Digital Geometry - 3D Scanning

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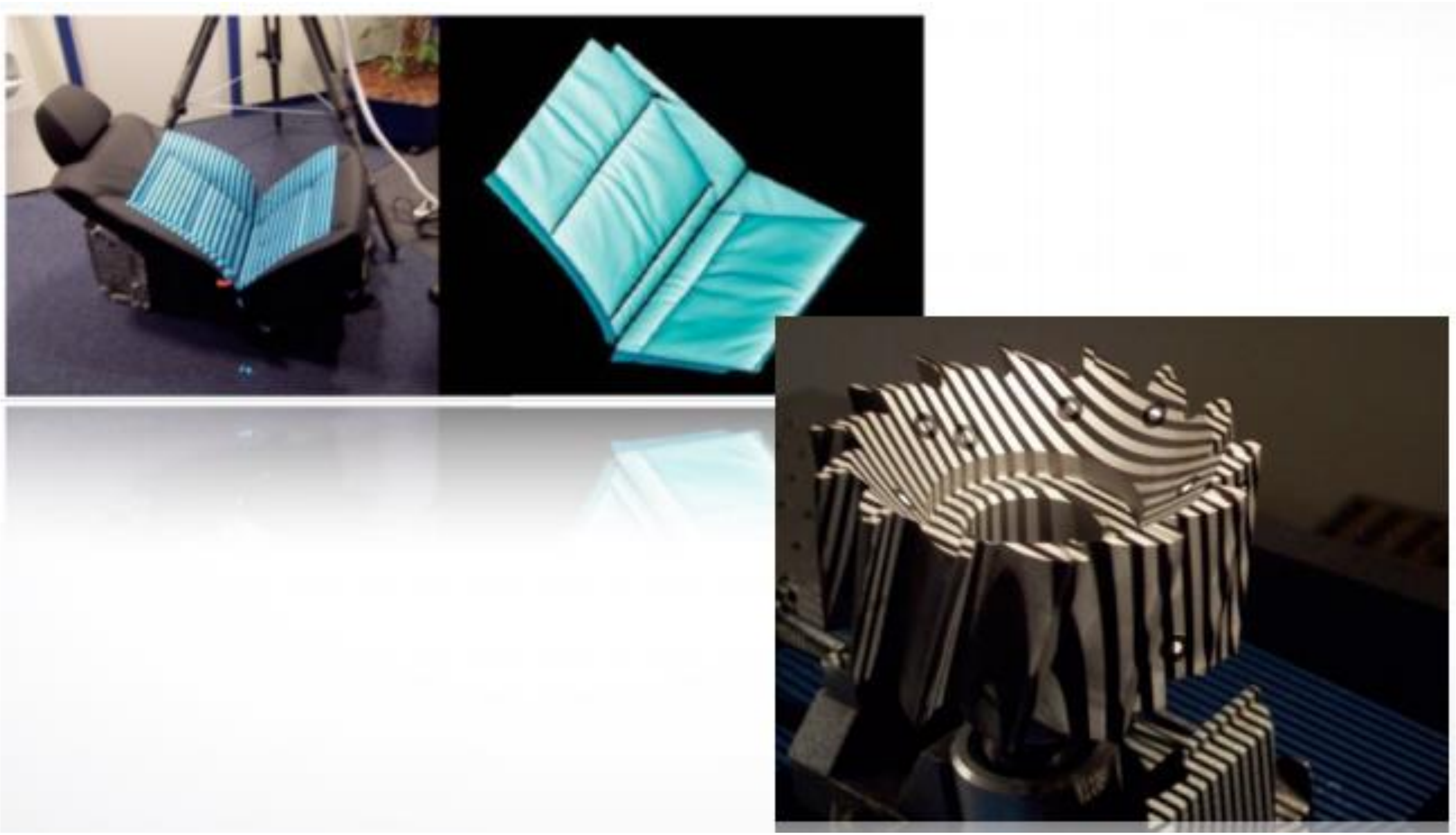
http://jjcao.github.io/DigitalGeometry/

Pleasure may come from illusion, but happiness can come only of reality.

Scanning Pipeline

Industrial Inspection

- Determine whether manufactured parts are within tolerances



Scanning Buildings

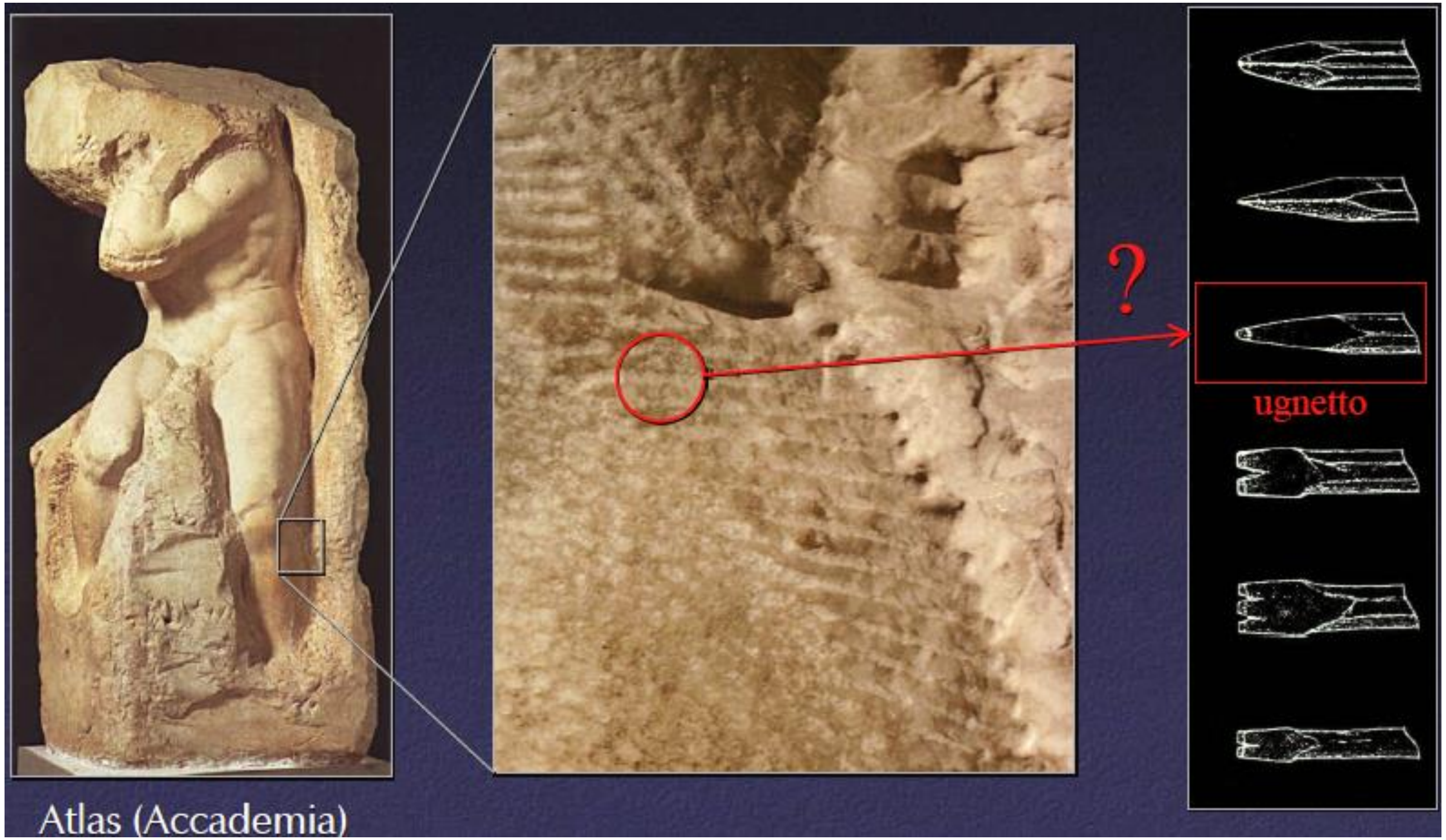
- Quality control during construction
- As-built models

