Watermarking Multiple Object Types in Three-Dimensional Models

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- Introduction
- Embedding Targets in 3D Models
- Algorithms
- Summary and Future Work

3D Model Data Embedding :

Example

- A 3D modeler with embedding capability.
- A watermark is embedded in a model.

Embedding

3D Model Data Embedding :

Example

- An enhanced browser.
- Both models are marked.

Extraction

3D Model Data Embedding :
Example

- An enhanced browser.
- Both models are marked.
- Click a model...

Extraction

3D Model Data Embedding :
Example

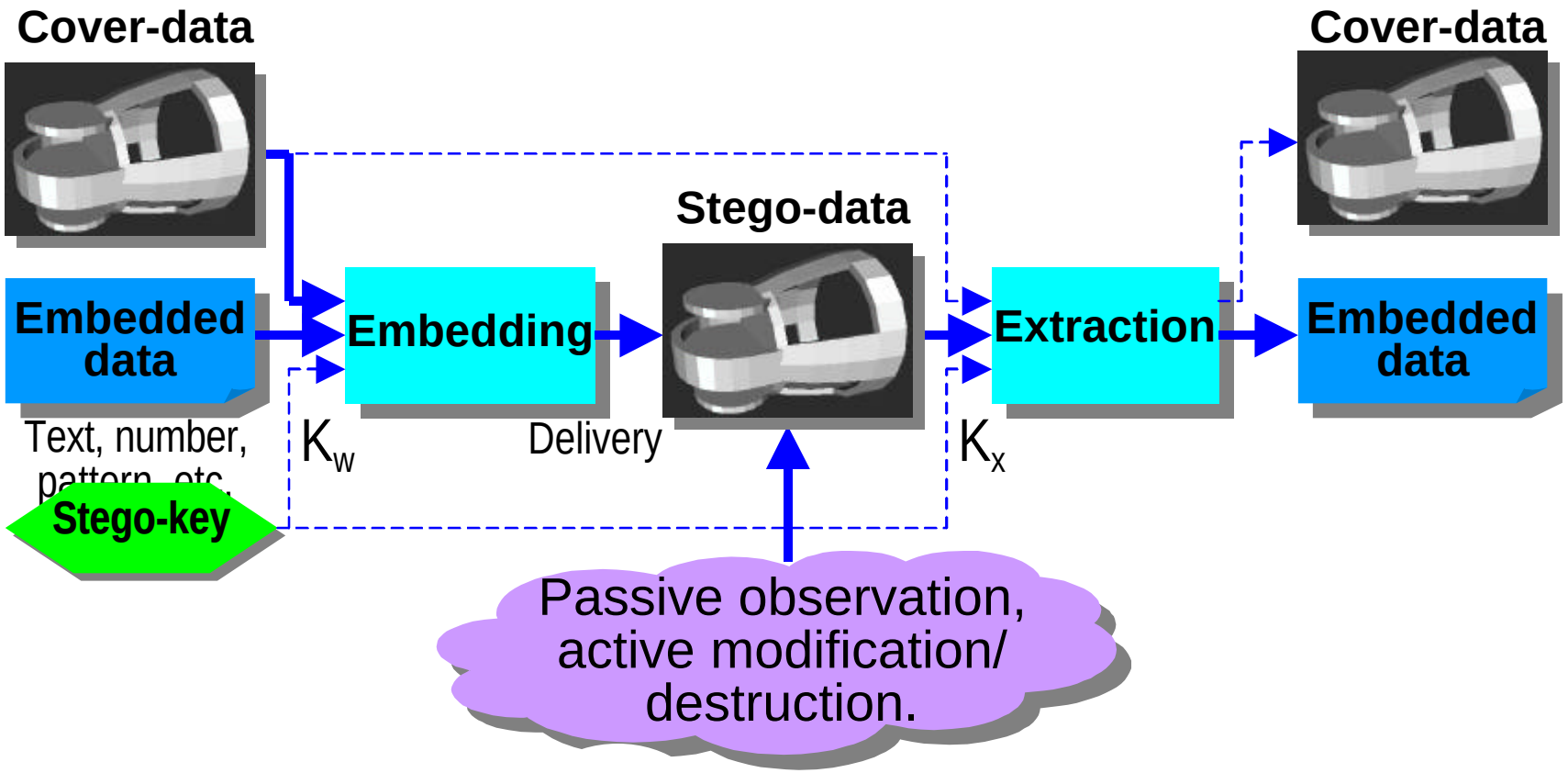
- An enhanced browser.
- Both models are marked.
- Click a model…
- The watermark is extracted and displayed.

Extraction

Data Embedding / Watermarking

- Embed message into data objects as (mostly) imperceptible structures called watermarks.
- Potential application examples
  - Theft deterrence.
  - Copyright notification.
  - Tamper detection, content integrity check.
  - Fingerprinting.
  - Delivery (e.g., playback) control.
  - Covert communication.

Data Embedding



Terminology compiled by Pfitzmann in “Information hiding terminology”, LNCS 1174, 1996.

