3D Scanning

Dr. Francesco Banterle,
francesco.banterle@isti.cnr.it
banterle.com/francesco

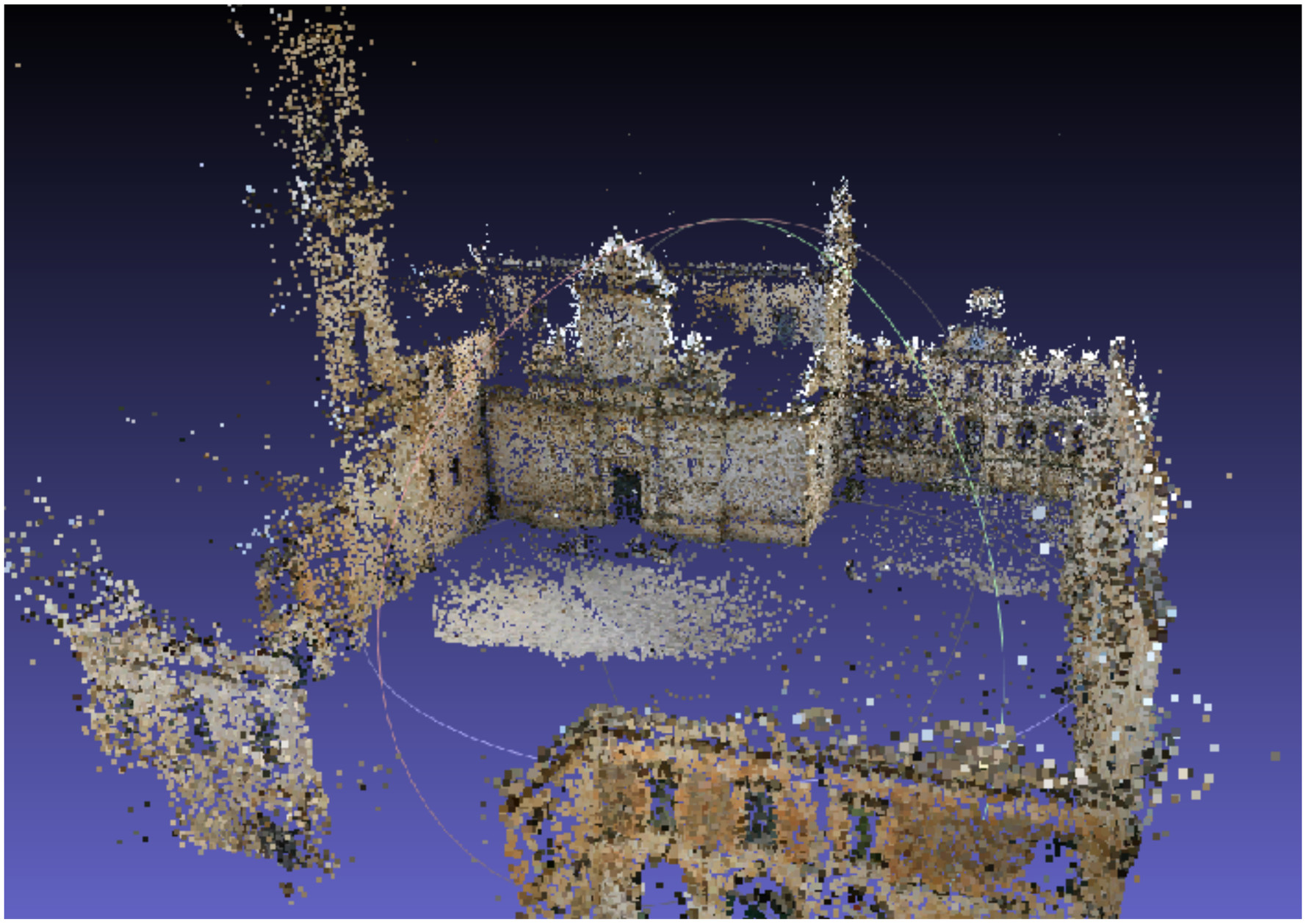
What is 3D Scanning?

- 3D scanning is the process of ***measuring*** 3D information; and it is the very first step when creating a complete 3D model.