Clothing

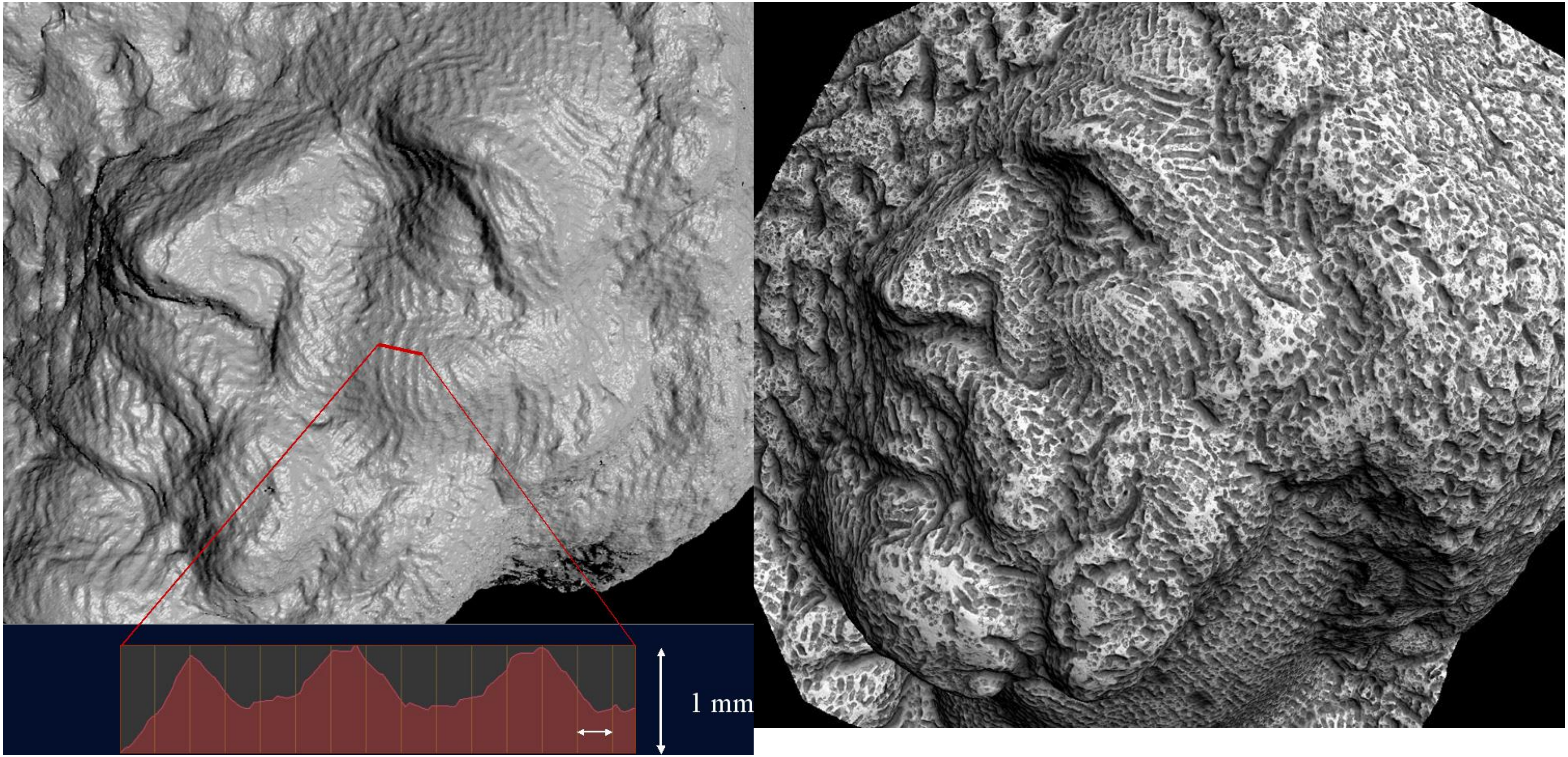
- Scan a person, custom-fit clothing
- U.S. Army; booths in malls

Digital Michelangelo Project

Why Capture Chisel Marks?

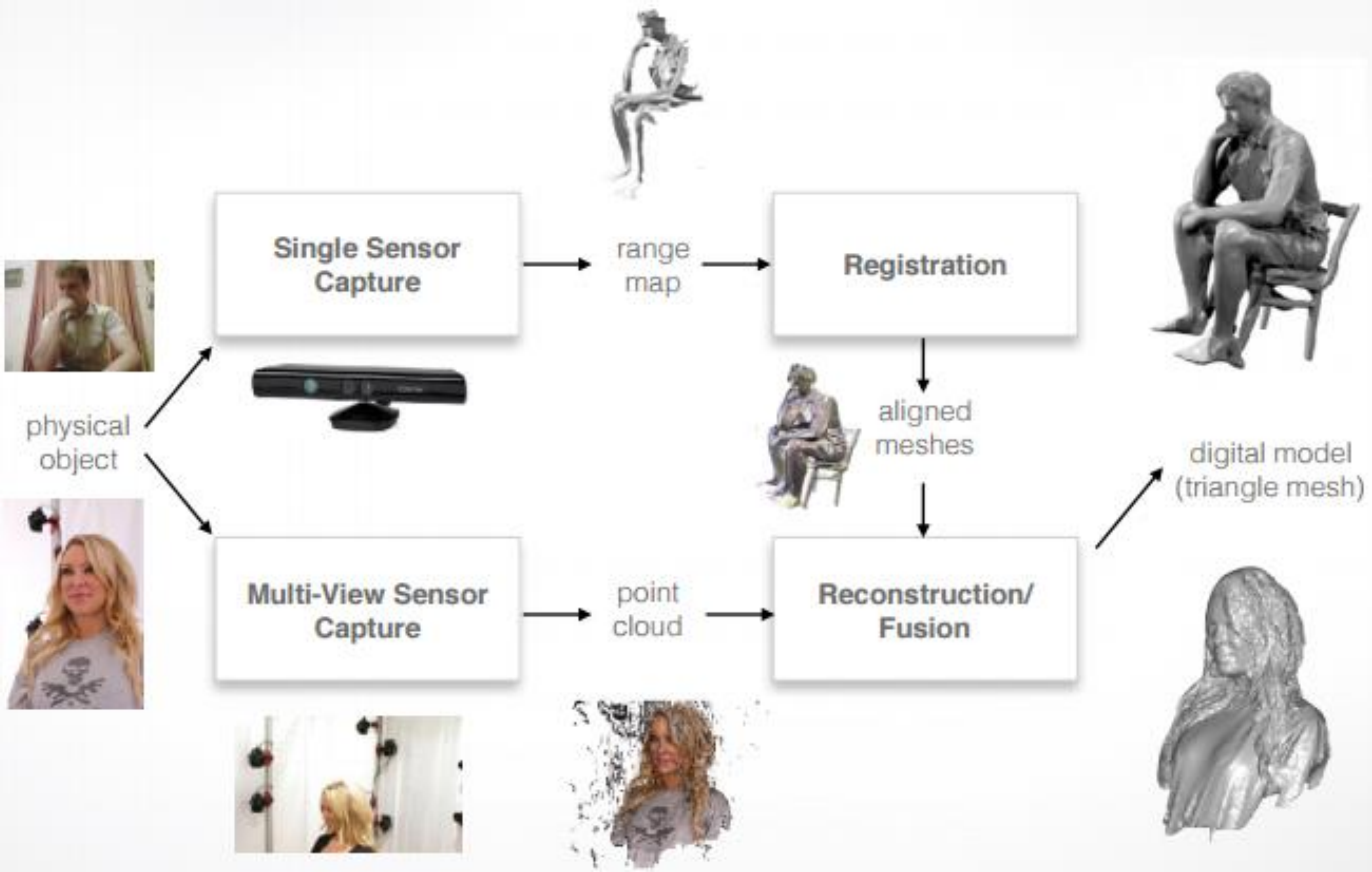


Why Capture Chisel Marks as Geometry?

