Lighting & Texturing

3D GM&P 21/22

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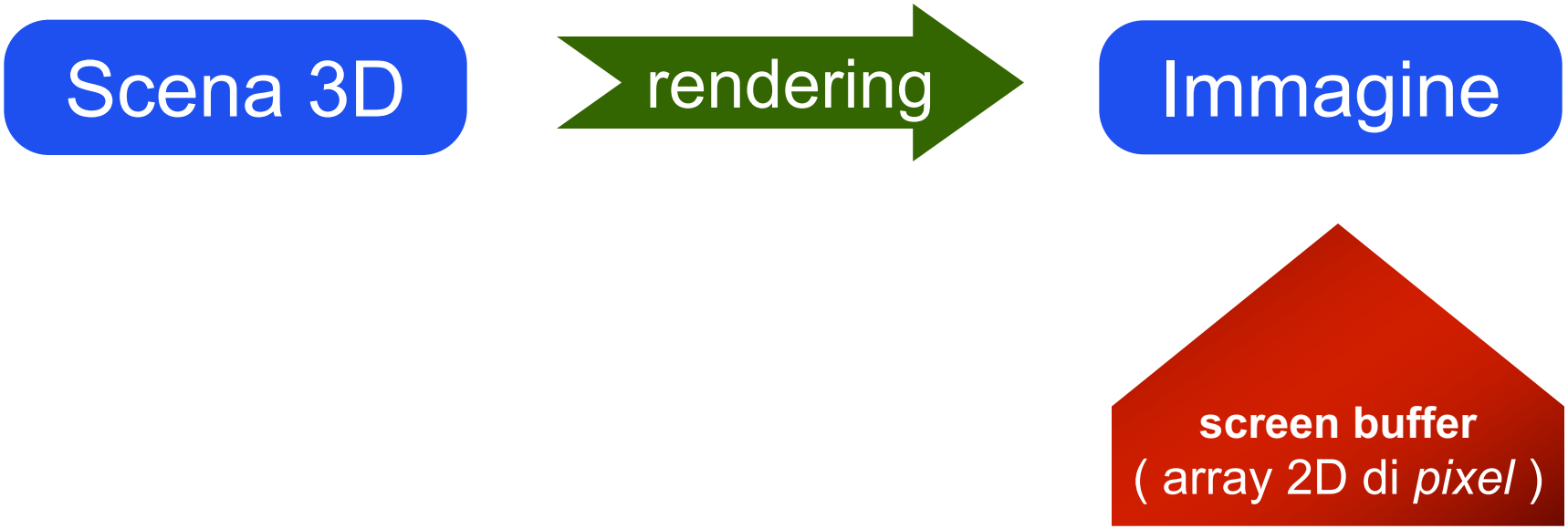
Thanks to M. Tarini for some of the slides

Rendering


Scena 3D
rendering
Immagine
screen buffer
(array 2D di *pixel*)

Rendering nei games

- Real time
  - (20 o) 30 o 60 FPS
- Hardware based
  - Pipelined, stream processing
- Complessità:
  - Lineare col numero di primitive
- Classe di algoritmi:
  - rasterization based

Rendering Algorithms Paradigms

RAY-TRACING

```
For each pixel p:
   make a ray r
   for each primitive o in scene:
      if intersect(r,o)
      then find color for o
           color p with it
```

LIGHTING

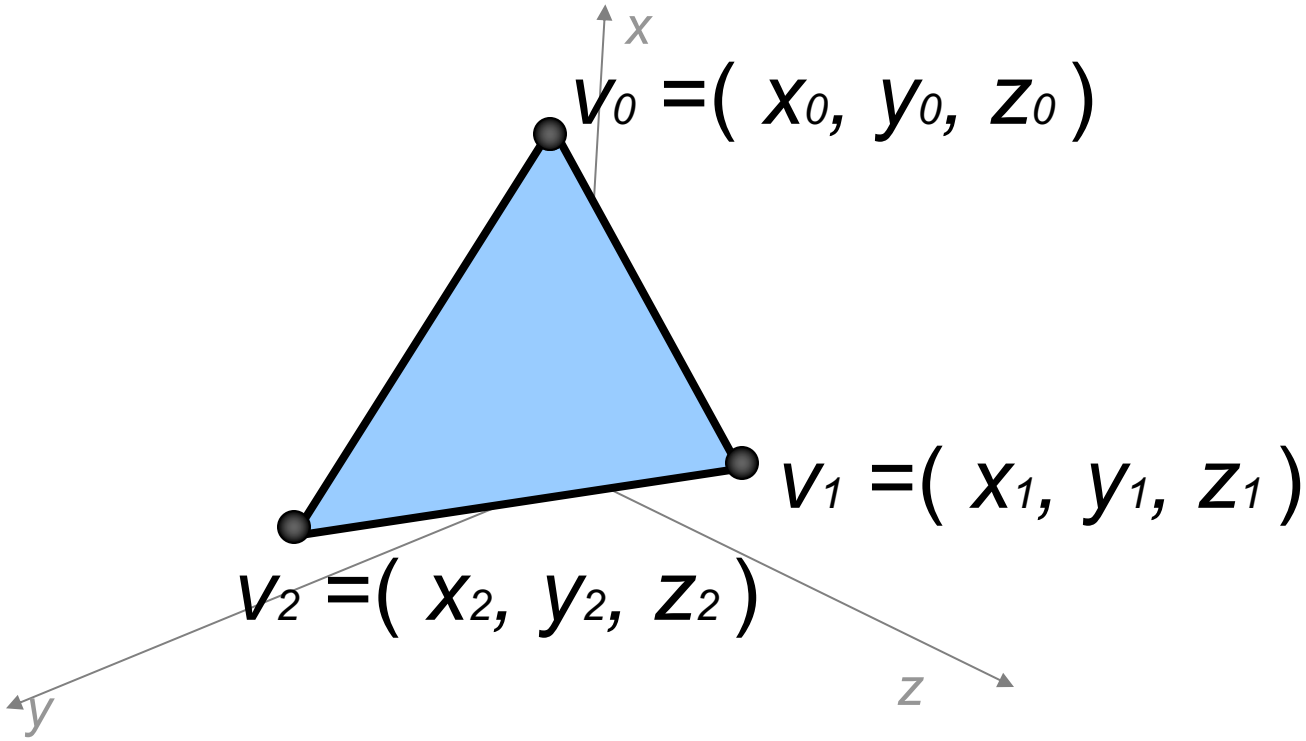
RASTERIZATION BASED:

```
For each primitive o:
   find where o falls on screen
   rasterize 2D shape
   for each produced pixel p :
     find color for o
     color p with it
```

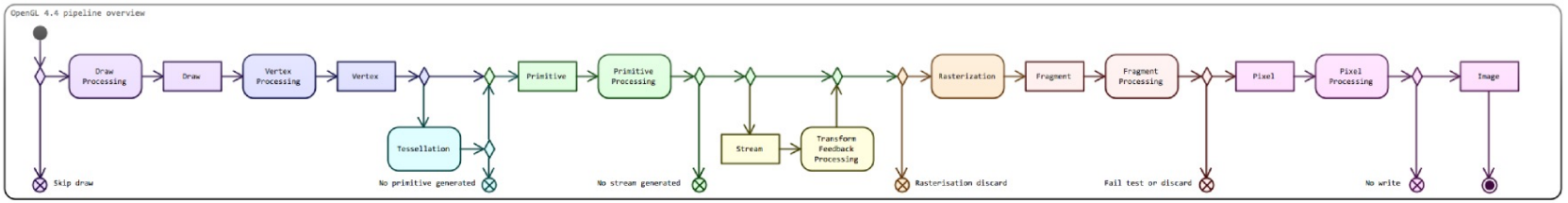
PROJECTION
3D → 2D
(aka TRANSFORM)

