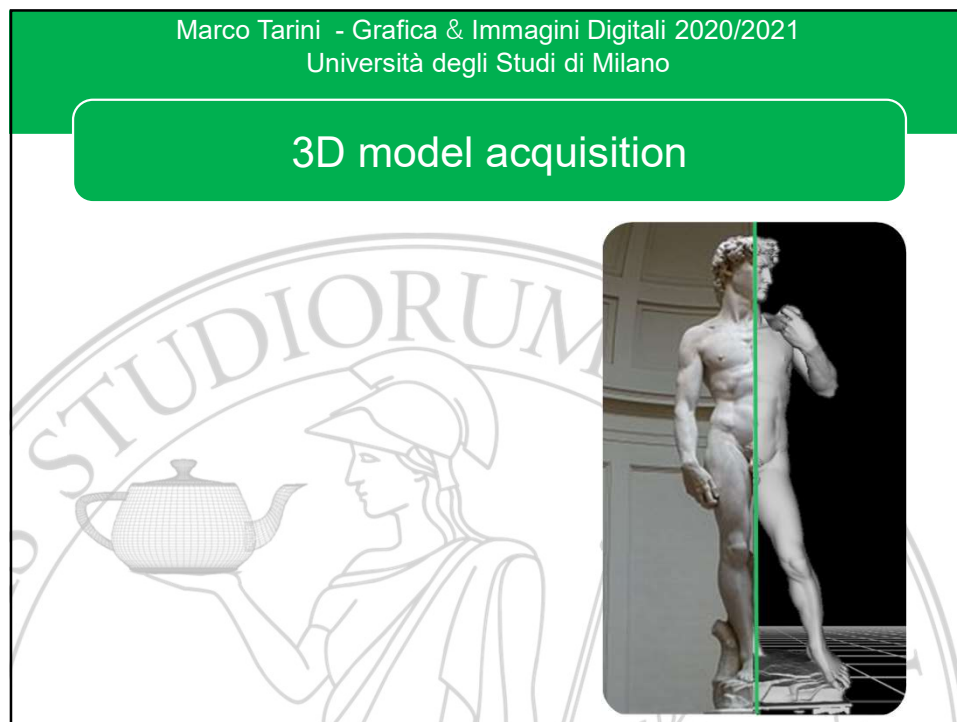
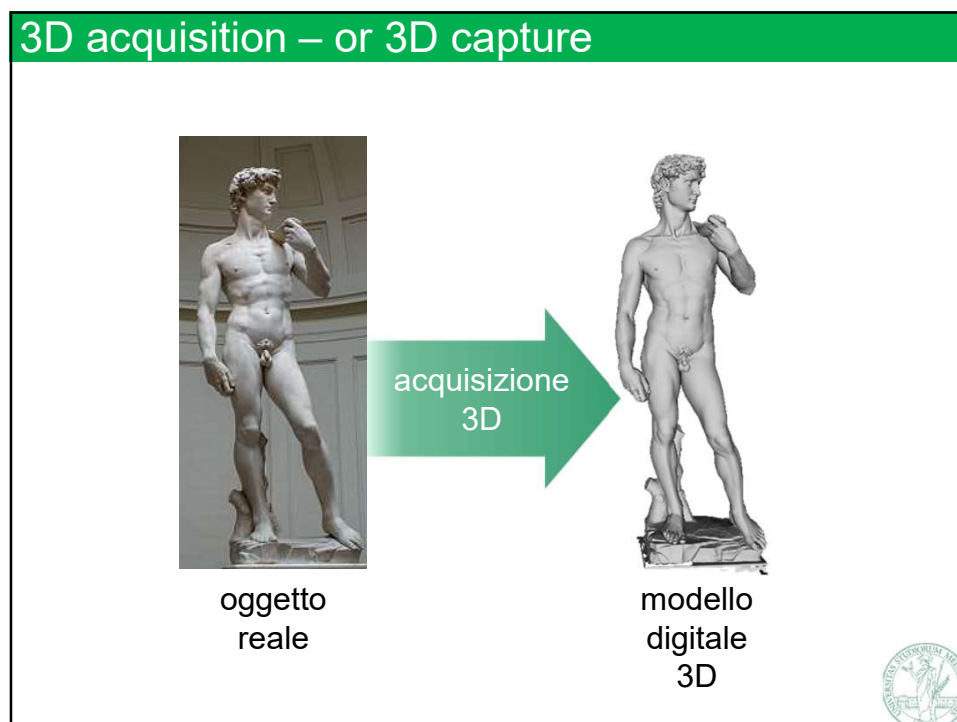
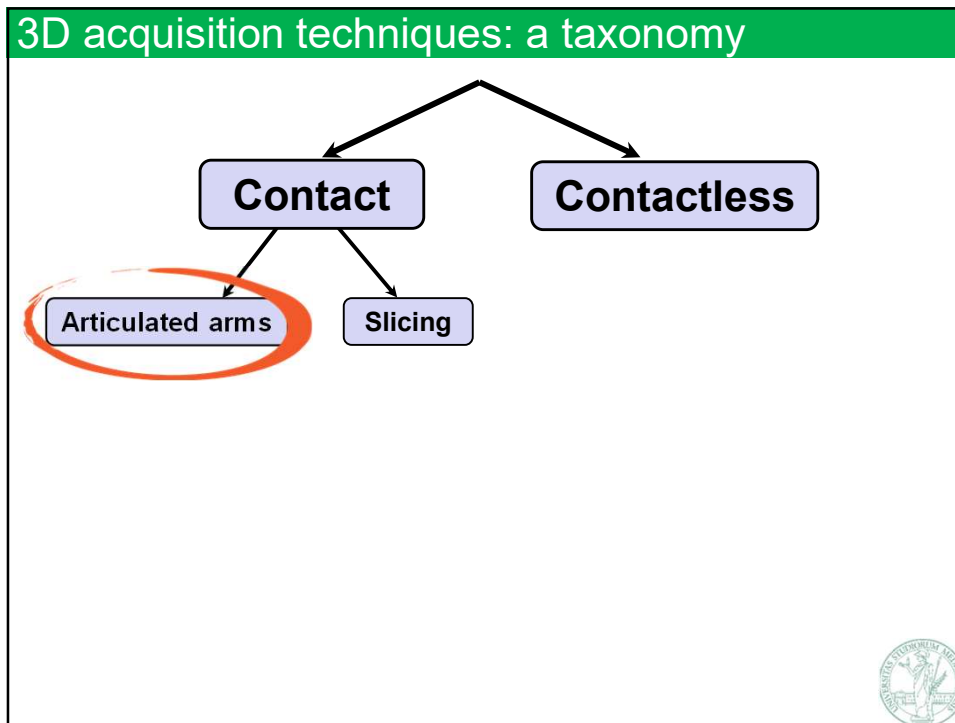




