Shape-from-Silhouette with Two Mirrors and an Uncalibrated Camera

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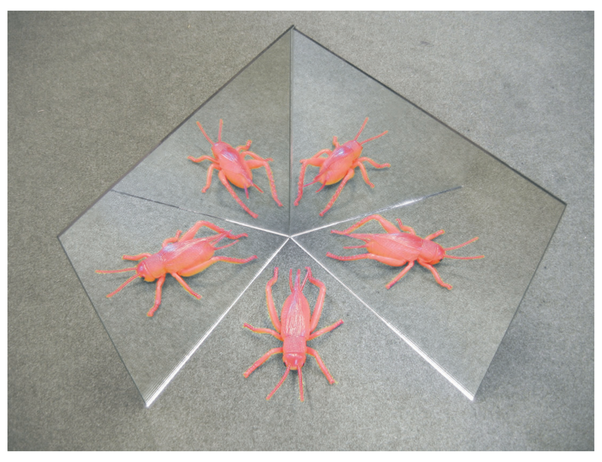
Goals

1. Reconstruct the 3D shape of real objects using only cheap and readily available equipment: two mirrors and a camera.

2. Self-calibrate the camera and mirror poses from the silhouettes alone.

Approach



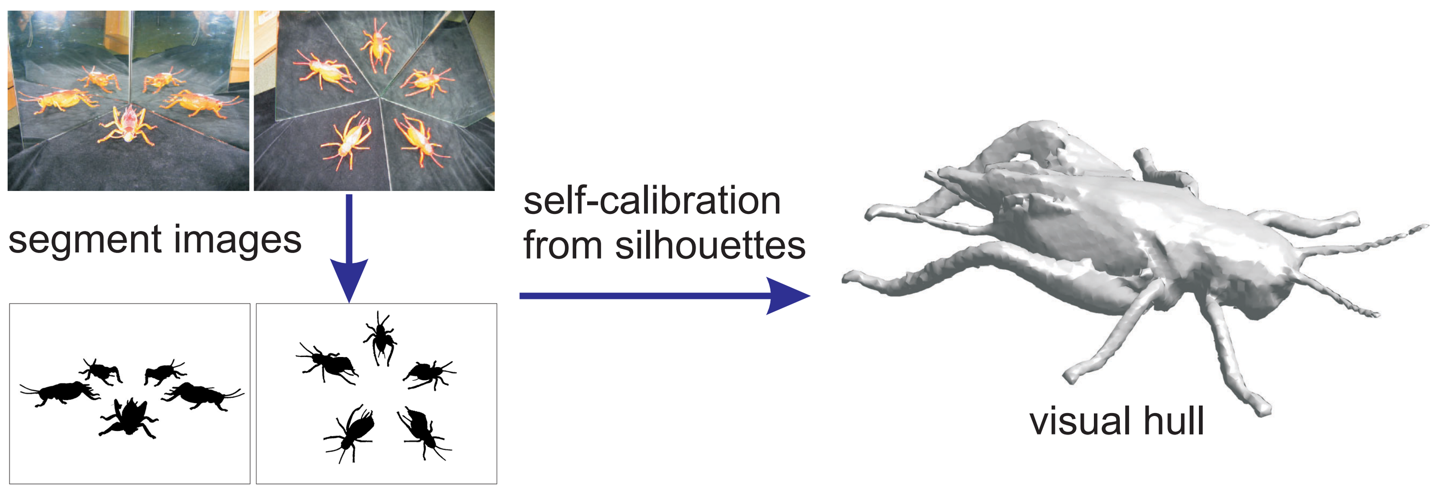
Position two mirrors so that five views of the object can be seen (as shown).

Take some photos of the scene from different viewpoints, and segment the images.

We provide closed form solutions for the internal camera parameters and view poses that are computed from the silhouettes.

