Grafica 3D per i beni culturali: Dense Stereo Matching, Intro

Lezione 11: 26 Aprile 2011

Image-based 3D Reconstruction

- 3D models can be built manually, acquired using special devices (laser scanner, structured light scanner) or produced starting from a set of images → image-based 3D reconstruction.
- Image-based reconstruction can be fully automatic or semi-automatic (assisted by an human user).
- Here we focus on fully automatic reconstruction.

Image-based 3D Reconstruction

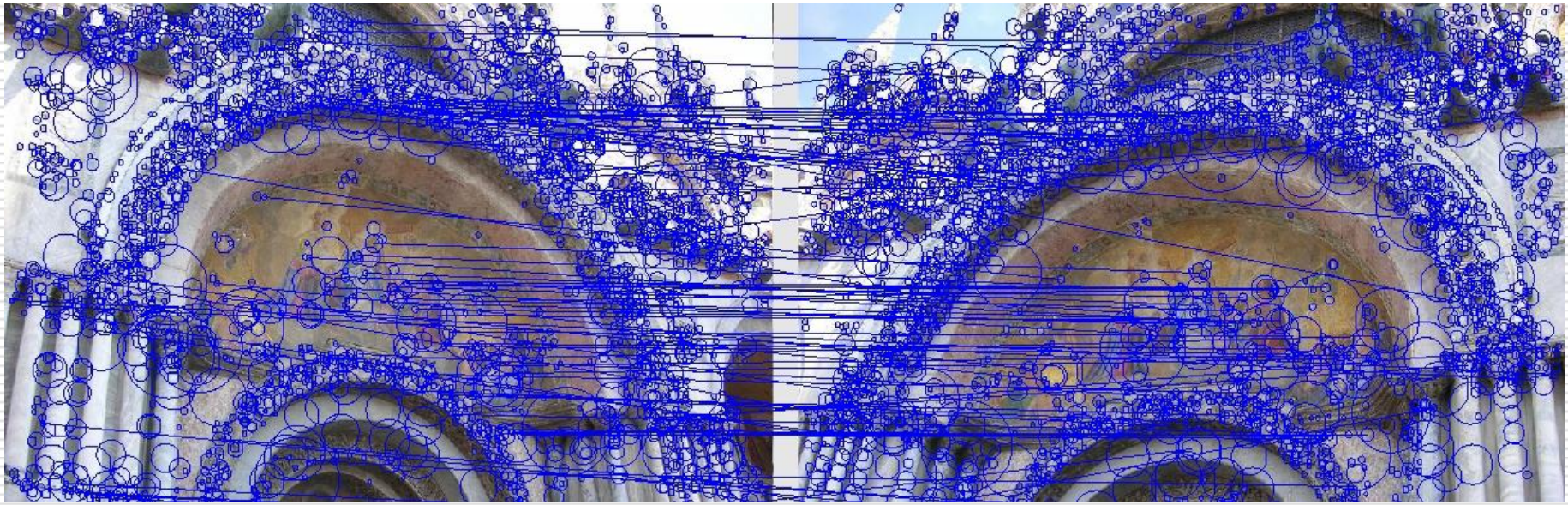
- Advantages:
  - Automatic
  - Fast (relatively to manual built)
  - Good scalability (both small and huge model can be acquired)
  - Non-expert users can create his/her 3D model.
  - Cheap!
- Disadvantages:
  - Accuracy (not so accurate)
  - Not all the objects can be acquired

How does it work?

- The 3D Webservice only uses images as input.
- Computer vision techniques are used to compute the results.
  - Automatic matching of images
  - Automatic computation of camera calibration
  - Automatic dense matching for depth map generation

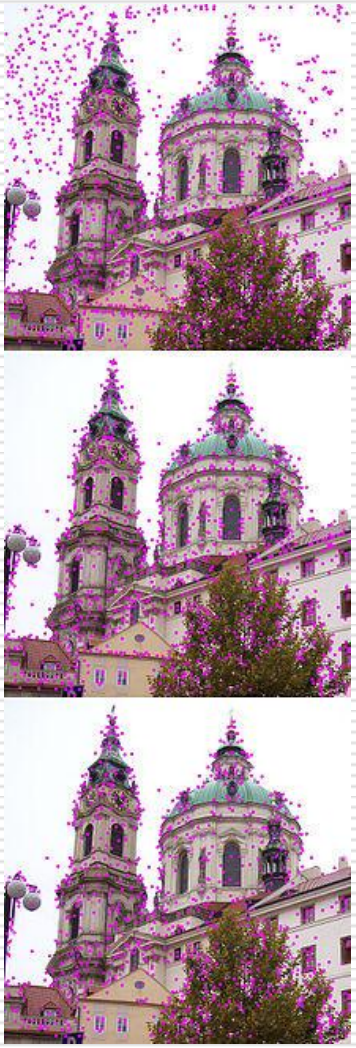
1 - Automatic matching of images

- The entire process is based on finding matches between images.
- *Record your pictures not too far apart, so the computer can match them easily!*



1 - Automatic matching of images

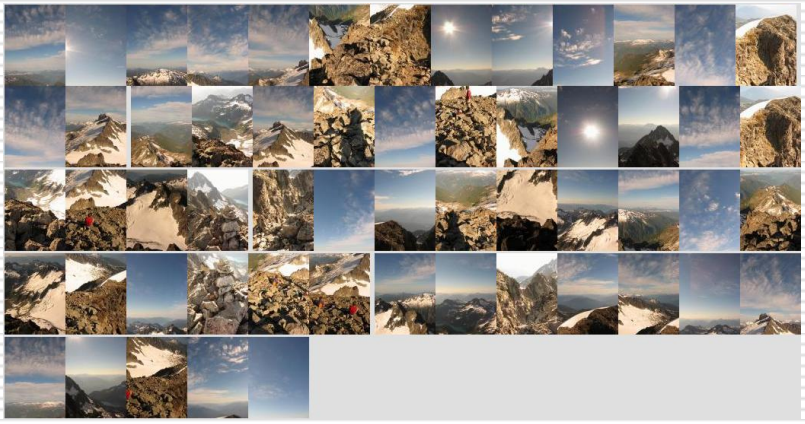
SIFT: Scale Invariant Feature Transform

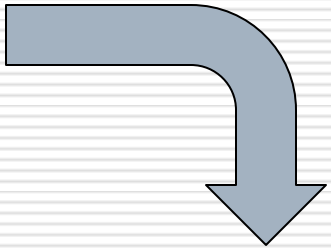


For any object in an image, interesting points on the object can be extracted to provide a "feature description" of the object.

