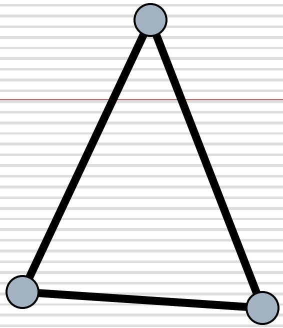
Grafica 3D per i beni culturali: 3D scanning

Lezione 6: 15-16 Marzo 2012

Digital Models...



... of *real* objects.

You have seen lots of them.
Digital representation of the surface of an object trough the use of a triangular mesh

We will discuss models that
Faithfully represent objects
that exist in reality, generated
using 3D scanning

What is 3D scanning ?

3D scanning

3D scanning is not a technology, but a family of technologies (and a quite large one)

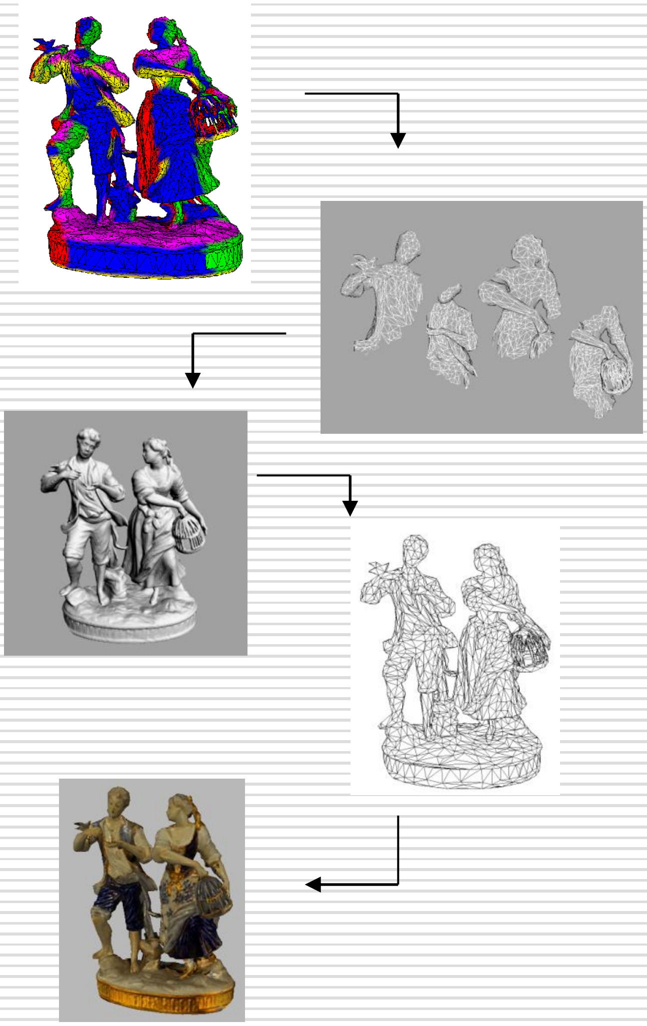
In all its incarnation, it is a form of **automatic measurement of geometric properties** of objects.

The produced digital model is formed by geometric information that have been measured and have a **metric** quality.
It may be imprecise and incomplete, but still has all the characteristics of a measurement result

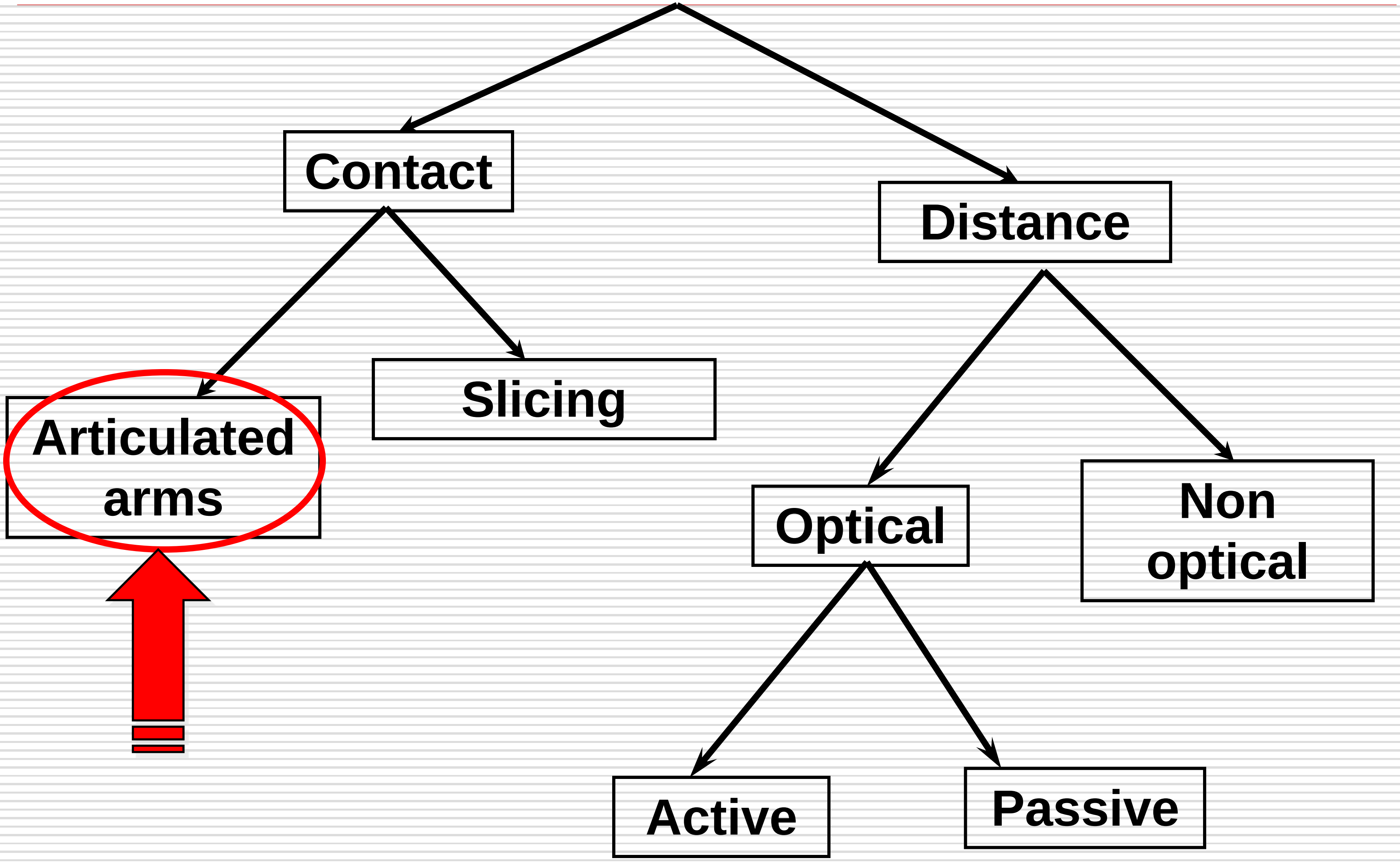
Measurement

3D Scanning Pipeline

- *[**Acquisition planning**]*
- **Acquisition** of multiple range maps
- Range map **filtering**
- **Registration** of range maps
- **Merging** of range maps
- Mesh **Editing**
- Interactive **visualization**
- **Capturing/Integration** of **appearance** (color acquisition, registration, mapping on surface, color visualization)
- Archival and data conversion



3D scanning: a taxonomy



Articulated arm

The probing point has a known position in every moment, thanks to the angle sensor at joints

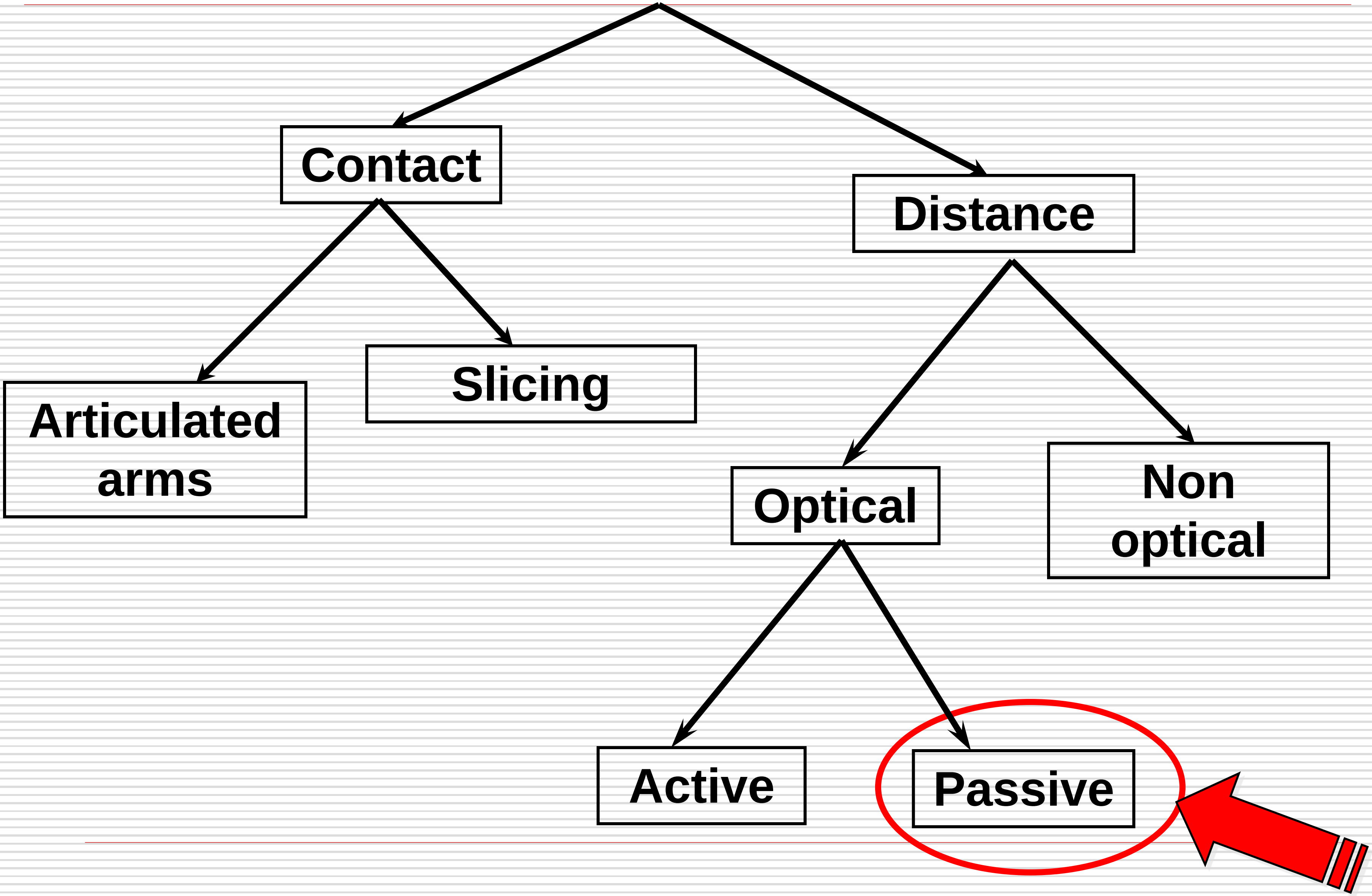
Object is “probed” in various points, generating a grid that wll use as a guide for modeling

Very “manual” method, still with lot of artistic influence

Industrial sensors:

The arm is autonomous and touches the surface using a predefined, regular, grid. Precisions in the order of microns