3D Scanning Outputs

- Each device outputs measure 3D information differently. The main outputs are:
  - 3D sparse points
  - Range maps
  - 3D volumes

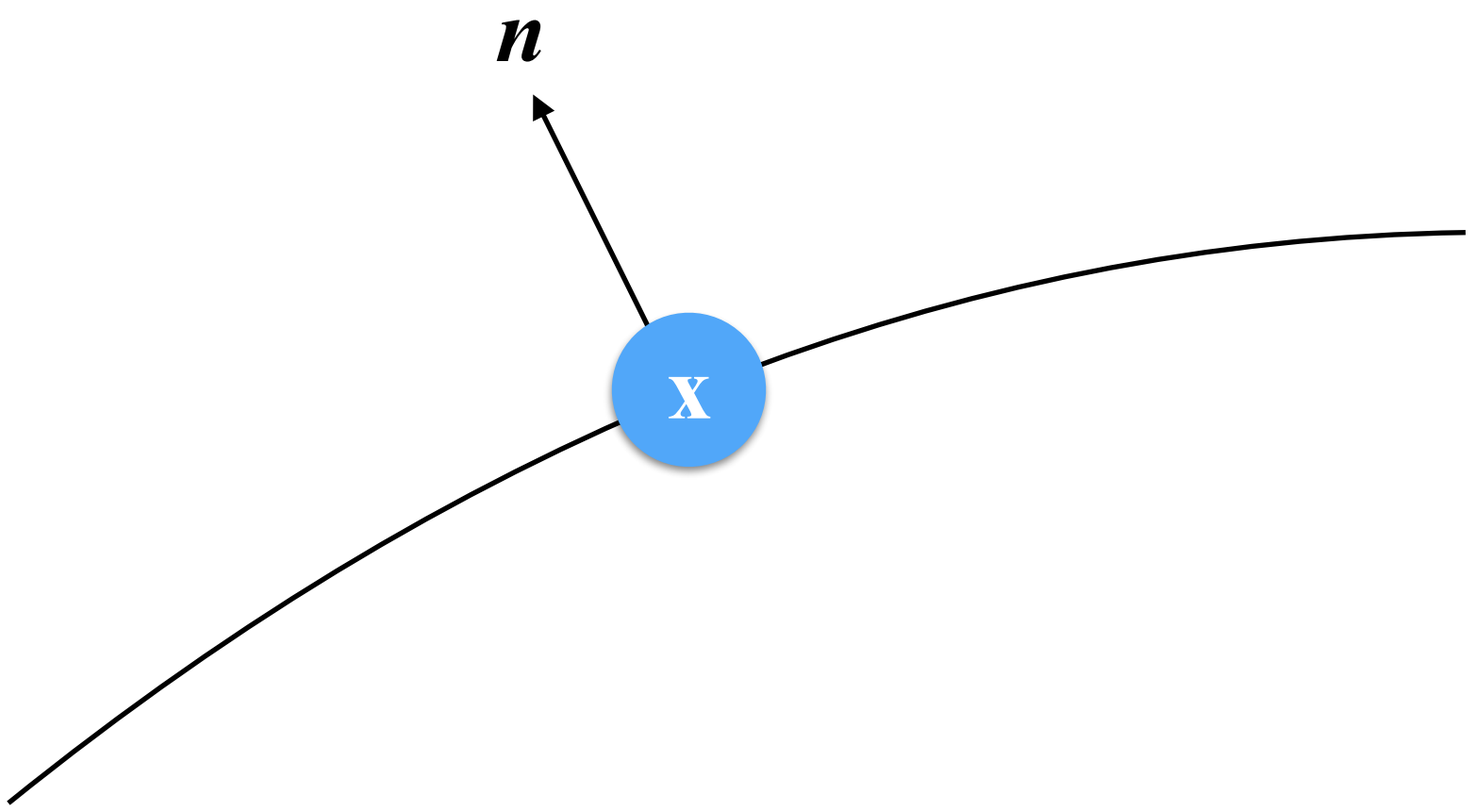
3D Scanning Outputs: Sparse Points



