Game Technology

Lecture 6 – 28.11.2017
Bumps and Animations

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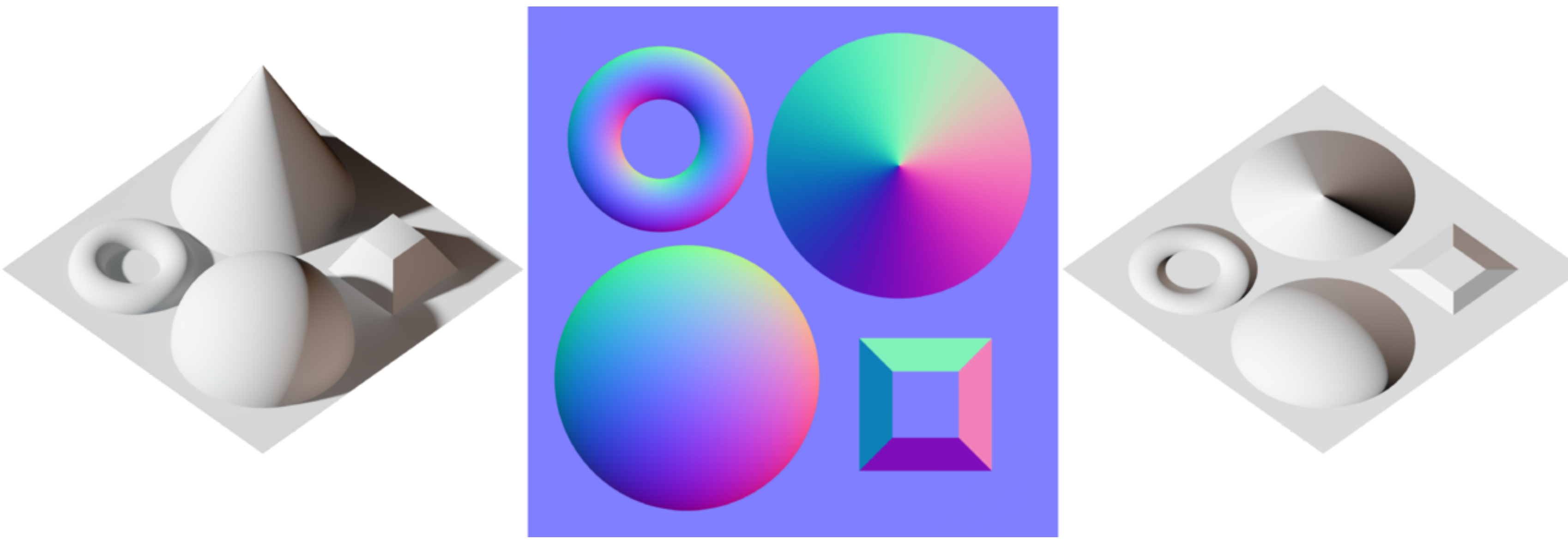


Dipl-Inf. Robert Konrad
Polona Caserman, M.Sc.

Prof. Dr.-Ing. Ralf Steinmetz
KOM - Multimedia Communications Lab

Ludum Dare@KOM

Game Jams

- Game development contest
  - Vague theme (e.g. “Running out of Power”)
  - Tight time constraints (e.g. 72 h)
  - Starting from scratch (design, assets, code, …)
- No excuses – just submit something…

Ludum Dare 40@TUD

- Sa., 2.12.2017, 9:00 – Mo., 4.12.2017 (night)
- Registration (first-come-first-serve): gamejam@kom.tu-darmstadt.de
- See last Jam: https://www.kom.tu-darmstadt.de/news-events/game-jams/?no_cache=1

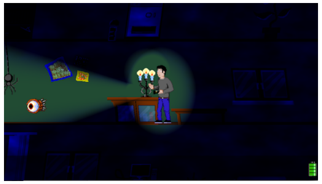
Ludum Dare

Extincti, LD#39

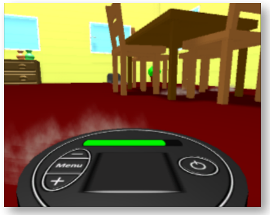
KOM Jam, 2016

Guardian Stone, LD#39

Watervapor, LD#39



Lightmare, LD39



Dustinator X9001, LD#37

It Came from the Dessert, LD#37

Game Jam Simulator, LD#37


ja!


Saskia


wacom


beam
INVERTIGO
DEAD PIXEL SOCIETY
CORE
CORE

TIME TO APOCALYPSE
2.912
PAUSE
Left Mouse
Shoot
Right Mouse
Grapple
Afterimage
ALWAYS LOOK HERE
Arrowkeys to move
(after timer ends)
AS WE ARE
Team2See
Use SPACE or "2" to switch to your new player
Look at
Pick up
YOU JUST DIED!
Cannibal Cage
Start Game
Mr. B
Mind your Decision
show inventory
take axe
Have Fun!!
Floor 1
Floor 0
Start Game
Tutorial
Credits
Quit
MONSTER
ARENA
Start
YOU ARE THE MONSTER

Bump Mapping

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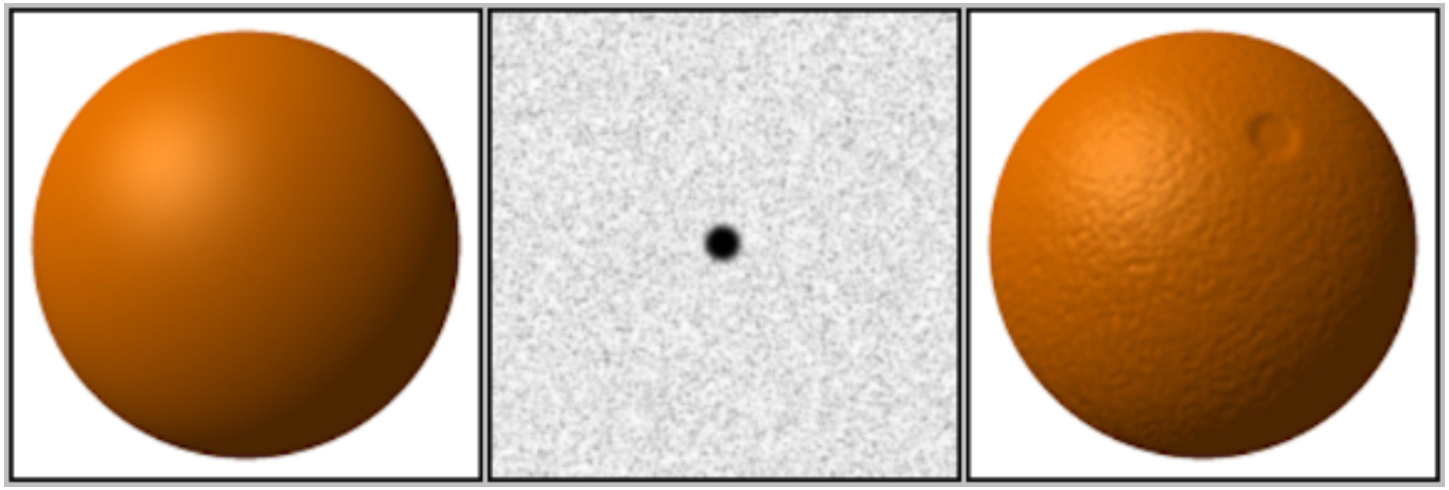
- Encode information about the surface
- Use during shading to simulate more detail than there is



Normal Maps

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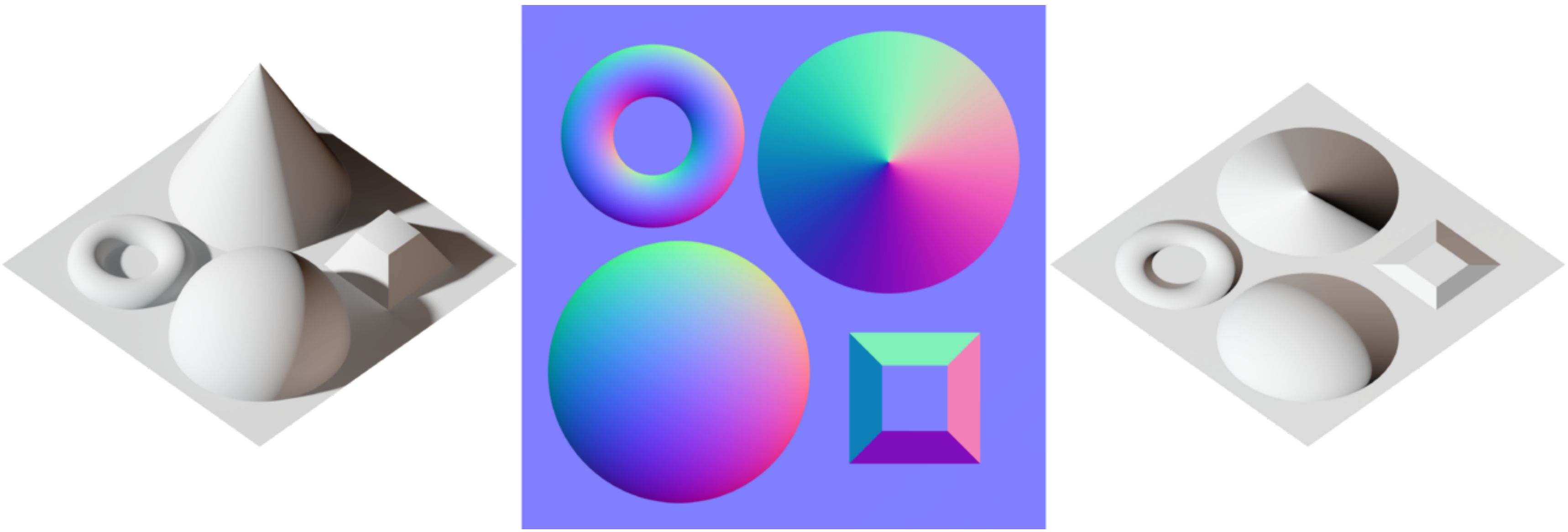
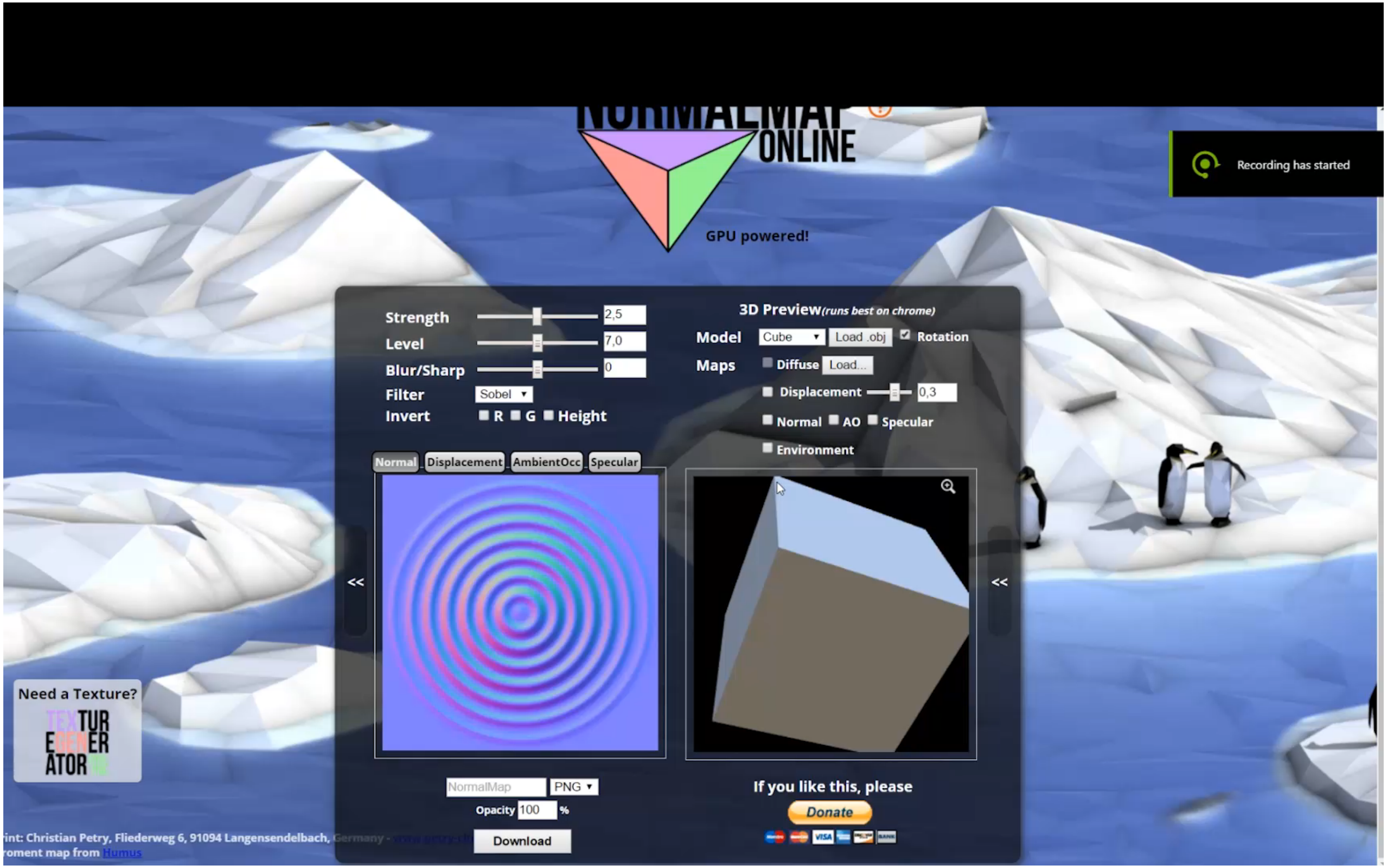
- Encode normals in the mesh
- „Bake“ from high-poly mesh
- Introduced 1996, Dreamcast (1998) first console with hardware support



Normal Mapping Examples

Doom 3, 2004

Normal Mapping Examples



Normal Maps

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Use a normal texture to encode the map

normal = 2 * color - 1;

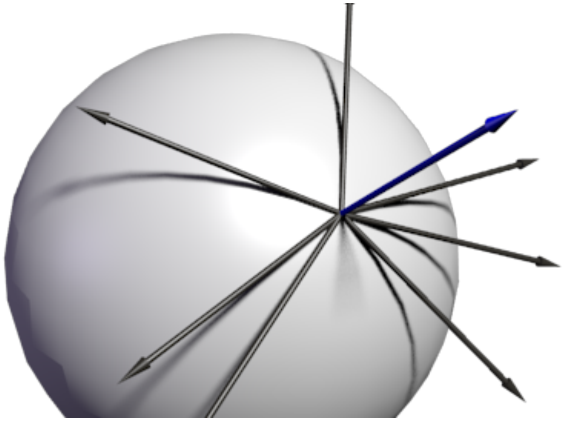
Default color is blueish

- (128, 128, 255)
- Geometric interpretation: Perpendicular to the x-y-plane

Tangent Space Normal Maps

Defines coordinate systems orthogonal to the surface

→ Infinite number of systems possible



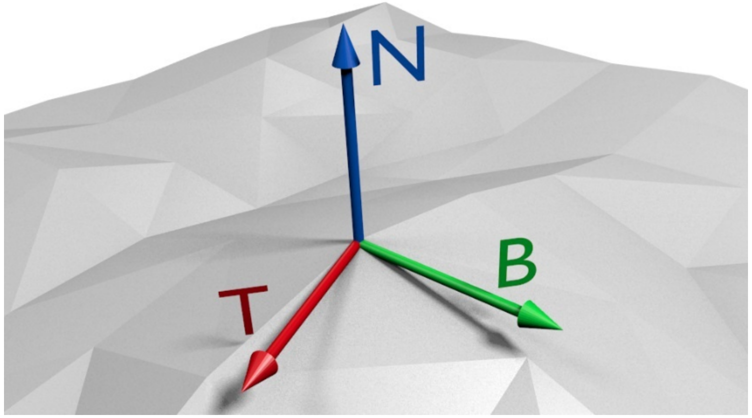
Reuse texture coordinates

- deltaPos1 = deltaU1 * T + deltaV1 * B
- deltaPos2 = deltaU2 * T + deltaV2 * B

Solve for T(angent) and B(itangent)