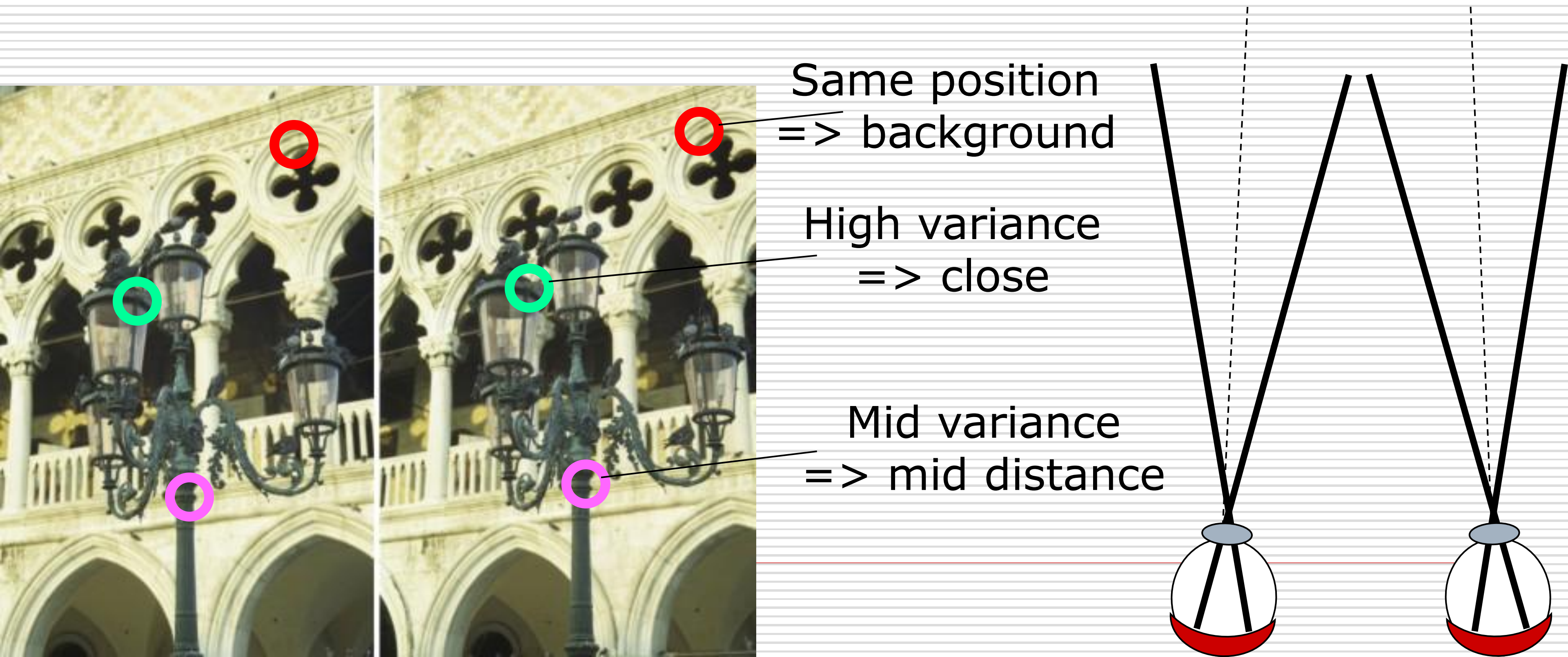
3D scanning: a taxonomy



Shape from Stereo

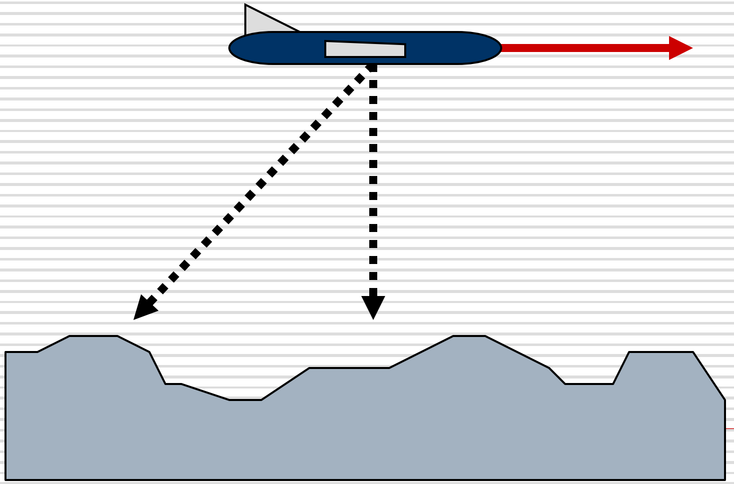
Based on the same principle of human stereo vision: two sensors that perceive the world from slightly different position. From parallax it is possible to obtain a depth for each visible point

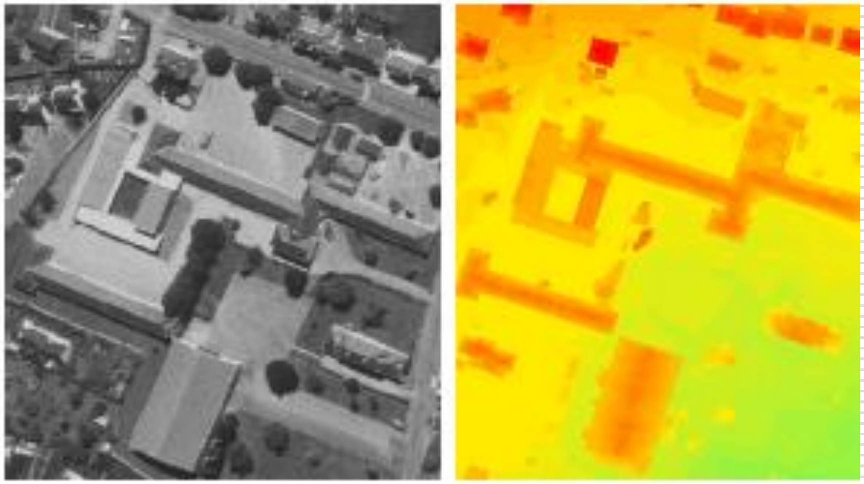
Our brain does this in automatic… A machine can be programmed to do the same



Aerial / Satellite

Same principle, features are isolated and matched to generate a depth map
Disparity comes from different view directions and/or the movement of the plane.
Same strategy is used also from satellites





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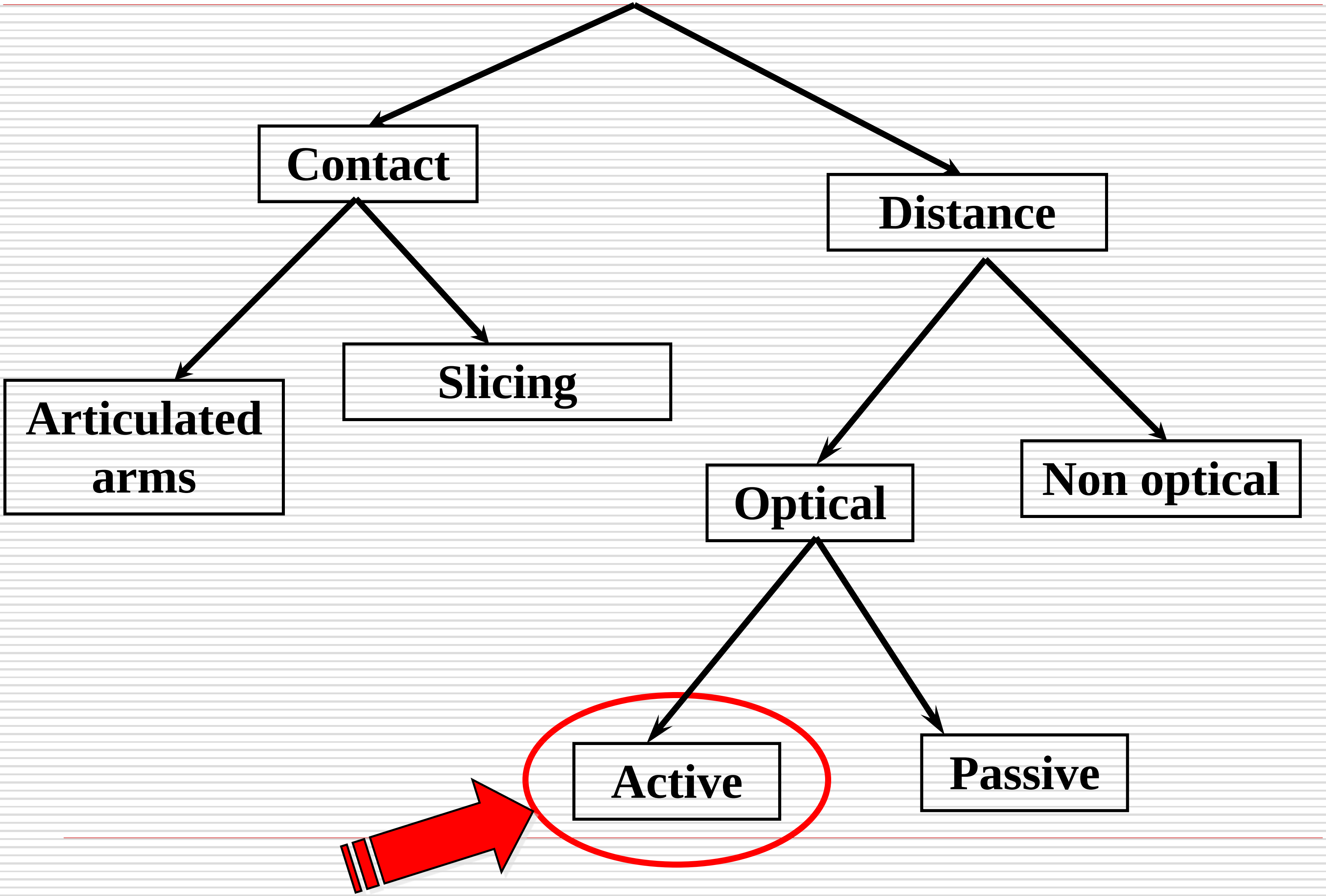
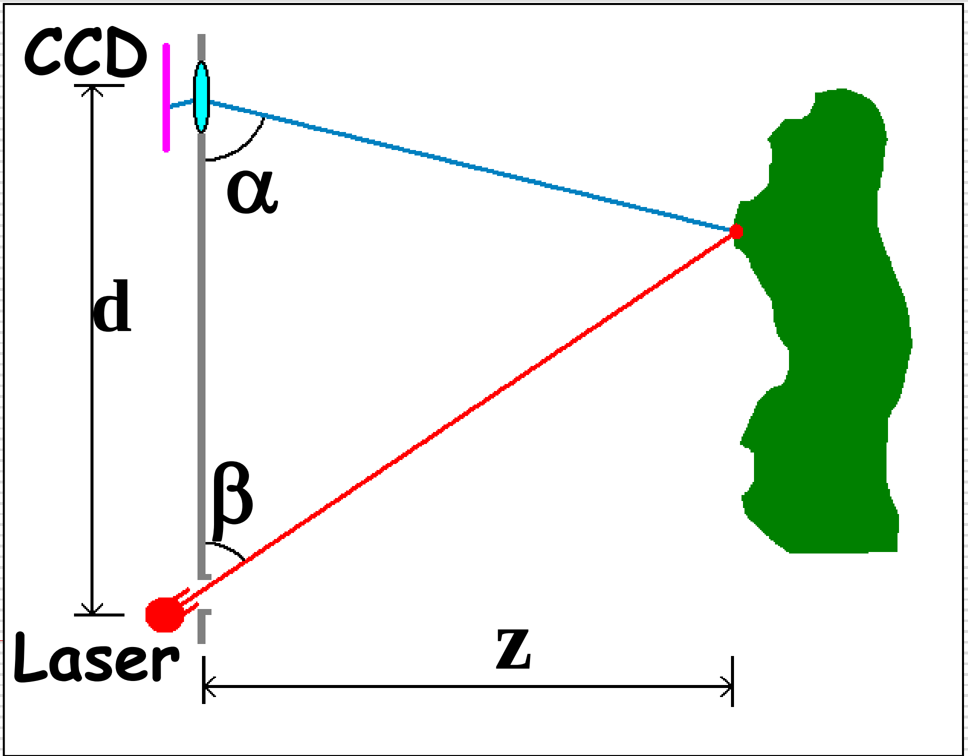


Triangulation

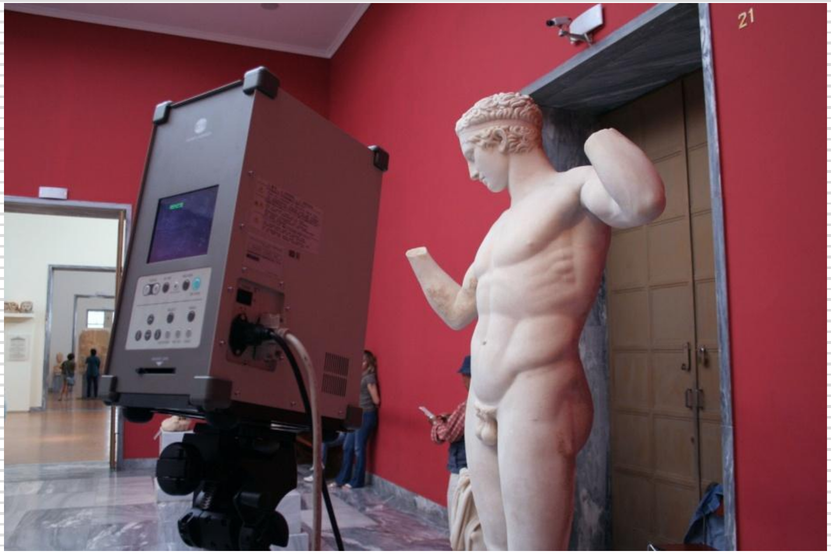
A light is projected on the surface and its reflection is read back by a sensor… Using trigonometric calculation it is simple to recover the 3d position of the illuminated points
The geometric principle is the simplest possible! The real problem, to obtain precision, is to carefully calibrate each component

Knowing the emission and reception angle, and using the distance between the emitter and the sensor, the distance of each sampled point is calculated



Minolta Vivid 910

- A commercial scanner, with high precision (0.2-0.3mm), but high cost (>30K euros).
- A laser line is swept over the object: 300K points are measured in 2.5 seconds.