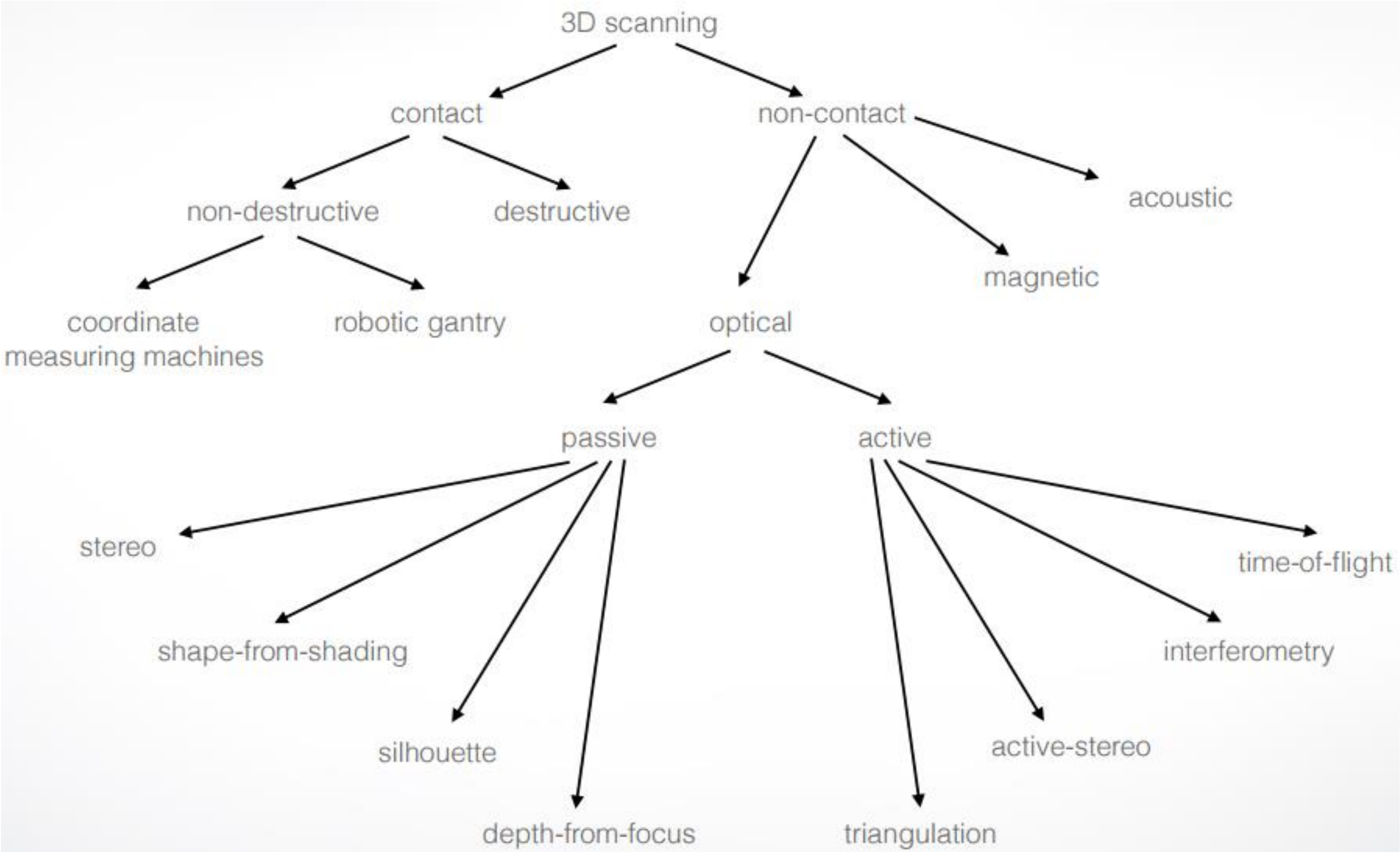


Medicine - Plan surgery on computer model, visualize in real time

Two Digitization Approaches

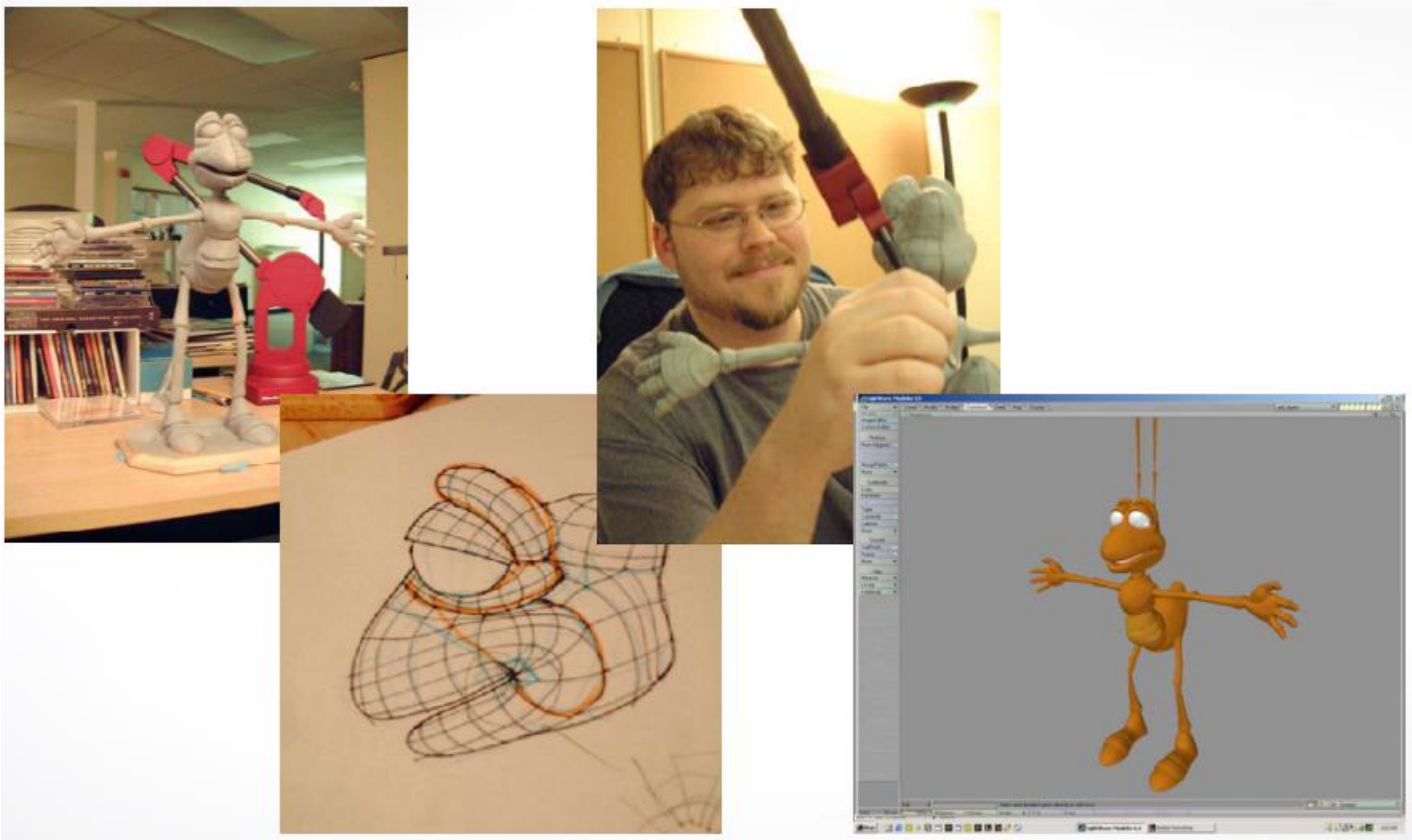


3D Scanning Taxonomy



Contact Scanners

Contact Scanners



[Immersion Microscribe, Magnetic Dreams]

Probe object by physical touch

- used in manufacturing control
- highly accurate

- reflectance independent (transparency!)
- slow scanning, sparse set of samples
- for rigid and non-fragile objects

[Zeiss]

Probe object by physical touch

- hand-held scanners

- less accurate
- slow scanning, sparse set of samples

[Immersion Microscribe]

Non-Contact Scanners

- Advantages
  - longer and safer distance capture
  - potentially faster acquisition
  - more automated