This description, extracted from a training image, can then be used to identify the object when attempting to locate the object in a test image containing many other objects

1 - Automatic matching of images





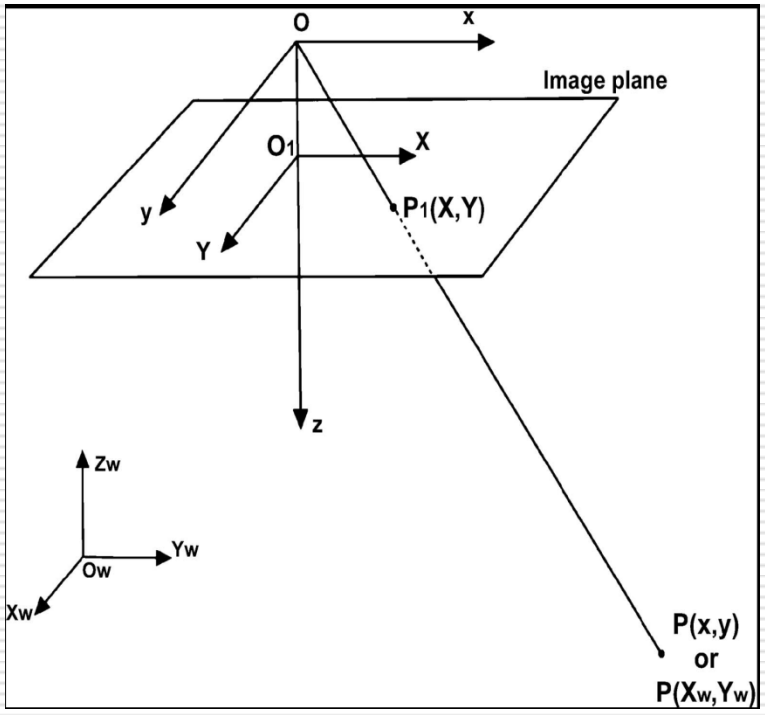
2 - Camera Calibration

- No prior knowledge about camera calibration is available, so all information must be recovered from the images
- It is therefore important that enough information is present in the images!
- Important factors:
  - Motion of the camera
  - General structure of the scene
  - Enough overlap (only points that are visible in at least 3 images are useful)
- *What you want reconstruct and how you get the photos have great influence on the final reconstruction (!!)*

Camera calibration: the camera model

Intrinsic and **extrinsic** parameters

- Extrinsic parameters: rotation matrix and translation vector
- Intrinsic parameters: focal length, lens distortion…

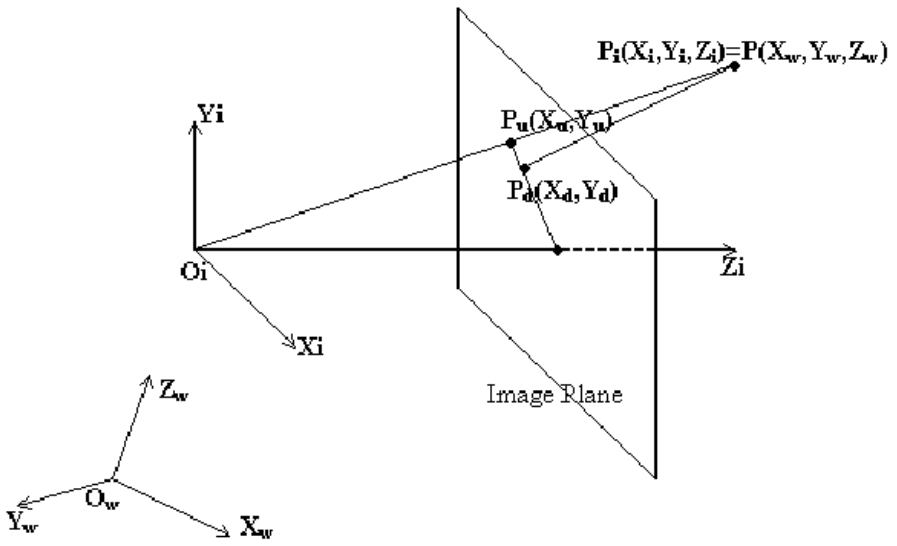


Camera calibration: the camera model

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = R \begin{bmatrix} x_w \\ y_w \\ z_w \end{bmatrix} + T$$