Previous Target Data Types

- Image
  - [Tanaka, Bender, Cox, Braudway, O'Ruandaidh, Smith, Tewfik, Zhao, ...]
- Video
  - [Hartung, Morimoto, ...]
- Audio
  - [Matsui, Gruhl, ...]
- Text
  - [Maxemchuk, ...]

  … and
- 3D polygonal model shape [Ohbuchi, et al]

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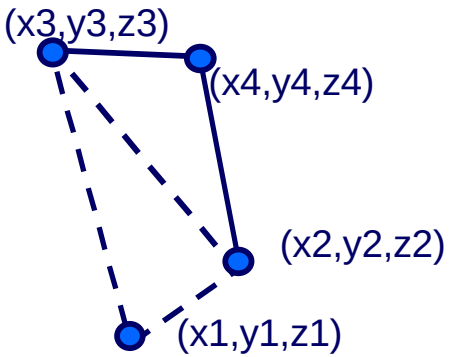
Embedding opportunities in 3D models

- Shape
  - E.g., Polygonal mesh topology and geometry.
- Shape attributes
  - E.g., Vertex color (opacity), texture coordinates, vertex normal vector.
- Animation parameters
  - E.g, VRML coordinate interpolator, MPEG 4 body animation parameter.
- Others
  - E.g, texture image, audio, behavioral script.

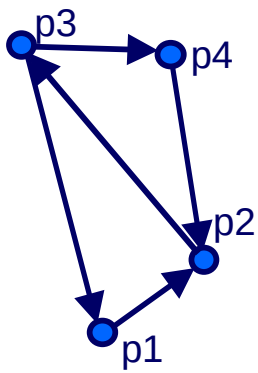
Shape and Shape Attributes in Polygonal Meshes

Shape

Vertex coordinates



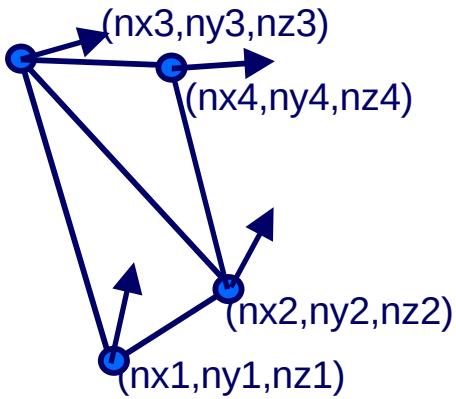
Vertex topology



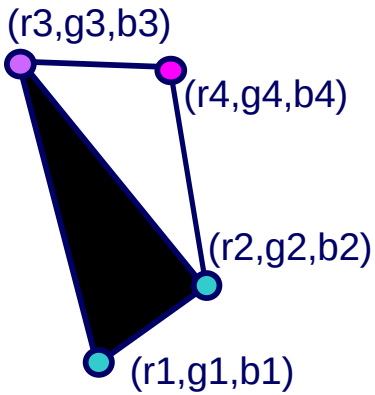
Poly1=
{(p3,p1),
(p1,p2),
(p2,p3),
(p3,p4),
(p4,p2)}