A cheap scanner: NextEngine

Entry-level 3D scanner, simple and cheap. Good quality/price ratio. Ideal to investigate the possible use of this technology in a laboratory/museum/superintendence

Pro:
- Small price (<2k euros)
- Good resolution and result coherence.
- Highly portable (small and lightweight)

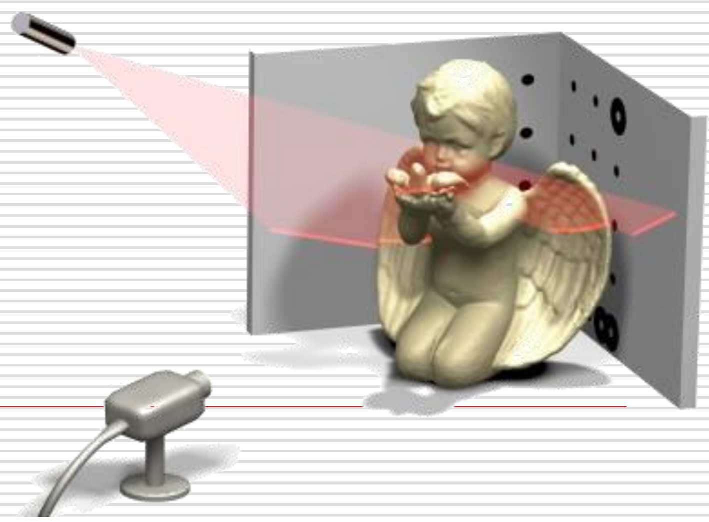
Cons:
- Fixed working distance
- Need parameter tweaking
- Does not work well on some materials

(dark & shiny)

http://www.nextengine.com

A home-made one: David Laser Scanner

- A DIY scanner: you need a webcam and a laser line (plus a couple printed target images).
- Has a simple calibration procedure and easy-to-use scanning process. But beware! to obtain good results you will need a carful setup and a steady hand...
- Quite versatile: can work at different scales (with larger/ smaller targets), setup gives some freedom of placement of the components.



David Laser Scanner

- Free version output a lower resolution meshes, but still good enough for home-made projects... Pay version has higher resolution, more options and implement the complete processing pipeline (even if MeshLab still works better :)).
- In the latest version, is also supported the use of a digital projector (structured light).

MAKER Scanner

- Another DIY scanner: uses the Playstation eye webcam and a laser line, mounted on a custom rig (which can be fabricated using a DIY 3d printer).
- Again, a simple setup (a plane is needed behind the object) and a simple scanning procedure.
- Never actually used it, but i've seen data coming from this device. Not bad, but a bit more crude w.r.t. David Scanner.

What *cannot* be scanned

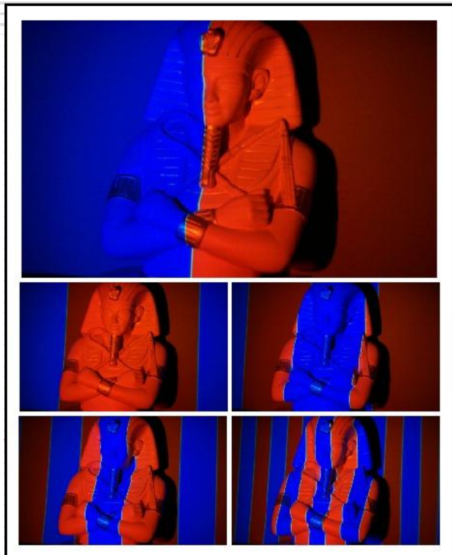
- Unfortunately, many different surfaces remains difficult or impossible to scan...
  - Objects too dark, absorbing colors
  - Transparent or Translucent surfaces
  - Shiny/mirror finish
  - Non-solid surfaces: hairs, furs, feathers
  - Moving objects
  - ...

Other technologies

- Beside lasers, a different light impulse may be used to measure geometry.
- Instead of a single (or multiple) laser line, project a large, structured pattern.
- These scanners uses the principle generally called: "*structured light*"

Structured Light

- The principle is still Triangulation, but different patterns are projected on the object. Can be more precise than laser-line triangulation, but require additional hardware (and has some problem on larger objects).
- Different companies are offering software able to control a camera and a projector. There are also free/open projects which do so...



Breuckmann GmBh

- A german company that produce and sell extremely precise (and extremely costly) structured light scanners.
- We have used this instruments for diagnostic purposes, with a sampling resolution of 0.05mm

At home

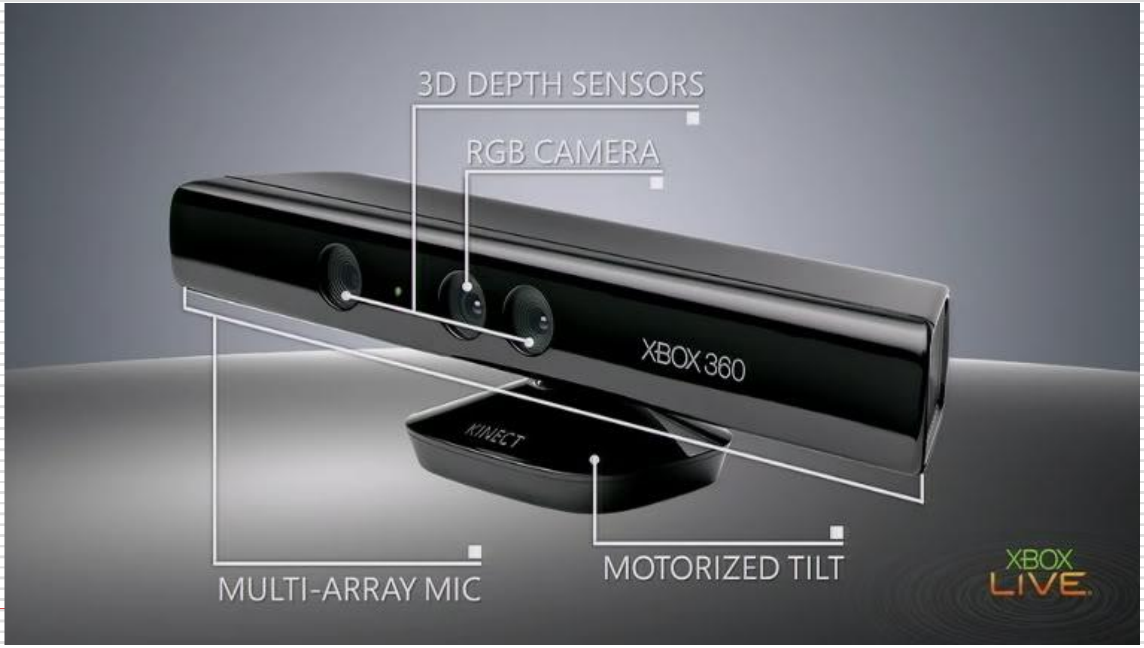
- David Laser Scanner (as said before).
- MakerBot 3D scanner (which seems to fade in and out support from time ot time).
- Structured-light project on Google Projects http://code.google.com/p/structured-light/

Many other projects (with different level of completeness) are available online, difficult to say which is good for your need... I hope to give you enough background in order to be able to decide by yourself.

Some guys just contacted us last week about a new product (russian3Dscanner)...

Microsoft KINECT

- It is basically a very fast (30fps) structured light that uses infrared light (in this way the pattern will be invisible). Resolution is not great, and the RGB color is not completely aligned witht he geometry.
- However, its cost and performances have shaken the community of 3D hobbysts but also of professionals



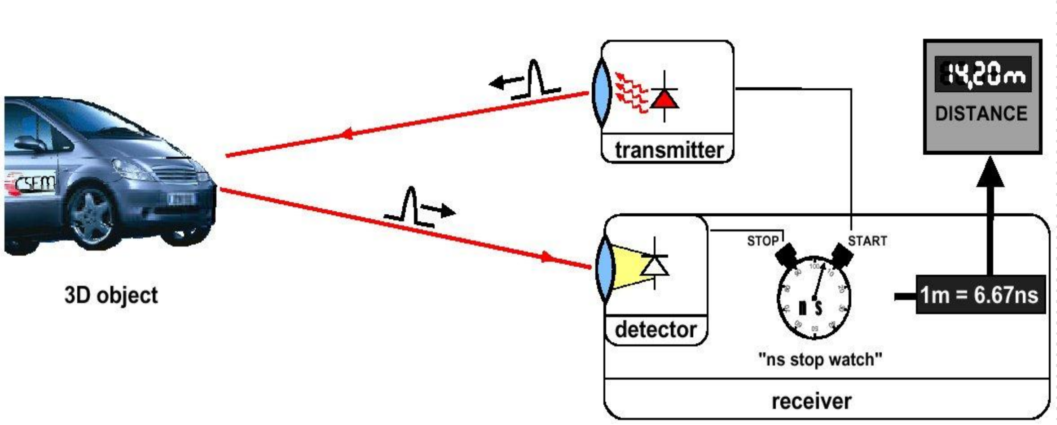
Microsoft KINECT

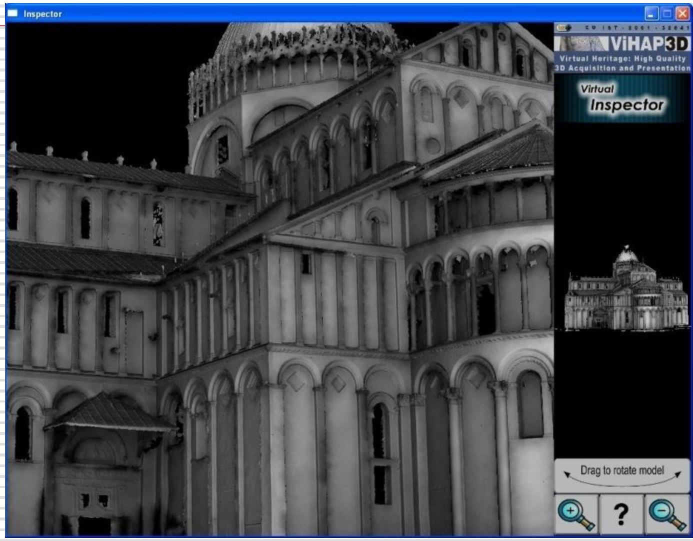
- It is possible (in theory) to use the Kinect to do a 3D scanning, however:
  - The kinect has been built for speed, not precision: you need a stable position of both the device and the subject. You may need to get more than a shot from the same position and combine it to reduce noise
  - The depth information is compressed, especially in the far area: the subject should stay as close as possible to the device

What about larger Objects ?

