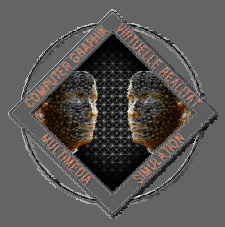
Consistent Normal Orientation for Polygonal Meshes



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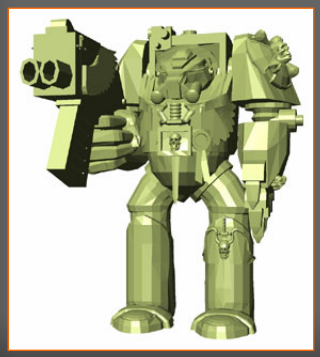
Inconsistent Normals

- Many models (especially, created with modelling tools) consist of many unconnected patches



Inconsistent Normals

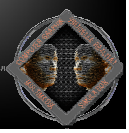
- Patches not necessary have consistent orientation of normals

Inconsistent Normals

- Problems
  - Real-time rendering:
    two-sided lighting is necessary
  - Mesh processing algorithms:
    for example, appearance preserving simplification using vertex normals needs correctly oriented normals

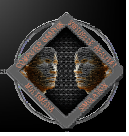
Related Work

- Proximity-based and boundary-based methods
  - Hoppe et al. 1992. *Surface reconstruction from unorganised points*
  - Laurini and Milleret-Raffort 1994. *Topological reorganization of inconsistent geographical databases: a step towards their certification*
  - Kernighan and van Wyk 1996. *Extracting geometrical information from architectural drawings*



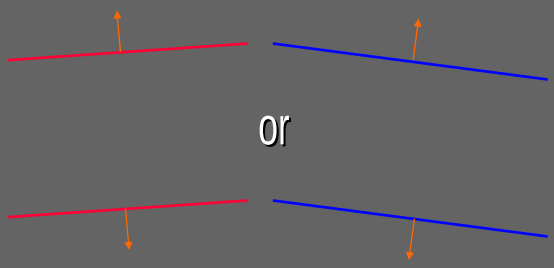
Related Work

- Solid-based methods
  - Thibault and Naylor 1987. *Set operations on polyhedra using binary space partitioning trees*
  - Teller and Hanrahan 1993. *Global visibility algorithms for illumination computations*
  - Murali and Funkhouser 1997. *Consistent solid and boundary representations from arbitrary polygonal data*



Basic Idea

- *Boundary coherence:* patches with close boundaries should be oriented consistently

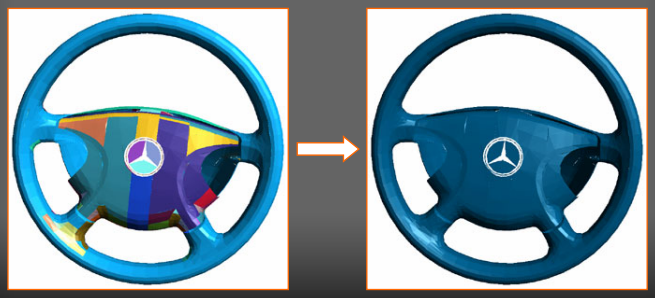


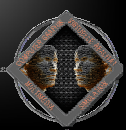
or

Basic Idea

- *Boundary coherence:* patches with close boundaries should be oriented consistently

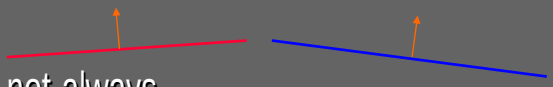
  - In "solid" cases it works



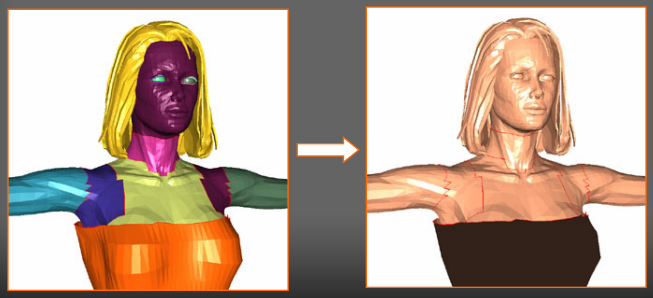


Basic Idea

- *Boundary coherence:* patches with close boundaries should be oriented consistently

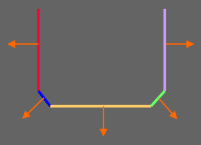


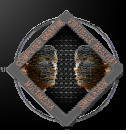
  - But not always...