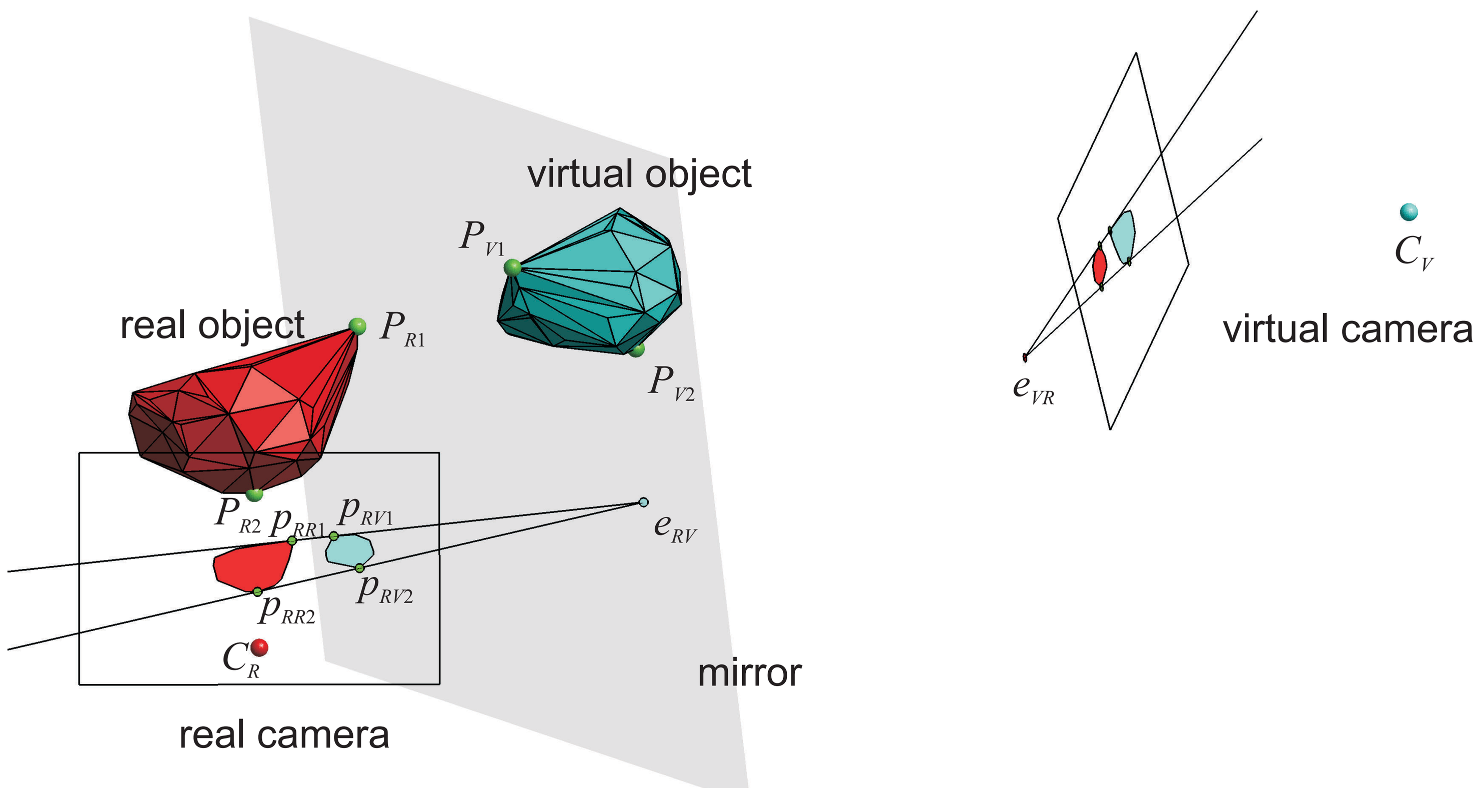
Parameter estimates may be further refined with iterative minimisation.

Once calibration parameters have been computed, the silhouettes can be used to create a 3D approximation to the object (by computing the visual hull, for instance).