$$X_u = f\frac{x}{z} \ , \ Y_u = f\frac{y}{z}$$

$$X_d + D_x = X_u \ , \ Y_d + D_y = Y_u$$



$$D_x = X_d(k_1 r^2 + k_2 r^4 + ...) \ , \ D_y = Y_d(k_1 r^2 + k_2 r^4 + ...)$$

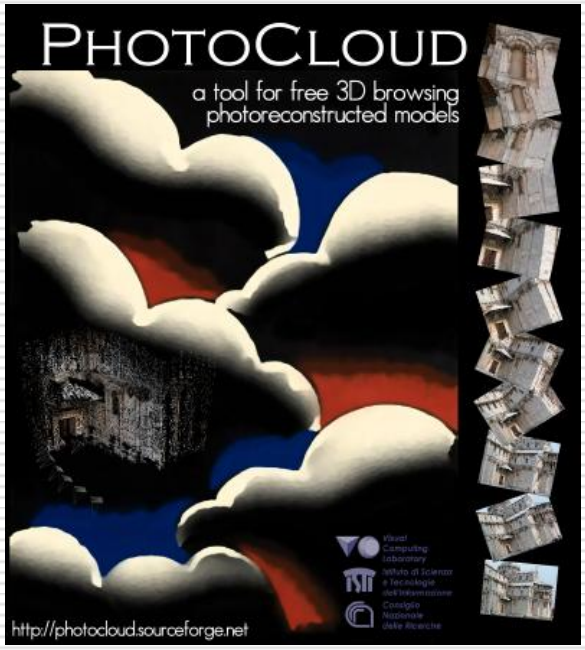
$$r = \sqrt{X_d^2 + Y_d^2}$$

Calibrated Cameras: what you can do with them

Photo Tourism

- *Having a set of (even etherogeneous) images, you can navigate the photo collection in a "spatially coherent" way. It evolved into PhotoSynth (see later).*

Calibrated Cameras: what you can do with them



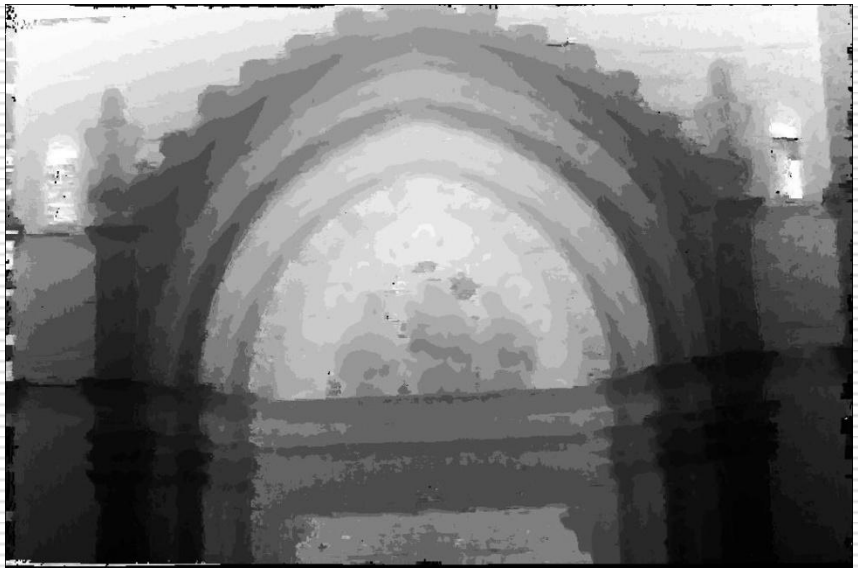
PhotoCloud

- *The ISTI alternative, similar in concepts, but the idea is to integrate even high detail 3D models.*

3 - Dense Matching

- After recovery of the camera calibration, dense depth maps are computed
- These contain the depth of every pixel and a quality measure (how confident we are of each particular pixel)

Depth Map



Final comments

3D reconstruction from image is a still emerging but nearly consolidated technology.

Some people claim it to be the alternative to 3D scanning, but there are some issues:

- Scale of the scene
- Estimation of intrinsics
- This is not a measuring system!
- No real numerical comparison wit 3D Scanning, or accuracy test
- A bit more difficult to know in advance if you will be able to acquire the object.