Basic Idea

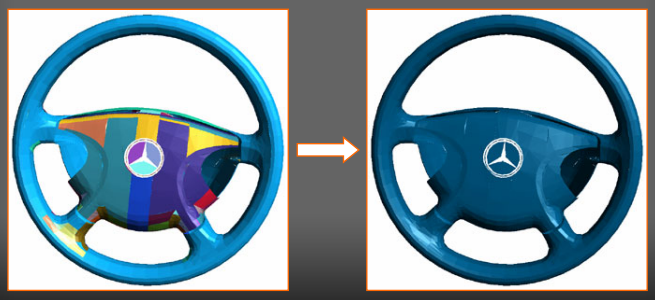
- *Visibility:* patches should be visible with their front-faces from most viewpoints





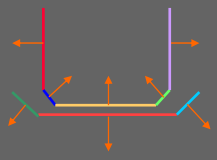
Basic Idea

- *Visibility:* patches should be visible with their front-faces from most viewpoints
  - Works in most cases



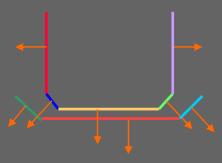
Basic Idea

- *Visibility:* patches should be visible with their front-faces from most viewpoints
  - But in some cases it causes inconsistency



Basic Idea

- *Combined approach*
  - Maximize consistency between patches with close boundaries
  - Maximize the *front-face visibility* of all patches

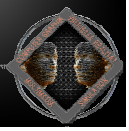


Algorithm Outline

1. Detection of patches
2. Calculation of boundary coherence
3. Calculation of visibility
4. Consistent orientation of patches

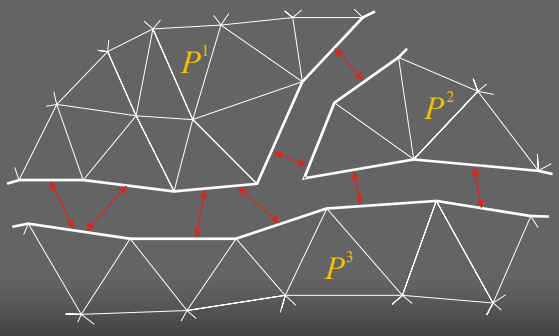
Detection of Patches

1. Detect boundary and non-manifold edges
2. Divide the model into a set of manifold patches
   - Not connected with each other or
   - Connected only at vertices or non-manifold edges
3. Consistently orient polygons inside each patch



Calculation of Boundary Coherence

- Find close boundary edges of different patches
  - 3D grid is used for acceleration



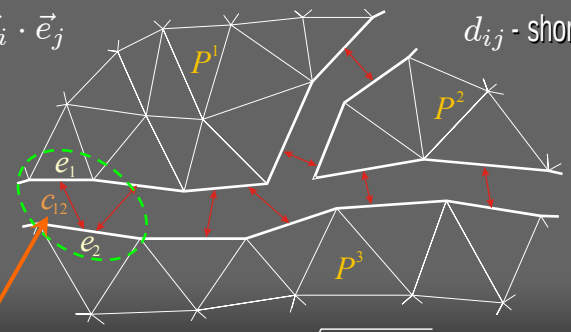
Calculation of Boundary Coherence

- For each pair of boundary edges calculate the *local boundary coherence:*

$$c_{ij} = -\operatorname{sgn}(s_{ij}) \cdot \sqrt{|s_{ij}|} \;/\; (1 + d_{ij})$$