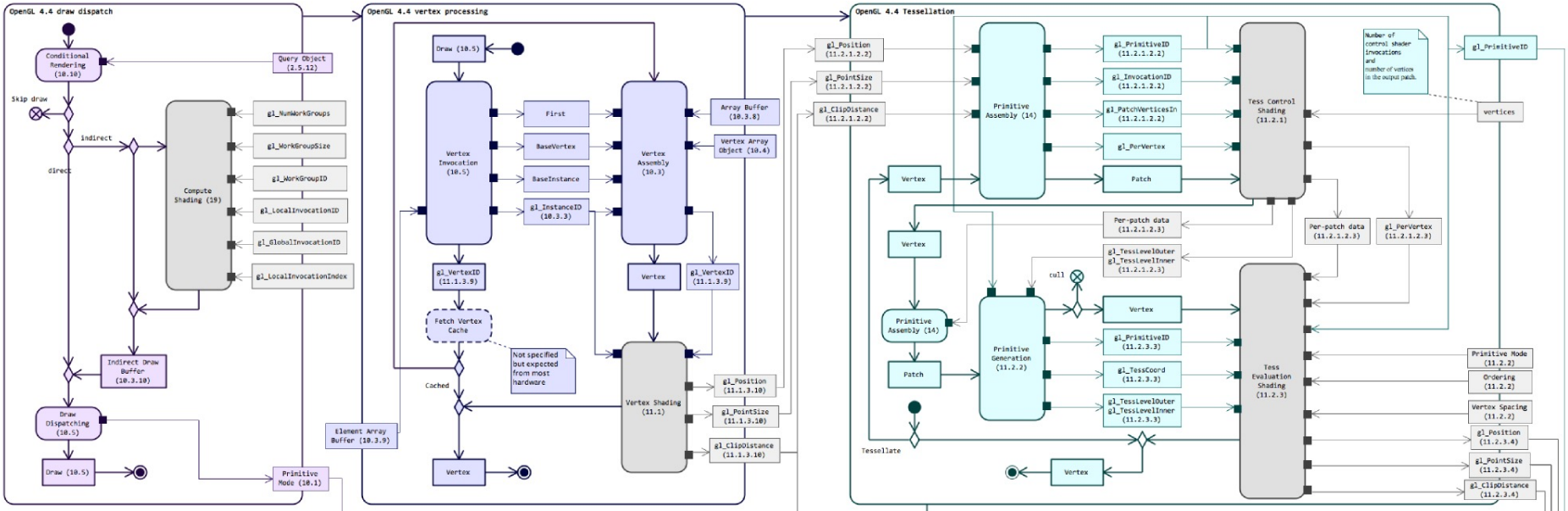
LIGHTING

Il triangolo

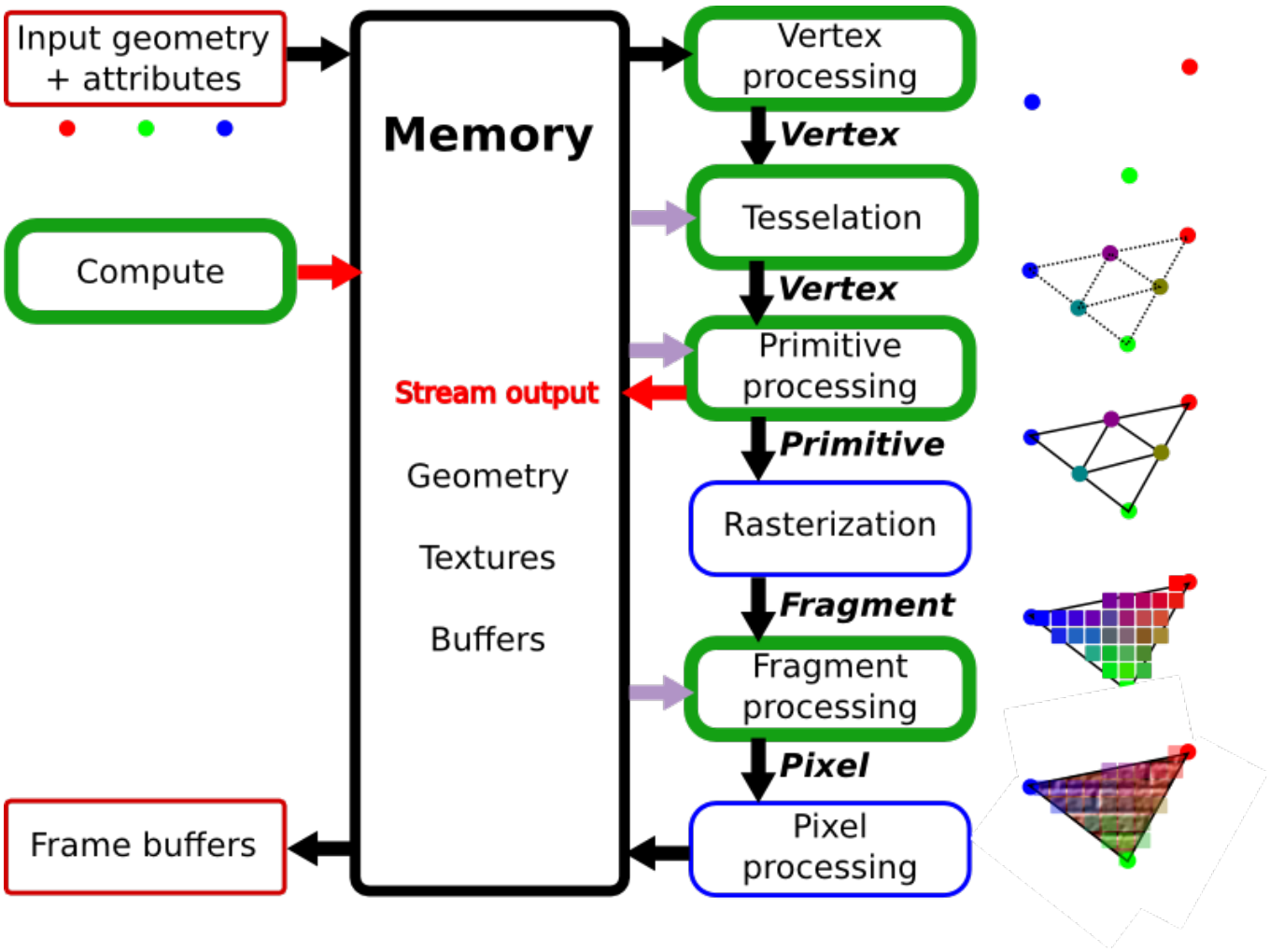


GPU pipeline

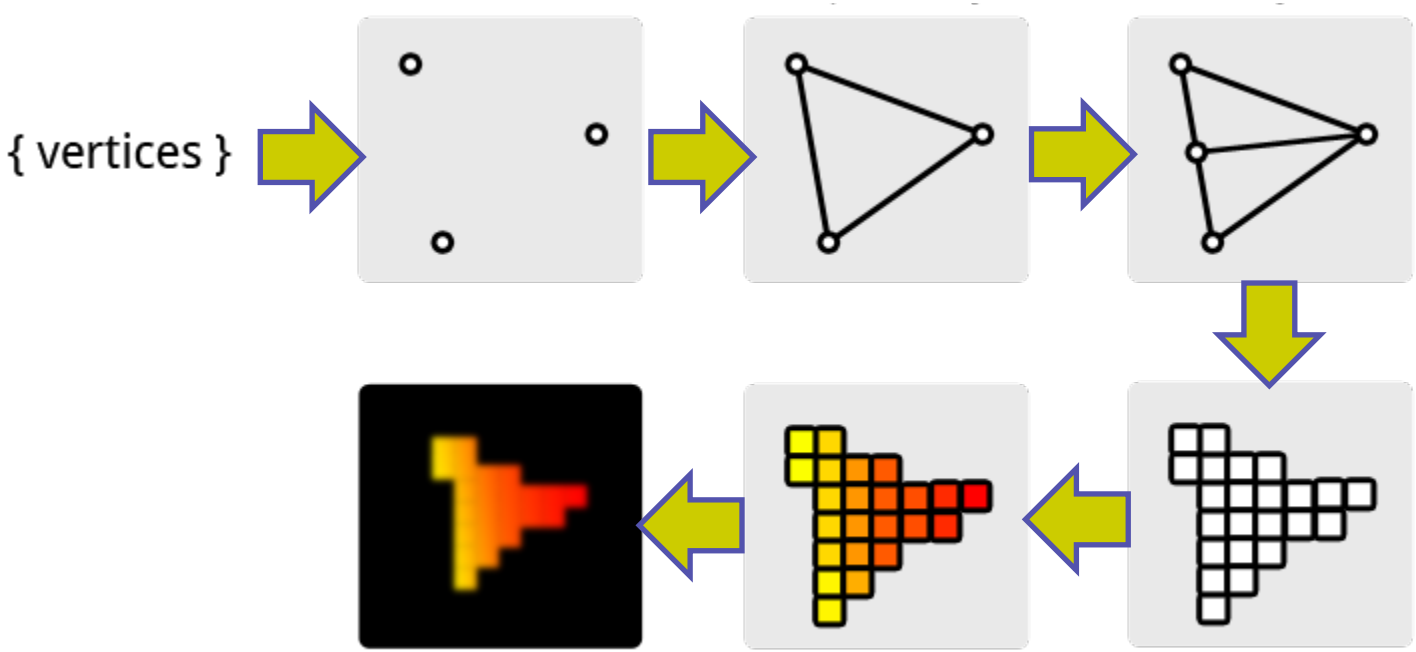




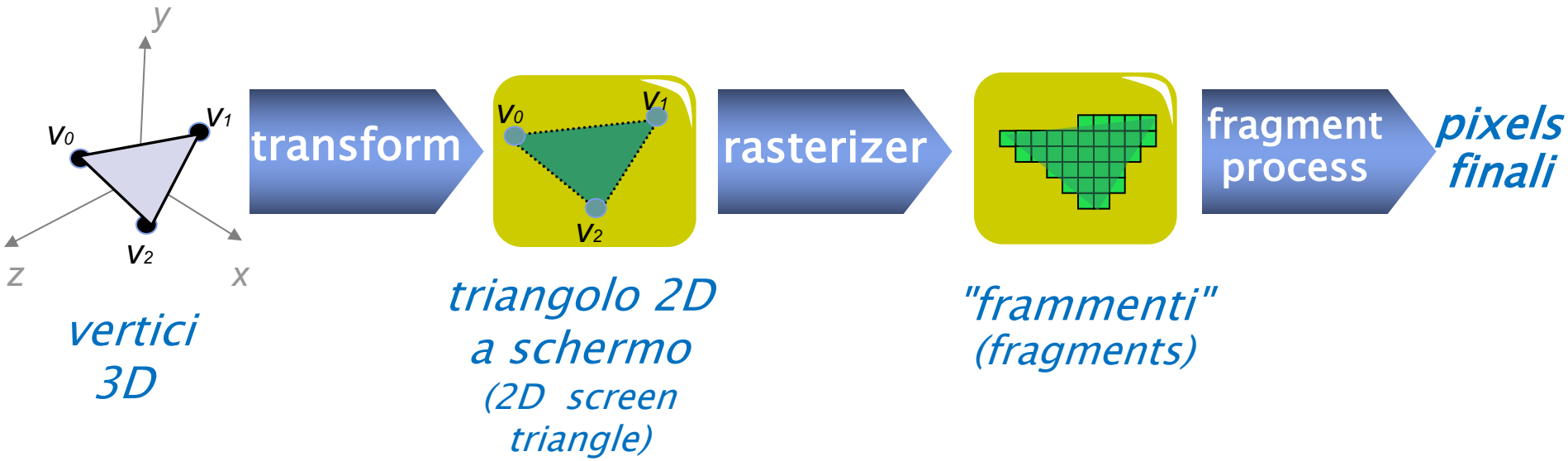
GPU pipeline – simplified



GPU pipeline – simplified *more*



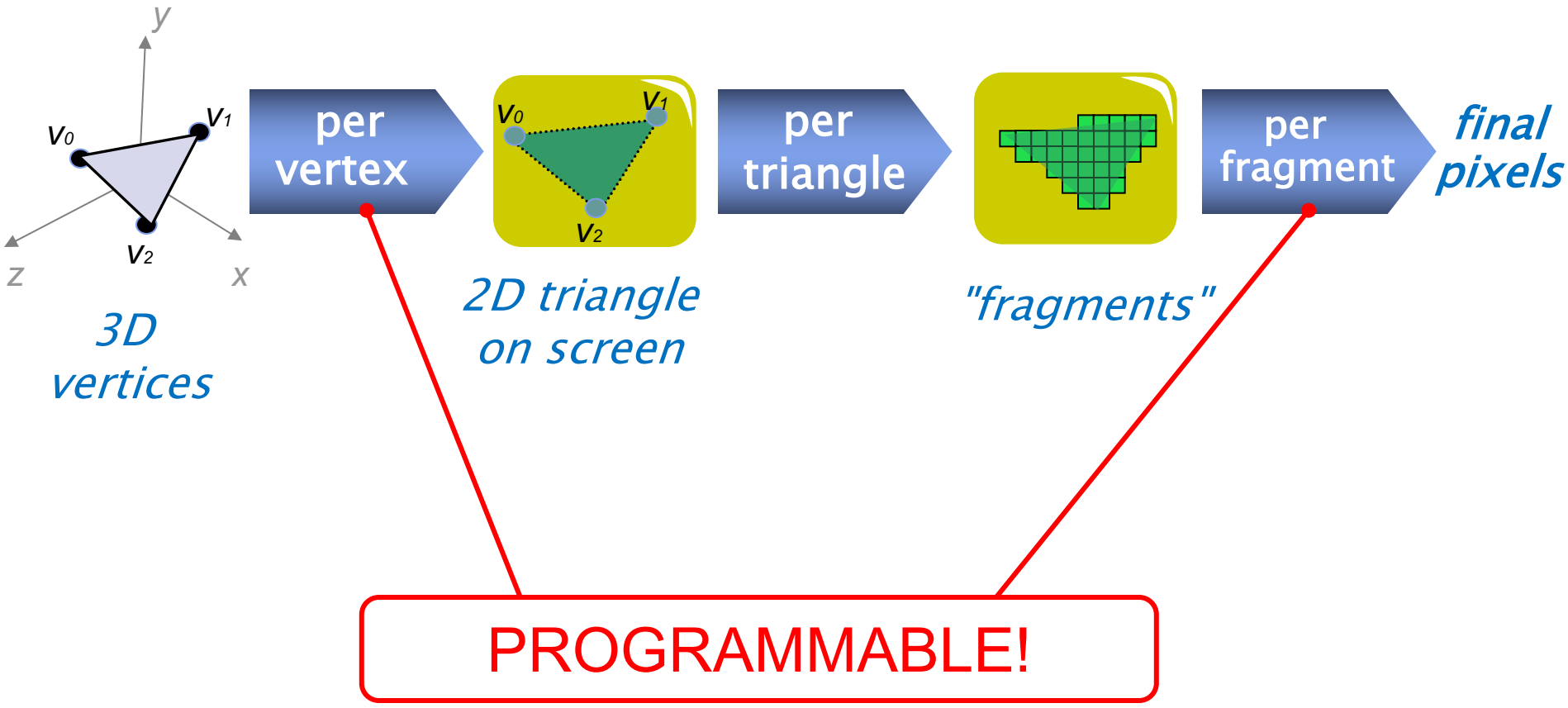
GPU pipeline – simplified even *more*



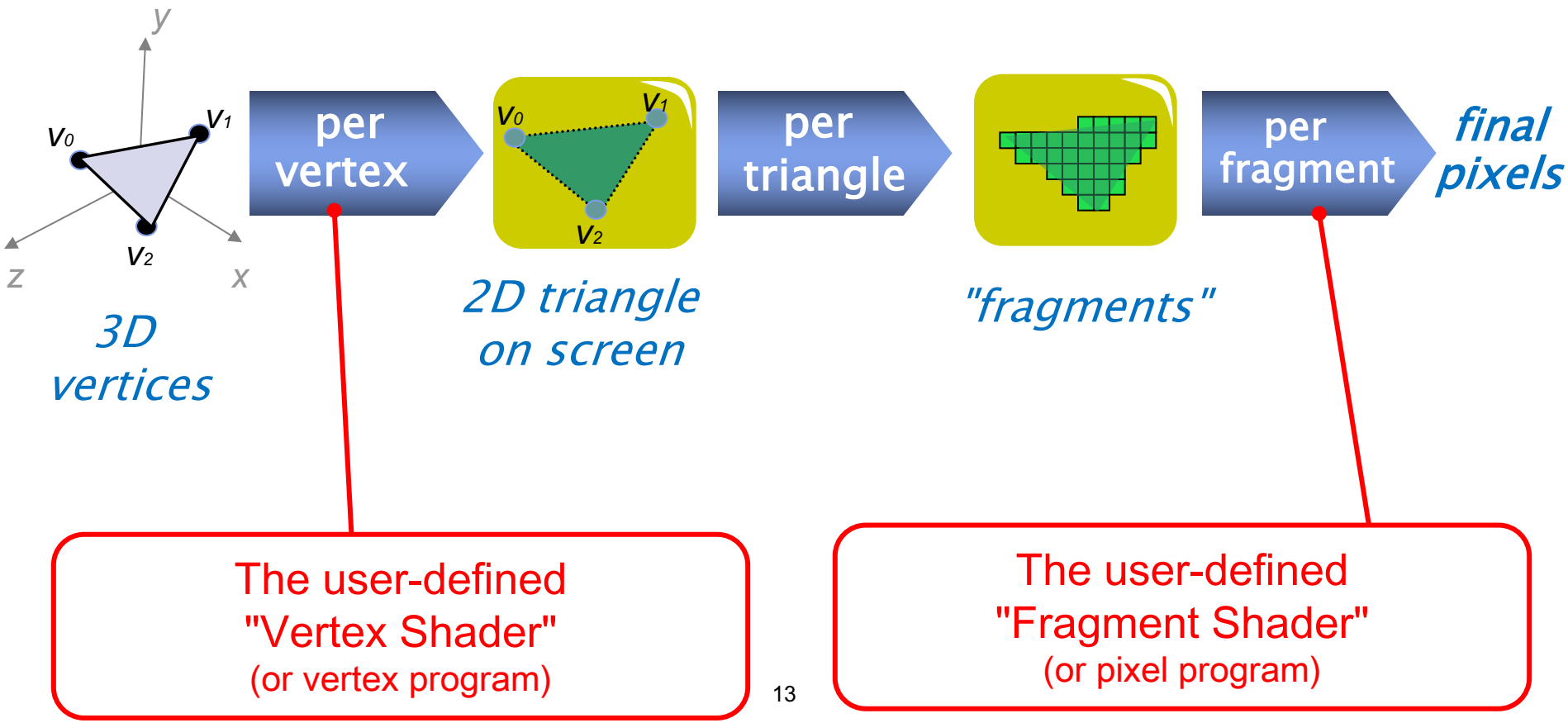
Rasterization based rendering: base schema

- Per vertice: (vertex shader)
  - skinning (from rest pose to current pose)
  - transform (from object space to screen space)
- Per triangle: (rasterizer)
  - rasterization
  - interpolation of per-vertex data
- Per fragment: (fragment shader)
  - lighting (from normal + lights + material to RGB)
  - texturing
  - alpha kill
- Per pixel: (after the fragment shader)
  - depth test
  - alpha blend

Rasterization-Based Rendering



Rasterization-Based Rendering



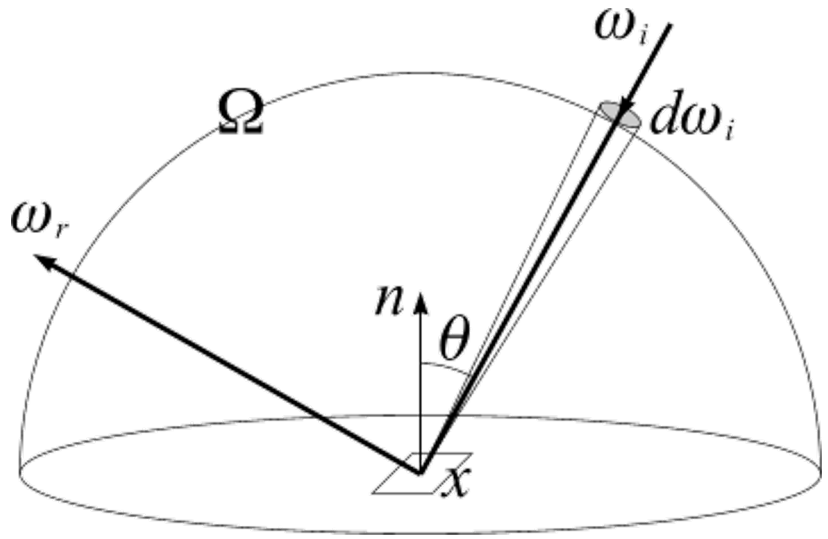
Shading languages

- High level:
  - **HLSL** (High Level Shader Language, Direct3D, Microsoft)
  - **GLSL** (OpenGL Shading Language)
  - **CG** (C for Graphics, Nvidia -- deprecated)
- Low lever:
  - **ARB** Shader Program
    (the “assembler” of GPU -- deprecated)

Modelli di illuminazione

- **Modello di illuminazione**: formulazione matematica dell'equazione del trasporto dell'energia luminosa
- L'equazione che risolve questo problema: **equazione di illuminazione**
- **Lighting**: calcolo del bilancio luminoso
- **Shading**: calcolo del colore di ogni pixel dell'immagine

The Rendering Equation



$$L_o(x, \vec{\omega_r}) = L_e(x, \vec{\omega_r}) + L_r(x, \Omega)$$

$$L_o(x, \vec{\omega_r}) = L_e(x, \vec{\omega_r}) + \int_\Omega f_r(x, \vec{\omega_i}, \vec{\omega_r}) L_i(x, \vec{\omega_i})(\vec{\omega_i} \cdot \vec{n}) d\vec{\omega_i}$$

The Rendering Equation

$$L_o(x, \vec{\omega_r}) = L_e(x, \vec{\omega_r}) + L_r(x, \Omega)$$

- La luce visibile in un punto della scena è data dalla somma della luce riflessa più la luce emessa

$$L_o(x, \vec{\omega_r}) = L_e(x, \vec{\omega_r}) + \int_\Omega f_r(x, \vec{\omega_i}, \vec{\omega_r}) L_i(x, \vec{\omega_i})(\vec{\omega_i} \cdot \vec{n}) d\vec{\omega_i}$$

- La luce riflessa è un integrale
- Somma i contributi di tutte le sorgenti luminose presenti nella scena e tiene conto dell'angolo di riflessione