Epipoles from Bitangents

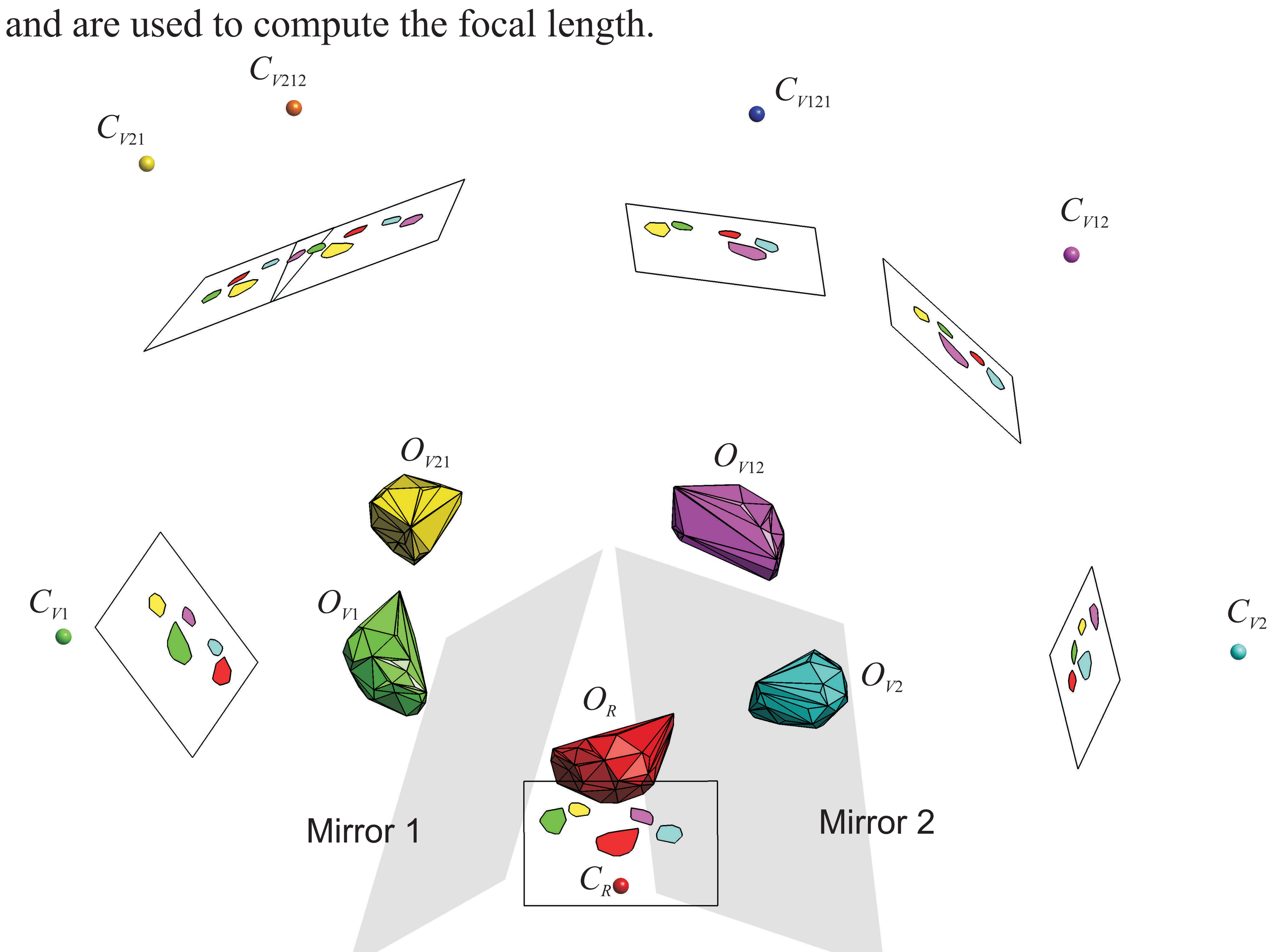
The epipole corresponding to a camera's reflection can be computed from the camera's silhouette image of an object and its reflection. It is the intersection of the two outer epipolar bitangents. This result will be used to compute the calibration parameters.



The points p_{RR1}, p_{RV1} and e_{RV} are collinear, and p_{RR2}, p_{RV2} and e_{RV} are collinear. This means that the epipole can be computed directly from the bitangents. Neither knowledge of the camera pose nor point correspondences are required.