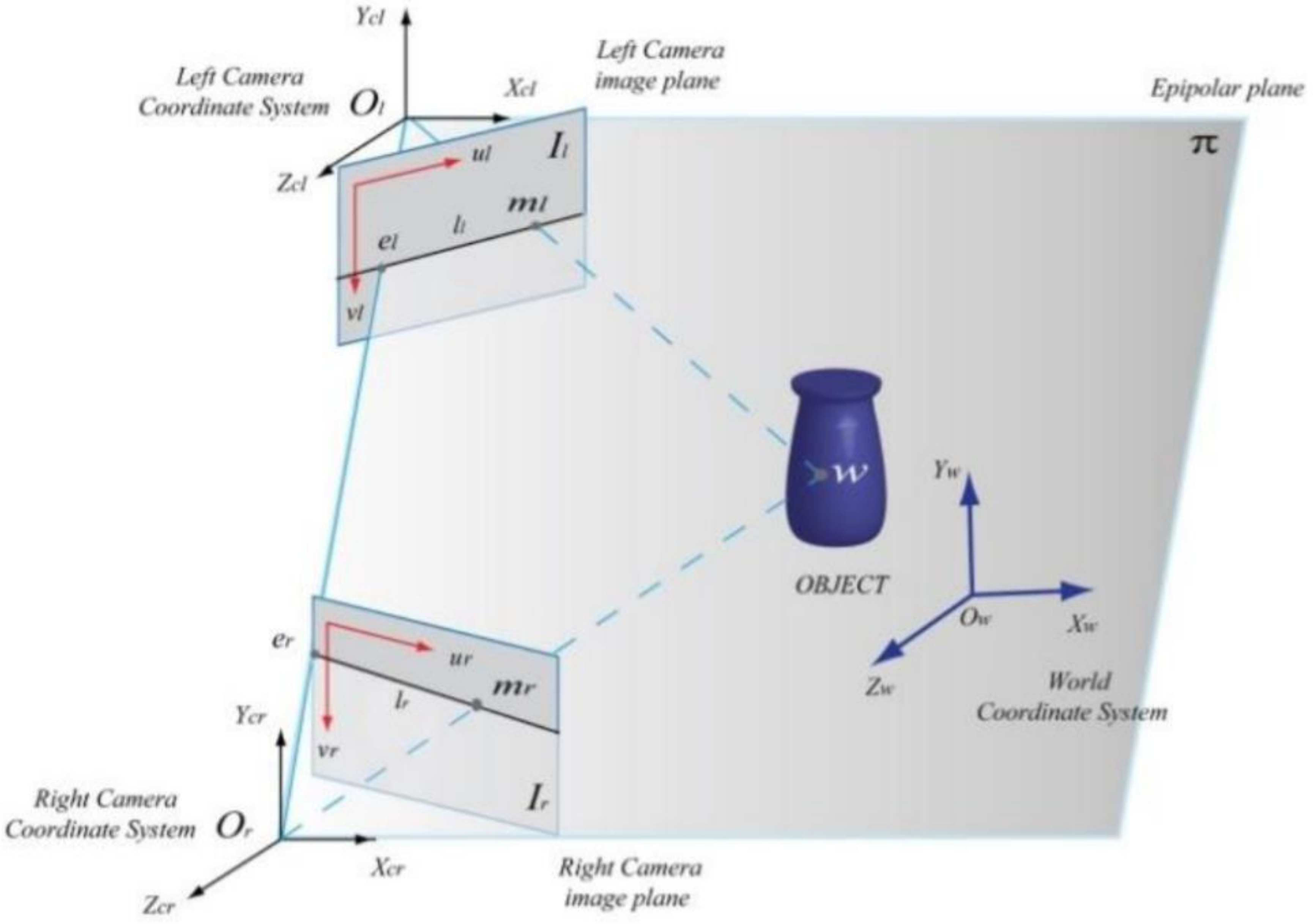
- Optical Approaches
  - most relevant and used (no special hardware requirements)
  - highly flexible
  - most accurate
  - passive and active approaches

Passive Optical Scanners

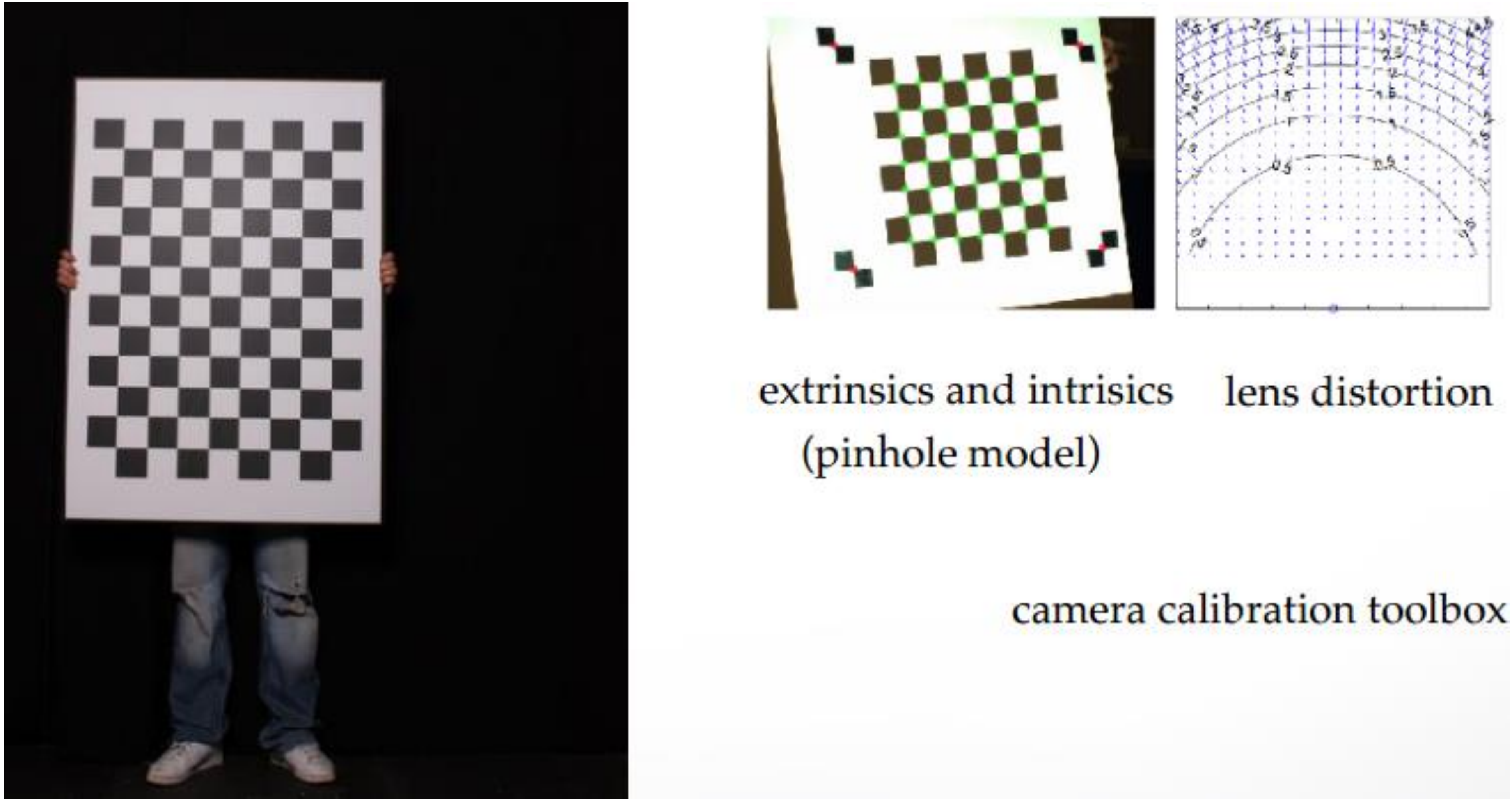
Passive

- exclusively based on sensor(s)
- computer vision-driven (stereo, multi-view stereo, structure from motion, scene understanding, etc.)
- main challenges: occlusions and correspondences
- typically assumes a 2D manifold with Lambertian reflectance

