A General Method for Preserving Attributes Values on Simplified Meshes

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Overview

- Mesh simplification
- Current approaches to preserve attribute detail in mesh simplification
- Our texture-based approach:
  - retrieval from the original mesh of the attributes detail
  - coding attributes detail into textures
- Evaluation of results
- Extension to multi-resolution representations
- Conclusions and further work

Mesh Simplification

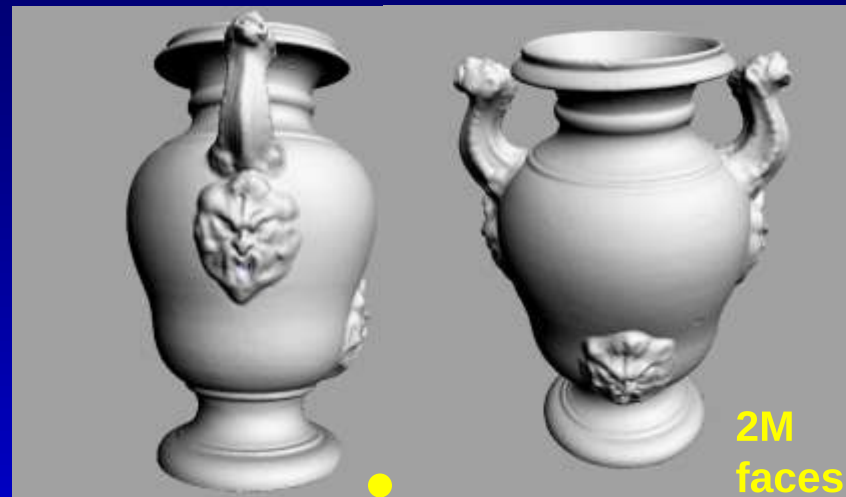
Mesh simplification and LOD encoding:

- Objective: produce the **simplest** mesh that satisfies the accuracy required by the application
- Many good solutions proposed for ***shape-oriented*** simplification
- What if the mesh holds also crucial **attributes** ?
  (e.g. color)

An example

A real object

Range scan



Mesh simplification

AND COLOR ??

Preserving detail on simplified meshes

- Problem Statement :

  how can we preserve on a ***simplified*** surface
  most of the **detail** (or **attribute values**)
  defined on the ***original*** surface ?

- What one would preserve:
  - **color** (per-vertex or texture-encoded)
  - **high frequency shape detail** (bumps)
  - **scalar/vector fields** (e.g. Sci.Viz. applic.)
  - **procedural textures** mapped on the mesh

Preserving detail : State of the art

Approaches proposed in literature:

- **integrated** in the simplification process
  (i.e. ad hoc solutions **embedded** in the simplification code)
  - use an enhanced **approximation evaluation metrics**
    [Hoppe96, Frank etal98, Garland etal98,Cohen etal98]
  - store removed detail in **textures**
    [Krish.etal96,Maruka95,Soucy etal96]
  - preserve **topology** of the attribute field
    [Bajaj98]

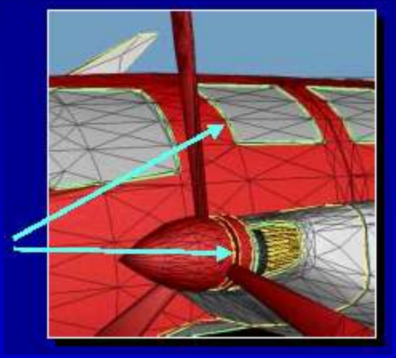


Image by H. Hoppe

Our approach:

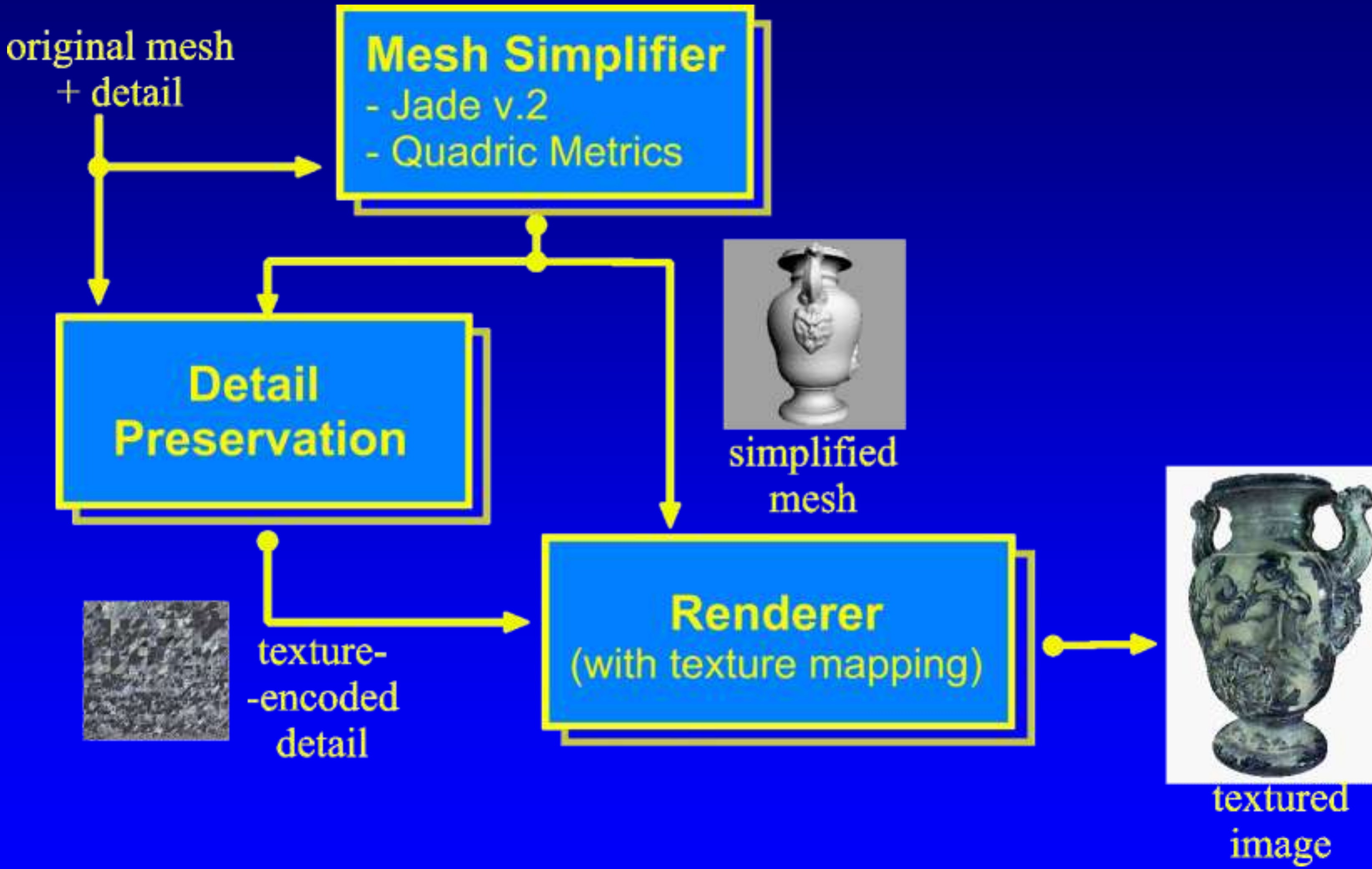
- **independent** from the simplification process
  (post-processing phase to restore attributes detail)

