A mesh processing library

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Intro

- Intro
- Capabilities
- Design/Structure
- Examples

What

- A C++ template based library
  - Include only, no compilation hassle
- Research Driven Library
  - The most amatorial professional library
- A rather rich and hopefully easy to use library for mesh processing
- The core of the well known MeshLab system.

Where

- Main site:
  - http://vcglib.net
- The code
  - No rigid release scheme
    - Sync with meshlab releases
  - Just clone the git repo
    - USE the ***DEVEL*** branch
      - git clone –b devel https://github.com/cnr-isti-vclab/vcglib.git
- Documentation by doxygen on the web
- A bunch of small samples
  - vcglib/apps/sample

Capabilities

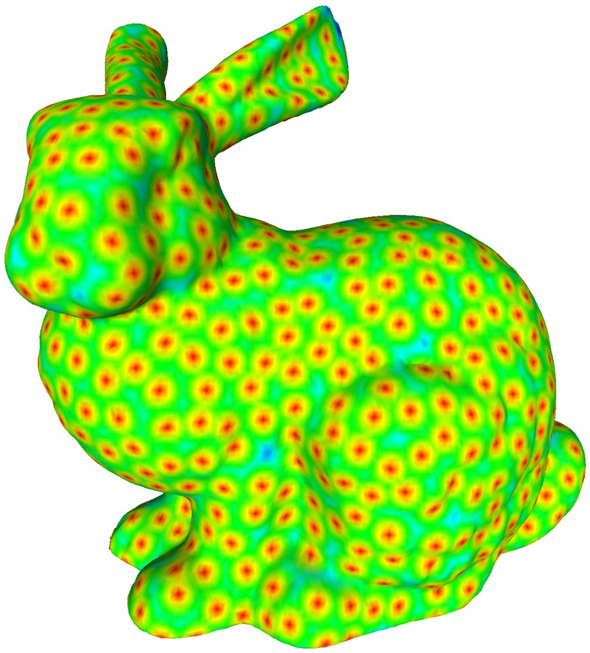
- VCG library feature a large number of different algorithms
- In the next slides a fast browsing of some of the most known things in the library

Simplification

- Fairly generic edge collapse simplification algorithms
- Probably one of the reason meshlab is famous.
- Link conditions for topology preserving
  - Two optimized specializations
    - Quadric error (with a few minor variants)
    - Quadric error with texture coords optimization.

Sampling

- A variety of algorithm for distributing points over the surface of a mesh
  - a reasonably practical and fast adaptive poisson sampling algorithm.
  - Unbiased montecarlo
    - Useful for computing sampled integral measures over meshes



Cleaning

- A variety of tools for correcting small annoying things
  - Duplicated, unreferenced mesh elements
  - Merging of close vertices
  - Small hole filling
  - Non manifold detection and correction
    - Split of non manifold vertexes
    - Heuristic Deletion of isolated non manifold faces

Color Processing

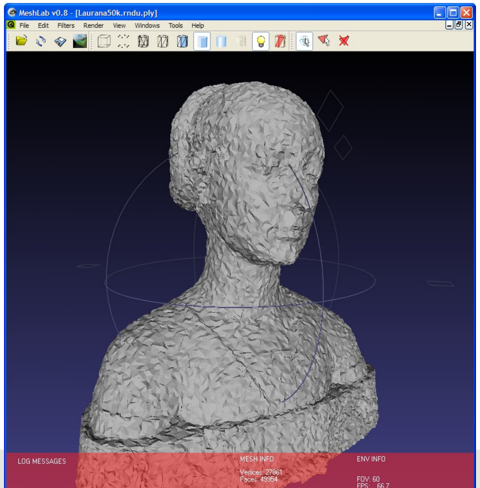
- VCG support color in various format
  - Per vertex
  - Per face
  - Per wedge
  - As texture
- Provides tools for converting from a representation to another one.

