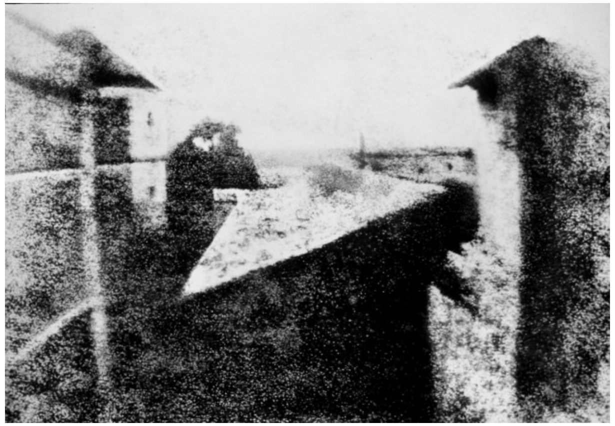
VIRTUAL OUTCROP GEOLOGY

Fundamentals of photogrammetry

Photogrammetry is the **art**, **science**, and **technology** of **obtaining reliable information** about physical objects and the environment **through processes of recording, measuring, and interpreting photographic images** and patterns of recorded radiant electromagnetic energy and other phenomena (Wolf and Dewitt, 2000; McGlone, 2004). In other words, **photogrammetry is the science of making measurements from photographs**.

Photogrammetry: the science of making measurements from photographs



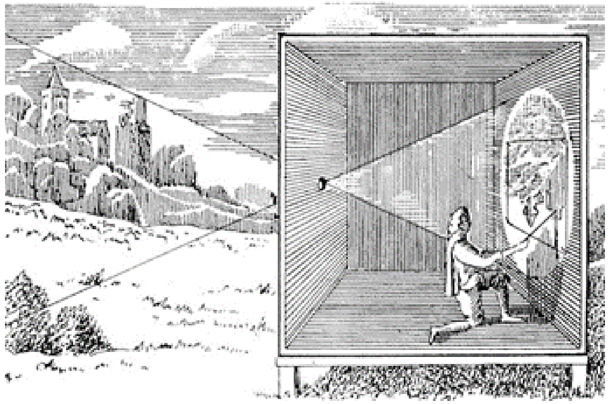
View from the Window at Le Gras, Niépce, 1826

Photogrammetry employs photographs (or digital imagery) for measurements. It has developed as a science since the 19th century.

Trinità, Masaccio, 1425-7

The basic concepts of photogrammetry, which deal with the concept of perspective and projective geometry, go back to the 15th century.

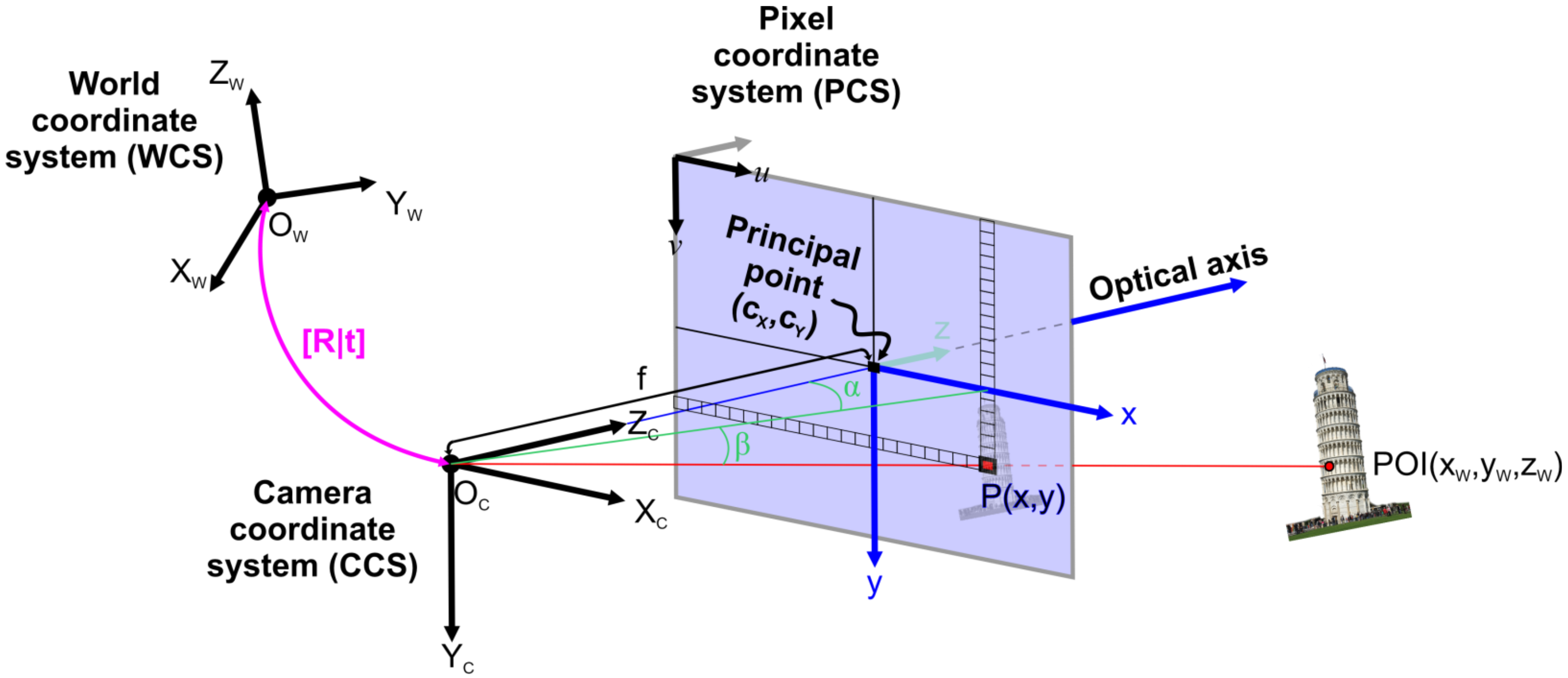
Photogrammetry: the science of making measurements from photographs



Light travels in straight lines

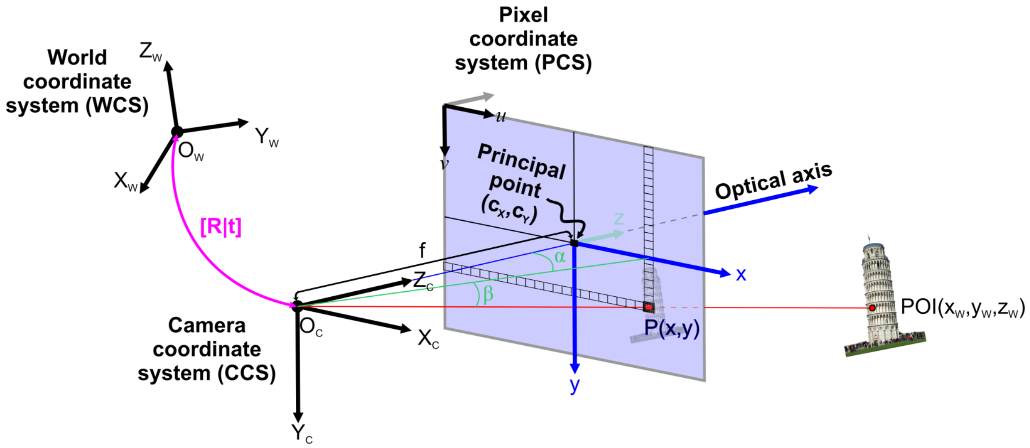
modello di camera stenopeica

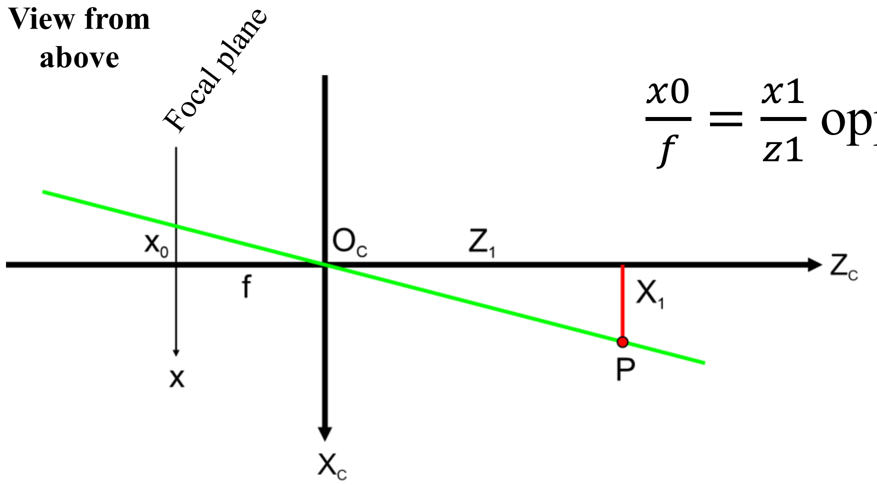
The **pinhole camera model** describes the relationship between the 3D coordinates of a point in space and its projection onto the image plane of an ideal pinhole camera (the aperture is a point and no lenses are used to focus light).



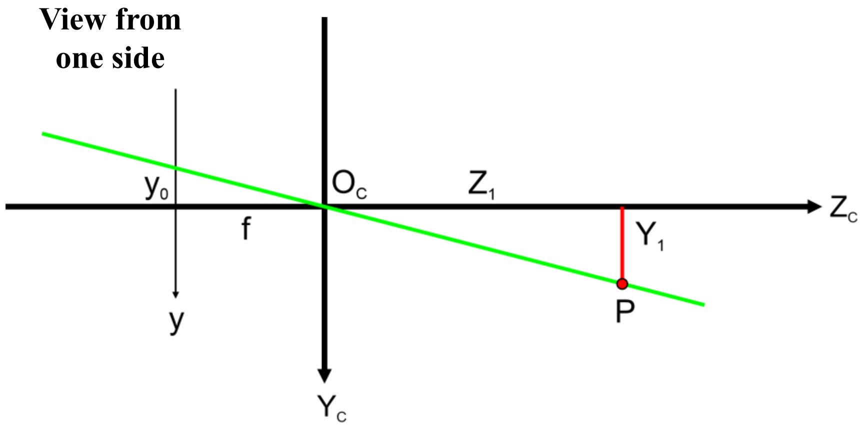
How 2D coordinates of P(x,y) are related to the camera coordinates POI(x_C,y_C,z_C)?

Photogrammetry: the science of making measurements from photographs





$$\frac{x0}{f} = \frac{x1}{z1} \text{ oppure } x0 = \frac{f \times x1}{z1}$$



$$\frac{y0}{f} = \frac{y1}{z1} \text{ oppure } y0 = \frac{f \times y1}{z1}$$

$$\begin{pmatrix} x0 \\ y0 \end{pmatrix} = \frac{f}{z1} \begin{pmatrix} x1 \\ y1 \end{pmatrix}$$

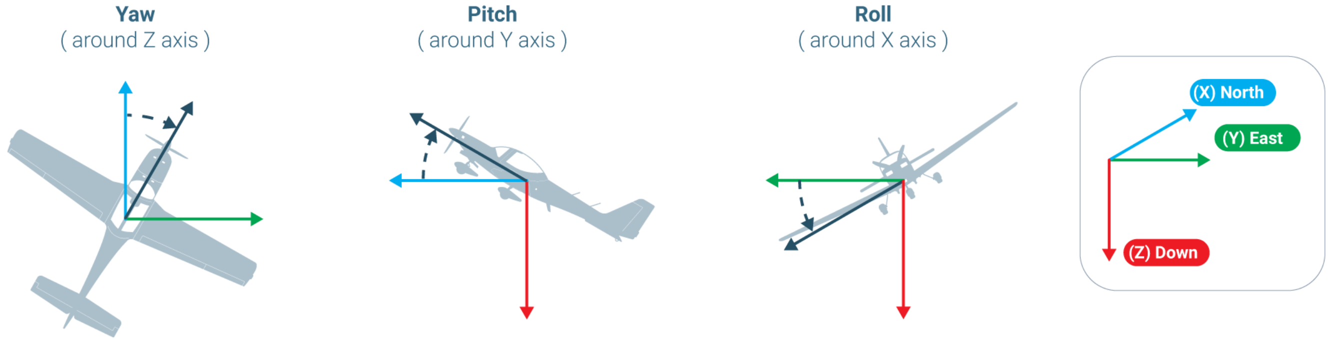
Applying a rotation matrix to rotate the point of view toward the observation point we can derive the collinearity equation.

Photogrammetry: the science of making measurements from photographs

To perform a rotation, we can use a rotation matrix.

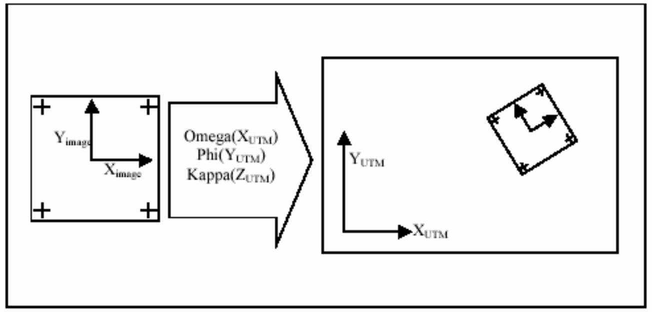
$$R = \begin{bmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{bmatrix} = R(\boldsymbol{\Phi}, \boldsymbol{\theta}, \boldsymbol{\psi})$$

Imbardata (ψ) **Beccheggio (θ)** **Rollio (Φ)**



Rotation of an aircraft around 3 axes with respect to its navigation coordinate system.