Passive Stereo



Calibration



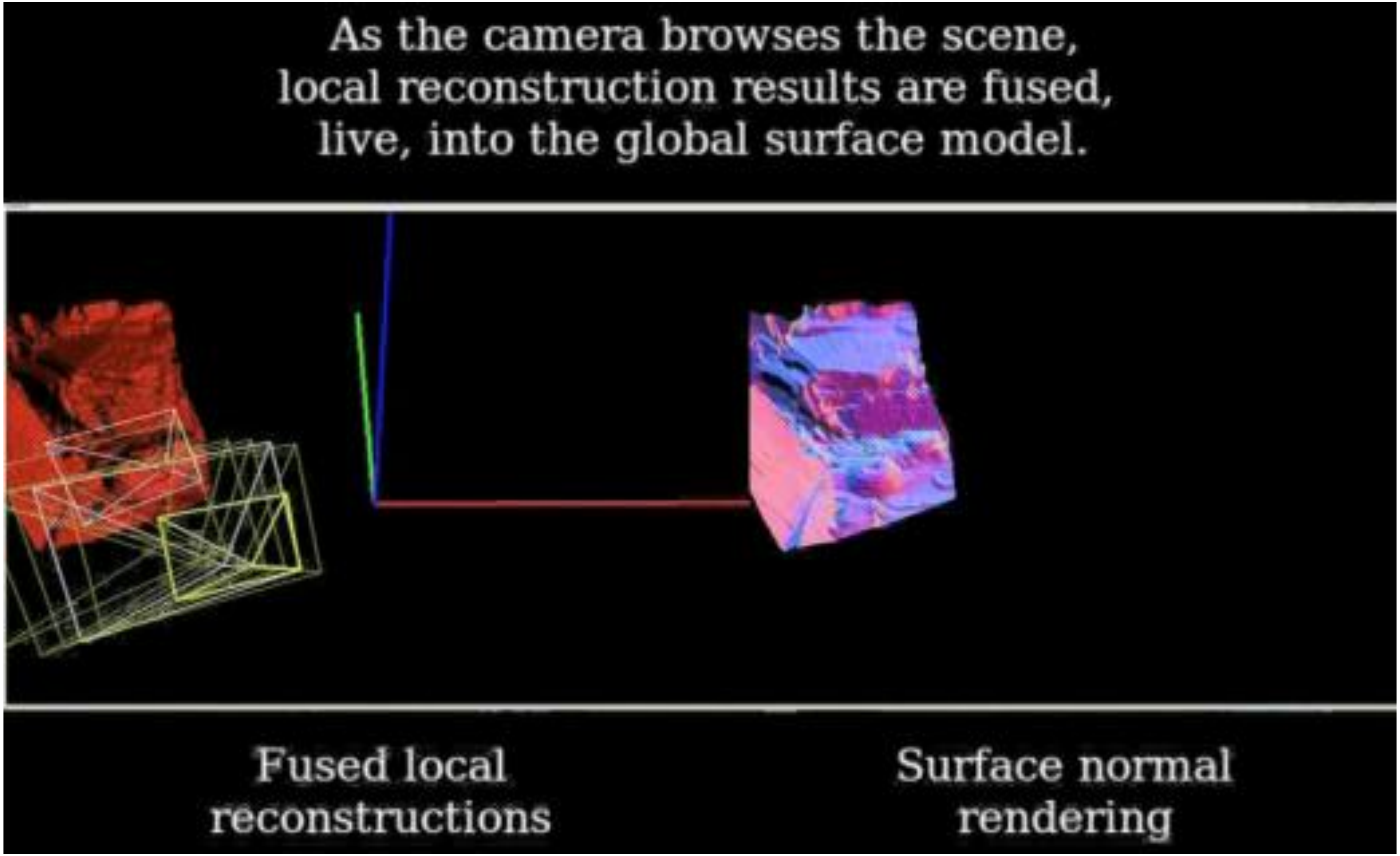
Multi-View Stereo

multi-view stereo

multi-view photometric stereo

Multi-View Stereo

Dense Structure from Motion



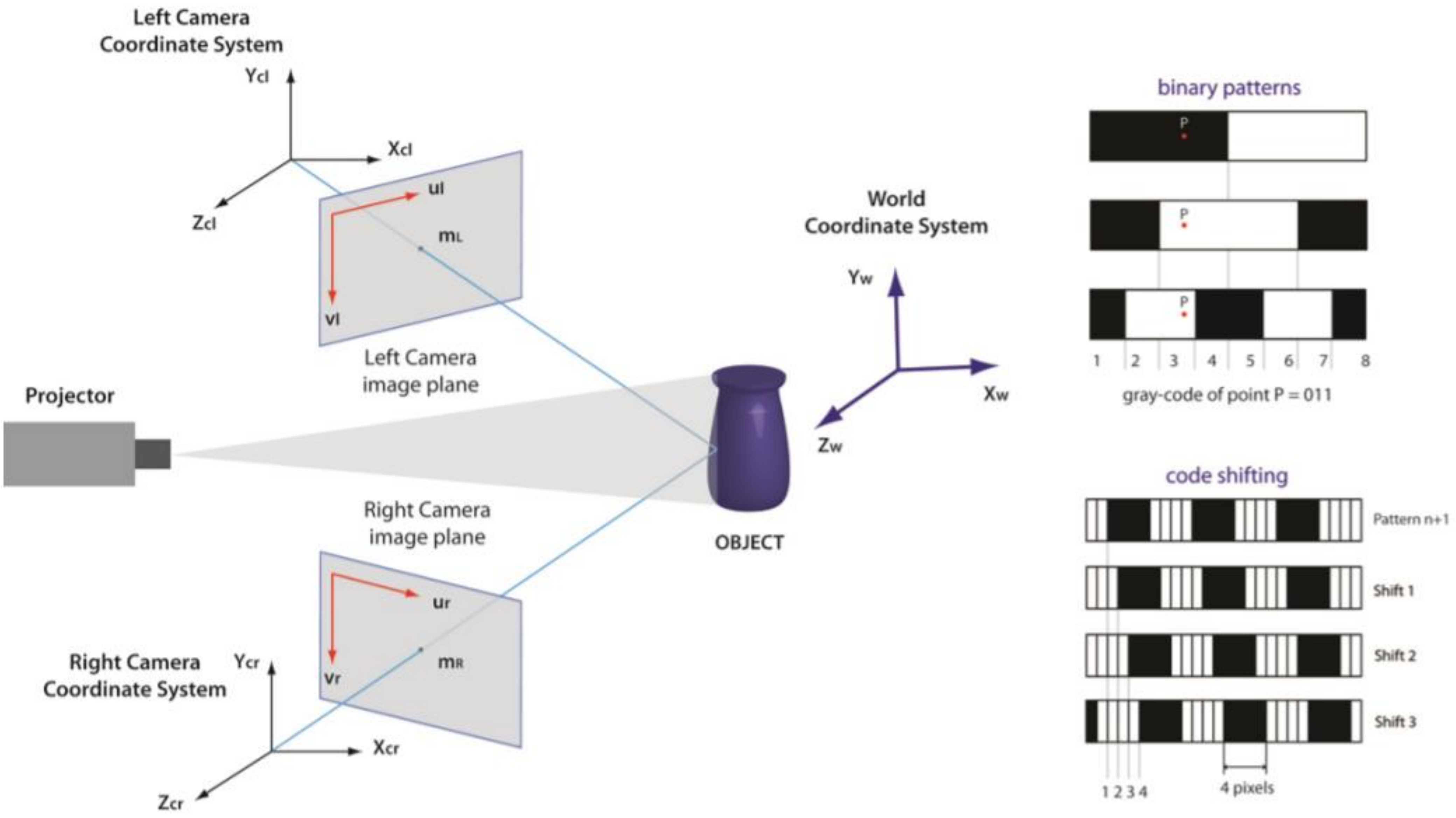
Active Optical Scanners

Active

- based on sensor and emitter (controlled EM wave)
- influence of surface reflectance to emitted signal
- correspondence problem simplified (via known signal) → less computation (realtime?)

- examples (laser, structured light, photometric stereo)
- high resolution and dense capture possible, even for texture poor regions
- more sensitive to surface reflection properties (mirrors?)