Our approach

Simplification-Independent detail preservation:

- ***general w.r.t. simplification:*** attribute/detail preservation is not part of the simplification process
  - de-couples **shape simplification** and **attribute preservation**
  - performed as a ***post-processing*** phase (after simplification)
  - any simplifier can be adopted
- ***general w.r.t. detail:*** any attribute can be preserved, by constructing ad-hoc ***texture maps***
  - preserving **multiple attributes** does not increase code complexity or processing overhead
- ***efficient in time***

...Our approach...



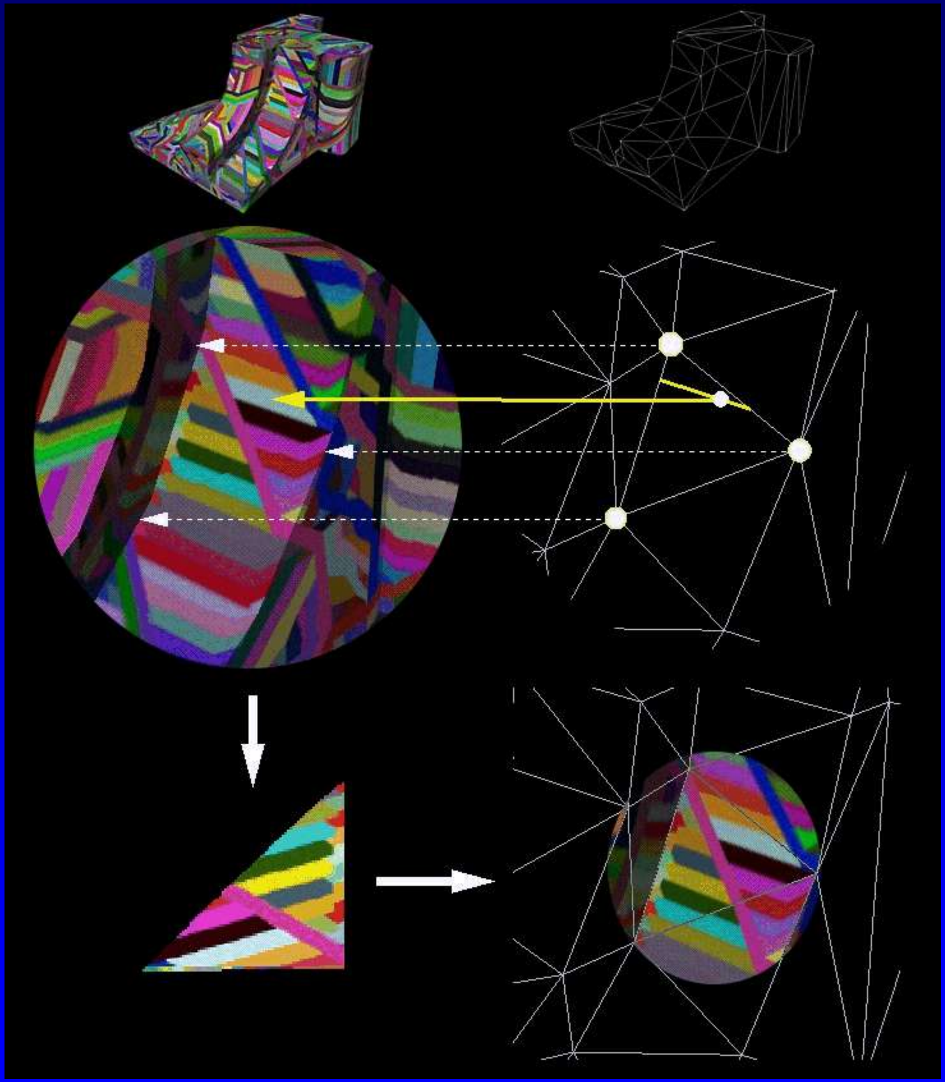
A simple idea :

Phase 1

- for each simplified face:
  - detect the original detail
  - store it into a **triangular texture patch**

Phase 2

- pack all textures patches into a std. rectangular texture



Phase 1: Recovering Detail

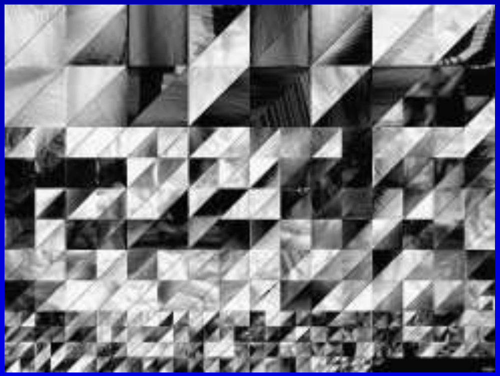
Given an original mesh **M** and a simplified mesh **S** :

for each triangular face of **S** produce a **texture patch**, which encodes the "detail" of **M** lost in **S**

- Scan-convert each face of **S**
  - for each sample point **p** :
    - find the corresponding point **p'** on the original **M**
    - **compute** the attribute value in **M** on **p'**
    - **store** this value into the corresponding **texel** of a **triangular texture patch**

Phase 2: Pack the Texture Patches

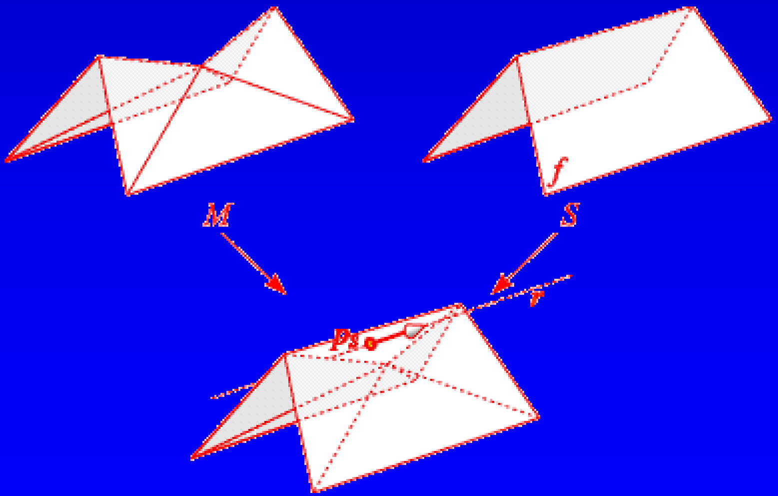
- Store **texture patches** in an efficient manner into a single, std. **rectangular texture**
  - use std. textures to be compatible with std. texture mapping sw/hw
    - ***rgbα*** textures rendering interactive on most graphics system
    - hw-assisted management of bump maps forthcoming
- Texture patches can be packed in two different manners:
  - restrict to **regular** texture patches [Maruka95,Soucy etal96]
  - support **not regular** patches shapes **<-- our choice**