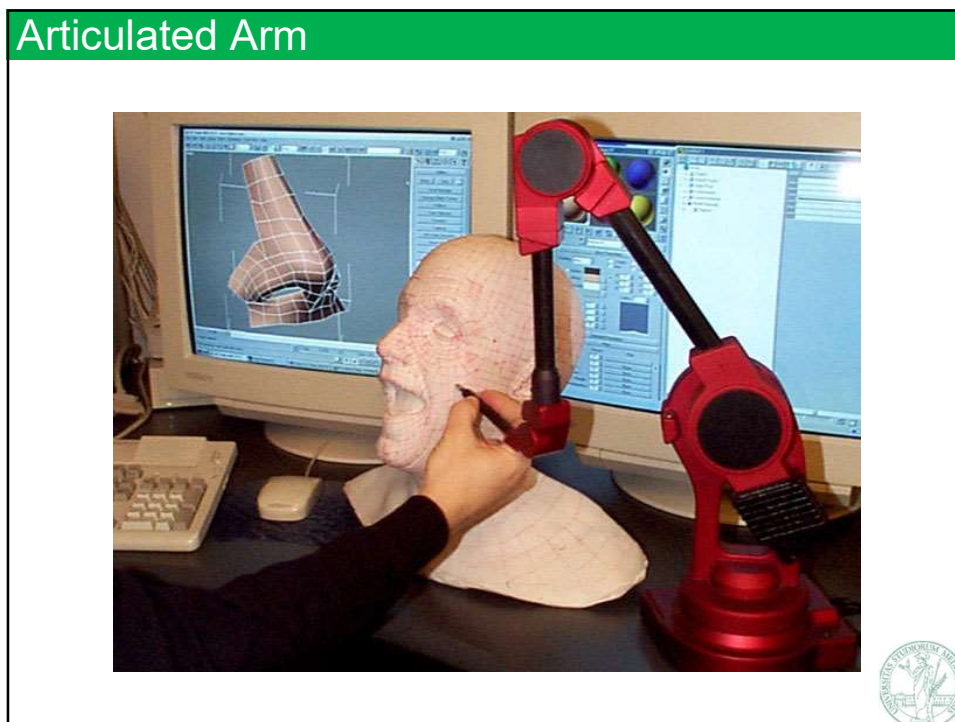
1



2



3



4

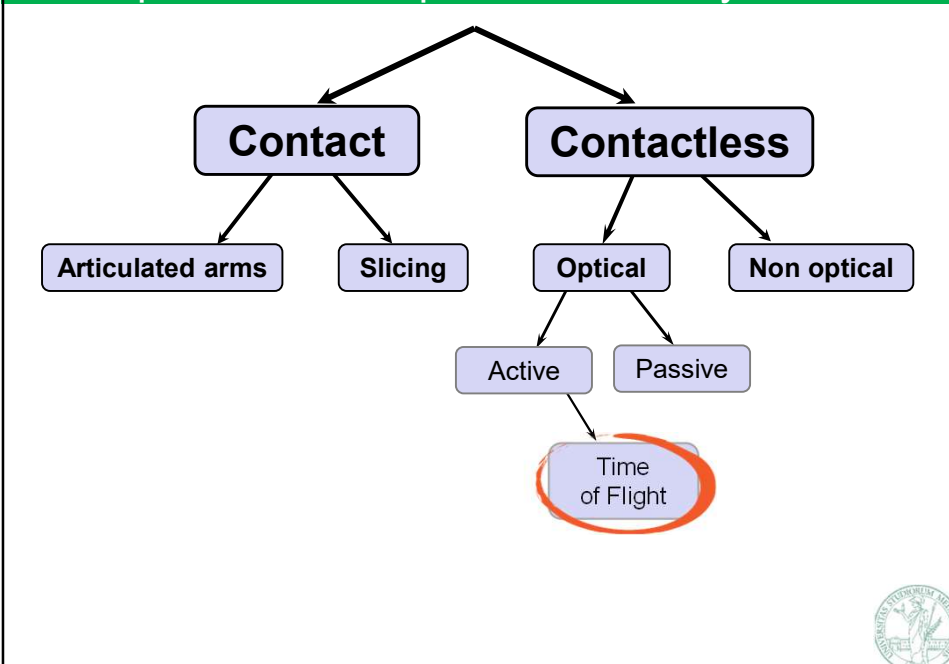
Metodo basato su Braccio Articolato

- ✓ Il punto toccato dall'estremità ha una posizione ricostruibile grazie ai sensori di angolo sui giunti
⇒ Applicazione di «cinematica diretta»
- ✓ Un oggetto reale viene sondato in vari punti, genera un vertice di mesh per ogni punto
- ✓ La connettività della mesh aggiunta per connettere i punti sondati
- ✓ La precisione di un campione può essere elevata (poche decine di micrometri)
- ✓ La risoluzione è molto limitata
- ✓ Metodo manuale, richiede tempo e richiede esperienza
- ✓ Produce mesh a bassa risoluzione



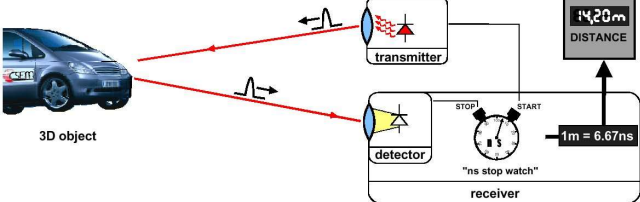
6

3D acquisition techniques: a taxonomy



7

Time of Flight

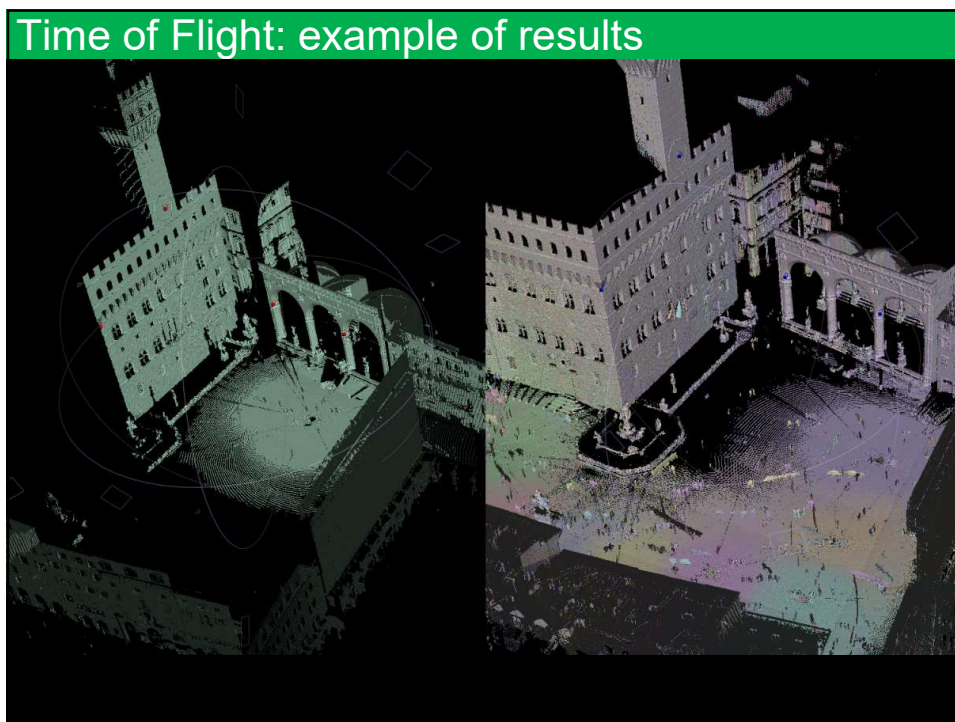


The diagram illustrates the Time of Flight (ToF) principle. A 3D object (a car) is shown on the left. Two red lines represent the emitted and reflected light waves. On the right, a 'transmitter' and a 'detector' are connected to a 'receiver'. The receiver contains a clock labeled 'ns stop watch' with 'STOP' and 'START' markers. A scale bar indicates '1m = 6.67ns'. A digital display shows '1420m' and 'DISTANCE'.

Si inferisce la distanza
del punto sondato
misurando il tempo intercorso
dall'onda luminosa



8



9

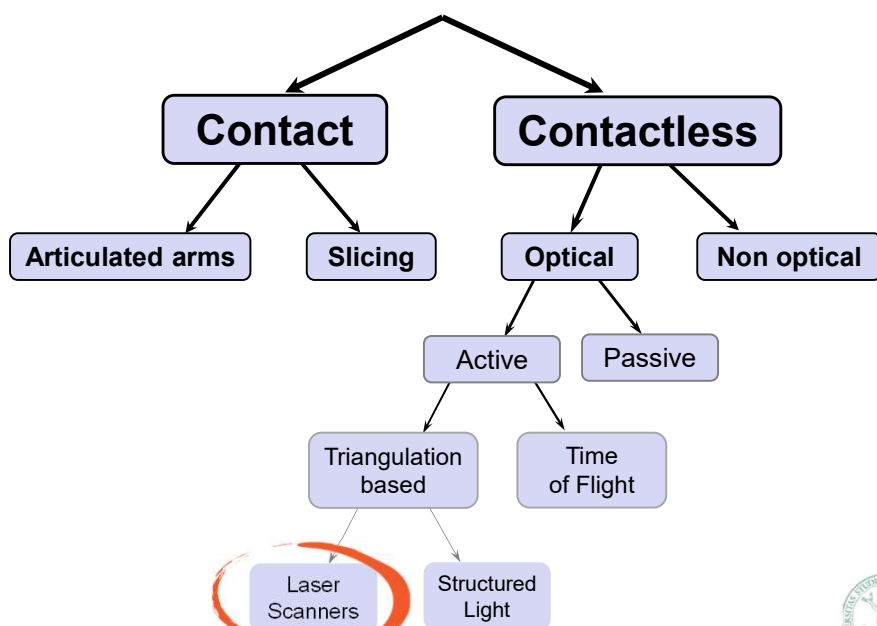
Time of flight: risultato

- ✓ Per ogni direzione (su una griglia 2D), si ottiene una profondità
- ✓ Il risultato di questo procedimento è dunque una depth image (o «range scan»)
- ✓ Vedi lezione corrispondente

