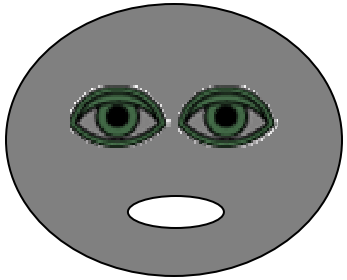
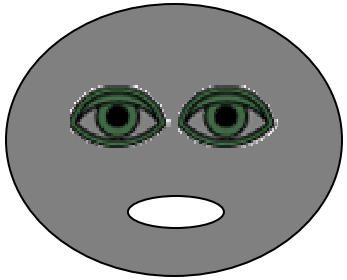


Robot Vision: A Holistic View

Reconstructive Vision



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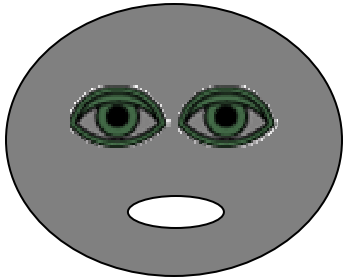
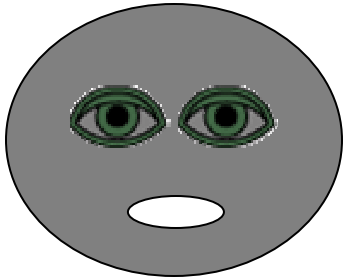


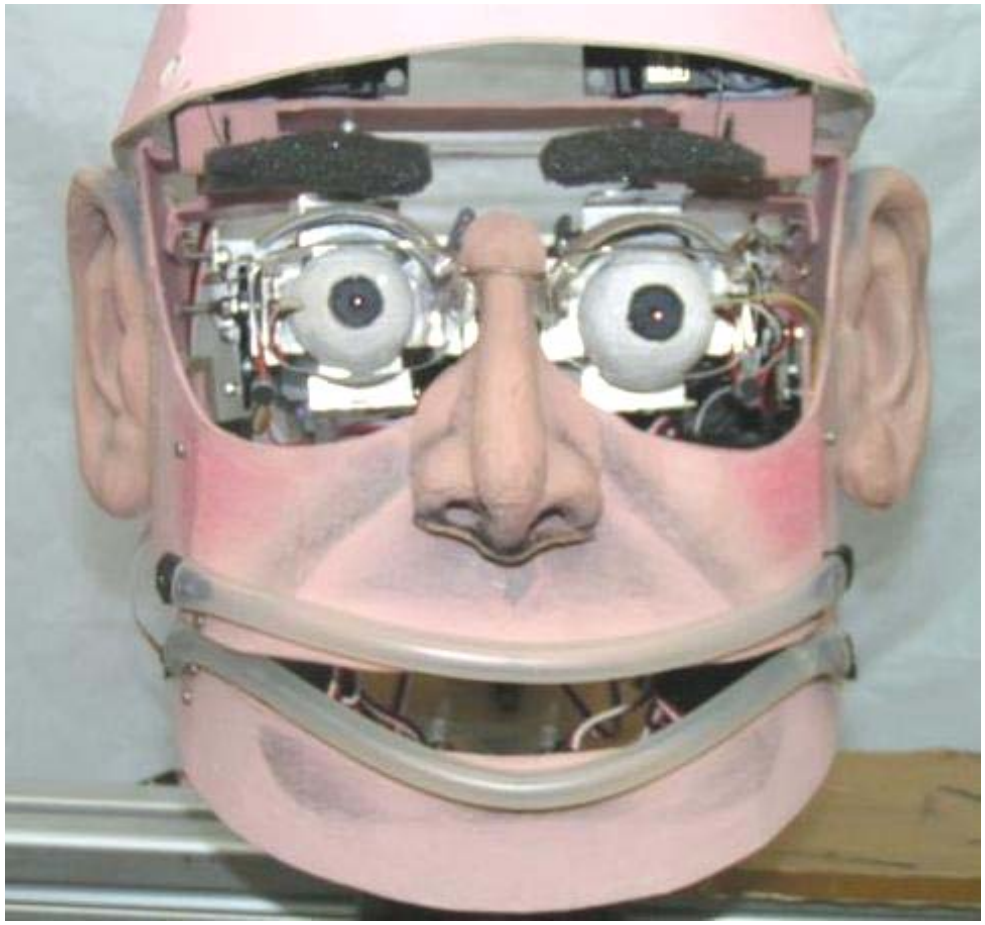
Introduction

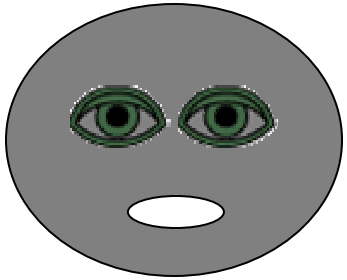
- Reconstructive vision is popularized by David Marr, Olivier Faugeras, Takeo Kanade, and many others.
- Reconstructive vision studies the aspect of inferring 3D geometry of a scene or object from (stereo) images. It is believed that reconstructive vision is a necessary step before visual guidance in robotics, and object recognition in machine perception.
- The general setting of reconstructive vision is a vision system with two cameras.
- In practice, one can add in more cameras to form special arrangements, such as: multiple-view, or multiple-focus, vision.
- However, the scientific problems concerning reconstructive vision are the same. They are: a) calibration, b) binocular correspondence, and c) geometry estimation.
- But, the most critical problem is “binocular correspondence”!!!



Introduction

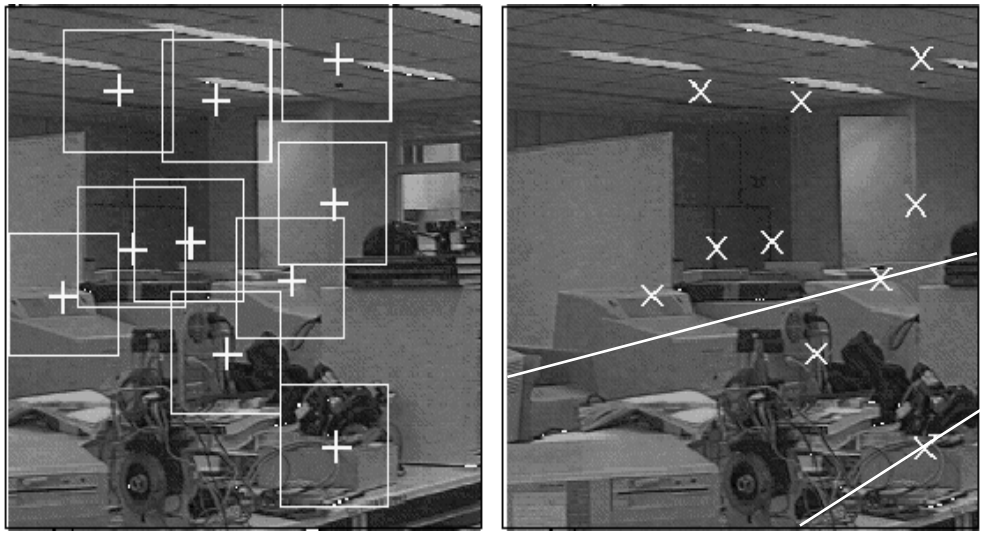
Binocular vision has, at least, two eyes.

