1. Template generation

To address the generation of the template I started from a small subset of shapes (from laser data) with the idea of creating an average. This has two important advantages: i) the use of real data so that the template is anatomically plausible; ii) the fact that the resulting average does not reflect the identity of any specific subject.

The main challenges to generate such an average, briefly speaking, are:

- The generation of correspondences across the different subjects: this was tackled by performing a conformal mapping into the 2D domain, constrained by the manually identified landmarks on the surfaces.
- The region covered by the template: it will cover a reduced area, resulting from the intersection of the areas covered by all averaged cases. This makes it necessary to carefully select the subjects to use, so that their scans cover all the area that is required and do not contain important holes

In principle, the sampling density can be controlled but right now I've generated a template that is (mostly) uniformly sampled so that it serves as a first iteration for discussion.

2. Template resolution

Requests:

Symmetric mesh – low resolution about 2000 points [statistical purposes]
Symmetric

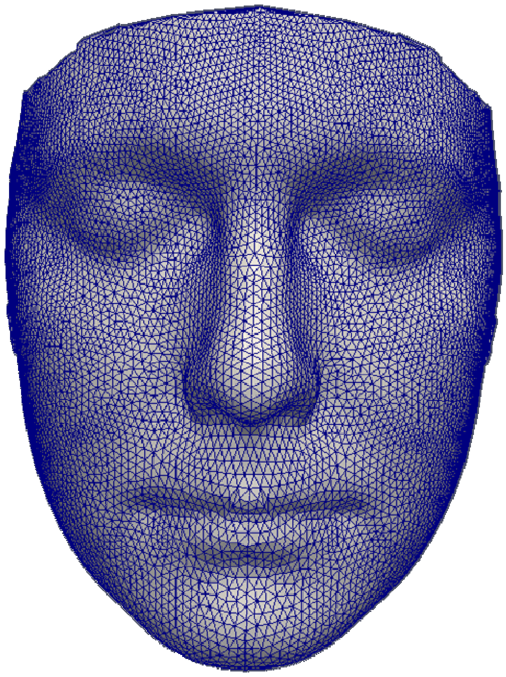
For this initial version, I have used a mesh resolution of 1.5 mm. This has resulted in approximately 8600 points, which can be controlled to some extent. Some quick calculations suggest that a template with 2000 points would have a mesh resolution of 3 mm or more, which seems too coarse. Nonetheless, right now we have a uniformly sampled template; hence we may revisit the issue once the sampling density is modified. With the lower resolution template in place, the higher resolution one should be easy to obtain by subdivision.

3. Template symmetry

Requests:

1. Points are symmetric across the mid-line (there should be points on the mid-line as well)
2. Triangulation is symmetric across the mid-line (there are points on the mid-line to fulfil this requirement)

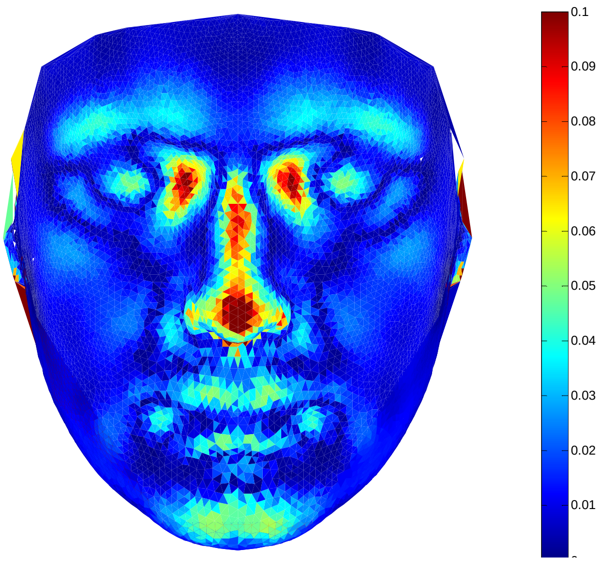
This has been done. The template was created by averaging of 20 scans from 10 subjects (original plus X-axis mirrored shape) and the points have been defined symmetrically with respect to the midline. The figure below shows a snapshot of the current template:



Snapshot of the uniformly sampled template

4. Sampling density and triangulation

Requests:
2.1 higher density around important anatomical structures [lower half of the nose, vermilion area (in Fig 1 left is the density very low), lips, eyes]
2.2 slightly lower density on the forehead and cheeks
2.3 homogeneous triangulation (see Fig 1 right)



Estimate of the total curvature of the template

As indicated previously, I have opted for a uniform sampling to start off. However, the algorithms I'm using should allow modifying the sampling density to a given target. The problem here is that such a target has to be defined quantitatively on top of the mesh: i.e. we need a scalar function defined over the mesh that indicates the sampling density. One possibility would be to make the sampling density proportional to the curvature. However, as you can see in the figure, this solution may not necessarily generate what you are proposing. Another alternative is to define the density "by hand".
Regarding the triangulation, if you mean a constant number of neighbors for every vertex, this is fulfilled for the majority of vertices but not for all of them.

5. Eyes and mouth

Requests:

3. Closed lips as in Fig 1 right [as in our recent stereo-camera captures]
4. Eyes – as in Fig 1 left but with triangulated eye balls (as in Fig 1 right)

As we generate the template from real data, we inherit the acquisition conditions: closed eyes and lips.

6. Template cut

Requests:

5. From (1)-(2) it is clear that the template is symmetrically cut, but there are more requirements around the boundary

5.1 chin cut – should be in the plane parallel to the *xz*-plane (if the face is oriented roughly in anatomical coordinate system, where nose is facing front) or parallel to the chin (visually the Euclidean distance of the boundary to chin should be about 5cm) [much lower than in Fig 1]

5.2 ear cut – following the line of the ear lobe

5.3 forehead cut – parallel to the *xz*-plane (visually the Euclidean distance of the boundary to the brow ridge should be about 5cm since we do not have landmarks on the forehead) [higher than in Fig 1 left] long as the facial width (around most lateral parts of zygomatic bone)

5.4 cut between forehead and ears – geometrically similar than in Fig 1 left or better as a geodesic between *otobasion superius* and forehead cut (see 5.3)

First of all, the template has been symmetrically cut to the overlap between mirrored areas of the original shapes. Cutting the template on the boundaries, however, can be more tricky:

- Again, the main limitation is the overlapping area of the scans that we use. We could select better scans but this is a strong constrain. The alternative is to use a single subject but, in principle, I think we should avoid that option.
- As I mentioned earlier, the mapping into a common 2D domain is constrained by the correspondences imposed by the manual annotations. Hence, the ears are being extrapolated and are unlikely to map correctly enough to allow averaging. Moreover, acquisition artifacts are very frequent in the ears. My suggestion would be to create a template up to the ear landmarks we're using, and remove the rest (i.e. no ears).
- Forehead, chin, etc: I guess the cutting here will be rather subjective but as long as it falls within the overlap area we can more or less cut the template arbitrarily where we want. Please have a look at the snapshots below and let me know if the covered area would be enough or not (if not, where specifically). Then we can iterate to define the exact cutting points.