Matrix TBN: Tangent space normal to model space

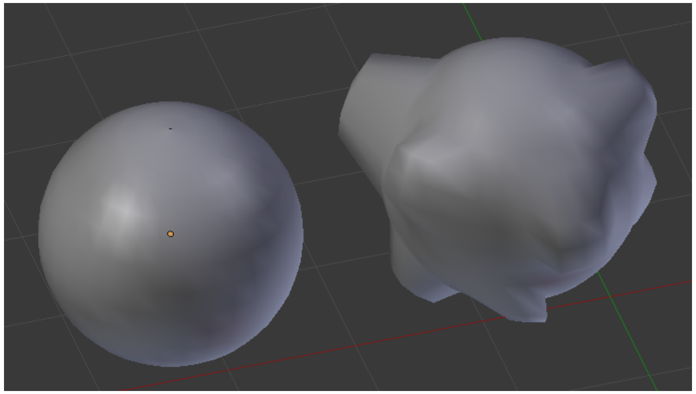
$$\begin{pmatrix} T & B & N \\ T & B & N \\ T & B & N \end{pmatrix}$$



http://www.txutxi.com/?p=316

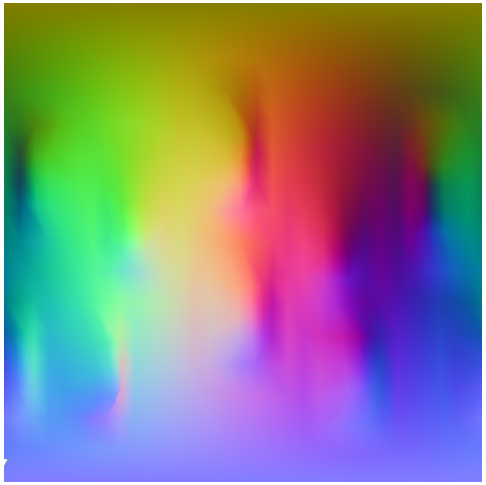
Object-Space Normal vs. Tangent-Space Normal Map

Low and high-poly mesh



Tangent space normals

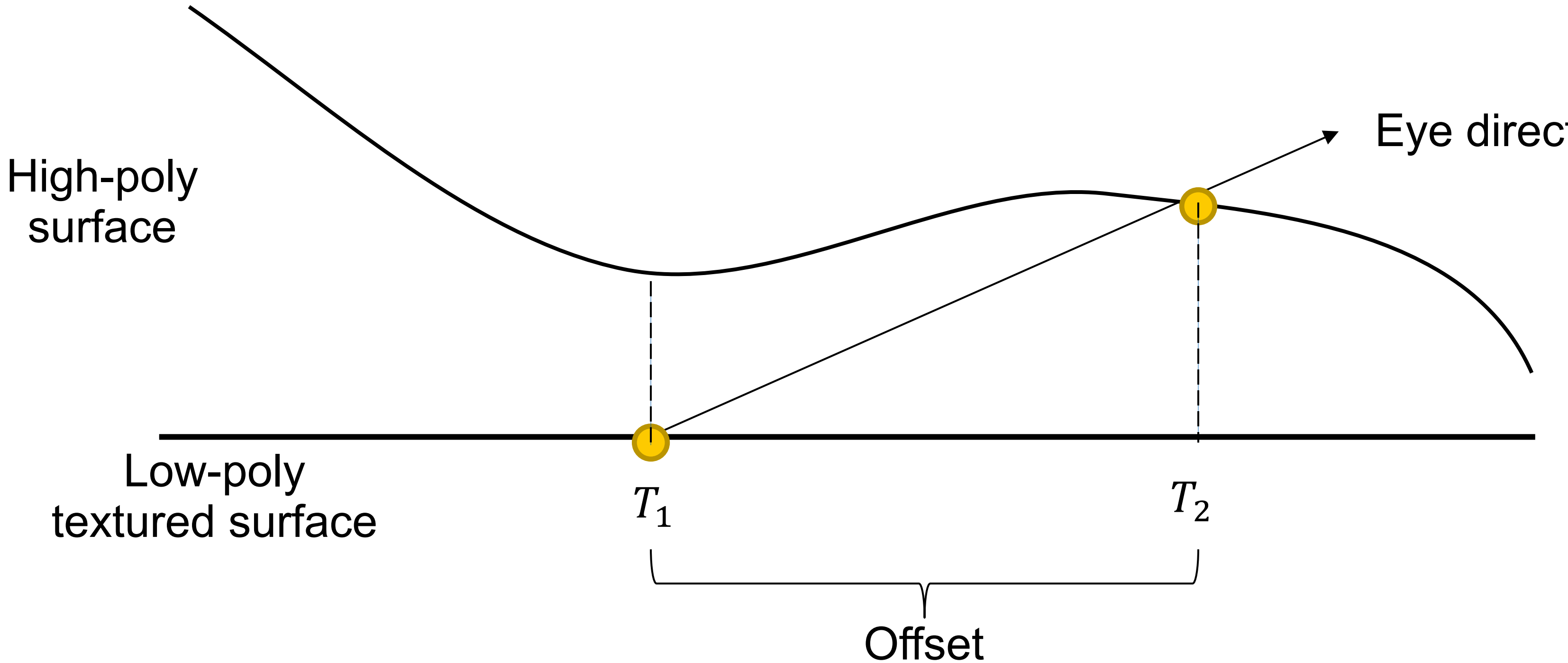
Object space normals



Parallax

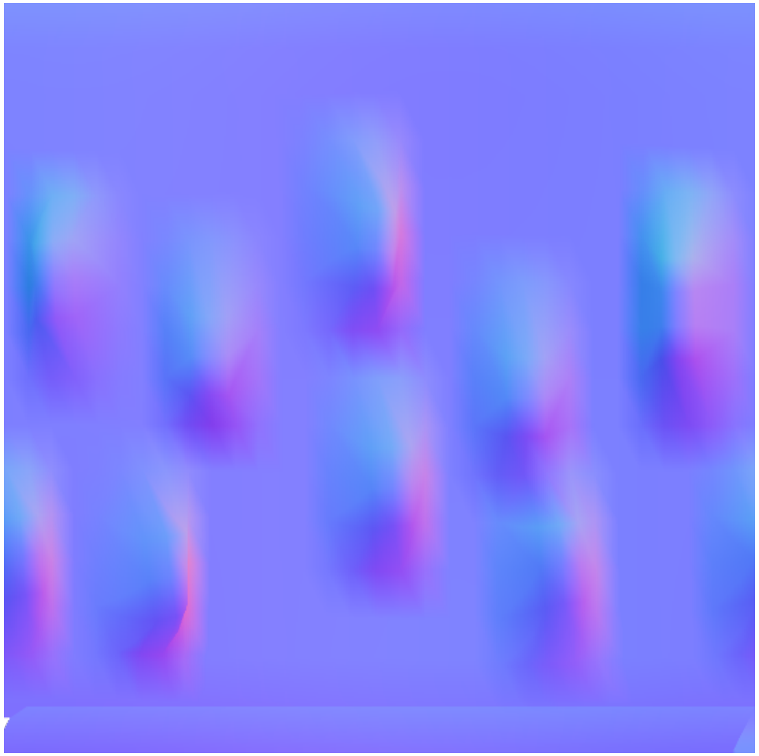
We should see the texture at T2, but we see the texture sampled at T1

→ Goal: find the correct offset to sample the texture at the correct position



Parallax mapping (2001)

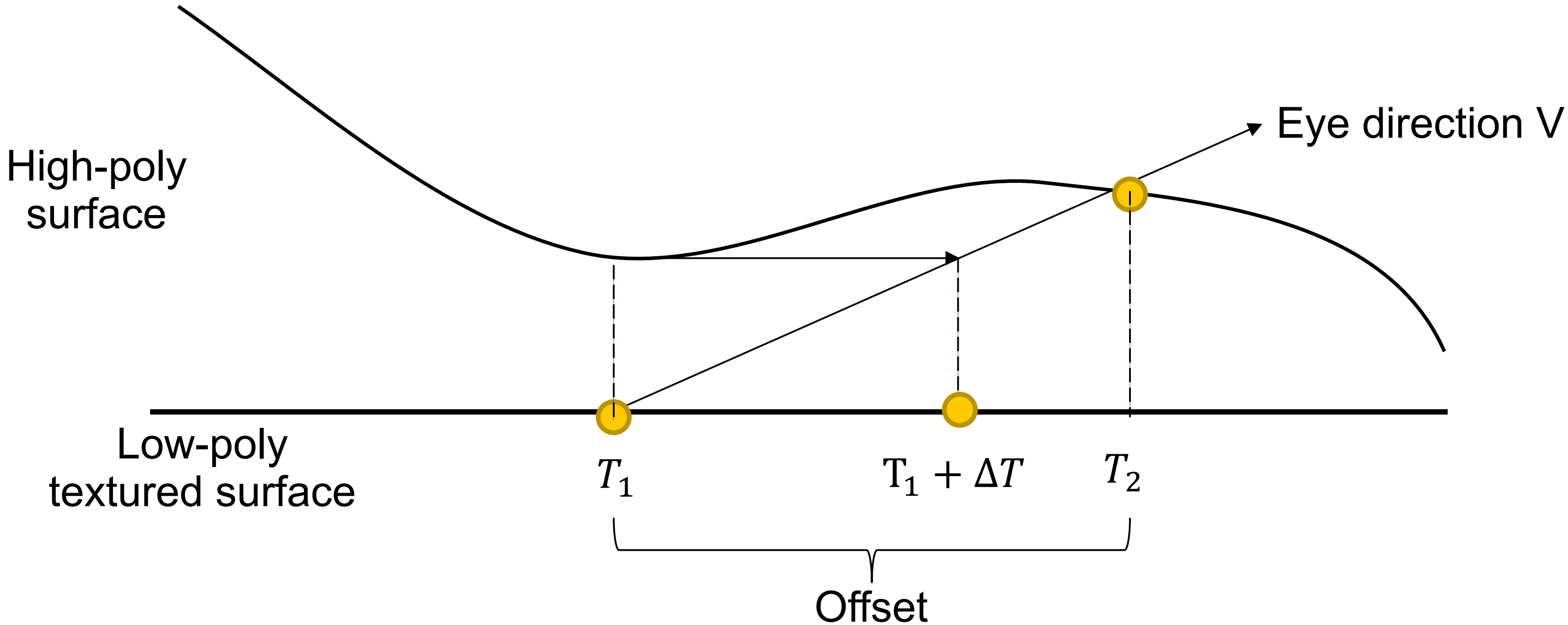
Additional input: Heightmap with values between 0 and 1



Parallax mapping (2001)

Approximation

- Get the height at T1
- Ray trace from this point parallel to the surface until it intersects view vector
- Use the length as the offset‘s approximation

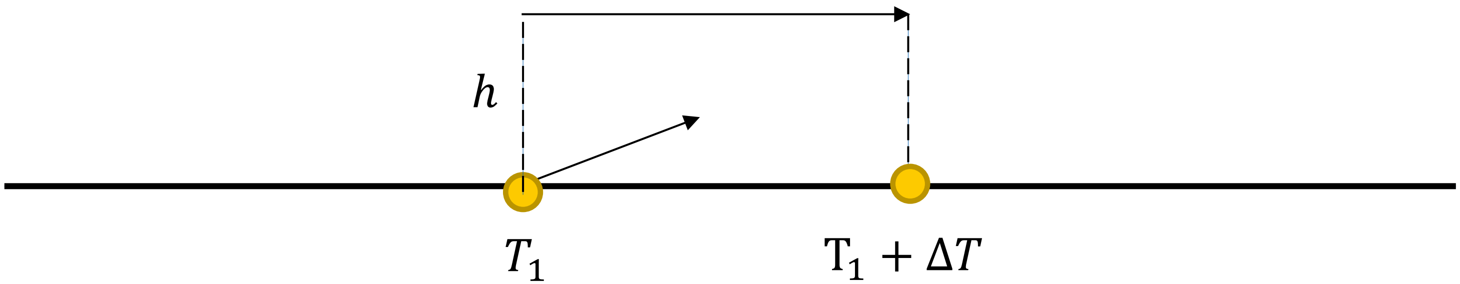


Calculation

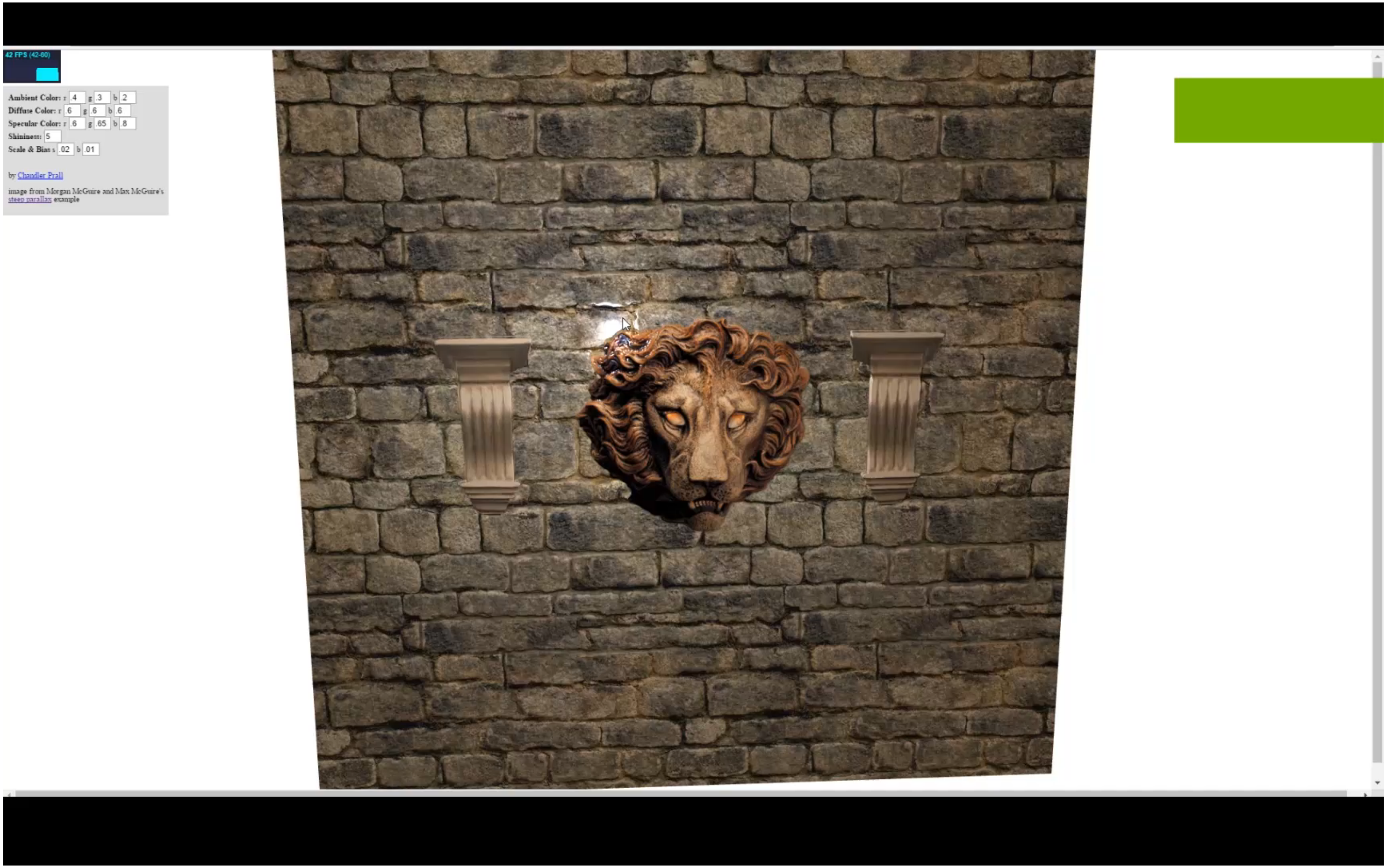
Bring view vector into tangent space

Normalize → $\mathrm{V} = \begin{pmatrix} V_x \\ V_y \\ V_z \end{pmatrix}$ where $\mathrm{V_{x,y}} = \begin{pmatrix} V_x \\ V_y \end{pmatrix}$ is a 2D vector in the plane and V_z points upwards

$$\Delta T = \frac{V_{x,y} \cdot h}{V_Z}$$



Parallax Mapping Example

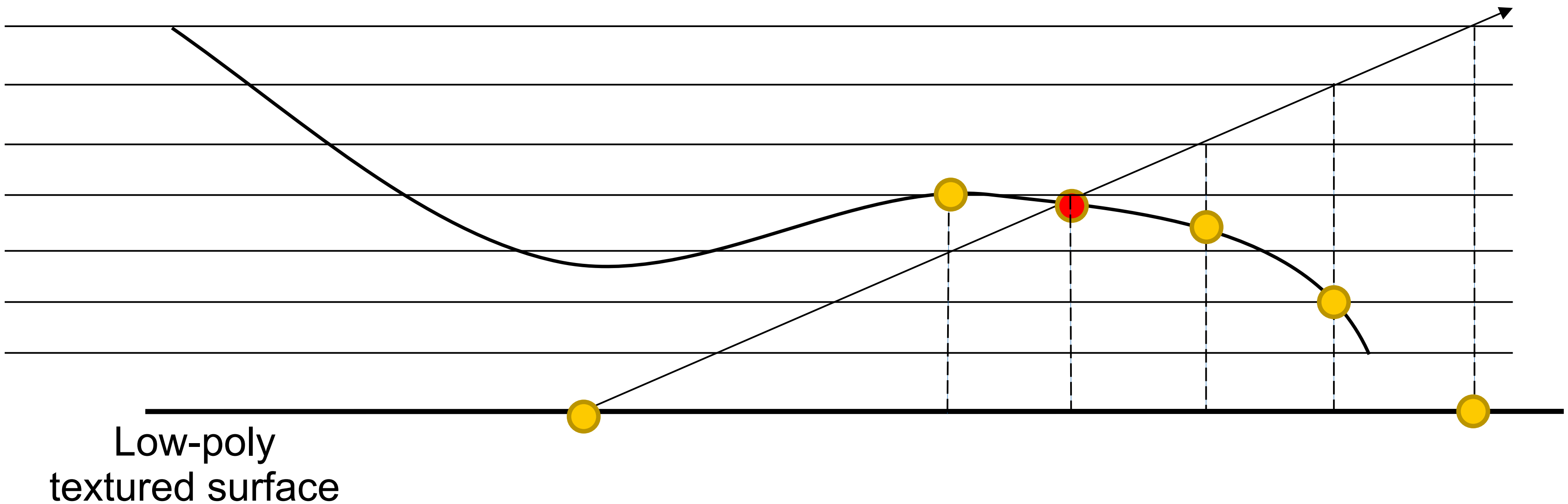


http://chandlerprall.com/webgl/bumpmaps/parallax.html

Steep Parallax Mapping (2005)