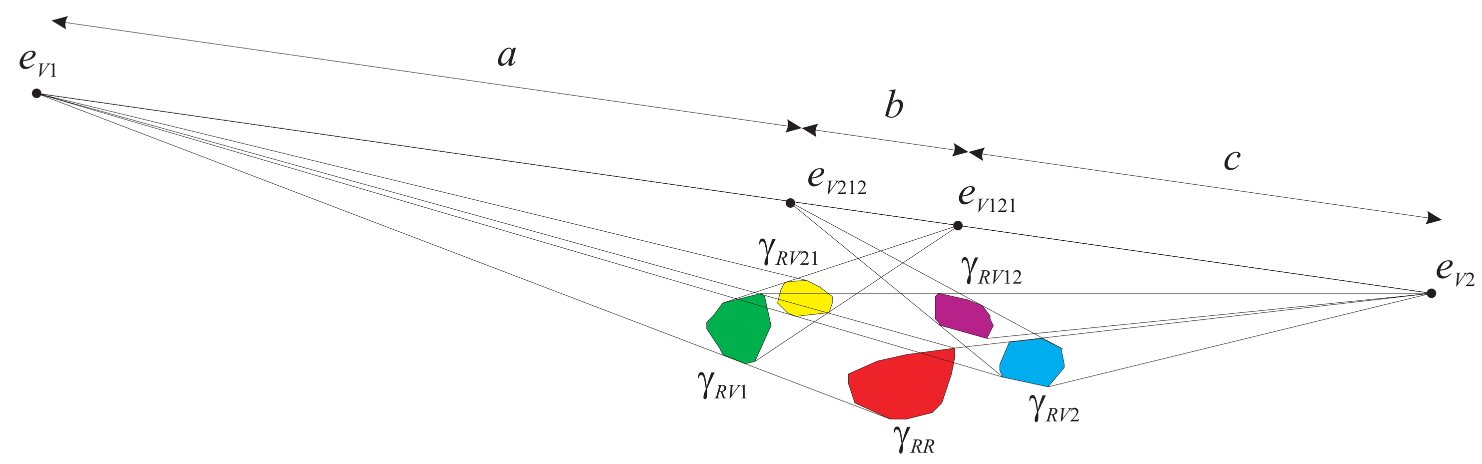
Double Mirror Setup

Six virtual cameras (reflections of the real camera) are of interest. Cameras C_{V1}, C_{V2}, C_{V12} and C_{V21} see silhouettes that are also seen by the real camera. Epipoles from C_{V121} and C_{V212} can be computed directly from the real camera's silhouettes and are used to compute the focal length.