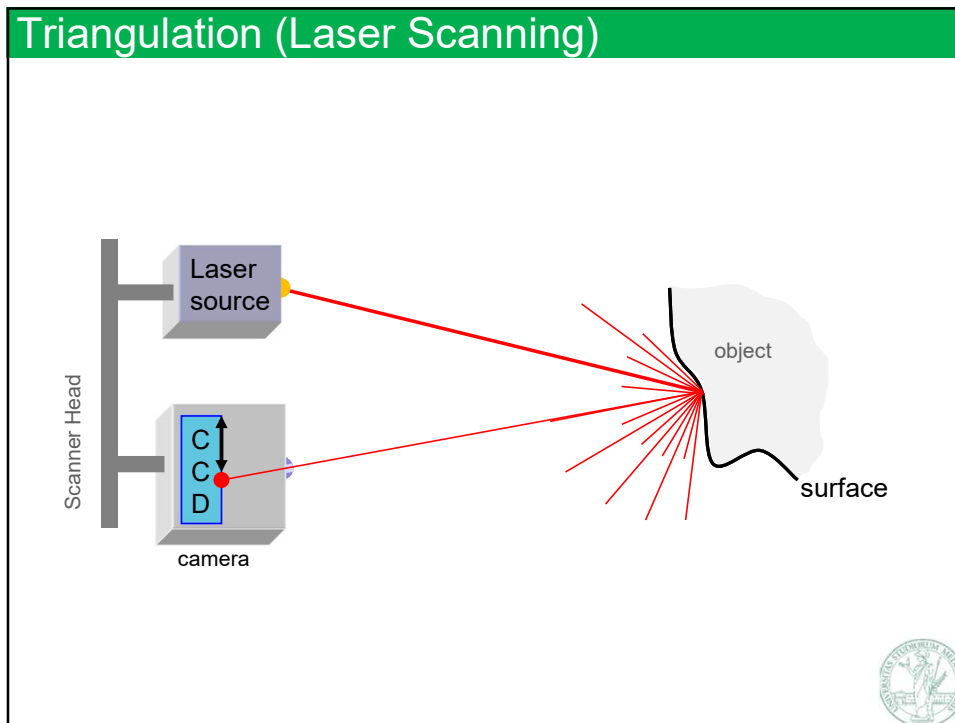


10

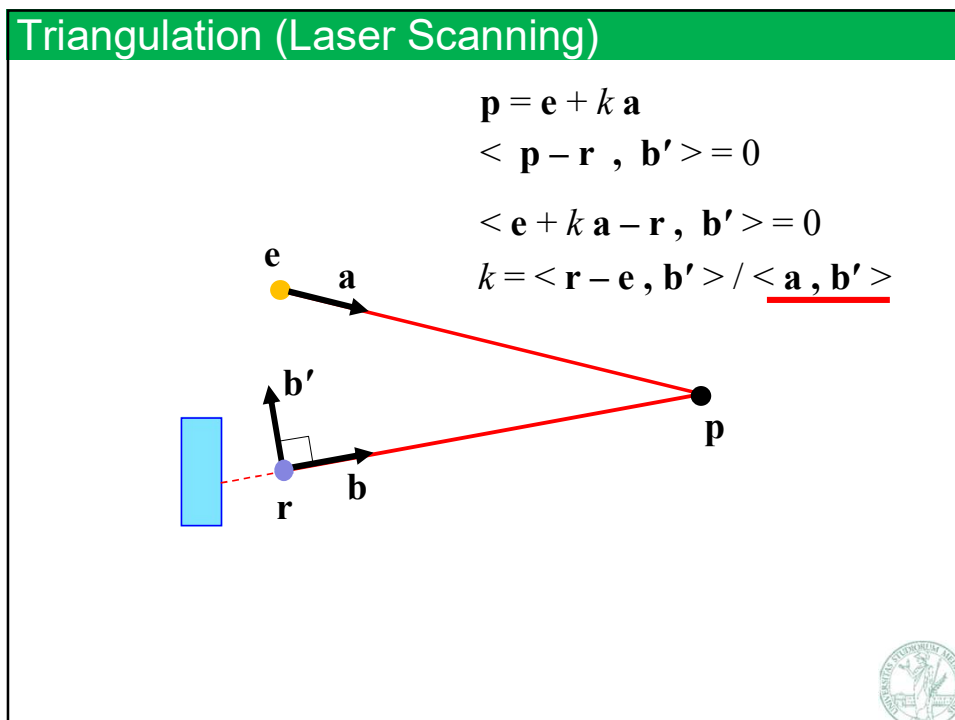
3D acquisition techniques: a taxonomy



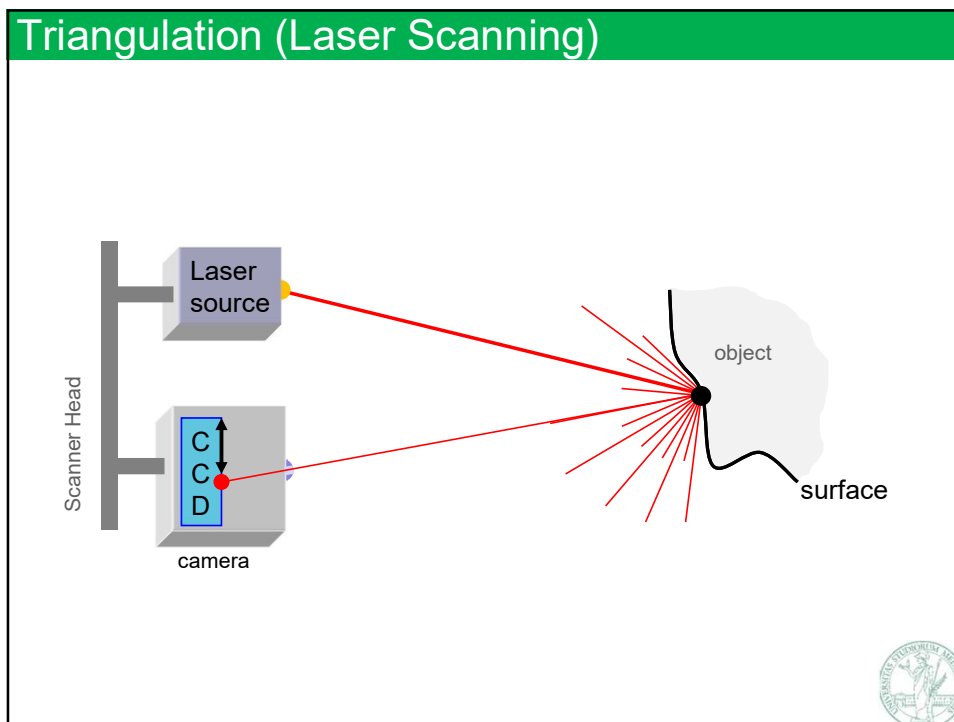
21



22



23



24

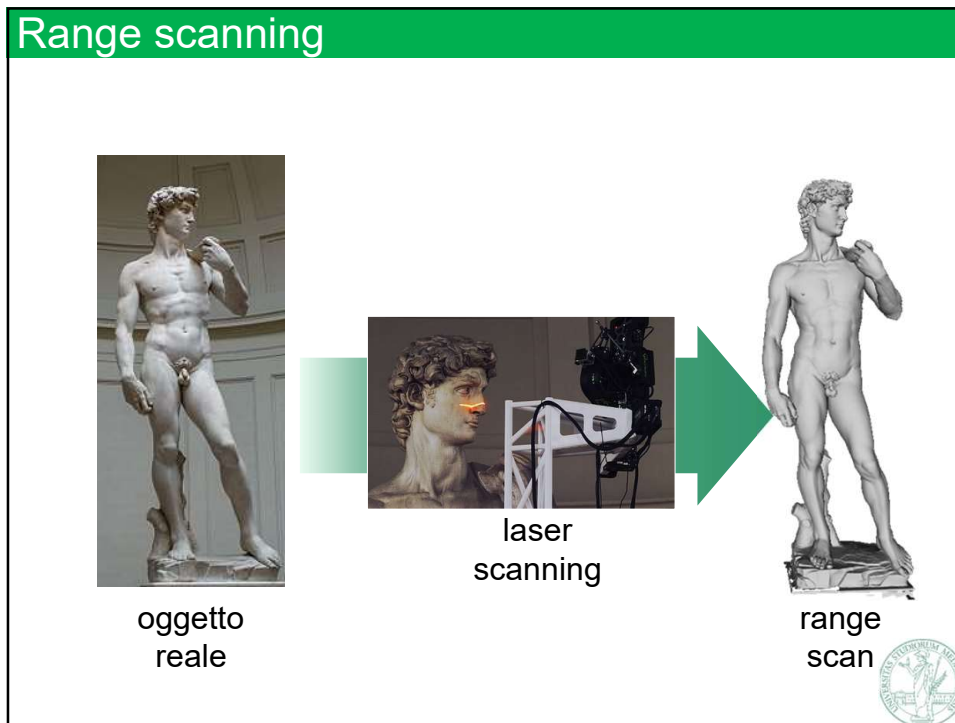
it's a 2D problem (all happens in a plane)

p is on outgoing ray $\rightarrow p = e + k a$
 p is on incoming ray $\rightarrow \langle p - r, b' \rangle = 0$
 substitute $\rightarrow \langle e + k a - r, b' \rangle = 0$
 and solve for k $\rightarrow k = \langle e - r, b' \rangle / \langle a, b' \rangle$

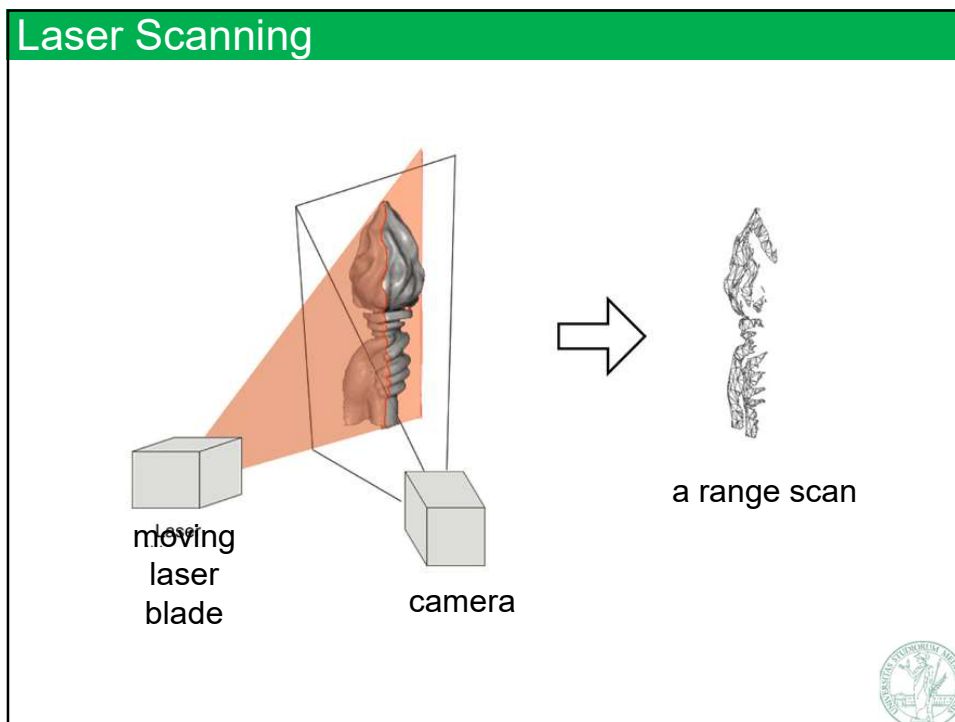
e : emitter (2D point)
 r : receiver (2D point)
 d : direction out (2D unit dir)
 b : direction in (2D unit dir)
 b' : orthogonal vector b (2D dir)
 p : [unknown] hit pos (2D pos)
 k : [unknown] pos of p along ray (scalar)