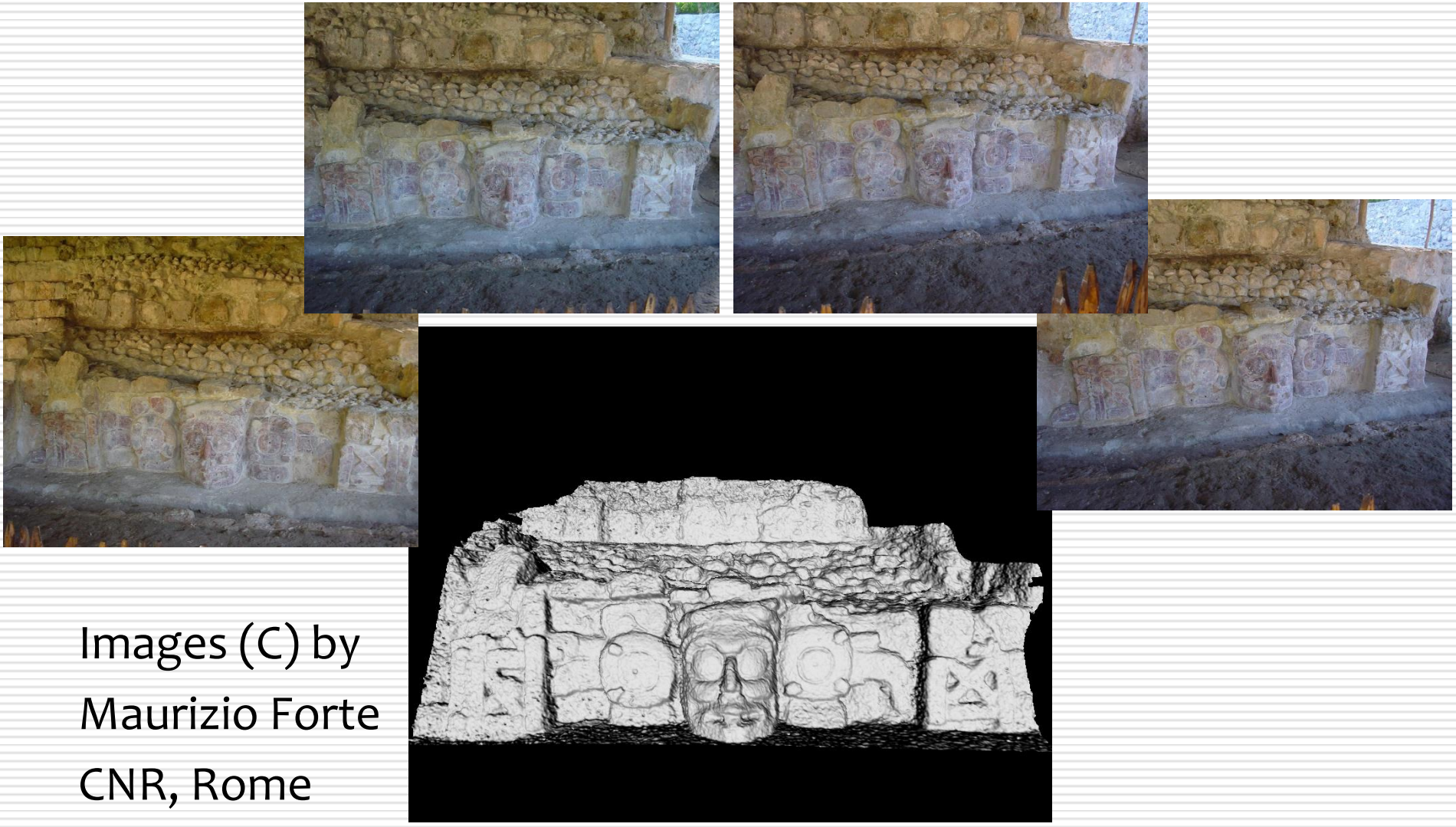
Examples of 3D reconstruction systems

- There’s plenty of systems for 3D reconstruction from images
- They essentially differ in the implementation, but the main steps are the same
- Web service/Black box vs. Local pipelines
- We’ll see two systems: Arc3D web service and Photosynth Toolkit

ARC3D Web Service

- ARC3D Web Service in a nutshell:
  - Register your account
  - Send your images (taken with your digital camera)
  - Get your 3D model
- **Authors:** Martin Vargauven and Luc Van Gool of University of Leuven (Belgium), in the ambit of EPOCH European Network of Excellence
- **Web Site:** *http://arc3d.be*
- **Further Information:** M. Vergauwen and L. Van Gool, *Web-based 3D Reconstruction Service*, in Machine Vision Applications (MVA), 17, pp. 411-426, 2006.

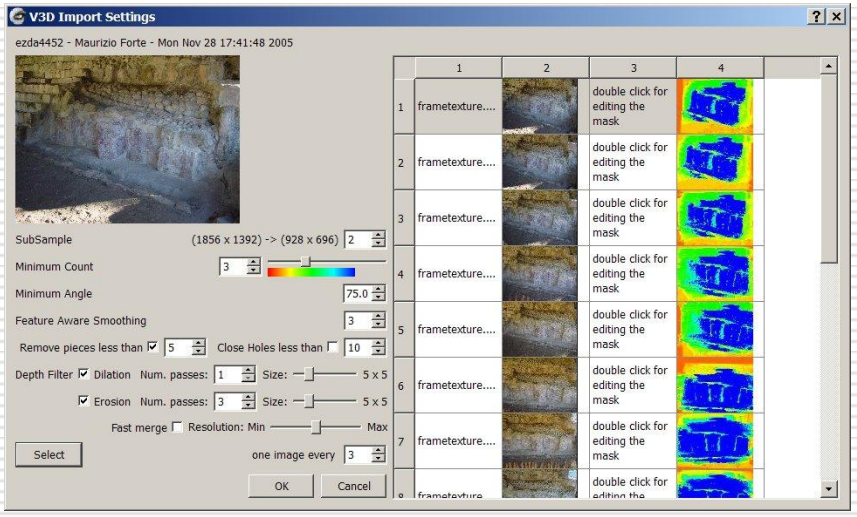
ARC3D Web Service

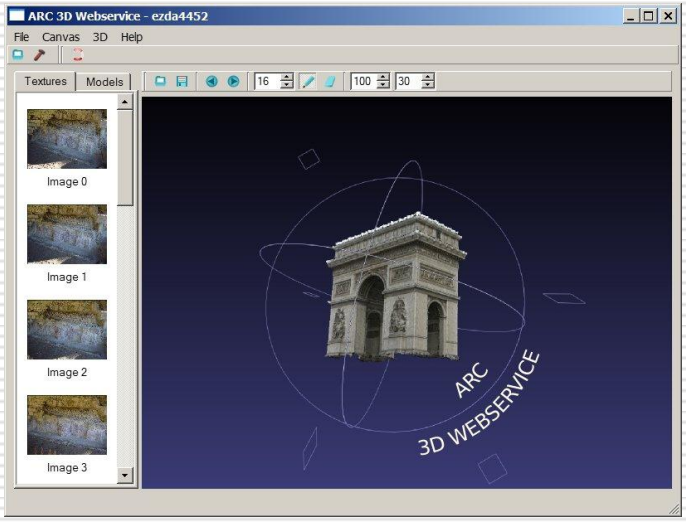


Images (C) by
Maurizio Forte
CNR, Rome

Visualize the Result

- Two tools are available for inspecting the results
- MeshLab, a tool developed by CNR-ISTI in Pisa, Italy (ARC3D Team recommends Meshlab)
- A simple model viewer comes with the ARC installer (ARC3D Model Viewer)