Improve the calculation by repeating it

Divide the heightmap into layers and test for each layer



Steep Parallax Mapping Example

http://chandlerprall.com/webgl/bumpmaps/steep_parallax.html

Parallax Occlusion Mapping (2006)

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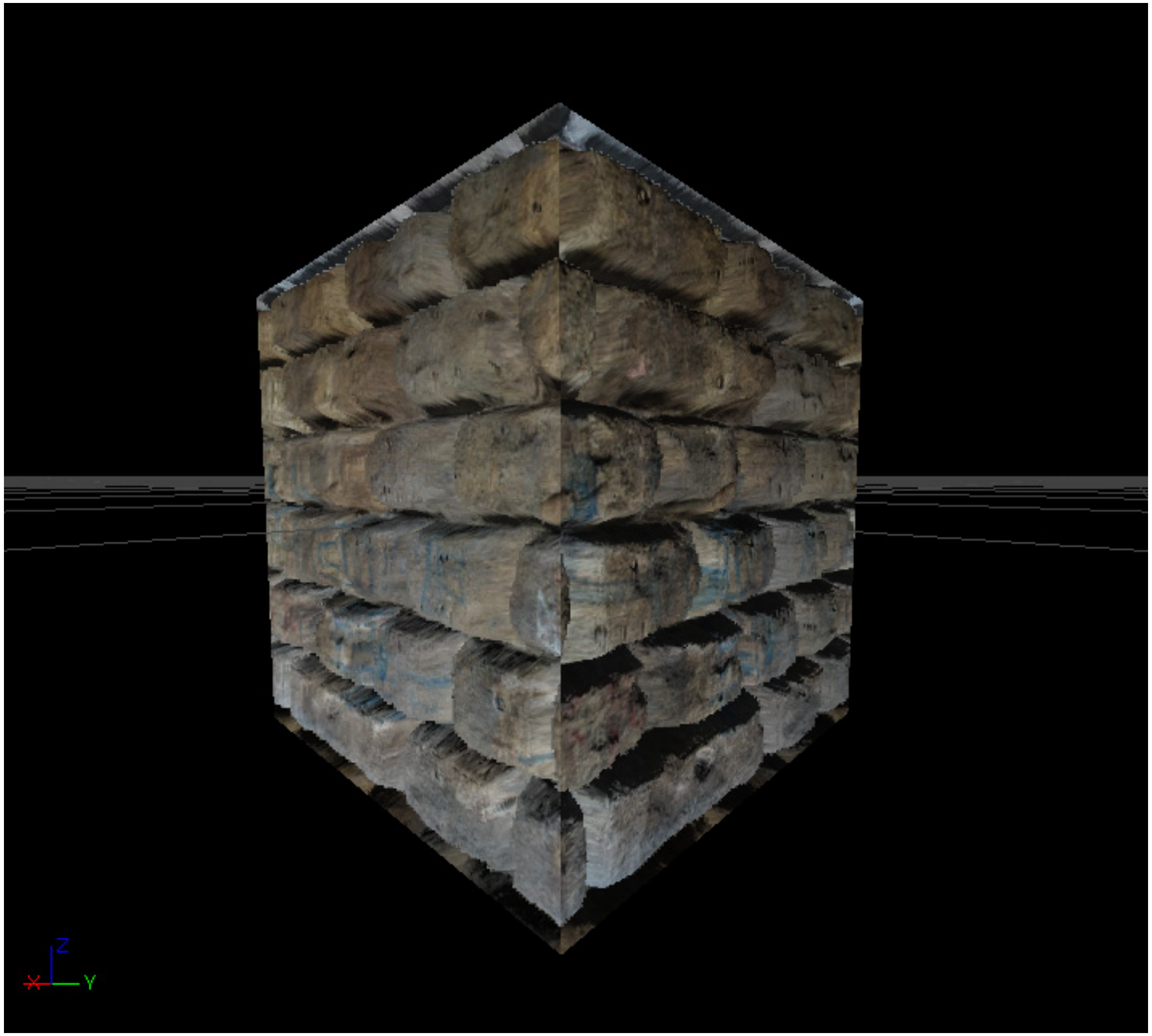
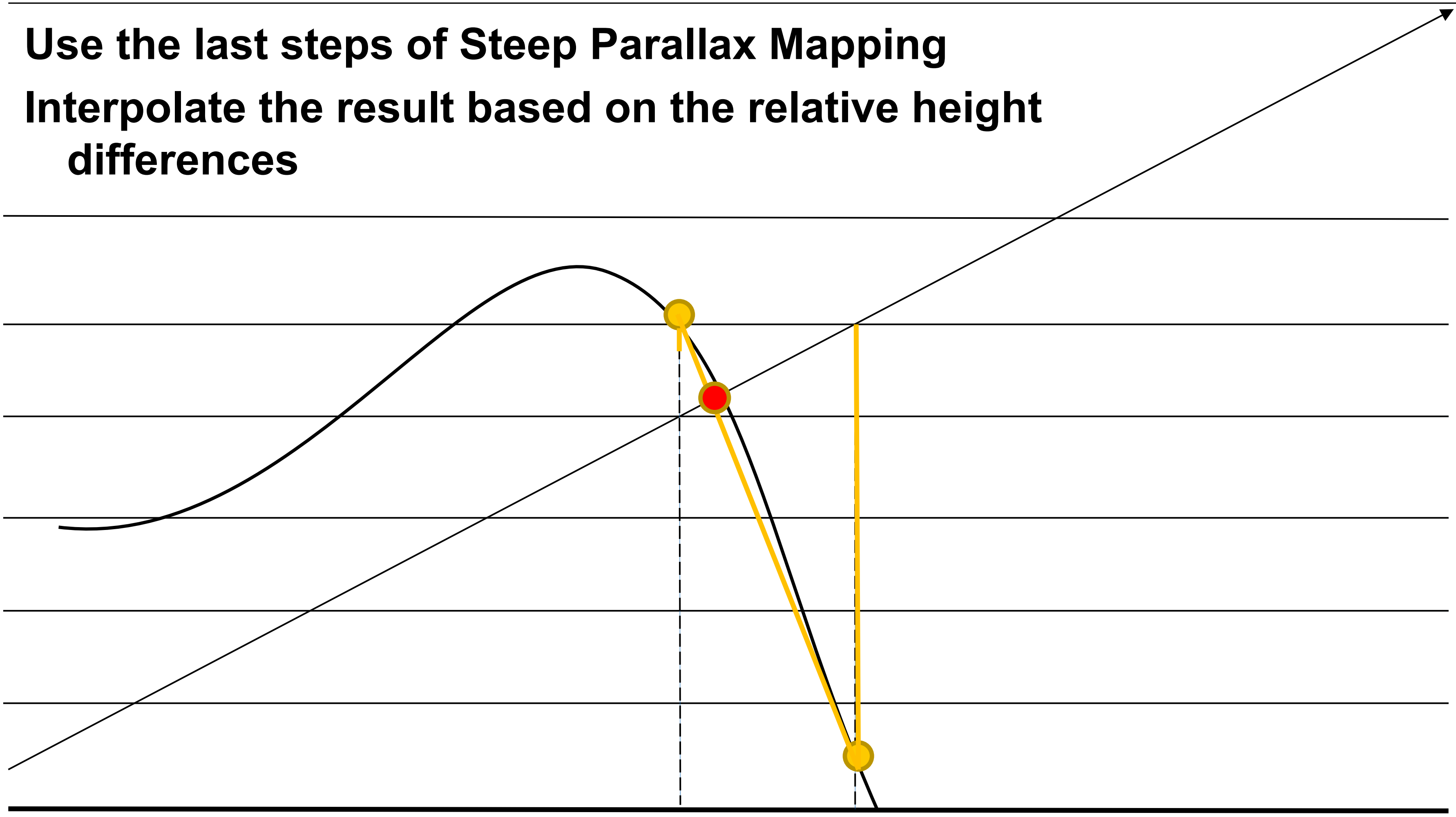


Parallax Occlusion Mapping

- Use the last steps of Steep Parallax Mapping
- Interpolate the result based on the relative height differences



Displacement Mapping

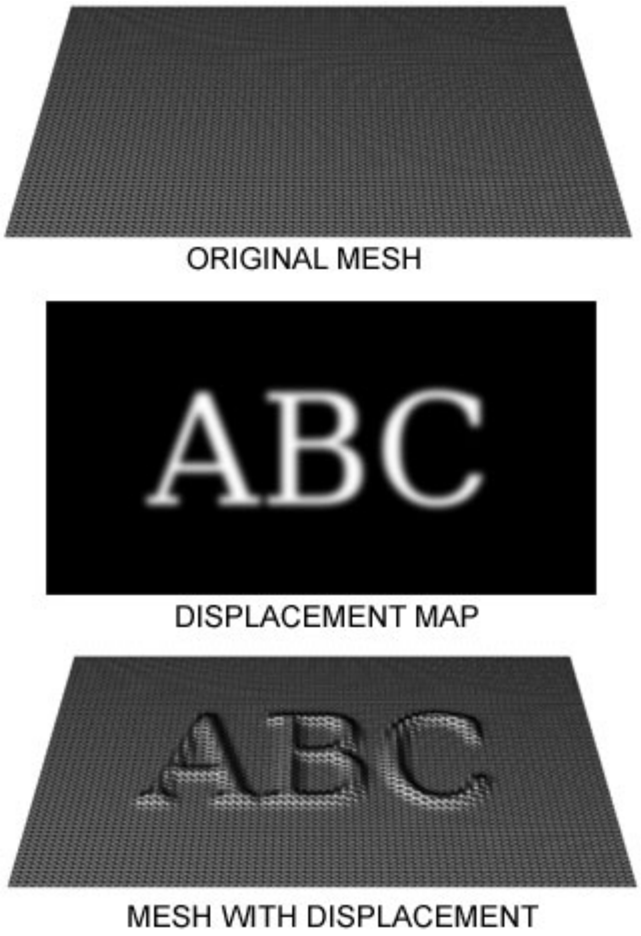
Bump/normal mapping add the illusion of depth during shading

Displacement actually changes the geometry by moving vertices

Really useful if GPU supports it

Goes well together will tesselation

- Add vertices where surface detail is needed



VR - The death of normal maps?

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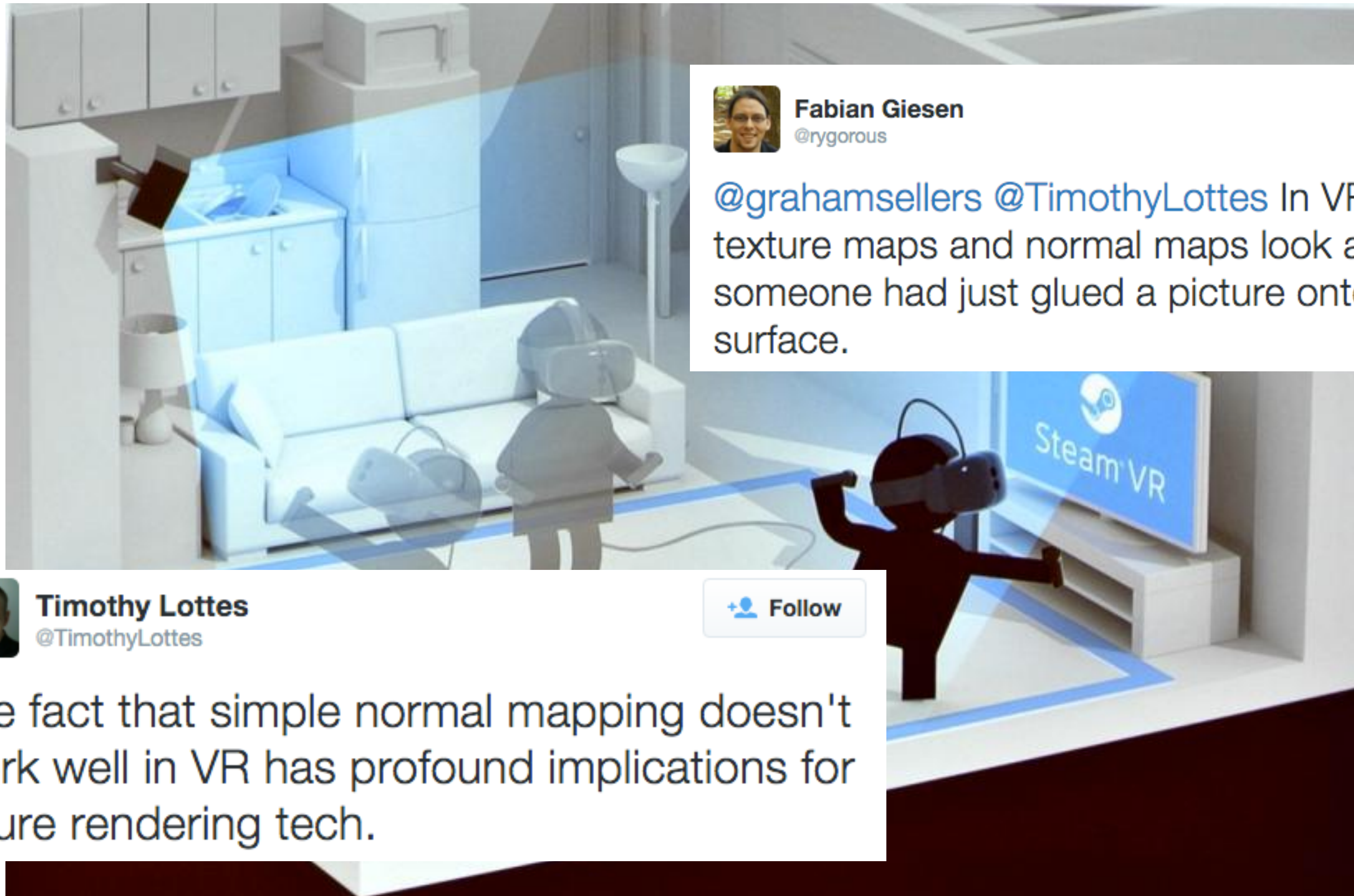


Fabian Giesen
@rygorous
Follow

@grahamsellers @TimothyLottes In VR, texture maps and normal maps look as if someone had just glued a picture onto a flat surface.

Timothy Lottes
@TimothyLottes
Follow

The fact that simple normal mapping doesn't work well in VR has profound implications for future rendering tech.

VR - The death of normal maps?