$\langle v_0, v_1 \rangle$: dot product

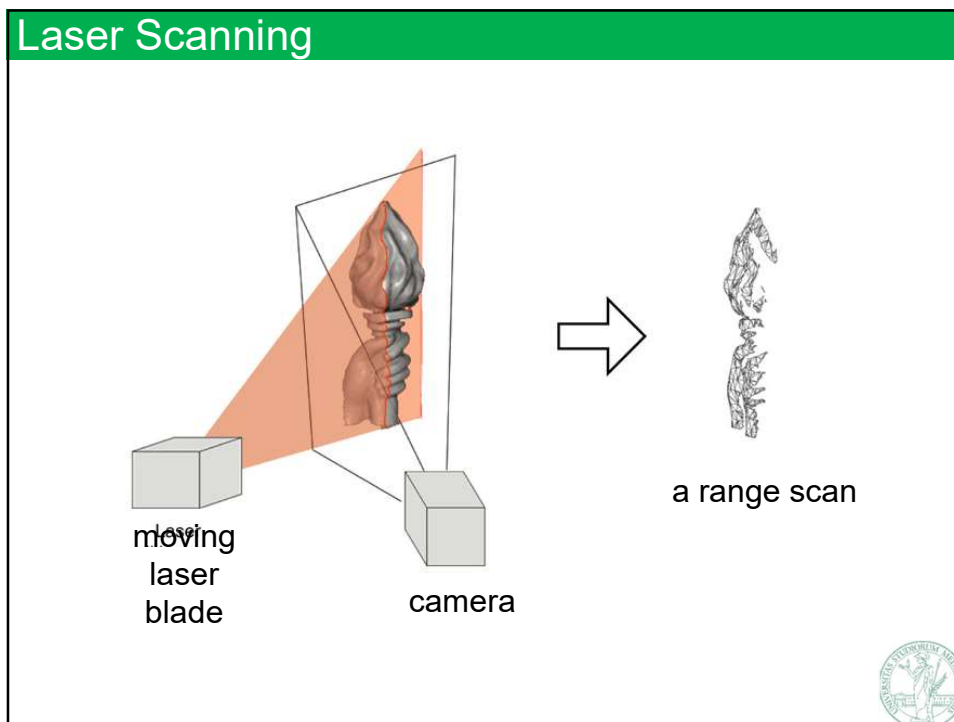
25



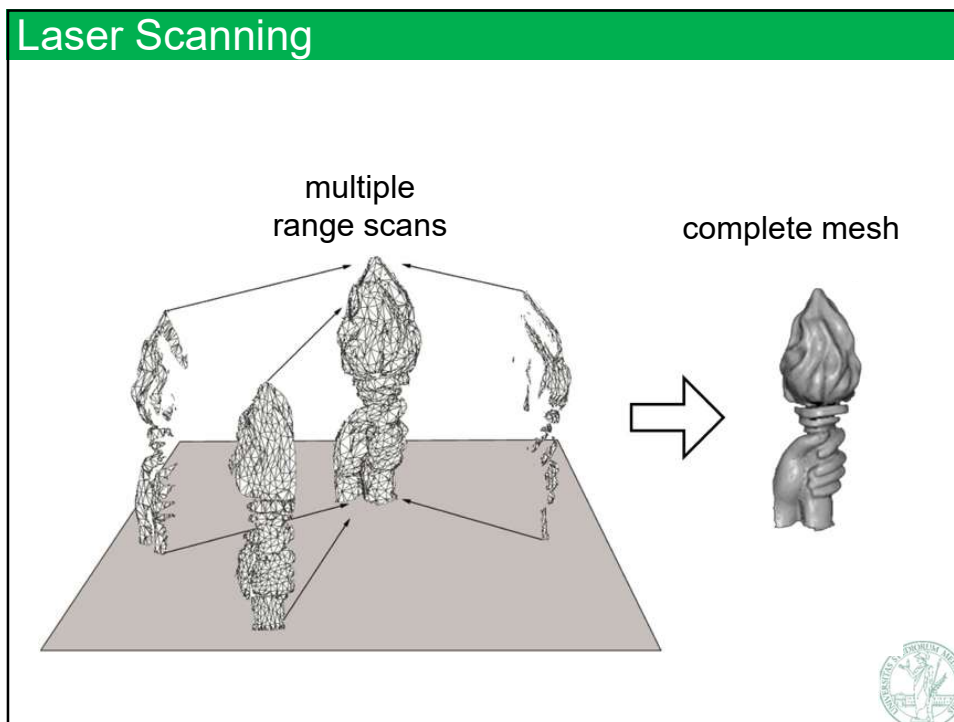
26



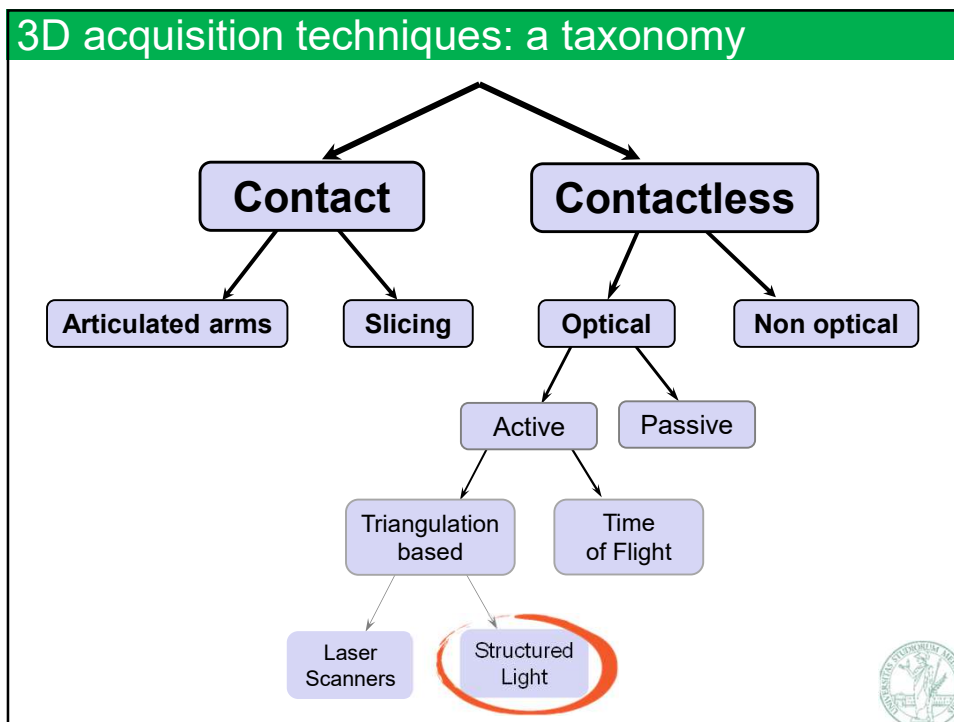
27



28



29



30

Structured Light

✓ Idea: replace the laser blade sweeping the object with a pattern of light sent from a projector
⇒ then still proceed by triangulation

The image shows a structured light setup on the left, consisting of a camera and a projector. On the right, there is a 3D model of a hand, with a color-coded depth map showing the surface geometry. The model is divided into red and blue regions, representing different depths or surface features.

31

Structured Light at home

- Equipment is cheap!
 - projector, camera
- Many cheap / DIY projects:
 - Structured-light project on Google Projects
<http://code.google.com/p/structured-light/>
- and, Microsoft Kinect!



32

comparing technologies (typical values)

Triangulation

(Laser scanning / structured light)

- Small/medium scale artifacts (e.g. good for statues)
- Small/medium workspace ($<1\text{m}^3$)
- More occlusions (from two rays)
- High accuracy ($<0.05\text{ mm}$)
- High sampling rates (0.2 mm)
- Fast (1 shot in $\sim 1\text{-}2\text{ sec}$)

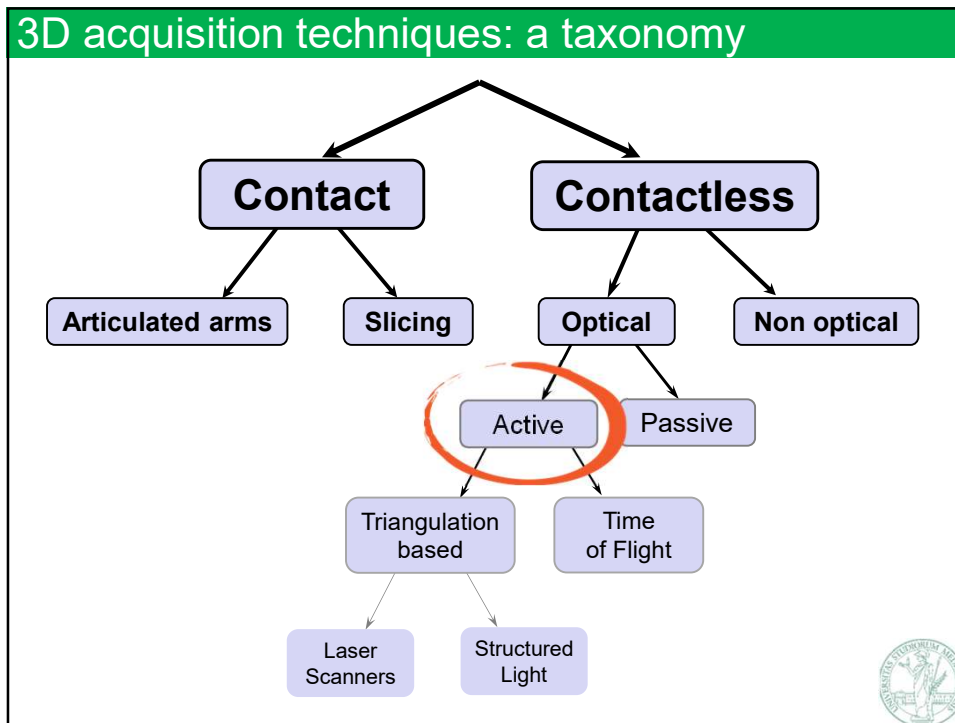


Time of flight

- Large scale artefacts (e.g. good for architectures)
- Wide workspace (several meters)
- Fewer occlusion (one ray only)
- Medium accuracy ($\sim 4\text{-}10\text{ mm}$)
- Medium sampling rates (10 mm)
- Slow (1 shot in $\sim 10\text{-}20\text{ min}$)