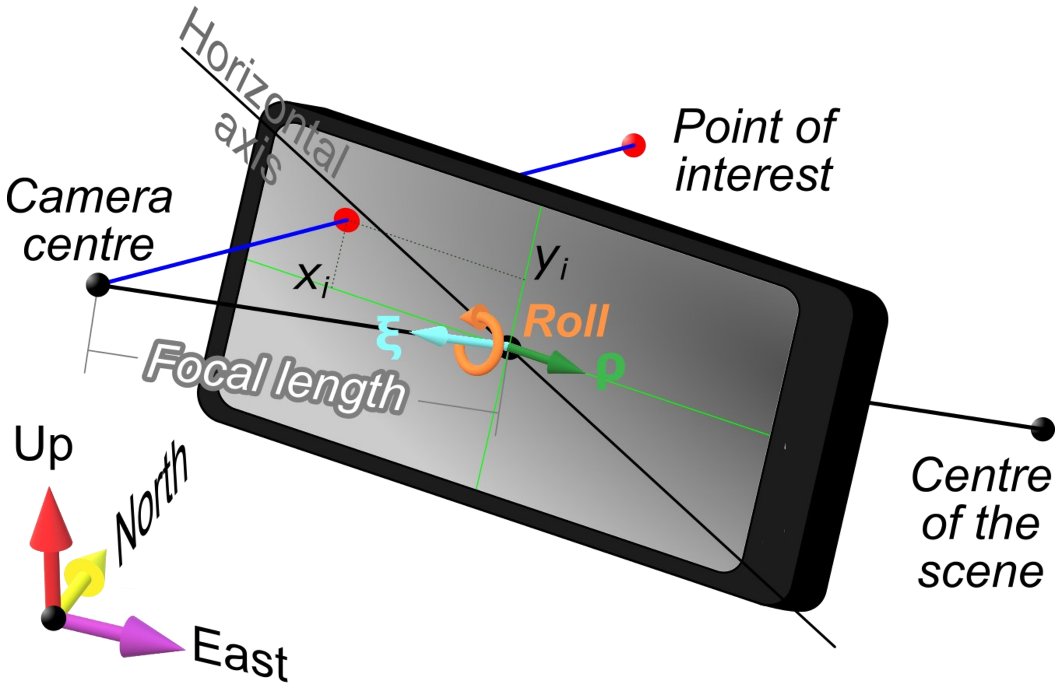
Kappa (κ), the rotation around the Z axis.
Phi (φ), the rotation around the Y axis.
Omega (ω), the rotation around the X axis.



The omega, phi, kappa angles are defined as the angles used in order to rotate an (X, Y, Z) geodetic coordinate system and align it with the image coordinate system.

$$x - x_0 = -c \frac{R_{11}(X - X_0) + R_{21}(Y - Y_0) + R_{31}(Z - Z_0)}{R_{13}(X - X_0) + R_{23}(Y - Y_0) + R_{33}(Z - Z_0)}$$

$$y - y_0 = -c \frac{R_{12}(X - X_0) + R_{22}(Y - Y_0) + R_{32}(Z - Z_0)}{R_{13}(X - X_0) + R_{23}(Y - Y_0) + R_{33}(Z - Z_0)}$$



The **collinearity equations** define the intersection between (1) the ray that joins the optical center of the camera and a certain point of interest in the scene and (2) the plane of the photo lying at a certain focal distance from the optical center of the camera.

int. Photo center

Focal length int.

Poi 2D coordinates

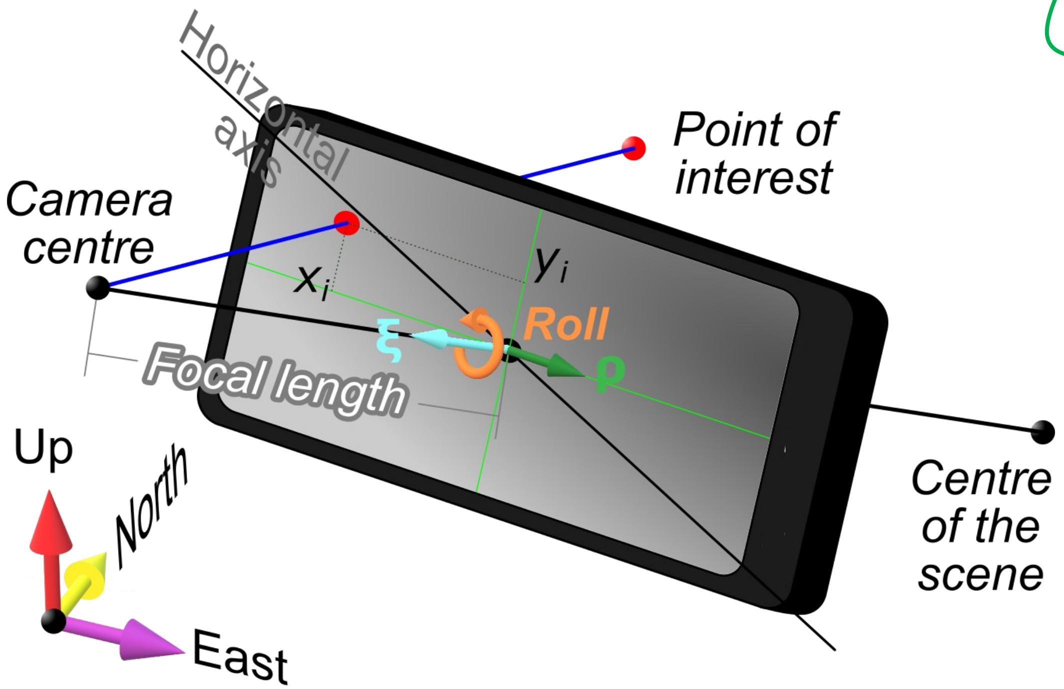
$$x - x_0 = -c\,\frac{R_{11}(X - X_0) + R_{21}(Y - Y_0) + R_{31}(Z - Z_0)}{R_{13}(X - X_0) + R_{23}(Y - Y_0) + R_{33}(Z - Z_0)}$$

$$y - y_0 = -c\,\frac{R_{12}(X - X_0) + R_{22}(Y - Y_0) + R_{32}(Z - Z_0)}{R_{13}(X - X_0) + R_{23}(Y - Y_0) + R_{33}(Z - Z_0)}$$

Rotation around X,Y,Z axes (ω, φ, κ) ext.

Space coordinates of POI

Space coordinates of camera position ext.



How can we solve the collinearity equations with unknown coordinates of POI (X, Y, Z)?

Photo center

Focal length

Poi 2D coordinates

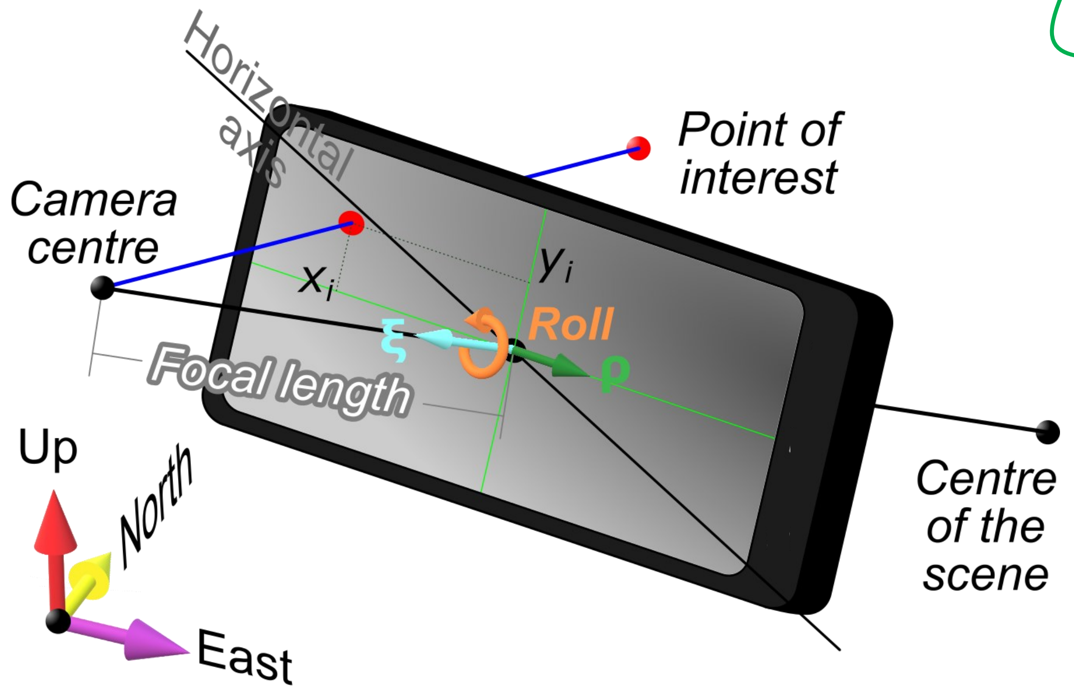
$$x - x_0 = -c\,\frac{R_{11}(X - X_0) + R_{21}(Y - Y_0) + R_{31}(Z - Z_0)}{R_{13}(X - X_0) + R_{23}(Y - Y_0) + R_{33}(Z - Z_0)}$$

$$y - y_0 = -c\,\frac{R_{12}(X - X_0) + R_{22}(Y - Y_0) + R_{32}(Z - Z_0)}{R_{13}(X - X_0) + R_{23}(Y - Y_0) + R_{33}(Z - Z_0)}$$

Rotation around X,Y,Z axes (ω, φ, κ)

Space coordinates of POI

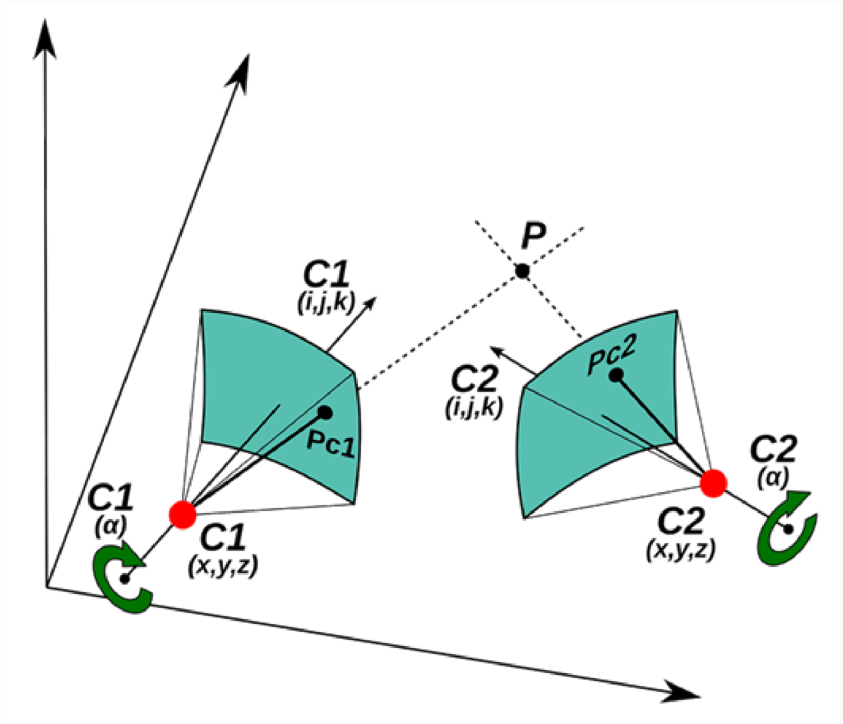
Space coordinates of camera position



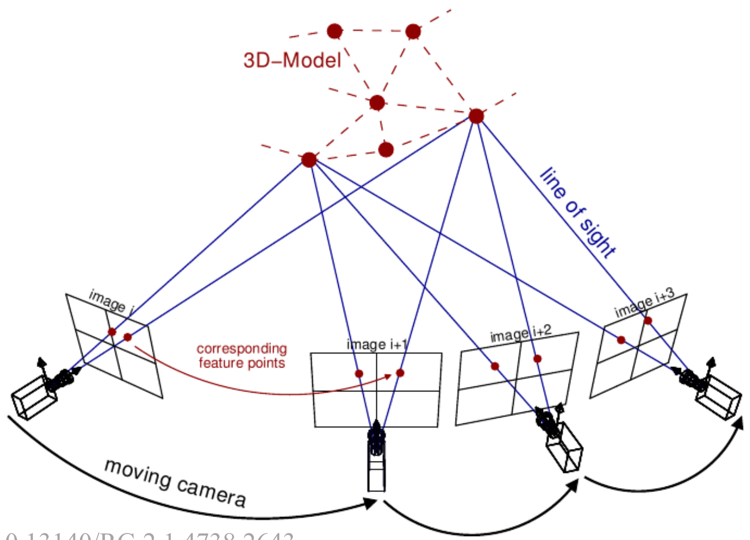
A system of two equations with 3 variables

$$x - x_0 = -c\,\frac{R_{11}(X - X_0) + R_{21}(Y - Y_0) + R_{31}(Z - Z_0)}{R_{13}(X - X_0) + R_{23}(Y - Y_0) + R_{33}(Z - Z_0)}$$

$$y - y_0 = -c\,\frac{R_{12}(X - X_0) + R_{22}(Y - Y_0) + R_{32}(Z - Z_0)}{R_{13}(X - X_0) + R_{23}(Y - Y_0) + R_{33}(Z - Z_0)}$$



Stereo photogrammetry is a sub-class of photogrammetry, which involves the **estimation of the 3D coordinates of points** using measurements made in two **overlapping photographs** taken from **different positions.**



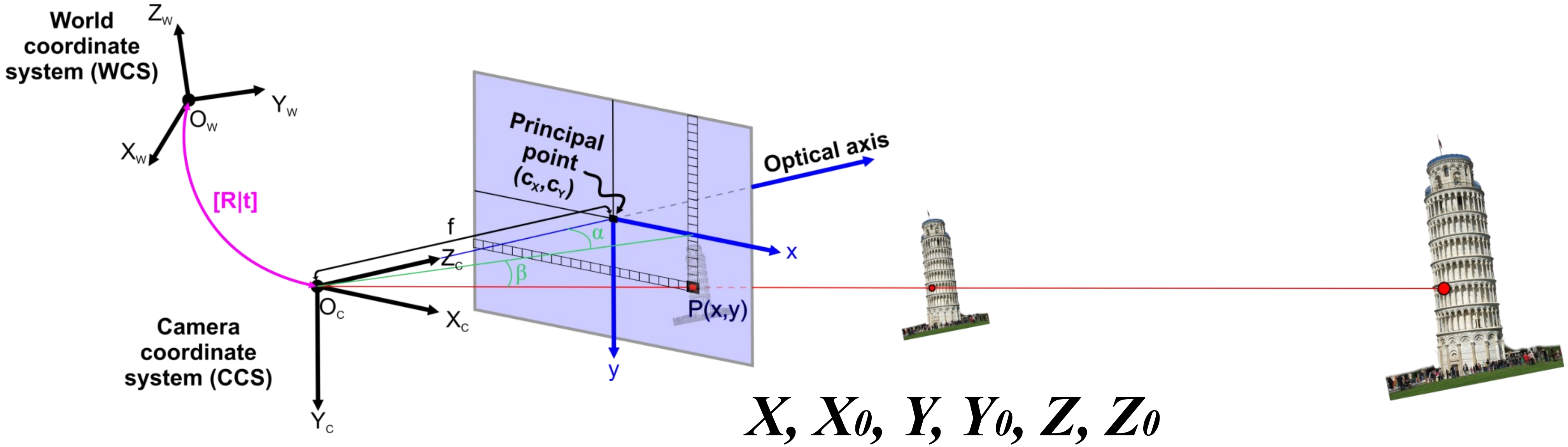
Source: doi:10.13140/RG.2.1.4738.2643

Structure from Motion – Multi View Stereo (SfM-MVS) photogrammetry is a **workflow** that utilizes multiple (overlapping) images of a landform/object taken from multiple viewpoints to reconstruct a 3D object or landform geometry.