Surface sampling

- **Sampling step** determines:
  - texture **size** and **quality,** running **time**

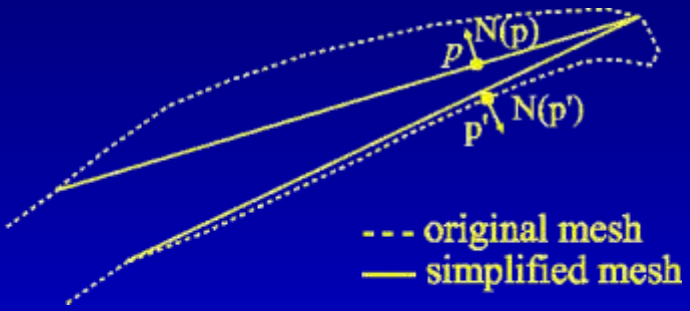
- Sampling:
  - scan-convert face ***f*** of ***S :***
  - for each sampling point ***p***
    - find nearest face ***f'*** in ***M*** (kernel action, efficient via the use of a **bucketing data structure**);
    - compute corresponding point ***p'*** on ***f'***



- Why looking for ***nearest points*** and **not** for points on the ***normal direction***?

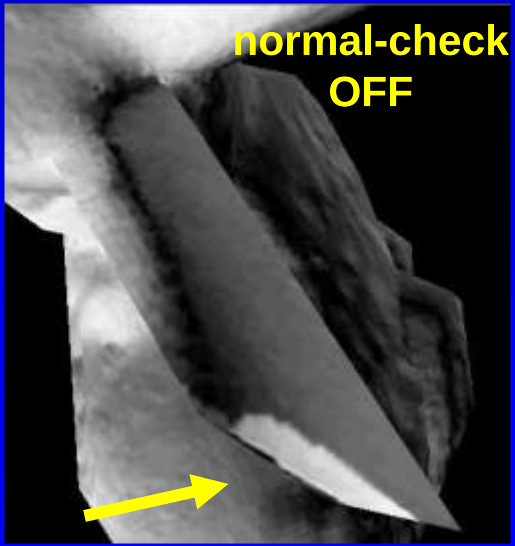
Sampling: a possible problem

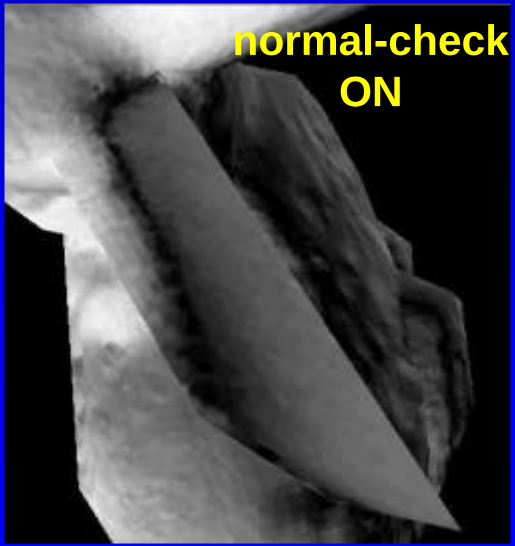
- when mesh section is very thin, incorrect "nearest points" can be produced



Heuristic adopted:

- return the nearest point ***p'*** such that the corresponding face has orientation compatible with that on point ***p***

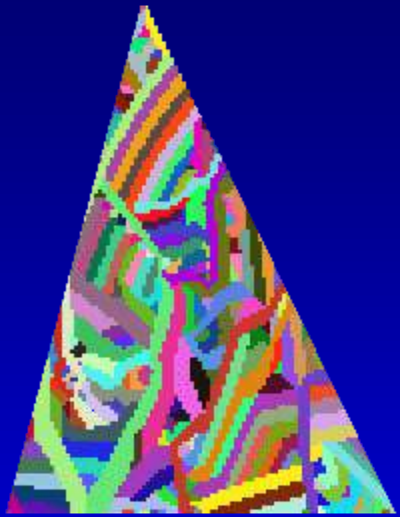




Multisampling

- improves texture quality, without increasing its size
- for each texel:
  - evaluate multiple samples
  - texel **:=** samples average
- particularly useful on meshes with highly discontinuous detail, reduces aliasing
- sampling times (R4400 200MHz) :

Multisampl. OFF	14.71 sec
Multisampl. 2x2	58.43 sec
Multisampl. 3x3	129.44 sec



off

on

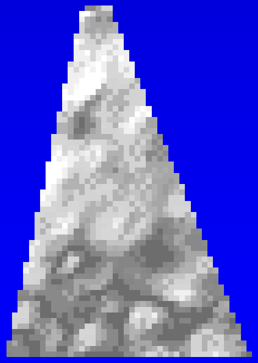
We can sample any field/quantity defined on the surface:

- RGB color, given on a **per-vertex** base
- RGB color, given via **texture**-s
- High frequency shape detail (interpolation of normals or distances ***d(M(p') - S(p))***)
- Scalar / vector field

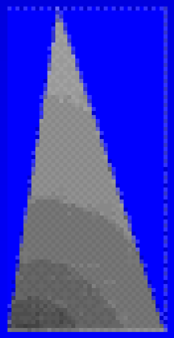
Output:

rgb texture

bump/displacement text.



field value text.