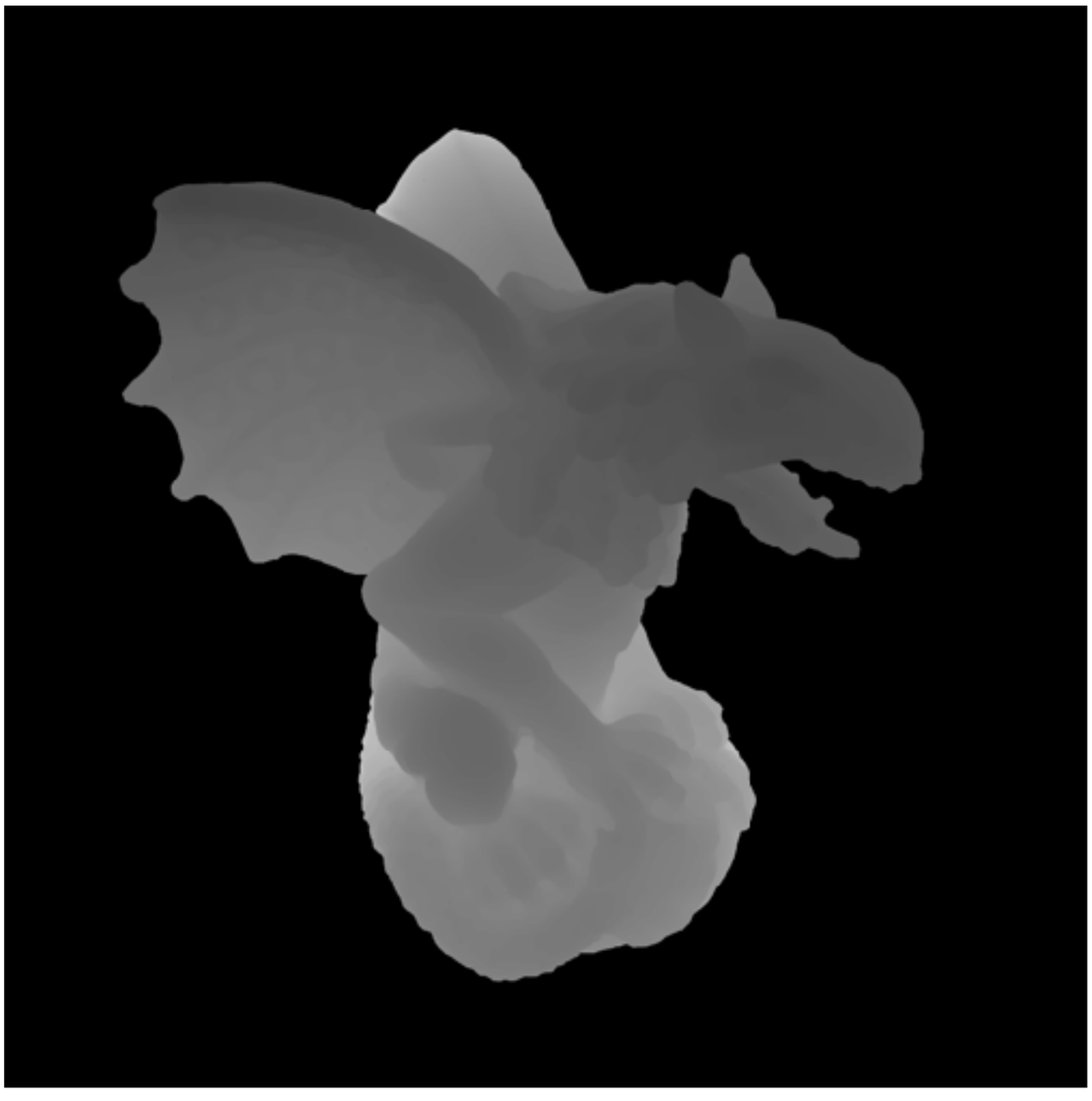
3D Scanning Outputs: Sparse Points

- Each point can have attributes:
  - An RGB color and/or optical properties
  - Surface's normal
  - …
- Metadata: position and orientation of the origin, and its scale