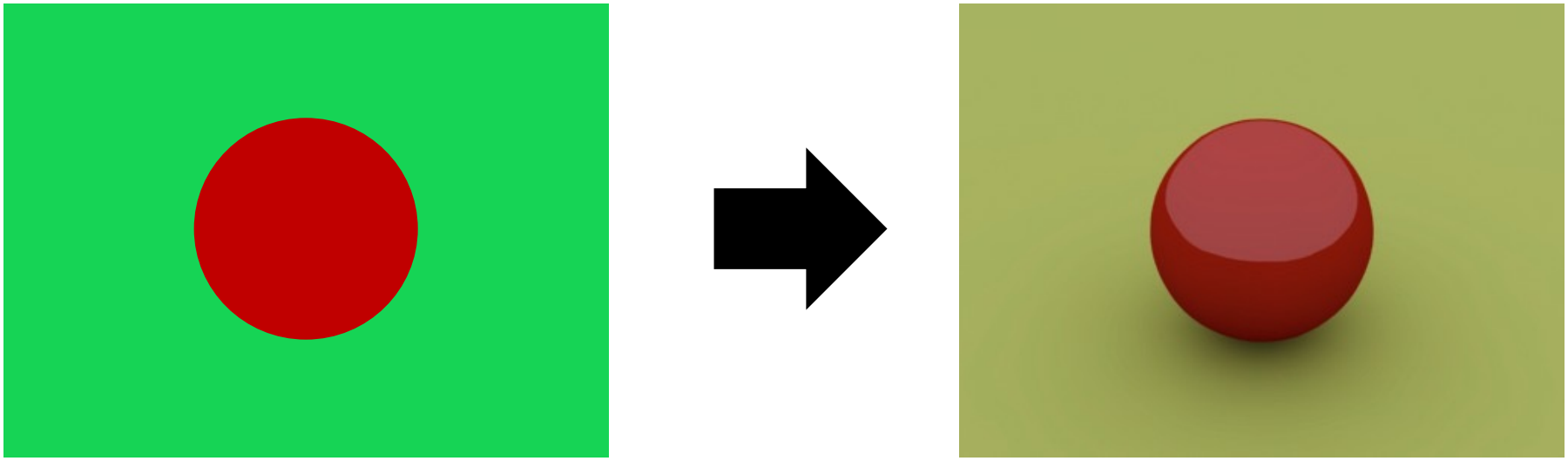
The Rendering Equation: parametri

- x punto sulla superficie in cui si calcola l'equazione;
- $\vec{\omega_r}$ direzione che unisce il punto alla posizione dell'osservatore
- $\vec{\omega_i}$ direzione da cui proviene il raggio incidente
- f_r funzione che determina la frazione riflessa di luce incidente
- $\vec{\omega_i} \cdot \vec{n}$ coseno dell'angolo di incidenza rispetto alla normale alla superficie

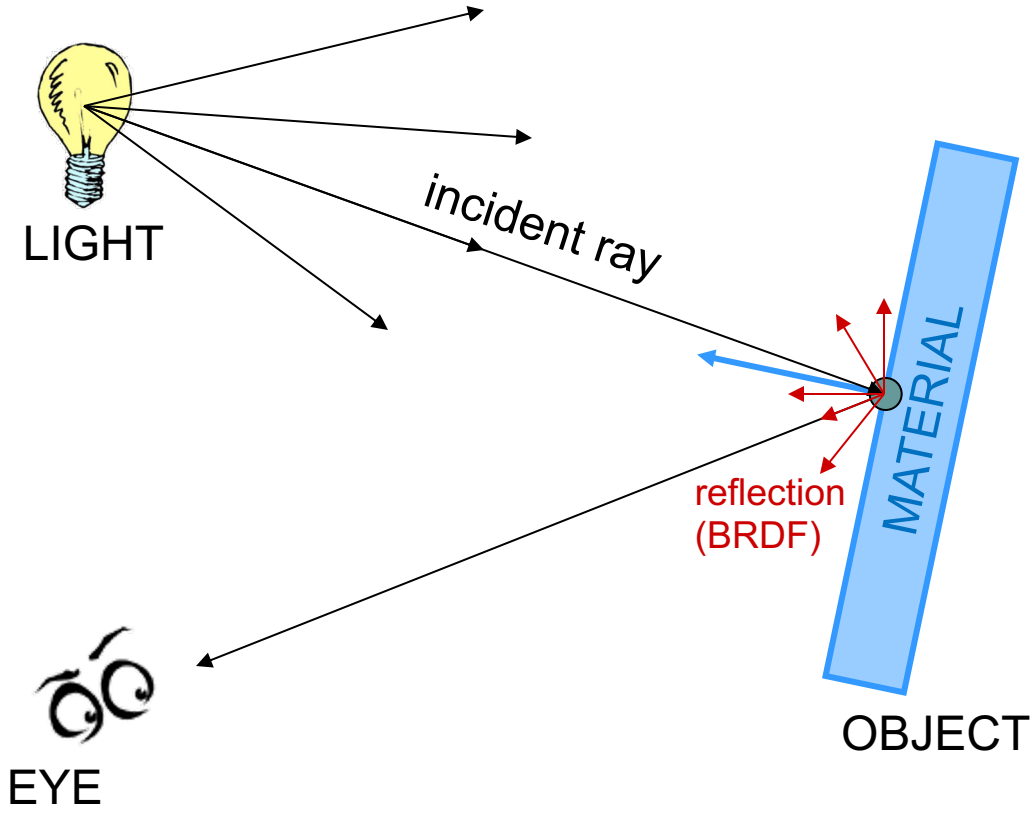
The Rendering Equation

- Calcolo esatto dell'equazione della radianza: operazione complessa e molto costosa
- Sistema di grafica interattiva: formula utilizzabile per tutti i punti della scena più volte al secondo
- Semplificazione dell'equazione

Rendering effects:
local lighting



Local lighting



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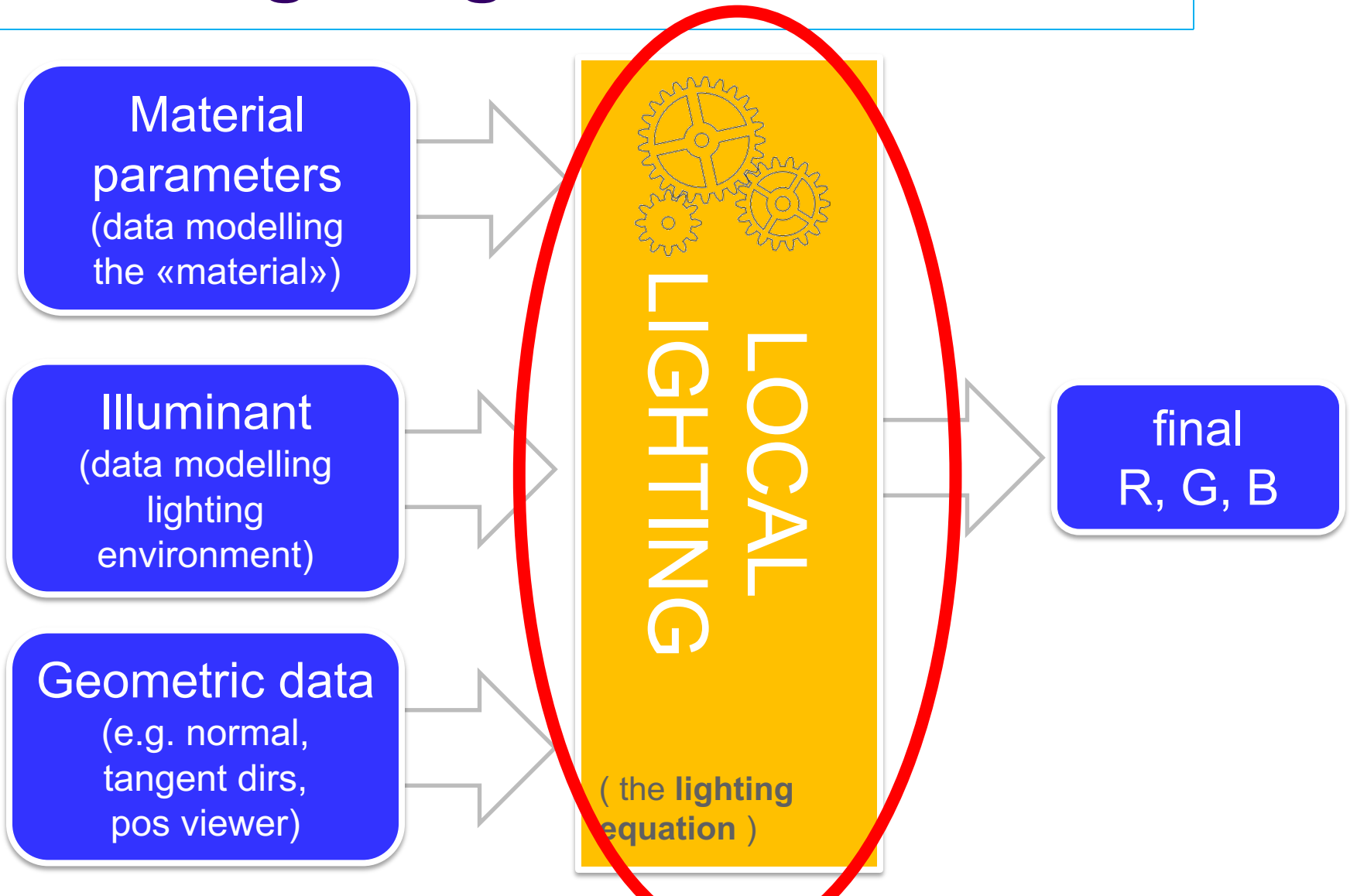


Lighting equations

- Many different equations…
  - Lambertian
  - Blinn-Phong

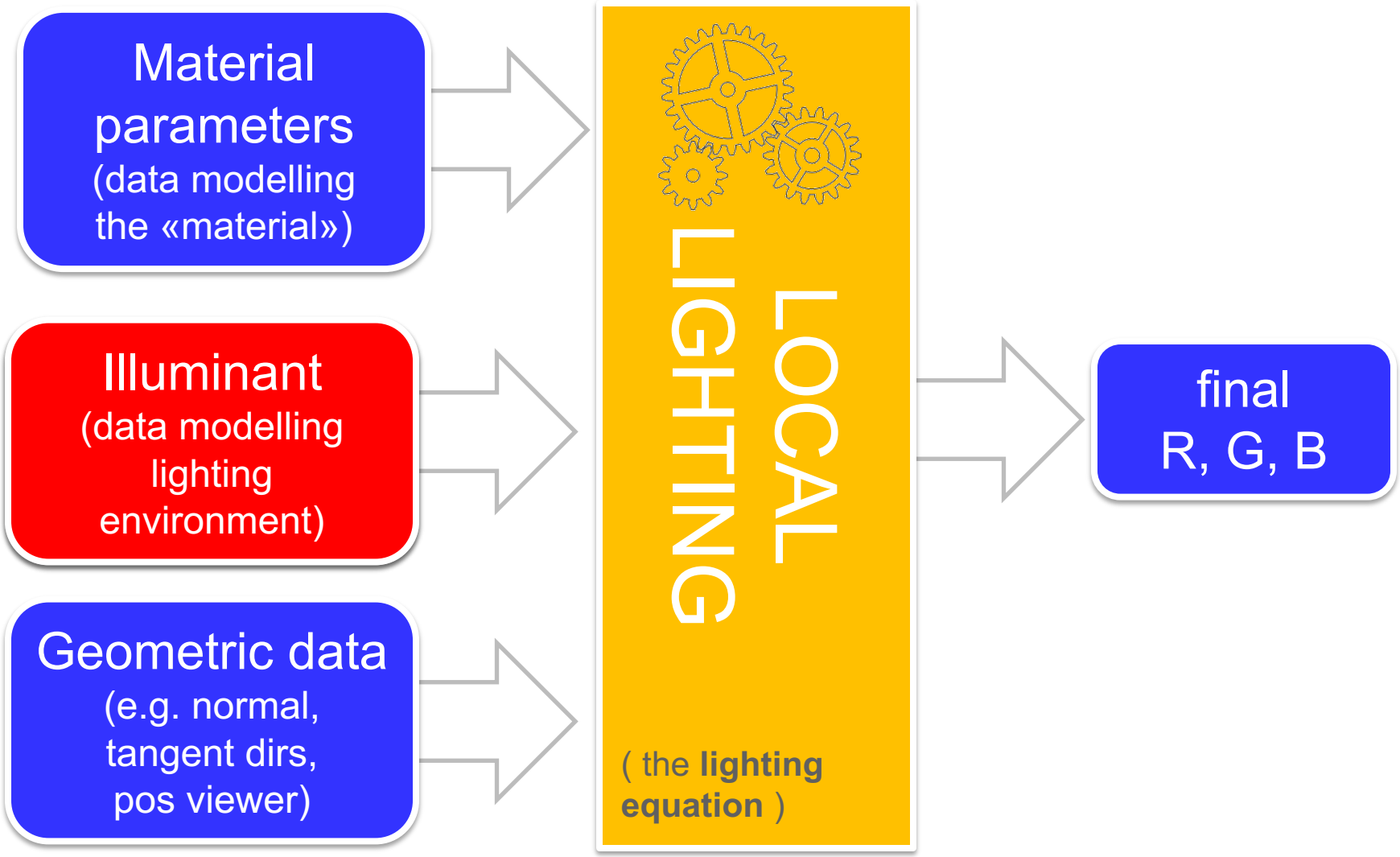
    } simplest, most commonly used
  - Beckmann
  - Heidrich–Seidel
  - Cook–Torrance
  - Ward (anisotropic)
  - …
  - add Fresnel effects
- Varying levels of
  - complexity
  - realism
    - (some are *physically based*, some are… just tricks)
  - material parameters allowed
  - richness of effects

Lighting equations: most common cases

- Diffuse (aka Lambertian)
  - physically based
  - only dull materials
  - only material parameter:
    - base color
      (aka albedo, aka “diffuse” color)

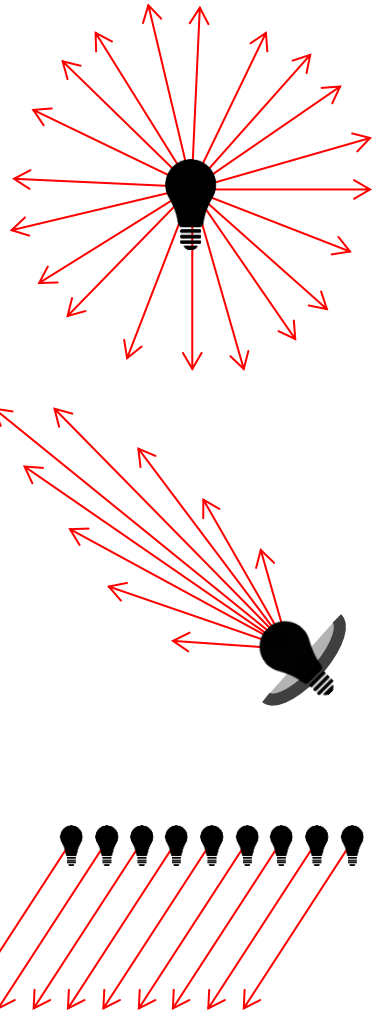
- Specular (aka Blinn-Phong)
  - just a trick
  - add simulated reflections (highlights)
  - additional material parameters:
    - specular intensity (or, color)
    - specular exponent (aka glossiness)