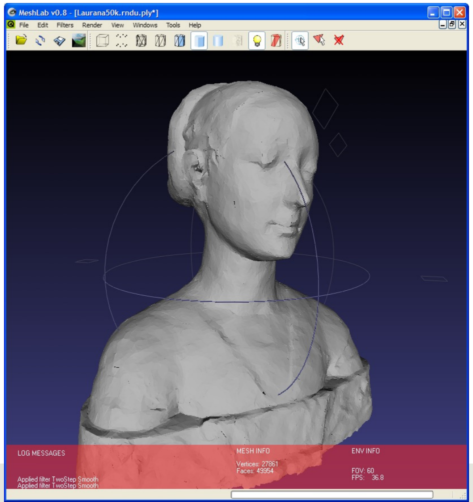
Measuring

- Integral measures
  - Volume, barycenter inertia tensor
- Distance between surfaces
  - Sampled Hausdorff distance
- Distance and intersection between a lot of geometric elements
  - (point-triangle, triangle-triangle etc)

Smoothing

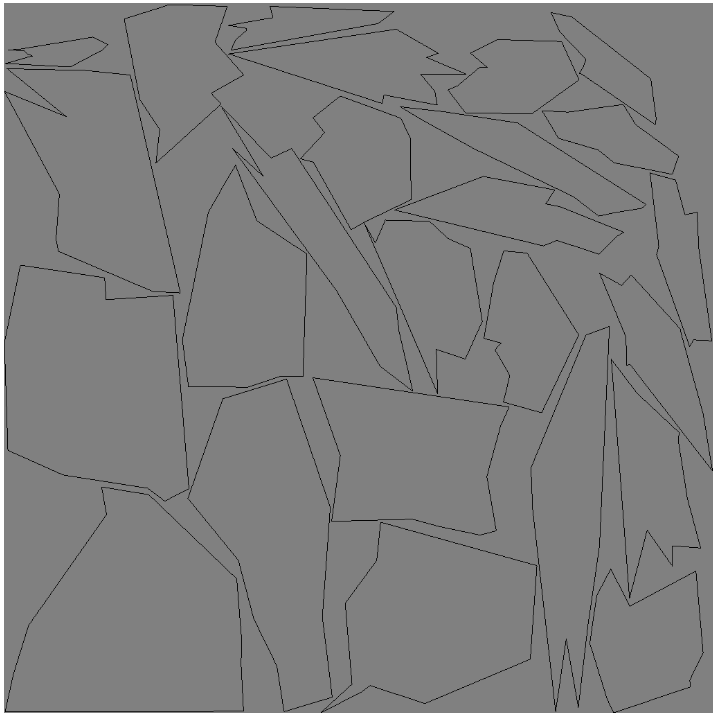
- A number of sophisticated noise removal tools.
- Basic laplacian (with or without cotangent weighting)
- Taubin smoothing
- Two step feature preserving smoothing.
- A number of smoothing algorithms can also be applied to various attributes like color, normal, scalar field over the mesh





Texturing

- Support of per vertex and per wedge text coords
- Conversion between representations
- Packing algorithms
- Various texture optimization



Remeshing

- Subdivision surfaces
  - (loop, butterfly)
  - Generic
    - Define your own predicate to decide if an edge has to be split and where.
- Ball Pivoting surface reconstruction
- Clustering simplification
- Marching cubes

Spatial Indexing

- Uniform Grid
  - Very good if your query points are quite near to the surface
- Kd-tree
  - Perfect for point clouds
- Hierarchies of Bounding Volumes

File Format

- VCGLib provides importer and exporter for several file formats:
- import:
  - PLY, **STL**, **OFF**, **OBJ**, 3DS, COLLADA, PTX, V3D, PTS, APTS, XYZ, GTS, TRI, ASC, X3D, X3DV, VRML, ALN
- export:
  - PLY, **STL**, **OFF**, **OBJ**, 3DS, COLLADA, VRML, DXF, GTS, U3D, IDTF, X3D
- Caveat it flattens everything to a polygon soup.
  - No scene graph information is retained for the most complex formats
  - Many file formats require linking to other piece (only the bold ones are .h pure