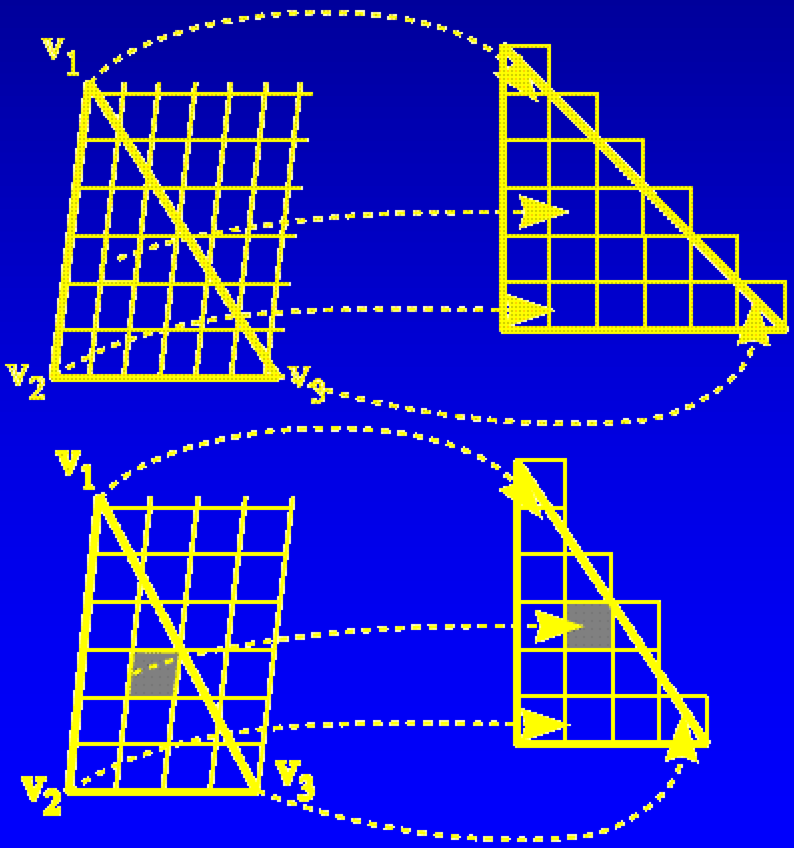
Texture patches

Patch size:

- discrete set of possible heights ($\mathbf{2^i}$ texels), to allow easy packing

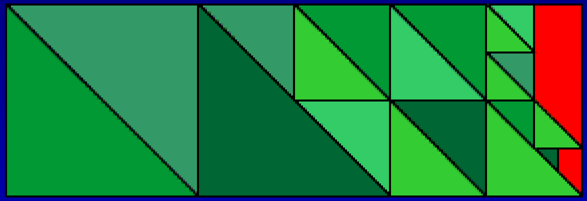
Packing algorithm depends on patch shape:

- **regular** shape (rectilinear):
  - very easy to pack
  - different sampling rate in the two axes
- **not-regular** shape:
  - slightly more complex to pack,
  - more compact in shape
  - lower aliasing (identical sampling step in the two directions)



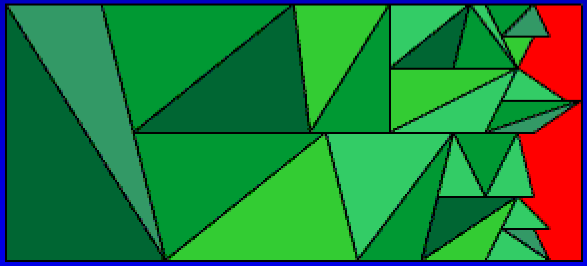
Packing Texture Patches

- Regular shape: straightforward
  [Soucy etal 96]



: texture wasted space

- Irregular shape:
  - use heuristic rules or an optimization process
    (optimal packing NP hard)
  - **our choice**: simple heuristic

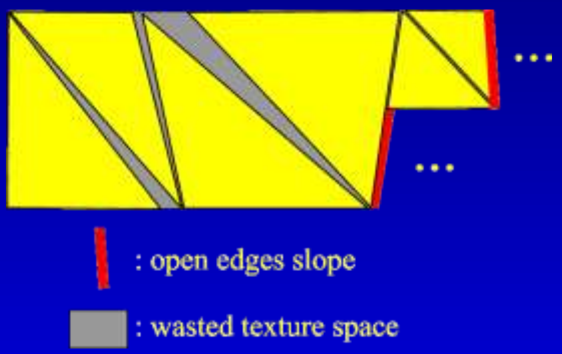


: texture wasted space

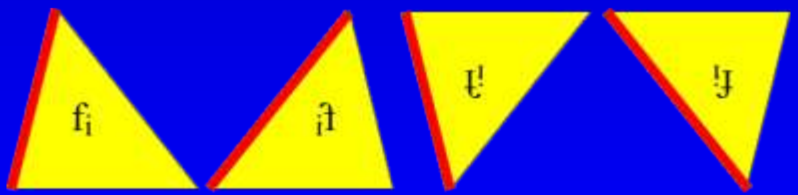
...Packing Texture Patches...

Packing heuristic

- divide patches in buckets, ordered by **height** (discrete set);
- process buckets in order of decreasing height (tallest first):
  - ❑ **loop**
    - ✧ find the face which adapts better to the ***open edge slope***
    - ✧ copy it in the texture
  - ❑ **until** no more faces in the bucket



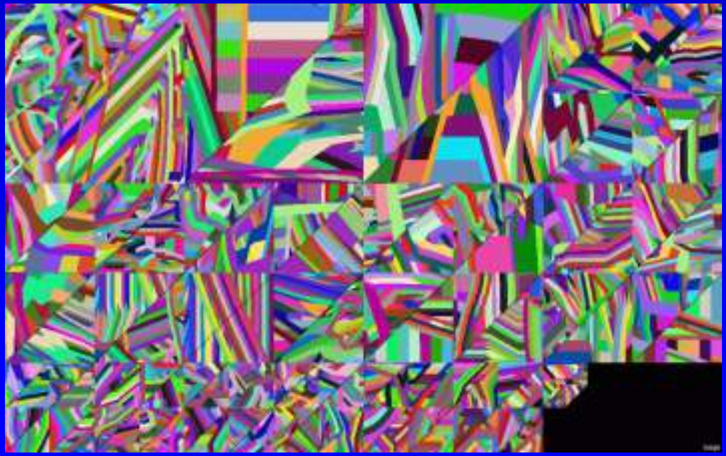
☞ each face has 4 possible slopes (flip in the two direction)



☞ gaps in the textures if slopes do not match precisely

- In average, texture sizes: ***regular ~= 2x non-regular***
- Overhad of ***non-regular packing*** on the ***bunny*** mesh***:***
  - patch_expansion (2^i height) 12%
  - patch_borders 28%
  - text_gaps 4%
  - text_tails 12% **Total 67%**
- An example on the **fandisk** mesh (98 faces) :