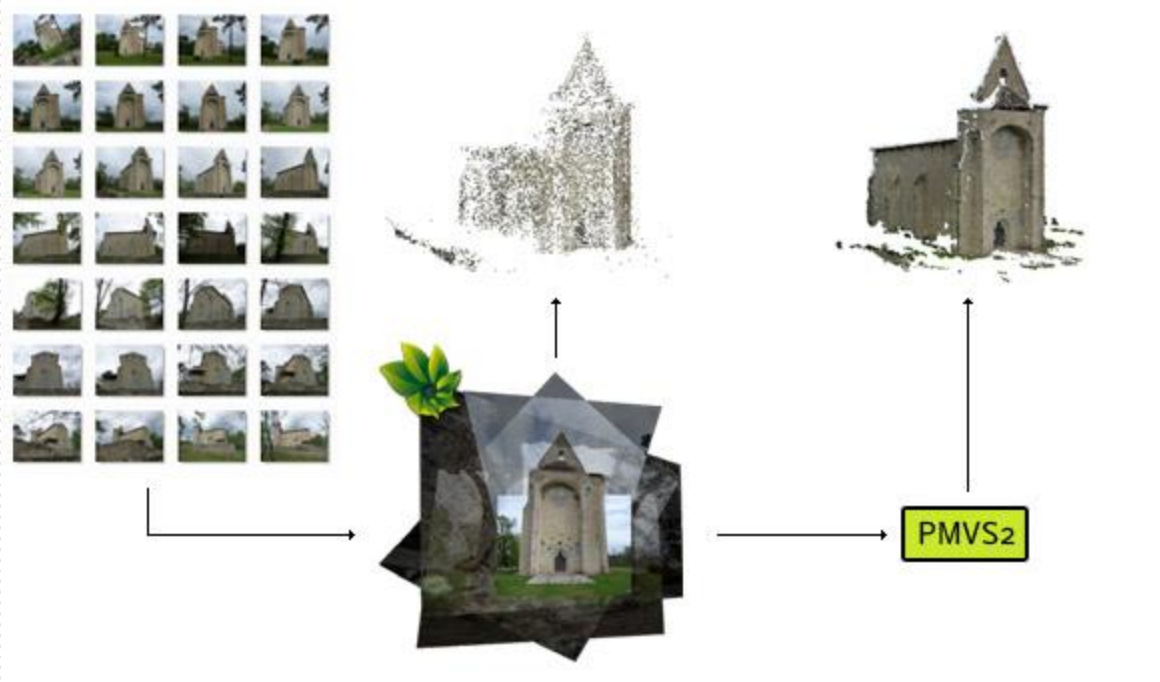




Photosynth Toolkit

- The Photosynth toolkit is the result of the work of people from a Blog (Visual Experiments)
- The code of Bundler (SIFT+Camera Calibration) has been made available recently
- In alternative, it’s possible to use the Photosynth service
- Moreover, further code for the surface reconstruction (CMVS -> PMVS)
- The Toolkit is available and works locally

Photosynth Toolkit



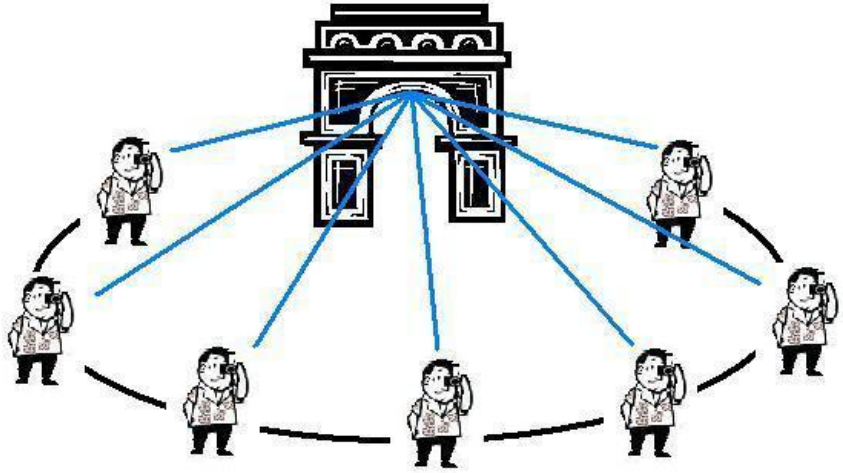
- Also the Photosynth toolkit can be integrated with MeshLab, so that the final result can be improved!

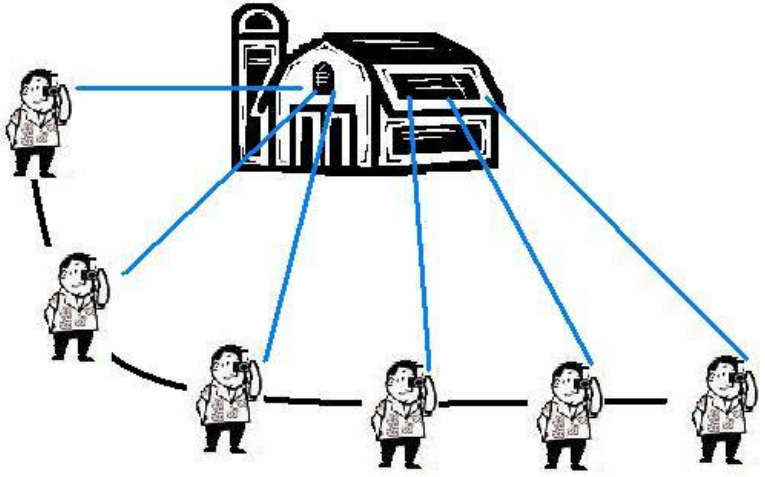
Best Practice

- How to do the photos? (good image sequence)
- Practical Problems and Hints (good scene to reconstruct)