Basic Concepts: The Mesh

- encode a mesh in several ways,
- the most common is three **vectors** of vertices edges and triangles.
- The following line is an example of the definition of a VCG type of mesh:

```
class MyMesh :
    public vcg::tri::TriMesh<
             std::vector<MyVertex>,
             std::vector<MyFace> ,
             std::vector<MyEdge>  > {};
```

- you need only to derive from vcg::tri::TriMesh and to provide the type of containers of the elements

Basic Concepts: The simplexes 1

- The face, the edge and the vertex type are the crucial bits to understand in order to be able to take the best from VCG Lib.
- A vertex, an edge, a face and a tetrahedron are just a user defined (possibly empty) collection of attributes
  - For example, a vertex could (or could not contain) *position normal color* etc.
- To build a simplex class you just derive from the base simplex templated with the desired attributes:

```
class MyVertex2  :
     public vcg::Vertex< MyUsedTypes,
                         vcg::vertex::Coord3f,
                         vcg::vertex::Color4b,
                         vcg::vertex::CurvatureDirf,
                         vcg::vertex::Normal3f,
                         vcg::vertex::BitFlags  >{};
```

Basic Concepts: The simplexes 2

- Caveat first of all you have to pre-declare what are the intended names for the various pieces

```
struct MyUsedTypes : public
    vcg::UsedTypes<
        vcg::Use<MyVertex>   ::AsVertexType,
        vcg::Use<MyEdge>     ::AsEdgeType,
        vcg::Use<MyFace>     ::AsFaceType>{};
```

- In this way when you are declaring a vertex you alredy know what are the types involved in mixed relations like the vertex type adjacency

Basic Concepts: Using the mesh

- Most of the stuff in the library came in the shape of static templated class;
- Most of the time you see stuff like

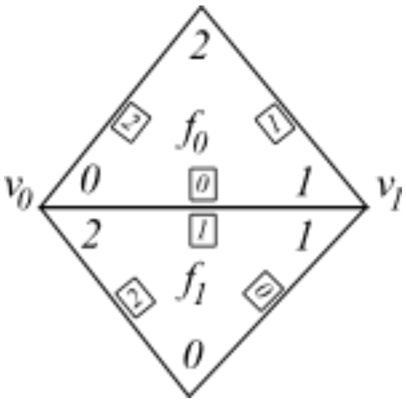
```
vcg::tri::UpdateNormal<MyMesh>::PerVertexNormalized(m);
```

Example 1: trimesh_base

- Basic example of minimal use
- Load a mesh and just dump some info about it
- Note that also the mesh loading is done by mean of templated class.

Basic Concept: Adjacency

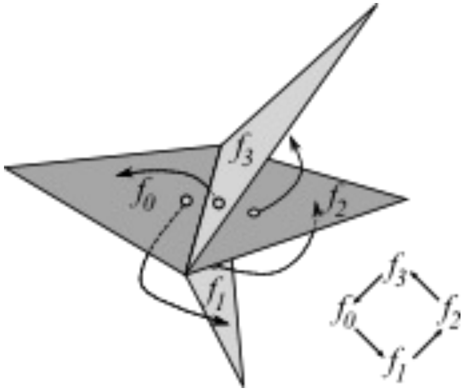
- Vertex, Edge and triangle can store different topological info:
- The most common is the VertexRef field of the face, that store for each triangular face three ptr to its vertexes
- Other commonly used relations are
- FF face face relation
- VF vertex face relation



- `tri::UpdateTopology<MyMesh>::FaceFace(m);`
- `tri::UpdateTopology<MyMesh>::VertexFace(m);`

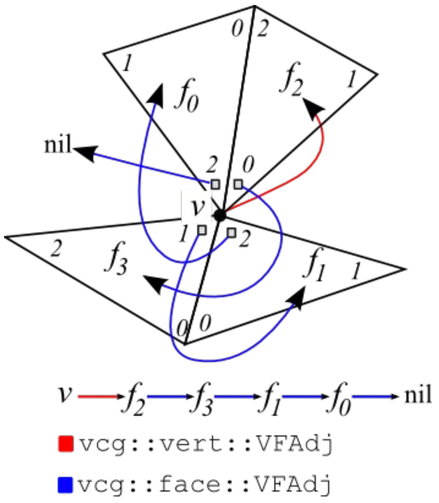
Basic Concept: Adjacency

- FF relation works for non manifold situations faces around an edge are ring connected