- This is a very common question... The answer is, you do need a different instrument
- Triangulation cannot work on very large objects, it would require an extremely large baseline...
- Always remaining in the kingdom of light signals and optical properties, a different strategy is used

Time of Flight (TOF)





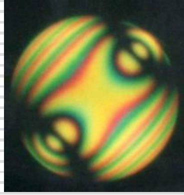
The distance of sampled point is obtained by measuring the time between the laser impulse and the sensor read-back, divided by (two times) the speed of light…

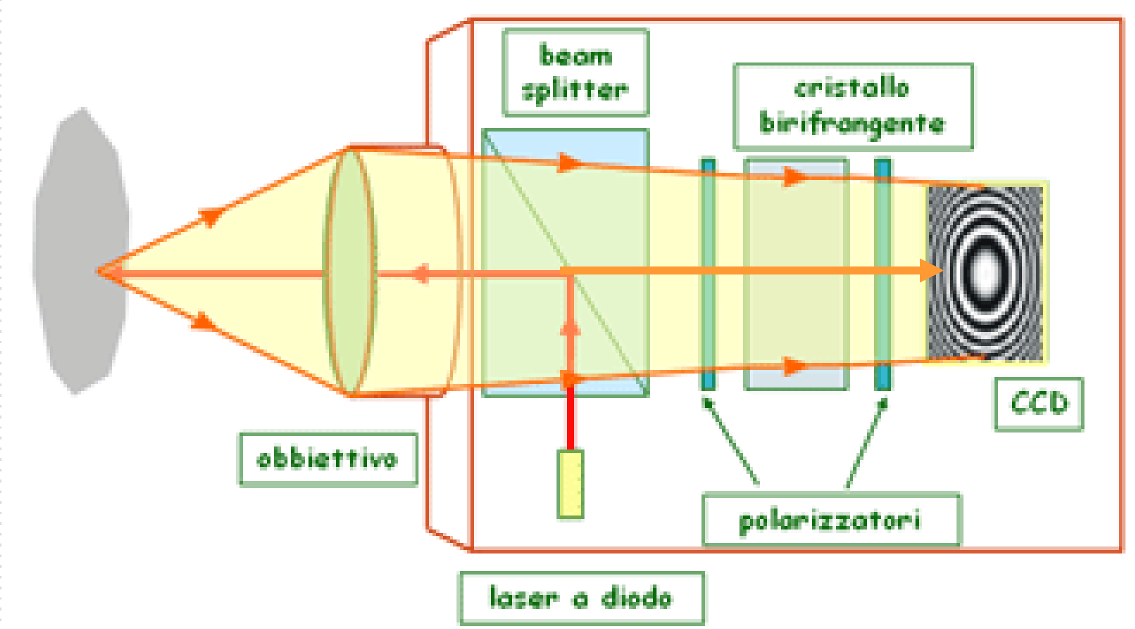
The measurements is repeated on a regular grid on the object surface

WARNING: playing with the *speed of light* reduce the measurement precision…

Average error on distance: 5-7 mm

Phase interference





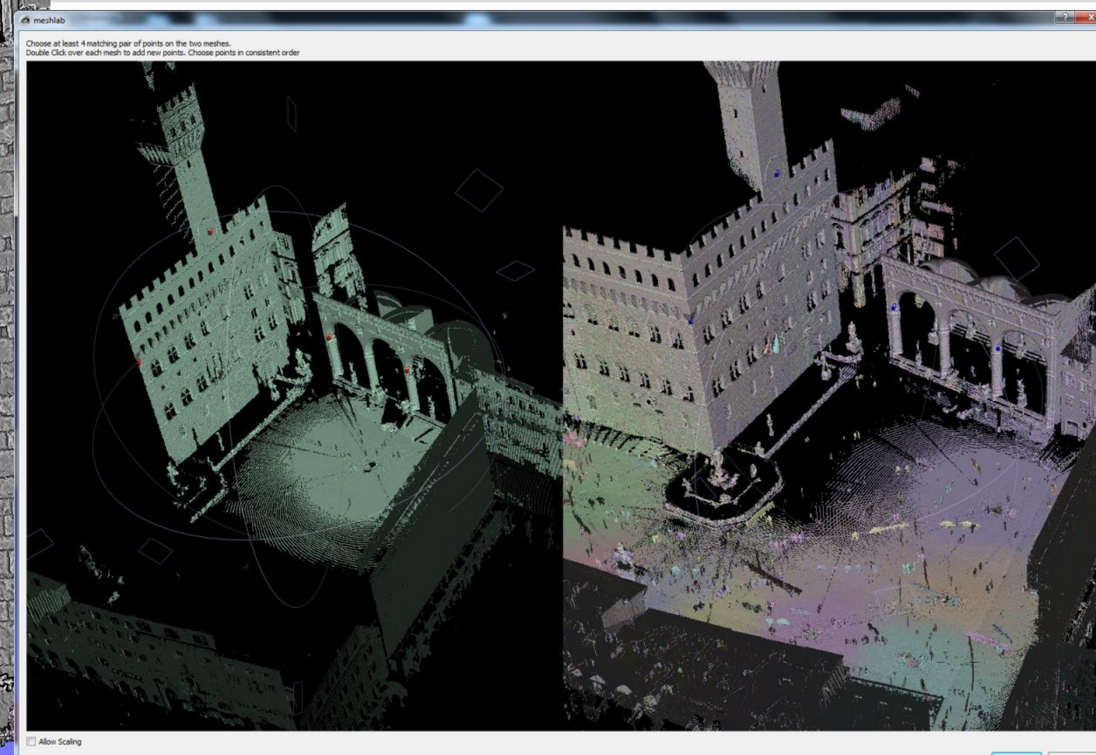
The direct and the reflected beam arrive on the crystal, frequencies are no longer aligned, producing interference… interference bands are used to determine the distance of the sample

The same principle is used on two different scales:

CONOSCOPY: coins, paintings, small relief
INTERFERENCE TOF: buildings

Time of Flight + interference

- More advanced systems also rely on interference patterns produced by different wavelenghts, making the devices faster and more accurate.
- They can also “see“ through vegetation...



LIDAR / SLR

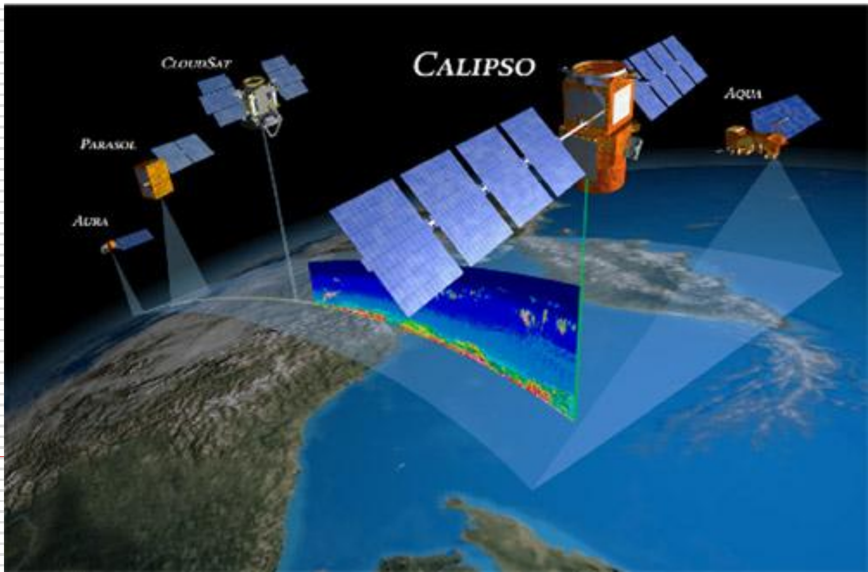
Elevation data measured by satellites. But not only geometry…

Used in combination with analysis of multiple returning signals, can "see" through vegetation

Using different frequencies and analyzing the returned signal, it is possible to distinguish the nature (building, road, water, cultures …) of the probed area

Average error on distance: a few meters

SLR
satellite laser ranging
LIDAR
light detection and ranging

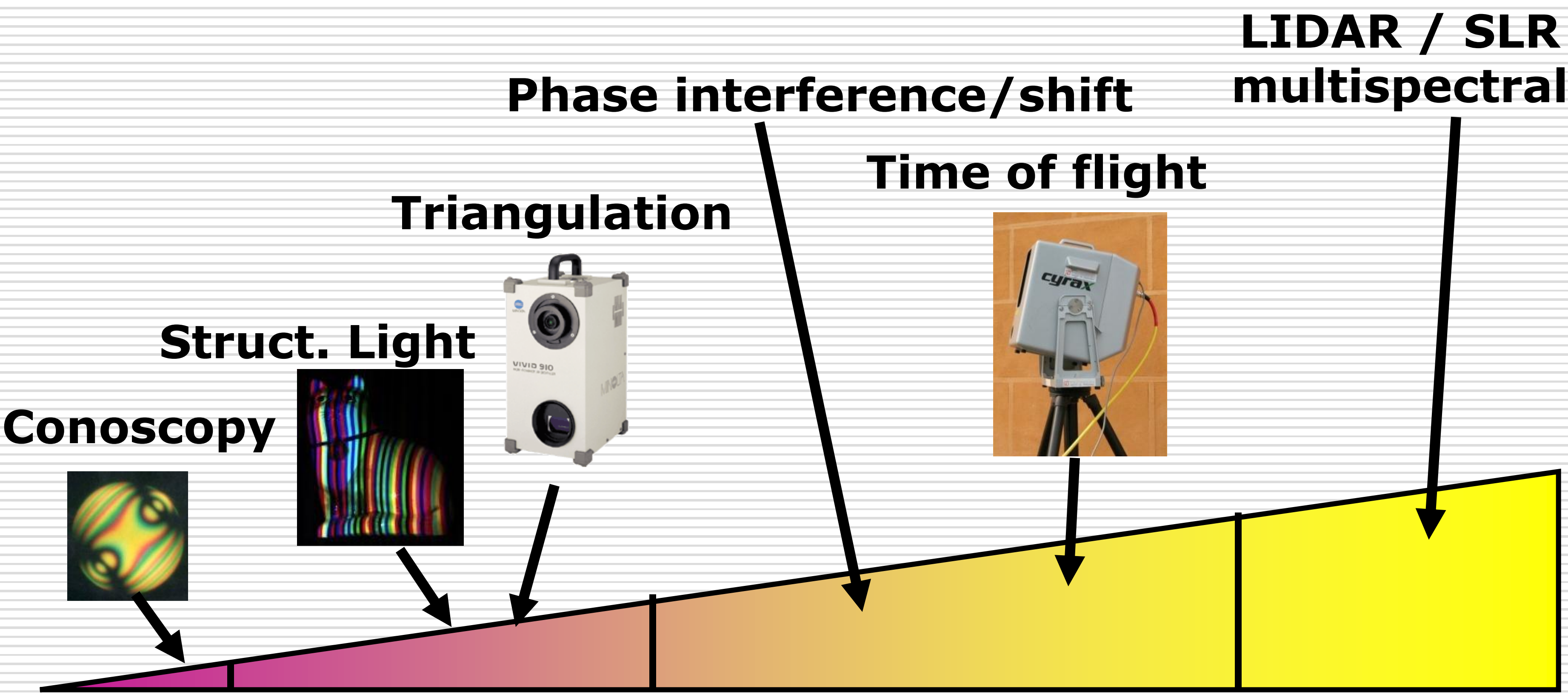


3D scanning devices

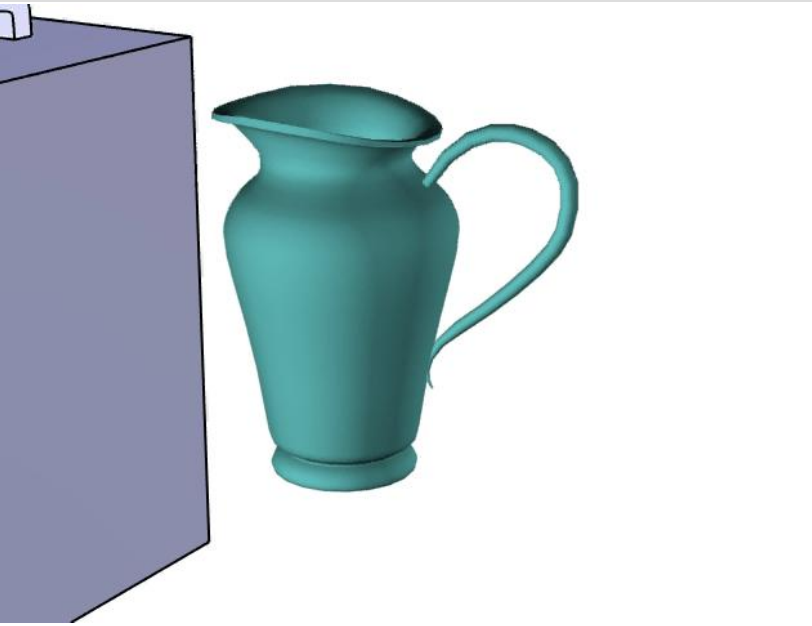
Sensor is no longer the main problem...