In contrast to traditional photogrammetry, **scene geometry, camera positions, and orientation are retrieved** simultaneously by SfM-MVS and **without the requirement for camera intrinsic and extrinsic parameters** to be known first.

$$x - x_0 = -c\,\frac{R_{11}(X - X_0) + R_{21}(Y - Y_0) + R_{31}(Z - Z_0)}{R_{13}(X - X_0) + R_{23}(Y - Y_0) + R_{33}(Z - Z_0)}$$

$$y - y_0 = -c\,\frac{R_{12}(X - X_0) + R_{22}(Y - Y_0) + R_{32}(Z - Z_0)}{R_{13}(X - X_0) + R_{23}(Y - Y_0) + R_{33}(Z - Z_0)}$$

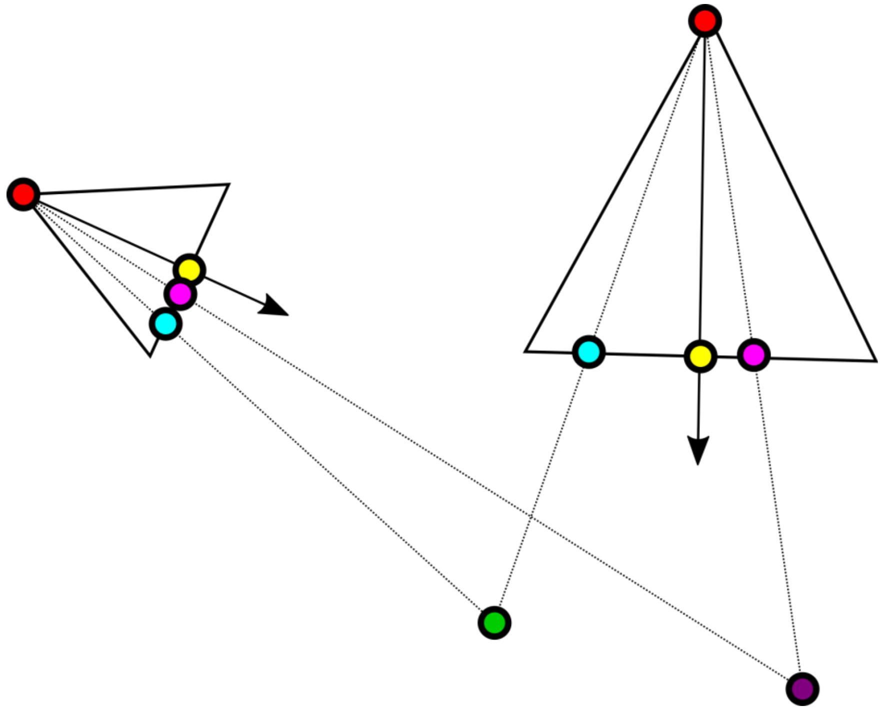


X, X_0, Y, Y_0, Z, Z_0

$2X, 2X_0, 2Y, 2Y_0, 2Z, 2Z_0$

$$\begin{bmatrix} X_{rw} \\ Y_{rw} \\ Z_{rw} \end{bmatrix} = C \begin{bmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{bmatrix} * \begin{bmatrix} X_{dw} \\ Y_{dw} \\ Z_{dw} \end{bmatrix} + \begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix}$$

Similarity transformation



Georeferencing and scaling of the model require a **minimum** of **three ground control points (GCPs)** with XYZ coordinates for a **seven-parameter linear similarity transformation**, which comprises **three global translation parameters**, **three rotation parameters**, and **one scaling parameter**.

Alternatively, **"direct" georeferencing and scaling** can be performed from known camera positions.

$$\begin{bmatrix} X_{rw} \\ Y_{rw} \\ Z_{rw} \end{bmatrix} = C \begin{bmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{bmatrix} * \begin{bmatrix} X_{dw} \\ Y_{dw} \\ Z_{dw} \end{bmatrix} + \begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix}$$

Surveying techniques and instruments

A **Total Station** is an integrated electronic instrument combining the capability of electromagnetic distance measuring instrument and electronic theodolite to collimate points of measurements. It is also equipped with a microprocessor and storage.

Collimation refers to the adjustment of the line of sight with the axis of the telescope.

Pro

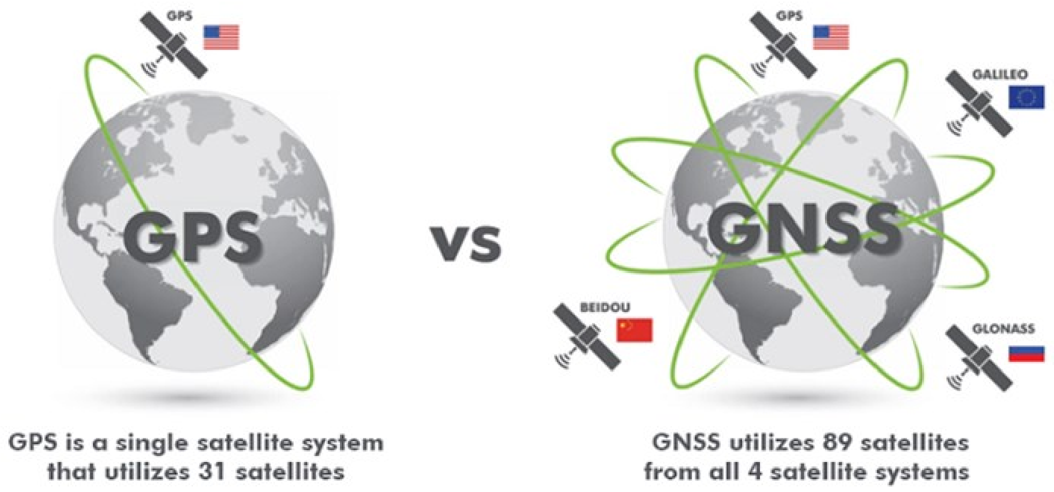
- High precision (2-3" and 1-2 mm with prisms)
- Long measurement range (> 600 m)

Cons

- Accessibility
- Instrument weight
- Time
- Need of a surveyor's assistant to use prisms.

Surveying techniques and instruments

GPS vs GNSS (even if they are often used as synonyms, they are not the same thing!)



The **GPS** refers to the US's NAVSTAR **G**lobal **P**ositioning **S**ystem, a constellation of satellites developed by the United States. Operational since 1978 and globally available since 1994 (with a constellation of 24 satellites).

GNSS stands for **G**lobal **N**avigation **S**atellite **S**ystem and it is an umbrella term that encompasses all global satellite positioning systems used for Position Navigation and Time (PNT) solutions on a global basis.

Surveying techniques and instruments

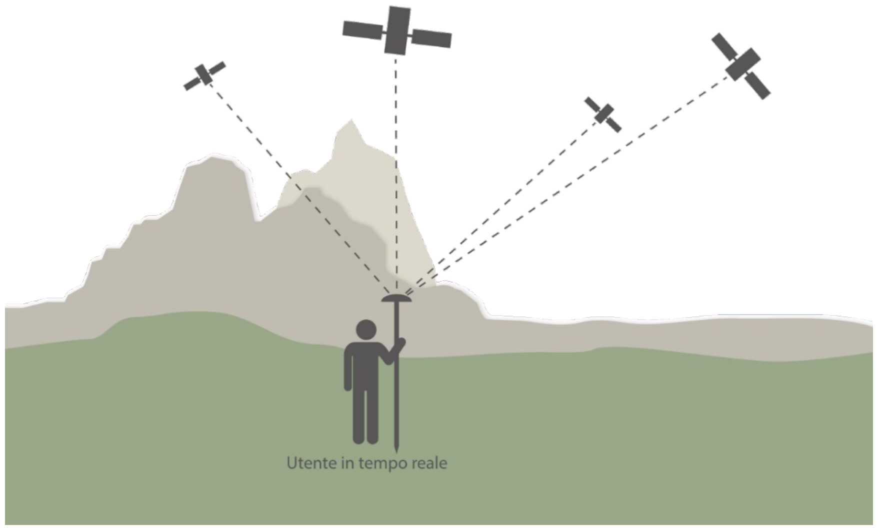
GNSS positioning system

speed of light (300.000 km/s)

$$D = v \times \Delta t$$

Distance satellite-receiver

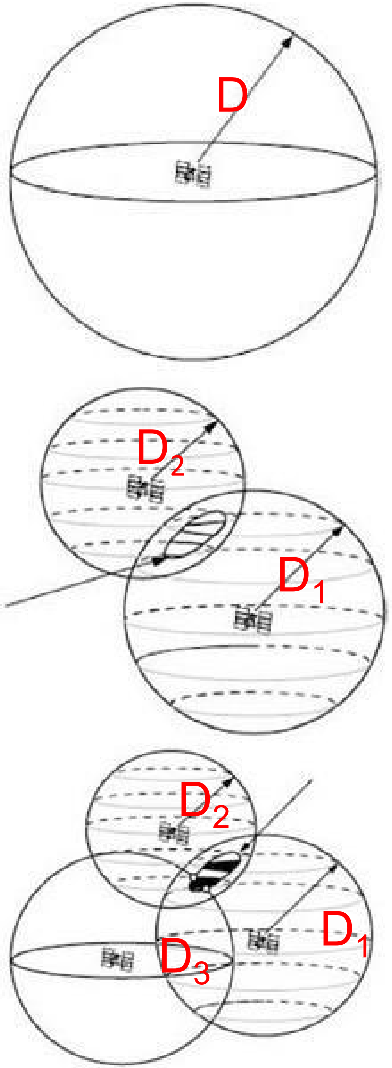
time spent by the signal emitted from the satellite to reach the receiver



At least 4 satellites are needed to determine the location of the receiver

<u>What is needed:</u>
1 GNSS receiver

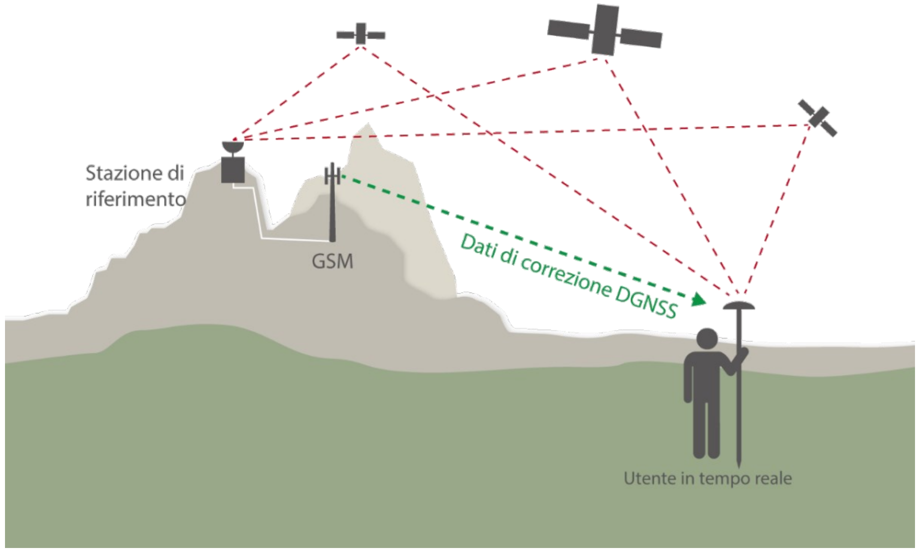
<u>Accuracy:</u>
~2 m in optimal conditions



https://www.swisstopo.admin.ch/it/conoscenze-fatti/misurazione-geodesia/sistemi-di-misurazione/misurazione-satellitare/misurazione-gps.html

Surveying techniques and instruments

GNSS, Differential GNSS and RTK-GNSS



GNSS system precision can be dramatically improved using GNSS correction data.

One way involves monitoring GNSS signals from a **base station** at a known location. Deviations from the base station's position (and here the term **differential**) are observed and sent to a **rover** allowing it to obtain more accurate position readings.

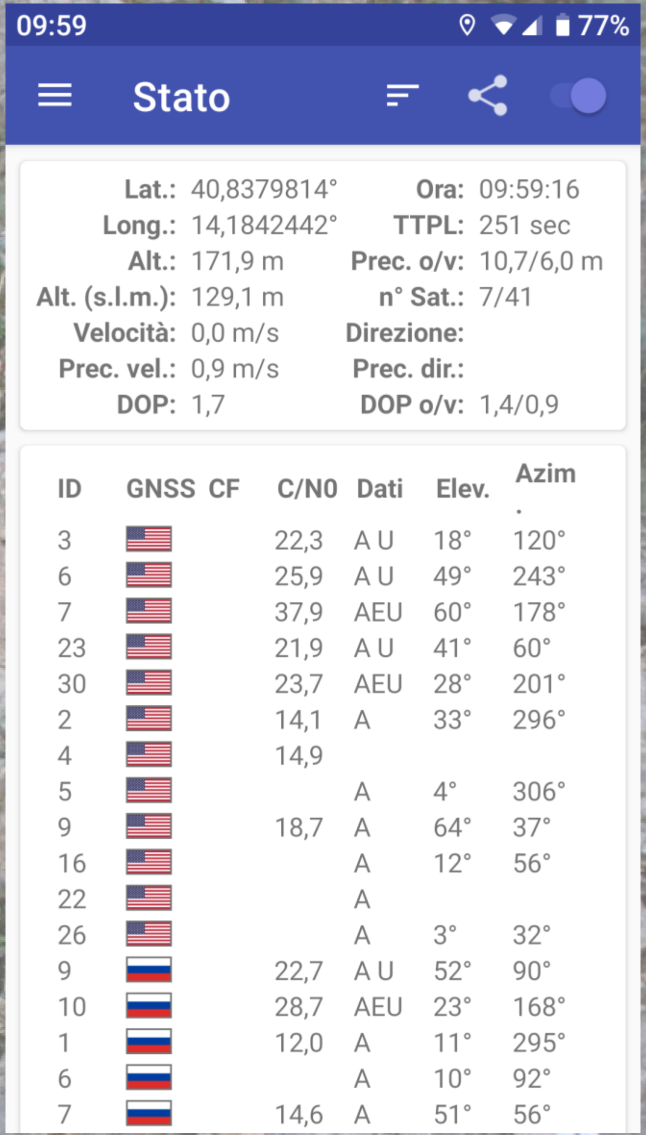
In favorable conditions, this approach can be used to achieve centimeter-level accuracy, provided that the base station and the rover are not too far apart.