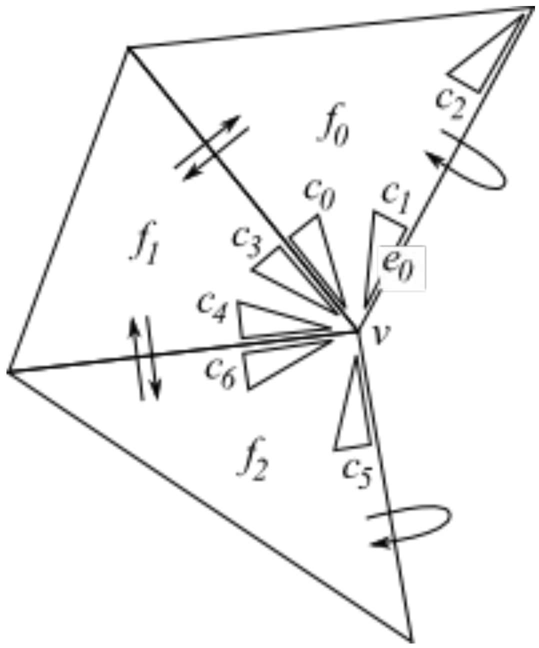
- FF relation on boundary just point back to the face itself

- VF relation does not involve any dynamic allocation, the chain of face is distributed onto the involved face



Basic Concepts: Navigating

- The Pos is the VCG Lib implementation of the Cell-Tuple and it abstracts the concept of position over a mesh
- A Pos in a triangle mesh is a triple made of
  pos = (v,e,f)
- For manifold meshes there are flip operators that allow easy navigation on the mesh
  - FlipV, FlipE, FlipF
- Each flip operator, applied to a pos simply changes only the indicated element
  - `c2 = c1.FlipV()`
  - `c0 = c1.FlipE()`
  - `c3 = c0.FlipF()`



Basic Concept: Navigating

- There are also classical retrieval functions:
- vcg::face::VFOrderedStarFF
  - Compute the ordered set of faces adjacent to a given vertex using FF adiacency
- vcg::face::VVStarVF
- vcg::face::VFStarVF
- vcg::face::VFExtendedStarVF
- vcg::face::EFStarFF

Example 2: trimesh_topology

- Note the face::FFAdj component in the face
- Note on marking
  - Simplex can have a mark component (face::Mark) that offers O(1) unmark of the whole mesh. Implemented by mean of counters, useful to avoid the usually required O(n) clearing.
- If your simplex has bitflags, you have also standard visiting/selection bits

Basic Concept: Allocation

- Simplex are kept into vectors
- Relations are kept by mean of pointers
- Pay attention to reallocations…
  - Always use the library functions to manage the simplex vectors

```
MyMesh::VertexIterator vi = tri::Allocator<MyMesh>::AddVertices(m,3);
  MyMesh::FaceIterator fi = tri::Allocator<MyMesh>::AddFaces(m,1);
```

Basic Concept: De-Allocation

- The library adopts a Lazy Deletion Strategy
  - i.e. the elements in the vector that are deleted are only flagged as deleted, but they are still there.
  - `m.vert.size() != m.VN()`
  - `m.face.size() != m.FN()`
- Therefore when you scan the containers of vertices and faces you could encounter deleted elements
- You can get rid of deleted elements by explicitly calling the two garbage collecting functions:

```
vcg::tri::Allocator<MyMesh>::CompactFaceVector(m);

vcg::tri::Allocator<MyMesh>::CompactVertexVector(m);
```