33

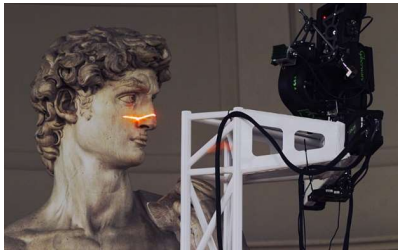


34

A pioneering case

Digital Michelangelo Project

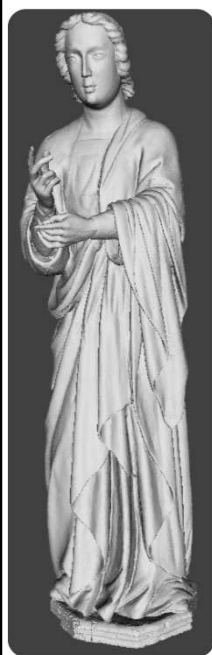
Stanford Univ.
Florence ~2000



- 1 year
- 0.29mm sampling rate
- 250 gigabytes of data
- subject: 10 statues + other minor objects
- laser scanners (Cyberware) on robotic arms (+ other techniques)

35

Today it is a more consolidated tech



Results:

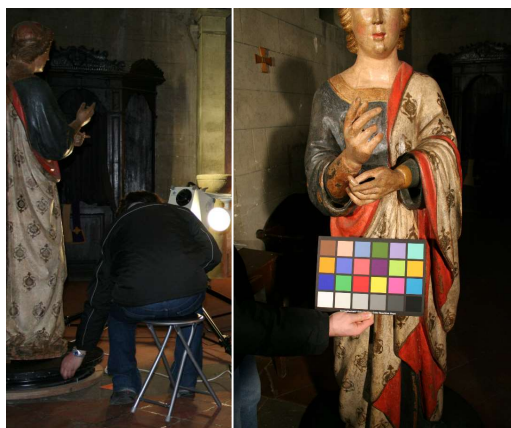
~ 3 millions polygons mesh:
~ 1.5 millions x,y,z samples
with
~ 6 millions color samples

Accuracy: <0.3 mm



36

Today it is a more consolidated tech



Example:

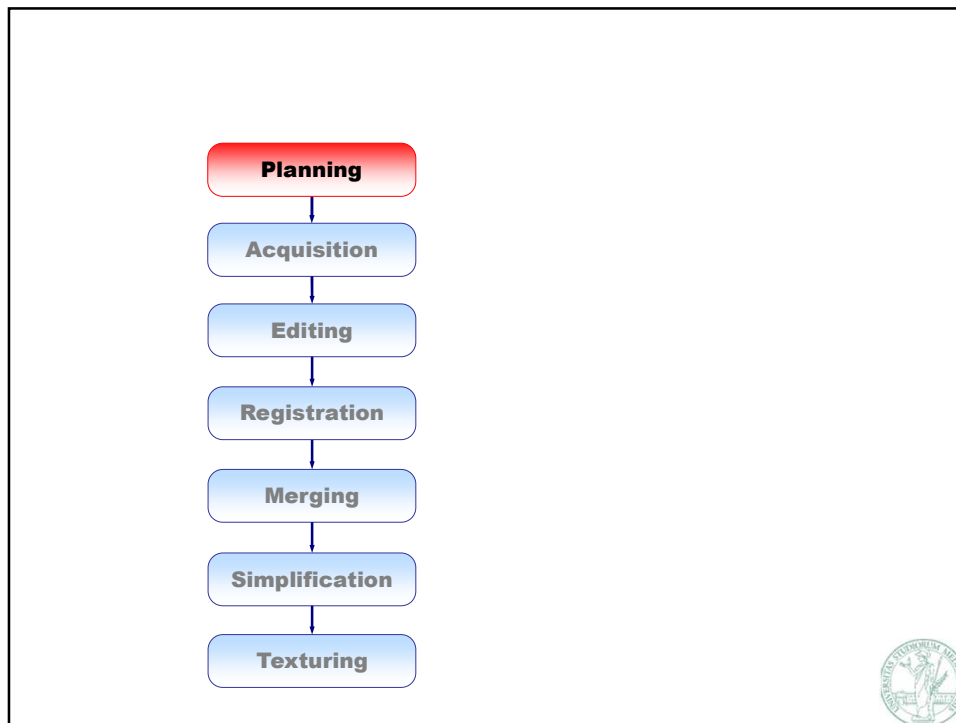
~8 h in field
200 range scans
(laser scanning),
70 photographs (for colors)

1.5 days in the lab
(processing pipeline)
of which:
~30 min of
computer processing...
the rest: manual
(exp. alignment)

By *expert* users



37



38

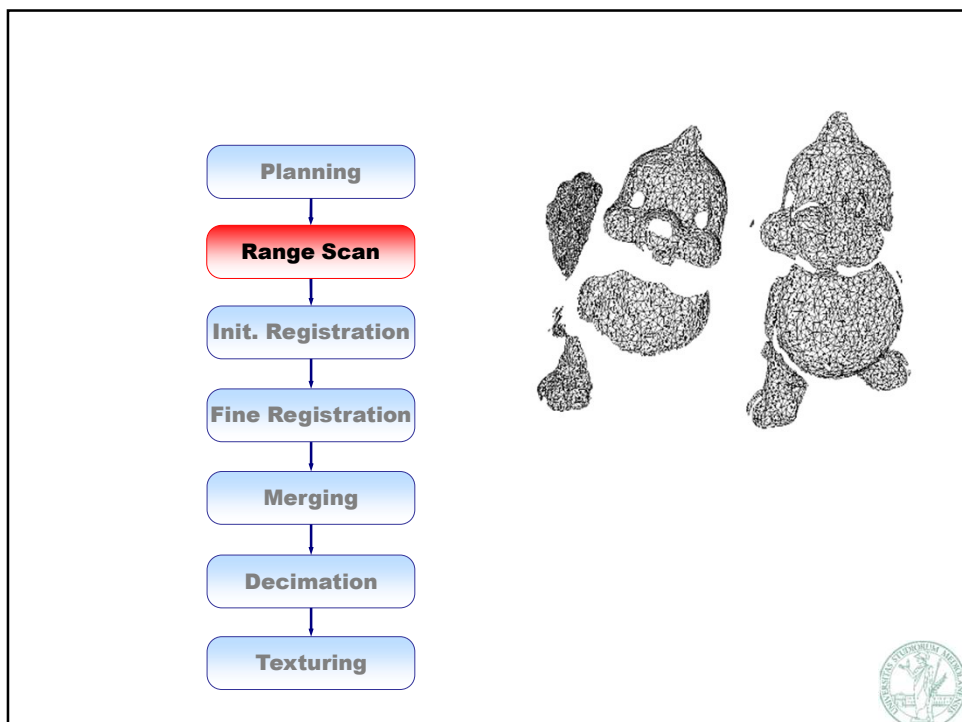
3D Scanning Pipeline: planning

- ✓ The task: choose a set of positions of the scan head such that:
 - ⇒ Every portion of the manifold surface is captured by *at least* one view
 - avoiding occlusions
 - avoiding grazing angles
 - ⇒ Pairs of adjacent scans have a sufficient overlapping region (necessary to align, see later)
 - ⇒ The number of scans is minimized
 - ⇒ It is actually possible to place the scan head there (e.g. no collisions with walls)
- ✓ The task requires expertise
 - ⇒ automatized approaches have been attempted