Local lighting



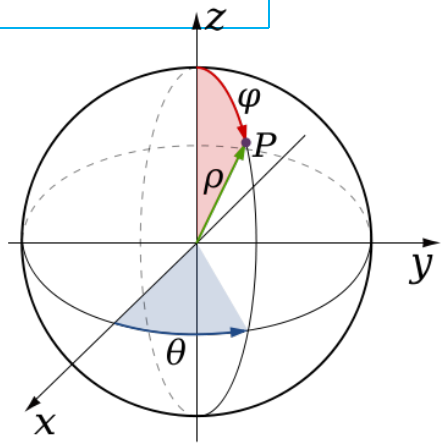
Illumination environments: discrete

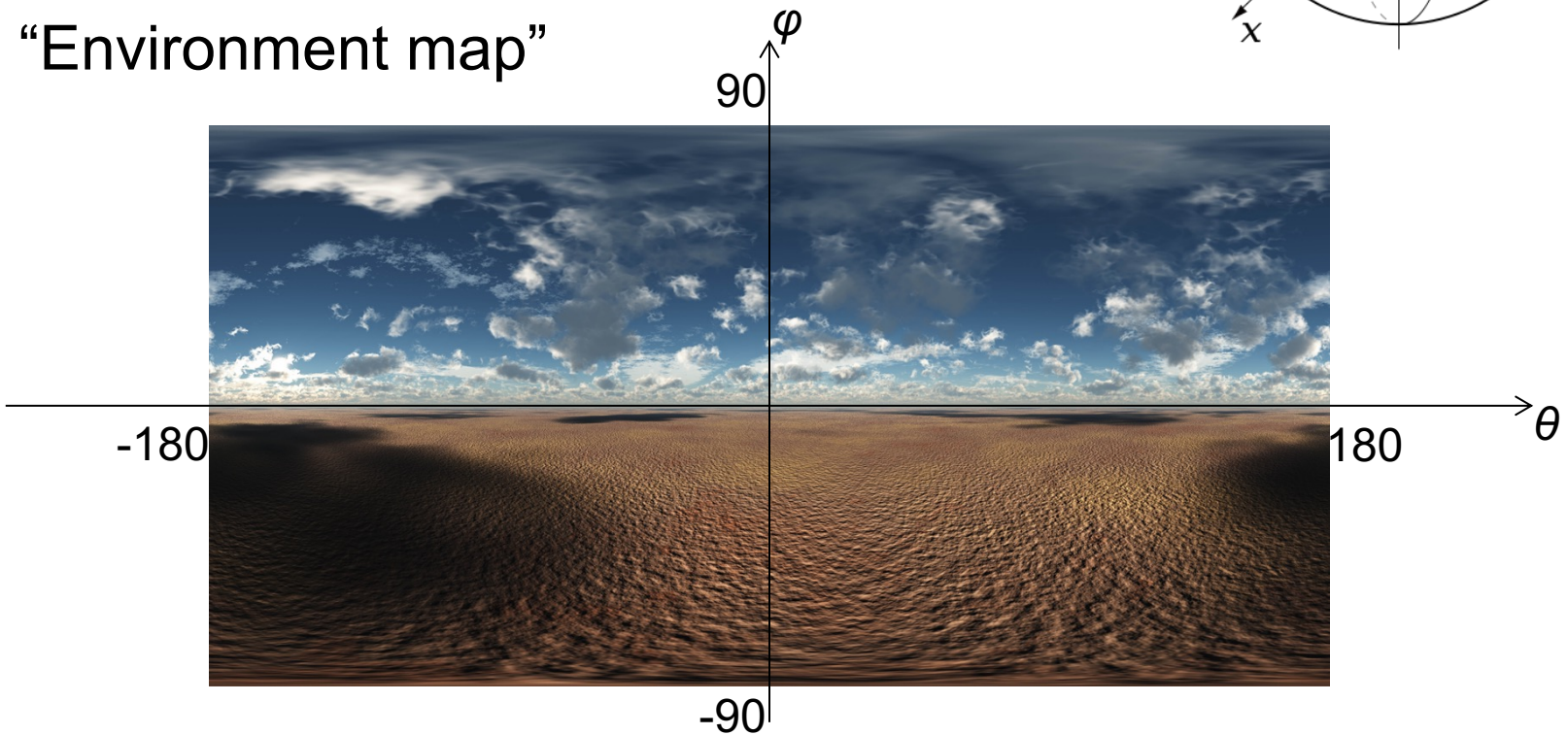
- a finite set of “light sources”
  - few of them (usually 1-4)
- each sitting in a node of the scene graphs
- types:
  - point light sources
    - have: position
  - spot-lights
    - have: position, orientation, wideness (angle)
  - directional light sources
    - have: orientation only
- extra attributes:
  - color
  - intensities
  - (other minor attributes)



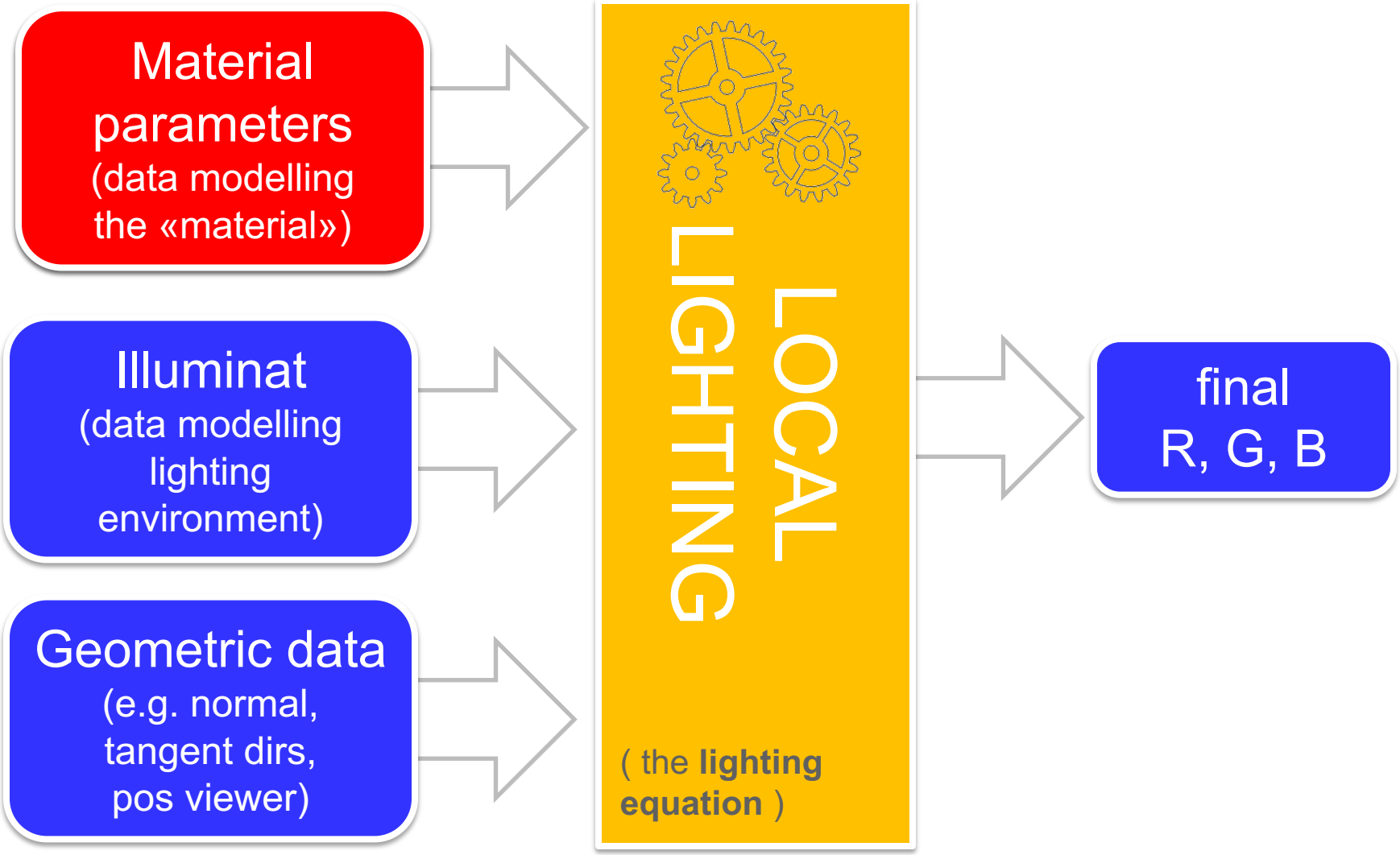
Illumination environments: densely sampled

- From each direction (on the sphere) a light intensity / color
- Asset to store that: “Environment map”





Local lighting



GPU rendering of a Mesh in a nutshell (reminder)

- Load…
  - store all data on **GPU RAM**
    - Geometry + Attributes
    - Connectivity

    THE MESH ASSET
    - **Textures**
    - **Shaders**
    - **Material Parameters**
    - **Rendering Settings**

    THE MATERIAL ASSET
- …and Fire!
  - send the command: "*do it*" !

Terminology

- Material parameters
  - parameters modelling the optical behavior of physical object
  - part of the input of the lighting equation
- Material asset
  - an abstraction used by game engines
  - consisting of
    - a set of textures (e.g. diffuse + specular + normal map)
    - a set of shaders (vertex + fragment)
    - a set of global parameters (e.g. global glossiness)
    - rendering settings (e.g. back face culling?)
  - corresponds to the status of the rendering engines

Material parameters

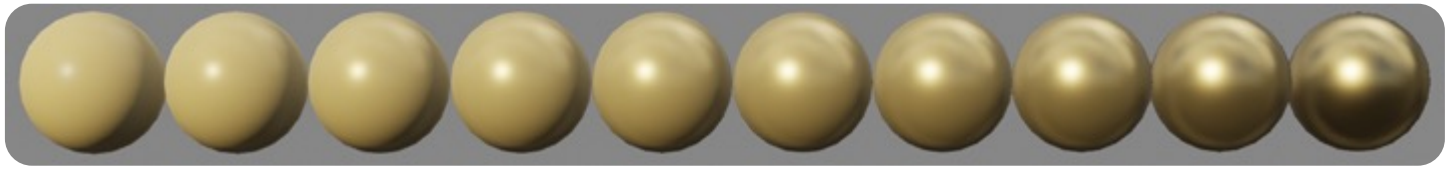
Authoring material parameters

- Q: which materials parameters needs be defined?
  A: depends on chosen lighting equation

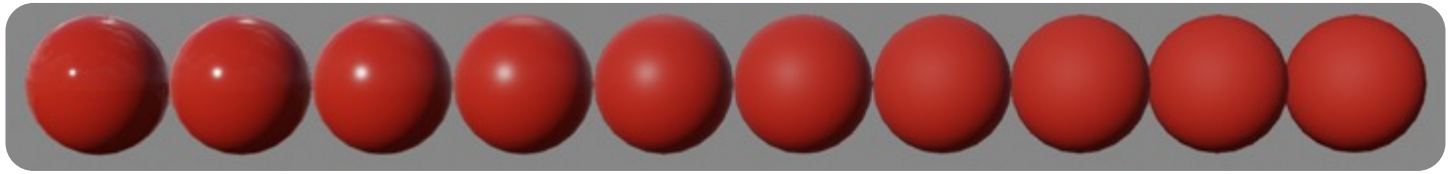
- Idea:
  game engine lets material artist choose *intuitively named* material parameters, then pick a lighting equation accordingly
  - the one best suiting them
  - “speak material-artist language”

Authoring material parameters

- Popular choice of “intuitive parameters”:
  - Base color (rgb)
  - Specularity (scalar)
  - “Metal-ness” (scalar)



  - Roughness (scalar)



images: unreal engine 4

Physically based materials (PBR)

- Basically, a buzzword ☺
- Meanings:
  - 1. use accurate material parameters
    - physically plausible
    - maybe measured
      - instead of: invented and tuned by intuition (by the material artist)
  - 2. keep each lighting element separated (e.g. its own texture)
    - use fewer shortcuts that usual
    - e.g. use:
      - base color: *one* texture
      - baked AO: *another* texture
    - instead of:
      - base color x baked AO : one texture

Ambient Occlusion: see later

Texture mapping
(aka params how to store them)

- Shading: funziona finché modello geometrico ha complessità della composizione del materiale
- La descrizione di un materiale non uniforme è corretta a partire da una rappresentazione geometrica con suddivisione (*tassellazione*) in primitive collegata alle discontinuità del materiale da rappresentare
- Altrimenti? Texture mapping!

Texture mapping
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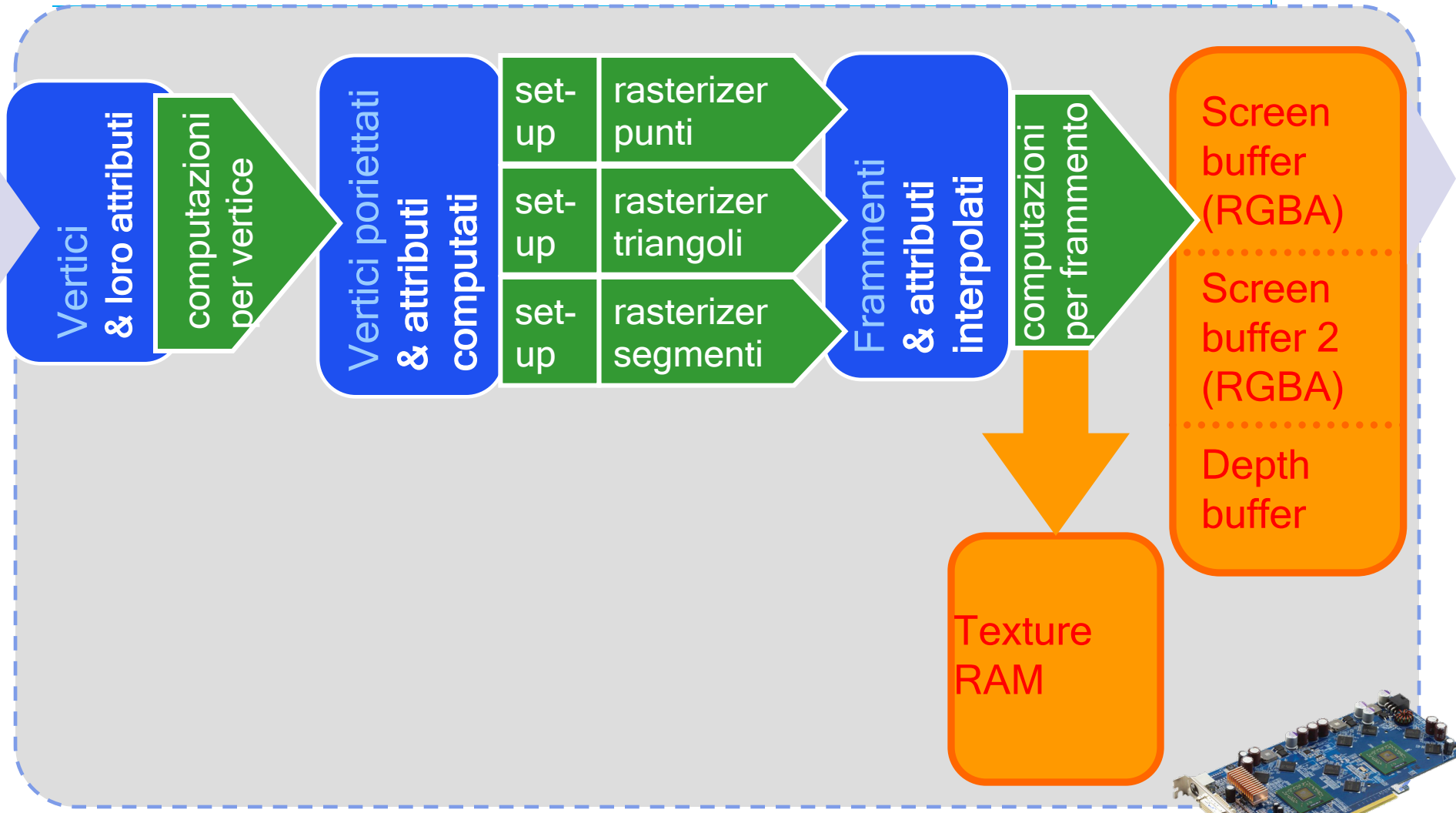
Memoria RAM nelle schede grafiche