Example 3: trimesh_allocate

- Note
- How to simply build a minimal mesh from scratch
- the use of the PointerUpdater to cope with vector reallocation
- The use of explicit function to copy a mesh onto another
- The pitfall of having deleted elements

Basic Concept: Reflection

- VCG Lib provides a set of functions to implement reflection,
  - i.e. to investigate the type of a mesh at runtime
- These functions follow the format
  - tri::Has[attribute](mesh)
  - tri::HasPerVertexNormal(m);
  - tri::HasPerFaceColor(m);
  - etc…
- Return a boolean stating if that particular attribute is present or not
- These functions are not statically typed and need the mesh object because of optional stuff…
  - But they are statically solved if no optional stuff arise in your code

Basic Concept: Requiring data

- Reflection is often used to check the availability of component for a given algorithm
- For example
  - subdivision surface algorithms require FF adjacency
  - Simplification require VF adjacency and per vertex marks
  - Etc.
- If something is missing an exception is raised
- Tri::RequireFFAdjacency(mesh);
  - Raise a **missing component** exception if the FF adj is missing

Basic Concept: Optional Component

- Simplex components imply storage
  - E.g. FF adjacency means 4 words per face.
  - Components are stored into the simplex type
- Most components can be done optional
  - E.g. you can control the allocation space of that component at runtime

```
class CFaceOcf     : public vcg::Face< MyUsedTypesOcf,
        vcg::face::InfoOcf, vcg::face::FFAdjOcf,
        vcg::face::VertexRef, vcg::face::BitFlags,
        vcg::face::Normal3fOcf > {};

class CMeshOcf     : public vcg::tri::TriMesh<
          vcg::vertex::vector<CVertex>,
          vcg::face::vector_ocf<CFaceOcf> > {};
```

Basic Concept: Optional Component

- Storage of optional component is separated
  - E.g. The data for the FF adjacency is stored in a ‘parallel’ vector alongside the face vector.
- Access is exactly the same.
- You explicitly control the allocation

```
assert(tri::HasFFAdjacency(cmof) == false);
cmof.face.EnableFFAdjacency();
assert(tri::HasFFAdjacency(cmof) == true);
```

Example4: trimesh_optional

- Note the different definition of the type
- Note the enabling of the needed components
- Try to raise exceptions by commenting out the needed enabling

Basic Concept: User Def Attribute

- VCG Lib provides a mechanism to associate **user-defined 'attributes'** to the simplicies and to the mesh
- Attribute vs Components
  - Components are conceptually inside the simplex
    - `(*vi).N();`
  - Attributes need an handle to be accessed
    - `irradHandle[vi];`
- To use an attribute
  - Build an handle (find or create the attribute)
  - Use the handle to access the data

Basic Concept: User Def Attribute

- Getting a named attribute handle

```
MyMesh::PerVertexAttributeHandle<float> named_hv =
   vcg::tri::Allocator<MyMesh>::GetPerVertexAttribute<float>
        (m,std::string("Irradiance"));
```

- Using an handle

```
MyMesh::VertexIterator vi; int i = 0;
for(vi = m.vert.begin(); vi != m.vert.end(); ++vi,++i)
{
 named_hv[vi]  = 1.0f;  // [] operator takes a iterator
 named_hv[*vi] = 1.0f;  //    or a MyMesh::VertexType object
 named_hv[&*vi]= 1.0f;  //    or a pointer to it
 named_hv[i]   = 1.0f;  //    or an integer index
}
```

Basic Concept: *ForEach* construct

- to traverse all the vertexes of a mesh you can simply write something like:

```
ForEachVertex(m, [&](const VertexType &v){
          MakeSomethingWithVertex(v);
 });
```

- There are similar constructs for edges and faces
- Main advantage, avoid verbose checking of deleted elements

```
MyMesh::VertexIterator vi;
for(vi = m.vert.begin(); vi != m.vert.end(); ++vi,++i)
{
  if(!vi->IsD())
  {
    MakeSomethingWithVertex(v);
  }
}
```

Example5: trimesh_attribute

- Note the creation/test/delete functions
- Note the multiple way of accessing thru handles