regular patches

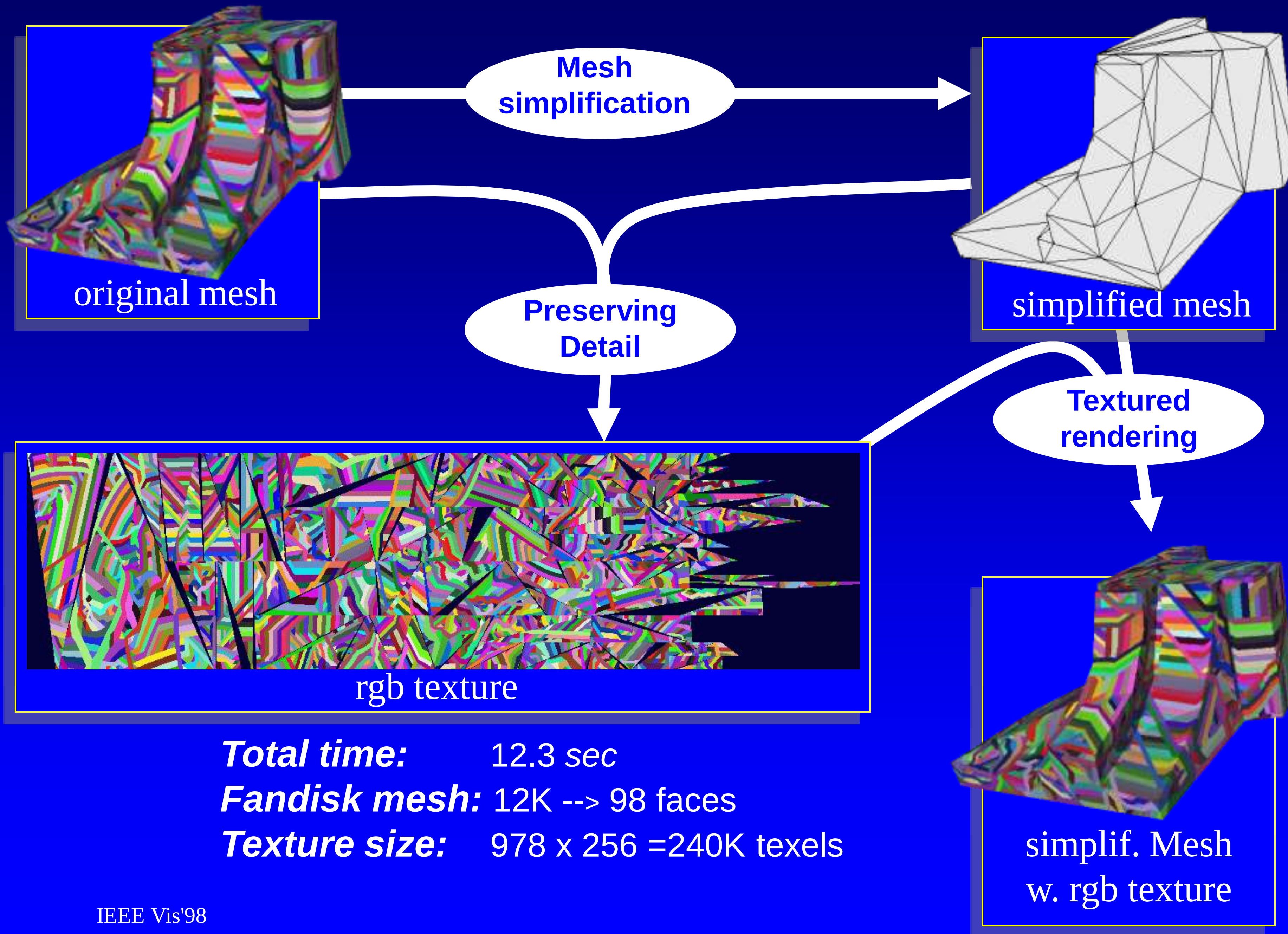


Size: 1024 x 640 texels

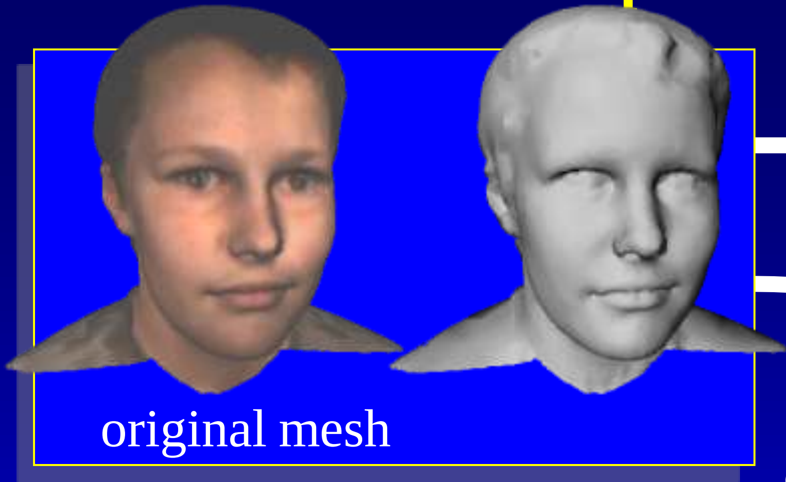
non-regular patches

Size: 978 x 256 texels

Results: preserving color detail

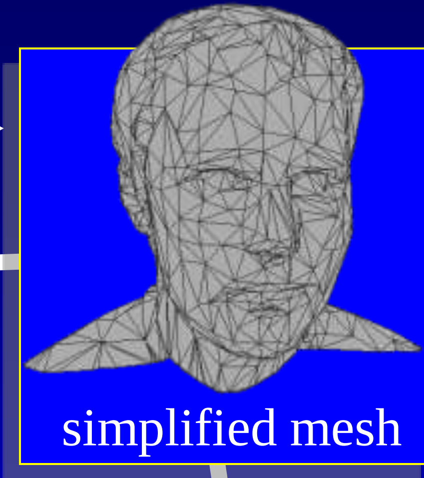


Results: preserving textured-color detail



original mesh

Mesh simplification



simplified mesh

Preserving Detail

rgb texture

Textured rendering

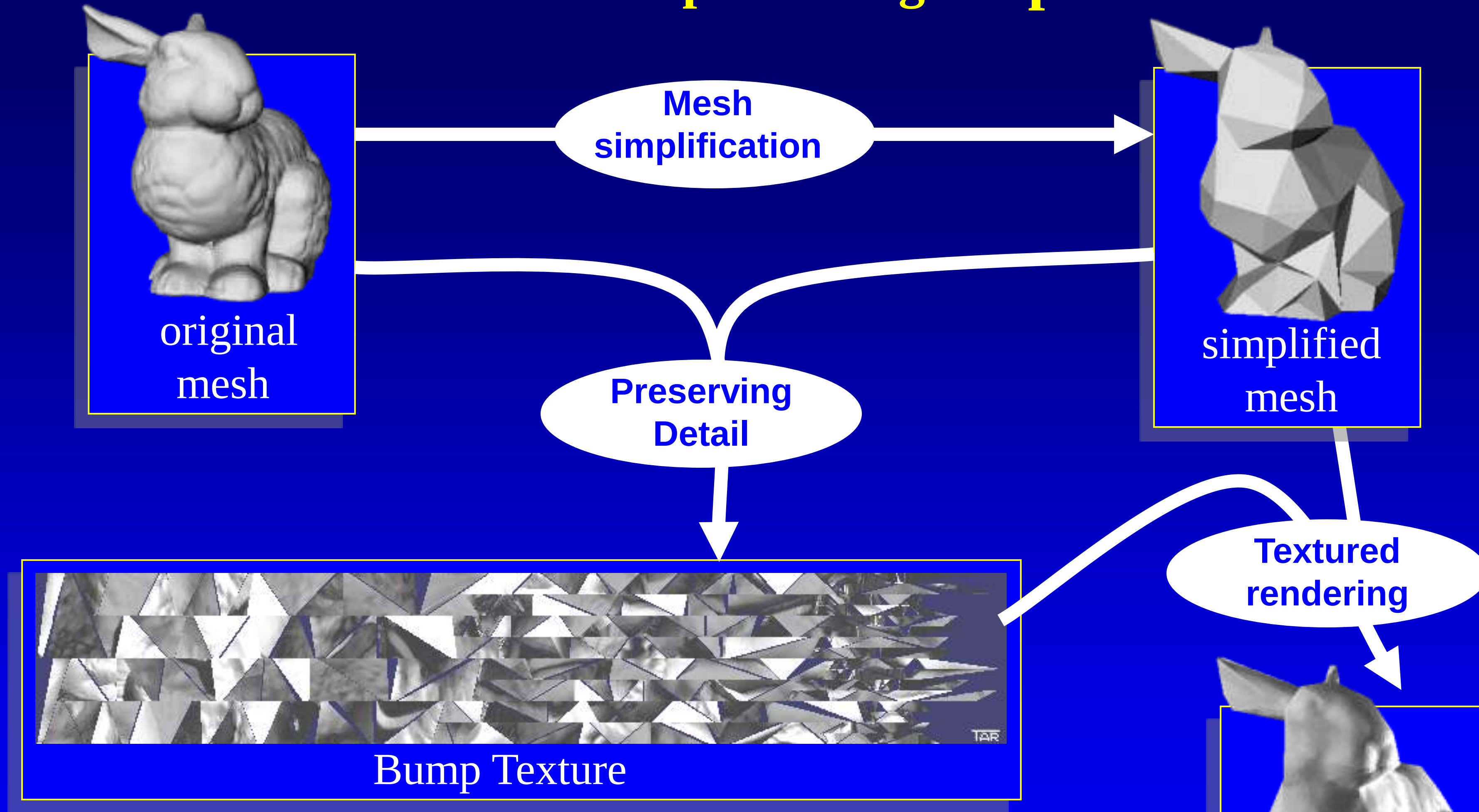
simplif. Mesh
w. rgb texture

Total time: 6.1 sec. (9.8 w. I/O)