Shape attributes

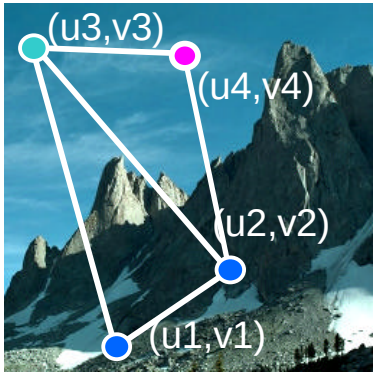
Vertex normal vector



Vertex color

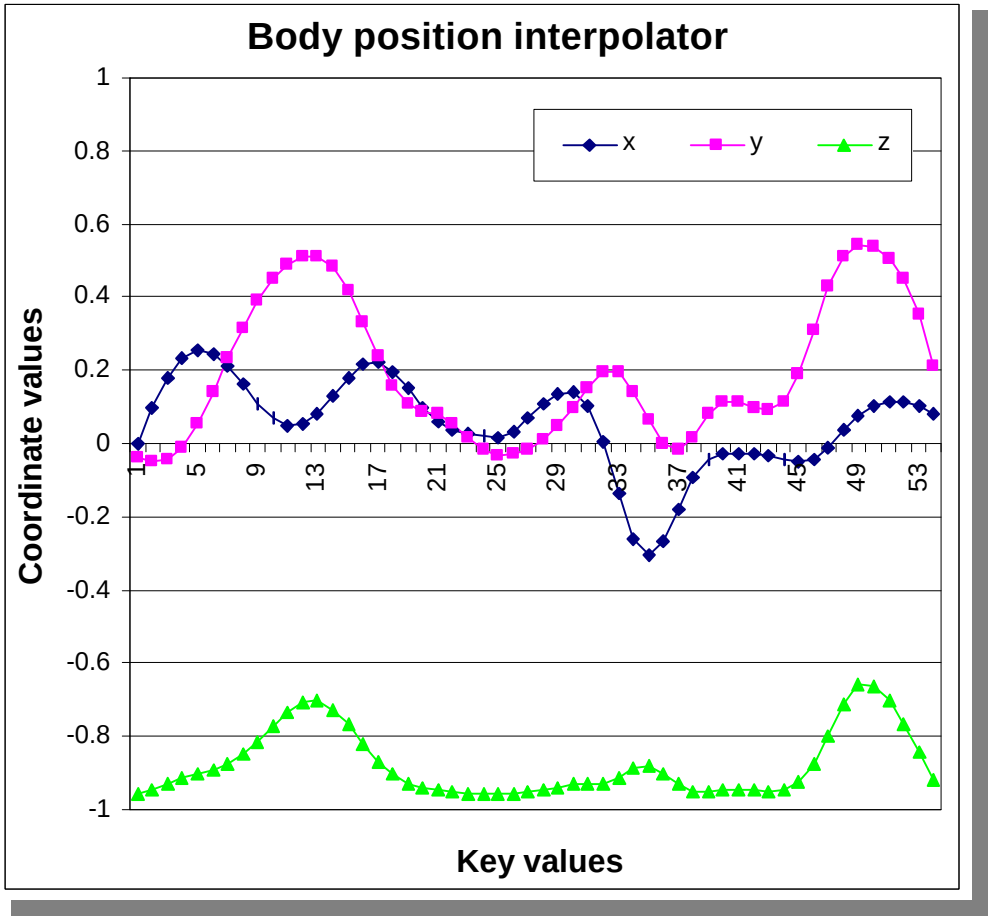


Texture coordinates



Animation Parameter

- Time sequence of scalar or vector values.
  - May be compressed.
- Examples
  - VRML coordinate interpolator.
  - MPEG 4 mesh animation param's.
  - MPEG4 body animation param's.



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  - Embedding in shape
  - Embedding in shape attributes
- Summary and Future Work

Embedding in Shape

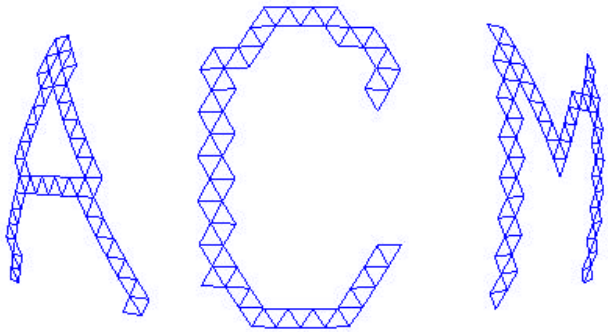
- Shape is the most important element.
  - Removal least likely.
  - Geometrical transformations, e.g., translation and scaling, are applied regularly.
- Shape = geometry + topology.
  - Geometry ≅ vertex coordinates.
  - Topology ≅ relations of vertices.

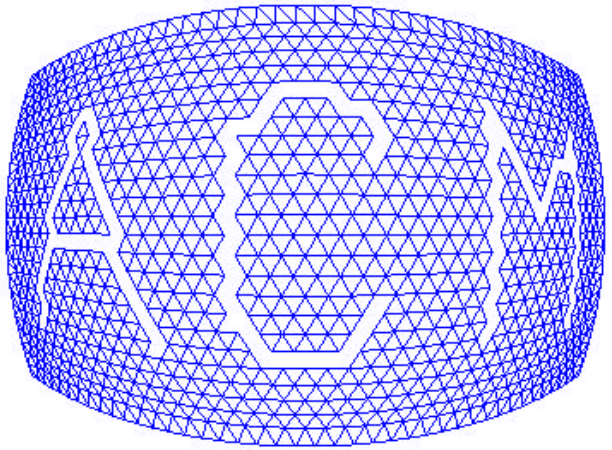
Shape Modification Primitives

- Geometrical primitives
  - Modify geometrical transformation *invariants*.
    - Indirectly modify vertex coordinates.
      - Vertex coordinates destroyed by any geometrical transformation, e.g., translation.
  - Ex. Affine transformation invariants
    - Ratio of lengths of line segments on a line.
    - Ratio of volumes of two polyhedrons.

Shape Modification Primitives

- Topological primitives
  - Encode data in how things are connected.
    - Connectivity of points, triangles, tetrahedrons, etc.
  - Unaffected by geometrical transformation.
  - Ex. Cut-out stencil patterns from a mesh.





Primitive Arrangement

- Embed data into an arrangement of primitives.

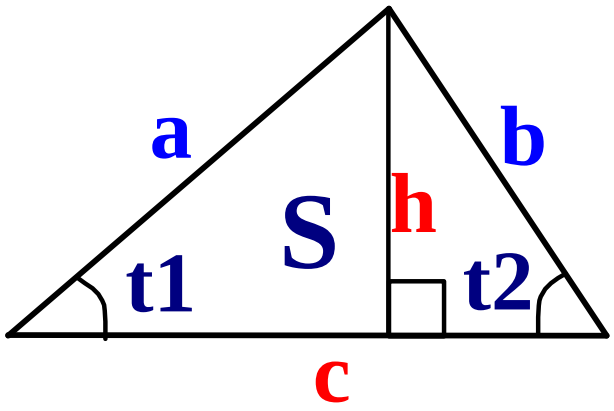
  {g,a,r,m,t,n,r,e,e,n,a} ➡ {a-r-r-a-n-g-e-m-e-n-t}