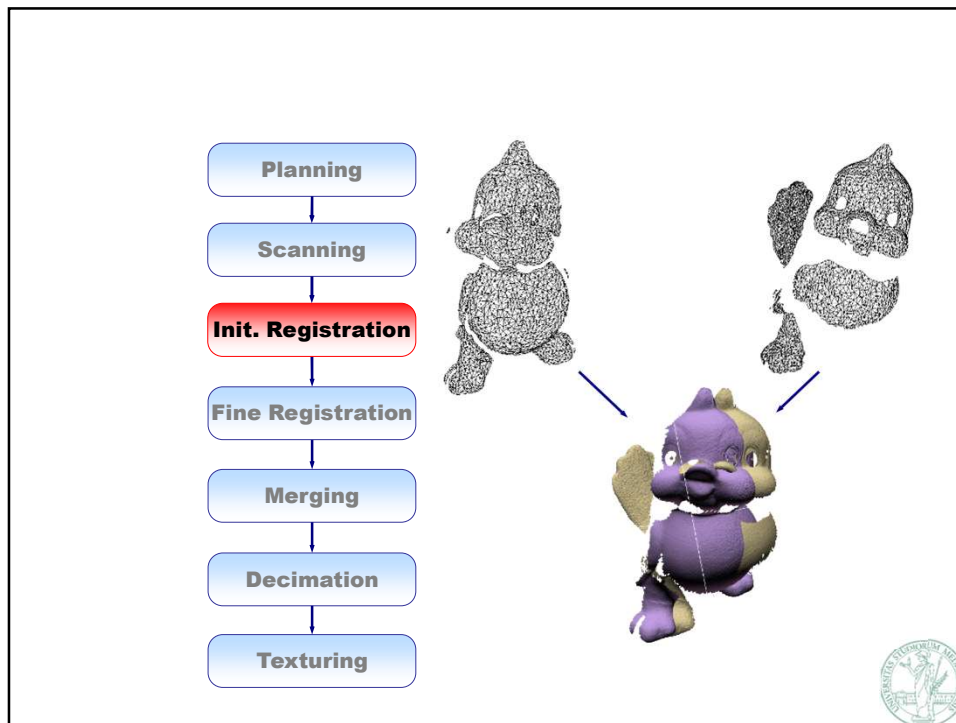
39



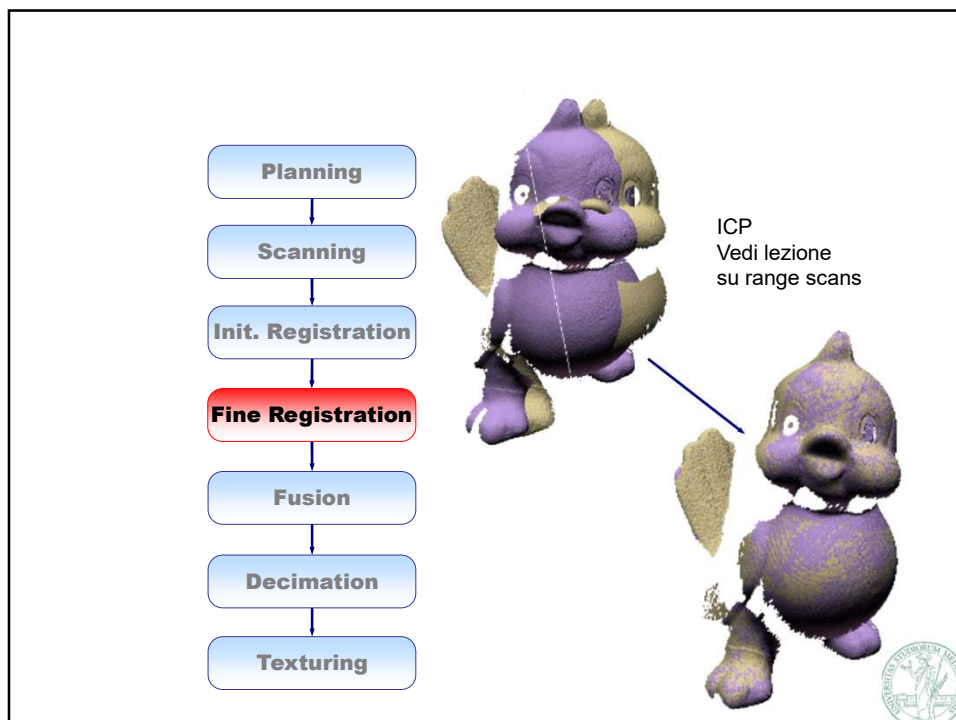
40



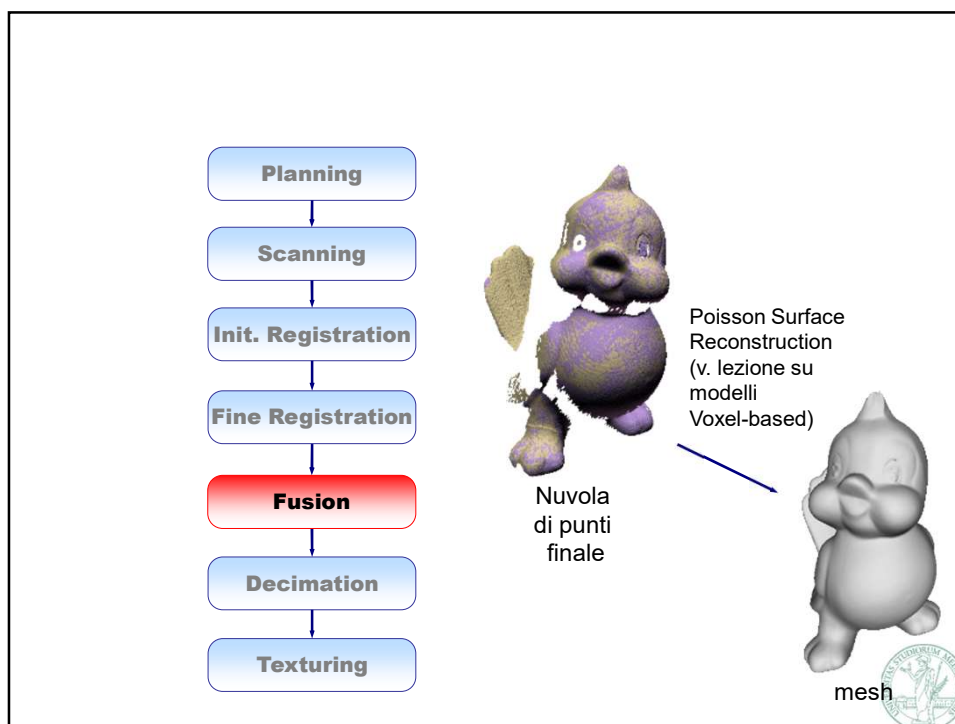
41



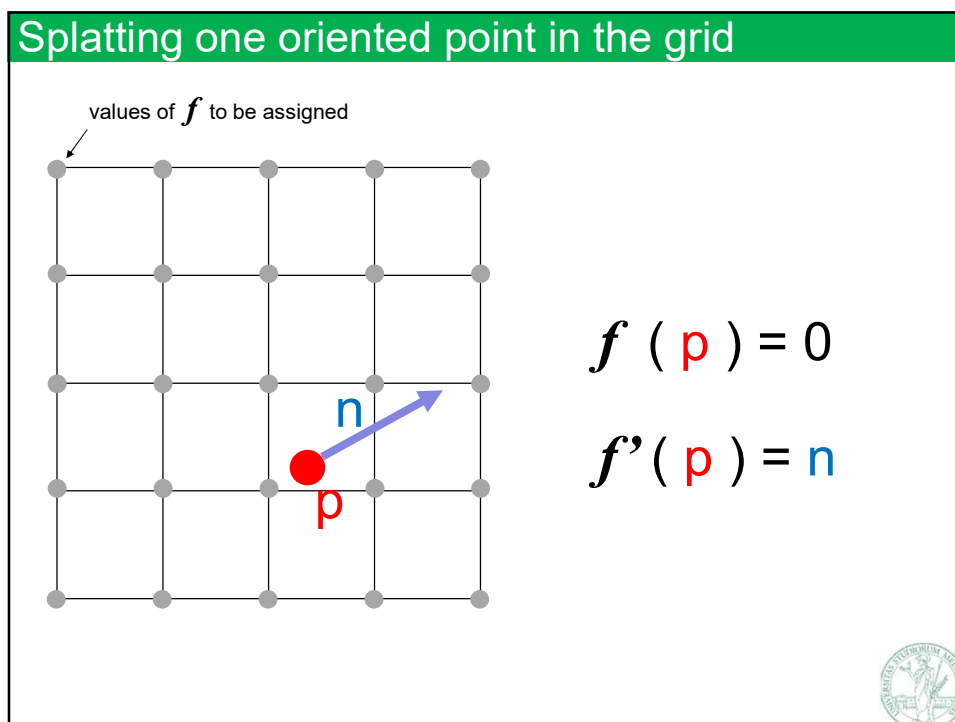
42



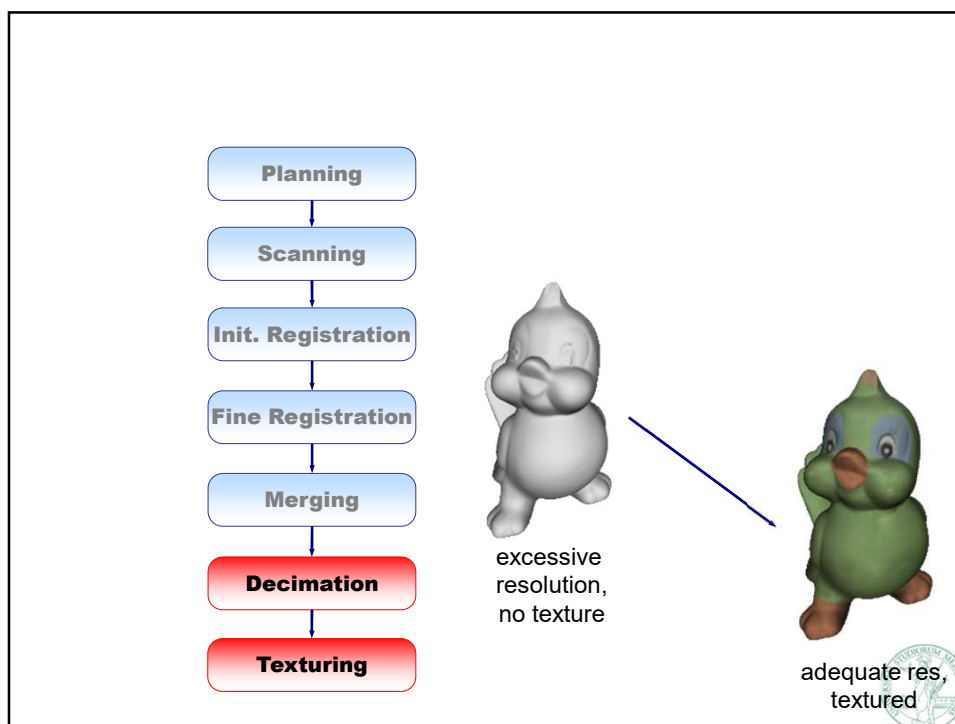
45



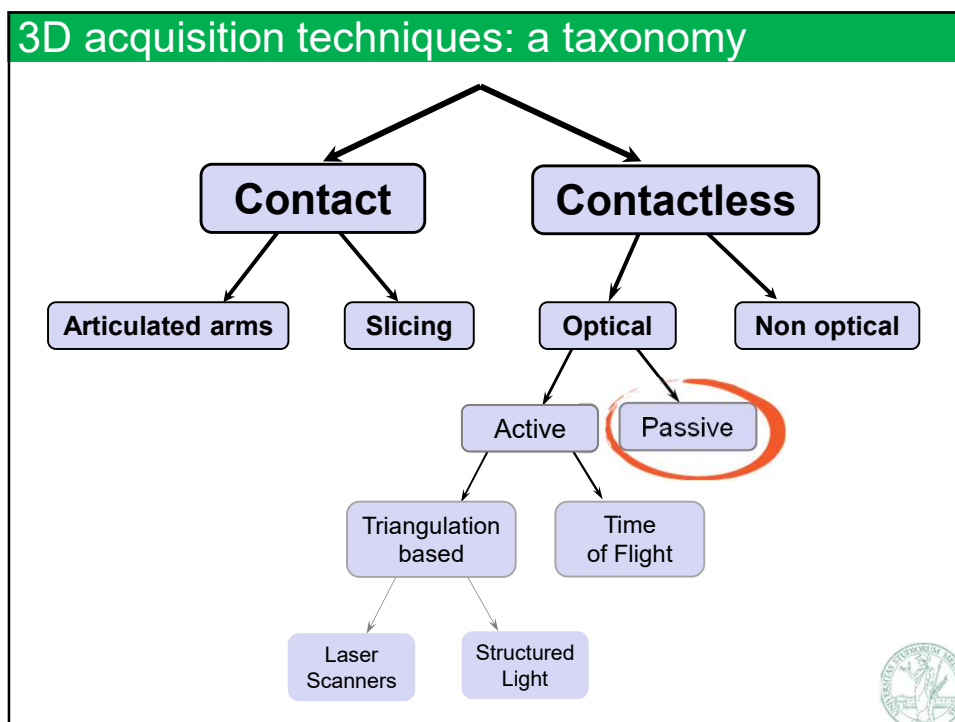
48



51

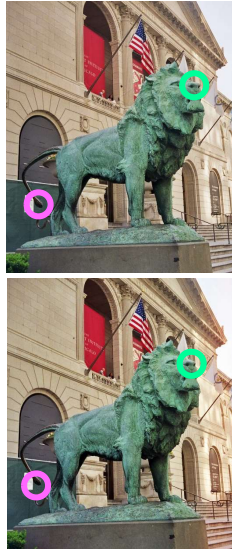


52



53

Stereo Vision



- ✓ Capture an image from slightly different positions (two cameras)
- ✓ For each point visible in both image: $\text{parallax} \Leftrightarrow \text{depth}$.