3D Scanning Outputs: Sparse Points



3D Scanning Outputs: Range Maps

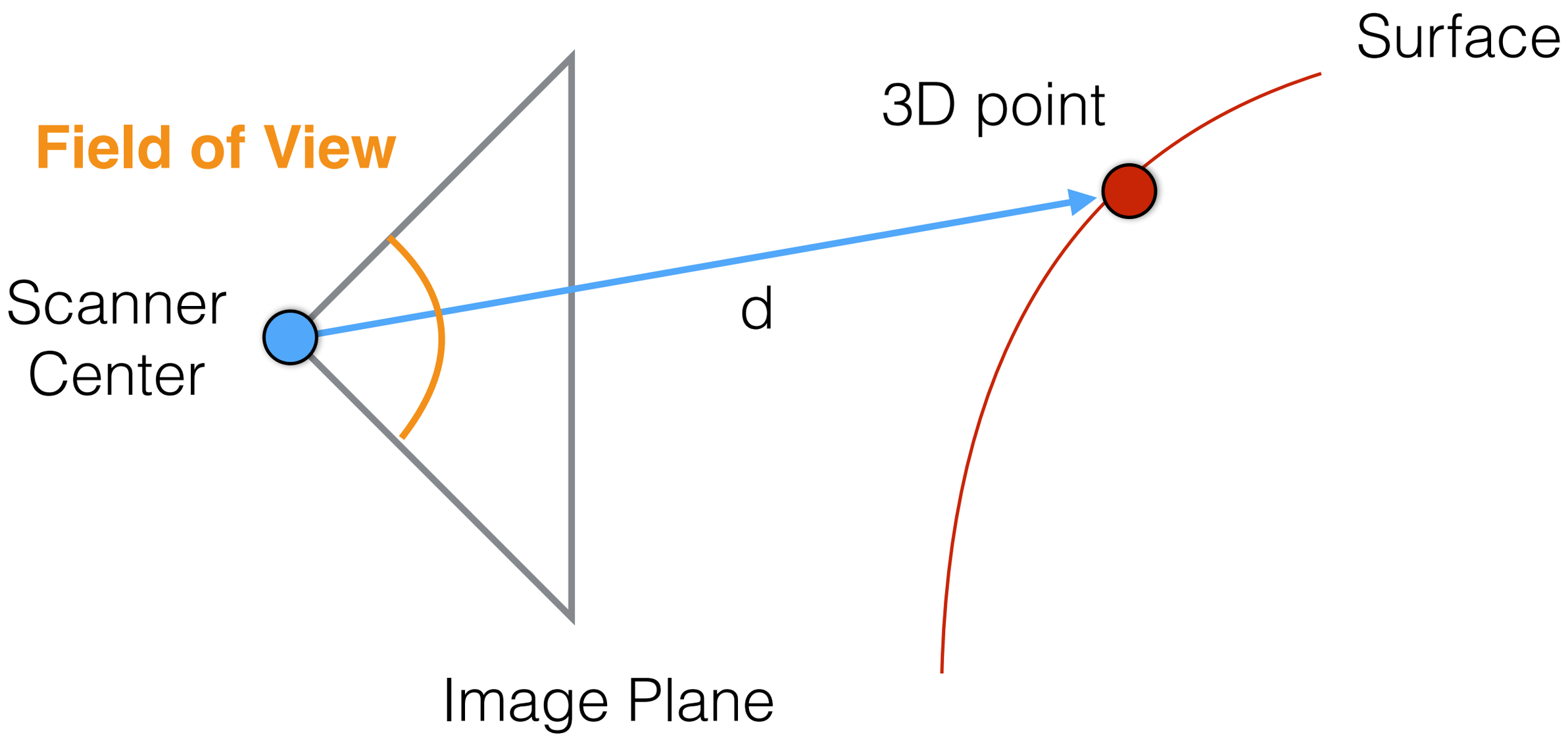


Each pixel in the image encodes the distance between the surface and center of the camera