Real **T**ime **K**inematics (**RTK**) is a differential GNSS technique that provides high-performance positioning in the vicinity of a base station through a communication channel with which the base broadcasts information to the users in real-time.

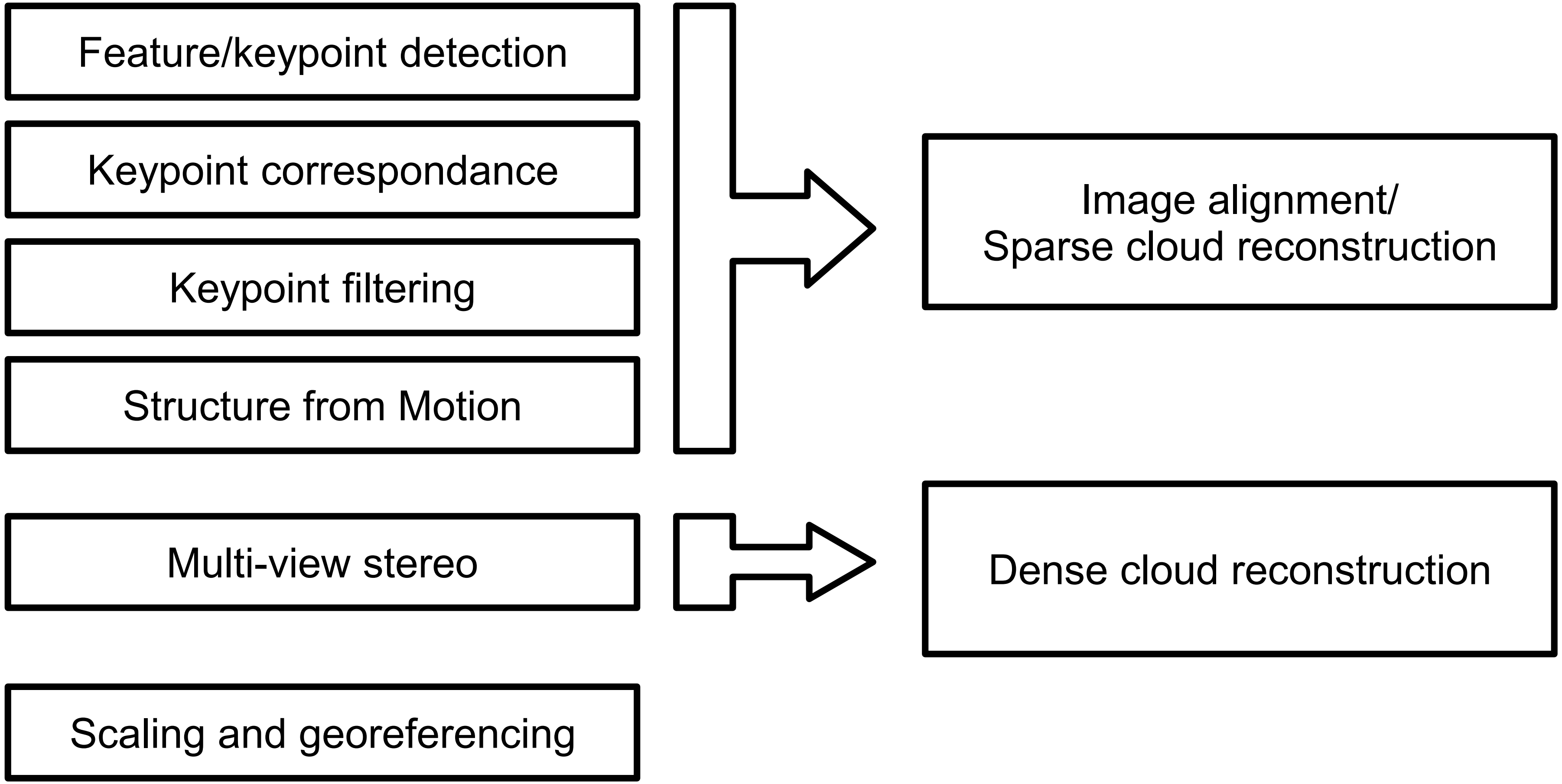
What is needed:
2 GNSS receivers

Accuracy:
D-GNSS: 1-10 cm
RTK-GNSS: ~ 1cm

$$\begin{bmatrix} X_{rw} \\ Y_{rw} \\ Z_{rw} \end{bmatrix} = C \begin{bmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{bmatrix} * \begin{bmatrix} X_{dw} \\ Y_{dw} \\ Z_{dw} \end{bmatrix} + \begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix}$$



Structure from Motion – Multi View Stereo photogrammetry (SfM-MVS)



Structure from Motion – Multi View Stereo photogrammetry (SfM-MVS)

Feature/keypoint detection

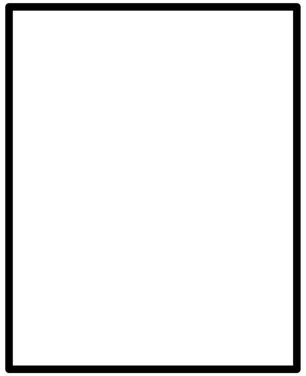
The first step of image matching involves the **detection of feature points** that are distinctive groups of pixels that are, to some extent, **invariant to changing camera viewpoints** on several different photographs.

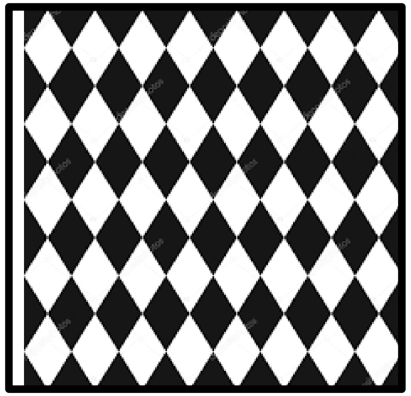
It is these **keypoints** that allow the different images to be matched and the scene geometry reconstructed.

The fundamental question driving the development of algorithms is **how to best extract** **descriptions** of local points in a way that allows the correct identification of correspondences between keypoints (often from a large dataset), but that is **insensitive to changes in orientation, scale, illumination, or 3D position**.

Structure from Motion – Multi View Stereo photogrammetry (SfM-MVS)

Feature/keypoint detection

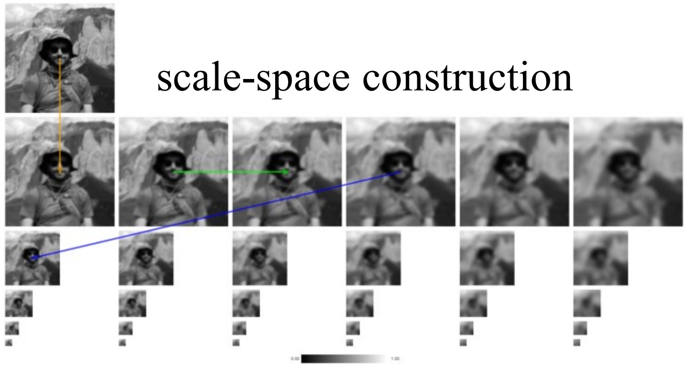




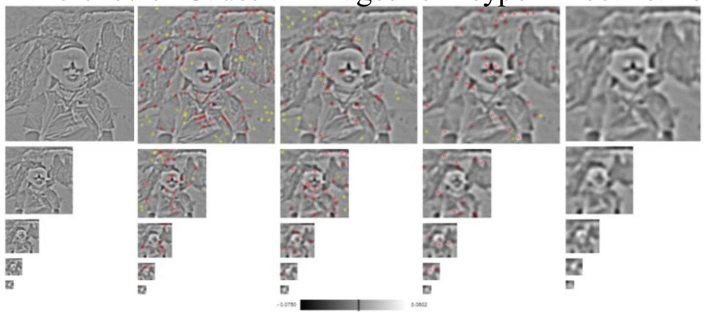
Structure from Motion – Multi View Stereo photogrammetry (SfM-MVS)

Feature/keypoint detection

scale-space construction



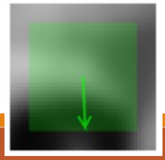
Difference of Gaussian images for keypoint localisation

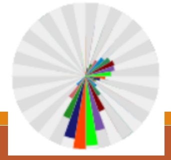


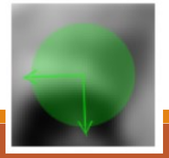
Scale Invariant Feature Transform (SIFT), Lowe (2004)

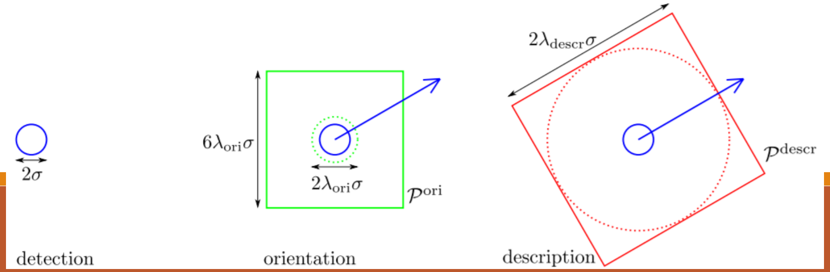
A **Gaussian scale-space representation** is a family of increasingly **blurred images simulating invariance to image scaling** and small changes in perspective. These are used to **compute scale-space local extrema of the Laplacian representation** (using the technique of the difference of Gaussian images). **Local extrema** are then detected by comparing each sample point with its eight neighbors in the current image and in the 18 neighbors in the scales above and below. **The density of keypoints identified in an image depends on the texture, sharpness, and resolution of the image**.

SIFT then samples for each one of these maxima a square image patch whose origin is the maximum and x-direction is the dominant gradient at the origin. For each keypoint, a description of these patches is associated.





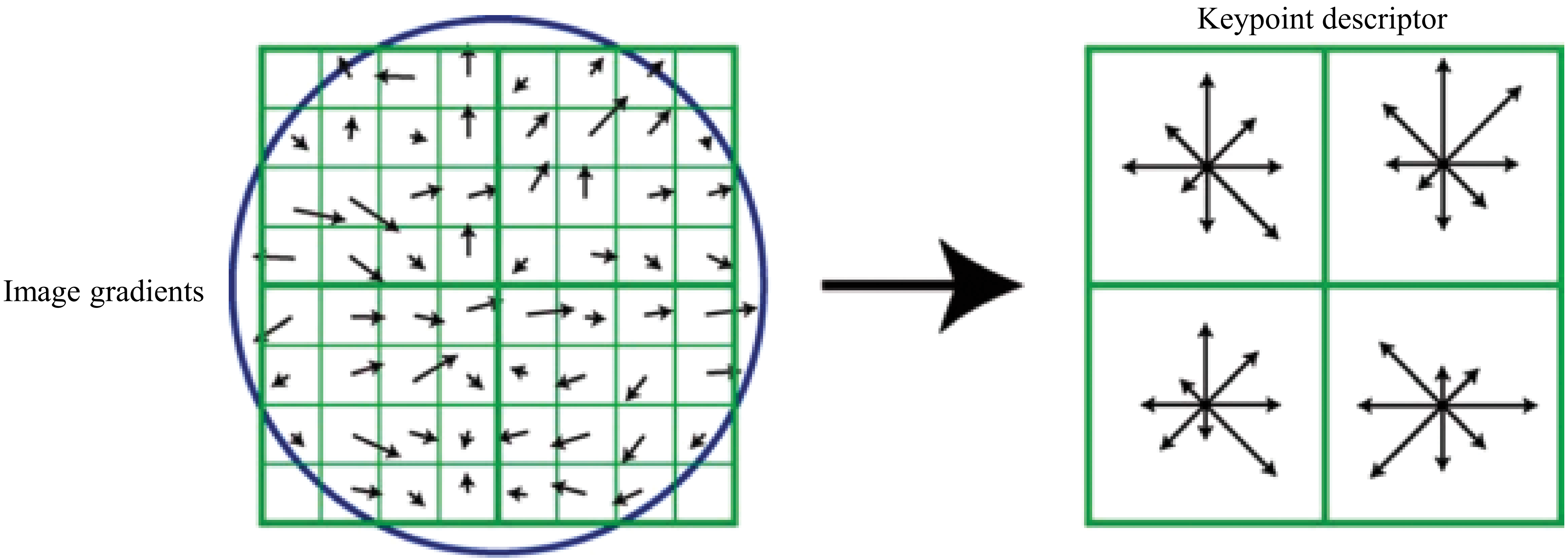




Ives Rey-Otero, Mauricio Delbracio, Anatomy of the SIFT Method, Image Processing On Line, 4 (2014), pp. 370–396.

Structure from Motion – Multi View Stereo photogrammetry (SfM-MVS)

Feature/keypoint detection



The descriptor information is relative to the keypoint and thus invariant against translations.
Computation relative to a reference orientation is supposed to make the descriptors robust against rotation.
Normalization of the histograms makes the descriptors invariant against global illumination changes.

Structure from Motion – Multi View Stereo photogrammetry (SfM-MVS)

Keypoint Correspondance

Once keypoints have been located in each image, **correspondences between keypoints in different images need to be determined**.