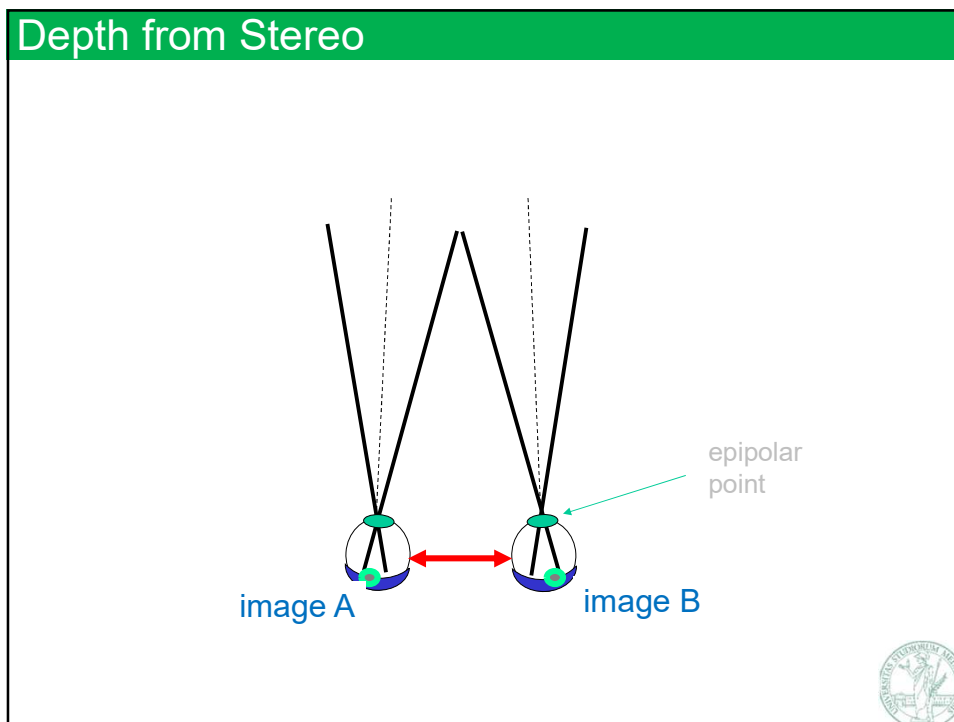
54

Depth from Stereo

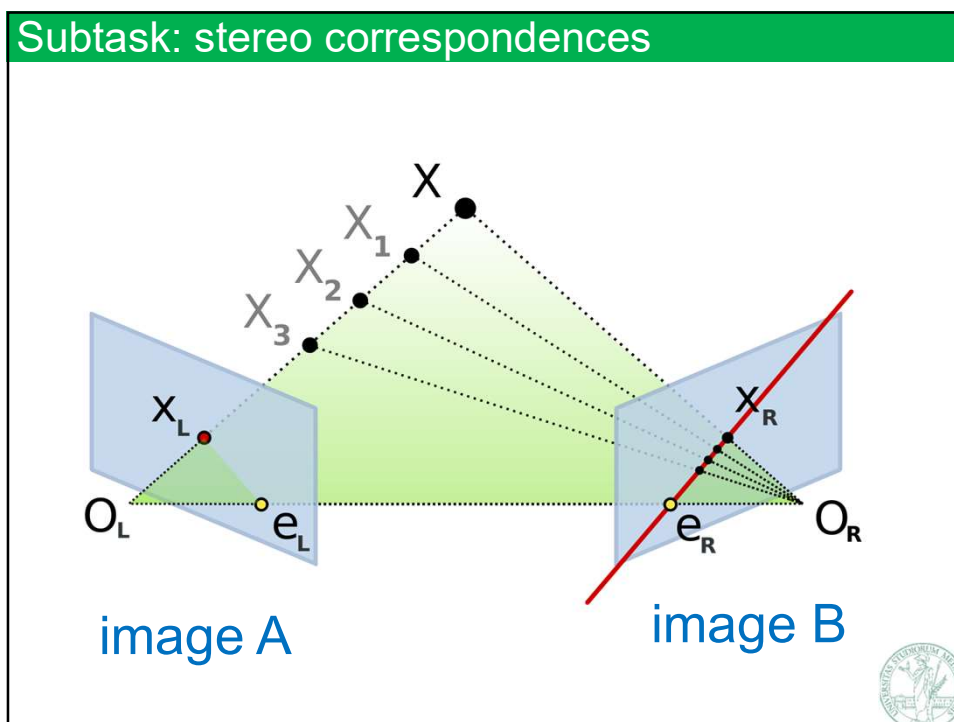
- ✓ Our brain does this in automatic!



55

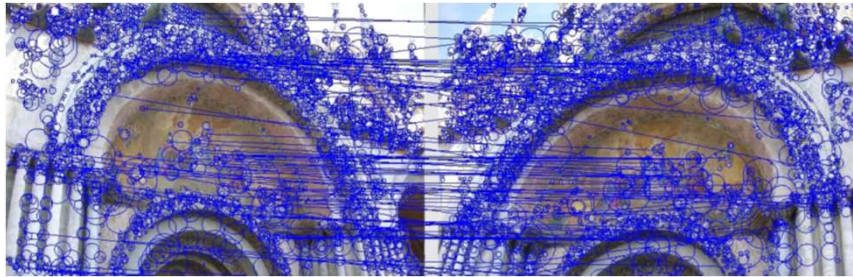


56



58

Dense stereo matching



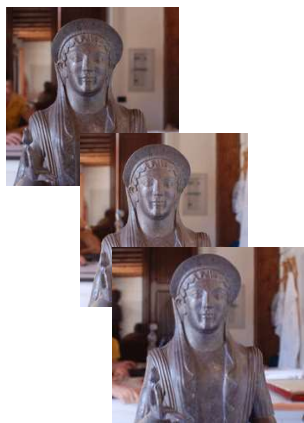
Do it for each pixel?

Result? A **range scan**!



59

Structure From Motion



Collezione di
molte immagini



Modello 3D
(una mesh)



62

Structure from Motion: un workflow pratico

✓ 1. Scattare molte foto all'oggetto

⇒ Per es, 30-500 scatti



...