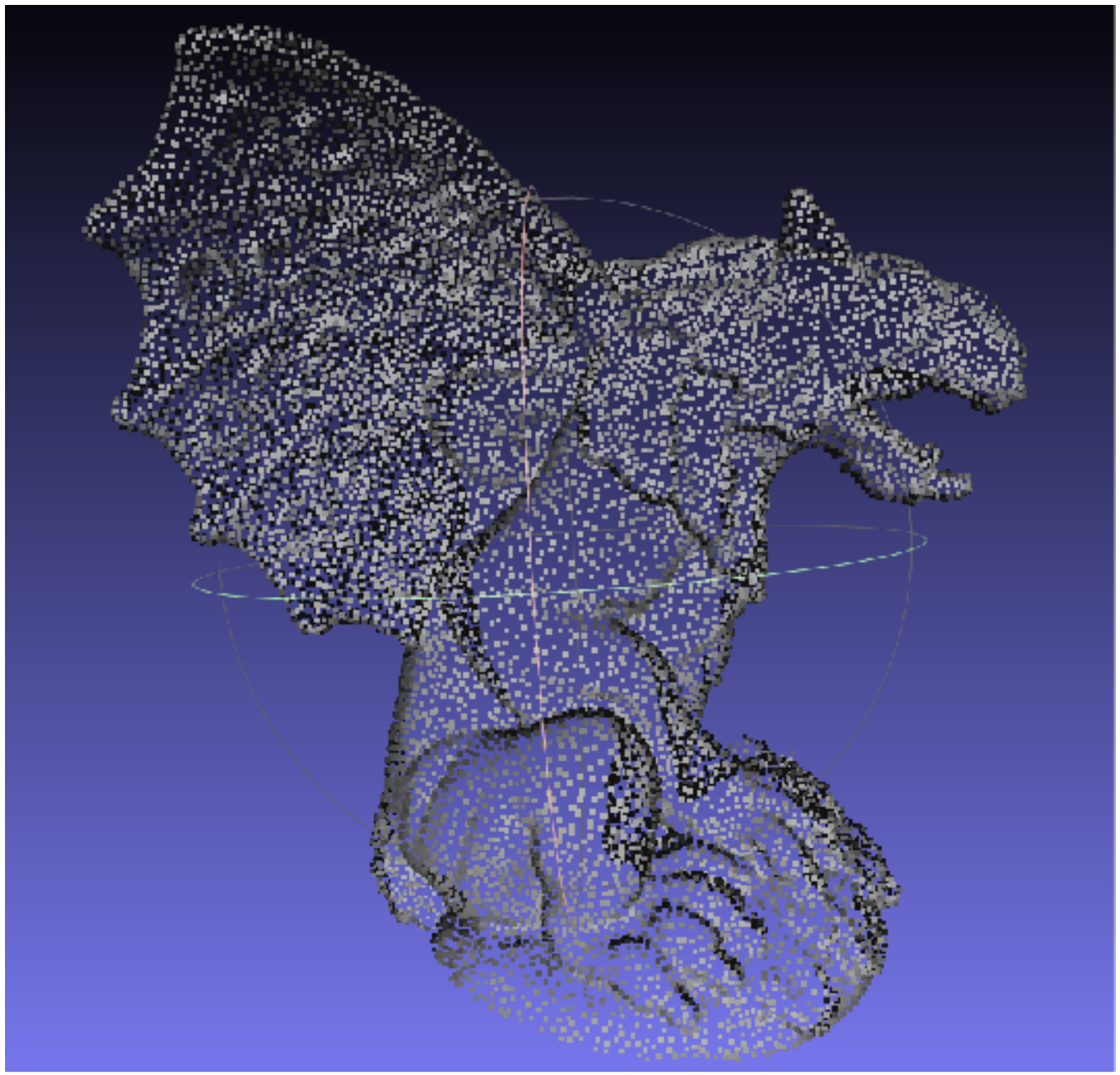
3D Scanning Outputs: Range Maps

- Metadata:
  - Camera extrinsics: position and rotation
  - Camera intrinsics: field of view, size of pixels in mm
  - Scale of distances
- From Metadata:
  - we can obtain 3D points!

3D Scanning Outputs: Range Maps



3D Scanning Outputs: Range Maps



3D Scanning Outputs: Range Maps

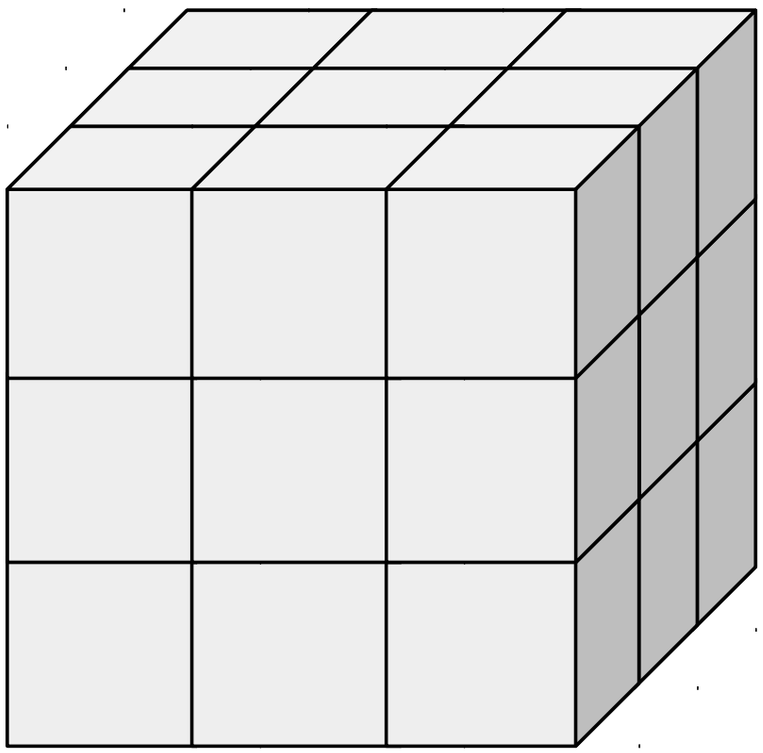
- A range map is already a 3D model… but it will be surely incomplete
- A single acquisition ***IS NOT enough*** to reconstruct an entire object
- Multiple shots are needed…
  - How many?
  - Which ones to choose?

3D Scanning Outputs: Range Maps

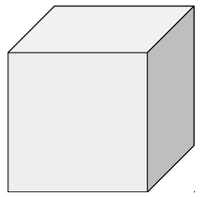
3D Scanning Outputs: 3D Volumes

- 3D space is discretized into a regular grid or ***volume***

- Each cube in the grid is called ***voxel*** (volume pixel) or a cube encodes a value in the range [0, 1].