Good sequence

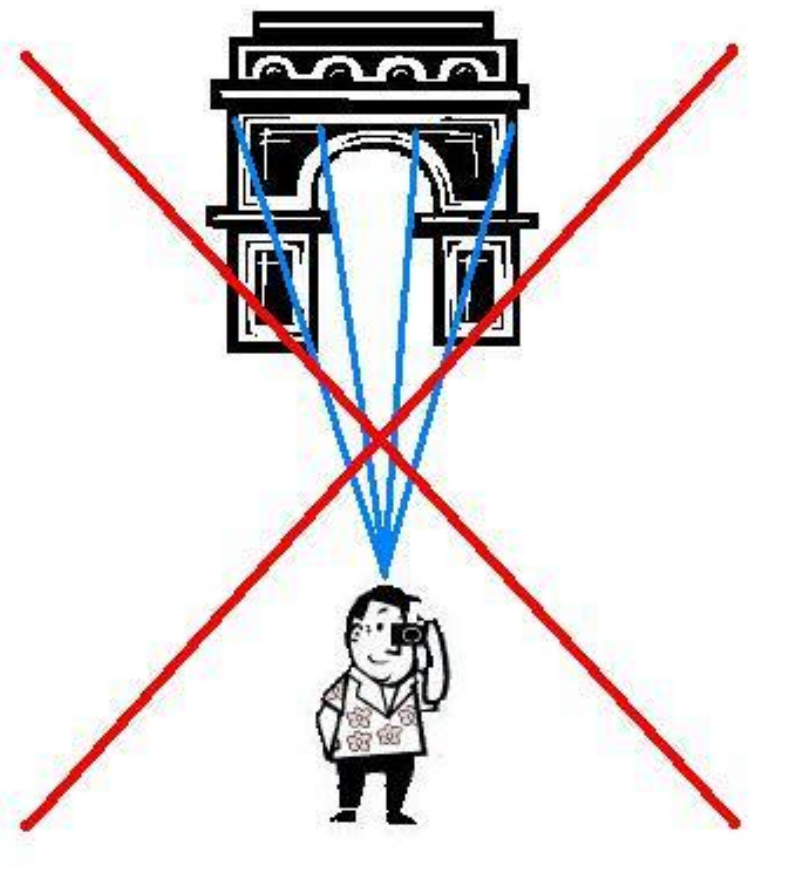
- **Shoot a picture of the same location for every step made in the shooting sequence. This results in multiple pictures of the same scene, but viewed from slightly different sides.**
- ***Walk with the camera in an arc around the scene, while keeping the scene in frame at all times (!)***
- ***Keep the zoom FIXED (!)***





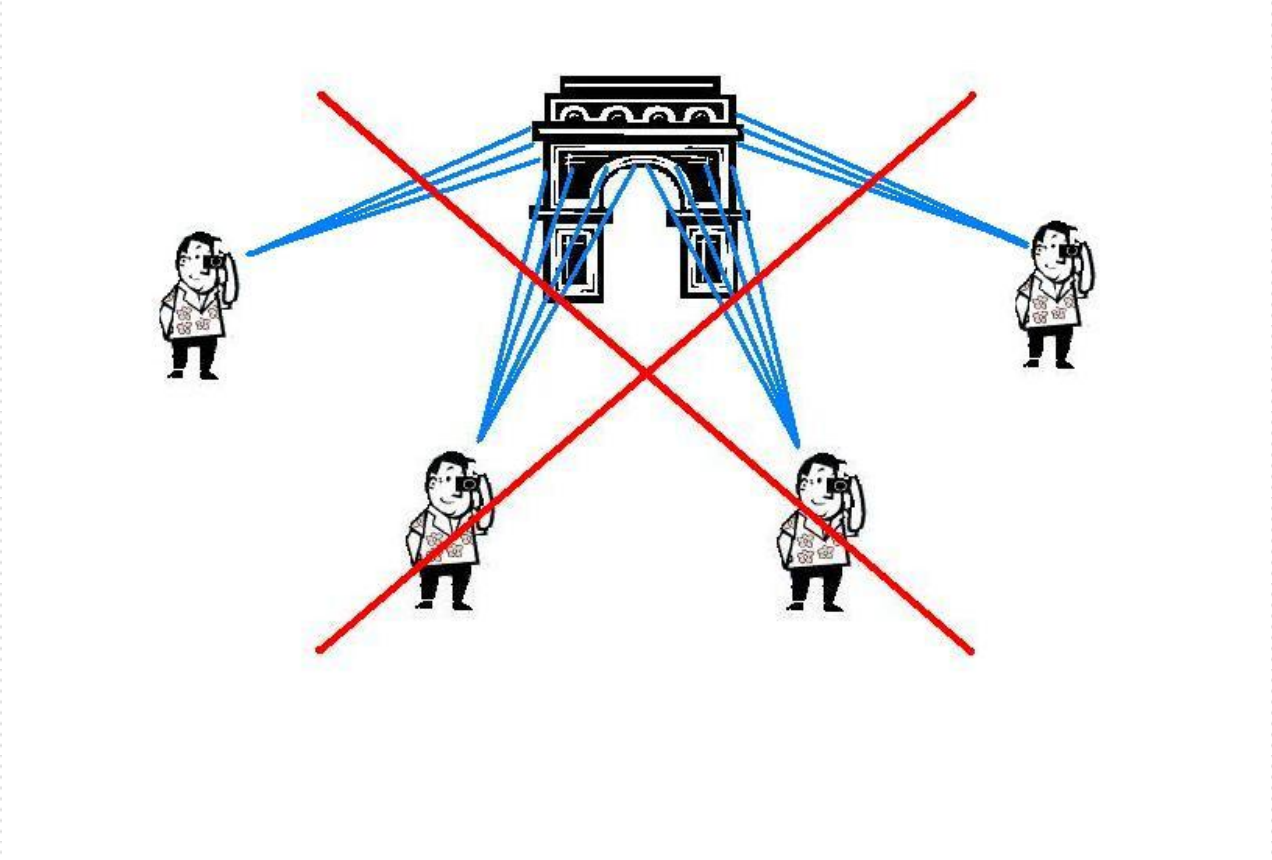
Bad sequences

- ***Do not pan from the same location***, as if you were recording a panorama. It is not possible to determine enough 3D information from such a sequence.