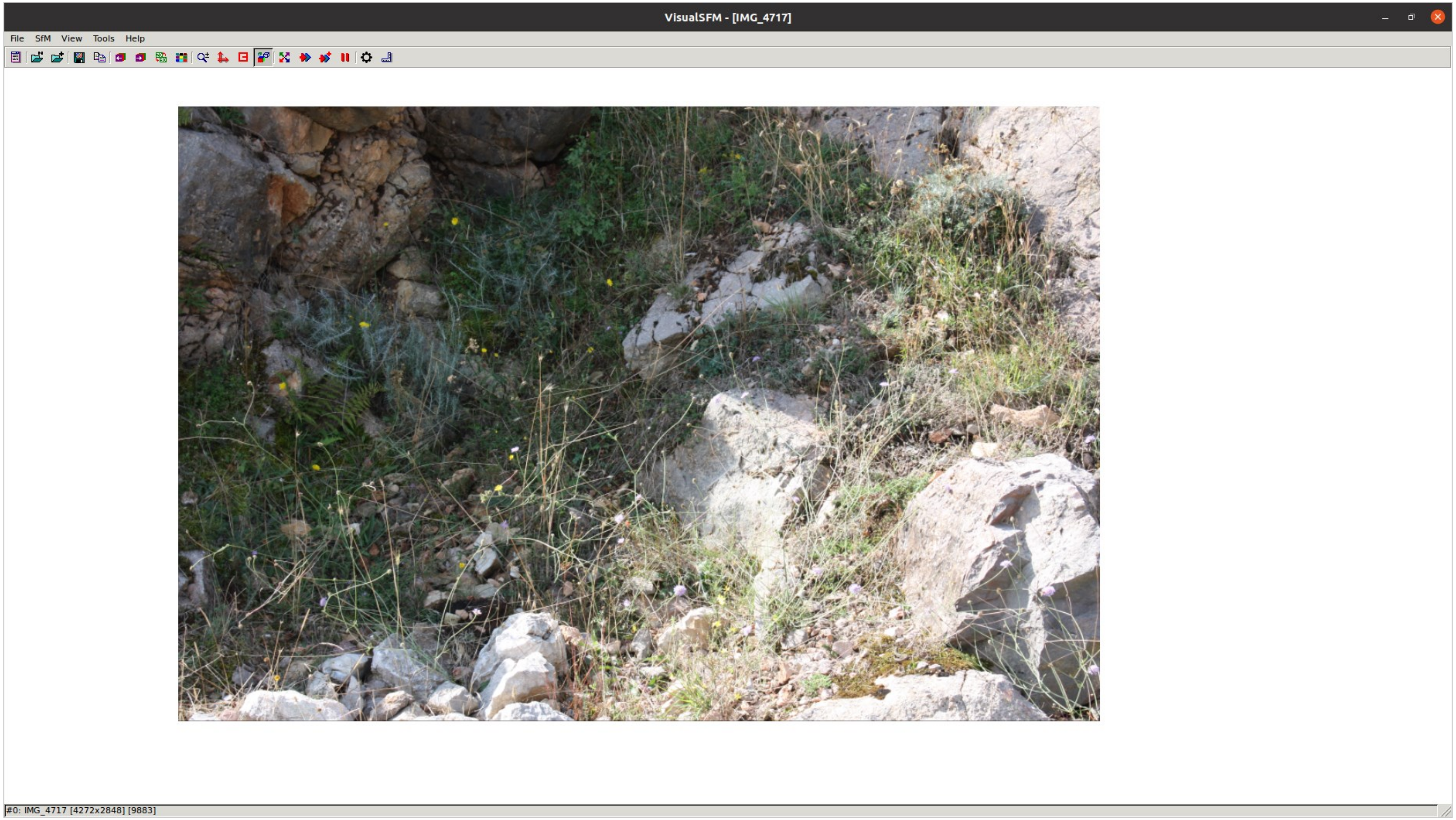
Yet, there is no guarantee that any given keypoint will have a partner in another image. Therefore, methods for discarding points with no good match are required.

Structure from Motion – Multi View Stereo photogrammetry (SfM-MVS)

Keypoint Filtering

To be confident that only correct correspondences remain, a further step is applied to filter out any remaining erroneous matches.

With the keypoints limited to those with geometrically consistent matches, the links between every image pair can be identified and organized.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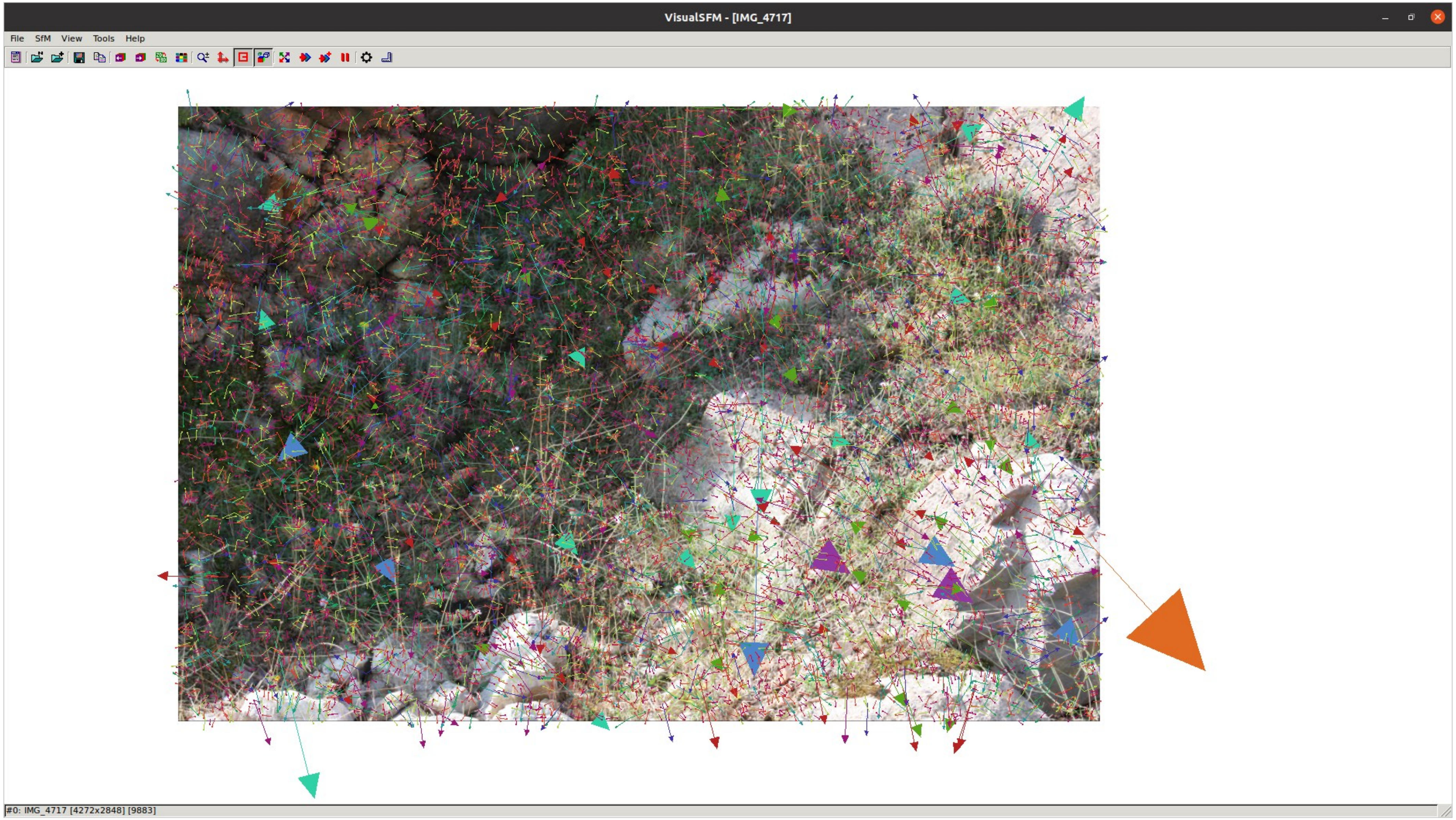
File SfM View Tools Help
#0: IMG_4717 [4272x2848] [9883]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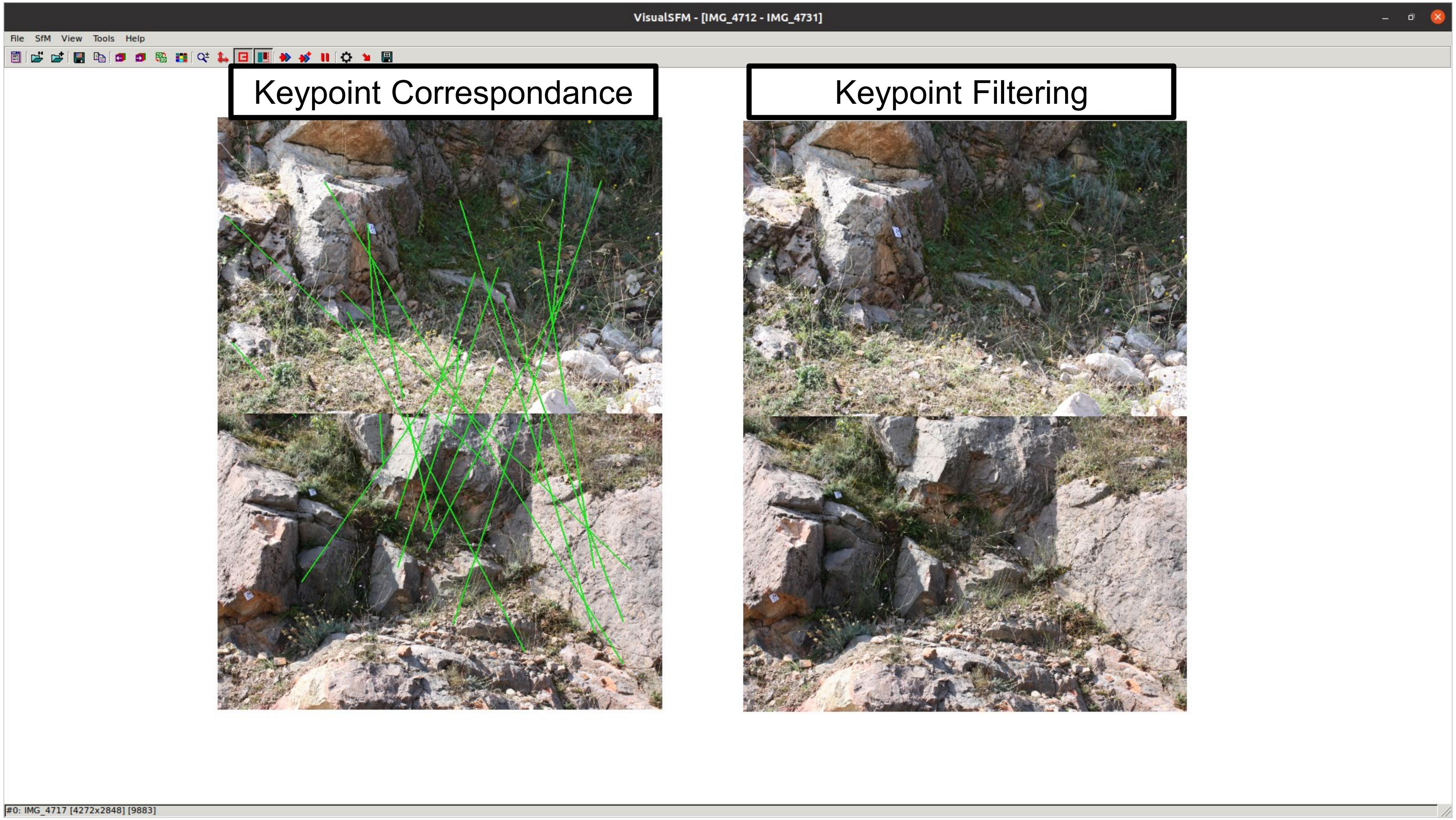
VisualSFM - [IMG_4712 - IMG_4731]
File SfM View Tools Help
Keypoint Correspondance
Keypoint Filtering
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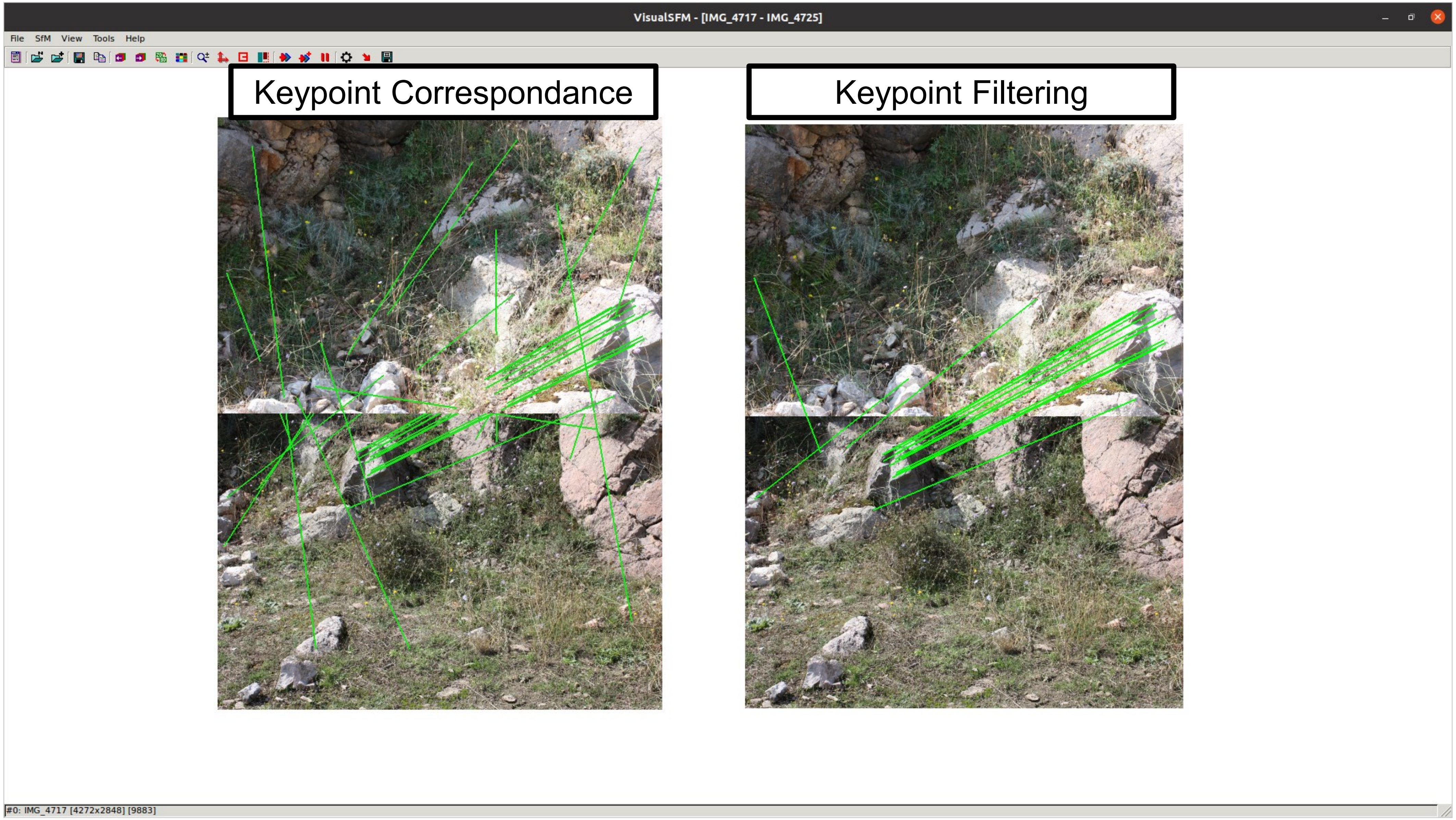
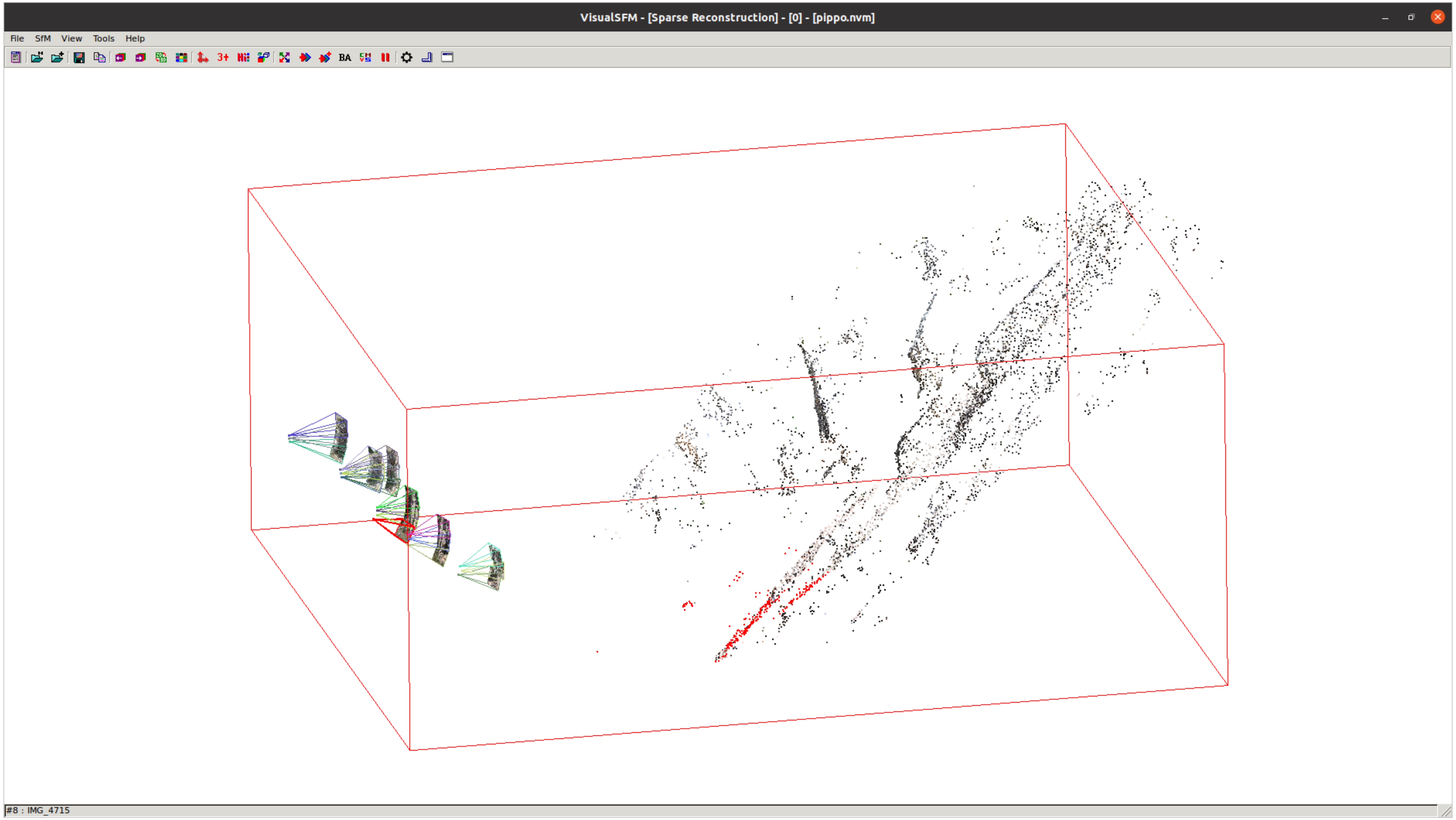