Volume



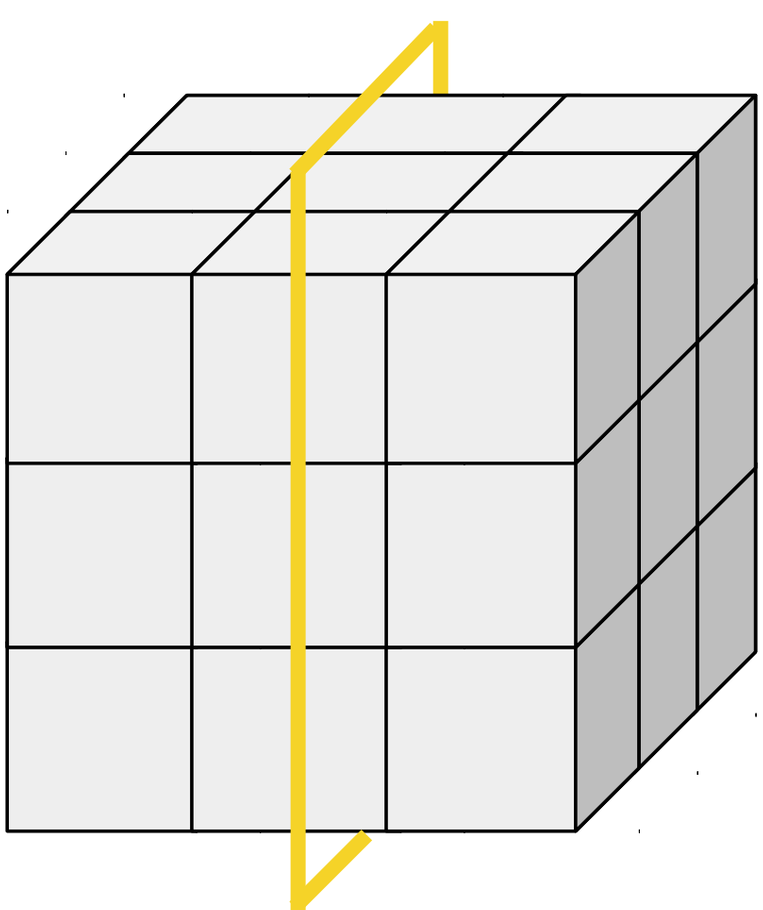
Voxel

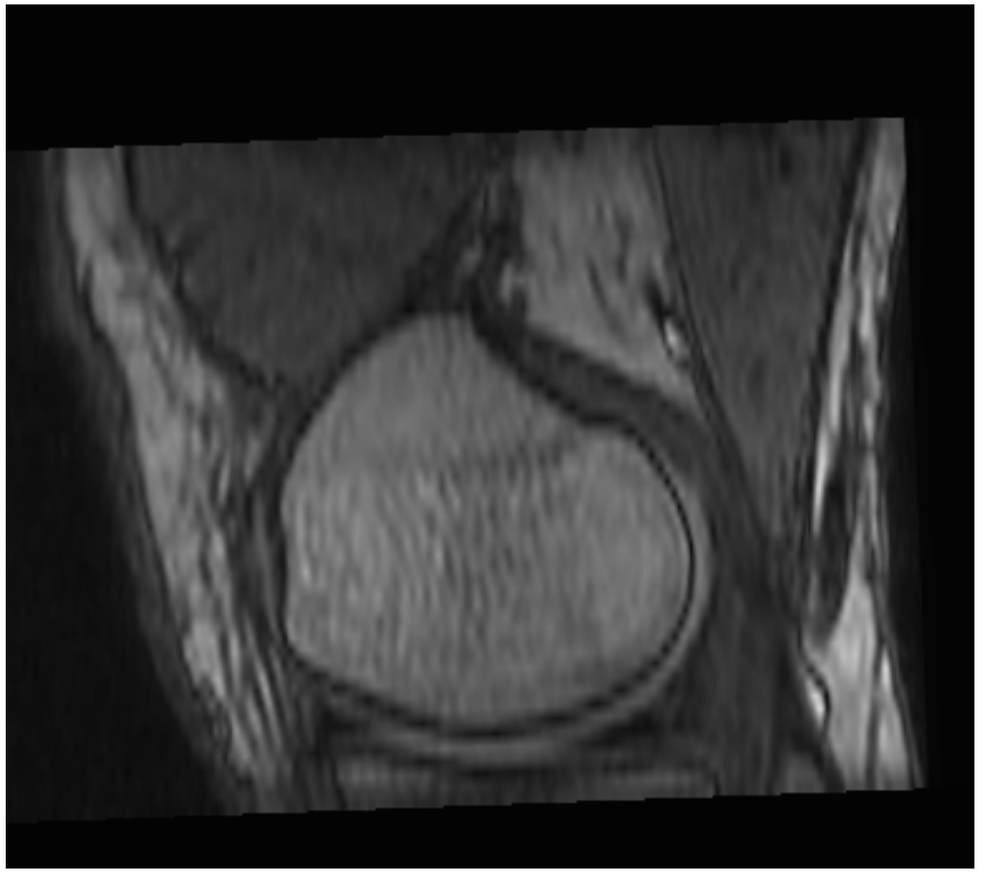
3D Scanning Outputs: 3D Volumes

- Metadata:
  - size of the pixel in mm for each slice
  - distance in mm between a slice and another
  - scale of the normalized values (typically encoded as 16-bit values)