Normals maps don't supply real height differences

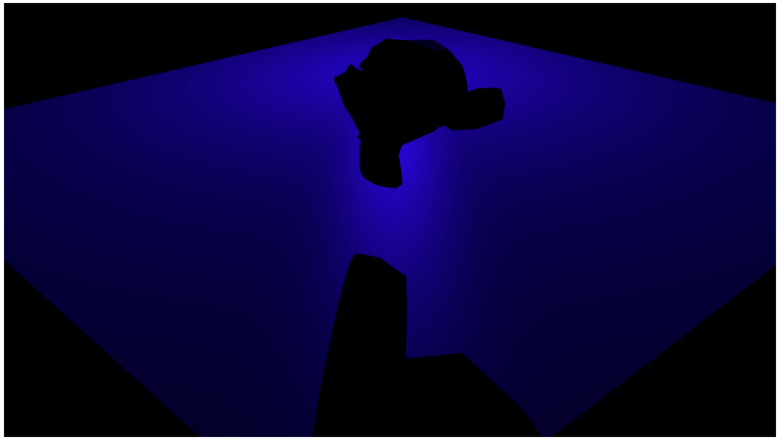
- No parallax

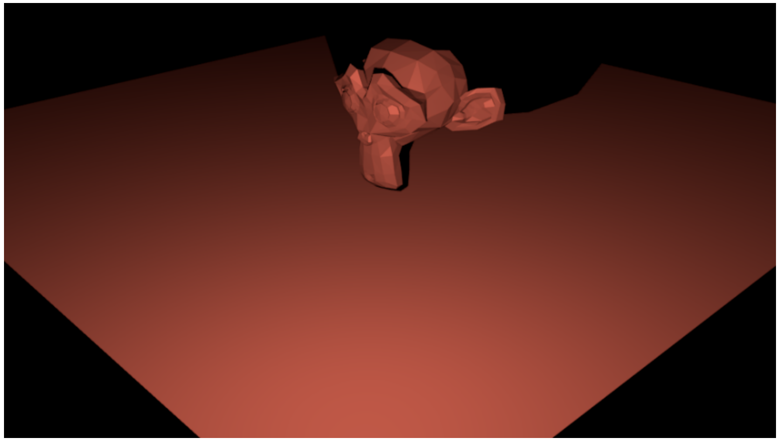
User can get close to most surfaces, can test for parallax with head movements

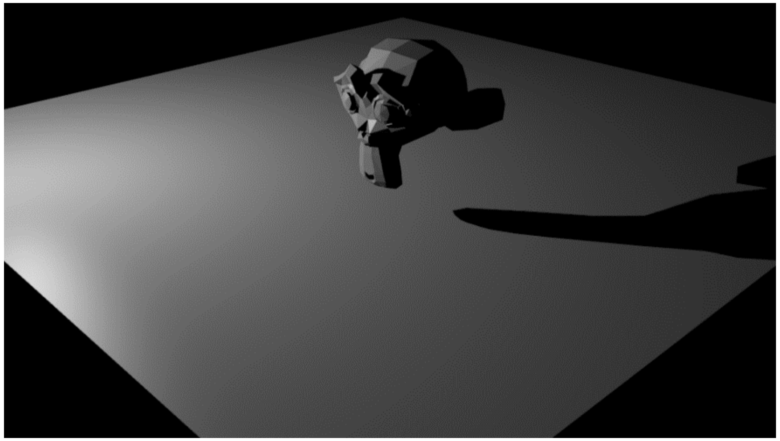
Solutions

- Use displacement or higher resolution meshes for everything that is close
- Use normal maps for fine details and relatively far-away surfaces
- Use parallax mapping

Forward Shading







Forward Shading

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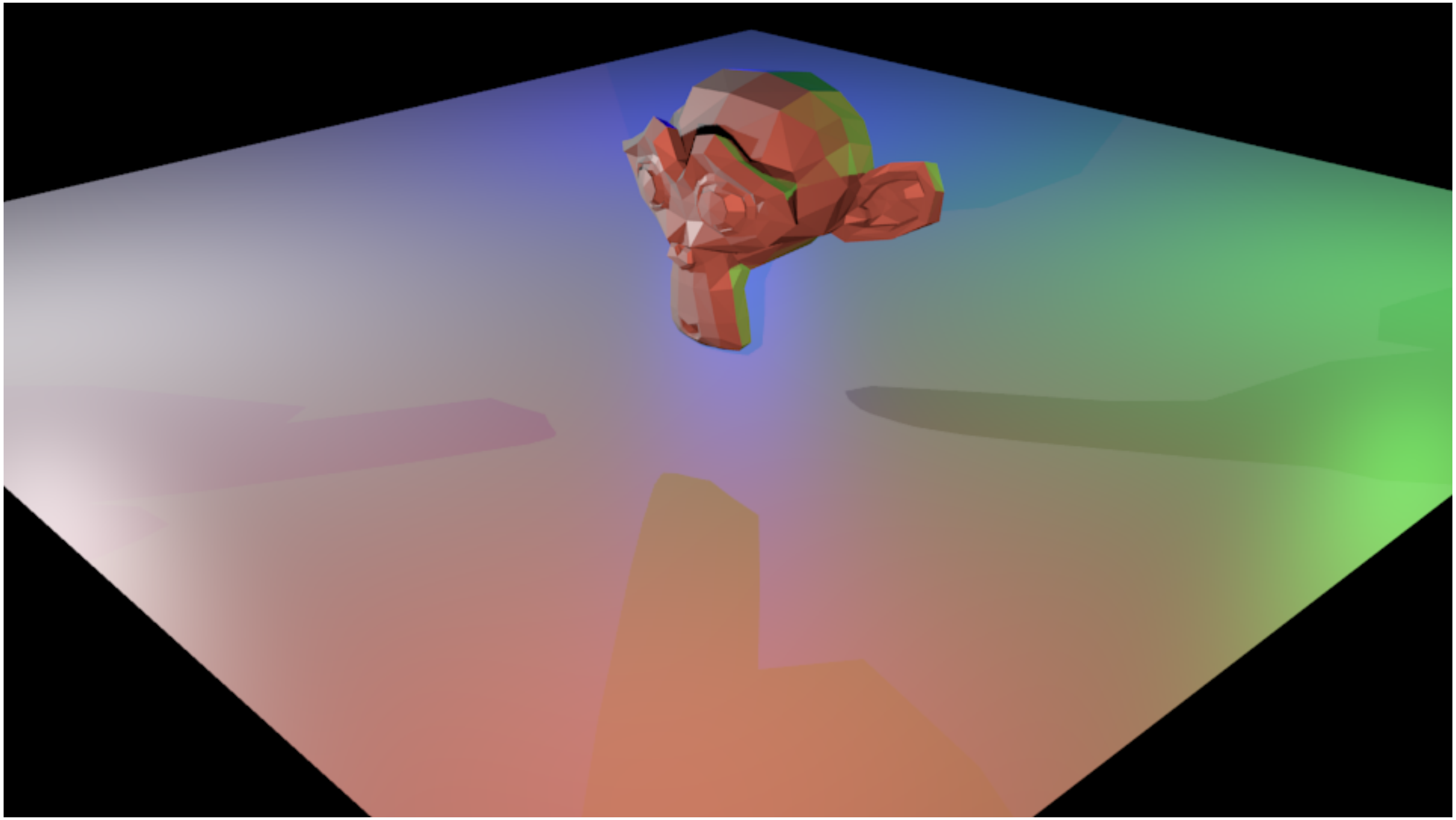


Forward Shading

a.k.a. what we have been doing so far

For each light source, render each object

- A certain number of lights can be batched into one pass, but still the shader will run several times
- Might use the closest x lights, but that changes the result

Blend/add together the influences in the frame buffer

If we have thousands of lights, we kill performance

Deferred Shading

Render the whole geometry into a (set of) buffer(s) (G-buffer), including

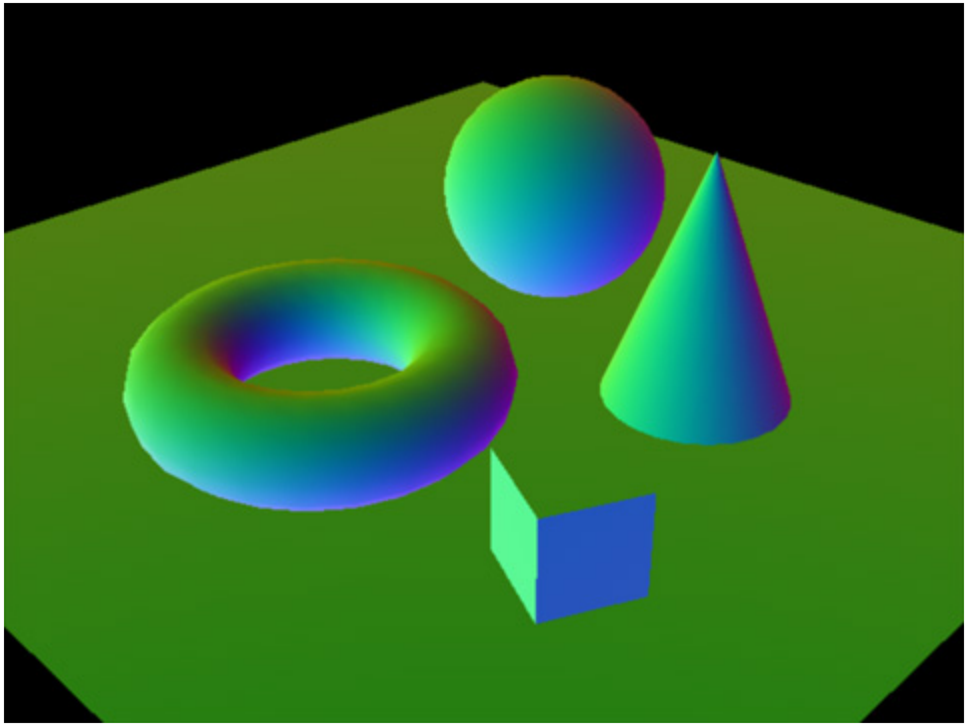
- Normals
- Colors
- Texture coordinates
- …

Calculate the shading, for each pixel once and only for the lights that influence the pixel

→ Main difference to forward rendering

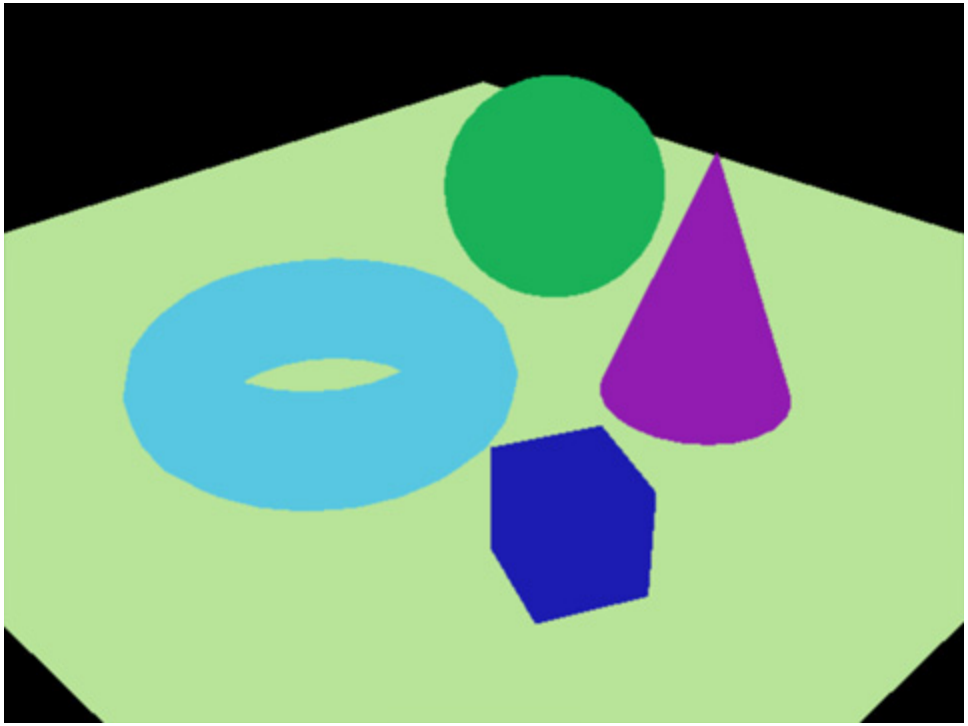
No need to render everything for each new light

Buffer for normals



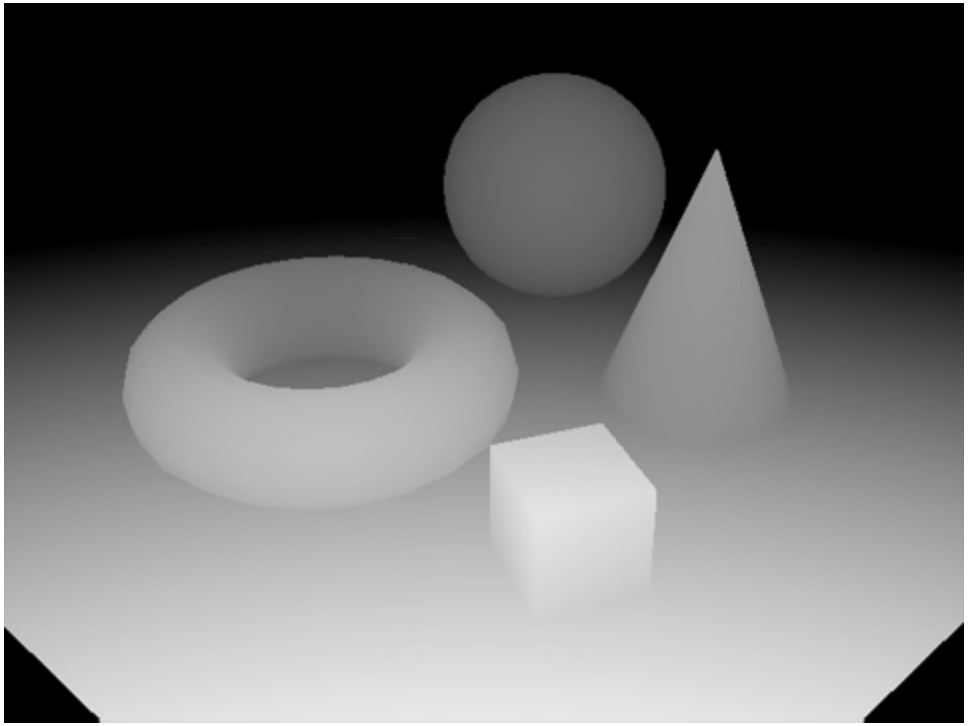
Deferred Shading

Buffer for different objects



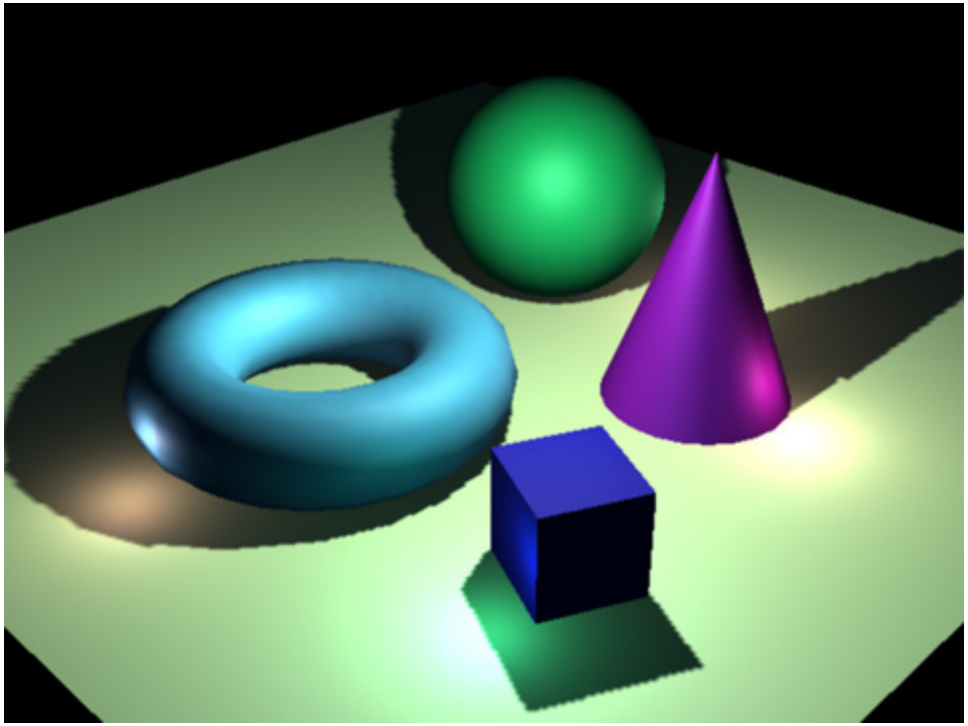
Deferred Shading

Depth Buffer



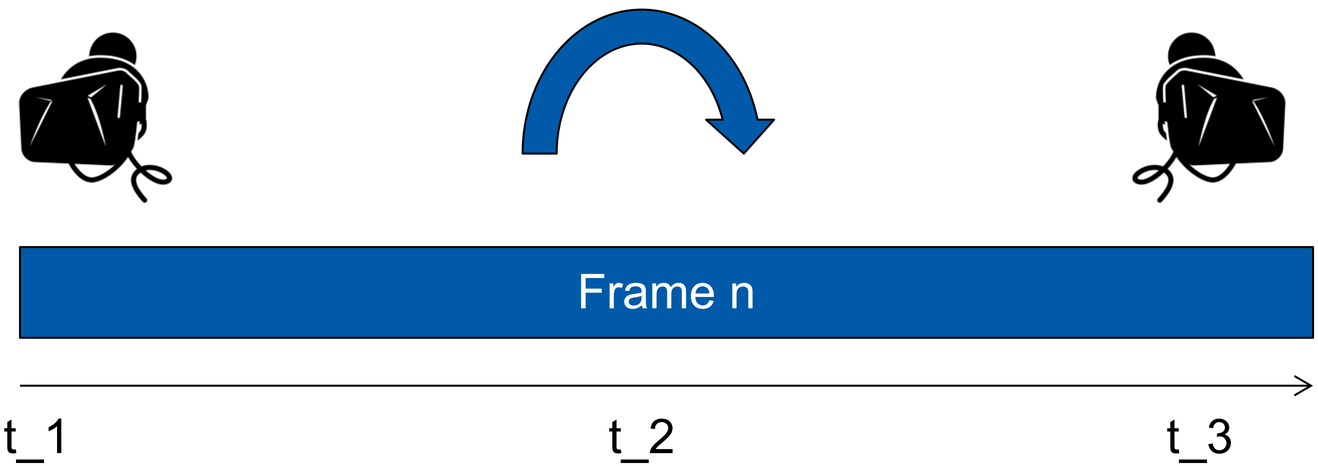
Deferred Shading

- Carry out lighting calculations on the buffers
- Each geometry rendered once
- Area of light effects for point/spotlights limited



Virtual Reality Frame Time

Which head position to use?