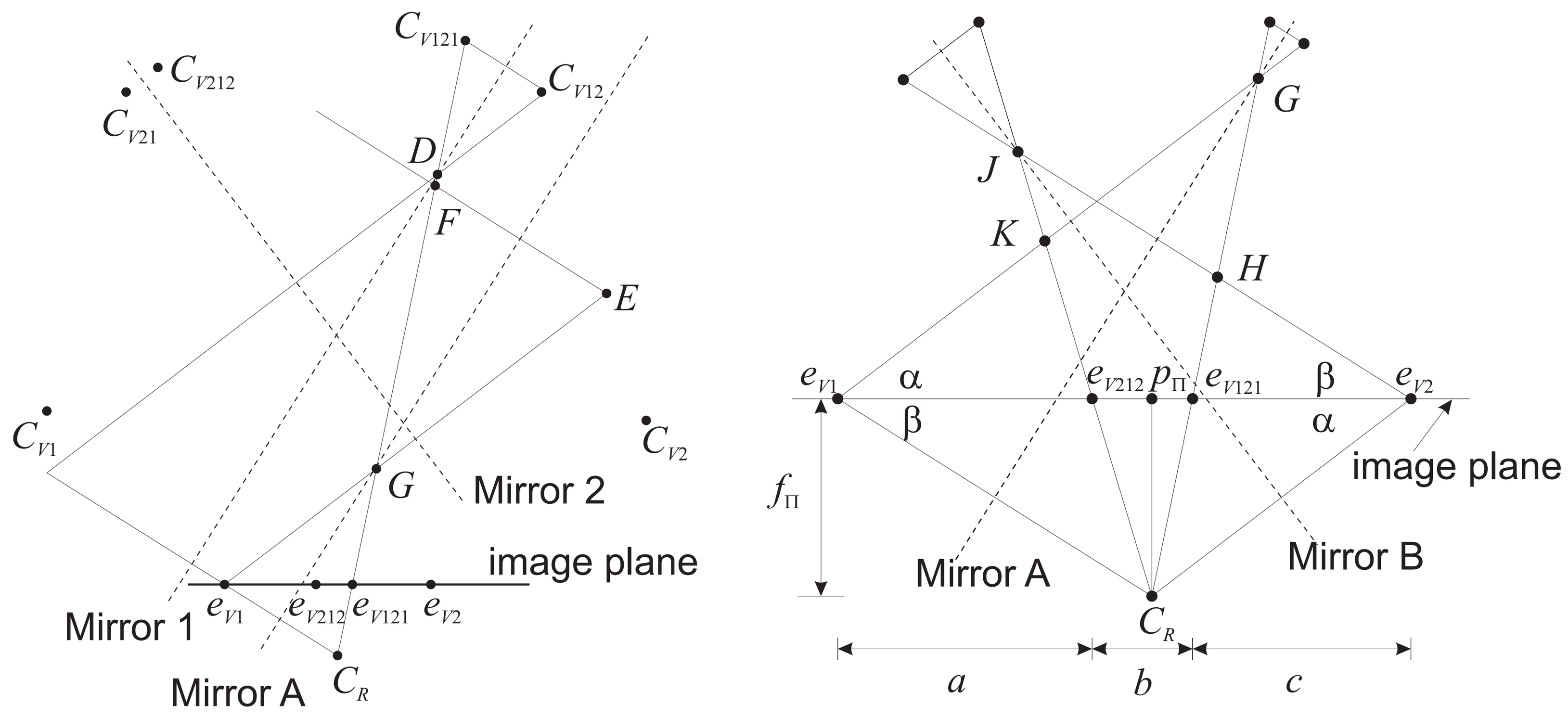
Four Epipoles from Five Silhouettes

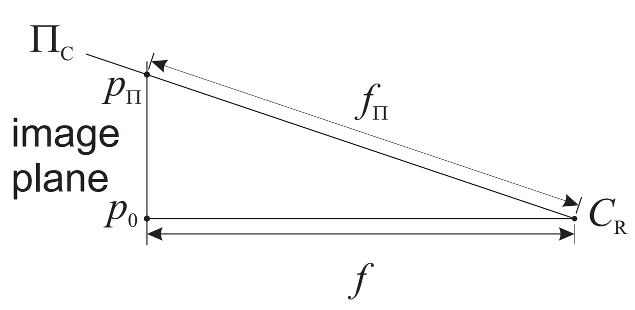
The epipoles e_{V1}, e_{V212}, e_{V121} and e_{V2} are computed from the silhouettes as shown.



Focal Length and Principal Point from Epipoles

Distances a, b, and c are used to compute the focal length f and principal point p_0. The equations are derived by considering similar triangles in the plane Π_C that contains all camera centres.





$$f_\Pi = 1/2\,\frac{(a+b+c)\sqrt{ac(3ac+4ab+4bc+4b^2)}}{a^2+ab+c^2+bc+ac}$$

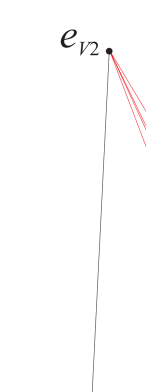
$$\mathbf{p}_\Pi = \mathbf{e}_{V1} + 1/2\,\frac{(2a+2b+c)\,a\,(a+b+c)}{a^2+ab+c^2+bc+ac}\,\frac{\mathbf{e}_{V2}-\mathbf{e}_{V1}}{||\mathbf{e}_{V2}-\mathbf{e}_{V1}||}$$