Texture Mapping

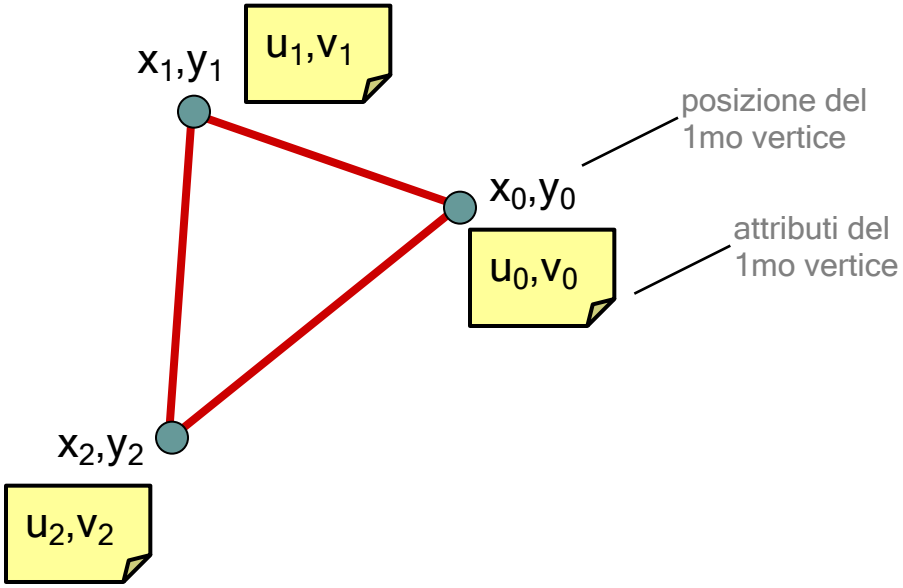
- Nelle operazioni per frammento si può accedere ad una RAM apposita: la Texture RAM strutturata in un insieme di Textures ("tessiture")
- Ogni tessitura è un array 1D, 2D o 3D di Texels (campioni di tessitura) dello stesso tipo

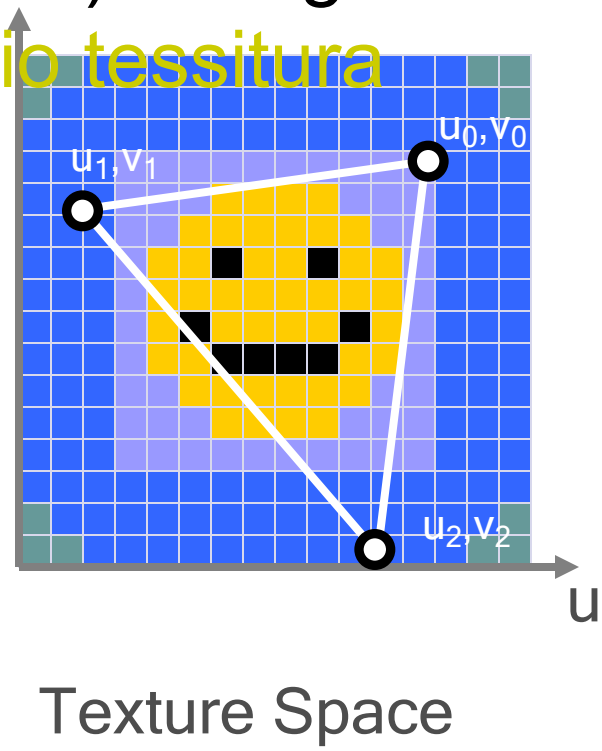
Texels

- Sono esempi di texels:
  - Ogni texel un colore (componenti: R-G-B, o R-G-B-A): la tessitura è una “color-map”
  - Ogni texel una componente alpha: la tessitura è una “alpha-map”
  - Ogni texel una normale (componenti: X-Y-Z): la tessitura è una “normal-map” o “bump-map”
  - Ogni texel contiene un valore di specularità: la tessitura è una “shininess-map”

Texture Mapping

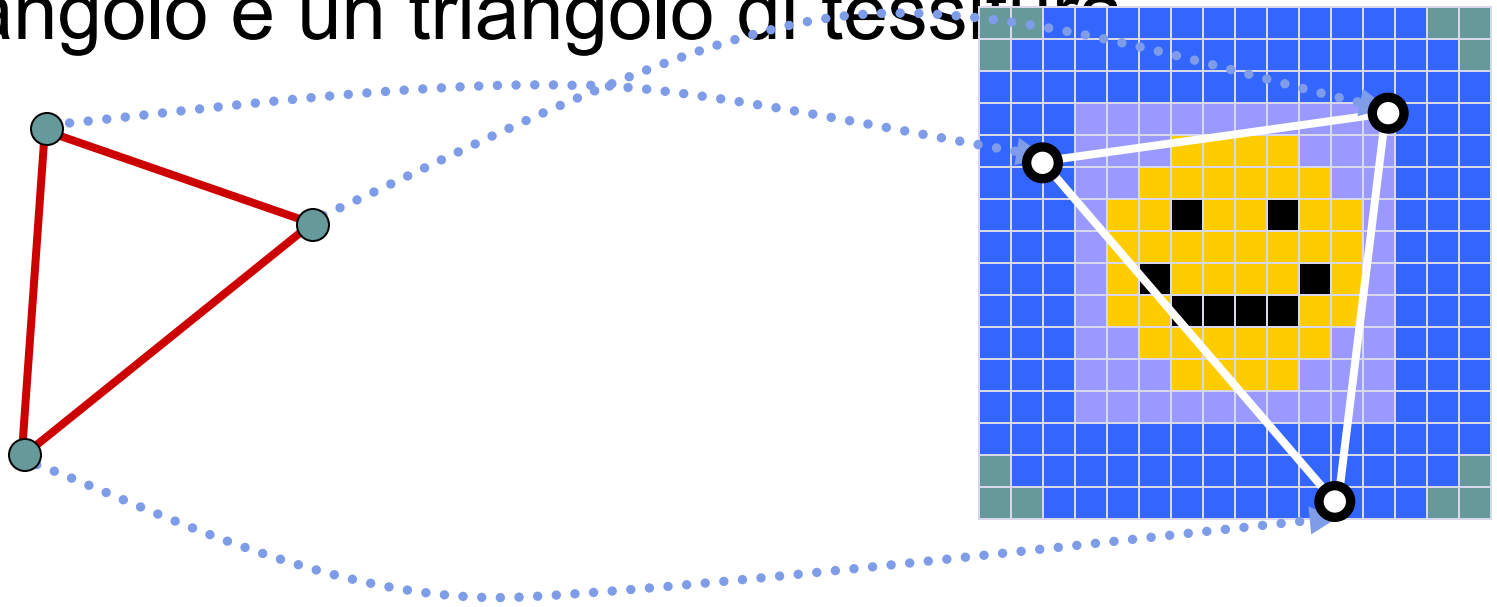
- Ad ogni vertice (di ogni triangolo) assegno le sue coordinate *u,v* nello spazio tessitura





Texture Mapping

- Così in pratica definisco un mapping fra il triangolo e un triangolo di tessitura

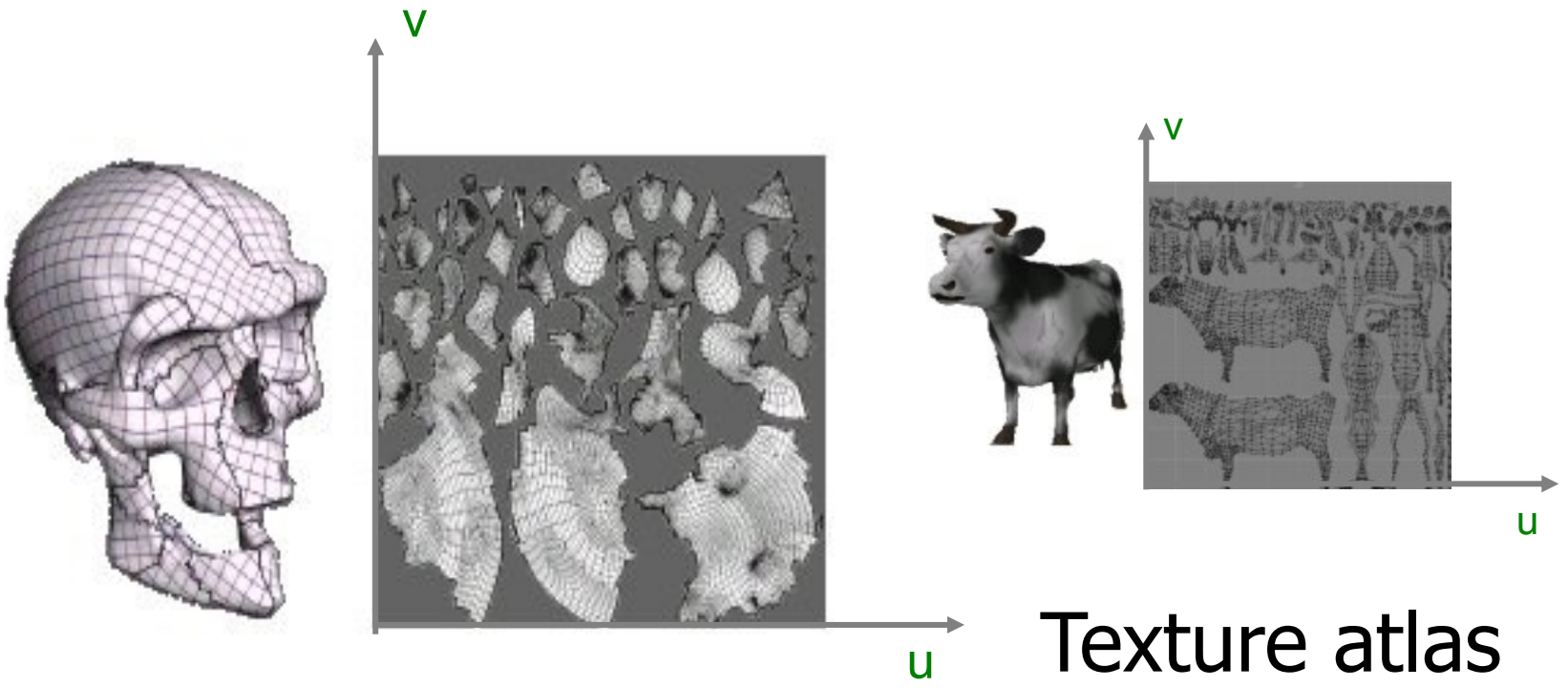


Assegnazione delle coordinate texture

- Due classi di soluzioni:
  - Calcolare le coordinate textures on-the-fly durante il rendering…
  - Precomputarle (e salvarle insieme alla mesh)
- Non esiste una soluzione ideale, dipende dall'applicazione che stiamo progettando
- Modelli con una sola texture l'avranno precomputata, per altri che variano dinamicamente l'assegneremo in rendering

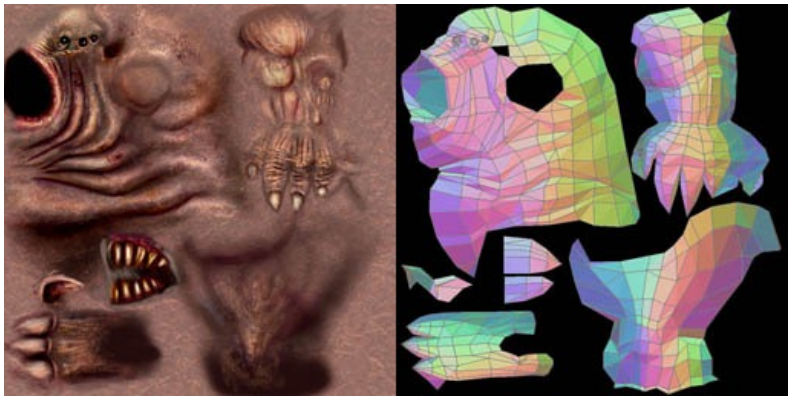
Problema difficile: u-v mapping

- Assegnare una coppia di coordinate textures ad ogni vertice della mesh in preprocessing