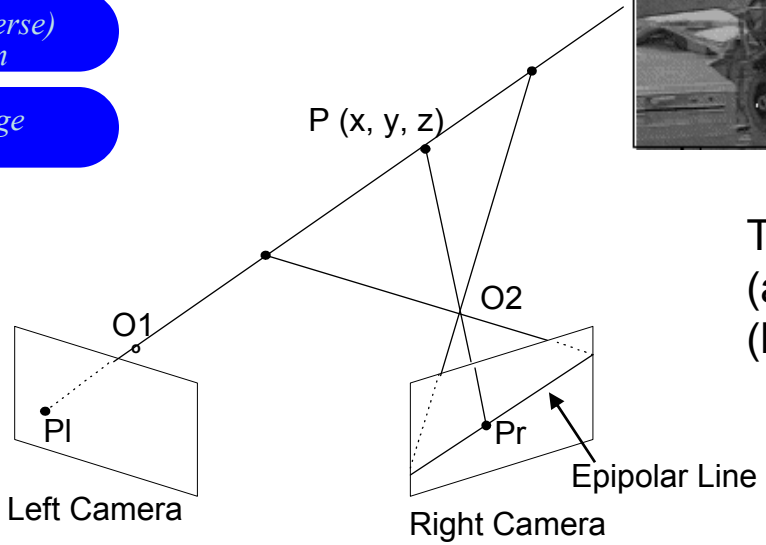




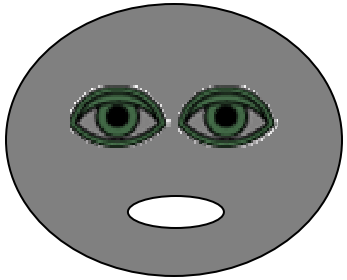
Introduction

The Most Critical Problem: Binocular Correspondence



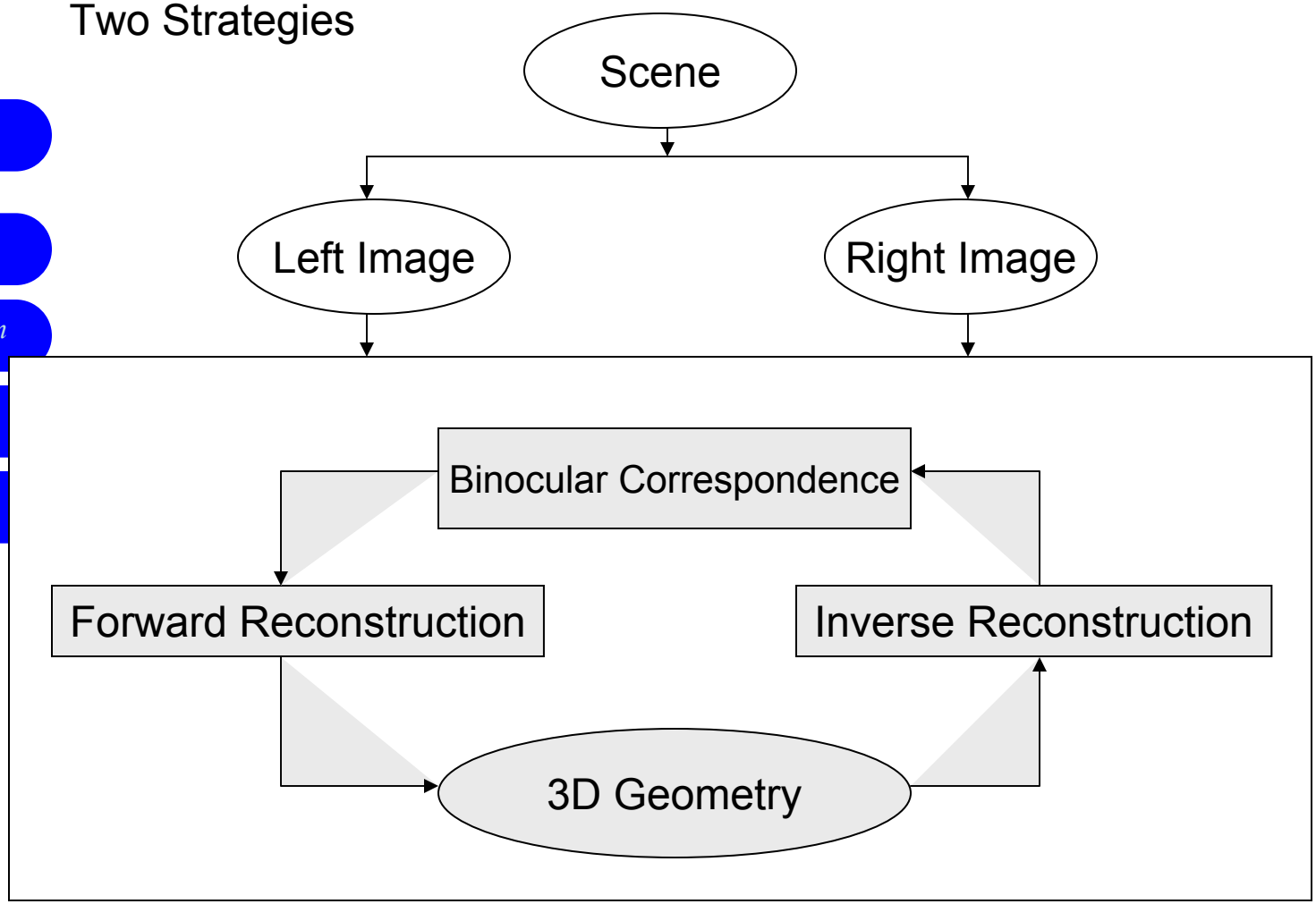


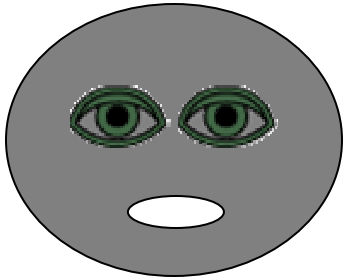
This difficulty leads to two strategies:
(a) Forward Reconstruction, and
(b) Backward (or Inverse) Reconstruction.