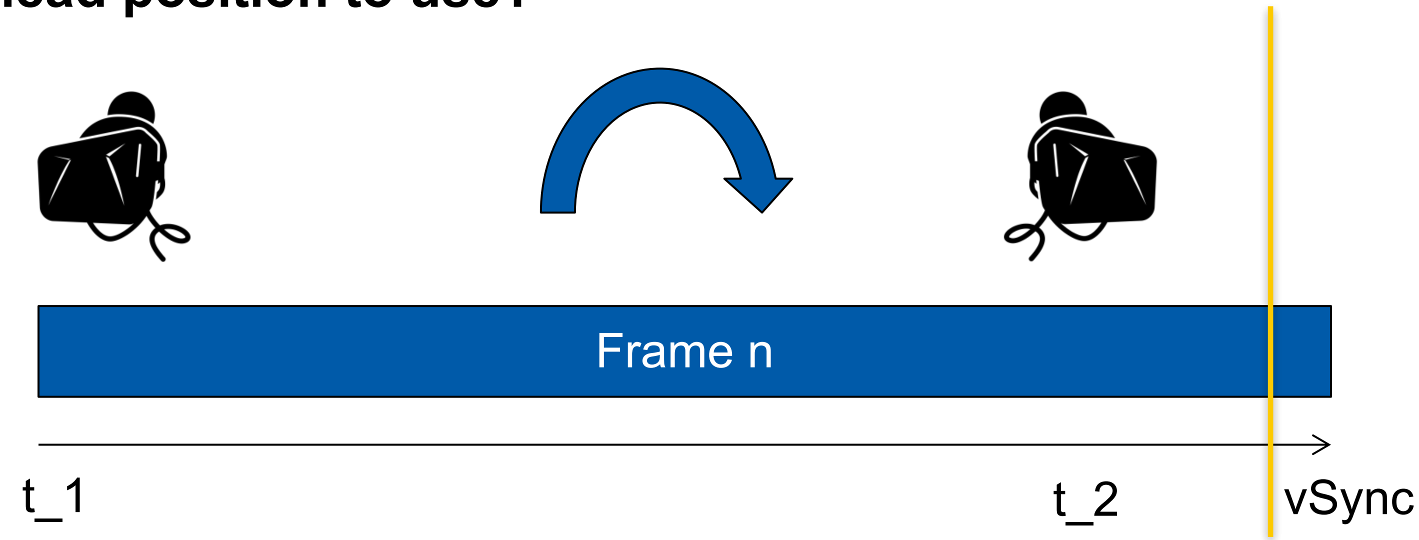
Future positions often predicted by HMD

- E.g. using the measured acceleration, physiological models
- Can use timewarp mechanism → will look at this in a later lecture

Icon by Hans Gerhard Meier, Noun Project

VR Frame Time: Time Warp

Which head position to use?



t1: Render image including depth buffer

t2: Update head position, reproject image

Time warp

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Render to texture

Project back from 2D to 3D

Apply new camera rotation (ideally only rotation)

Re-project to 3D

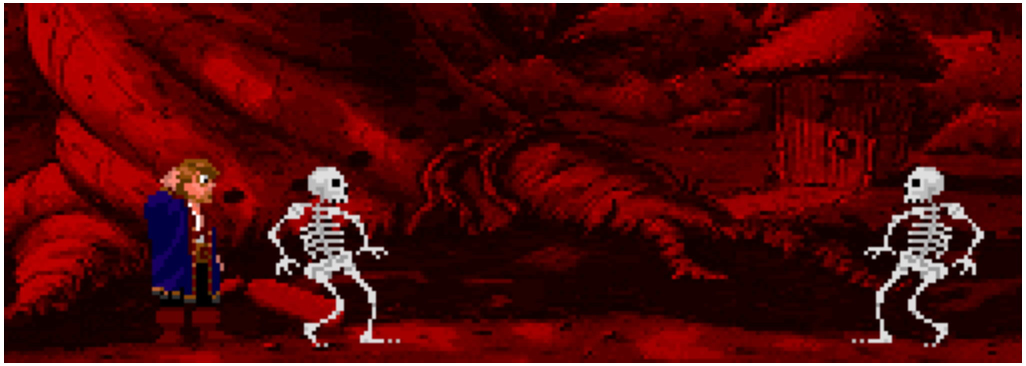
"Pulling in black"

- We only have a 2D image as the reference
- Pixels that are occluded are not in the image – "shadowed"
- If we move too fast or don't use pure rotation: We have nothing to interpolate with
  - Display black
  - Display blend of nearby colors
  - …

Time warp explanation

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

Animations



Monkey Island 2, 1991

Animating whole objects – MVP matrix

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projection * view * model

Animate the model matrix to animate an object

Animate the view matrix to change the camera‘s viewpoint

Animate the projection matrix for FOV changes (scopes, binoculars)

Be careful about the order

→ Can be reversed depending on matrix layout

Rotation Off-Center

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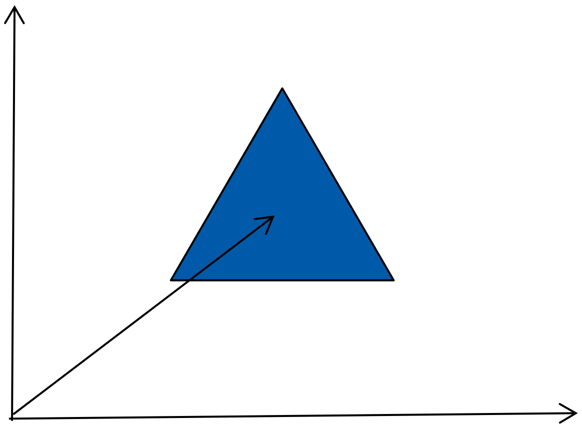
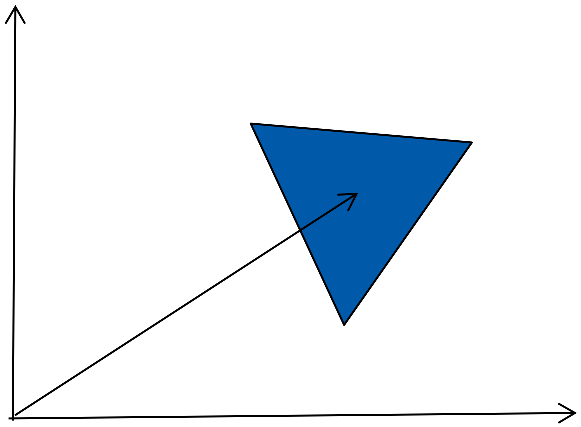
model = (translate to end position) * rotation
*** (translate rotation center to 0)**

Needed when the object is to be moved off-center (pivot point not at the model's origin)





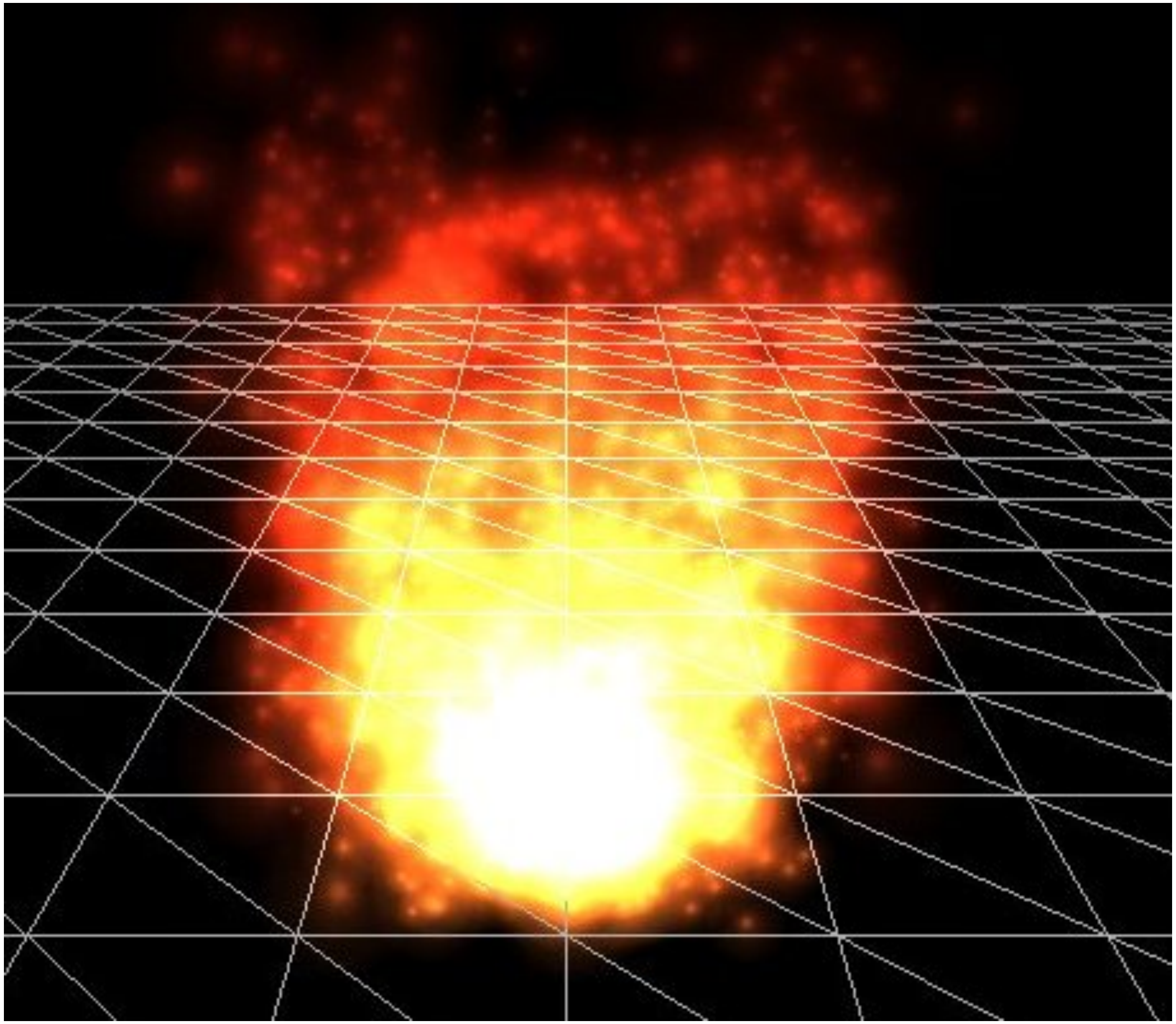
Scale

Super Mario 64, 2004

Shear

Motor Toon Grand Prix, 1994

Particle Systems (more in 2 lectures)

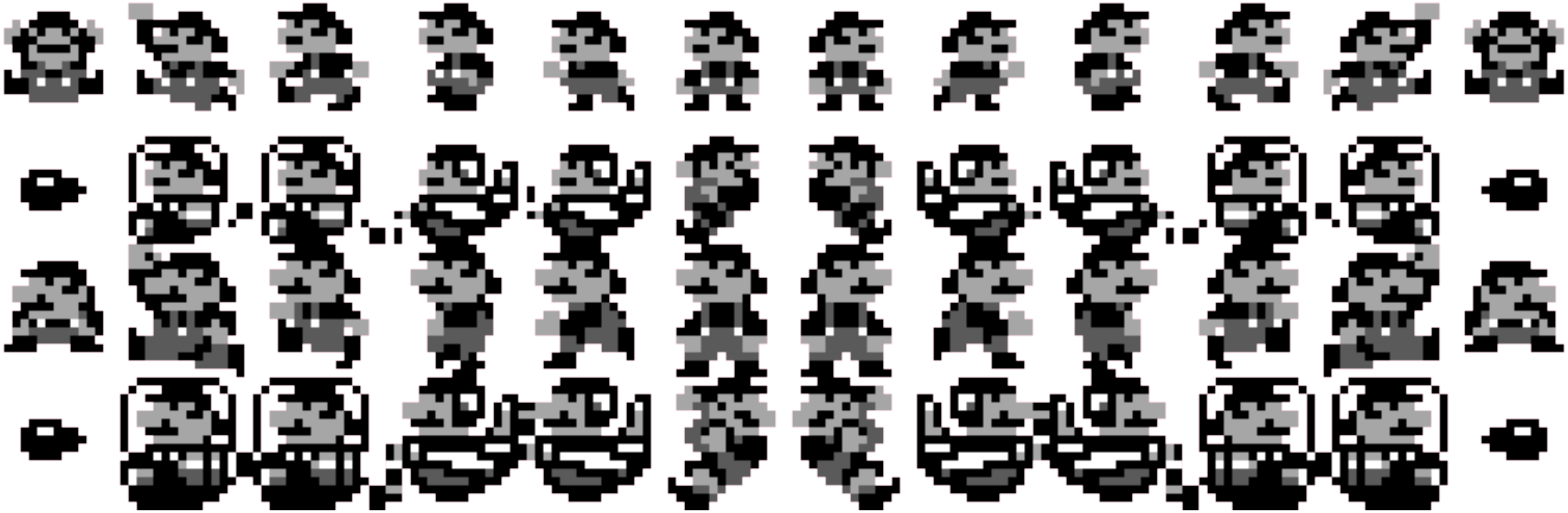


Fluids

PixelJunk Shooter 2, 2011

https://www.youtube.com/watch?v=7q8s7DMOOD4

Characters - Sprite Sheets



Vertex Animations

Quake, 1996

Vertex Animations

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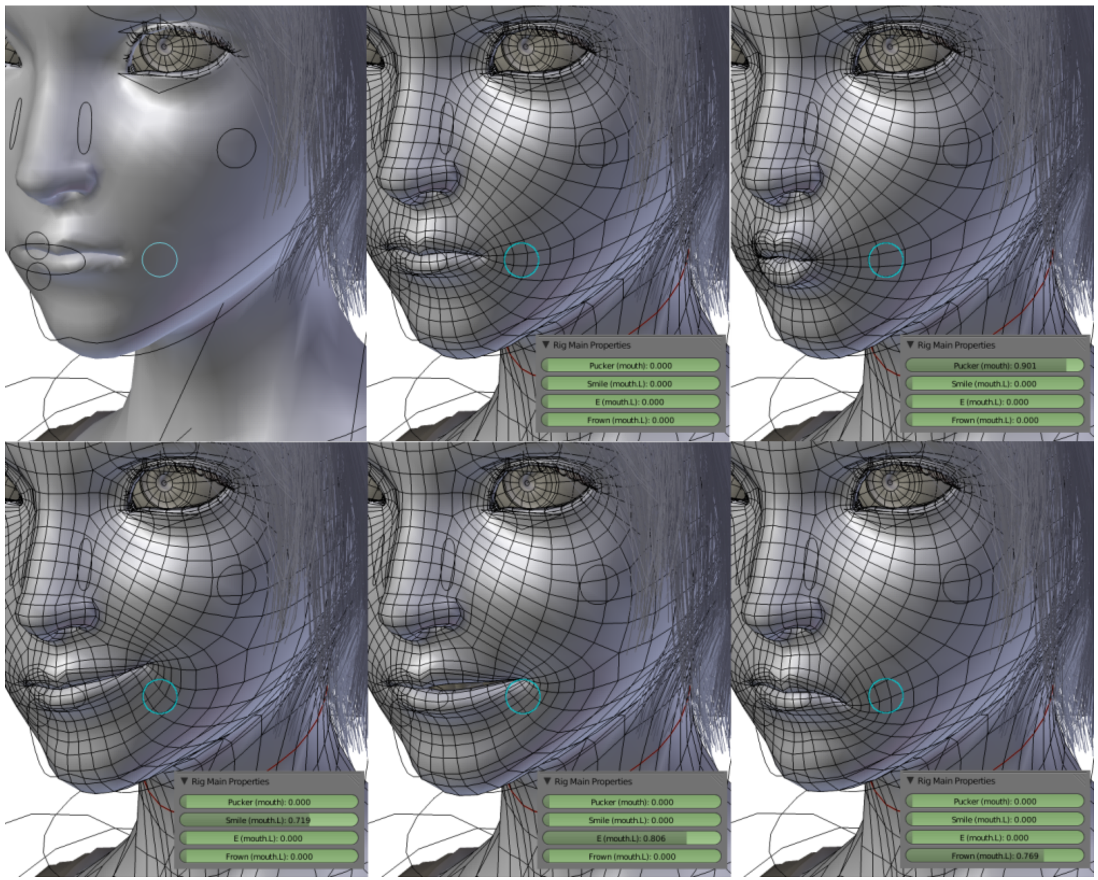
100 frames * 100000 vertices = lots of data