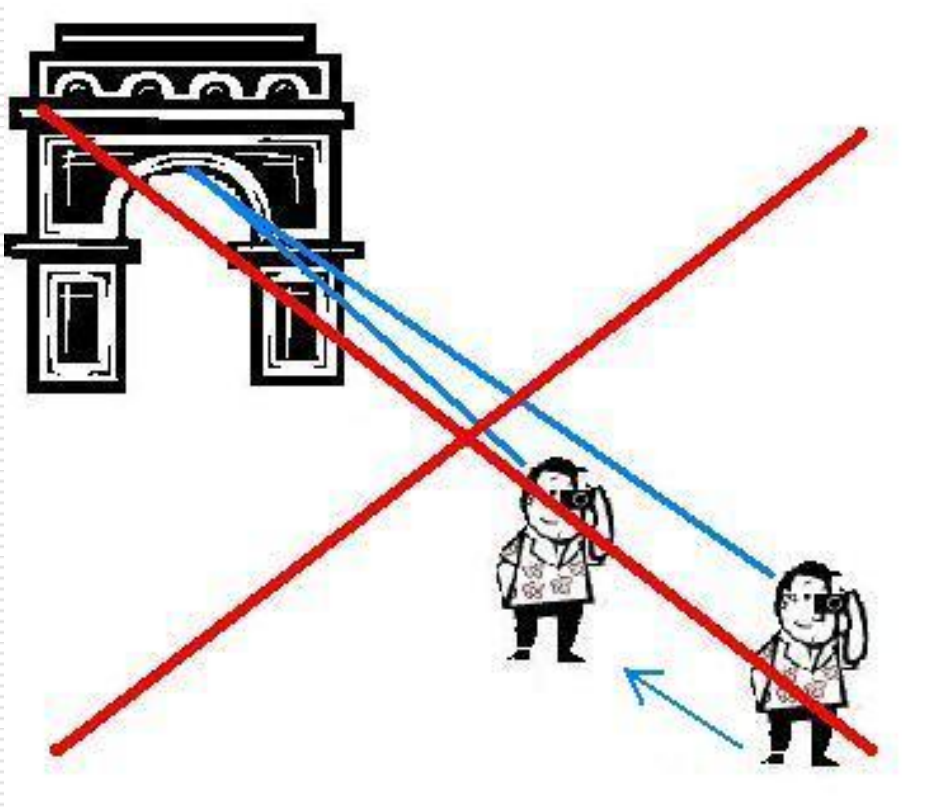
Bad sequences (2)

- Don’t shoot multiple sub-sequences from different viewpoints



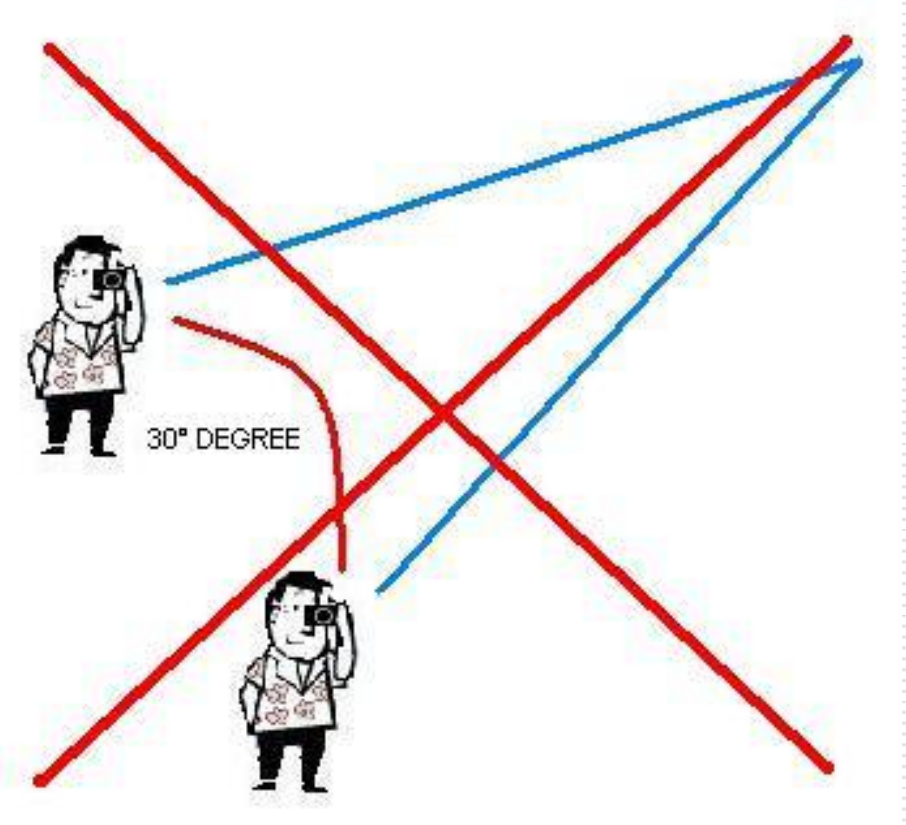
Bad sequences (3)

- Do not walk in a straight line towards or inside the scene you want to reconstruct



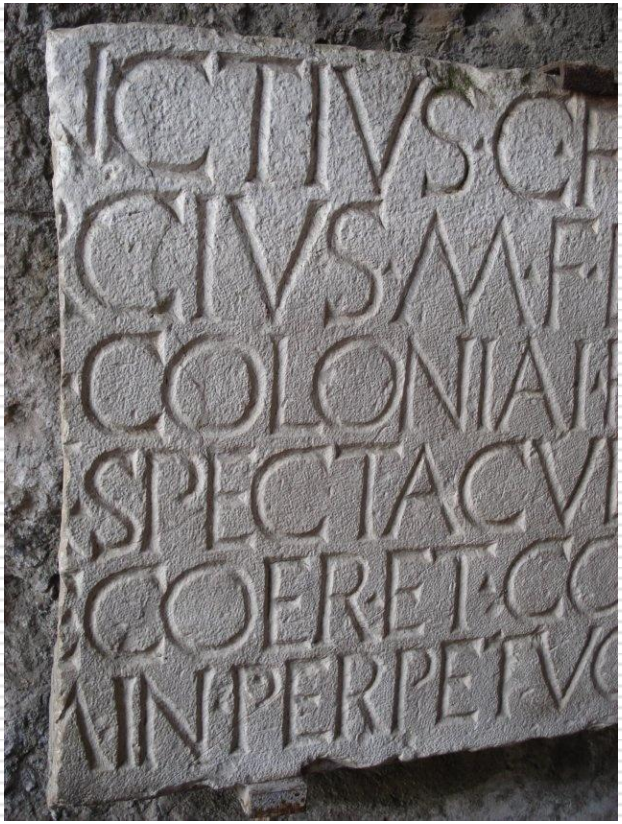
Bad sequences (4)