Active Stereo

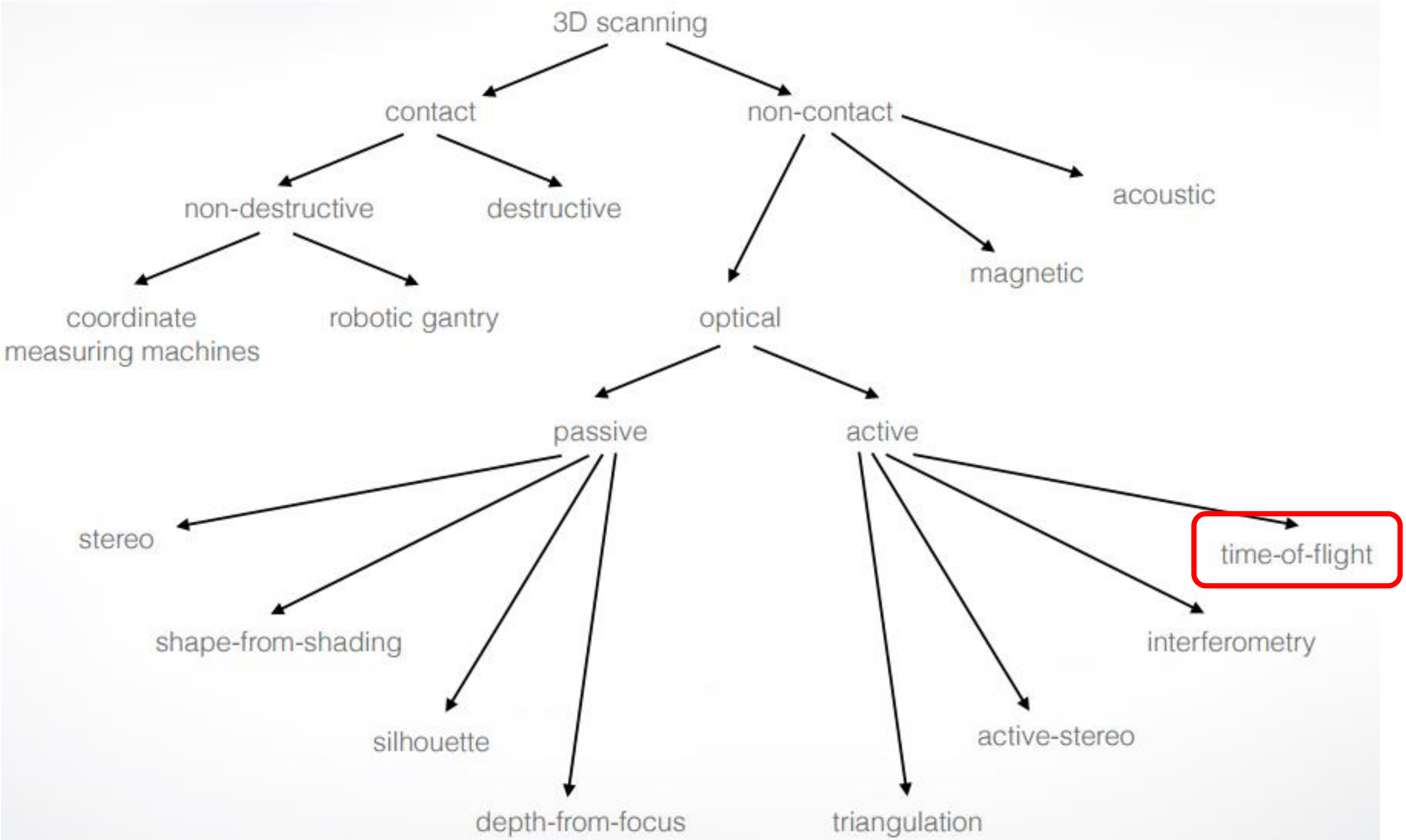


Photometric Stereo

Lightstage 6 (USC-ICT)

8 Normal Maps / Frame

3D Scanning Taxonomy



Time-of-Flight Cameras

- Probe object by laser or infrared light
  - Emit pulse of light, measure time till reflection from surface is seen by a detector
  - Known speed of light & round-trip time allows to compute distance to surface

- Laser LIDAR
  - Light Dectection and Ranging
  - Good for long distance scans
  - 6mm accuracy at 50 m distance

[Leica]

Time-of-Flight Cameras

- Probe object by laser or infrared light
  - Emit pulse of light, measure time till reflection from surface is seen by a detector
  - Known speed of light & round-trip time allows to compute distance to surface

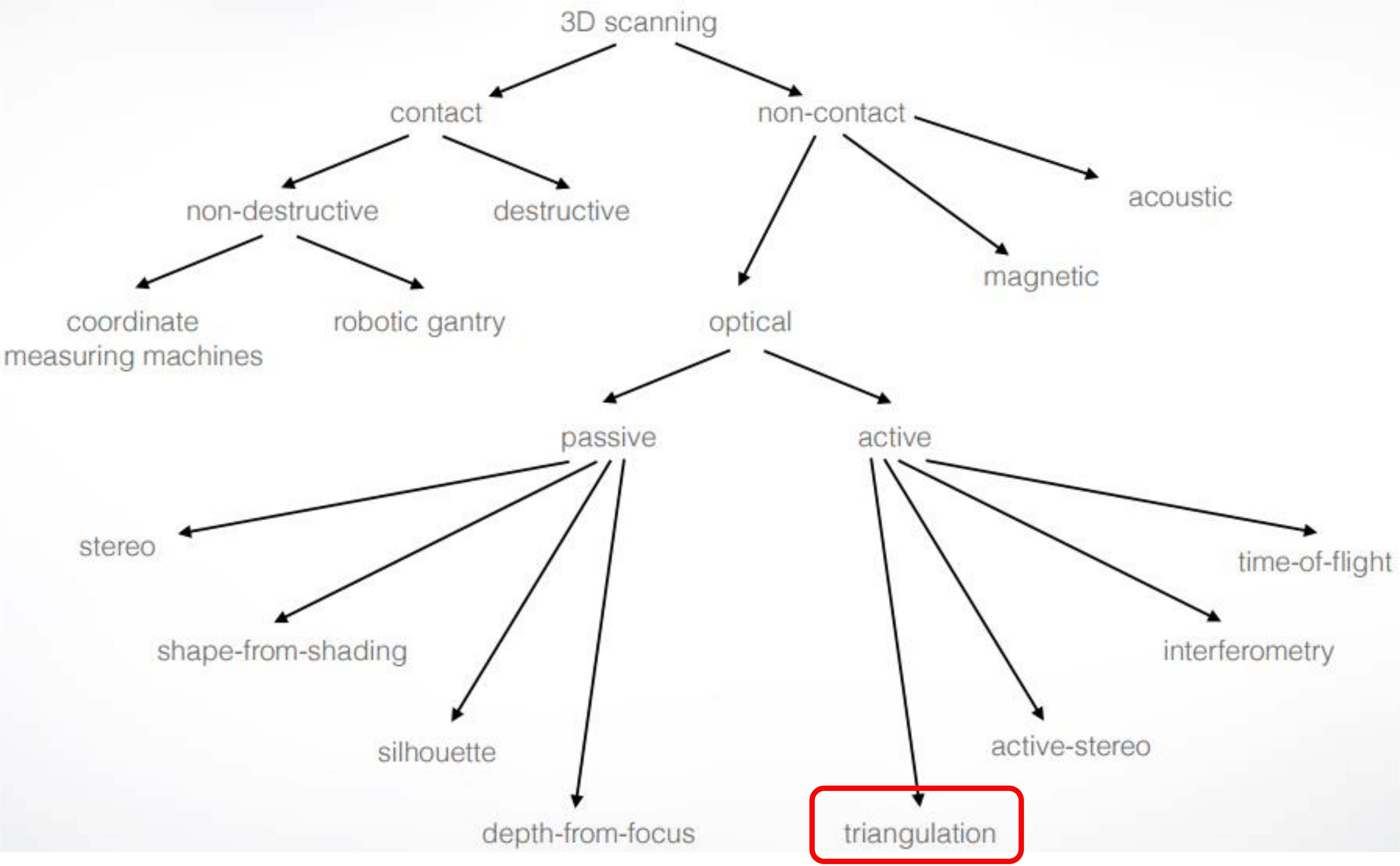
- Infrared light
  - 176x144 pixels, up to 50 fps
  - 30 cm to 5 m distance
  - 1 cm accuracy
  - technology is improving drastically

[Mesa Imaging]

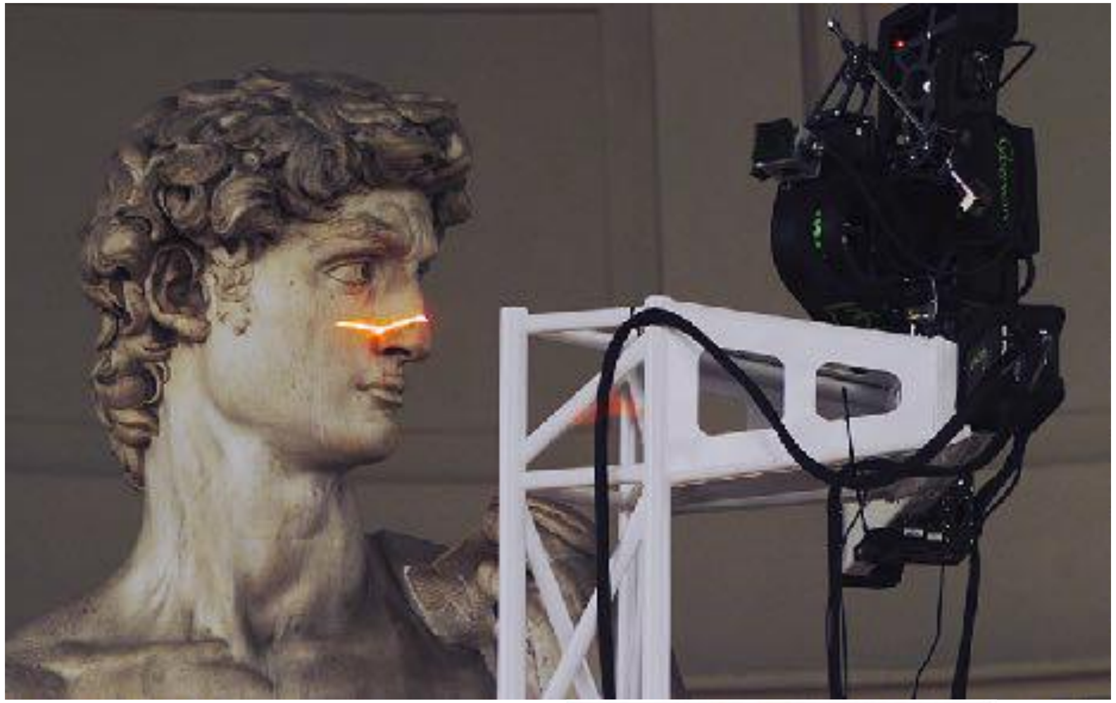
Kinect One (= second gen Kinect)