Introduction

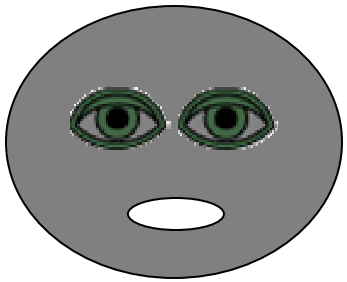
Two Strategies





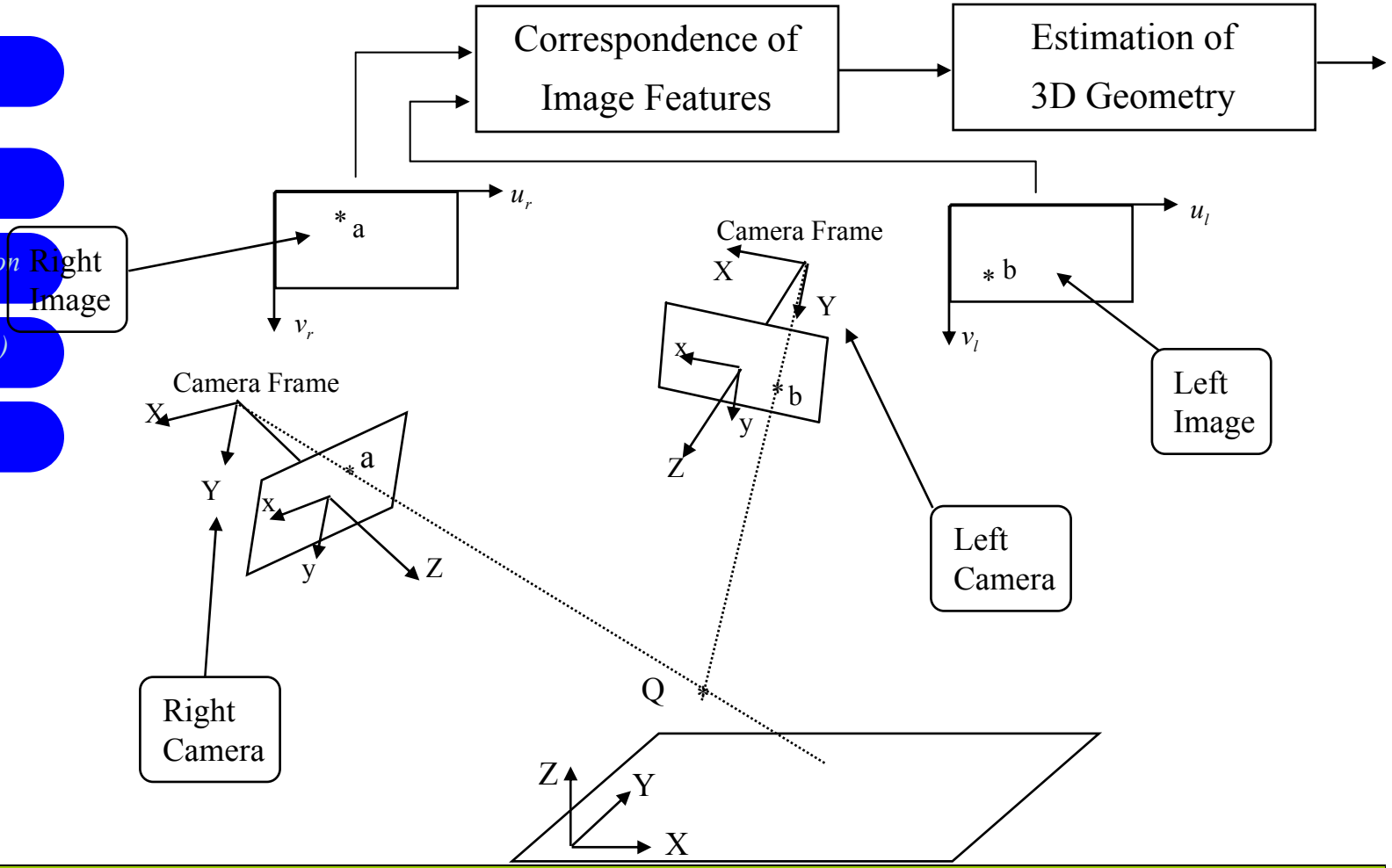
Forward Reconstruction

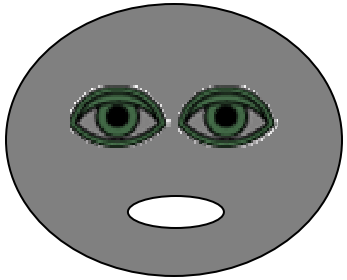
- In its standard version, the forward reconstruction starts with binocular correspondence, which is also called stereo matching.
- So far, there is no commonly accepted solution to binocular correspondence.
- This explains why there are so many stereo matching algorithms in literature, each of which has its own merits and shortcomings.
- However, it is noted that it is relatively easy to tackle stereo matching with more structured features than with individual pixels.
- Given the correct results of binocular correspondence, it is straightforward to estimate 3D geometry, assuming that the cameras are calibrated.