63

Structure from Motion: un workflow pratico

✓ 2. Su ogni foto: identificare *feature points*

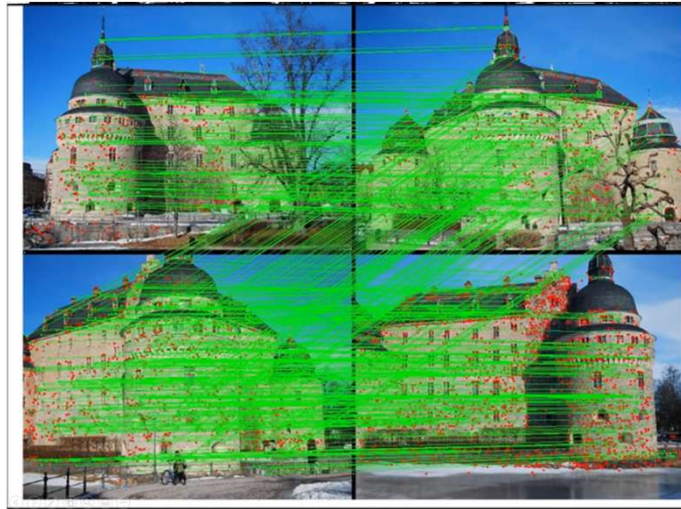
⇒ punti con un intorno che sia possibile rintracciare in altre immagini



64

Structure from Motion: un workflow pratico

- ✓ 3. trovare coppie di feature point corrispondenti fra le varie immagini (non tutti saranno corretti)



65

Structure from Motion: un workflow pratico

- ✓ 4. Global calibration:
un procedimento che consiste nel determinare simultaneamente:
 - ⇒ Di ogni feature point: la posizione 3D
 - ⇒ Di ogni fotografia:
 - * La posizione di scatto
 - * L'orientamento di scatto

i parametri «estrinseci» della scatto
 - I parametri interni usati come
 - * La lunghezza focale
 - * Altri dati relativi a l'ottica usata

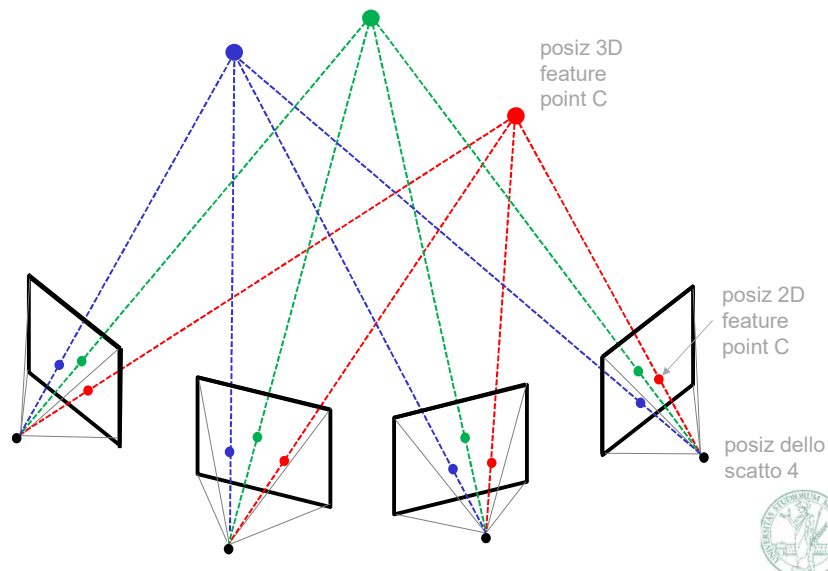
i parametri «intrinseci» dello scatto, a volte estraibili dai metadati associati all'immagine (exif)
- ⇒ In modo che i feature points siano proiettati in ogni immagine nella posizione 2D rilevata



66

Structure from Motion: a workflow

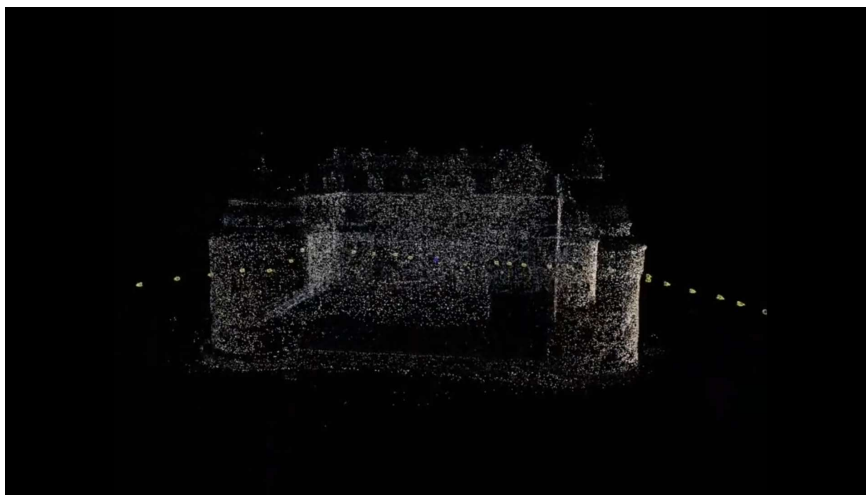
✓ 4. Global calibration



67

Structure from Motion: un workflow pratico

✓ 4. Global calibration: risultati



Structure from Motion: a workflow

- ✓ 5. Dense 3D reconstruction
 - ⇒ Effettuare una ricostruzione densa di depth images da coppie di immagini vicine
 - ⇒ Risultato: una nuvola di punti densa
- ✓ Nei passi successivi si ricostruisce una mesh 3D, con texture
 - ⇒ A partire dalla nuvola di punti ottenuta



69

Structure from Motion / Photogrammetry

- ✓ Esistono molti software commerciali ed open source per ottenere questi risultati



Metashape



Meshroom



3DF ZEPHYR
The Complete Photogrammetry Solution

COLMAP



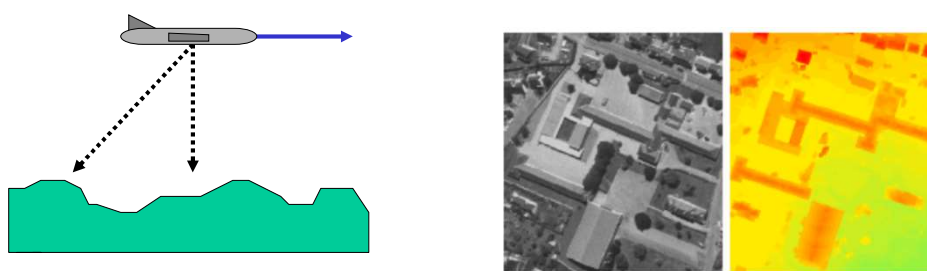
Regard3D



70

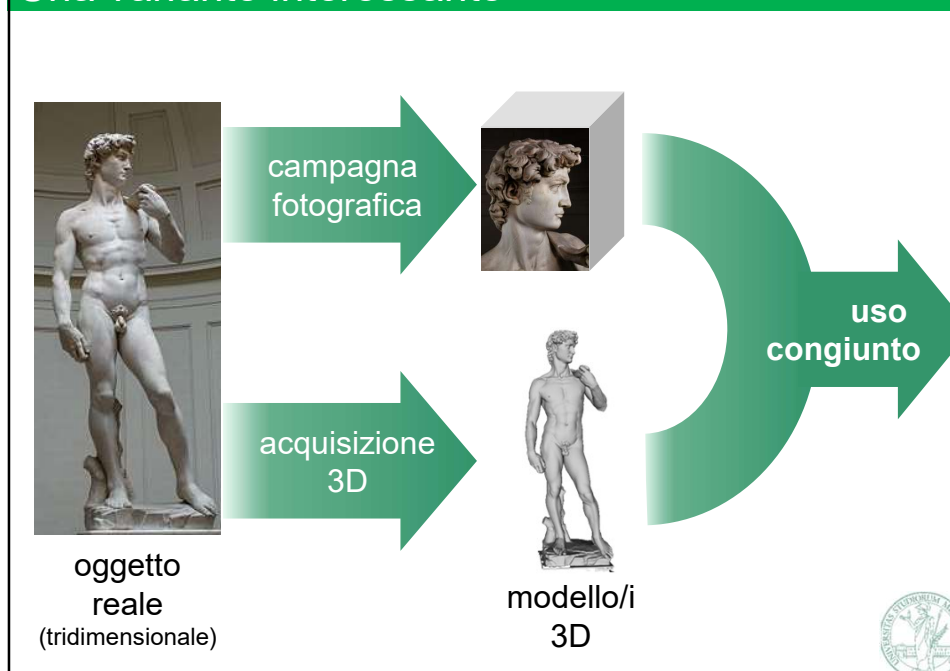
Aerial / Satellite

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



72

Una variante interessante



74

2D images + 3D models = perfect combo

- ✓ 3D models. Good because:
 - ⇒ they are viewable from any direction
 - ⇒ they are relightable
 - ⇒ they are navigable (spatial metaphors)
- ✓ 2D images. Good because:
 - ⇒ they provide context (incl. difficult to capture like e.g. sky, trees)
 - ⇒ they document time variations (e.g. day/night, seasons,
 - ⇒ they are browsable
 - ⇒ they are easy to capture
- ✓ Combination: best of the two worlds?



75

2D images + 3D models = perfect combo

Tool examples:

- ✓ **PhotoSynth**,
(Microsoft and Univ. of Washington)
[discontinued?]
- ✓ **PhotoCloud**,
(ISTI/CNR & Univ. Insubria)



76