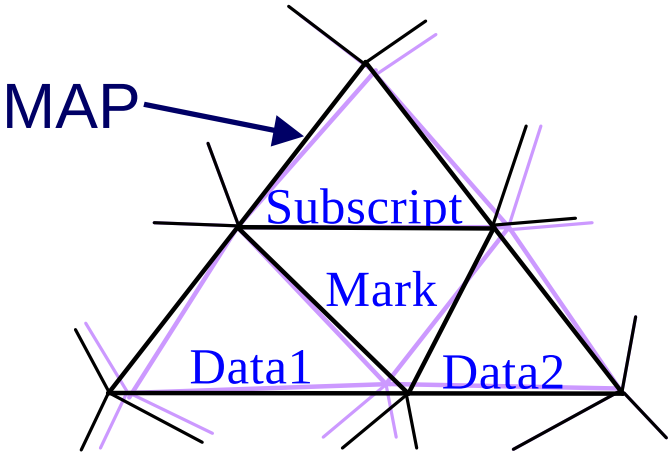
  - Ex. Embed a visible pattern in a 2D arrangement.
  - Ex. Embed a symbol string in a 1D arrangement.
- Arrangement = (Initial condition) + (Ordering)
  - Both must withstand expected disturbances.
- Arrangement is easier in audio, image, text, or movie data.

Triangle Similarity Quadruple Method

Embed in Vertices of Poly-Meshes

- Primitive
  - Dimension-less quantities {a/b, h/c} that defines a set of similar triangles.
  - Invariant to translation, uniform-scaling, and rotation.
- Arrangement
  - by subscript in *Macro Embedding Primitives (MAP)*

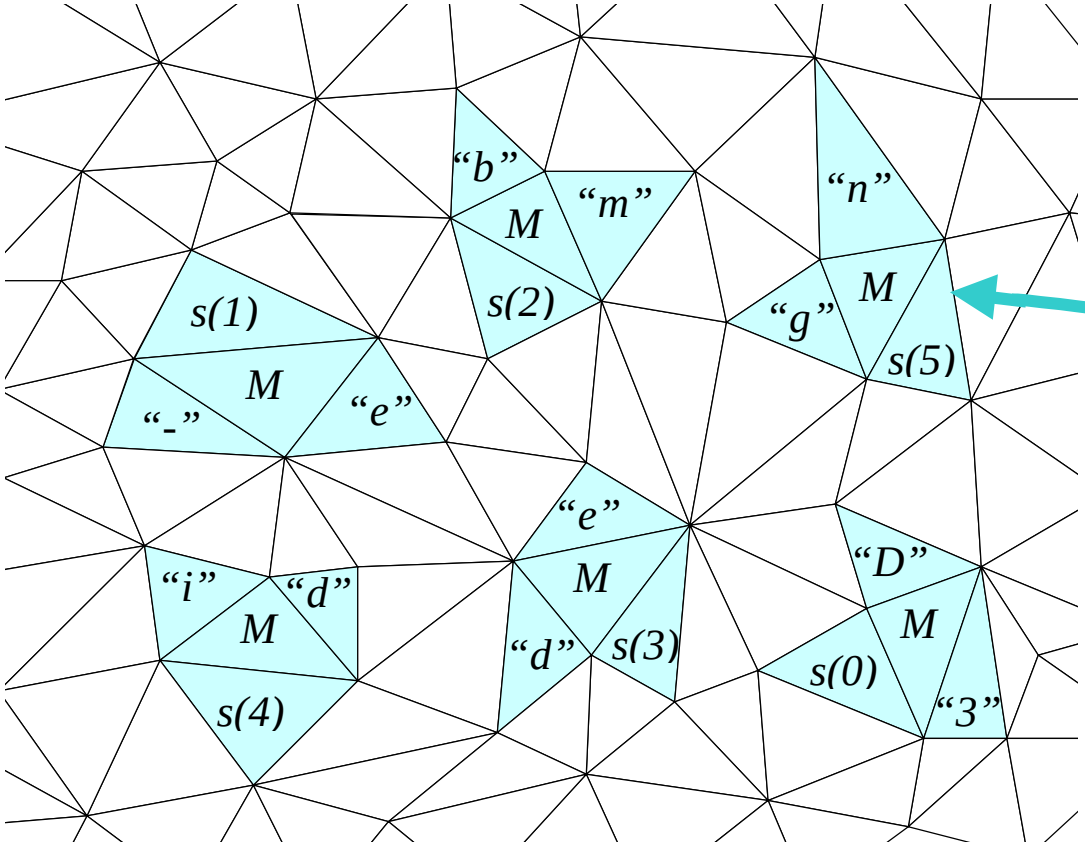




Triangle Similarity Quadruple Method

Embed in Vertices of Poly-Meshes

- Embedding example.



Triangle Similarity Quadruple Method

Embed in Vertices of Poly-Meshes

- Resistant to resection due to
  - Subscript-arrangement.
  - Repeated embedding.