Blend Vertex Positions

Dragon Quest 8, 2004

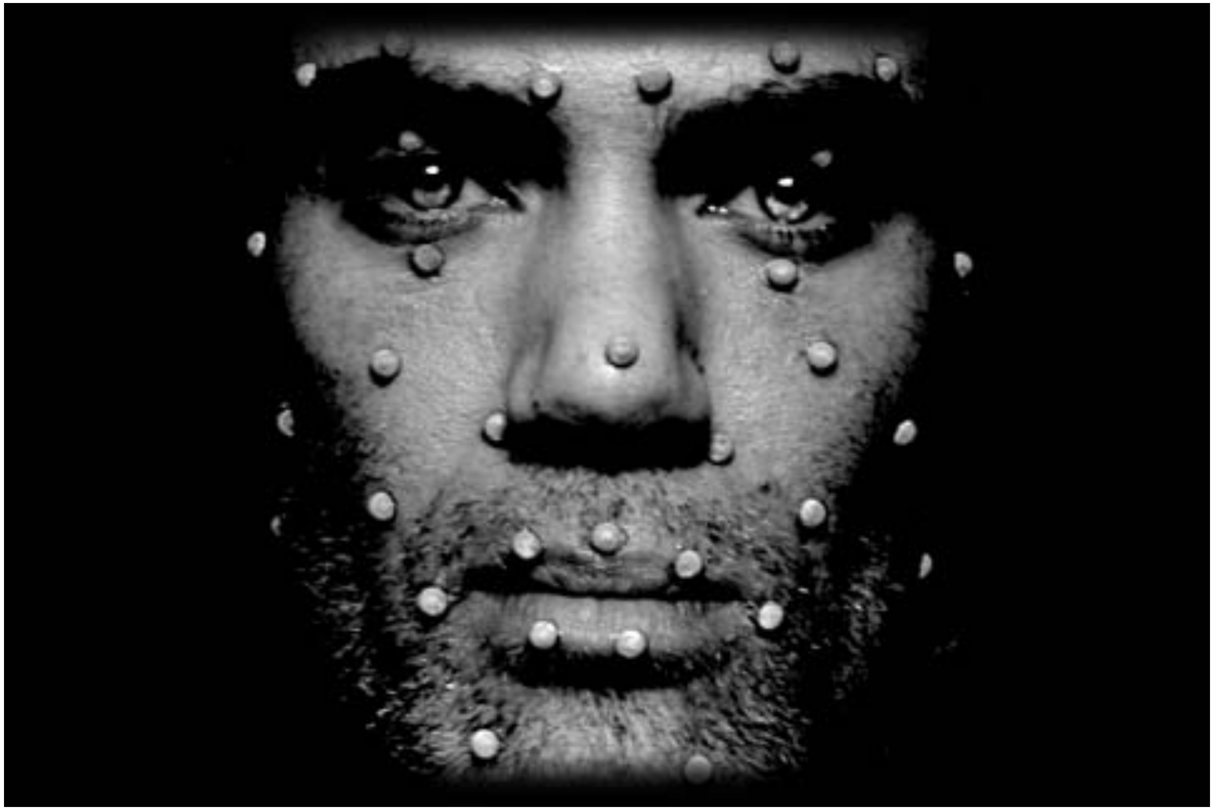
Faces

Morph target animation



https://en.wikipedia.org/wiki/Portal:Animation/Selected_picture/48

Performance Capture



Skeletal Animation

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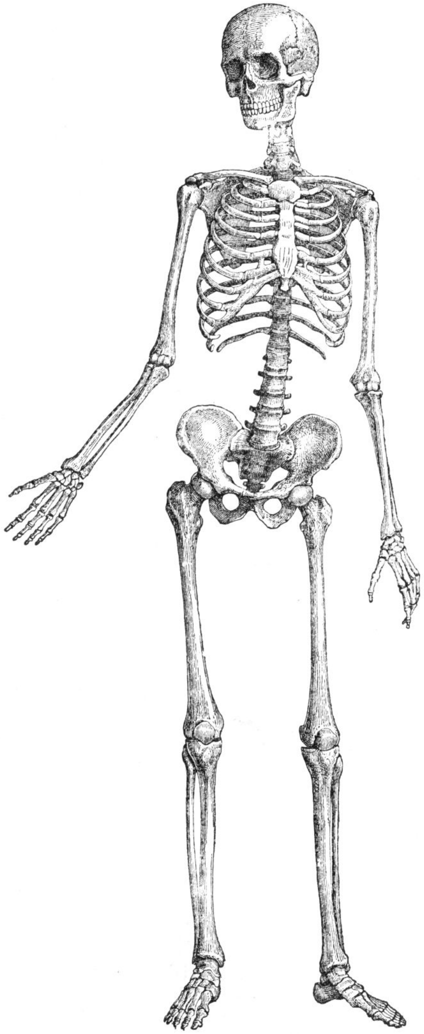
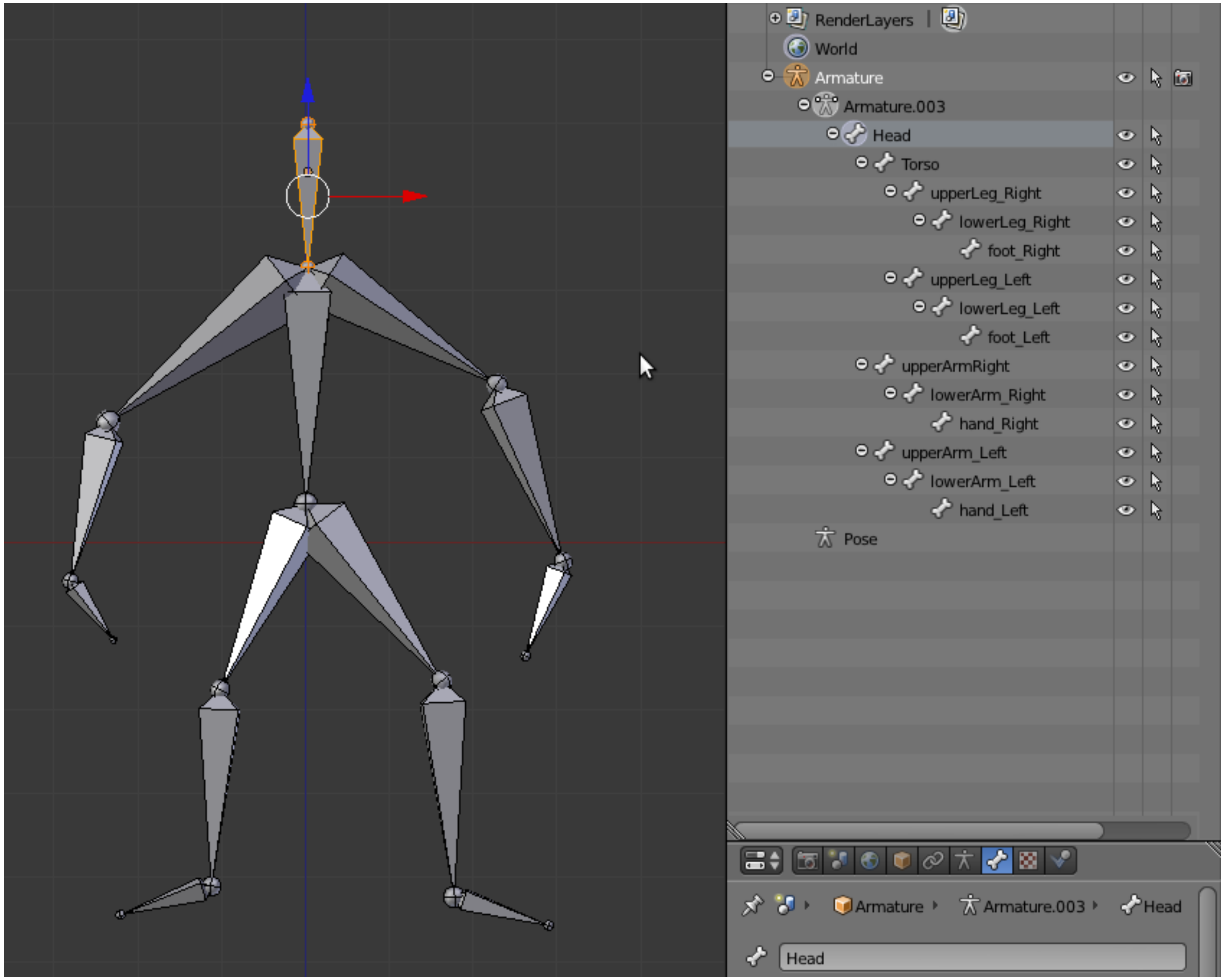
Skeletal Animation



Skeletal Animation



Skeletal Animation

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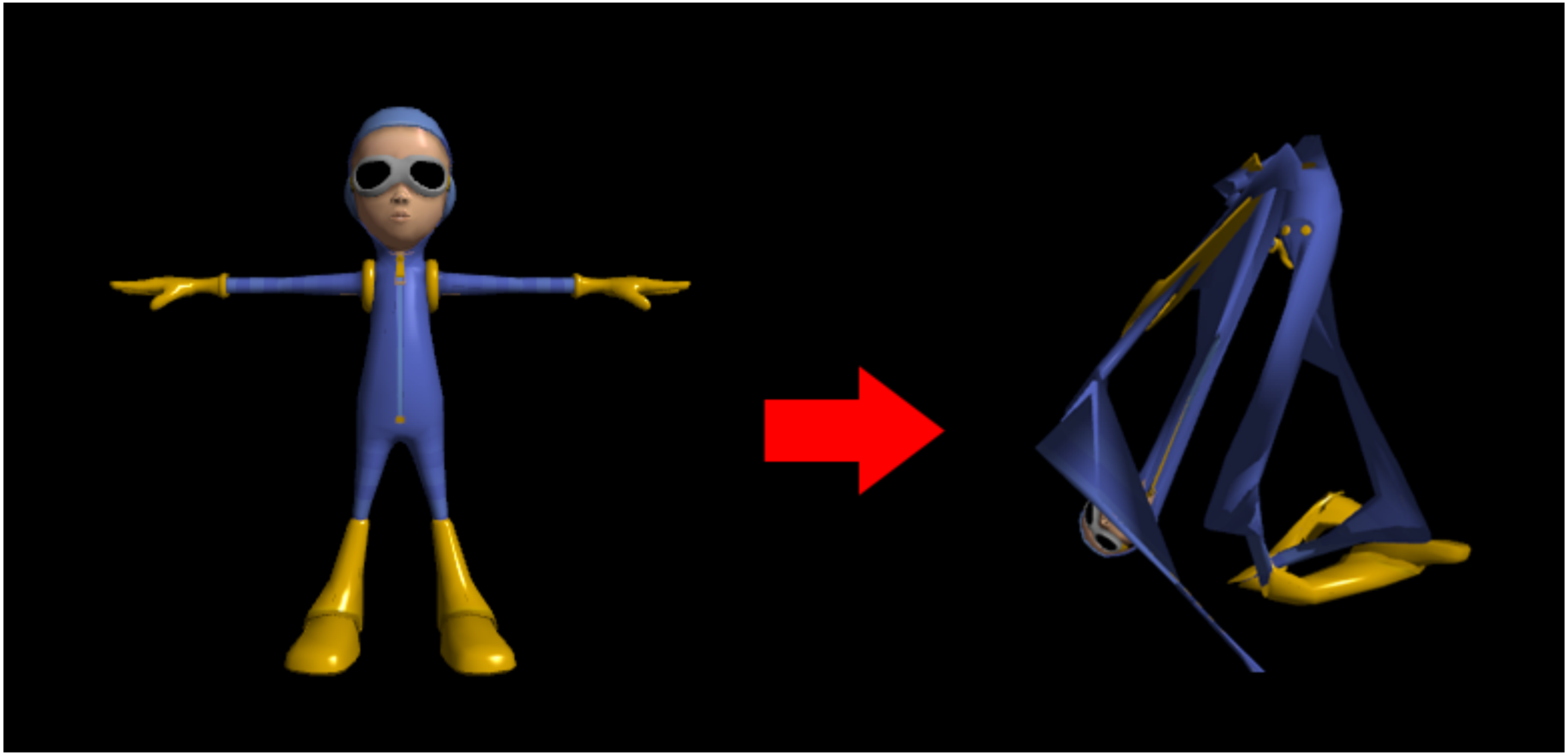
One bone – One Transformation matrix

- Or just a rotation
  - Depends on your gfx tool

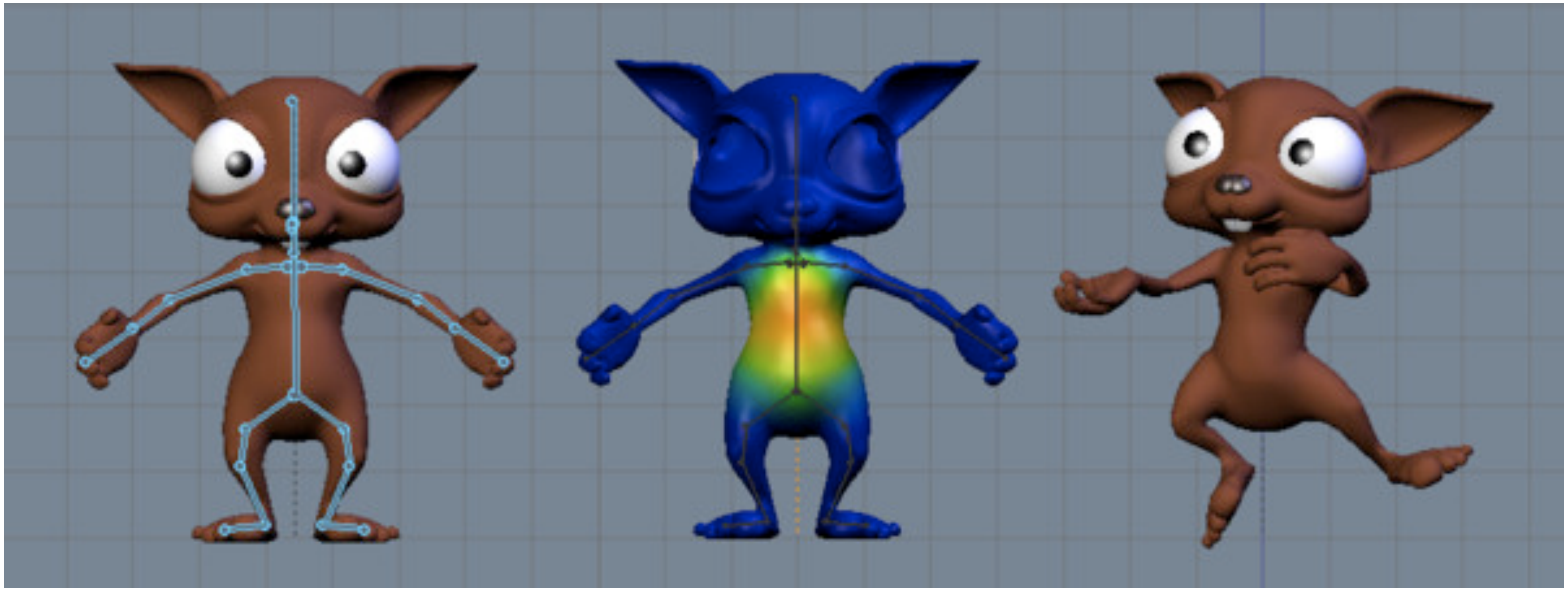
Animation

- Just an array of small transformation matrix arrays
- Framerate can be low
  - Interpolation works fine

Skinning (gone wrong)



Skinning



Skinning

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For each vertex

- Array of (weight, index)

At start

- Compute inverse of every bone transform matrix (multiply all along the way to the bone) → goes from model space to bone space

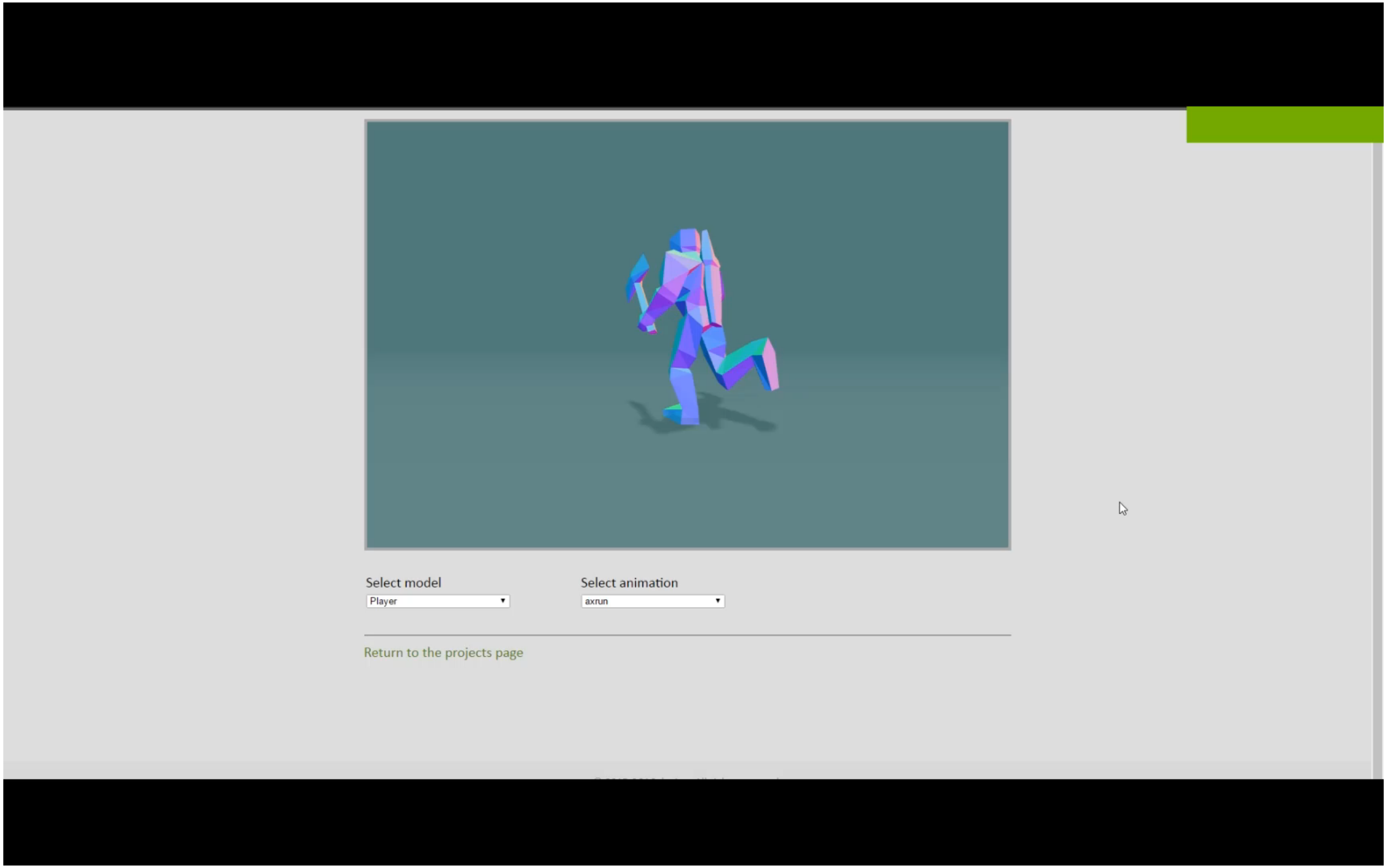
For each animation step

- Compute new transform matrices
- For each bone compute new transform * inverse

For each vertex

- For each weight (usually <=4 or 8)
  - Compute (new transform * inverse * vertex) * weight
- Sum it up

Quiz: Which animation?