3D Scanning Outputs: 3D Volumes

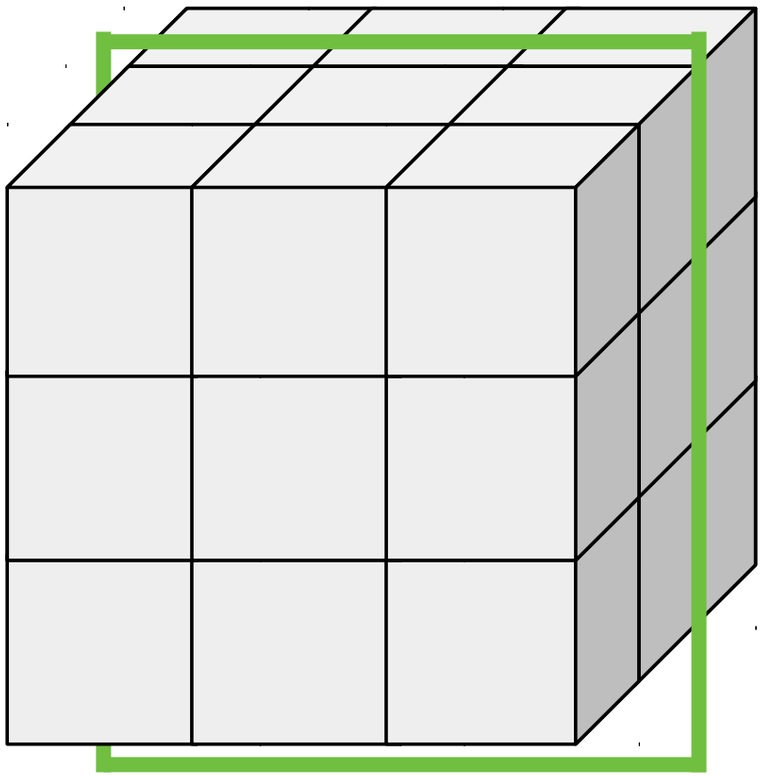
- A ***sagittal plane*** is an anatomical plane that divides the body into right and left parts