Resection and data loss

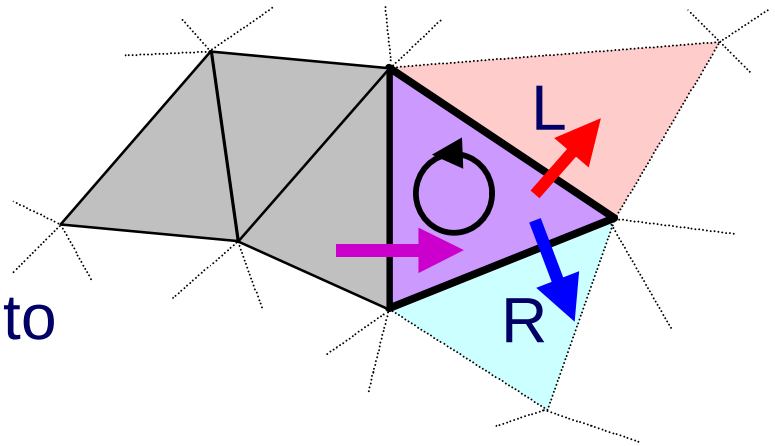
(a) (b) (c) (d)

	No. of f $\$$	Data remained intact
a	4889	6 copies, 132 bytes each.
b	2443	132/132 bytes
c	1192	102/132 bytes
d	399	85/132 bytes

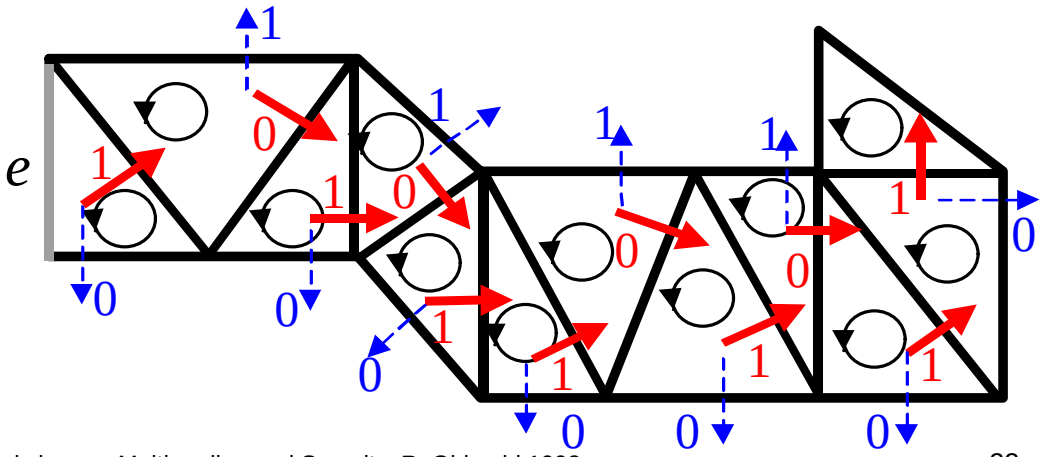
Triangle Strip Peeling Method

Embed in Topology of Poly-Meshes

- Symbol Sequence Embedding
- Primitive and arrangement
  - Adjacency of triangles in a triangle strip.
  - Interleave “steering symbols” to steer growth of the strip.