VisualSFM - [IMG_4717 - IMG_4725]
File SfM View Tools Help
Keypoint Correspondance
Keypoint Filtering
#0: IMG_4717 [4272x2848] [9883]

Structure from Motion – Multi View Stereo photogrammetry (SfM-MVS)

Structure from Motion

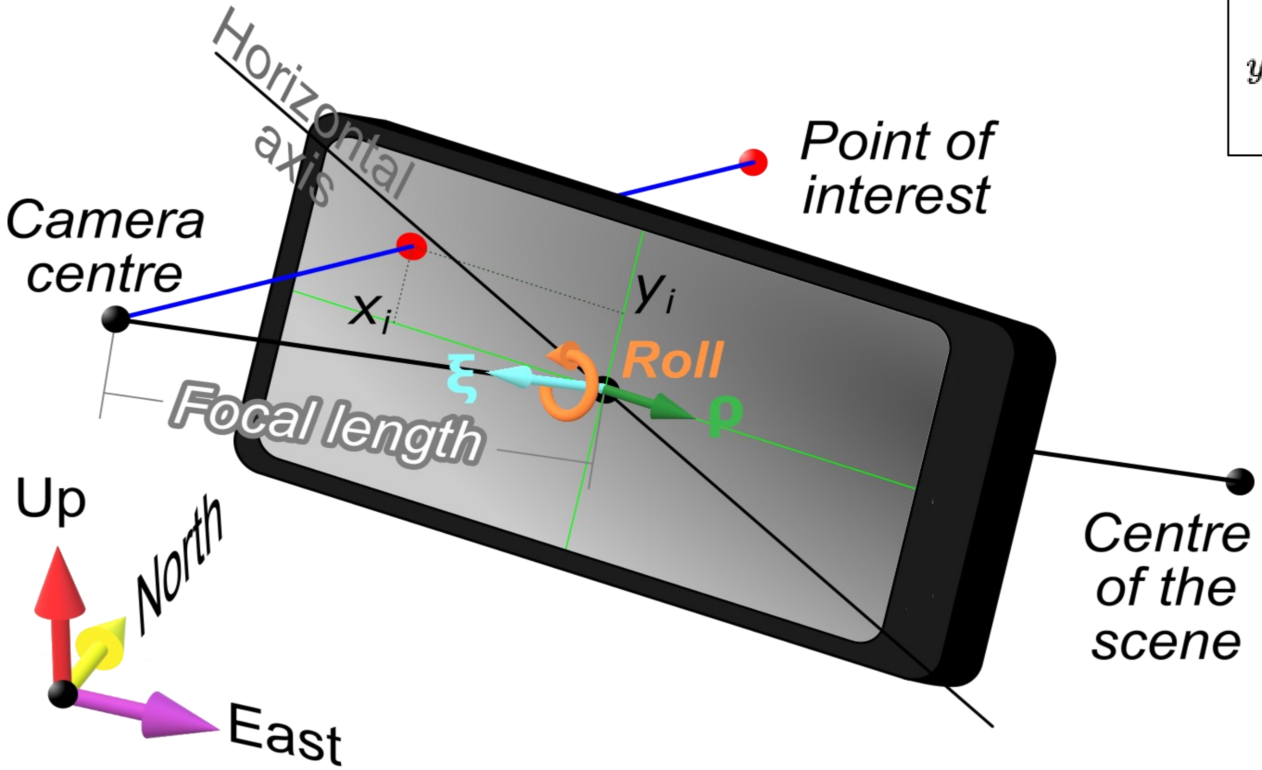
Structure-from-motion is the problem of recovering the 3D structure of the scene and the camera motion from a set of images. **Bundle adjustment** is a particular optimization algorithm used to solve it.

When the cameras' intrinsic parameters and camera extrinsic parameters (i. e. camera poses) are known, you can actually compute the point cloud from the matching points using multi-view triangulation without bundle adjustment. You need to do non-linear optimization when your estimate of the camera poses is uncertain, and the bundle adjustment is the standard algorithm used for that.


VisualSFM - [Sparse Reconstruction] - [0] - [pippo.nvm]
File SfM View Tools Help
#8 : IMG_4715

Structure from Motion – Multi View Stereo photogrammetry (SfM-MVS)

The doming effect

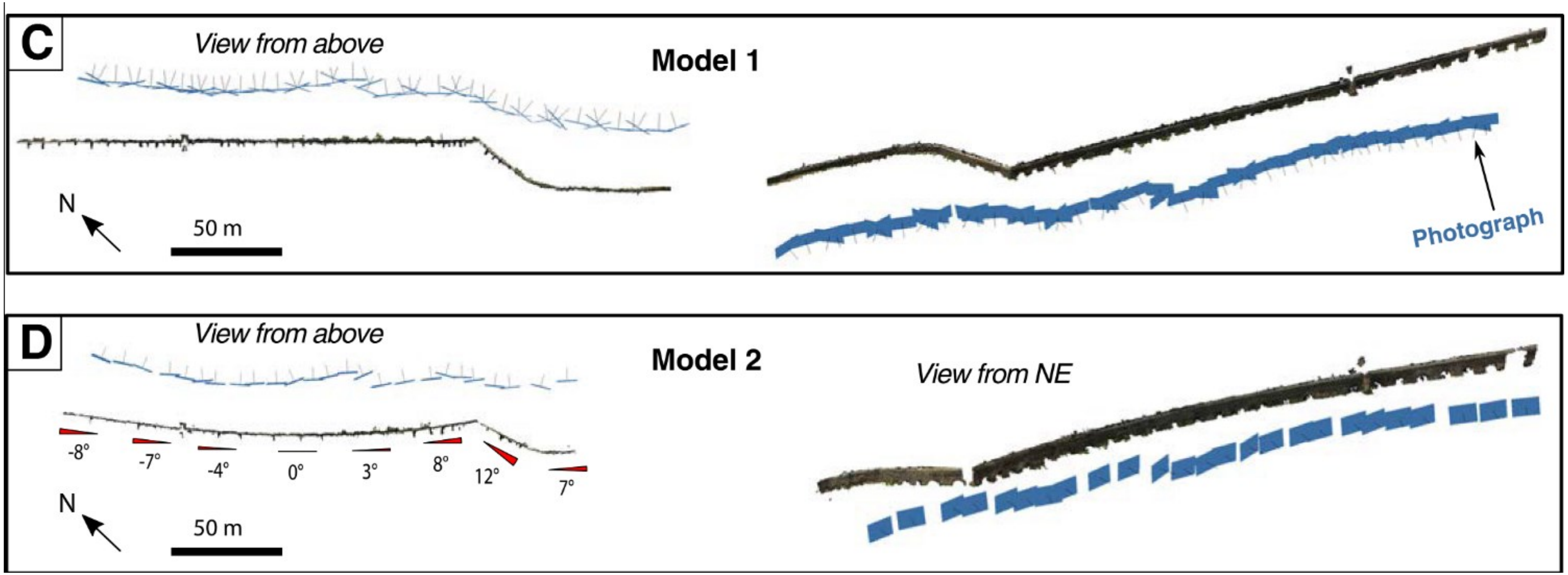


$$x - x_0 = -c\frac{R_{11}(X - X_0) + R_{21}(Y - Y_0) + R_{31}(Z - Z_0)}{R_{13}(X - X_0) + R_{23}(Y - Y_0) + R_{33}(Z - Z_0)}$$

$$y - y_0 = -c\frac{R_{12}(X - X_0) + R_{22}(Y - Y_0) + R_{32}(Z - Z_0)}{R_{13}(X - X_0) + R_{23}(Y - Y_0) + R_{33}(Z - Z_0)}$$

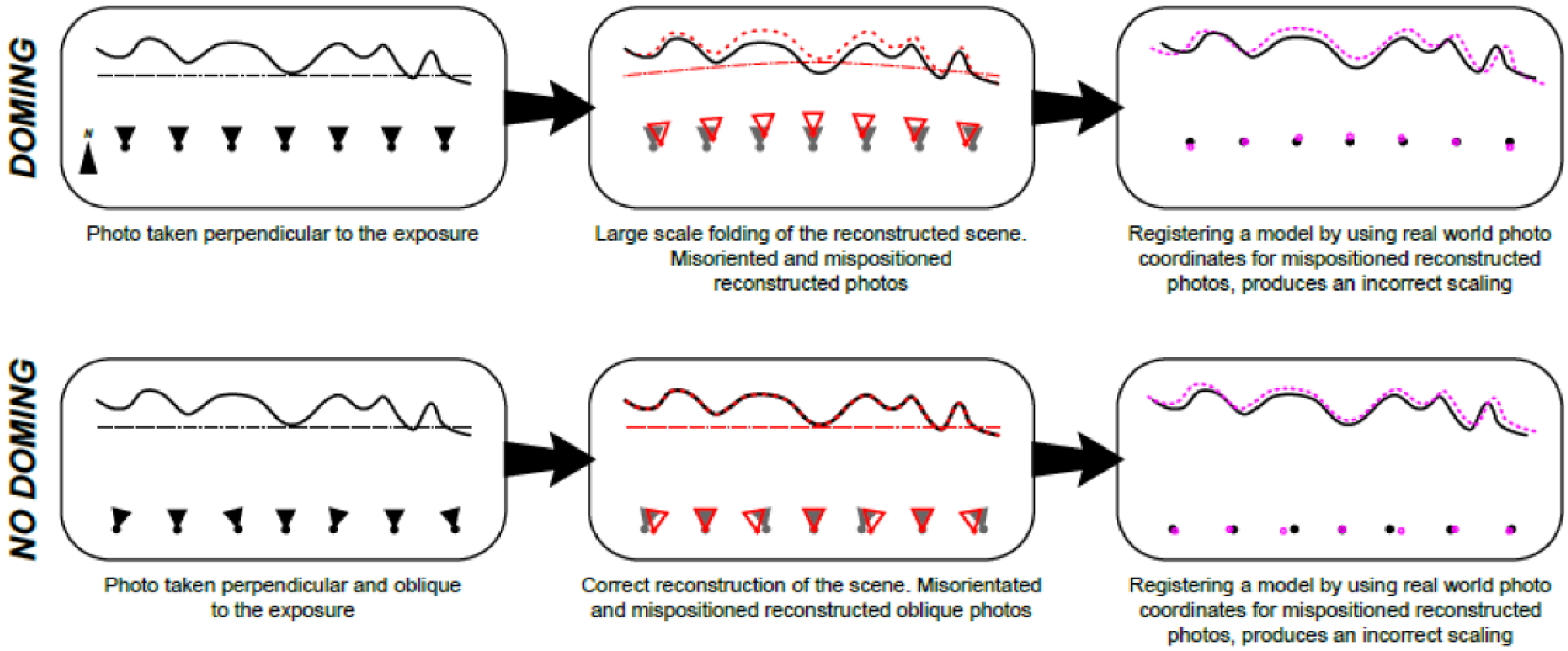
Structure from Motion – Multi View Stereo photogrammetry (SfM-MVS)

The doming effect



Structure from Motion – Multi View Stereo photogrammetry (SfM-MVS)

The doming effect



Structure from Motion – Multi View Stereo photogrammetry (SfM-MVS)

Multi View Stereo

A sparse point cloud generated by SfM is often only an intermediary step in the production of much more dense point clouds using MVS. **The goal of MVS is to provide a complete 3D scene reconstruction** from a collection of images of known camera intrinsic and extrinsic parameters. Compared with a sparse point cloud generated by SfM, a dense point cloud generated by MVS shows an **increase in the point density of at least two orders of magnitude**.