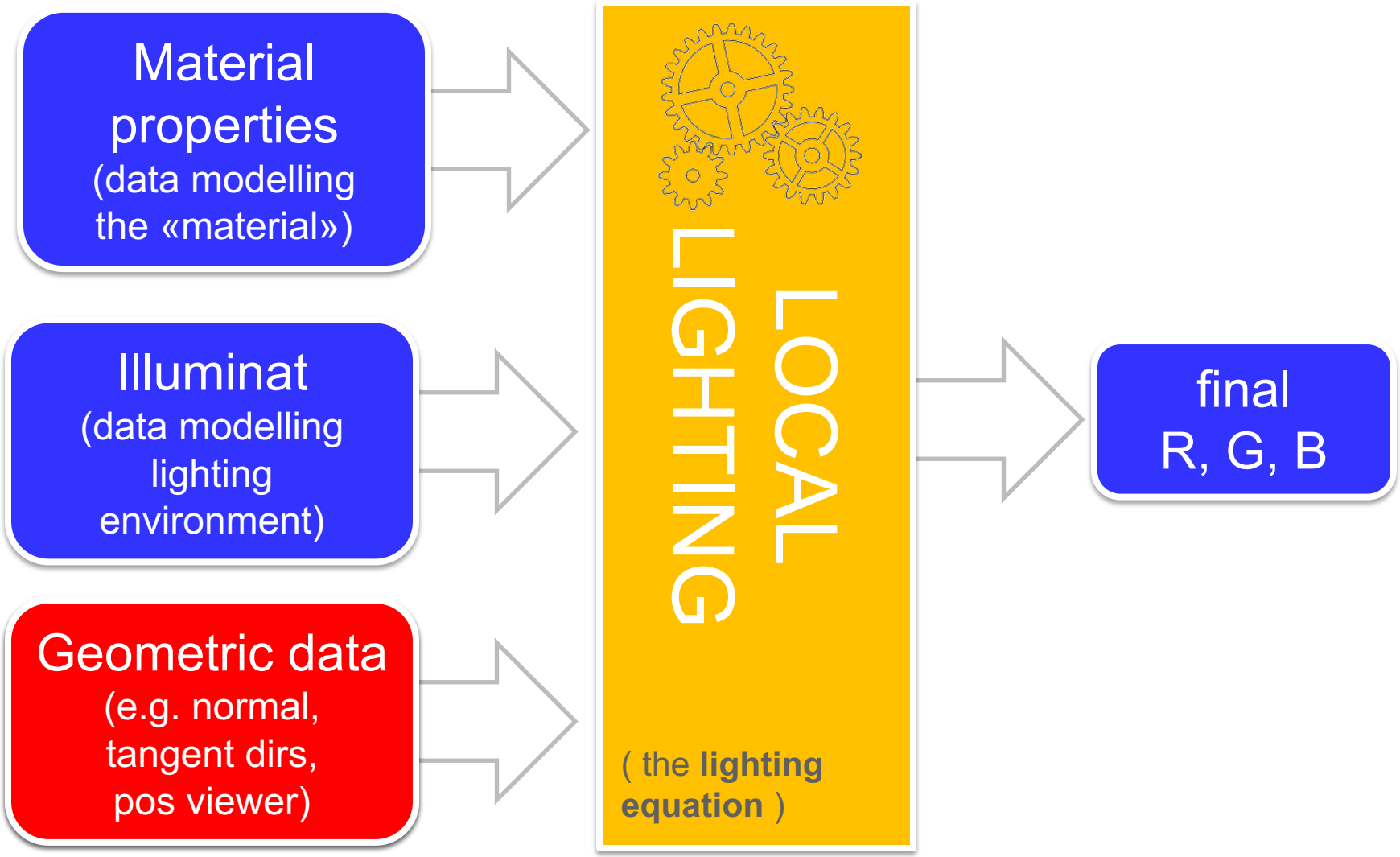


Problema difficile: u-v mapping

fatto a mano,
o automatizzato

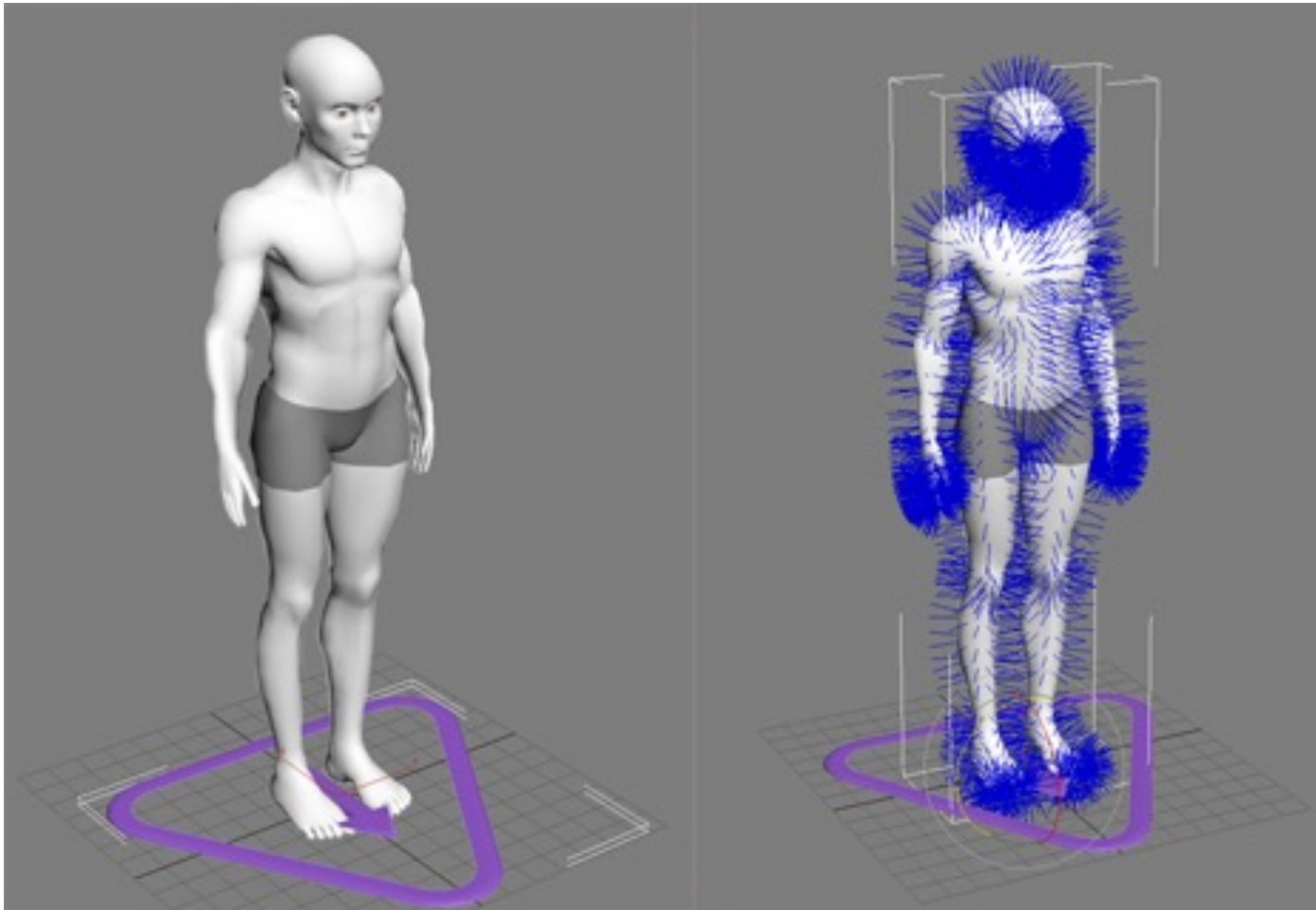


Local lighting in brief

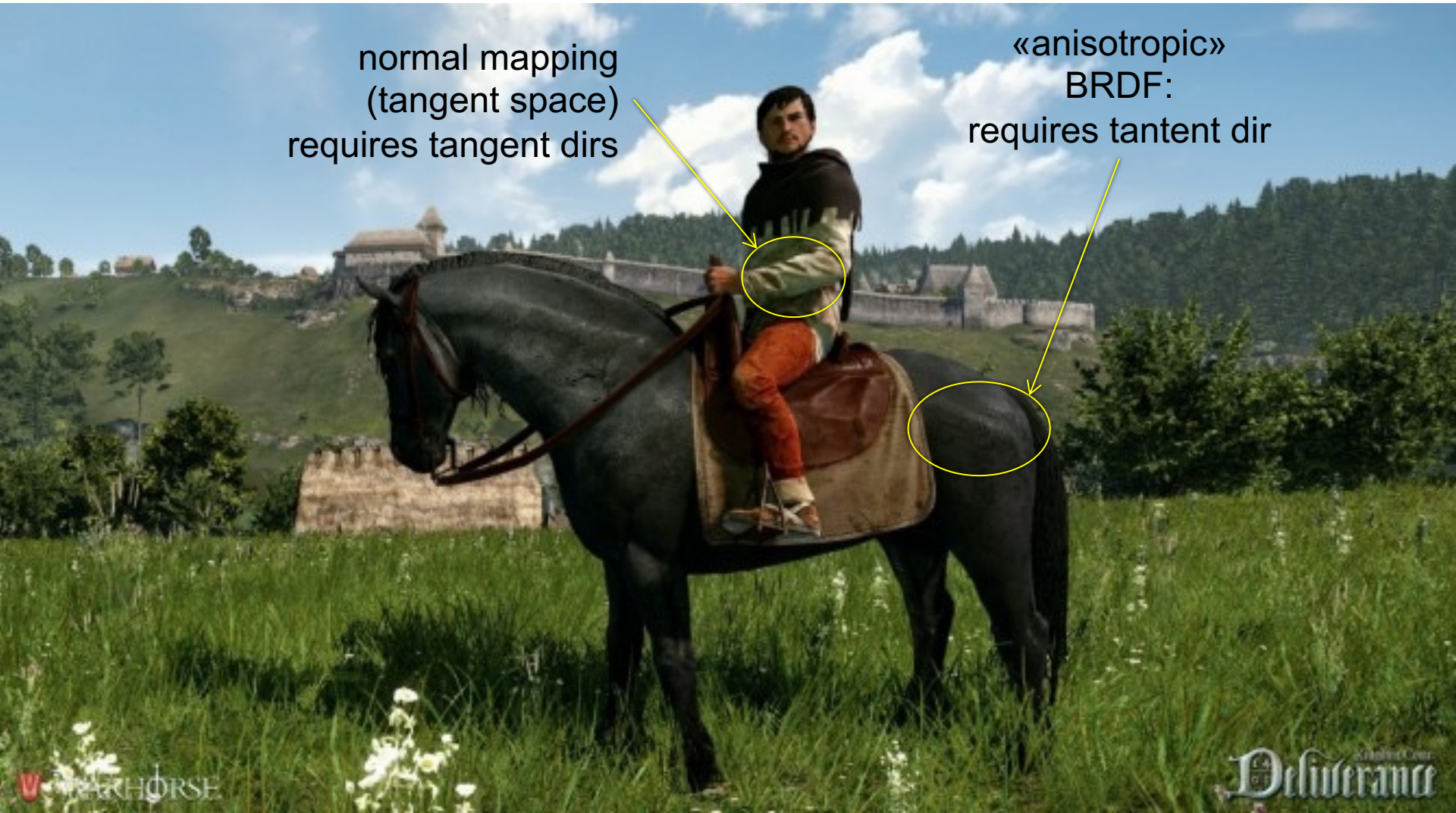


Reminder: normals

- Per vertex attribute of meshes



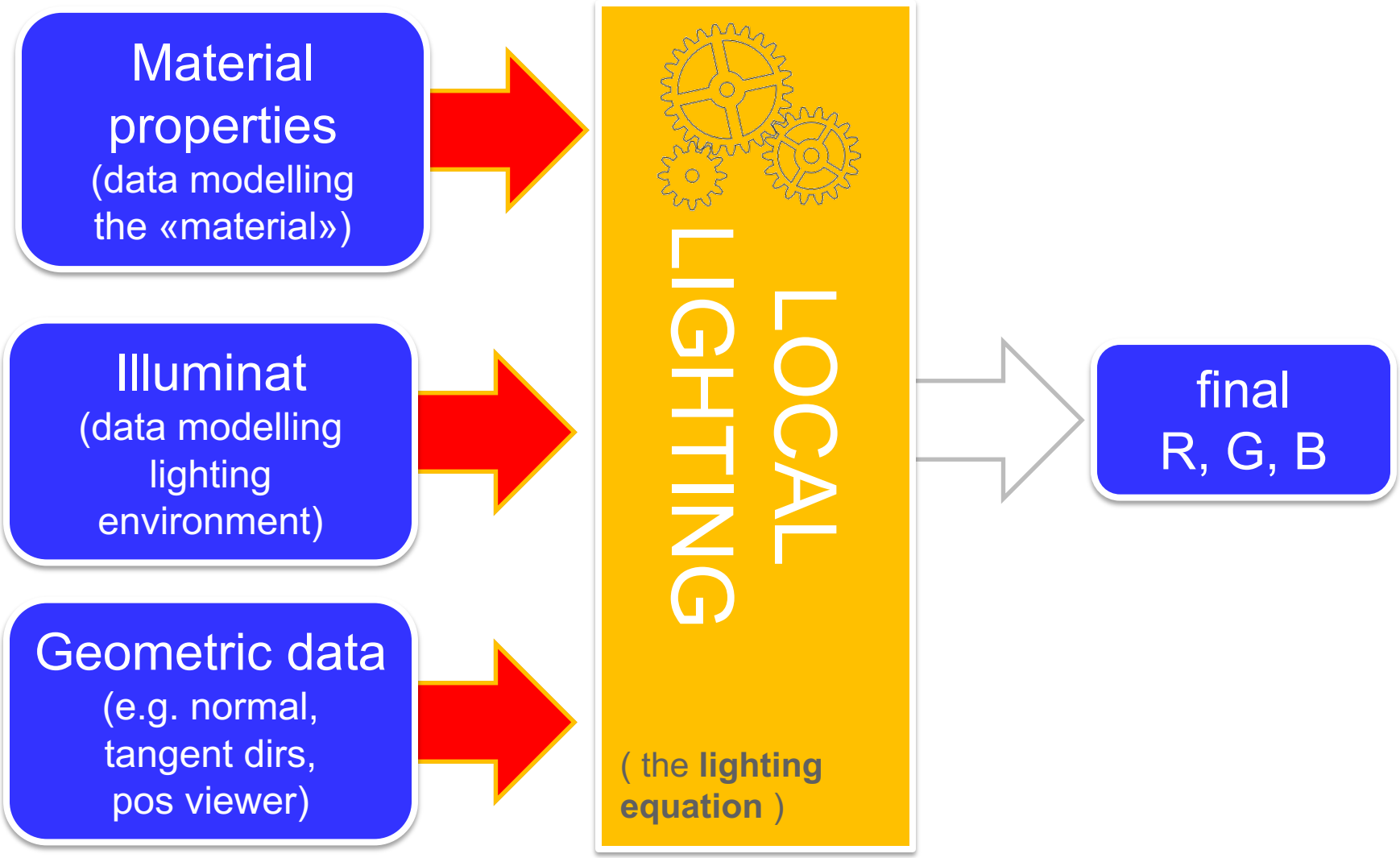
Reminder: Tangent dirs



Material qualities: improving

Material qualities: improving

Local lighting in brief



Lighting equation: how

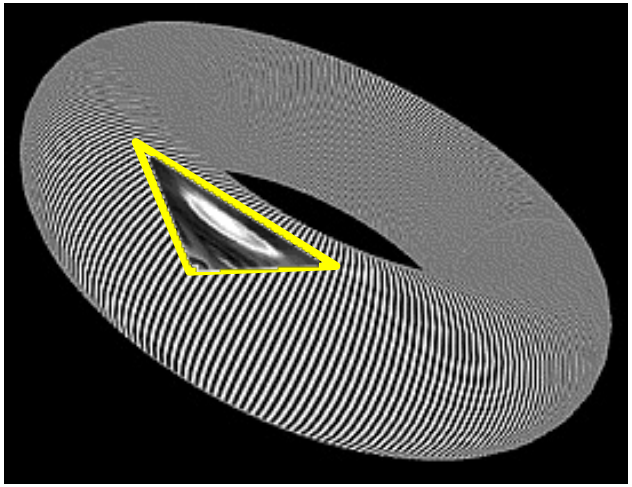
- Computed in the fragment shader
  - most game engine support a subset as default ones
  - any custom one can be programmed in shaders!
- Material + geometry parameters stored :
  - in textures (highest freq variations)
  - in vertex attributes (smooth variations)
  - as “material assets” parameter (no variation)
  - for example, where are
    - diffuse color
    - specular color
    - normals
    - tangent dirs

  typically stored?

Environment mapping: sferico

Environment map: una tessitura
che memorizza il colore dell'ambiente "riflesso"
da ogni normale della semisfera.

Come coordinata tessitura, basta usare
la normale trasformata!

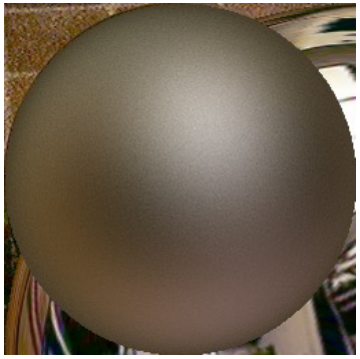


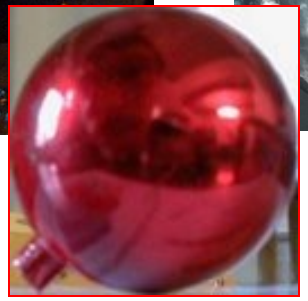
Environment mapping: sferico

simula oggetto a specchio che riflette uno sfondo lontano



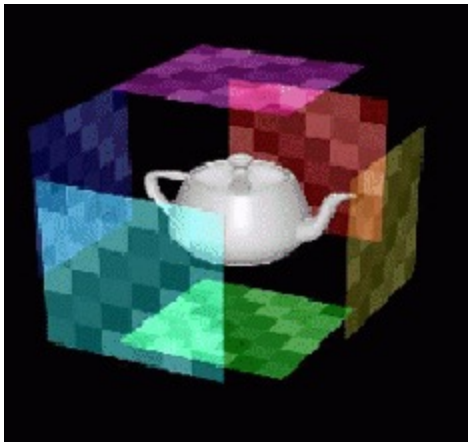


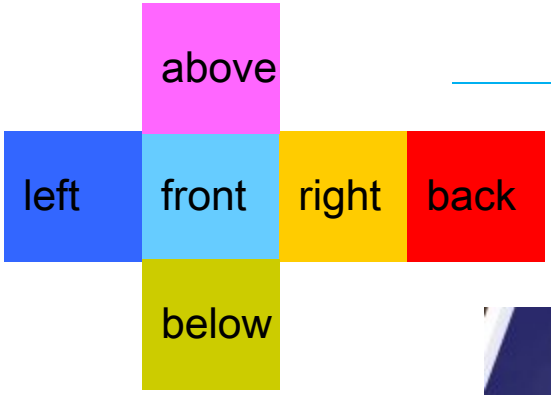


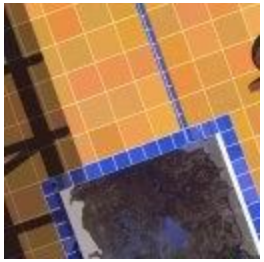




simula un materiale complesso
(condizioni di luce fisse)