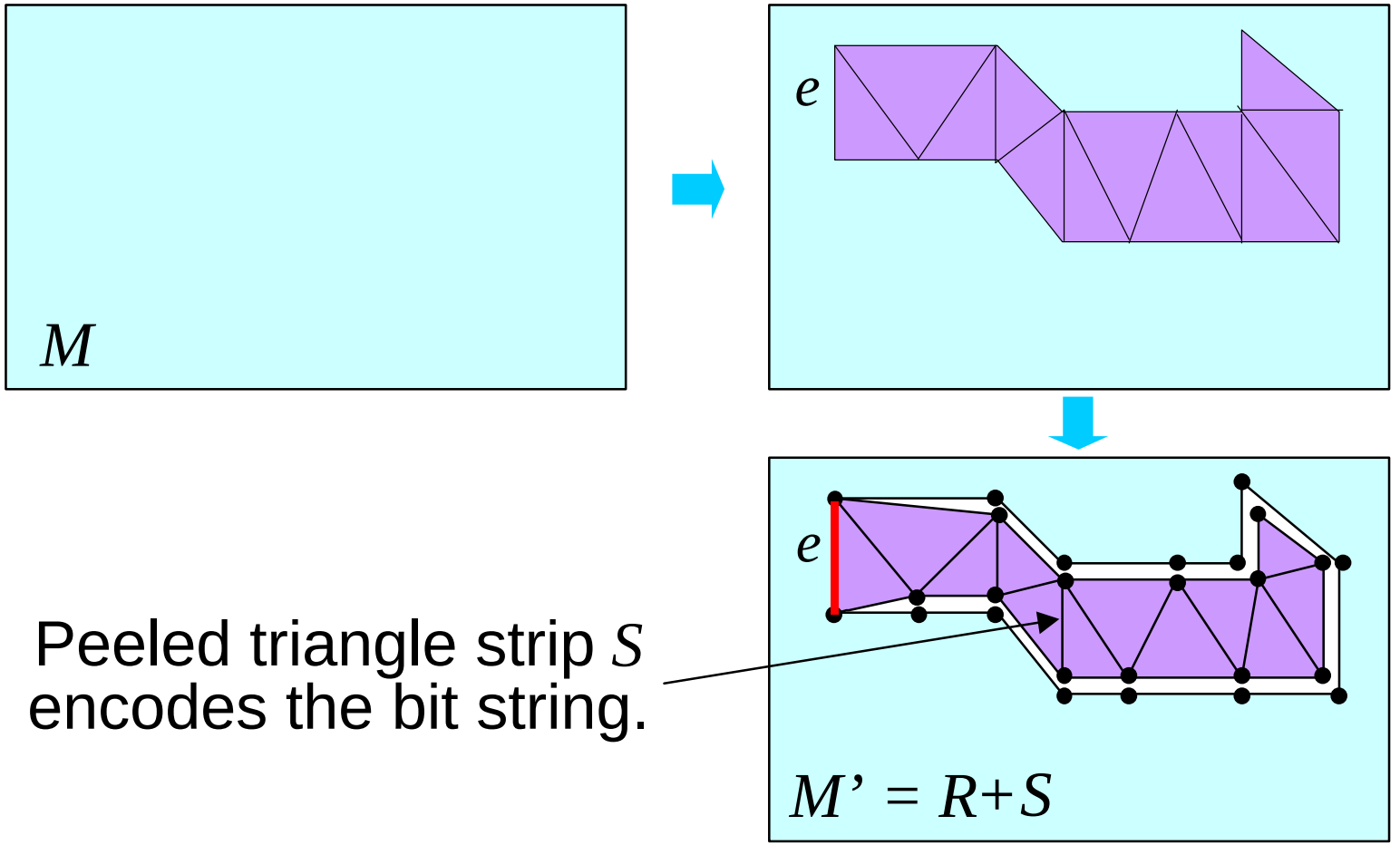


“10101101011”



Triangle Strip Peeling Method

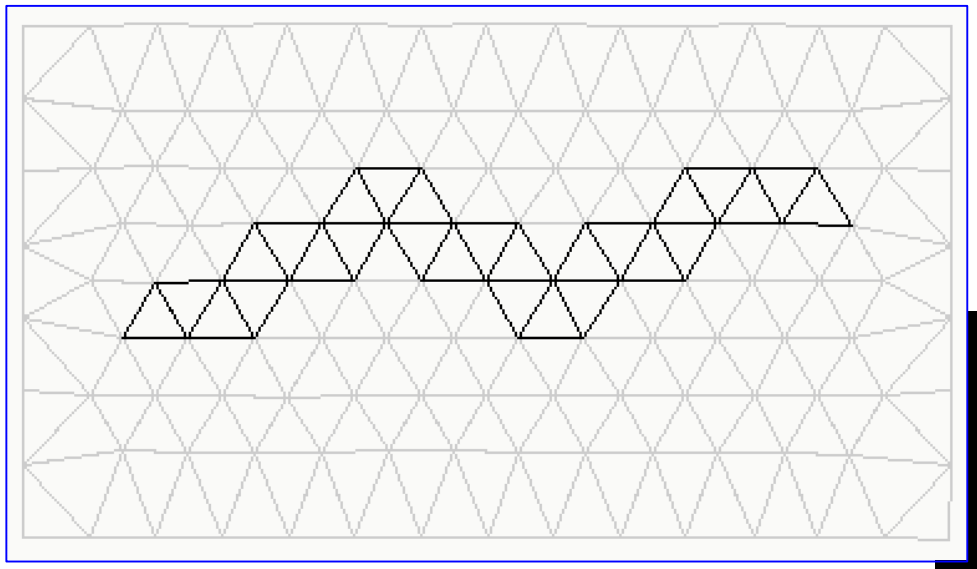
Embed in Topology of Poly-Meshes



Peeled triangle strip S encodes the bit string.

Triangle Strip Peeling Method

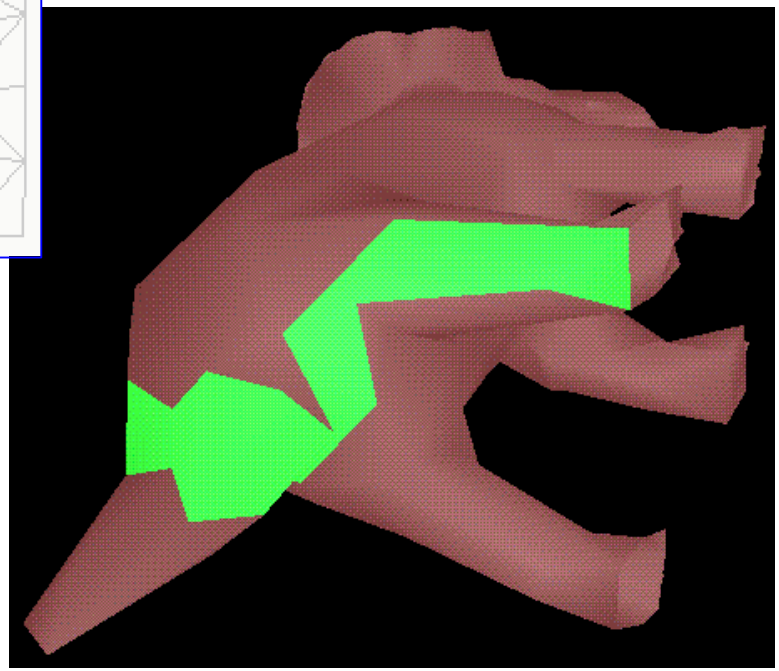
Embed in Topology of Poly-Meshes



- Triangle strip to the left (27 triangles) encodes 13 data bits.