Forward Reconstruction

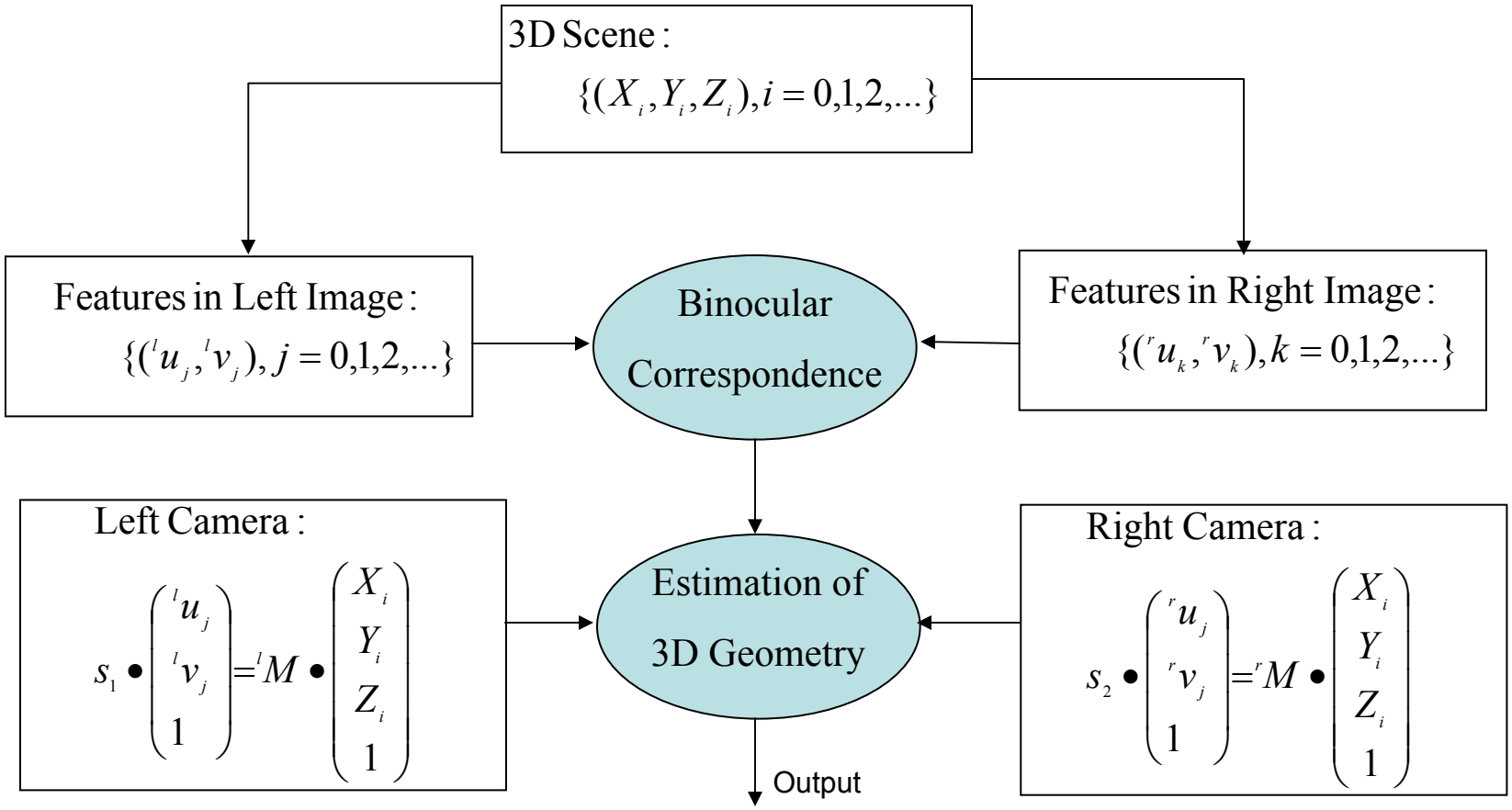
Illustration

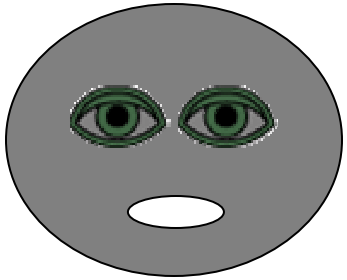




Forward Reconstruction

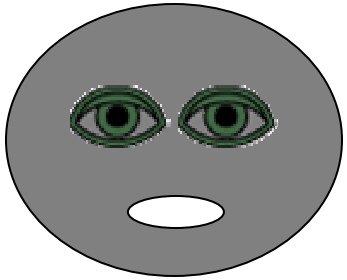
Schematic Diagram



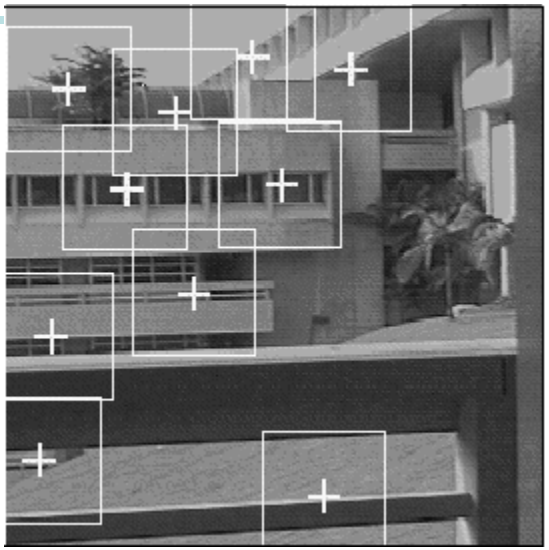


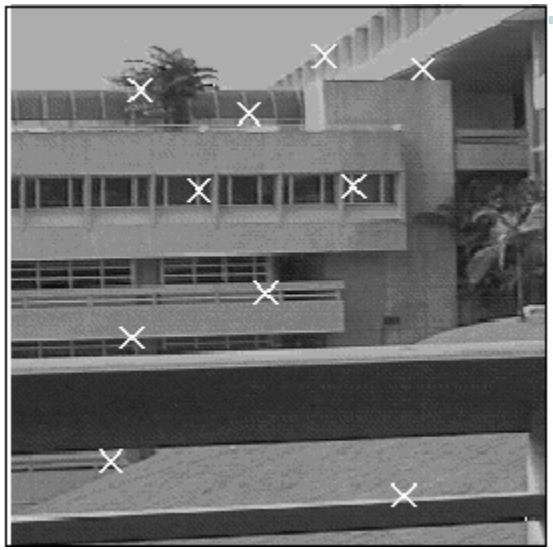
Forward Reconstruction

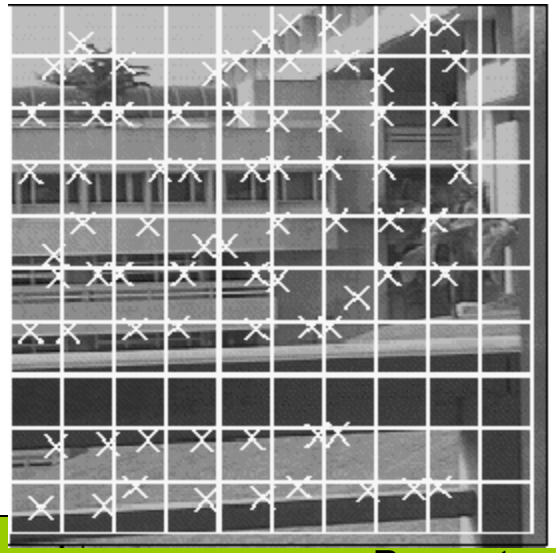
Example

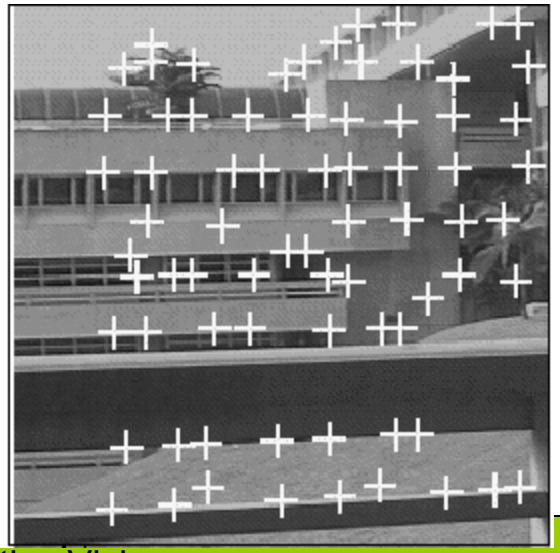


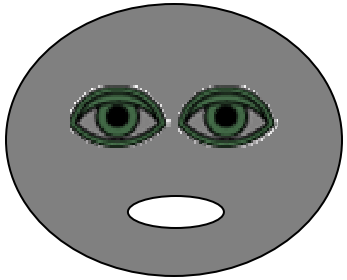
Forward Reconstruction











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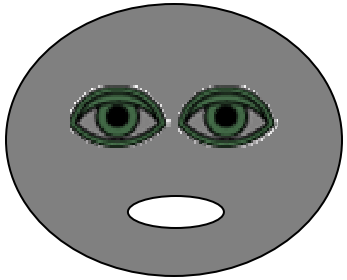
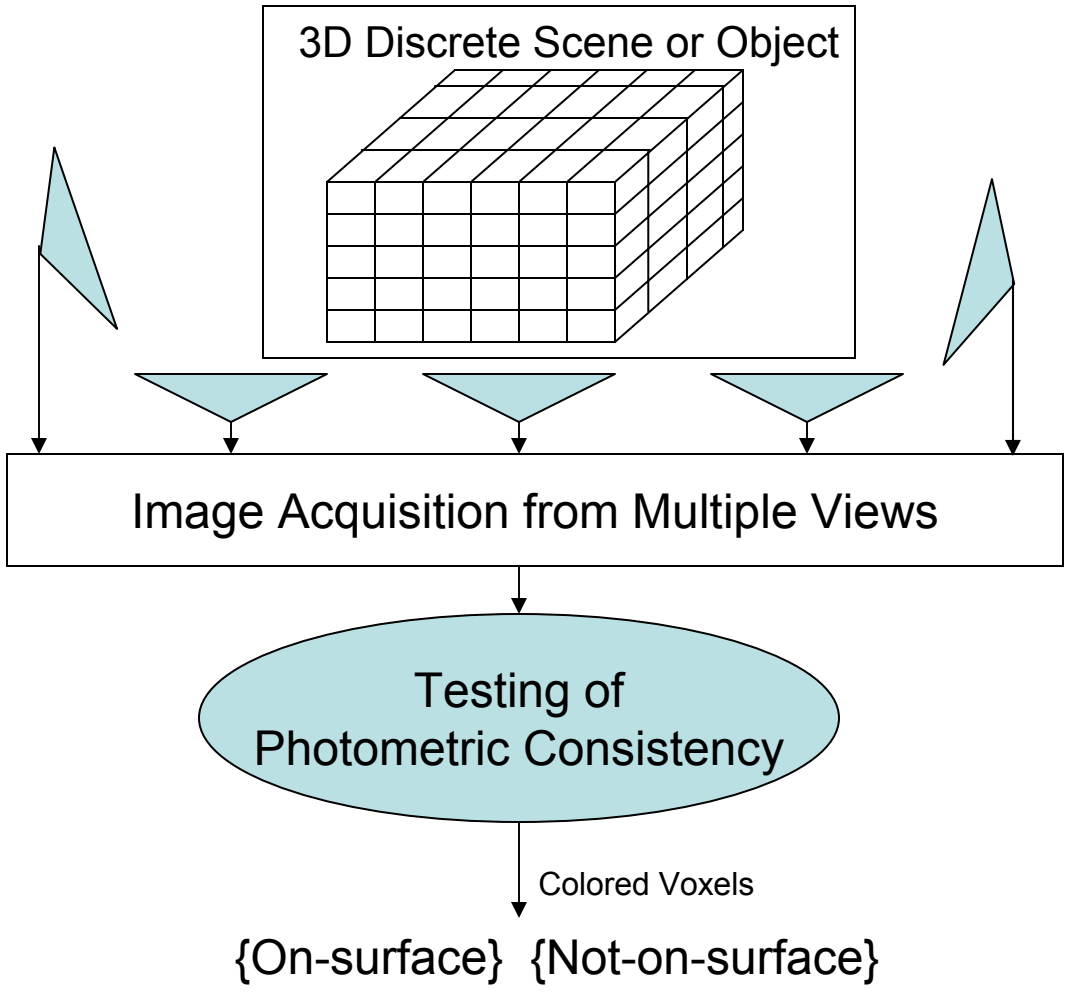
Inverse Reconstruction

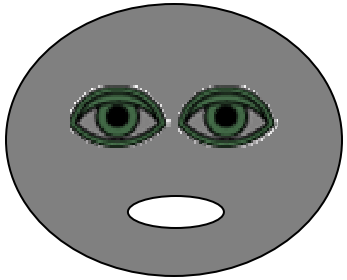
- Inverse Reconstruction is a new terminology in robot vision.
- There are two established algorithms, which justify the importance of inverse reconstruction. They are: a) the algorithm of voxel coloring, and b) the algorithm of discrete epipolar line.
- Voxel coloring algorithm and its variants are advocated by Yang et al (1993), Collins (1996), and Seitz et al (1999).
- Discrete epipolar-line algorithm is advocated by the speaker (1997), and is simpler and more practical.
- Inverse reconstruction starts with 3D discrete scene and ends with feature matching in binocular, or multiple, views.
- Inverse reconstruction has three notable advantages: a) controllable accuracy of 3D geometry, b) fast (e.g. time-independent of image-resolution), and c) less ambiguity of matching (but it still suffers the ambiguity of matching due to occlusions and photometric discrepancy in stereo images!).