$$f = \sqrt{f_\Pi^2 - ||\mathbf{p}_0 - \mathbf{p}_\Pi||^2}$$

Computing Silhouette View Poses

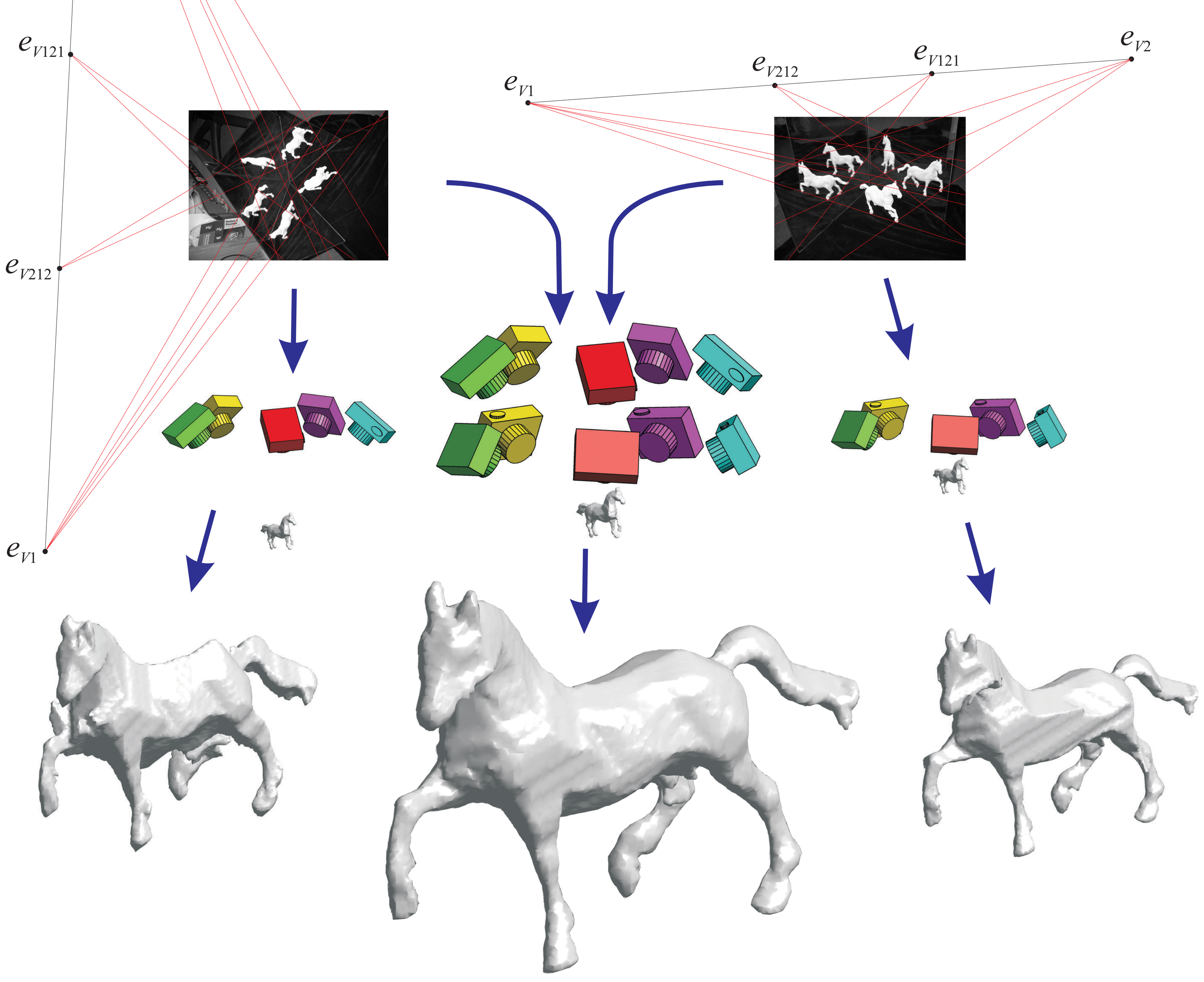
Mirror normals are computed from the epipoles, principal point and focal length. These allow the orientations of the virtual cameras to be specified in the reference frame of the real camera. Camera positions are computed using the *epipolar tangency constraint*: a silhouette tangent that passes through an epipole must be tangent to the corresponding point in its projection into the opposite view.

Five-view silhouette sets are combined into a single large set of silhouettes by aligning the mirror locations across sets. Scale and position are computed using the epipolar tangency constraint.



Finally, the solution can be refined by considering the distances between epipolar tangencies and projected tangents across all silhouette pairings. All parameters are adjusted simultaneously using the Levenberg-Marquardt method to minimise the sum of squared distances.

Experimental Results



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