Polygonal mesh of 214 triangles.

A triceratops model with a peeled strip.



Texture Coordinate Modulation Method

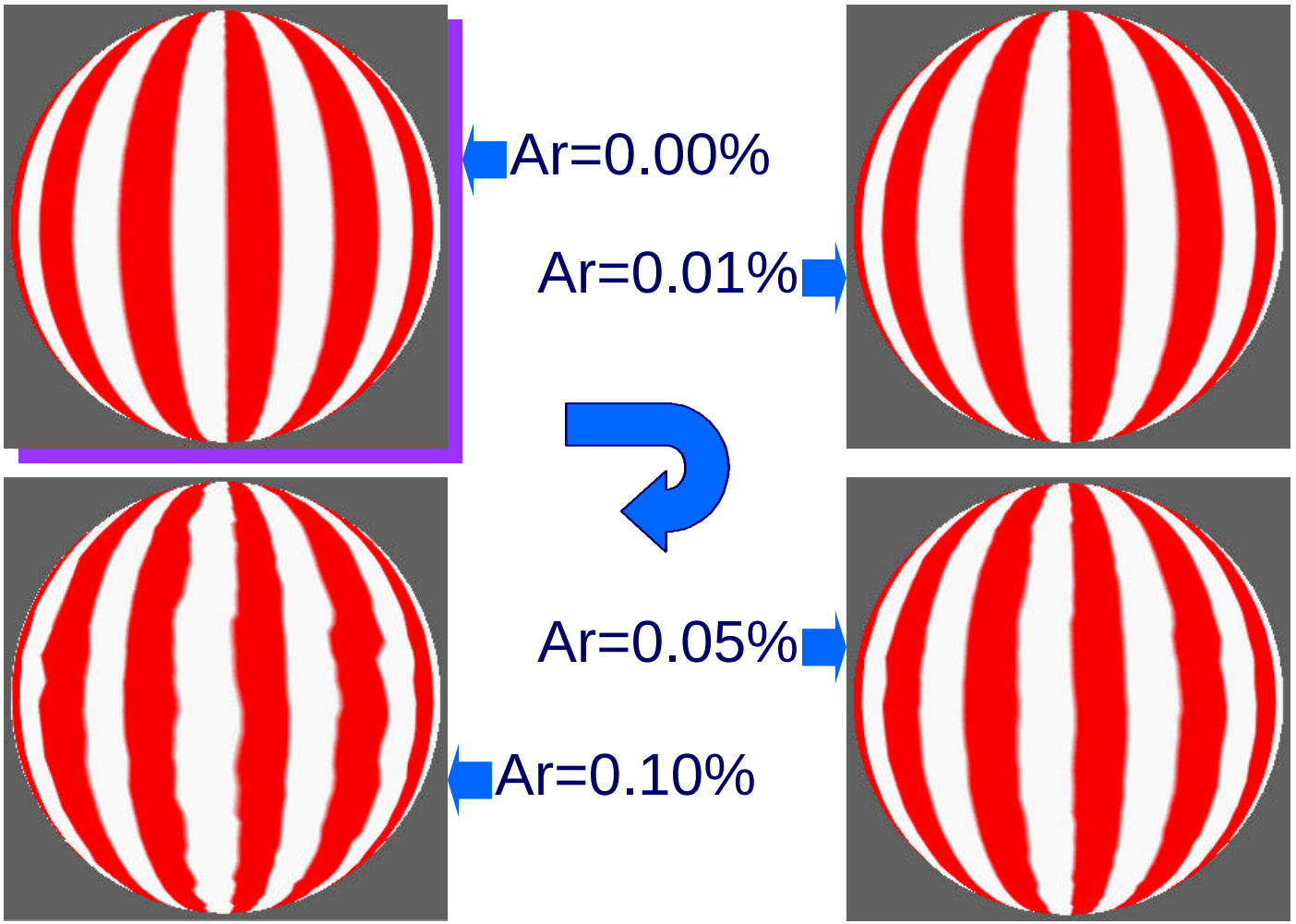
Embed in a Shape Attributes

- Symbol sequence embedding
  - By modifying texture coordinate.
- Primitive
  - Displaced texture coordinate.
    - Texture coordinate is unaffected by geometrical transformation of vertex coordinate.
- Arrangement
  - By any of a number of methods.
  - Ex. As they appear in the file, by geometrical quantity (e.g., area of triangles), by topology.

Texture Coordinate Modulation Method

A sphere (961 vertices) with simple stripe texture.