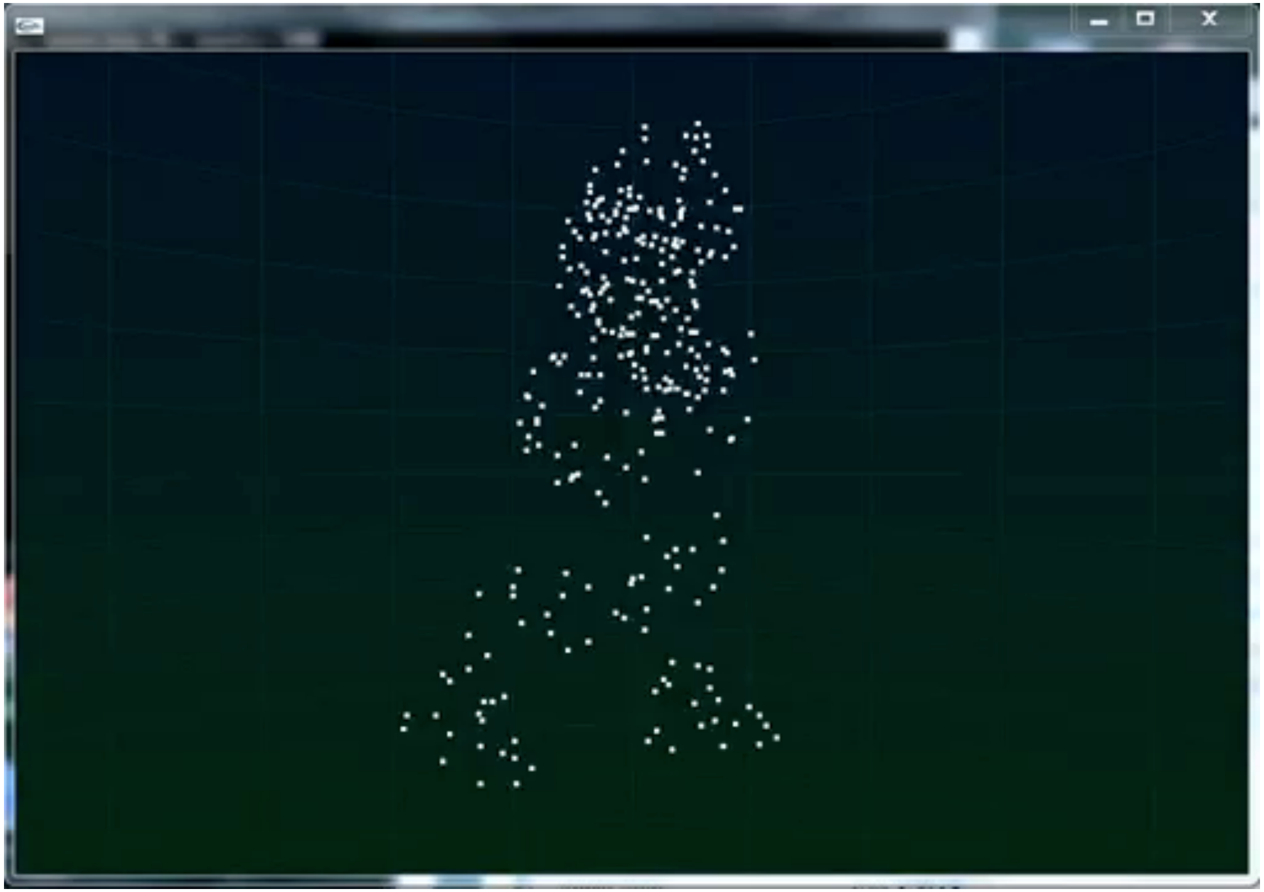


http://decino.nl/?p=quake-model-viewer

Quiz: Which animation?

https://www.youtube.com/watch?v=J8JPVj-AYTw

Quiz: Which animation?



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

Motion

Root Motion: Save motion of root bone during animation

- Motion is "hard-coded“
- Can be fine-tuned by the designers, e.g. different speeds at different points

+ Exact control (for animators)

- Somewhat less control for gamers

- More animations needed

No root motion: Character stays in one place

+ Can be blended easier

+ Can be used more versatile

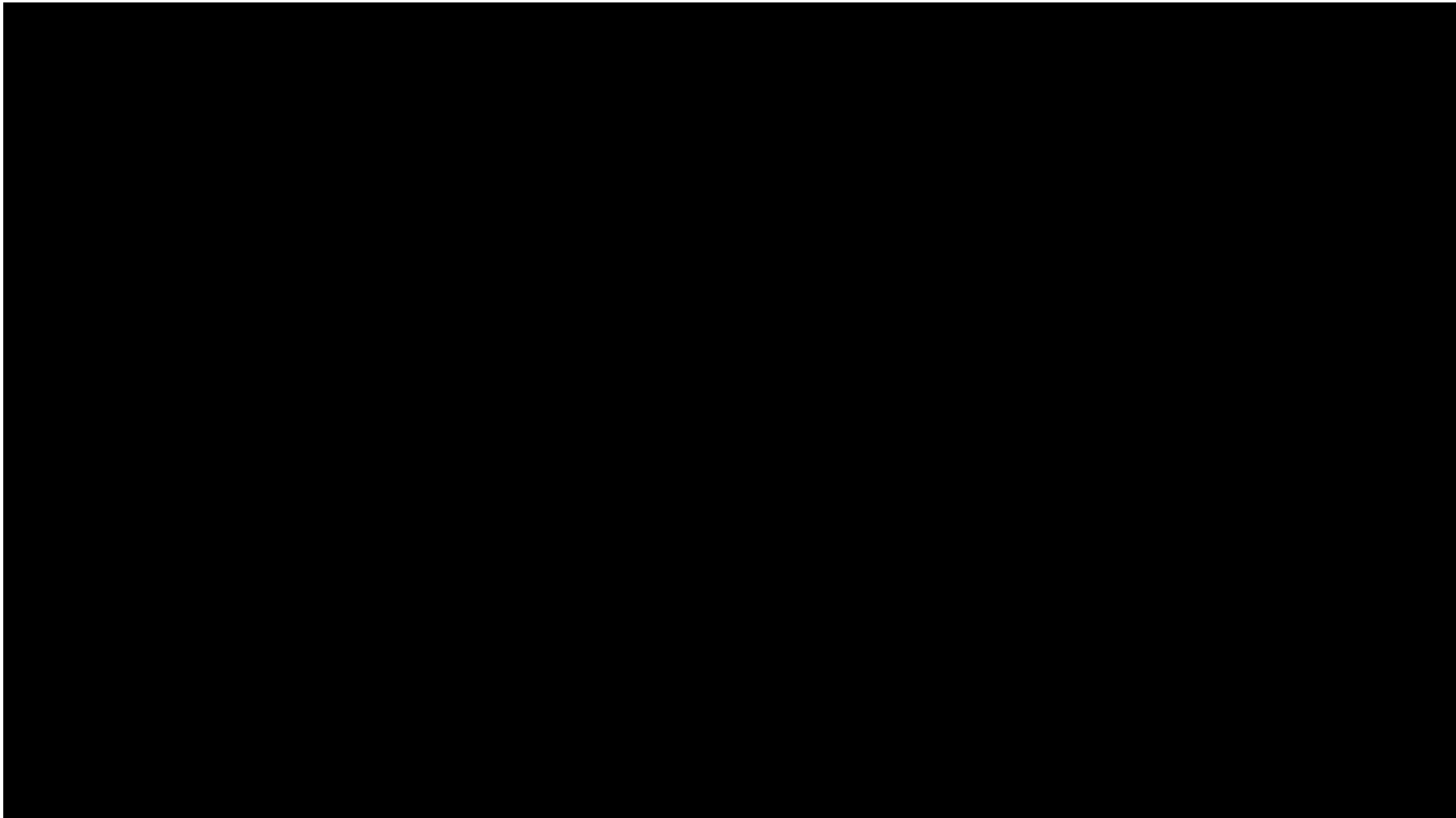
- Footskating

- Accelerations

- …

http://research.cs.wisc.edu/graphics/Gallery/kovar.vol/Cleanup/

Root Motion Example



https://www.youtube.com/watch?v=c-eq0FRqDNM

Motion Capturing

Motion Retargeting

https://www.youtube.com/watch?v=Vn-vVzMGgec

Inverse Kinematics

Forward Kinematics

Input: Bone rotations

Output: Final positions

Inverse Kinematics

Input: Final positions

Output: Bone rotations

Inverse Kinematics

Super Mario Sunshine, 2002

Inverse Kinematics

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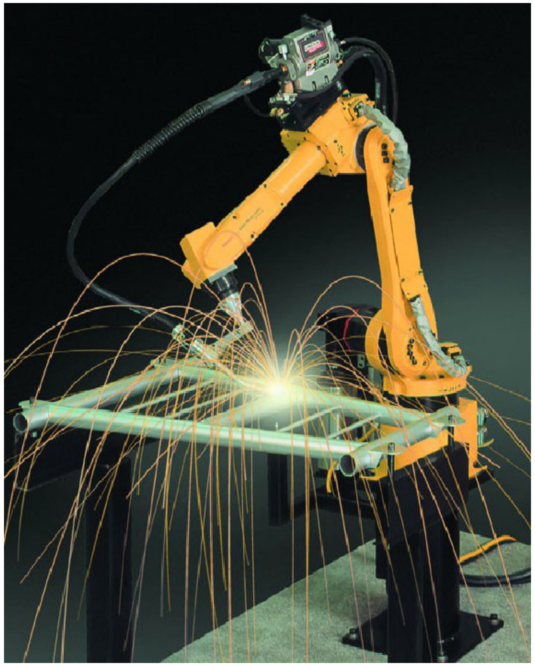
Numerical, iterative solution using Jacobi Matrix

- See Robotics Lectures



Unexpected Deformations

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„Achselhölle“, Candy Wrapper Problem

Spherical Skinning

- http://www.crytek.com/download/izfrey_siggraph2011.pdf

Dual Quaternion Skinning

- https://www.youtube.com/watch?v=4e_ToPH-I5o

„Achselhölle“ visualized

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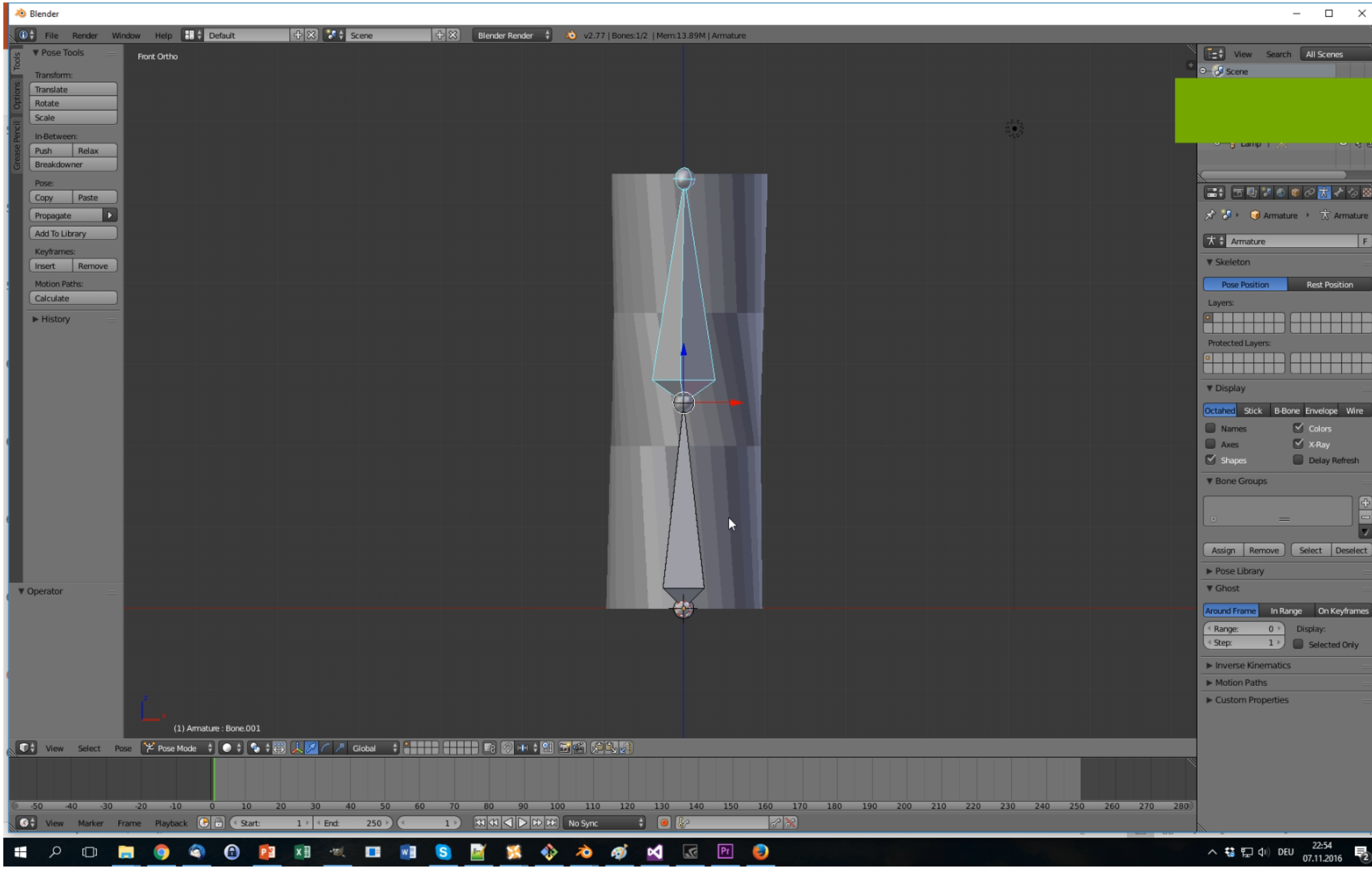