Environment mapping: cubico

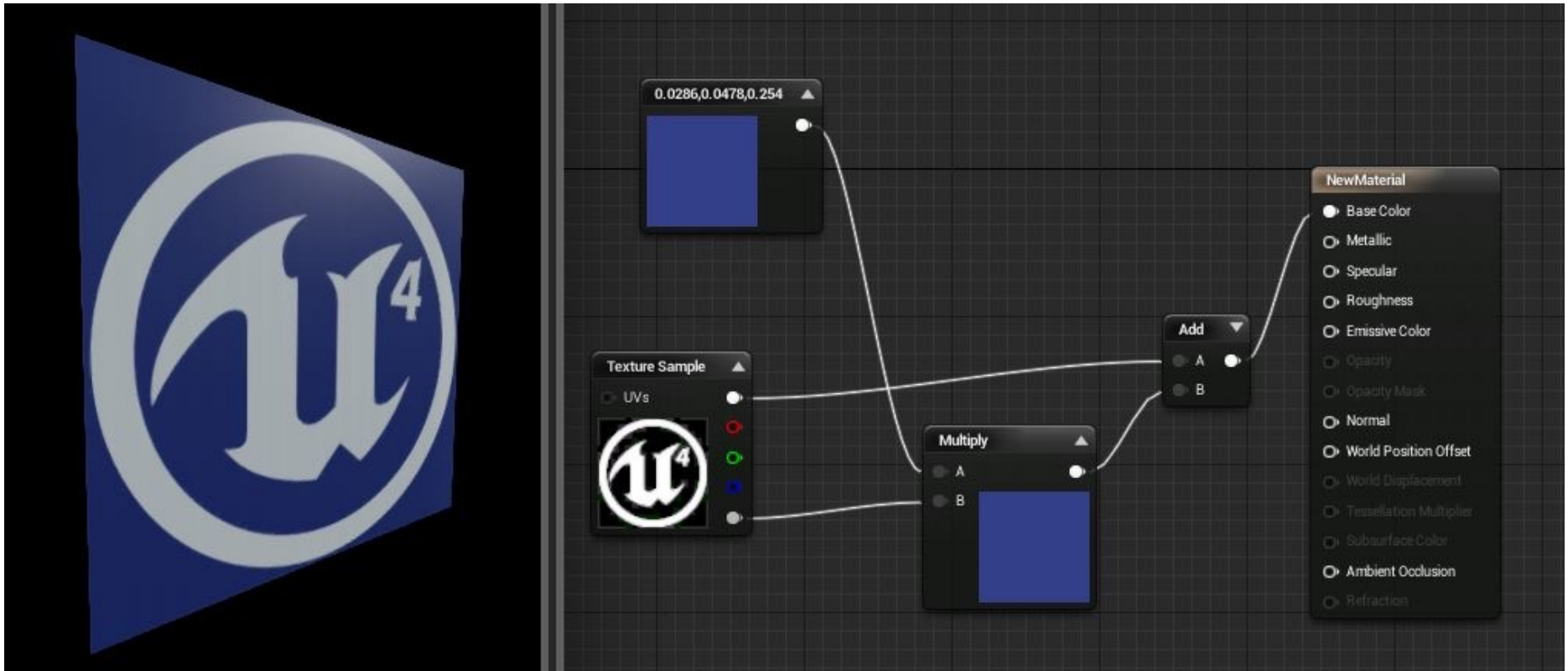






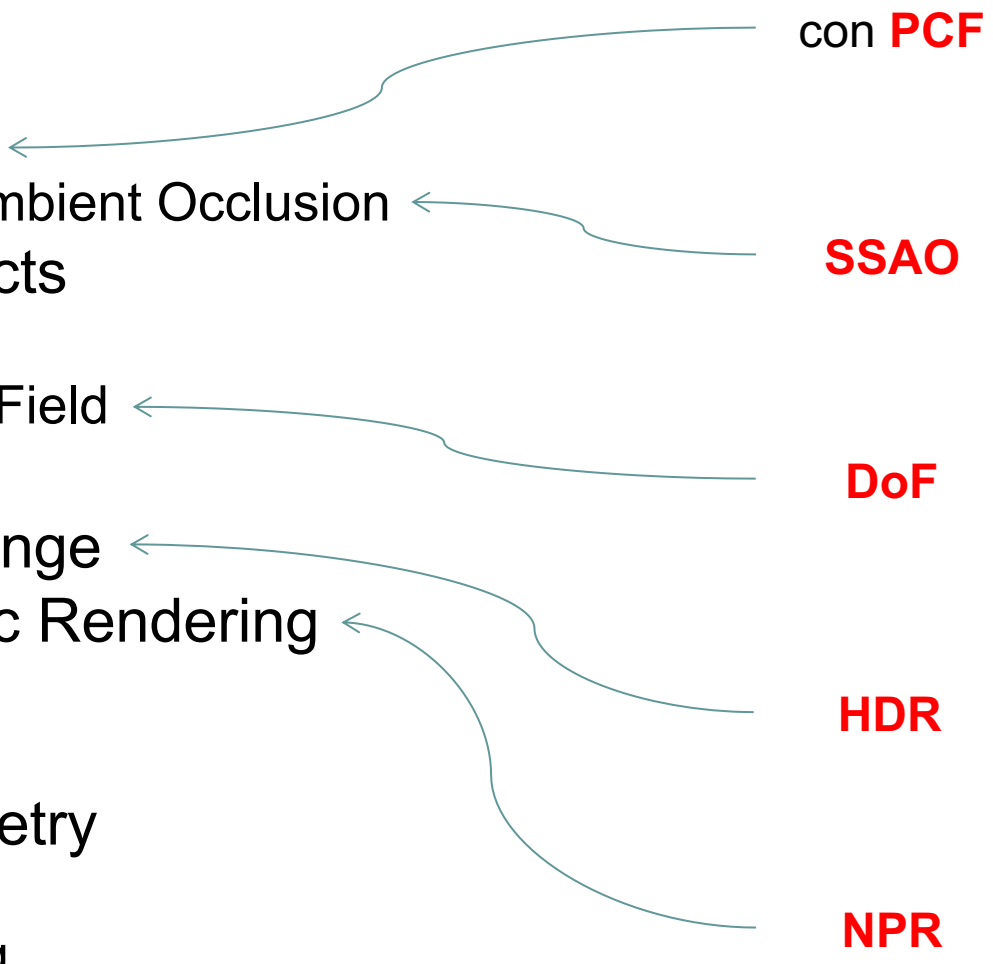
How to feed parameters to the lighting equation

- Hard wired choice of the game engine
- WYSIWYG game tools
  - E.g. in Unreal Engine 4



Rendering techniques popular in games

- Shadowing
  - shadow mapping
  - Screen Space Ambient Occlusion
- Camera lens effects
  - Flares
  - limited Depth Of Field
- Motion blur
- High Dynamic Range
- Non Photorealistic Rendering
  - contours
  - toon BRDF
- Texture-for-geometry
  - Bumpmapping
  - Parallax mapping



Shadow mapping

Shadow mapping

Shadow mapping in a nutshell

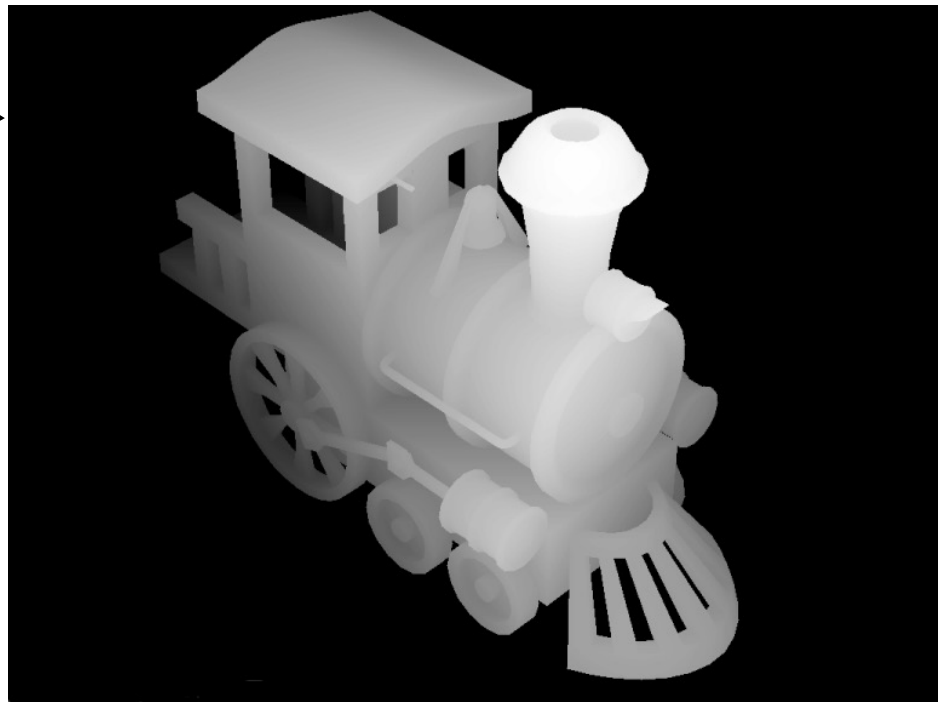
Two passes.

1st rendering: camera in light position

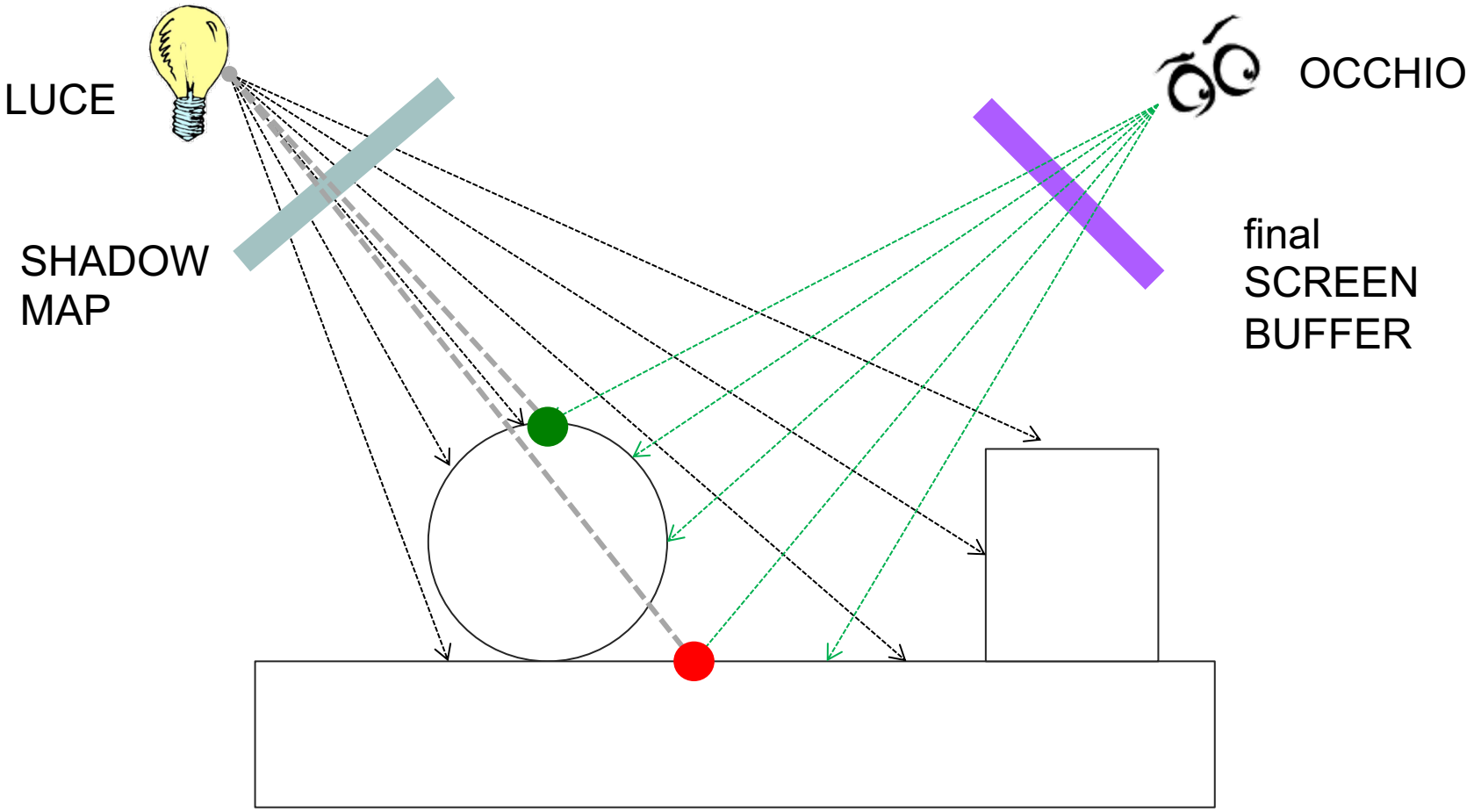
- produces: depth buffer
- called:
  the shadowmap

2nd renedring:
camera in final position

- for each fragment
- access
  the shadowmap once
  to determine
  if fragment is reached
  by light or not



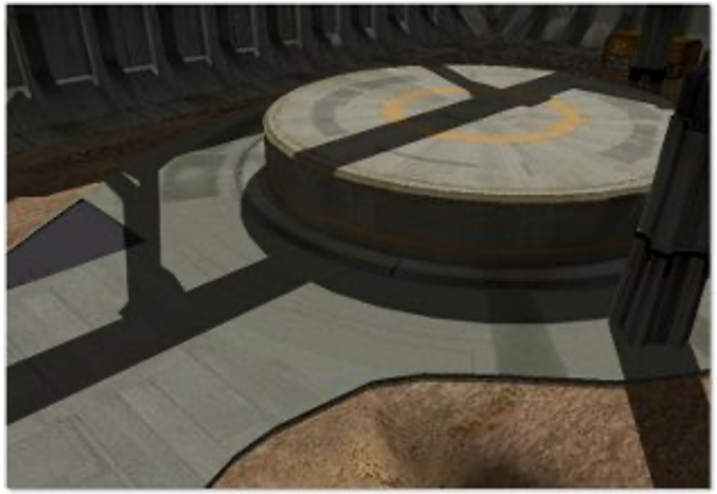
Shadow mapping in a nutshell



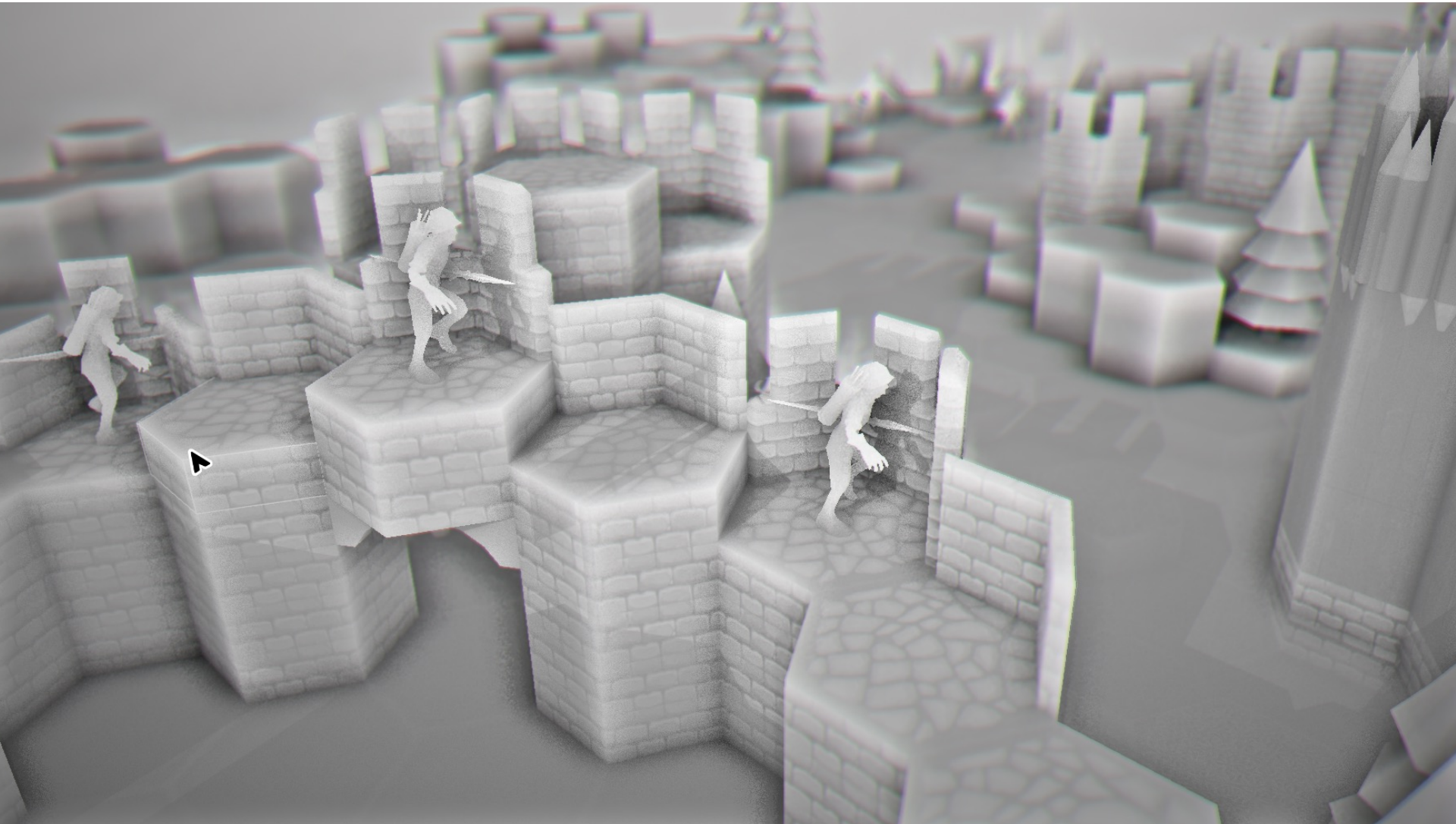
Shadow Mapping: issues

- Rendering shadomap:
  - redo every time object move
  - can bake once and for all for static objects
  - (jet another reason to tag them)
- Shadowmap resolution:
  - it matters! aliasing effects
  - remedies: PCF, multi-res shadow-map

optional topics
(no exam)