- It is better to shoot a lot of pictures than few ones. A minimum of five or six images are required for a good reconstruction. The reconstruction could fail with less than four images.
- The viewing angle between images should not be too small, i.e. adjacent images should not be too far apart



Bad sequences (5)

NO TURNTABLE



NO PLANAR SCENE

Equipment

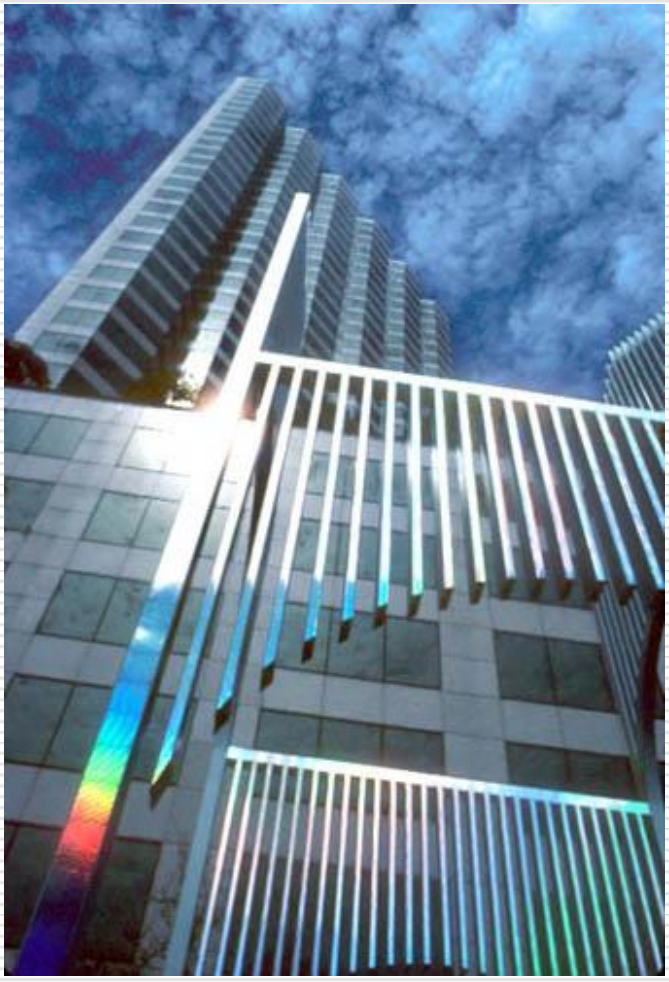
- What kind of camera should I use?
  - More pixels = more 3D points = longer upload and processing time
  - 5MP (2500x2000) is typically good enough
  - Good lens → less distortion → better result
  - Good lens → more light → better result

Practical Problems

- All information is retrieved from the images, so take care when you shoot them!
- The texture (color, intensity) of the scene – object is critical!
  - Enough texture must be available on the object
  - Appearance of object must stay the same!

Not Enough Texture

No Constant Appearance



No Constant Apperance

No Constant Apperance

No Static Scene

Dynamic Scene cannot be reconstructed (!)

Don’t use blurry images

- Blurry images (due to movements or out-of-focus) must avoided (!)
- This causes problems during the reconstruction process and/or degrades the final result (!)

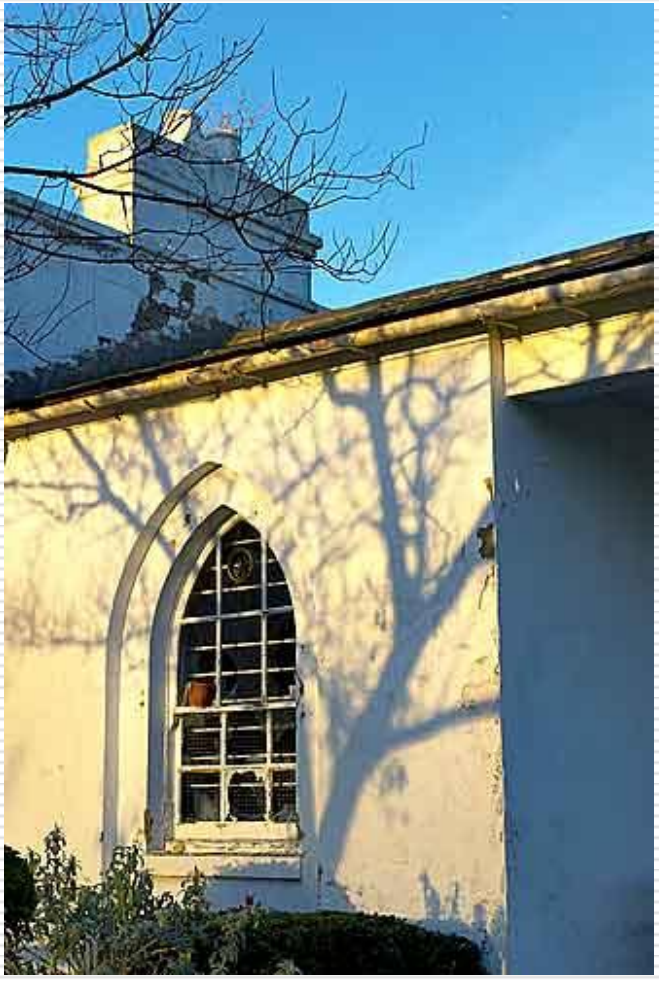
Self-Occlusions

- Self-occlusions have to be treated with care (be sure that your photos cover all the self-occluded parts).

Lighting Conditions

Overcast sky is perfect due to uniform illumination.

Moving Shadows should be avoided...



In general changing conditions should be avoided (!)

Next in line…

Next lesson:

- Dense stereo matching: Arc3D Web-Service

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