The gamut of measurable object is increasing, in terms of both size and material

New hardware is made available as we speak...

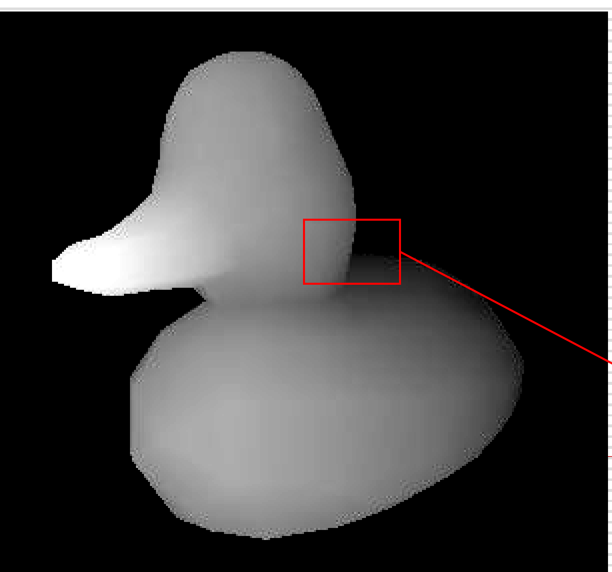


Range map

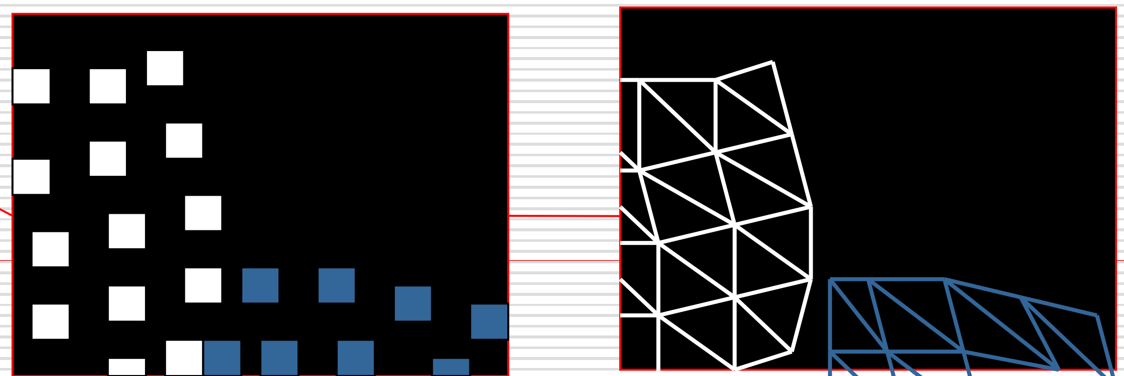


What is recovered from most of the scanning equipment after a single shot is a depth value for each pixel in its sensor

These depths are converted in a point grid that is promptly triangulated using this intrinsic regularity.



The result of a single scan is called a RANGE MAP

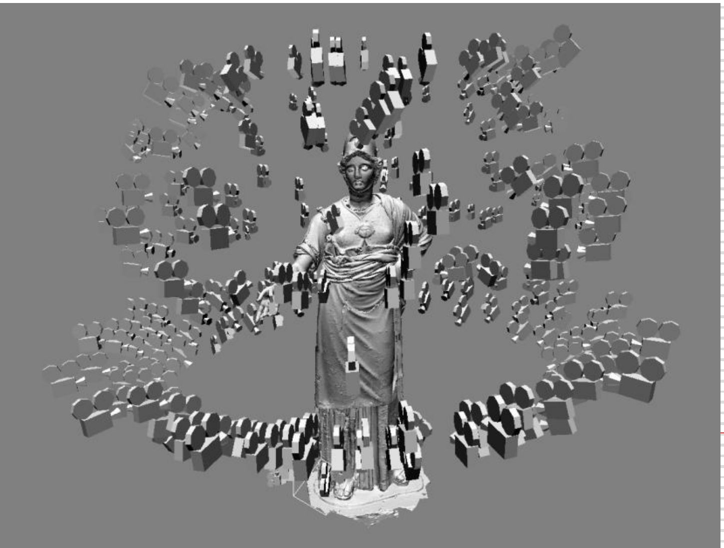


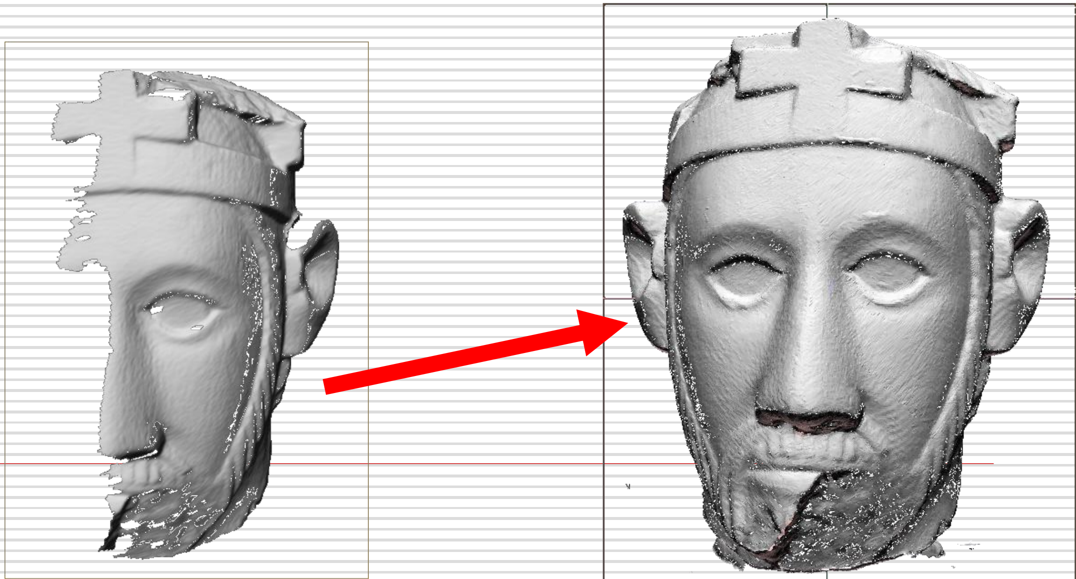
All that remains

A range map is already a 3D model… but it will be surely incomplete

A single acquisition **IS NOT** enough to reconstruct an entire object
Multiple shots are needed… How many? Which one to choose ?

The scanning is just the first step to obtain a complete model





3D scanning technology: limitations

3D scanners can cover a variety of objects, but there are still some limitations. Some of them can be overcome, others are intrinsic:

- Visibility (direct, cone of visibility)
- Color (black, pure color)
- Material (reflective, transparent and semi-transparent, peculiar BRDFs)
- Acquisition environment (temperature, illumination, crowded places)
- Size vs. Single map acquired (accumulation of alignment error)
- Non-rigid stuff

3D scanning technology: key terms

It’s not easy to compare 3D scanners. There are some key terms that need to be clear, at least:

- Accuracy (precision): error/distance. Difference between triangulation and other technologies.
- Resolution (essentially, no sense)
- Speed (points/min)
- Working distance (min/max)

Acquisition planning, a key step

The preparation of the acquisition is a fundamental step. The more you scan, the better you plan. Some of the "general" things to take into account are:

- Overlap between (subsequent) scans
- Generic coverage + "sottosquadra"
- Better "more" than "less"
- Space around the object, possibility to move it
- Geometric detail vs. area coverage
- Target error for reconstruction (what is the use of the model?)

Generation

3D Scanning Pipeline

- *[**Acquisition planning**]*
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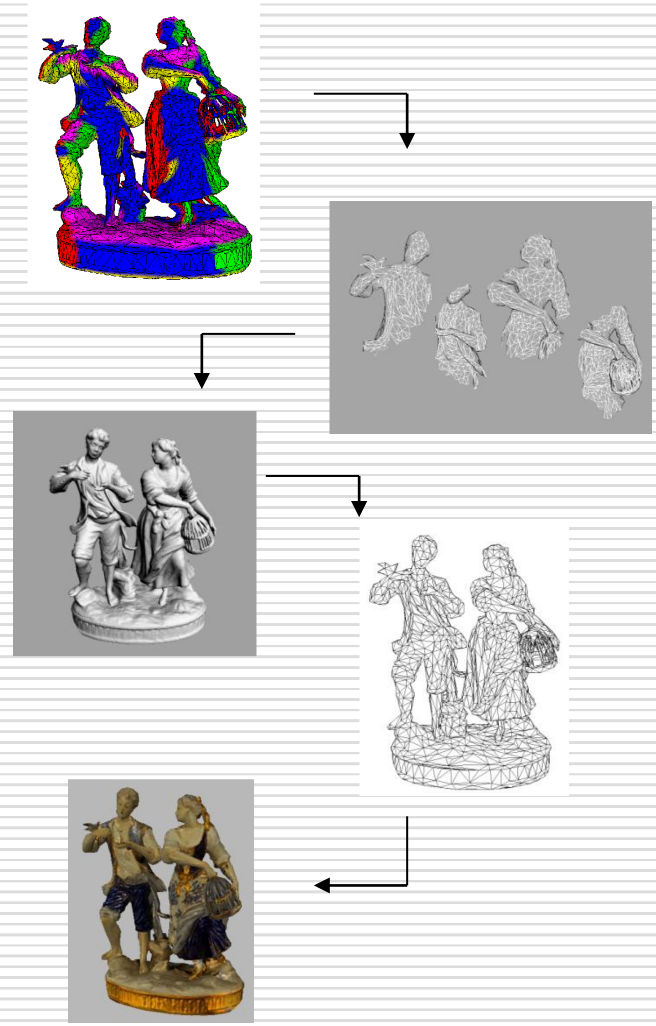


Alignment

Each part of the model is in its own coordinate system. There is no spatial relationship between the different parts, as they have been generated in a different processing run

Goal: bring all the parts in a common reference system (like a 3D jigsaw puzzle)

Beware: lot of manual intervention is needed!

Two steps:

1. **Rough** alignment: user manually positions the various chunks in more or less the correct position
2. **Fine** alignment: the computer automatically perfecs the alignment using the shared area between the range maps

Redundancy is MANDATORY

Manual Alignment

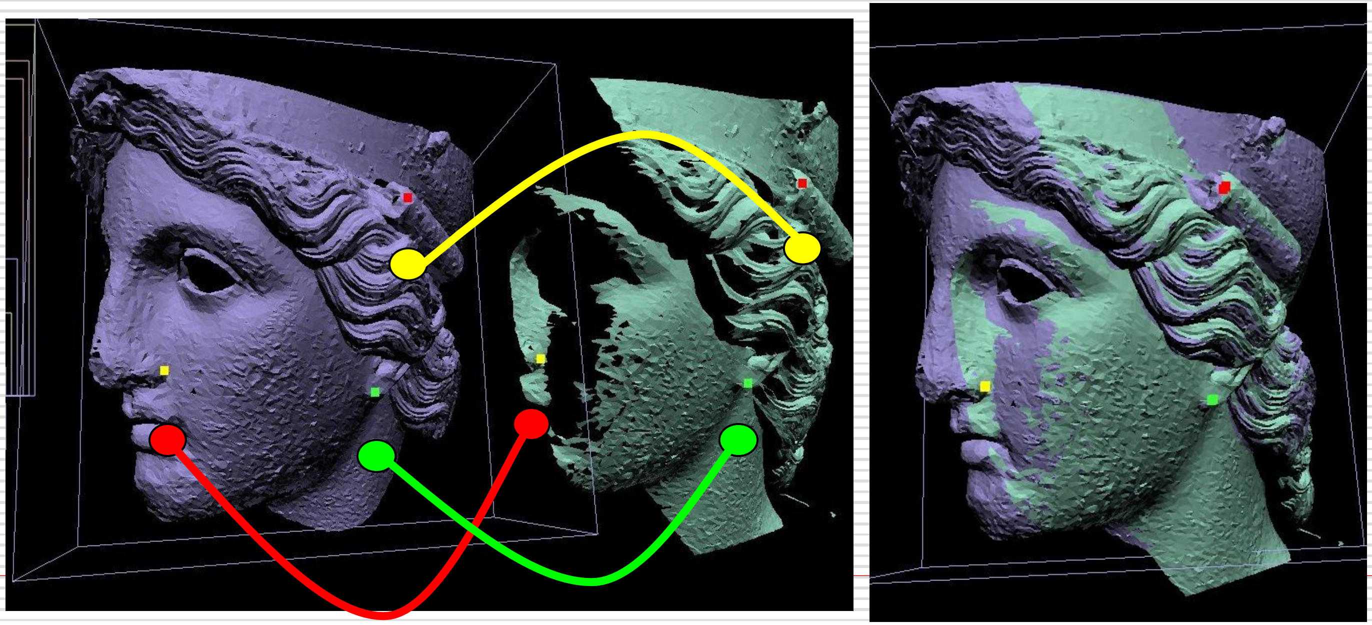
First step.