Face mesh: 10K --> 1,745 faces

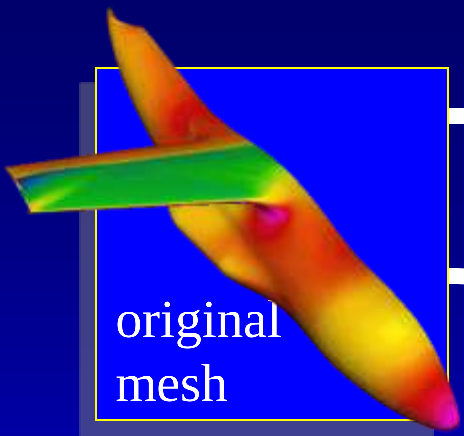
Texture size: 702 x 128 = 87K texels

Results: preserving shape detail



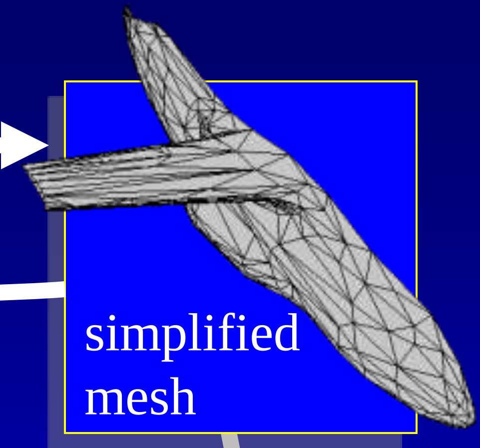
Total time:	27.2 sec. (38.7 w I/O)
Bunny mesh:	69K--> 251 faces
Texture size:	719 x 128 = 83K texels

Results: preserving field detail



original mesh

Mesh simplification

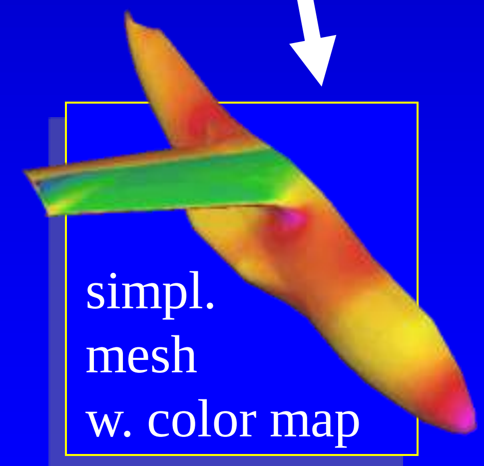


simplified mesh

Preserving Detail

Textured rendering

Field value texture (after Trasf.Funct. Mapping)