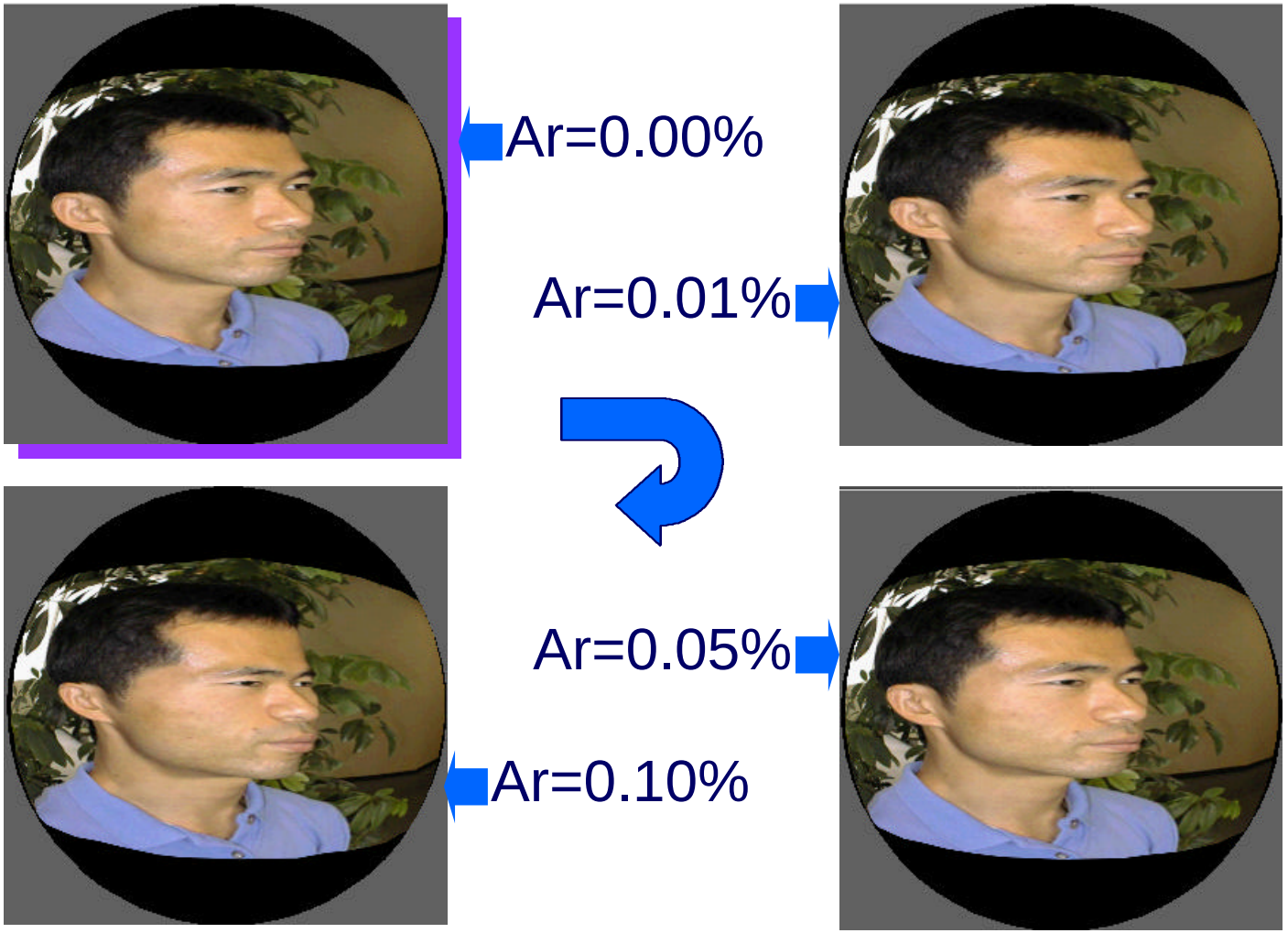
More noticeable with a geometric texture.



Texture Coordinate Modulation Method

A sphere (961 vertices) with human face texture.

Less noticeable with a complex texture.



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Summary

- Embedding data in 3D polygonal models
  - For VRML, MPEG 4 SNHC, etc.
  - For theft deterrence, tamper detection, etc.
- Possible embedding targets
  - Shape
    - E.g., Polygonal mesh topology and geometry.
  - Shape attribute
    - E.g., Vertex color and texture coordinate.
  - Animation parameter
    - E.g. VRML coordinate interpolator.

Summary

- Algorithms
  - In *shape* of 3D polygonal meshes.
    - Geometry (vertex coordinate) modification.
      - E.g., Triangle similarity quadruple algorithm.
    - Topology (triangle connectivity) modification.
      - E.g., Triangle strip peeling algorithm.
  - In *shape-attributes* of 3D polygonal meshes.
    - Non-shape defining attribute modification.
      - E.g., Texture coordinate modification algorithm.

Future Work

- Embedding in animation parameters.
- Deal with compression.
  - Loss-less compression.
    - E.g., Geometry compression *a la* Taubin's.
  - Lossy compression
    - E.g., Levels-of-details, progressive-transmission,
    - E.g., DCT based compression of MPEG 4 mesh animation parameters.
- Realistic application scenarios.