It is necessary to have an overlap region with some common feature

Common method: picking shared reference points.

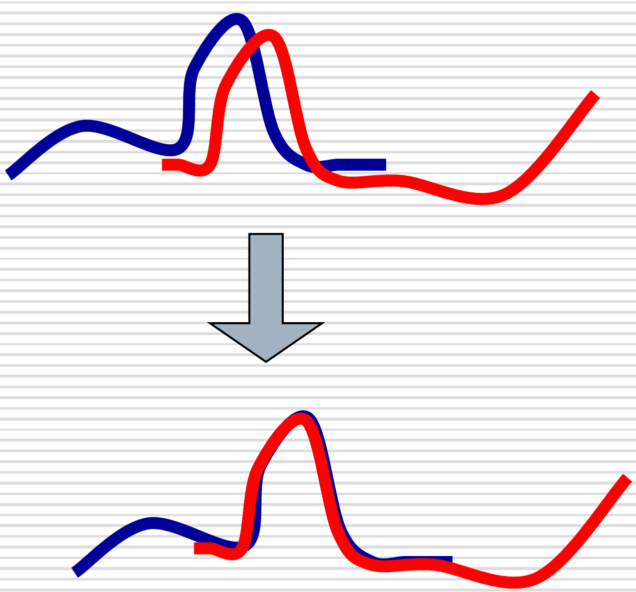
Models are roughly positioned according to the point couples

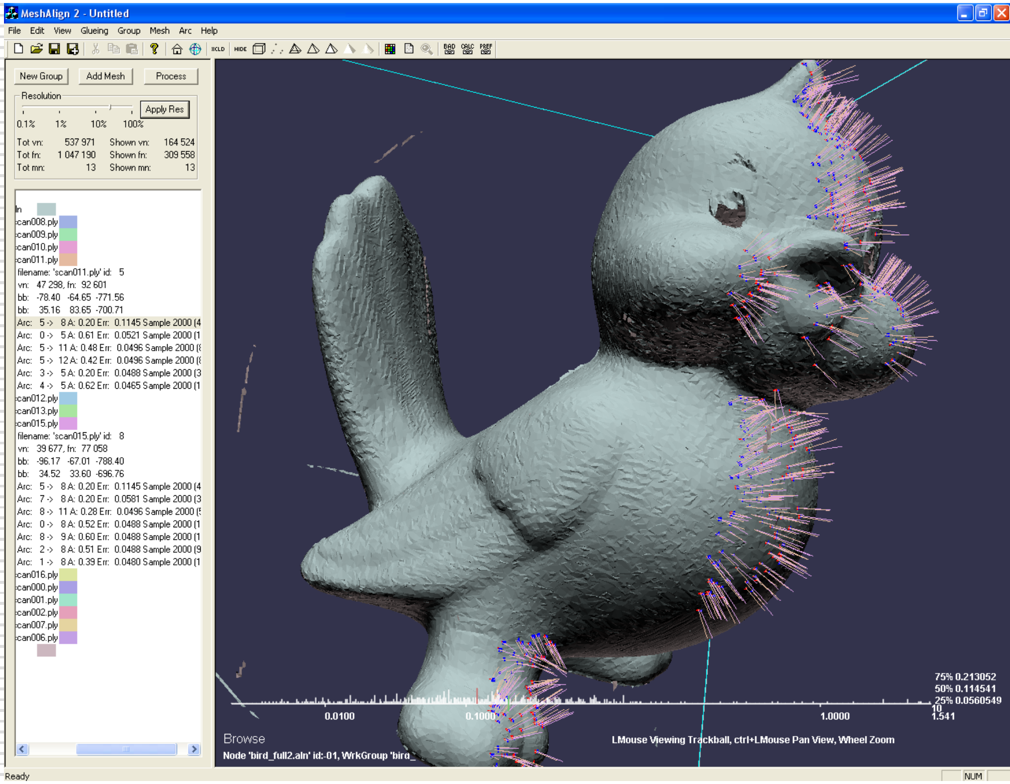
selected. Not a perfect alignment, but enough to start the next phase



Fine alignment

All the range maps are finely registered using redundant areas that are present in adjacent range maps.
Range maps are moved until the common parts are sticked together





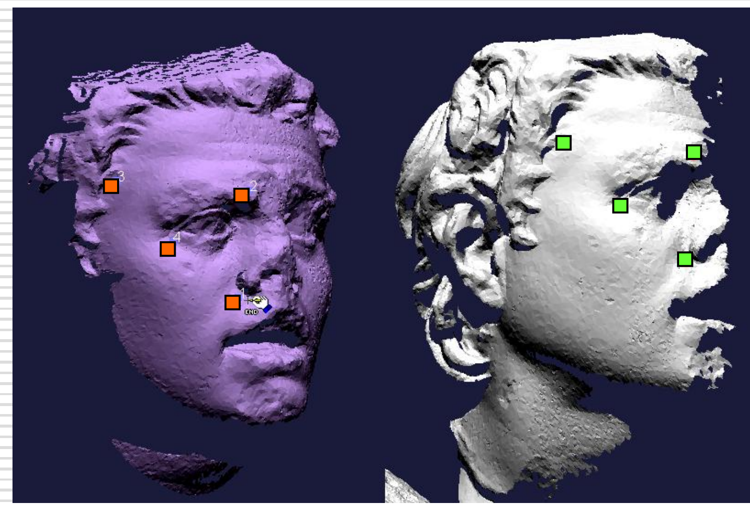
Example: MeshAlign and MeshLab

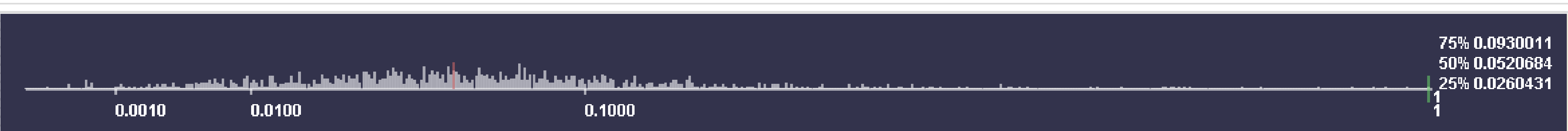
Our internal alignment tool (MeshAlign)

With a multiresolution data representation can work with hundreds

of range maps at the same time

- 4 point matching
- group management
- tweakable alignment parameters
- really powerful, but not so easy to use without training

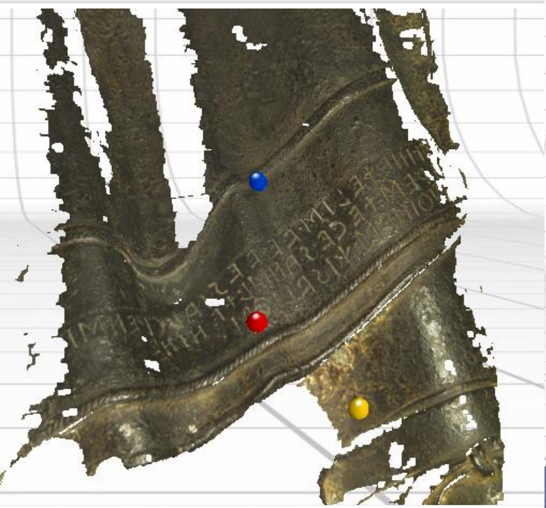
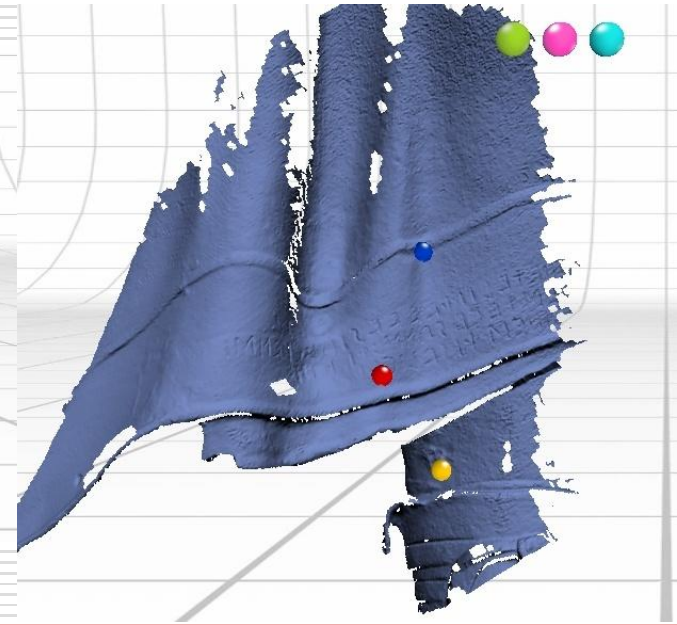
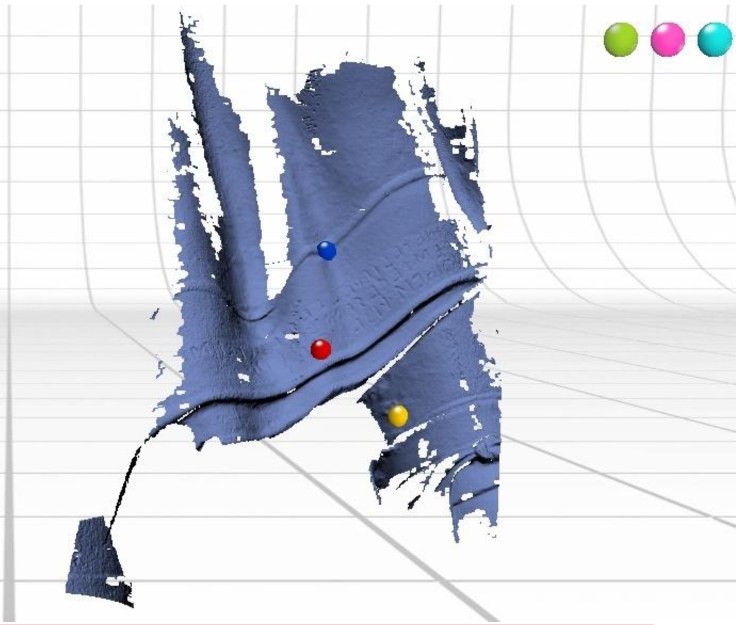




Example: NextEngine ScanStudio

Bundled with NextEngine Desktop Scanner

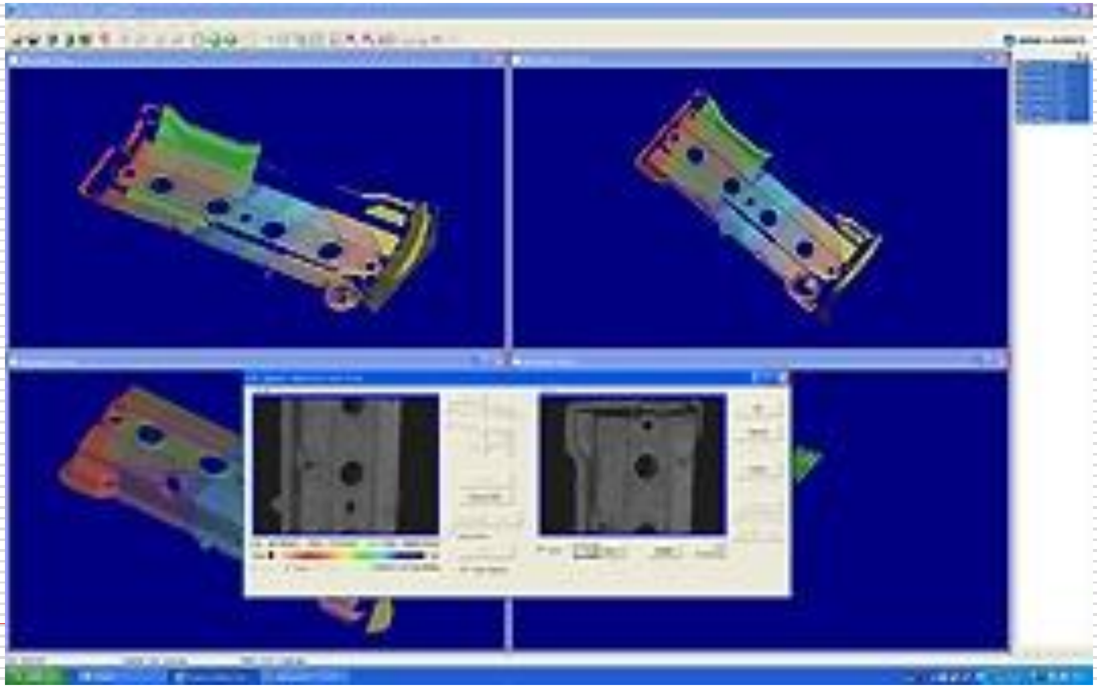
- 3 or more points rough alignment (on geometry or geometry +color)
- semi-automatic alignment for rotary stage scans
- Fully automatic fine alignment (just with target error)