$s_{ij} = \vec{e}_i \cdot \vec{e}_j$

d_{ij} - shortest distance between e_i and e_j

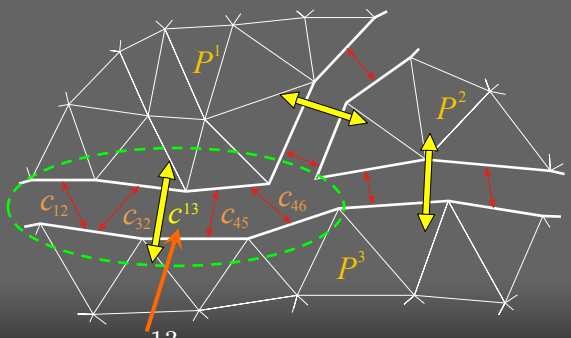


$$c_{12} = -\operatorname{sgn}(\vec{e}_1 \cdot \vec{e}_2) \cdot \sqrt{|\vec{e}_1 \cdot \vec{e}_2|} \;/\; (1 + d_{12})$$

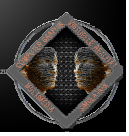
Calculation of Boundary Coherence

- Sum up all local coherences from two patches into the *boundary coherence coefficient:*

$$c = \sum_{i,j} c_{ij}$$



$$c^{13} = c_{12} + c_{32} + c_{45} + c_{46}$$

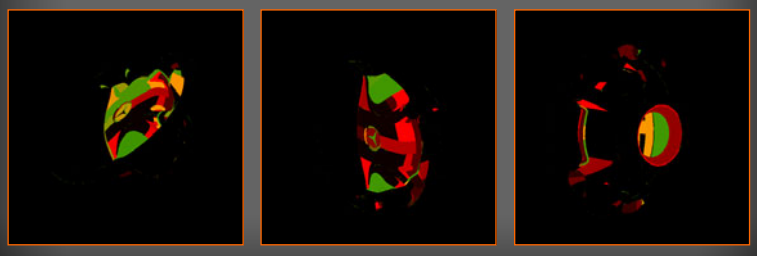


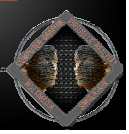
Calculation of Visibility

- Three methods
  - *Ray shooting* method
  - *5D octree* method
  - *GPU-based* method

Calculation of Visibility

- *GPU-based* method
  - Distribute viewpoints uniformly around the model
  - For each viewpoint render the mesh
  - Draw each side of each patch in an unique colour

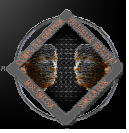




Calculation of Visibility

- *GPU-based* method
  - Read and process the frame buffer
  - For each non-black pixel increase the counter (for appropriate patch and side)
  - For each patch calculate the *front-* and *back-face visibility coefficients:*

$$v_f = \frac{n_f}{n_t \cdot a}, \quad v_b = \frac{n_b}{n_t \cdot a}$$



Consistent Orientation of Patches

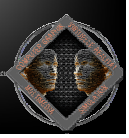
- *Overall front-face visibility*

$$V_f = \frac{\sum_m v_f^m \cdot a^m}{\sum_m a^m}$$

- *Overall coherence*

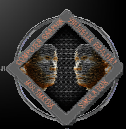
$$C = \sum_{m,n} c^{mn}$$

- **Goal**: find orientation of all patches that maximizes both V_f and C



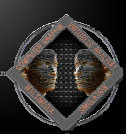
Consistent Orientation of Patches

- Greedy approach
  - Sort pairs of patches according to boundary coherence coefficients
- Orientation loop
  - Pop from the queue a pair of patches
  - Compare all coefficient of both patches
  - If coefficients conform
    - Connect patches into a *super-patch*



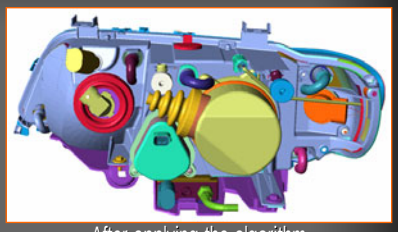
Consistent Orientation of Patches

- Orientation loop
  - If coefficients do not conform
    - Boundary coherence - higher priority
    - If boundaries are "close":
      coherence is strong $\Longrightarrow$ connect patches
    - Otherwise $\Longrightarrow$ compare visibility coefficients:
      - If for one of two patches v_f and v_b "differ not much"
        $\Longrightarrow$ connect patches
      - Otherwise $\Longrightarrow$ change nothing
- Result: global orientation of all patches