- Time-of-Flight Technology
- 30 fps
- Depth map x/y resolution: 512 x 424
- z-resolution 1 mm & accuracy:
  - <1.5 mm (depth < 50 cm)
  - < 3.9 mm (depth < 180 cm)
  - < 17.6 mm (depth < 450 cm)
- 1080 HD for RGB input
- uses Kinect2 SDK

3D Scanning Taxonomy

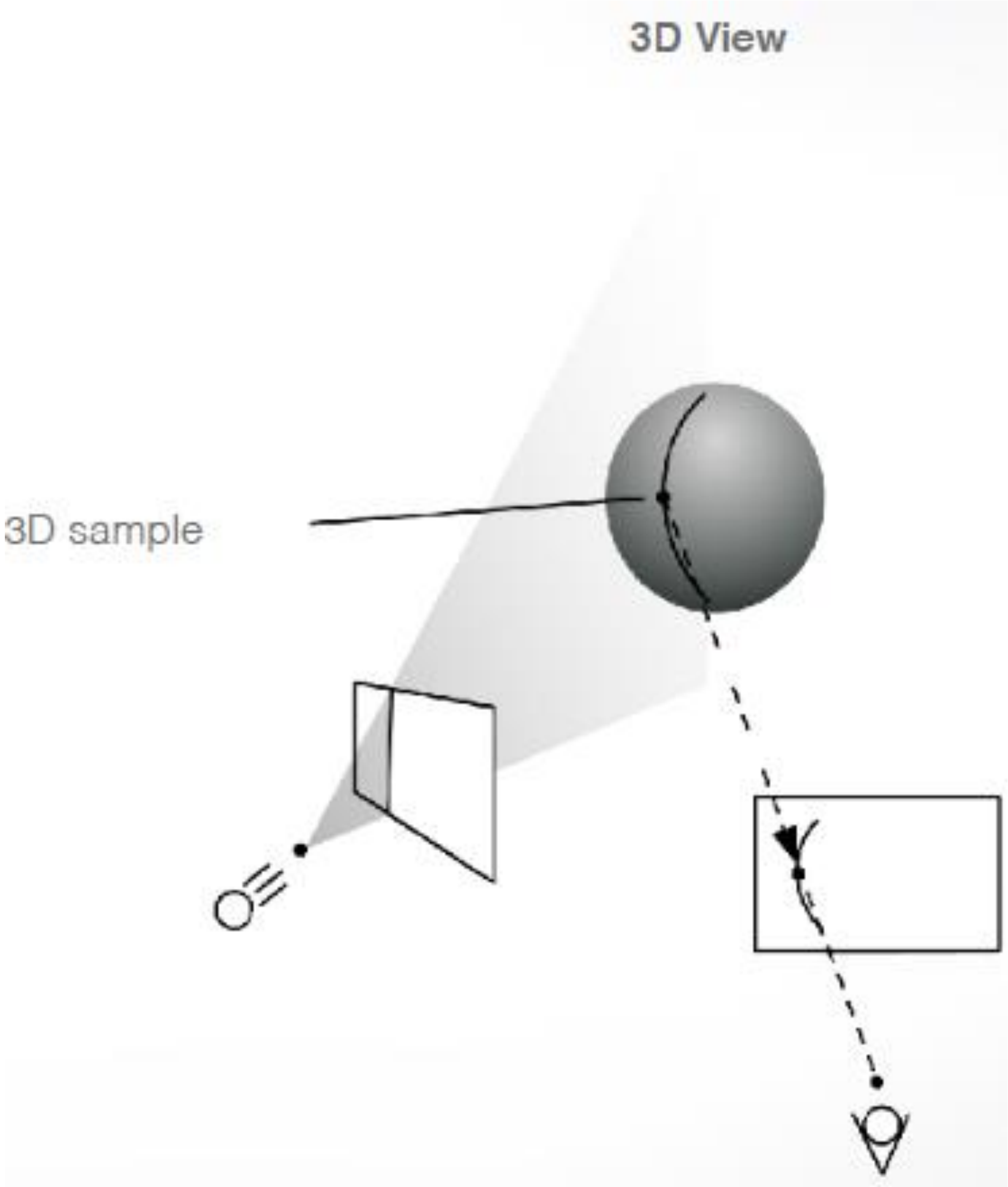


Optical Triangulation - Laser-Scanning



Konica Minolta

Cyberware



Laser-Based Optical Triangulation

- gained popularity for high accuracy capture (< 1mm)
- professional solutions are still expensive

- long range

- very insensitive to object's color (e.g. black) and lighting conditions

- may lead to laser speckle on rough surface → space time analysis

- slow process (plane-sweep) → no suitable for dynamic objects

Optical Triangulation - Single-View Structure Light Scanning

[Rusinkiewicz et al. ‘02]