Example: Minolta PET

Minolta tool for mesh acquisition and processing

- alignment during acquisition, selecting points on the viewfinder
- 1 point alignment (if possible)
- Automatic alignment for rotary stage scans
- Fully automatic fine alignment (some parameters)



Not always necessary

Not all scans need the alignment step or, at least, an explicit

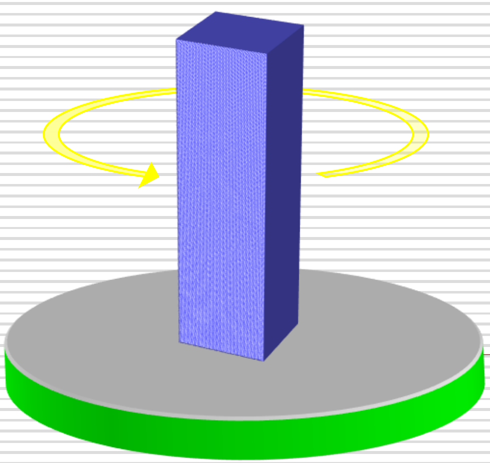
alignment step.

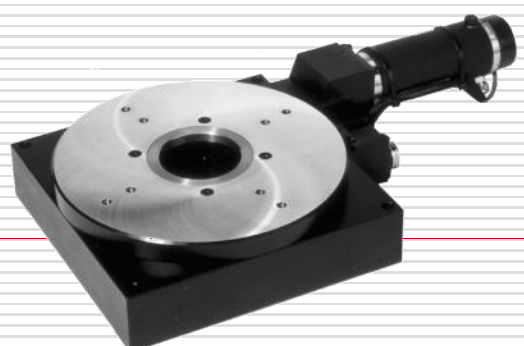
- Aerial/satellite is aligned while produced
- Automatic matching and alignment is possible in some cases
- Scans can be aligned using reference markers…

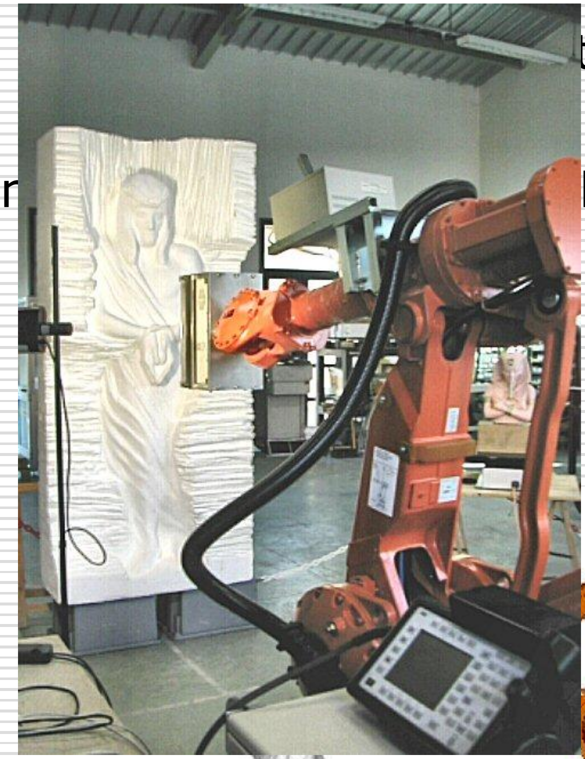
Scanner tracking

If scanner position is known in each shot, alignment phase can be reduced (rough alignment) or completely eliminated

- **Rotary stage**: PC-controlled, 1 DOF angle rotation. Simple and effective
- **Arm positioning system**: 2 to 6 axis, t very high precision ans speed-up
- **Tracking system**: generally wireless, r but flexible







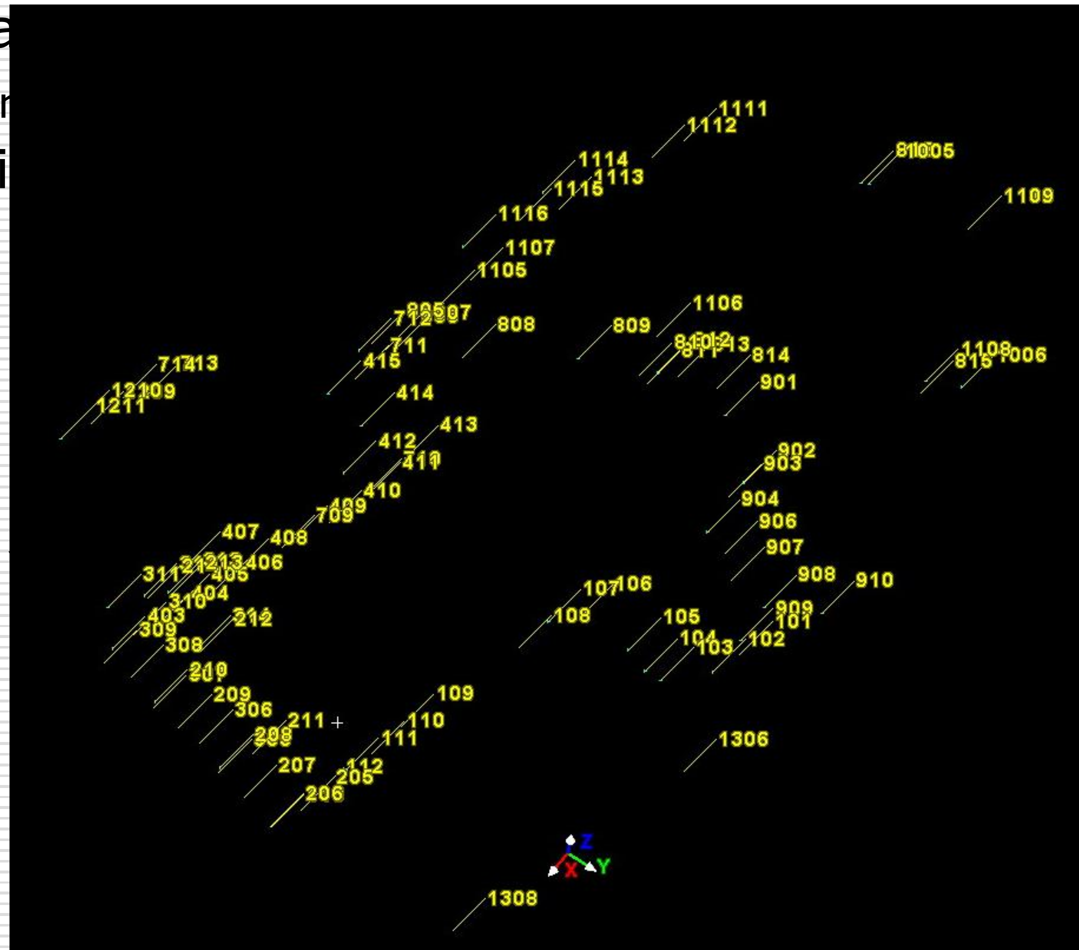
Markers

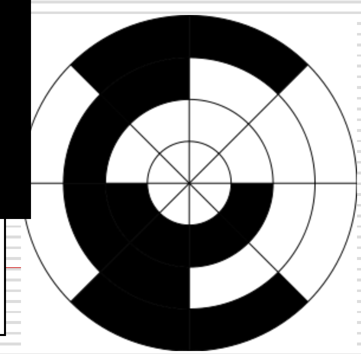
Markers are physical objects placed near/onto the surface to be acquired that a … erns/geometries, color-codes, mater …

Their position i … e registration

“Total Station” … ng of building a theodolite is … nce points.

This technique … ble (we have used it in the last 7000 …





Alignment: comments

The alignment step is a key one in the scanning pipeline. In order to go on with the merging phase, an indication about the error is needed. Final error is bounded by one of these two values:

- Acquisition error: the error for the single acquisition. Dependent on object, hardware, acquisition environment.

- Alignment error: the error in alignment of the range maps. Dependent on object, scans quality and number, overlapping.

Both the values are “statistically” known, the alignment error cannot be less than the acquisition error.

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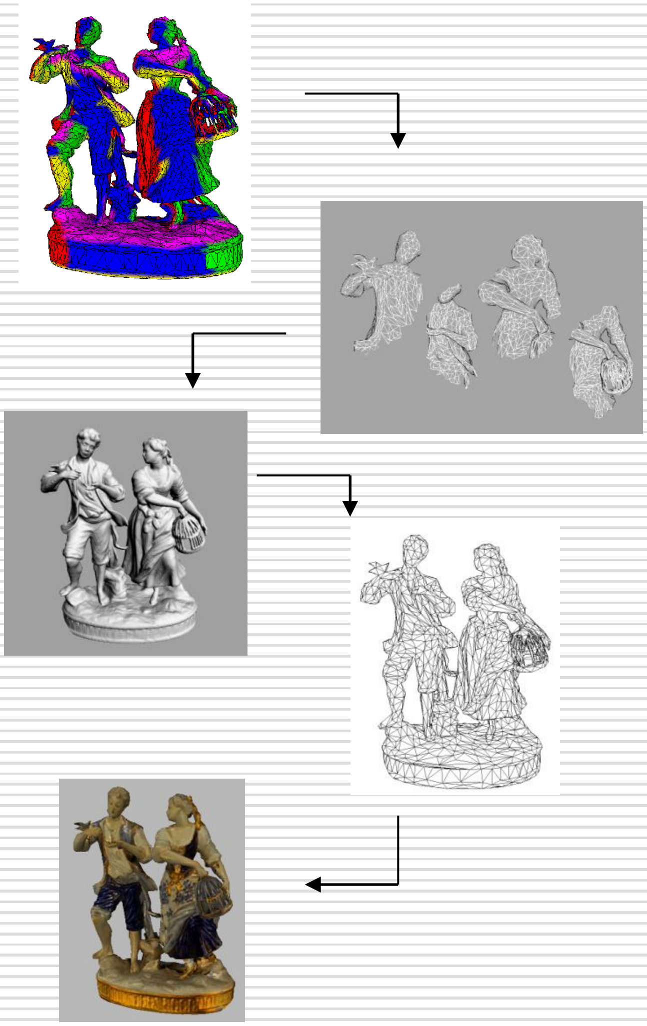


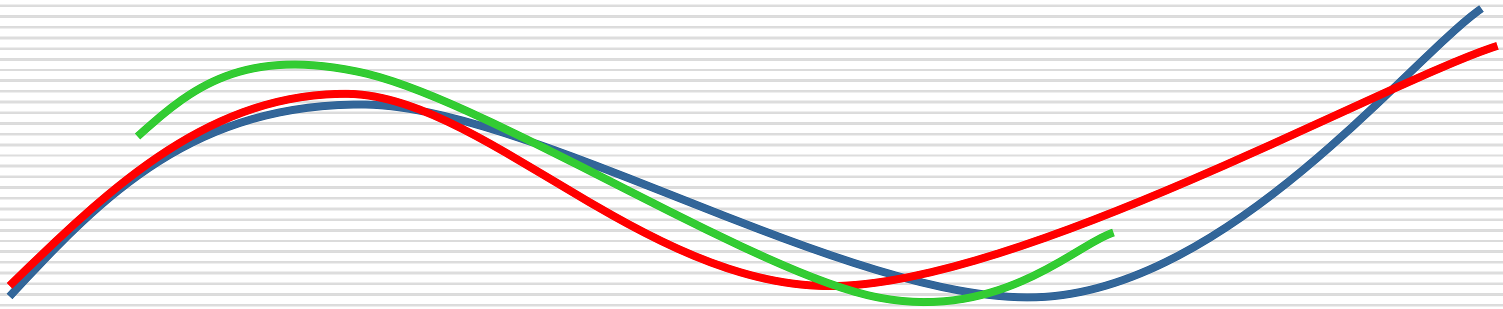
Range maps Merging

When all maps have been generated, cleaned and aligned, it is time to generate a single surface

Why ? to cover the entire surface we need all maps, but more maps covers the same area, with intersecting and overlapped triangles… Moreover, the sum of all map has too many triangles to be used…

Problem:

more maps covers the same area, which one is the correct one?