Muscles

Physical Animations

Goat Simulator, 2014

Hair, Cloth,…

Tomb Raider, 2013

Rag Dolls

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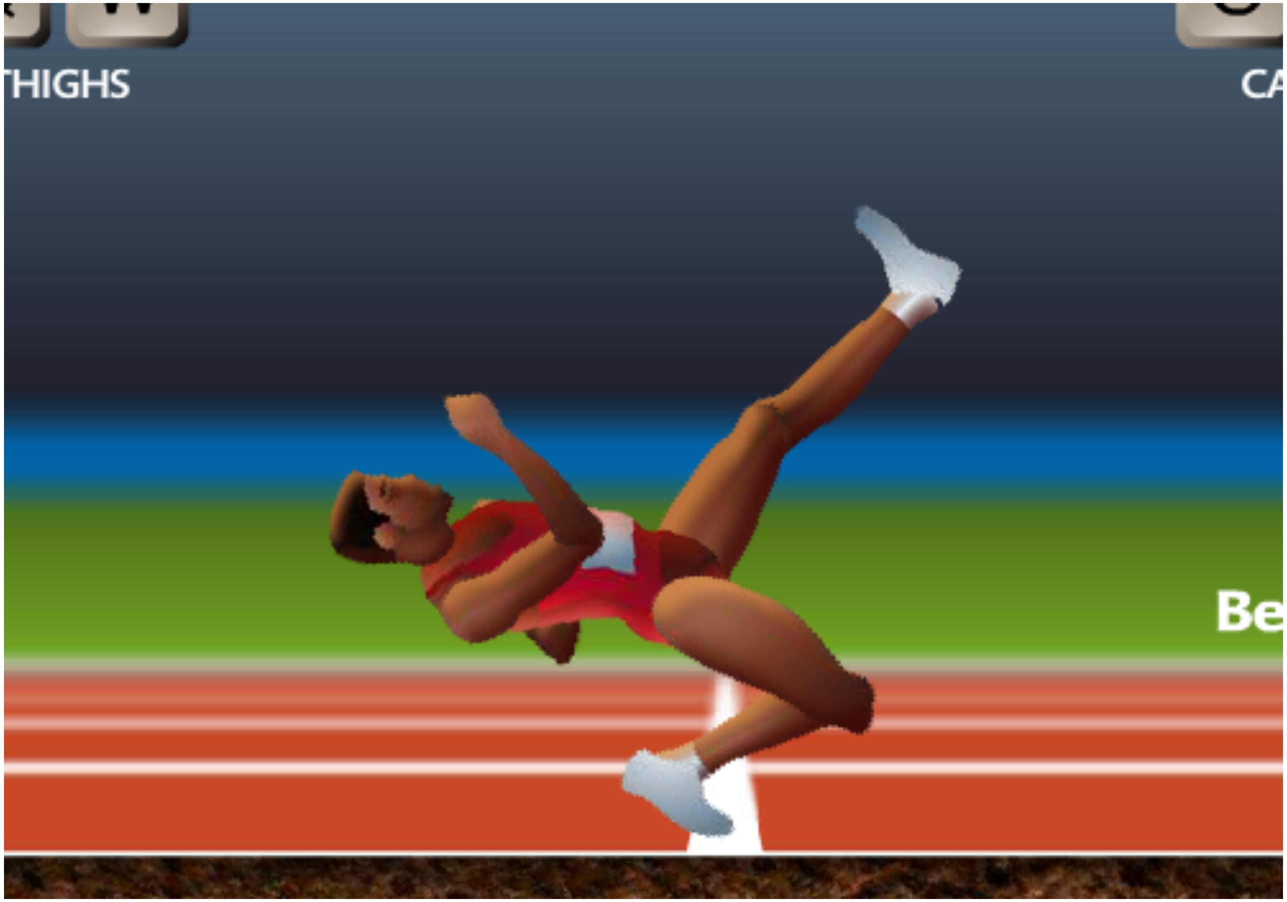


QWOP (2008)

Mixture between forwards and physically based

During regular animation

→ Driven by forward animation

Physical Interactions

- On becoming unconscious
- On stumbling
- → Switch to ragdoll behavior

On regaining control

→ Blend to the forward kinematics again

Summary

Normal maps, bump mapping

- Increase the visual quality without increasing vertex count
- Bake from higher-poly version or paint/generate

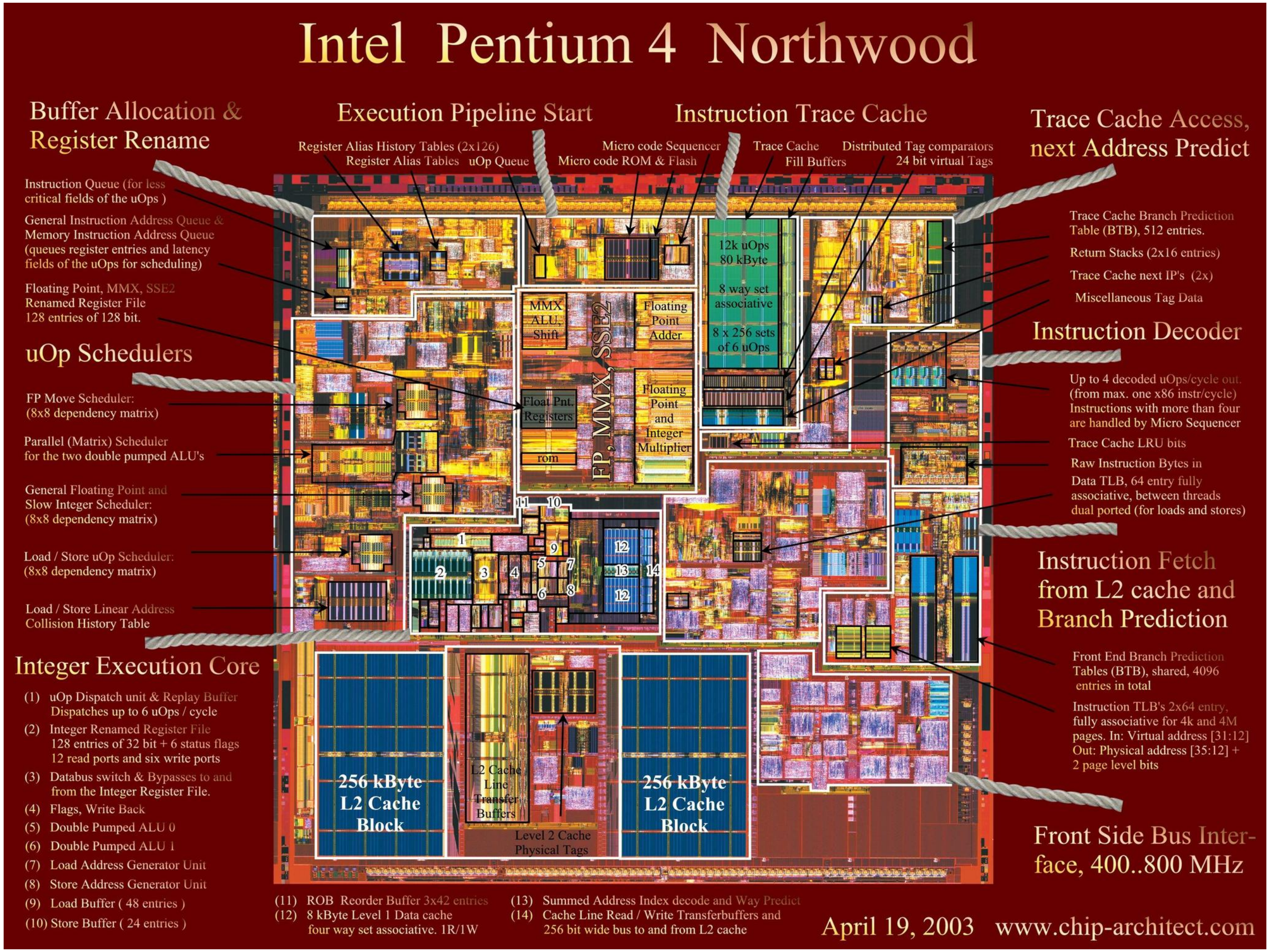
Displacement maps

- Increase visual quality by increasing vertex count
  - But our badass GPU does it for us

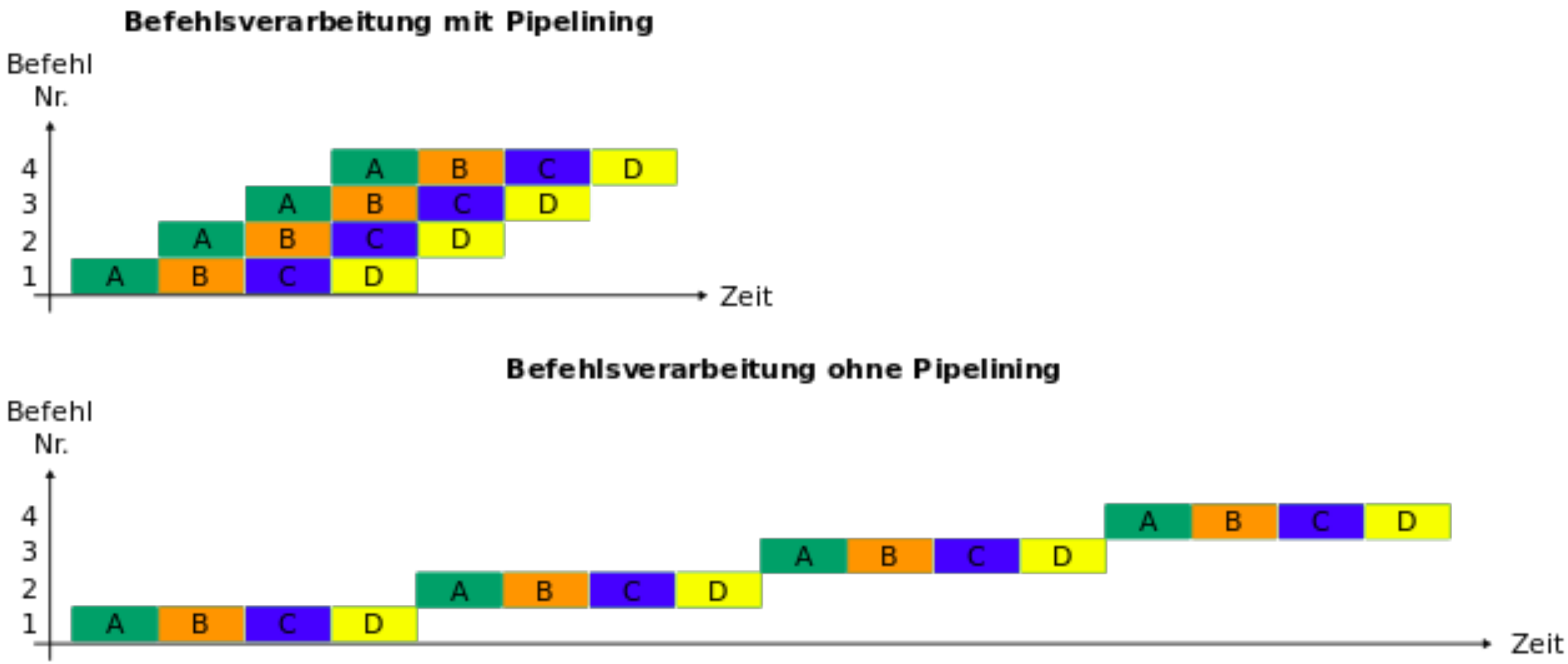
Animation techniques

- Morph Targets
- Skeletal animation

CPU internals



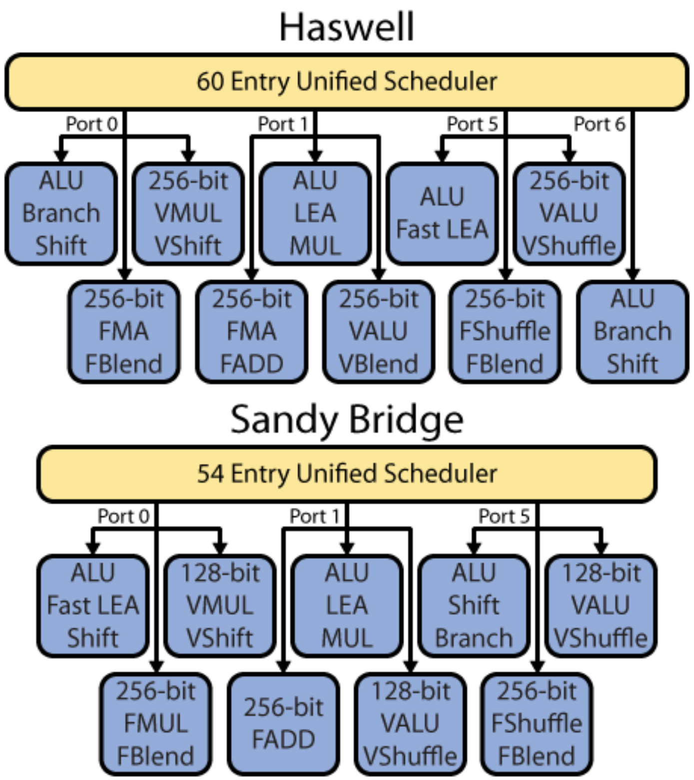
Pipelining



https://de.wikipedia.org/wiki/Pipeline_(Prozessor)

Multiple Execution Units

- „ Note that Figure 3 does not show every execution unit, due to space limitations.“ (from http://www.realworldtech.com/haswell-cpu/4/)



Hazards

Structural Hazards

- Out of hardware

Data Hazards

- Data dependencies

Control Hazards

- Dynamic branching

Structural Hazards

Example

- One command is in the fetch state and wants to read memory
- One command wants to write to the memory

Modern CPUs add more ALUs

Already at a very high level

Data Hazards

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Sometimes just register uses, but not real data dependencies

#	Instruction
1	`R1 = M[1024]`
2	`R1 = R1 + 2`
3	`M[1032] = R1`
4	`R1 = M[2048]`
5	`R1 = R1 + 4`
6	`M[2056] = R1`

→

#	Instruction	#	Instruction
1	`R1 = M[1024]`	4	`R2 = M[2048]`
2	`R1 = R1 + 2`	5	`R2 = R2 + 4`
3	`M[1032] = R1`	6	`M[2056] = R2`

→ Register renaming

- CPU uses more registers internally than can be directly addressed

Data Hazards

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Compiler can help

- Reorder instructions
- Depends highly on CPU

Out-of-Order CPUs

- Can reorder instructions themselves
- Can incorporate current situation in decisions
- All current x86 CPUs are out-of-order
- More and more ARM CPUs are out-of-order
- PS360 are in-order
- Current generation consoles are out-of-order

Control Hazards

Speculative execution

- Branch Prediction more and more sophisticated

Branch prediction example

```
int main()
{
    // generate data
    const unsigned arraySize = 32768;
    int data[arraySize];

    for (unsigned c = 0; c < arraySize; ++c)
        data[c] = std::rand() % 256;


    // !!! with this, the next loop runs faster
    std::sort(data, data + arraySize);


    // test
    clock_t start = clock();
    long long sum = 0;

    for (unsigned i = 0; i < 100000; ++i)
    {
        // primary loop
        for (unsigned c = 0; c < arraySize; ++c)
        {
            if (data[c] >= 128)
                sum += data[c];
        }
    }

    double elapsedTime = static_cast<double>(clock() - start) / CLOCKS_PER_SEC;

    std::cout << elapsedTime << std::endl;
    std::cout << "sum = " << sum << std::endl;
}
```

http://stackoverflow.com/questions/11227809/why-is-processing-a-sorted-array-faster-than-an-unsorted-array

Memory Access

Cache Hierarchy critical for performance

L1 cache ~ KiloBytes

L2 cache ~ MegaBytes

Main memory ~ GigaBytes

L1 cache ~ 0.5 ns

L2 cache ~ 7 ns

Main memory ~ 100 ns

More information

Scott Meyers - CPU Caches and Why You care
https://vimeo.com/97337258

http://gameprogrammingpatterns.com/data-locality.html

Memory Access

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Access pattern prediction

- Works best when data is reused or for sequential data reads

Cache Lines

- Memory read in blocks
- ~ 64 Bytes
- Proper data alignment can help

POD

„Plain old data“

```
struct Data {
 int a;
 float b;
};
```

Predictable data structures

No constructor calls during array allocation

No additional data for virtual function pointers

Data data[64];

Linear data of 64*sizeof(Data) bytes

Memory alignment

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Add unused data

Use system specific things

- posix_memalign(..)

Use alignas in C++ 11

```
struct alignas(16) Data {
 int a;
 float b;
};
```

alignas(128) char cacheline[128];

Packed structures

```
struct InsufficientParticle       //total size 44 bytes
{
  bool visible;                   //31 bits of padding
  Texture* texture;               //pointer to texture
  int alpha;                      //only needs 0 to 256
  int type;                       //enumeration – 4 possible types
  Vec3 position;
  Vec3 velocity;
}
```

Steve Rabin: Game Programming Gems 8: Game Optimization through the Lens of Memory of Data Access

Packed structures

```
struct Efficient particle          //total size 30 bytes
{
  Vec3 position;
  Vec3 velocity;
  unsigned char alpha;             //saved 3 bytes (0-255)
  unsigned char rotation;          //saved 3 bytes (0-255 degrees)
  unsigned texture:4;              //saved 28 bits (texture index)
  unsigned type:2;                 //saved 29 bits (enumeration)
  unsigned visible:1;              //saved 31 bits(single bit)
}
```

Cache efficiency

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Order from largest to smallest members to reduce padding

- sizeof(MyStruct) gives you the size including padding

Separate hot and cold data

- Keep hot data (often used) close together
- Watch out for gaps between hot data

Prefetch data

- Available on some platforms
- Make sure data is available on time

Lock the cache

- Some platforms, e.g. Wii, allow parts of the cache to be locked and managed by the application

Summary

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CPU Internals

Hazards

- Structural Hazards
- Data Hazards
- Control Hazards

Memory access

Memory alignment

Evaluation of Redirected Walking Methods in Virtual Reality

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Dauer:
- ~30min

Ort:
- S3/20 103, Rundeturmstraße 10,

Eintragen hier:
- https://doodle.com/poll/trhg73ibtp5a2esn

Das Wichtigste:
- Es gibt Kekse für alle Teilnehmer :D

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