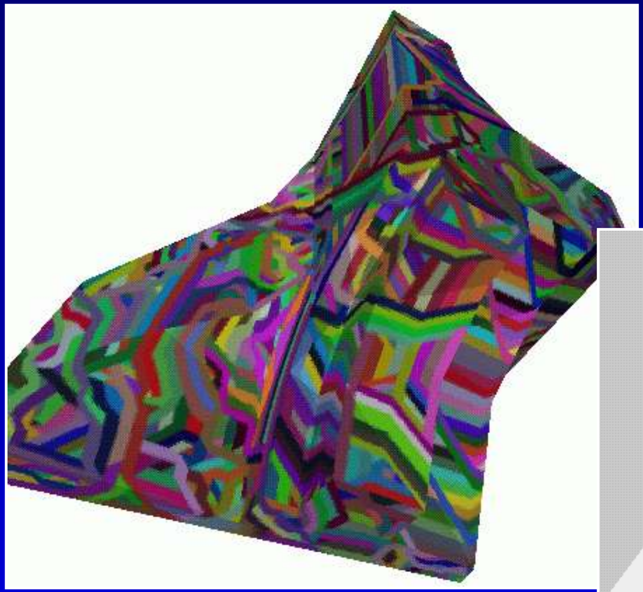


simpl. mesh w. color map

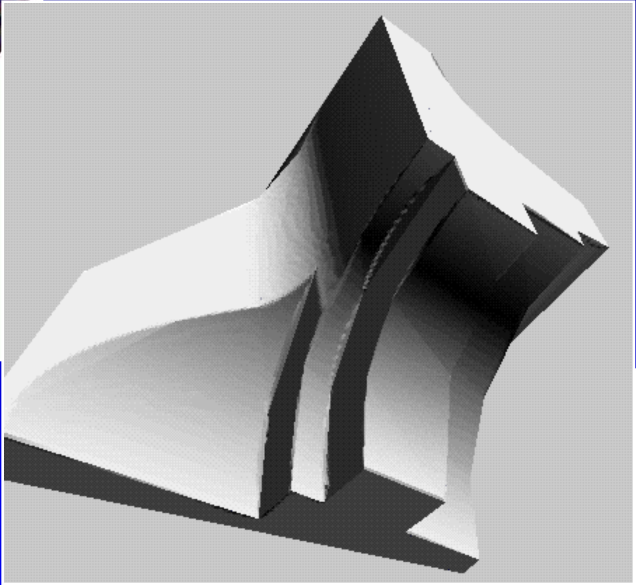
Total time:	26.2 *sec.* (88.6 w. I/O)
Plane mesh:	87K --> 500 faces
Texture size:	656 x 128 = 82K texels

Integrating different detail maps

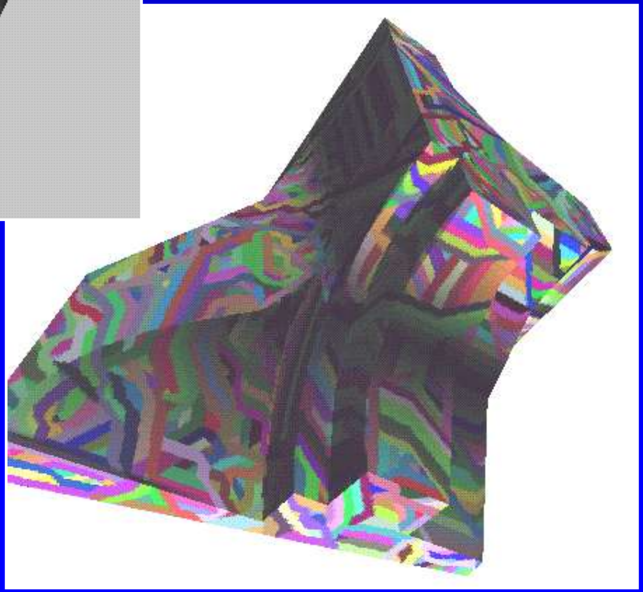
Color only
(RGB texture, HW gouraud shading)



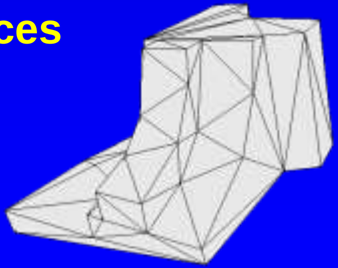
Shape only
(pre-shaded bump map)



Color + shape
(pre-shaded RGB texture using bump map, SW)



Geometry used in all 3 images:
- simplif. fandisk, **98 faces**



Procedural Textures

- **Procedural textures**:
  - widely used to synthesize complex materials
  - require **software** rendering

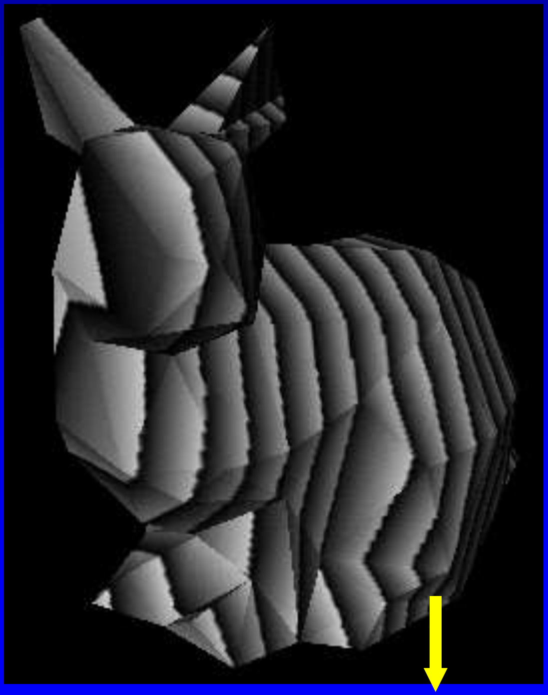
- Use the same approach also to produce a ***std. 2D texture*** which stores all the detail that the ***procedural texture*** paints on the object surface:
  - sample the surface,
  - for each sampling point evaluates the procedural texture

- Use procedural textures also on HW-assisted systems!

geometry (3250 faces) +
2D "procedural" texture

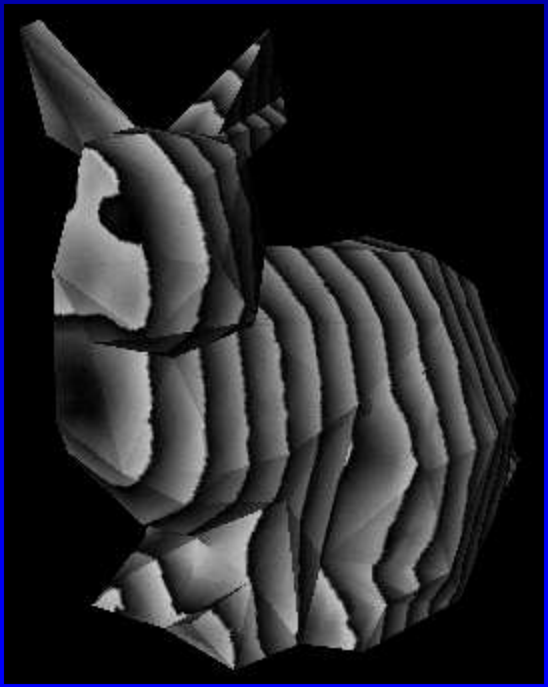
- If we have a simplified mesh,
  procedural textures may be applied (or, in our case, sampled) on:

texture : sampled on simplified mesh
rendering : simplified mesh

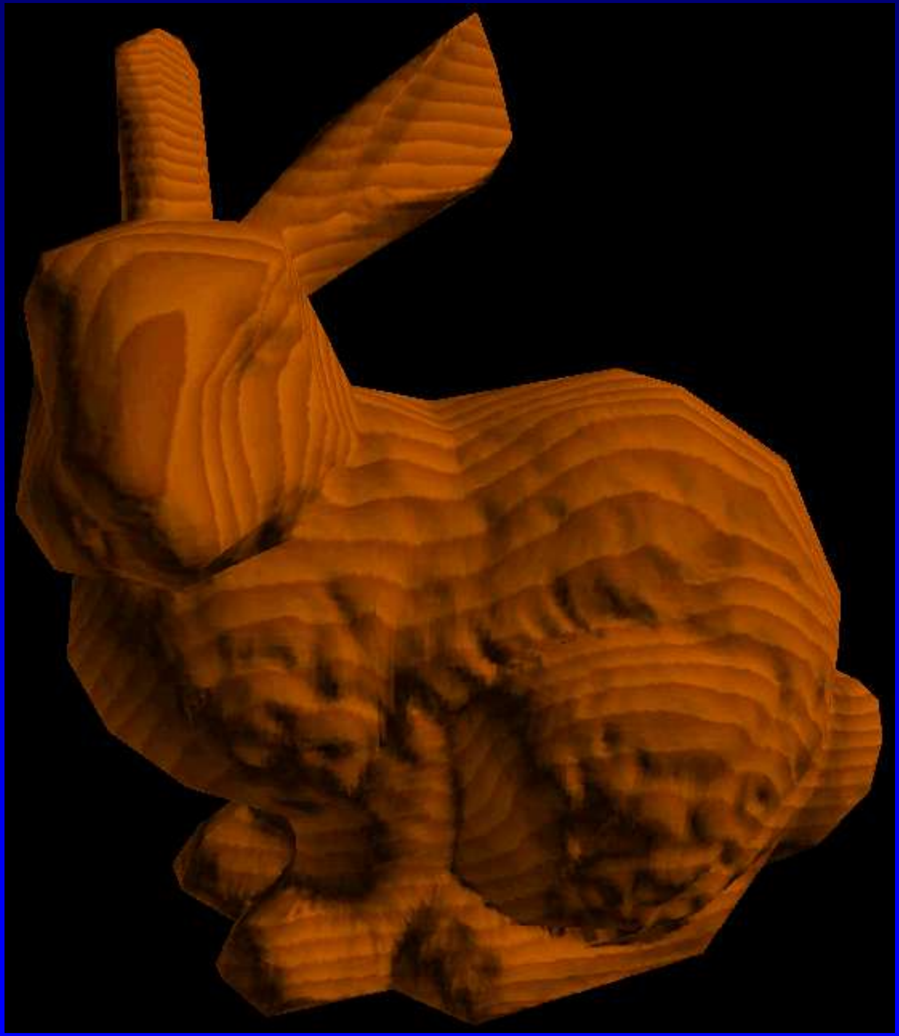


equivalent to applying proc.text
to the simplified mesh

texture : sampled on original mesh
rendering : simplified mesh



- A “wooden” bunny
  - ❑ procedural text.
  - +
  - ❑ shape text.
- geometry:
  - ❑ 251 faces



Results

- **Show meshes...**

Multiresolution Management

Extend this approach to multiresolution repr.:

- Linear sequences
  - list ***F* = { *f*$_i$ }** of all the faces produced during simplification
  - for each face ***f*** we store its accuracy interval ***(min$_f$,max$_f$),*** such that ***f*** is part of a simplified mesh at accuracy **ε** IFF:

$$\min_f \le \varepsilon \le \max_f$$

- Preserving detail on **linear sequences** :
  - ***pre-processing:*** build the detail texture associated to the list ***F***
  - ***run-time:*** given an accuracy **ε_1**
    - extract from ***F*** all faces ***F'={ f }*** such that: $\min_f \le \varepsilon_1 \le \max_f$
    - extract from the multires texture all texture patches associated to ***F'*** and pack them in a new texture map

When we sample texture patches for a multiresolution mesh:

- sampling step may be **constant**
- sampling step may **depend on** current face **accuracy** (lower is accuracy, coarser is sampling)

Choice depends on applications:

- similar quality of preserved detail on meshes with different size
- detail quality proportional to geometric size (e.g. construction of LOD models)

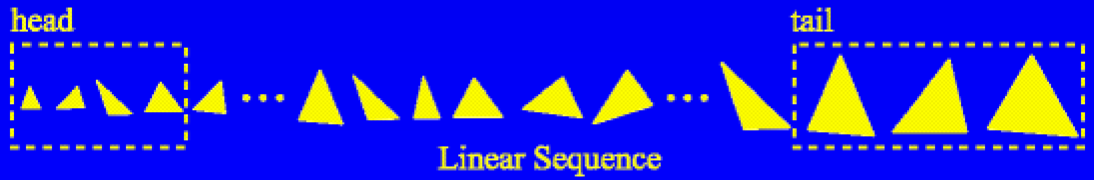
Multiresolution Detail Textures:

- number of faces in a **linear sequence** is ~2.5 no. faces in original mesh
- **size** of **multires. detail texture** depends on the total surface area of the faces in the linear sequence
- on a number of experiments: **3x .. 10x**

To **reduce** multires. texture size :

- do not represent faces in the ***head*** and the ***tail*** of the linear sequence

  (i.e. with accuracy < $\boldsymbol{\varepsilon_{min}}$ and > $\boldsymbol{\varepsilon_{max}}$)



Conclusions

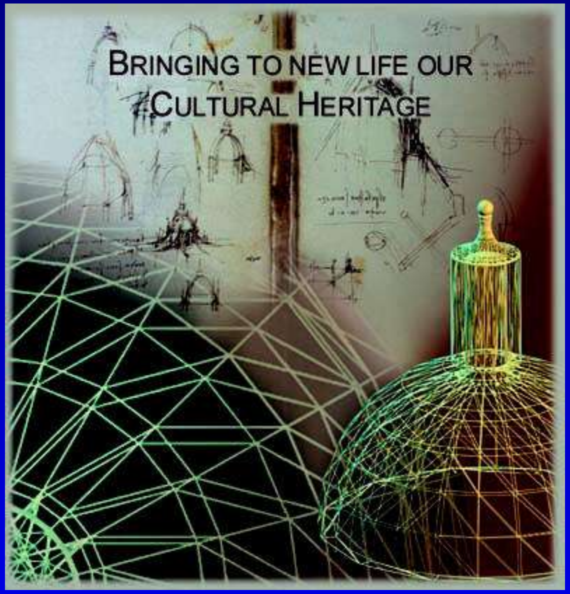
Detail preserved via **patched textures**

- general solution, simplification-independent
- allows to recover multiple attributes
- highly efficient (<1min)
- accuracy depends on sampling resolution (user-selectable)

Extensions

- detect faces whose texture patch is “linear” with the values on the vertices, use an **hybrid mesh encoding**
  - **non-linear faces** have texture coordiates to a text. patch;
  - **linear faces** are defined with per-vertex coded detail (color, normal)
- improve **multiresolution** management

Eurographics '99 Conference



"Bringing to new life our Cultural Heritage"

Milano (Italy), Sept. 7-11, 1999

Deadlines

- **Tutorials** Nov. 15th, 1998
- **State of the Art Reports** Nov. 15th, 1998
- **Papers** Jan. 15th 1999