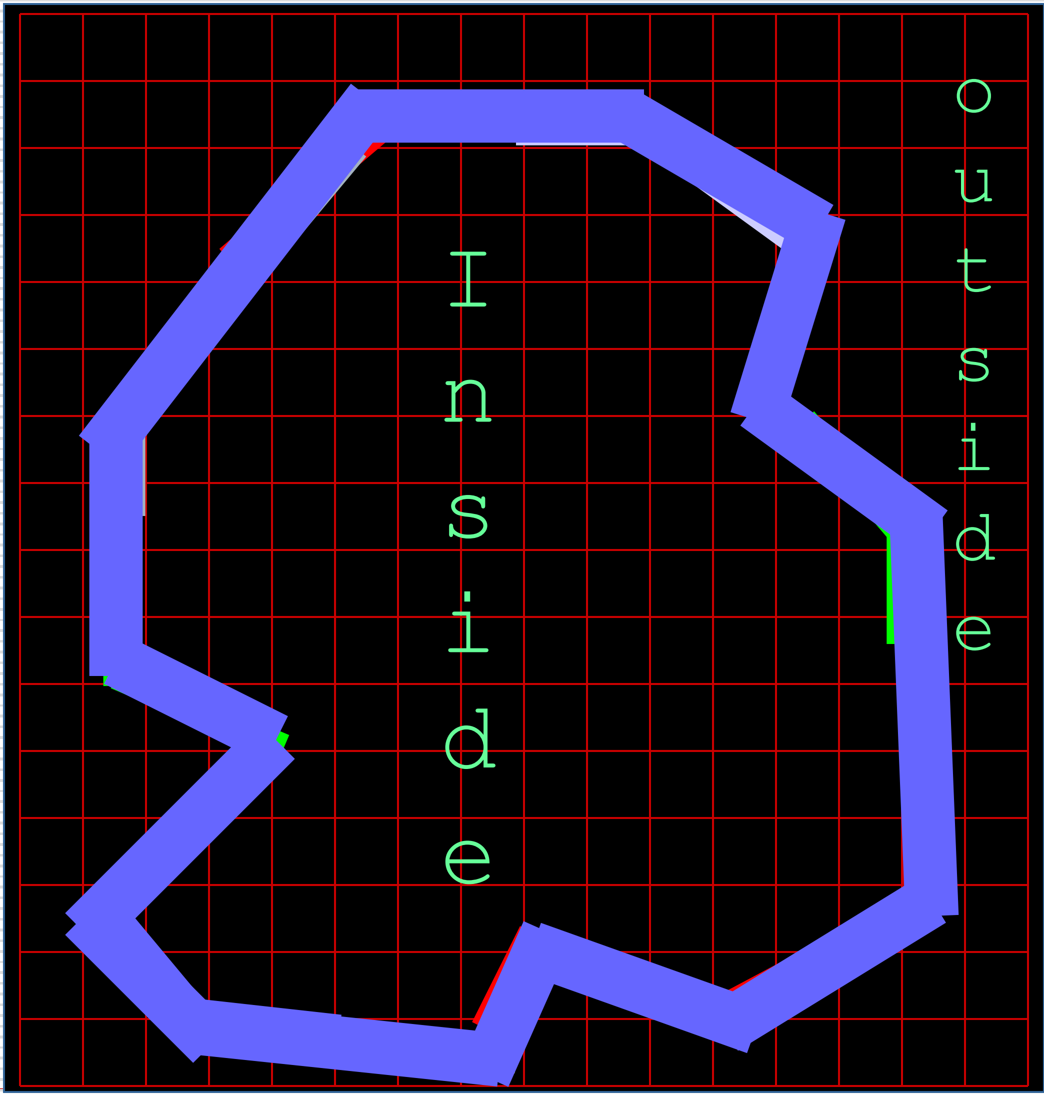


Answer: None

Volumetric Methods

Range maps are immersed in a volumetric grid: the final surface will be built using some criteria that work in each cell that contains some part of the original model.

Inside each non-empty cell the contribution of the various range maps will be combined in order to obtain a consensus surface, extracted then using (generally) a variant of the MARCHING CUBE algorithm



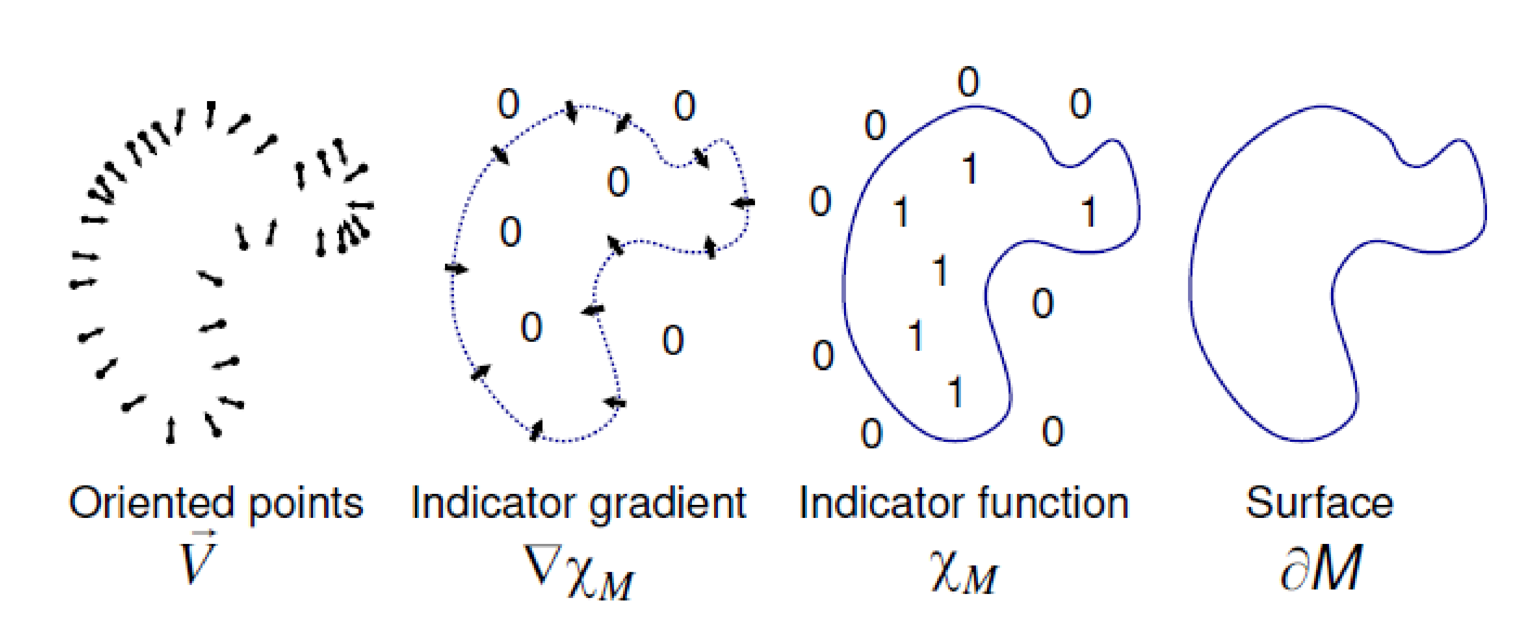
Implicit surfaces

- Another possible approach:
  - Use the data to build a mathematical surface of approximation
  - Triangulate the mathematical surface using some tessellation OR similarly to the volumetric methods (computing triangulation in each cell)

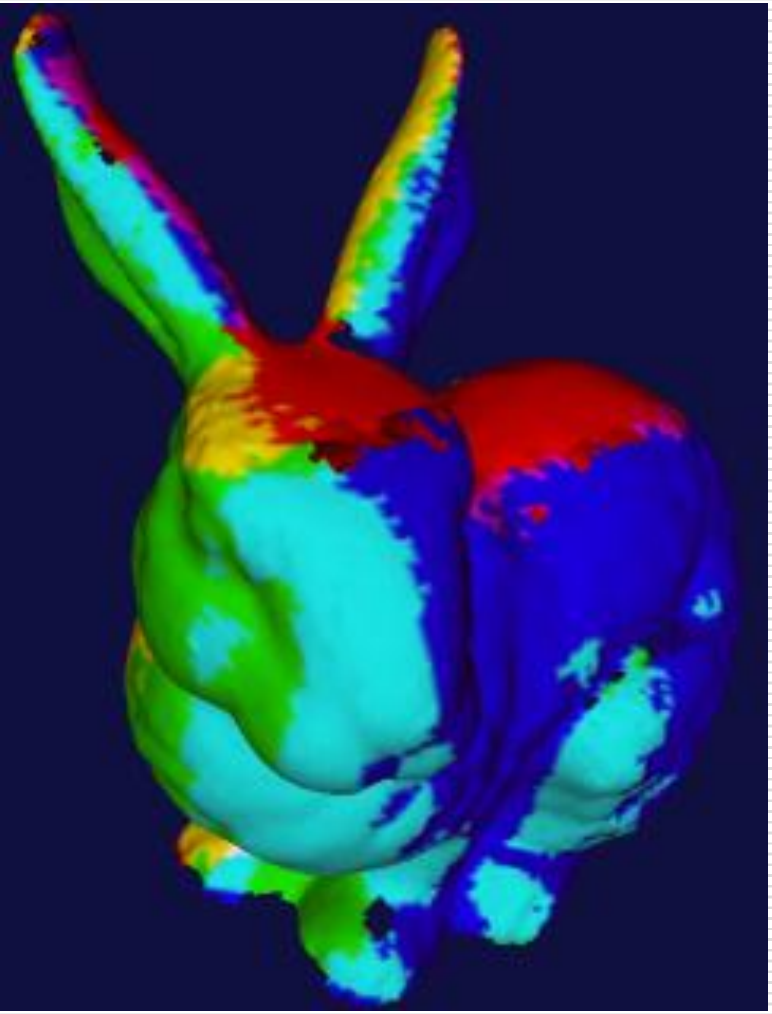
The use of an intermediate mathematical/analytical representation helps creating smoother surfaces and correct problems in the input data (like closing holes)

Poisson reconstruction

A recent (2006) work implementend the Poisson reconstruction. This formulation considers all the points at once, without resorting to heuristic spatial partitioning or blending, and is therefore highly resilient to data noise. -> Closed surface!



Zippering



Quite an old method, but still used in many
tools.

The surface is built using parts of each single scan, simply joined together.

Can be distinguished from triangulation: some areas are covered with a regular triangle grid, joined by strips of triangles (zipper).

It is simple and fast, but does not use the
geometric redundancy to eliminate some of the sampling error

Just an example

Just an example

Just an example

Merging: comments

Regardless of the technical details, three possible merging approaches are shown:

- Volumetric (VCG filter in MeshLab): the user defines the resolution of reconstruction, possibility to “split” the model to handle complexity, only sampled surfaces are reconstructed.

- Zippering: quite simple “puzzle like” approach, bad triangulation.

- Poisson (Poisson filter in MeshLab): the output is always a closed surface, very good results with noisy surfaces, no real possibility to handle complexity.

Big Names

Industrial tool for mesh processing and 3D scanning managements are used also in CH field.
Very powerful, high robustness (industrial grade), not really easy to use for non-trained personnel

RapidForm	generic scanning/mesh processing
GeoMagic	generic scanning/mesh processing
Cyclone (semi-bundle)	time of flight

Hundreds of small companies have their own software… really hard to choose without a proper knowledge. Ideal solution is to find someone of the field to help you decide

Next in line…

Next lesson:

- 3D Scanning: hands-on

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