Inverse Reconstruction

Voxel Coloring Algorithm:





Inverse Reconstruction

Discrete Epipolar-line Algorithm:

3D Discrete Scene :

$$\{(X_i, Y_i, Z_i), i = 0,1,2,...\}$$

with one discretized coordinate, say :

$$Z_i = Z_{\min} + i \bullet \Delta Z$$

Features in Left Image :

$$\{({}^{l}u_j, {}^{l}v_j), j = 0,1,2,...\}$$

Binocular Correspondence

Features in Right Image :

$$\{({}^{r}u_k, {}^{r}v_k), k = 0,1,2,...\}$$

Left Camera :

$$s_1 \bullet \begin{pmatrix} {}^{l}u_j \\ {}^{l}v_j \\ 1 \end{pmatrix} = {}^{l}M \bullet \begin{pmatrix} X_i \\ Y_i \\ Z_{\min} + i \bullet \Delta Z \\ 1 \end{pmatrix}$$

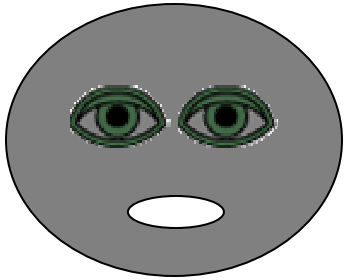
Validation

$$(X_i, Y_i, Z_i)$$

Output

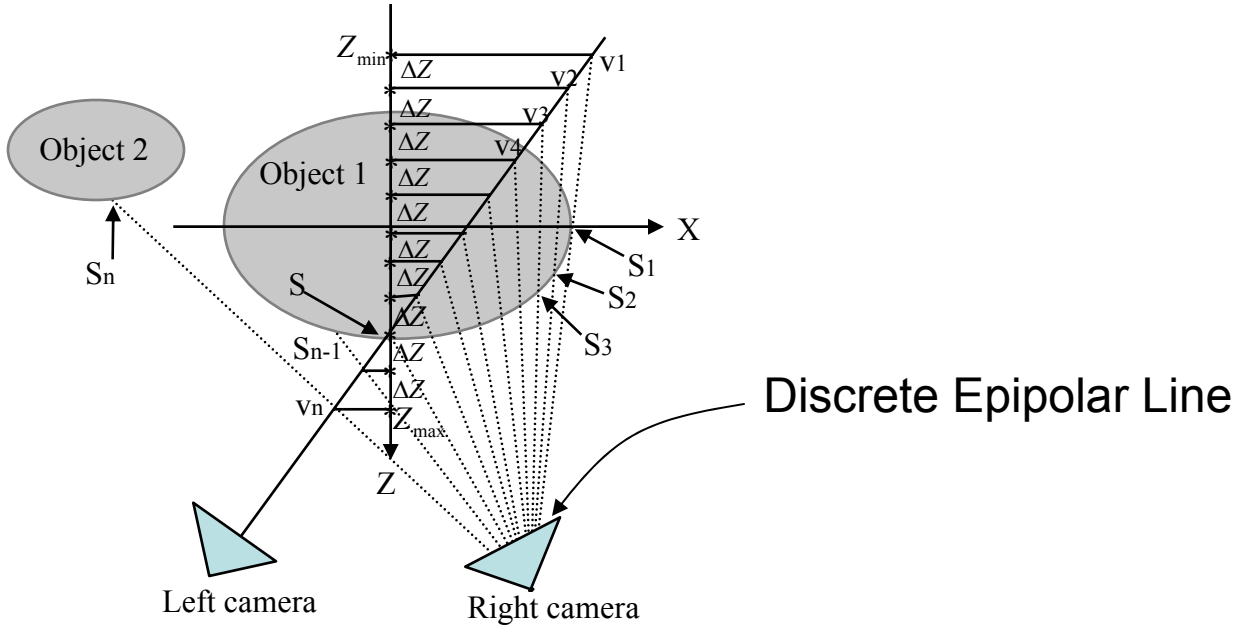
Right Camera :

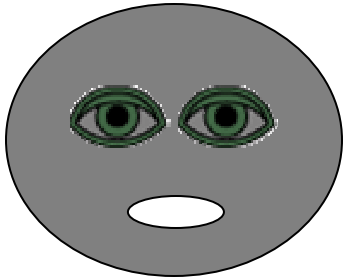
$$s_2 \bullet \begin{pmatrix} {}^{r}u_k \\ {}^{r}v_k \\ 1 \end{pmatrix} = {}^{r}M \bullet \begin{pmatrix} X_i \\ Y_i \\ Z_i \\ 1 \end{pmatrix}$$