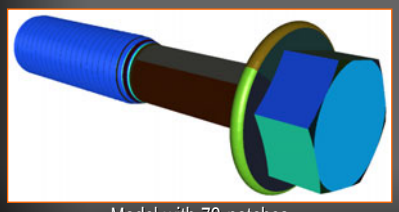


Results

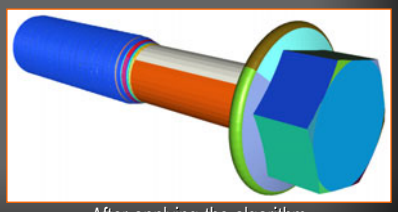
Model with 323 patches



After applying the algorithm



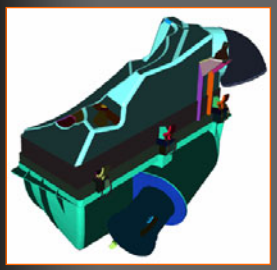
Model with 78 patches



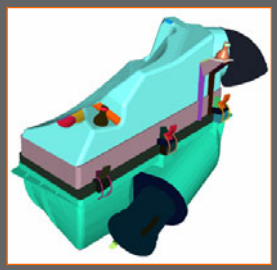
After applying the algorithm

Results

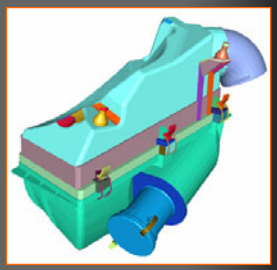
- Boundary coherence is not a sufficient criterion



Model with 71 patches



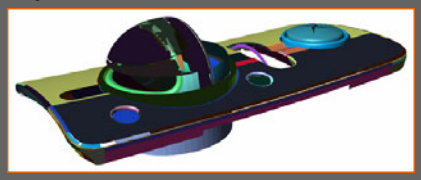
Only boundary coherence used



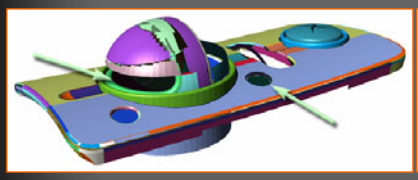
Boundary coherence and visibility used

Results

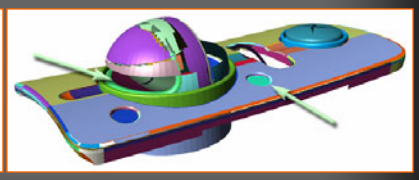
- Only visibility is not a sufficient criterion



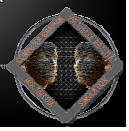
Model with 137 patches



Only visibility used



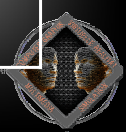
Boundary coherence and visibility used



Results

- Performance rates: 3 models at 3 levels of detail

	Number of polygons	Number of patches	Patch detection time (s)	Coherence calculation time (s)	Visibility calculation time (s)
	180252 60080 18019	78 80 83	5.6 1.5 0.4	0.7 0.6 0.5	17.7 6.6 2.5
	194668 64648 19142	1508 1509 1511	5.9 1.8 0.4	3.4 2.0 1.1	19.0 6.8 2.6
	300836 84673 14327	3310 2040 2067	10.5 2.7 0.4	9.2 2.8 0.9	29.1 9.1 2.5



Ambiguous Cases

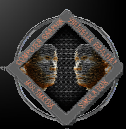
- Hard to define the *best* orientation, even for humans

Overlapping Patches

- Could cause errors
- Special handling needed (not done yet)

Conclusion

- Consistent and sensible orientation of all normals of arbitrary polygonal models
- First method for arbitrary meshes
- Produces desirable solution for almost all practical cases
- Applicable to objects consisting of other primitives, such as NURBS



Thank you

The bot model is courtesy of Michael Beals
Models of automotive parts are courtesy of DaimlerChrysler AG