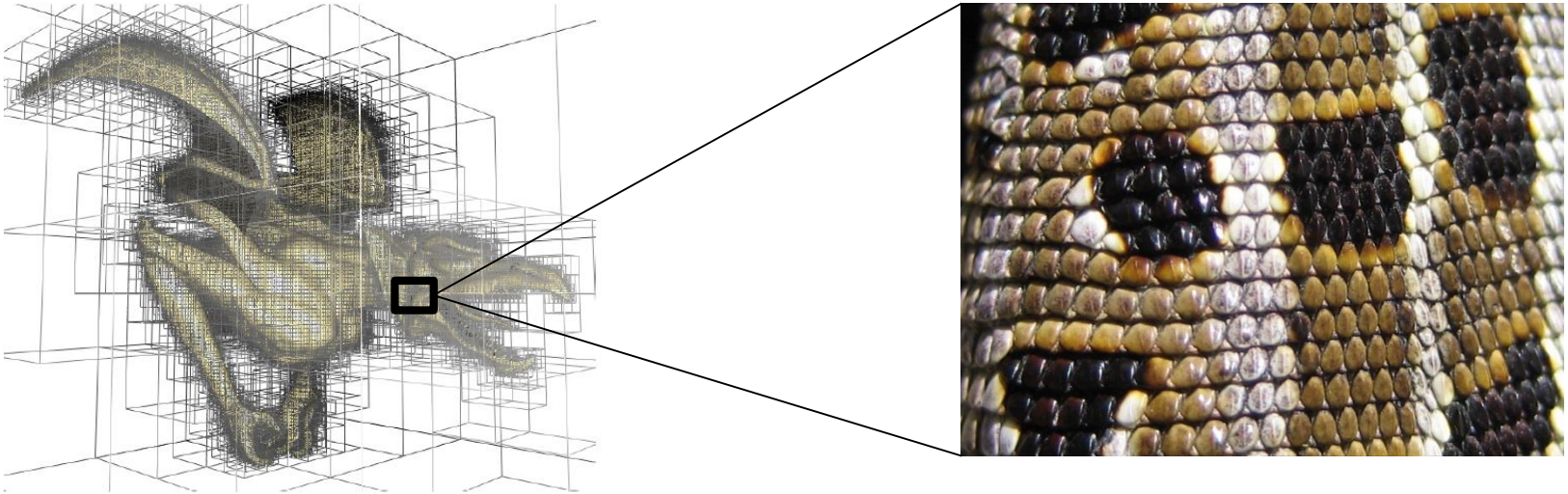
As in Minecraft – Generate parts of the world not yet seen

Fill in PCG details after a certain level of detail



Literature

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Julian Togelius

- IT University of Copenhagen
- http://julian.togelius.com/

Procedural Content Generation in Games - A textbook and an overview of current research

- Available for free at http://pcgbook.com/

PCG Wiki

- http://pcg.wikidot.com

Ebert, Musgrave, Peacheay, Perlin, Worley:

Texturing & Modeling – A procedural approach