Inverse Reconstruction

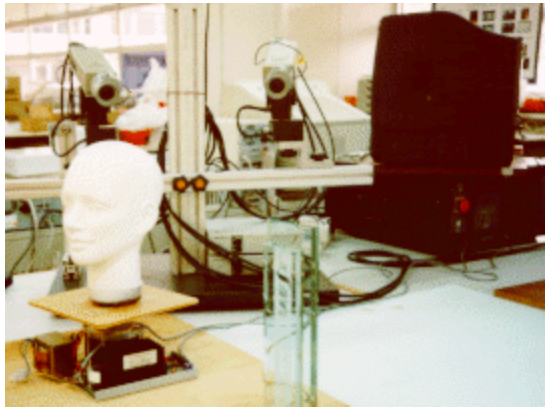
Illustration of Discrete Epipolar Line

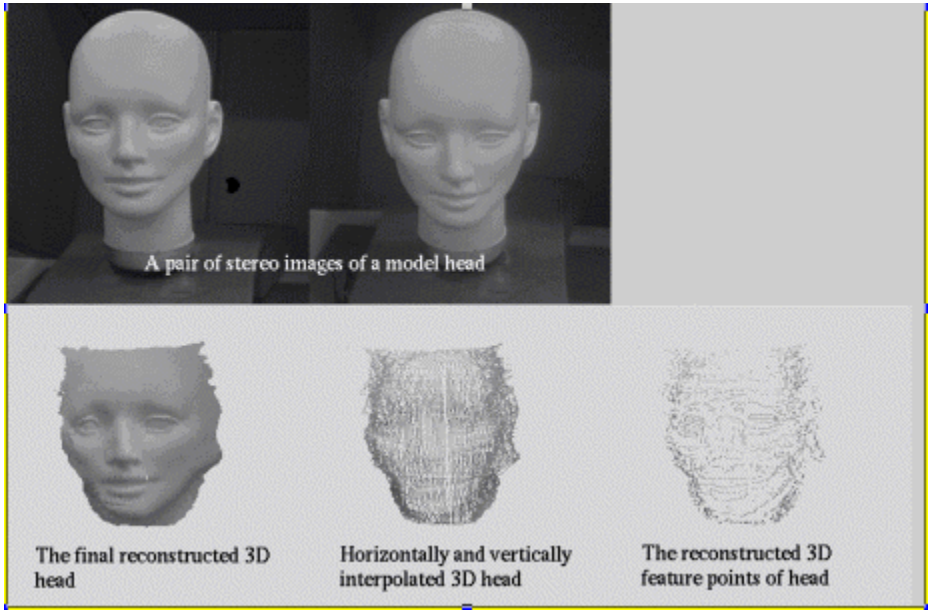


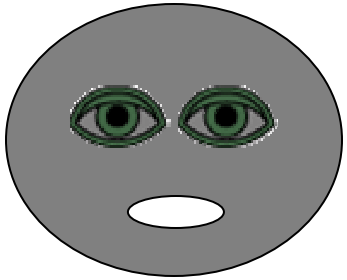


Inverse Reconstruction

Example

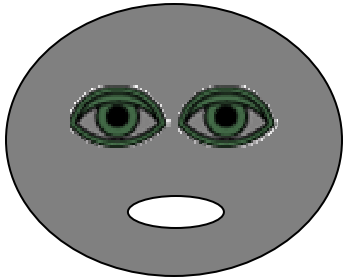






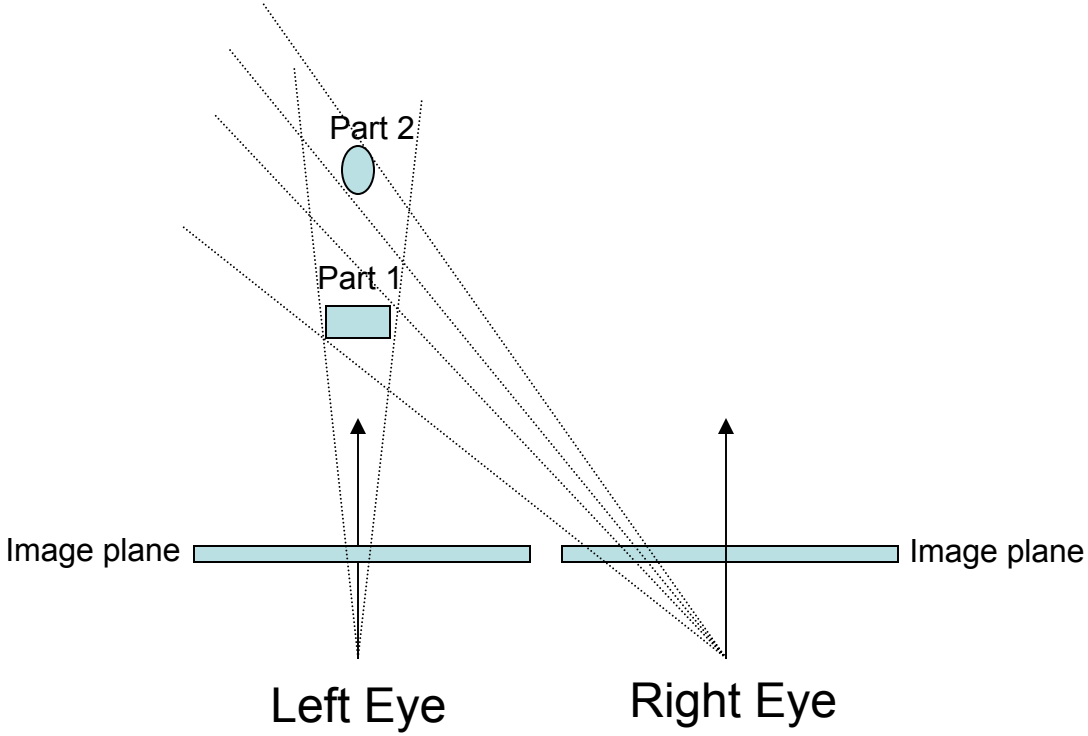
Future Challenge

- Until today (by the time of writing), it is still a challenge to infer the geometry of a 3D object or scene in a general setting of binocular vision.
- The major obstacle is “binocular correspondence” in general.
- There are two perpetual problems, which cause the trouble (i.e. the ambiguity of matching) to binocular correspondence.
- They are: a) occlusion, and b) photometric discrepancy.

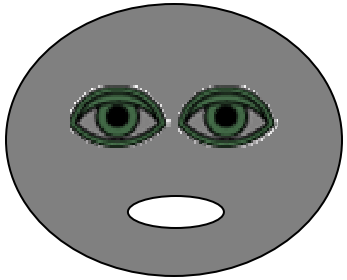


Future Challenge

Problem of occlusion:

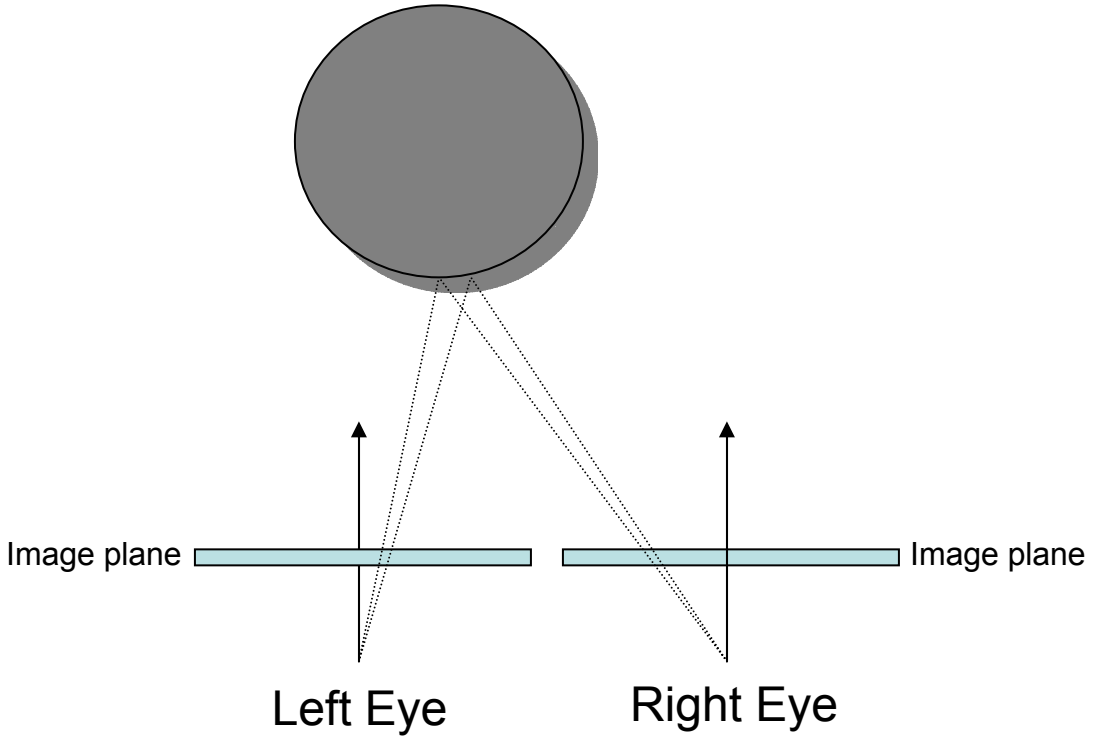


We have to have solutions that are able to live with occlusions!

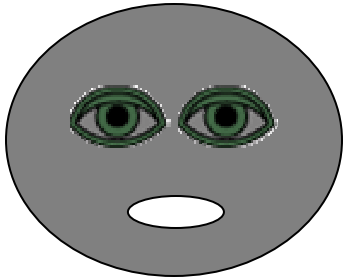


Future Challenge

Problem of photometric discrepancy:



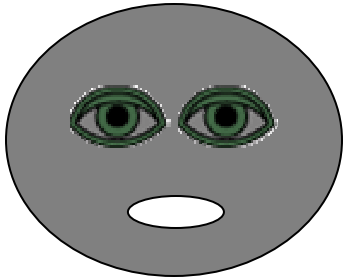
We have to have solutions that are able to tolerate appearance variations!



Future Challenge

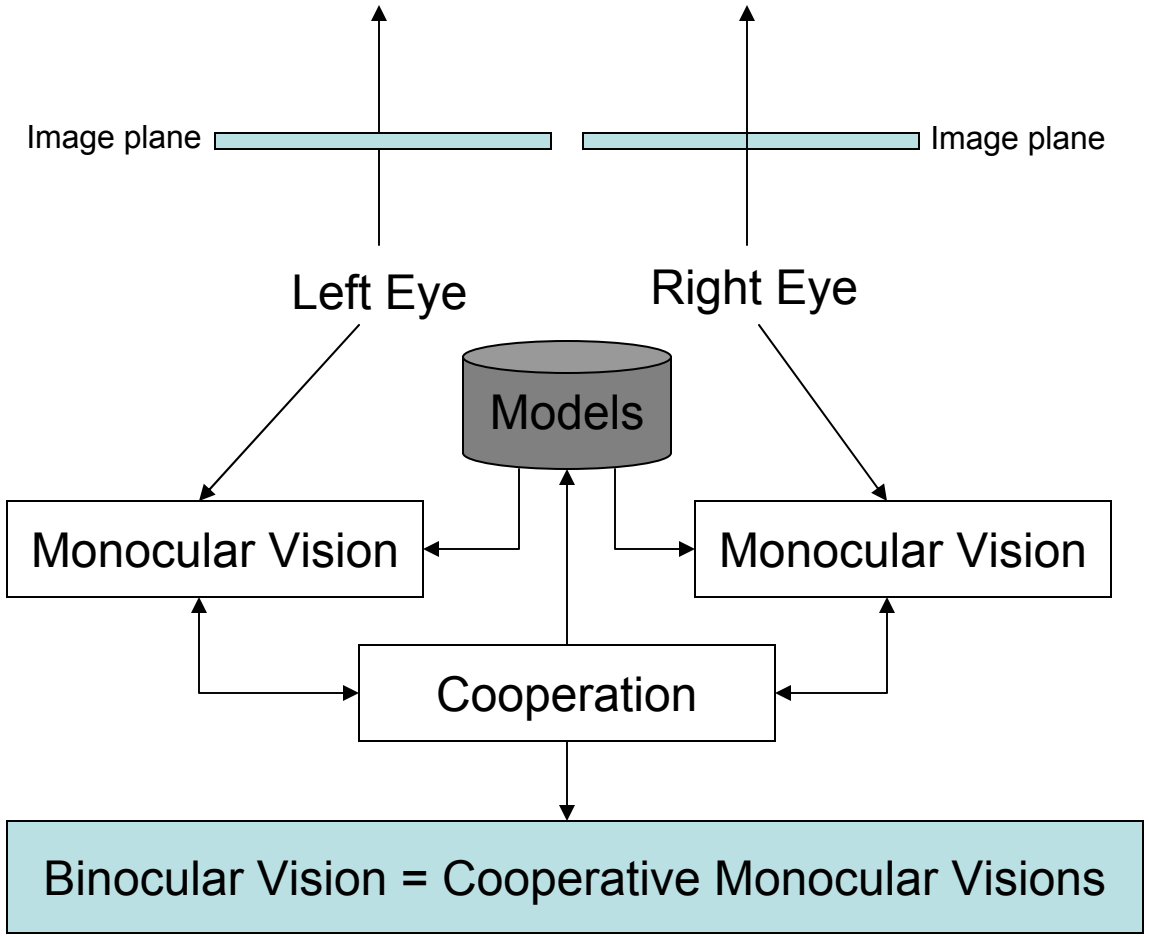
- We believe that a binocular vision should be treated as the combination of two cooperative monocular visions.
- In particular, each monocular vision must consider “models” and “meanings” at the level of knowledge, instead of geometry alone.
- This idea leads us to further believe in the importance of model-based, or even knowledge-based (i.e. cognitive), vision.

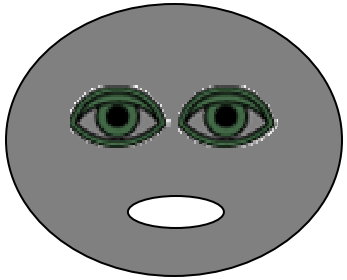
(to continue …)



Future Challenge

Cooperative Monocular Visions, Which are Model-based.





End of Reconstructive Vision