Artec Group

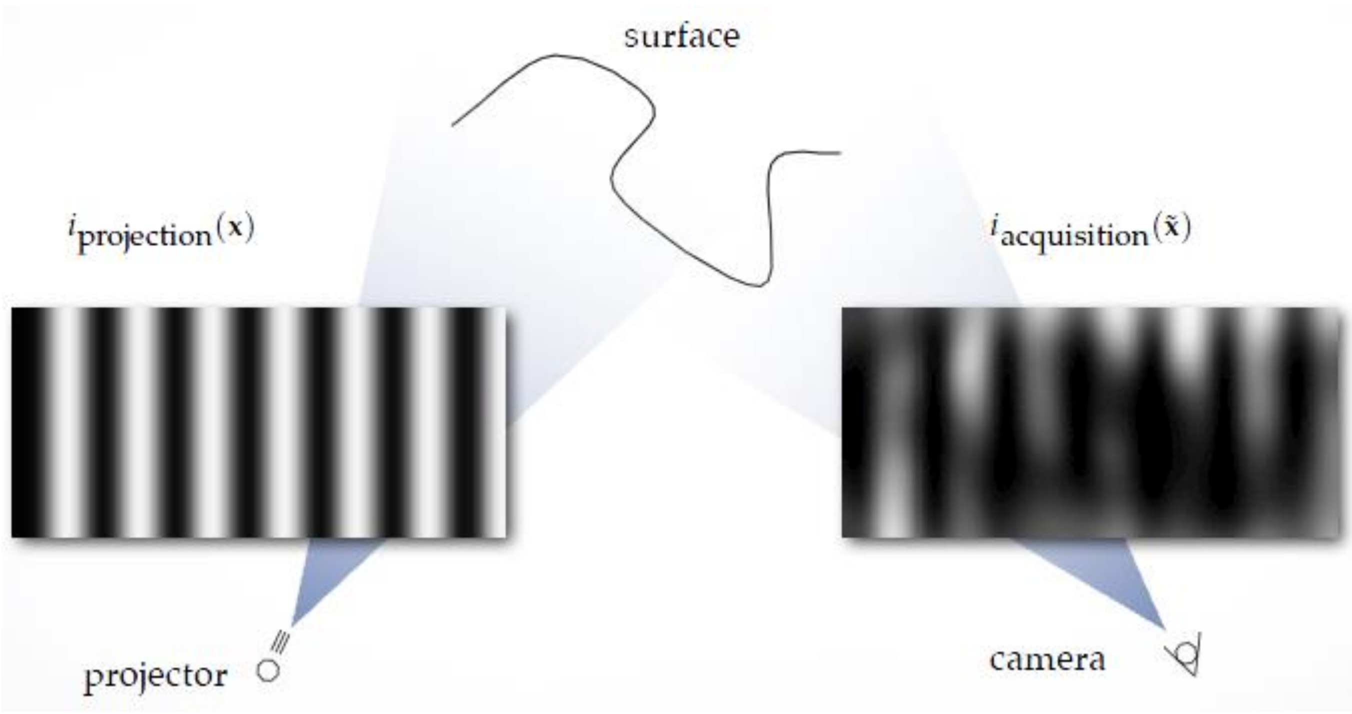
[Newcombe et al. ’11]
KinectFusion

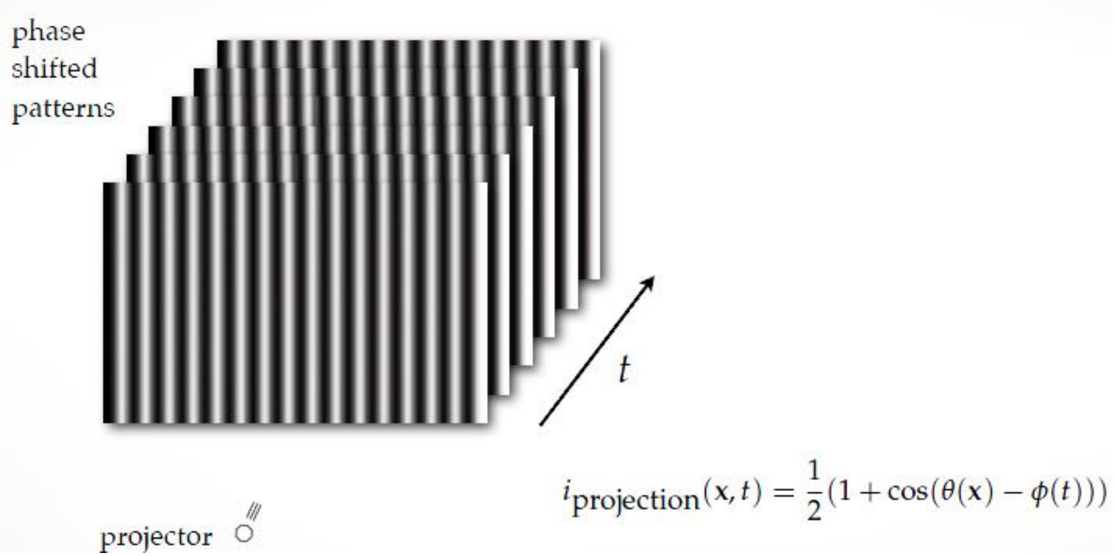
Structured Light Scanning

- developed to increase capture speed by simultaneously projecting multiple **stripes or dots** at once
- increase accuracy using edge detection
- due to cost and flexibility, based on a **video projector**

- challenge: recognize projected patterns (**correspondence**)
  - under occlusions
  - different surface reflection properties (furry object?)
  - less projections → faster but correspondence harder
- typically assumes a **2D manifold** with **Lambertian reflectance**

Phase Shift Patterns





Kinect (= 1st gen Kinect) for XBOX 360

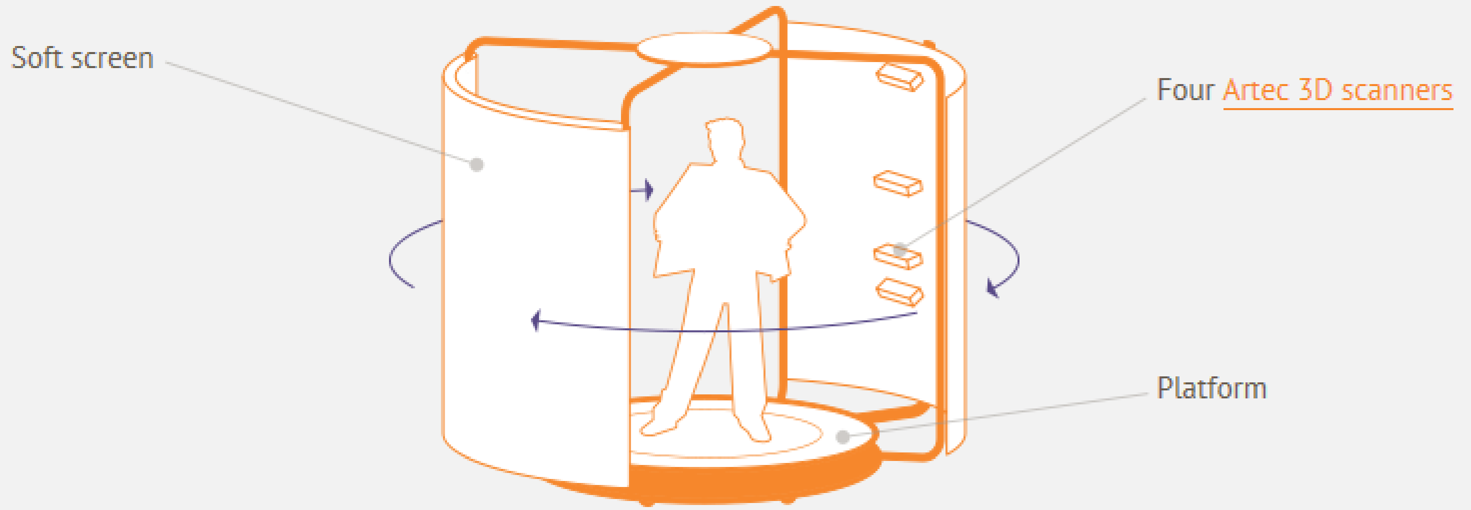
- Structured Light Technology (Primesense Sensor)
- 640 x 480 @ 30 fps
- 1280x960 @ 12 fps
- accuracy:
  - < a few mm (depth < 50 cm)
  - < 4 cm (depth < 500 cm)
- VGA for RGB input
- uses Kinect1.x SDK

Summary - The Future will be more accessible

- Real-time depth sensors (smaller, more accurate, higher resolution, less noise, larger working volume, portable)
    - TOF, structured Light, camera Arrays

- Multi-view stereo capture (sparser, better algorithms, realtime, very large working volume, high speed, portable)
    - Robotic camera tracking

Artec Shapify Booth



Dimensions
3.3x3.3x2.8 meters

Scanning time
12 seconds

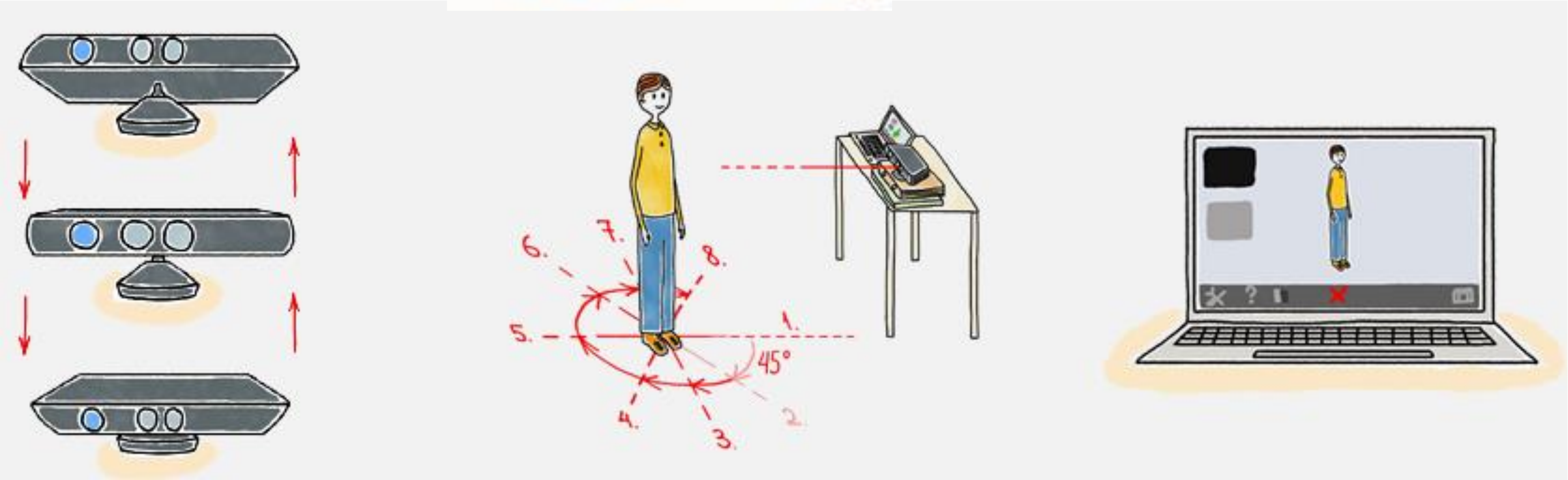
Printable model in
15 minutes

Polygons
400K

Throughput
10 customers per hour

Make your shapie

- https://www.shapify.me/



References

1. Interesting: http://www.cs.princeton.edu/courses/archive/fall09/cos429/notes/cos429_f09_lecture19_3dscanning.pdf
2. Lanman and Taubin, “Build Your Own 3D Scanner: Optical Triangulation for Beginners”, SIGGRAPH 2009 Courses
3. Newcombe & Davison, “Live Dense Reconstruction with a Single Moving Camera”, CVPR 2010