Screen Space AO



Screen Space AO

Screen Space AO

Screen Space AO in a nutshell

- First pass: standard rendering
  - produces: rgb image
  - produces: depth image
- Second pass:
  screen space technique
  - for each pixel, look at depth VS its neighbors:
    - neighbors in front?
      difficult to reach pixel: darken ambient
    - neighbors behind?
      pixel exposed to ambient light: keep it lit

Parallax Mapping

Parallax Mapping

Parallax mapping: in a nutshell

- Texture-for-geometry technique
- Texture used:
  - displacement maps
  - color / rgb map

(limited) Depth of Field

(limited) Depth of Field in a nutshell

- First pass: standard rendering
  - rgb image
  - depth image
- Second pass:
  screen space technique:
  - pixel inside of focus range? keep
  - pixel outside of focus range? blur
    - (blur = average with neighbors pixels
      kernel size ~= amount of blur)

HDR - High Dynamic Range (limited Dynamic Range)

HDR - High Dynamic Range in a nutshell

- First pass: normal rendering, BUT use lighting / materials with HDR
  - pixel values not in [0..1]
  - e.g. sun emits light with = RGB [500,500,500]:
  - >1 = “overexposed”! “whiter than white”
- Second pass: screen space technique:
  - blur image, *then* clamp in [0,1]
  - i.e.: overexposed pixels lighten neighbors
  - i.e.: they will be max white (1,1,1), and their light bleeds into neighbors


HDR IN PHOTOGRAPHY
NO HDR
HDR
NO HDR
"HDR"
HDR IN VIDEO GAMES

Part of a general pattern

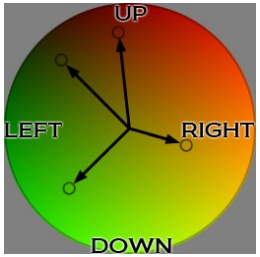
- We are used to defects in real world images so they ***must*** be emulated for more realism
  - Lens flare/bloom
  - Lens distortion
  - Color aberration
  - Film/CCD Noise
  - Motion blur
  - Atmospheric haze
  - Depth of field

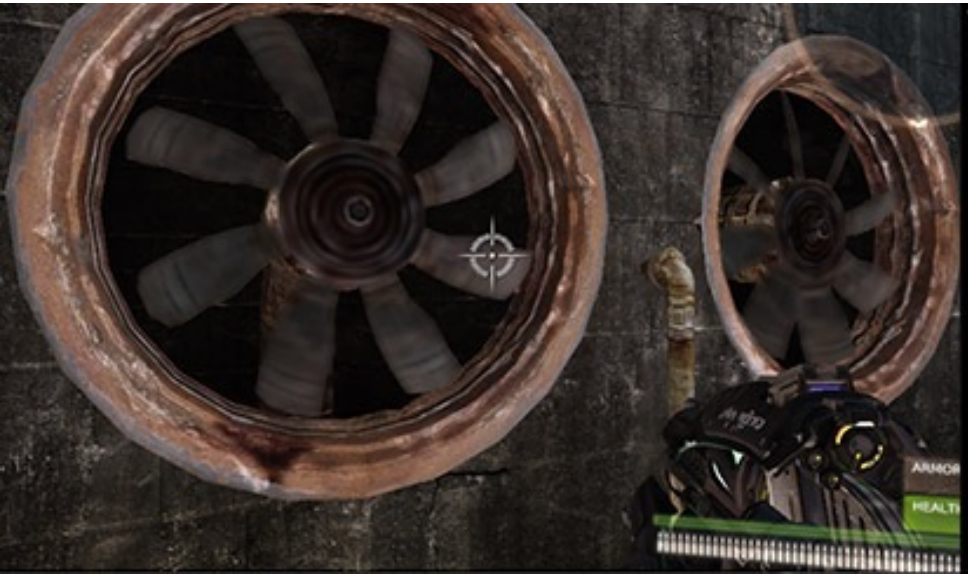
You can google both:
- Removing XXX with photoshop/GIMP
- Adding XXX in Unreal/Unity

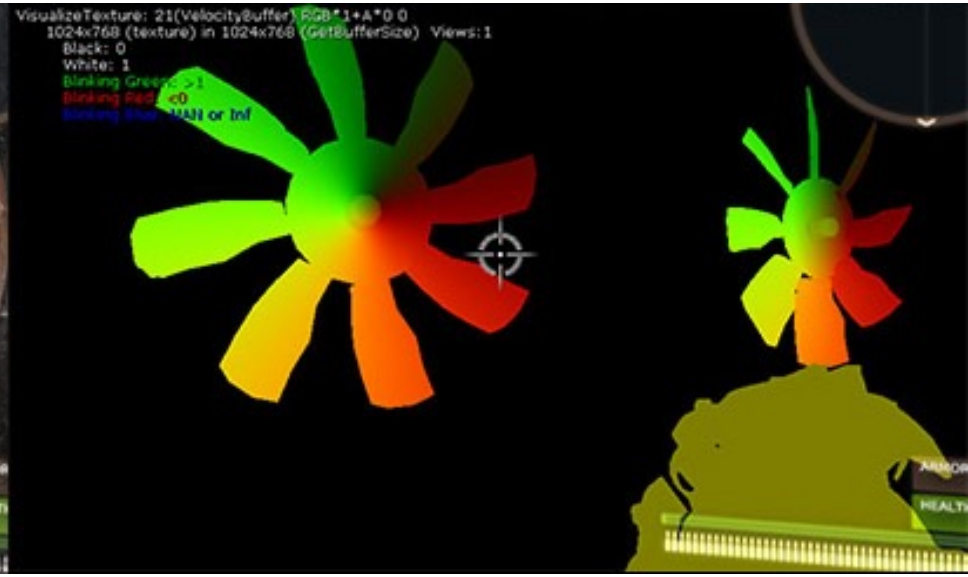
Motion Blur

Motion blur

- Two main approach
  - Multi frame integration
  - **Velocity vector blur**

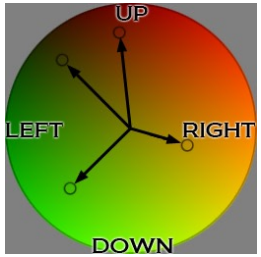


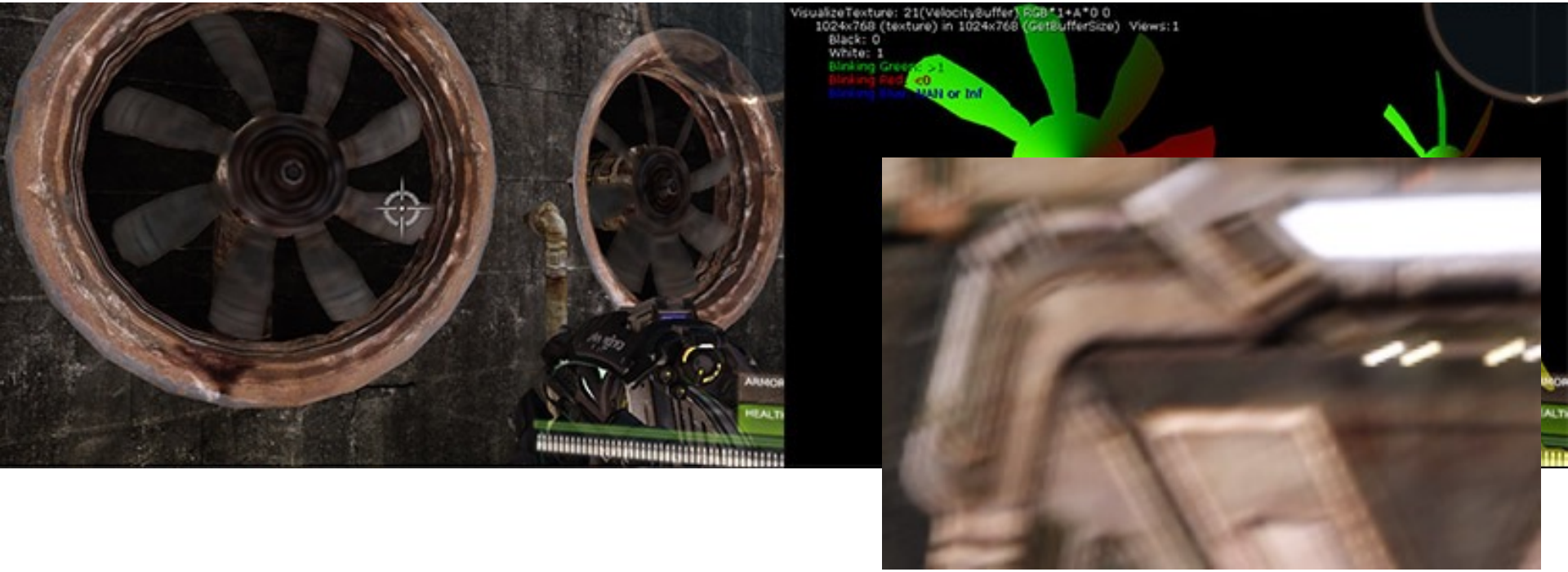




Motion blur

- Two main approach
  - Multi frame integration
  - **Velocity vector blur**





NPR rendering /
Toon shading / Cel Shading

NPR rendering:
Toon shading / Cel Shading

Toon shading / Cel Shading in a nutshell

- Simulating “toons”
- Two effects:
  - add lines
    - at discontinuity lines of:
      1. depth,
      2. normals,
      3. materials
  - quantize lighting:
    - e.g. 2 or 3 tones: light, medium, dark instead of continuous
    - simple variation of lighting equation

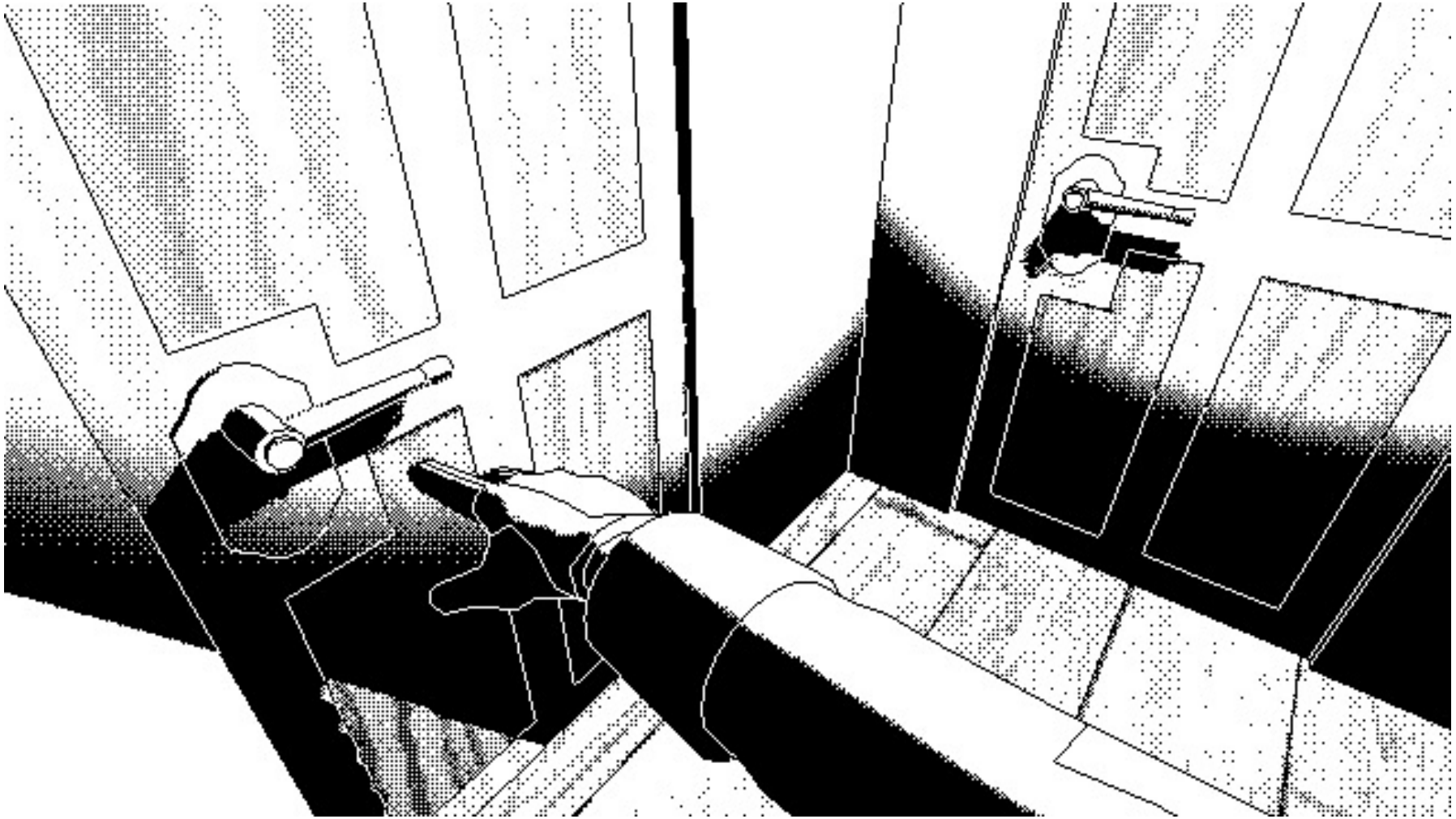
NPR rendering: simulated pixel art

img by Howard Day (2015)

NPR rendering: simulated pixel art

img by Dukope

NPR rendering: simulated pixel art



img by Dukope

Frame Breakdown

- Plain Unreal (2019)
  http://viclw17.github.io/2019/06/20/unreal-frame-breakdown-part-1/
- GTA V (2015)
  https://www.adriancourreges.com/blog/2015/11/02/gta-v-graphics-study/
- Una compilation
  https://www.adriancourreges.com/blog/2020/12/29/graphics-studies-compilation/
- DemoScene
  https://www.iquilezles.org/prods/index.htm
  https://www.pouet.net/