Structure from Motion – Multi View Stereo photogrammetry (SfM-MVS)

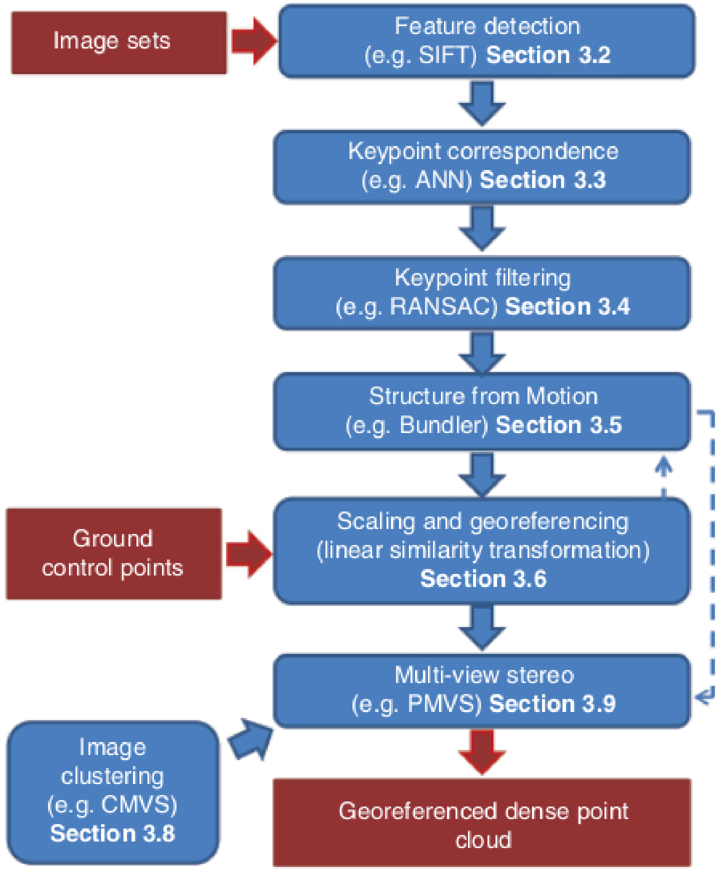
Multi View Stereo

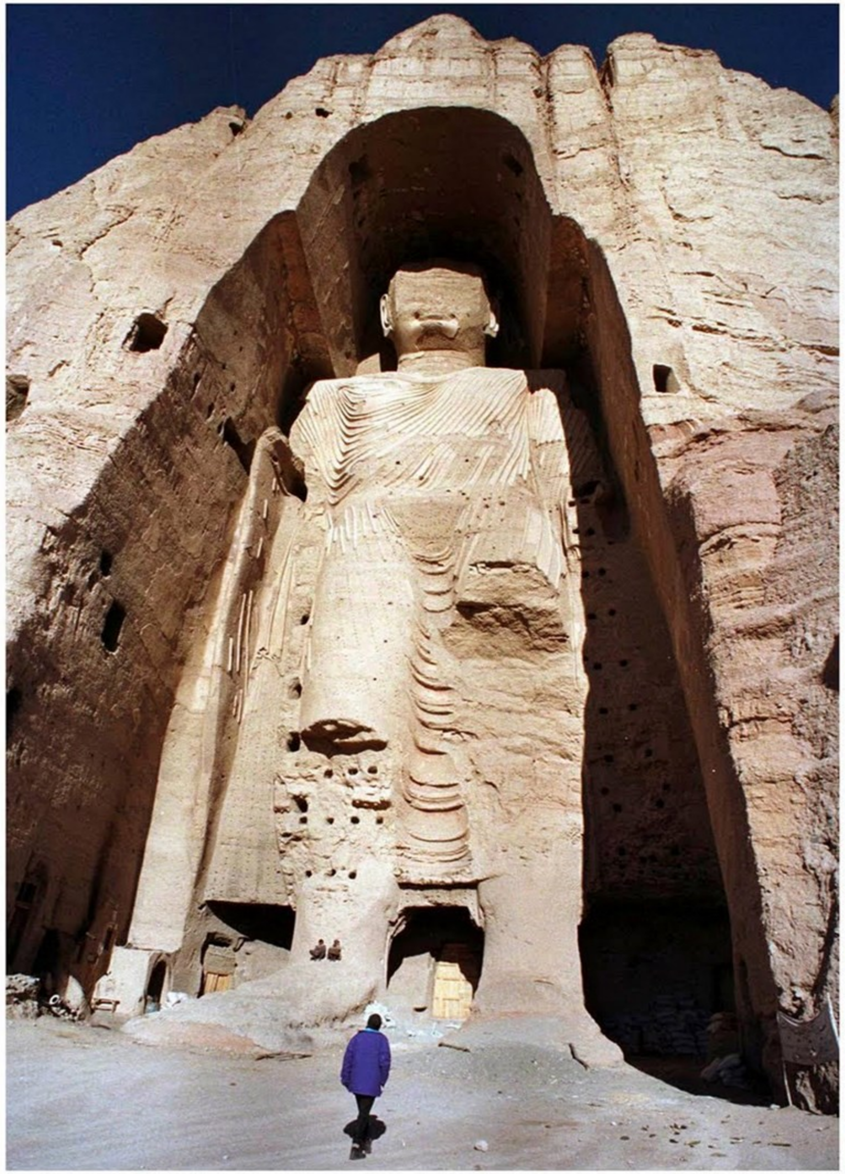
Before MVS techniques are applied to the point cloud there is an additional, optional step that may be required in projects with large image sets.

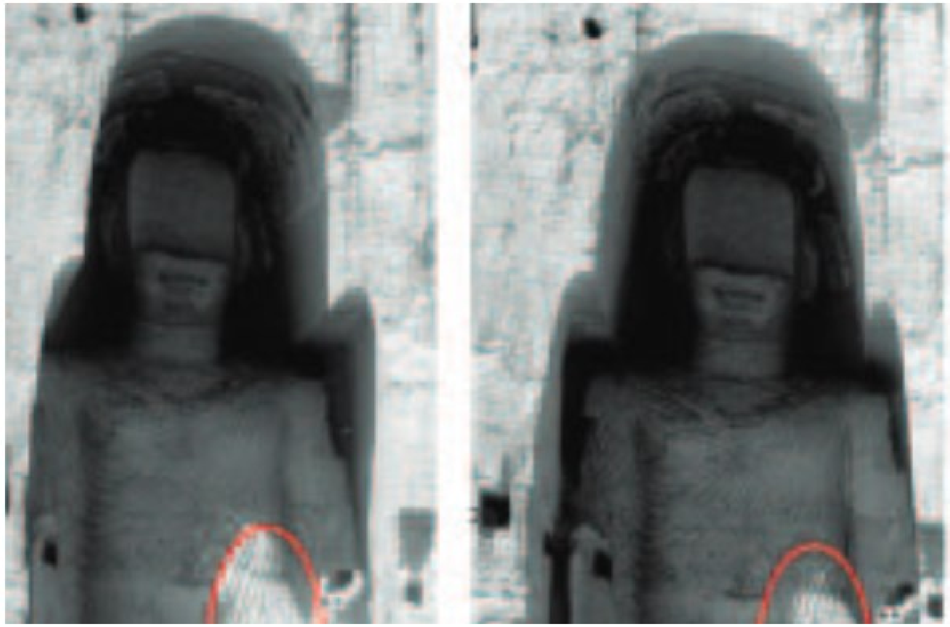
Some MVS algorithms solve a **depth map** for each image in turn (using nearby images) and then merge the separate reconstructions. This permits parallelization but at the expense of noisy and highly redundant depth maps that require further post-processing to clean and merge.

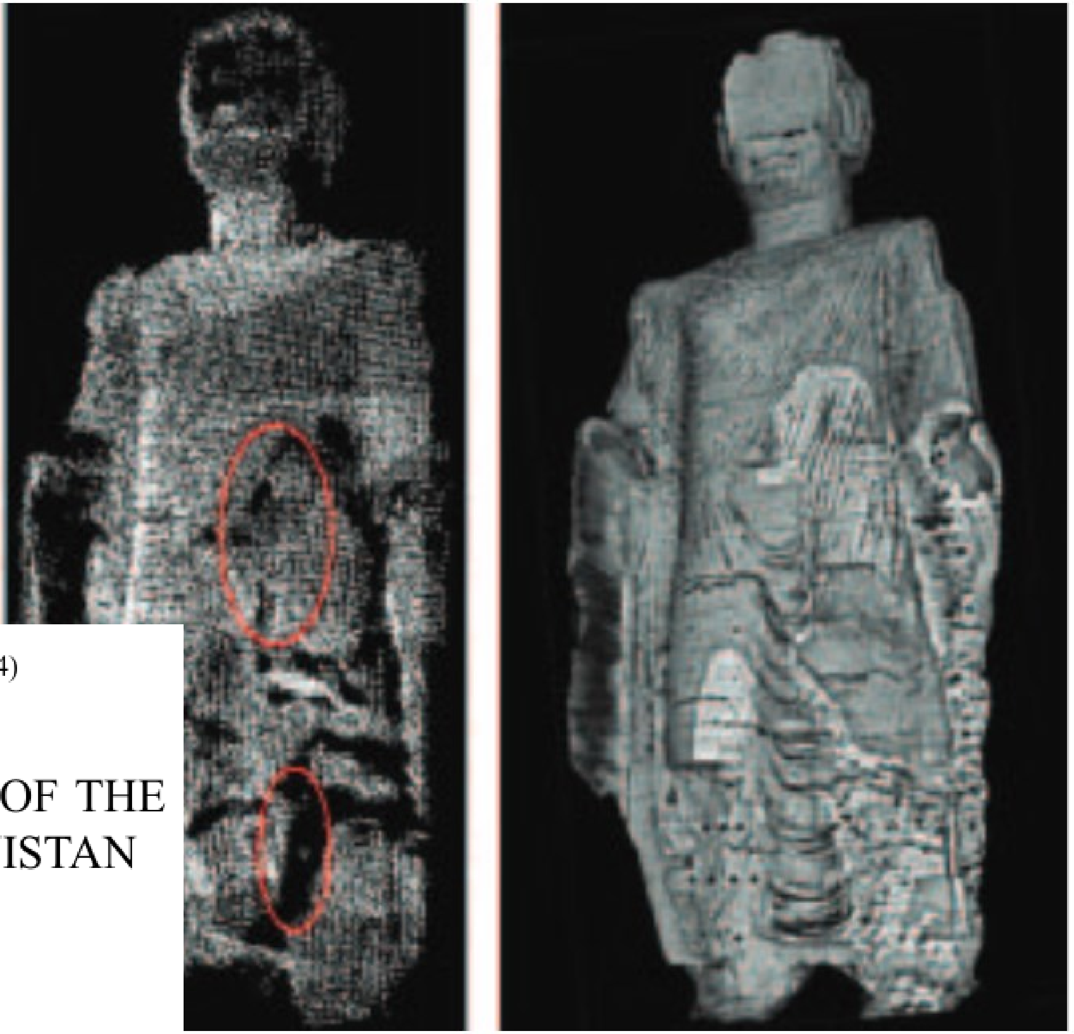
In contrast, many of the **best-performing MVS algorithms reconstruct scene geometry globally using all images simultaneously**. When the number of images increases, **the computational burden of such an approach increases rapidly** and issues of scalability emerge.
RAM requirements increase with the number of images used in the reconstruction and place a practical limit on the number of images that can be matched simultaneously.

Photogrammetry: the science of making measurements from photographs







The Photogrammetric Record 19(107): 177–199 (September 2004)

PHOTOGRAMMETRIC RECONSTRUCTION OF THE GREAT BUDDHA OF BAMIYAN, AFGHANISTAN

Armin Grün (agruen@geod.baug.ethz.ch)

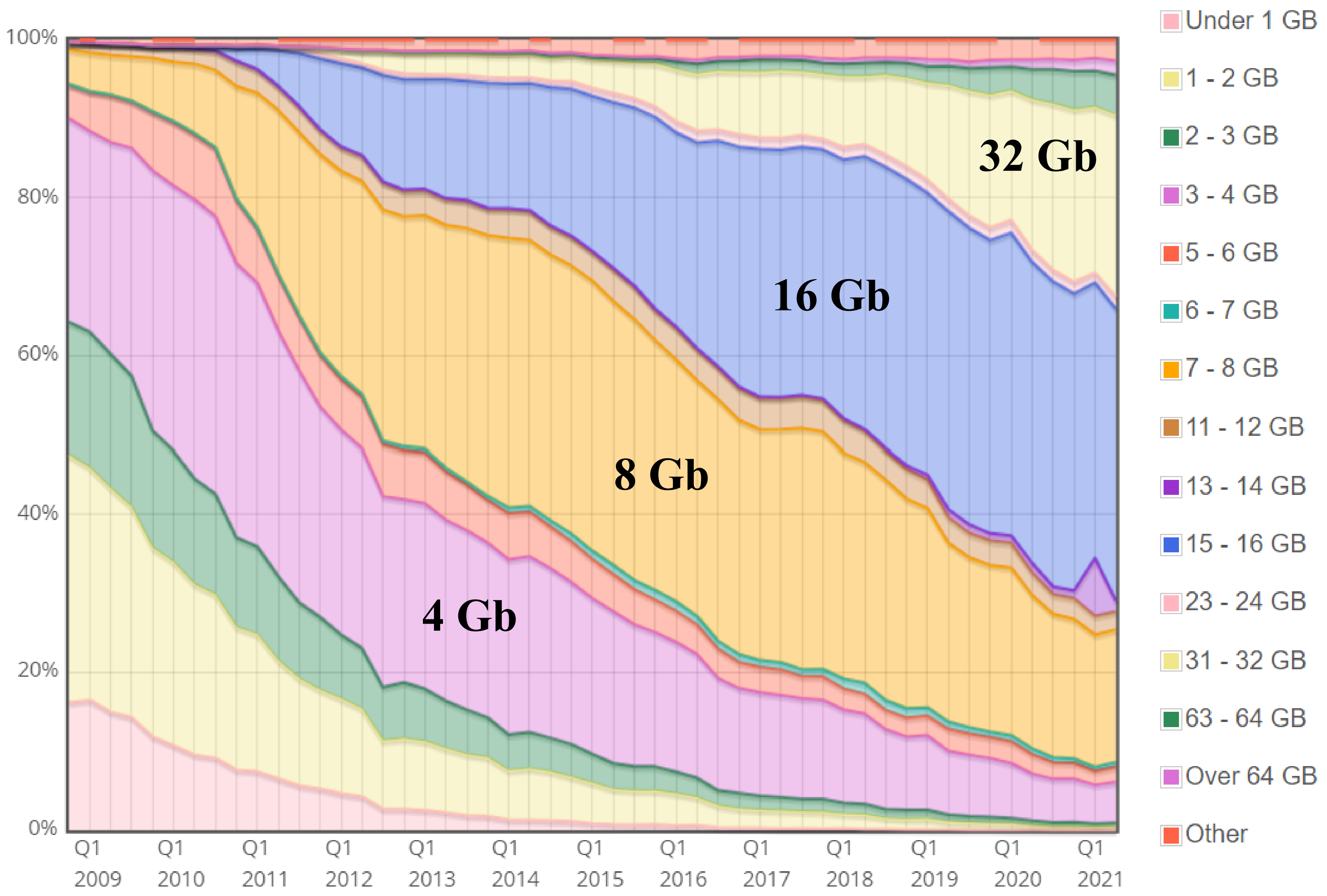
Fabio Remondino (fabio@geod.baug.ethz.ch)

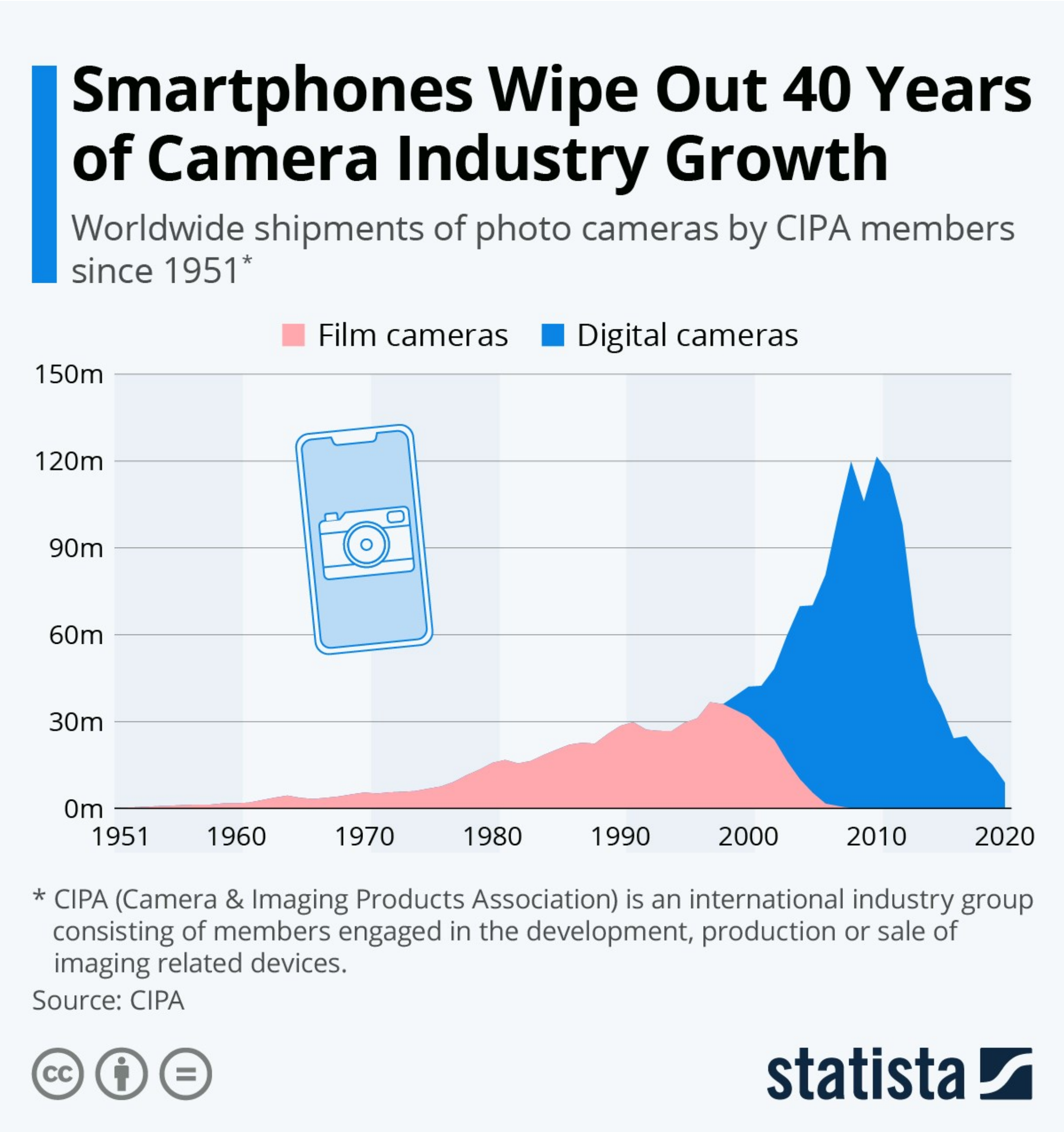
Li Zhang (zhangl@geod.baug.ethz.ch)

Swiss Federal Institute of Technology (ETH), Zurich

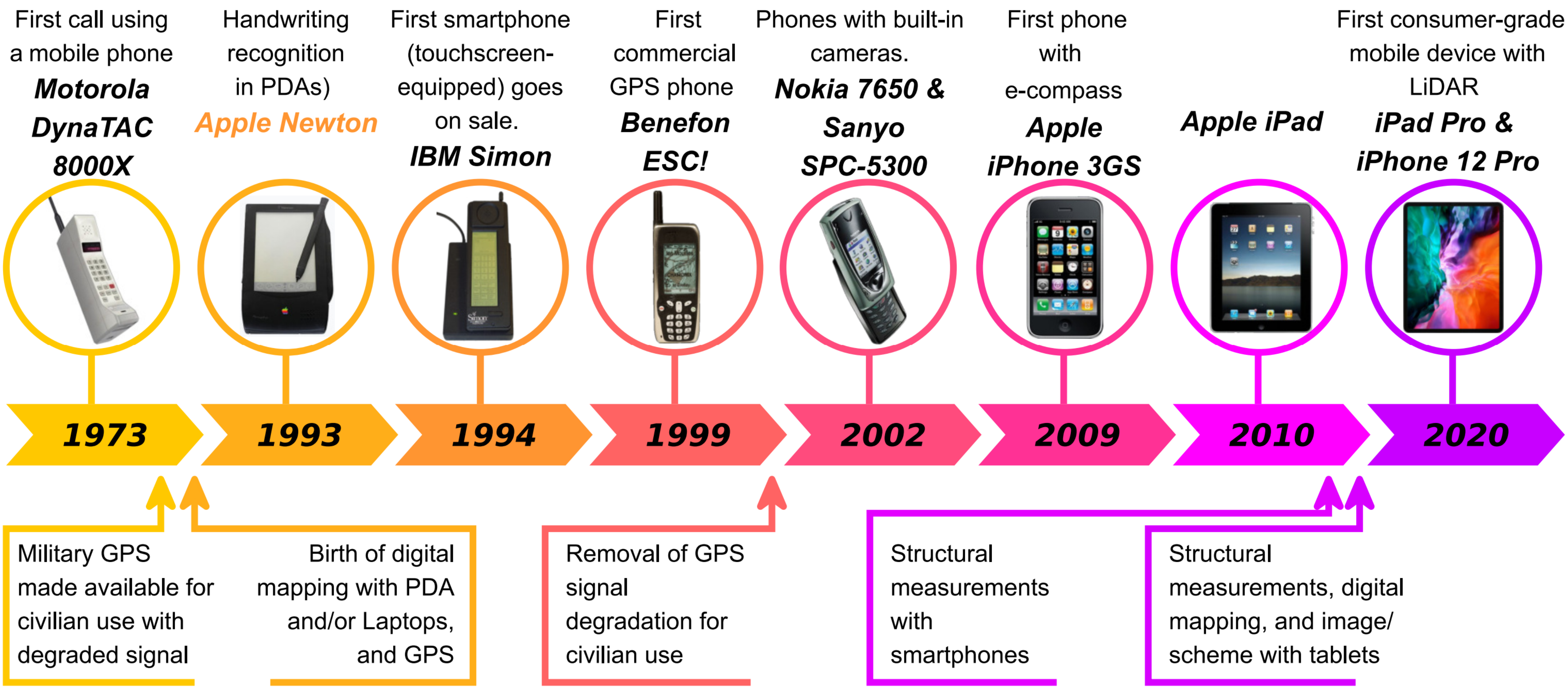
The IBM Model 350 disk file with a storage space of 5MB from 1956 and a Micro SD Card

Amount of RAM Installed in PCs. https://www.memorybenchmark.net/

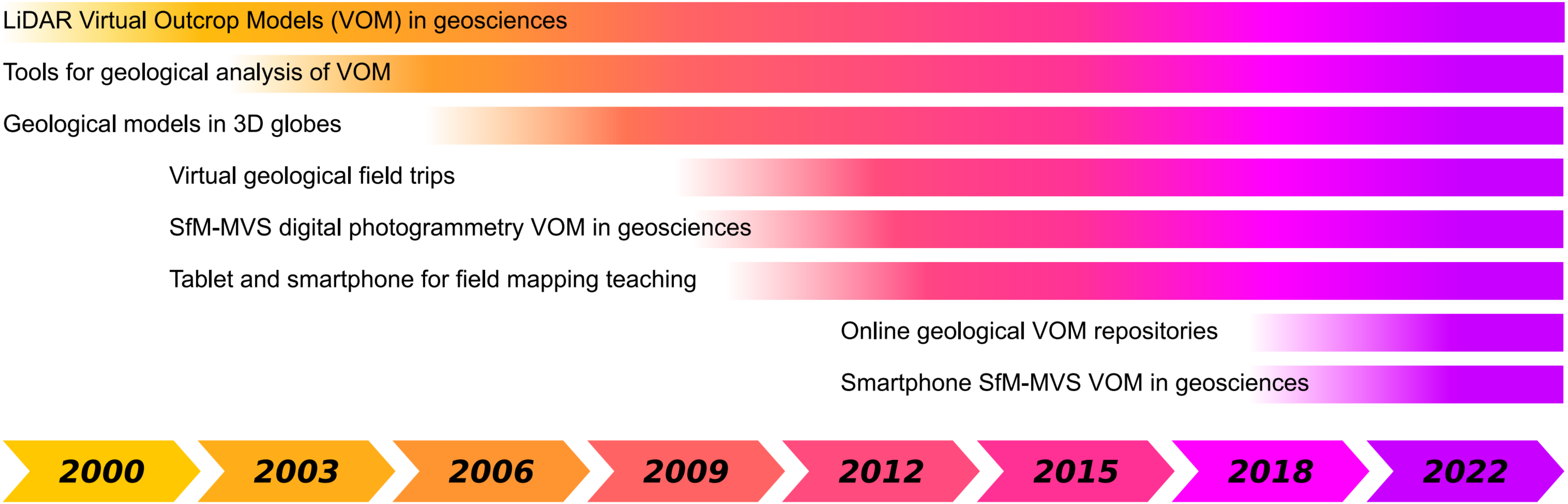




Source: https://www.statista.com/



Earth-Science Reviews. Tavani et al. 2022



Earth-Science Reviews. Tavani et al. 2022

3D Photogrammetric software

Name	Type	OS	Price
COLMAP	Aerial, Close-Range	Windows, macOS, Linux	Free
Meshroom	Aerial, Close-Range	Windows, Linux	Free
MicMac	Aerial, Close-Range	Windows, macOS, Linux	Free
Multi-View Environment	Aerial, Close-Range	Windows, macOS	Free
OpenMVG	Aerial, Close-Range	Linux, Windows, MacOS	Free
Regard3D	Aerial, Close-Range	Windows, macOS, Linux	Free
VisualSFM	Aerial, Close-Range	Windows, macOS, Linux	Free
3DF Zephyr	Aerial, Close-Range	Windows	From $300/month
Autodesk ReCap	Aerial, Close-Range	Windows	$340/year
Agisoft Metashape	Aerial, Close-Range	Windows, macOS, Linux	From $179
Bentley ContextCapture	Aerial, Close-Range	Windows	On request
Correlator3D	Aerial	Windows	From $295/month
DroneDeploy	Aerial	Windows, macOS, Android, iOS	From $99/month
Elcovision 10	Aerial, Close-Range	Windows	On request
iWitnessPro	Aerial, Close-Range	Windows	On request
IMAGINE Photogrammetry	Aerial	Windows	On request
Photomodeler	Aerial, Close-Range	Windows	From $59/month
Pix4Dmapper	Aerial	Windows, macOS, Android, iOS	From $160/month
RealityCapture	Aerial, Close-Range	Windows	$10 for 3500 PPI credits, or $3,750 for unlimited access
SOCET GXP	Aerial	Windows	On request
Trimble Inpho	Aerial, Close-Range	Windows	On request
WebODM	Aerial	Windows, macOS	$57

Source: https://all3dp.com/1/best-photogrammetry-software/