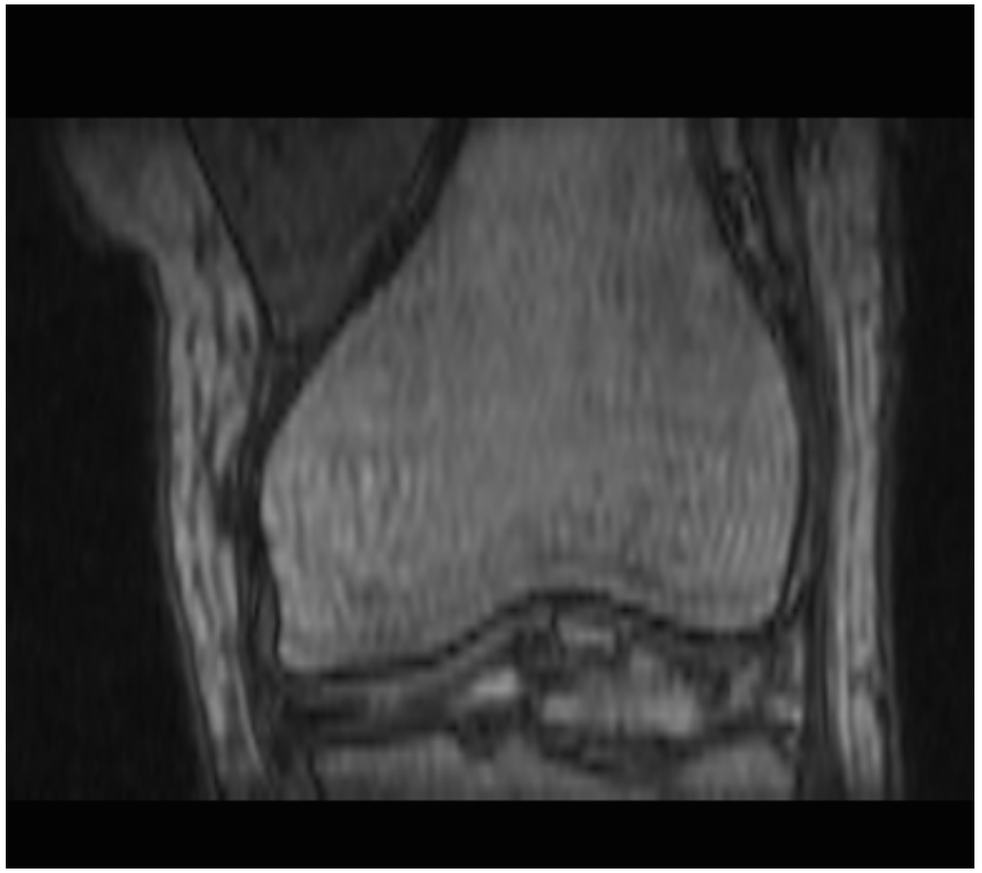




3D Scanning Outputs: 3D Volumes

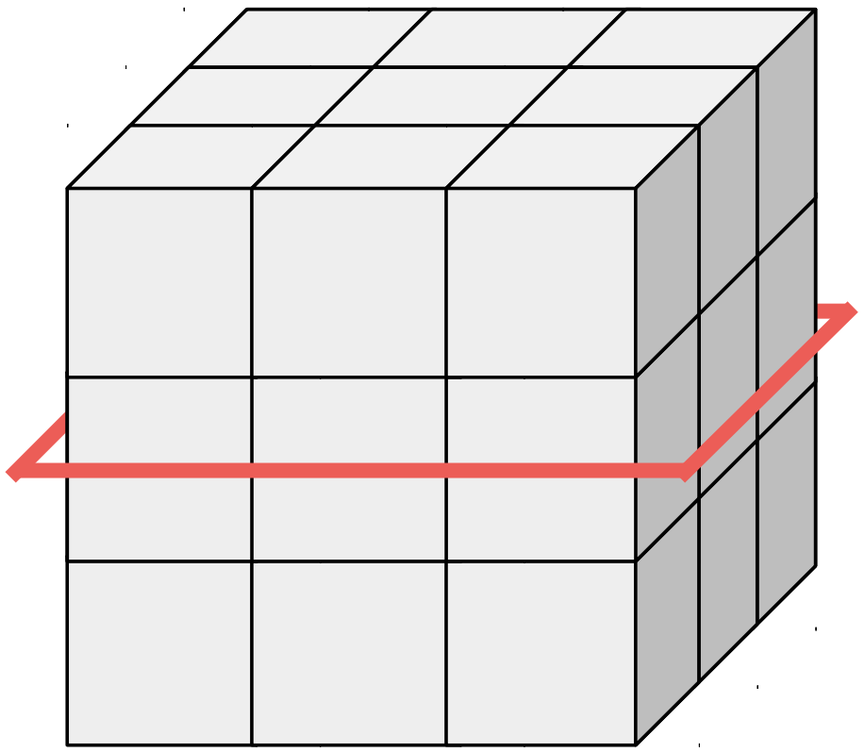
- A ***coronal plane*** is an anatomical plane that divides the body into ventral and dorsal parts

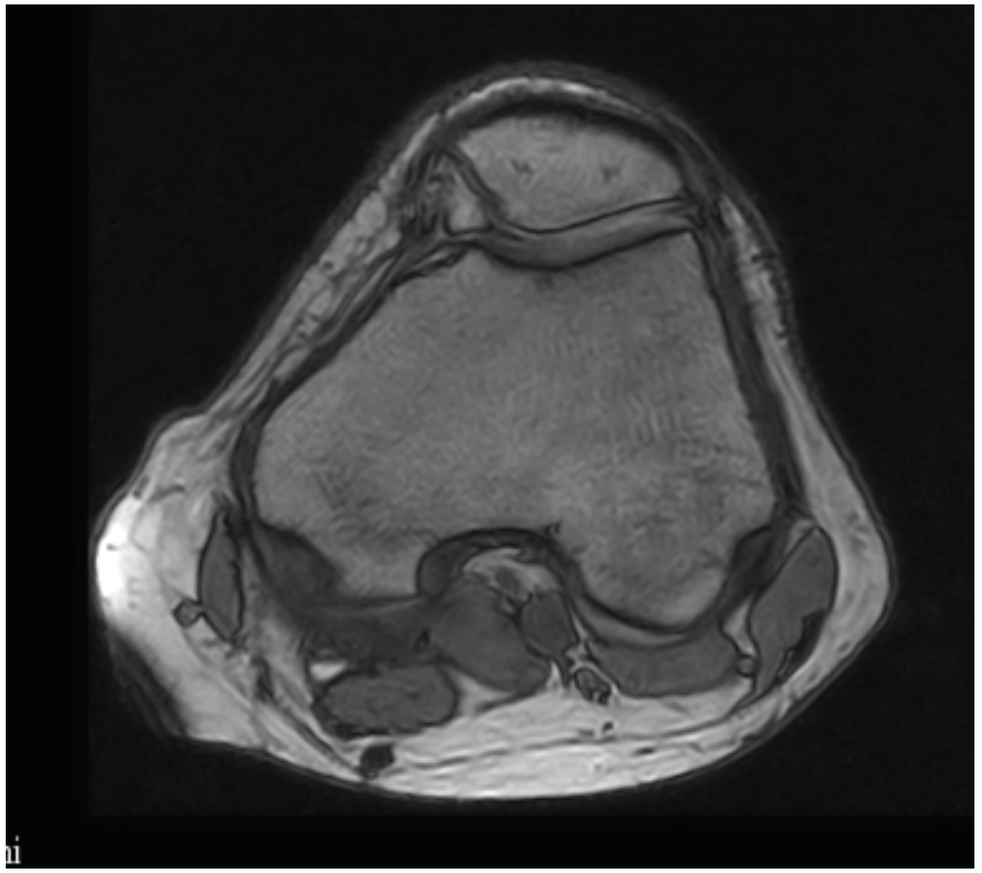




3D Scanning Outputs: 3D Volumes

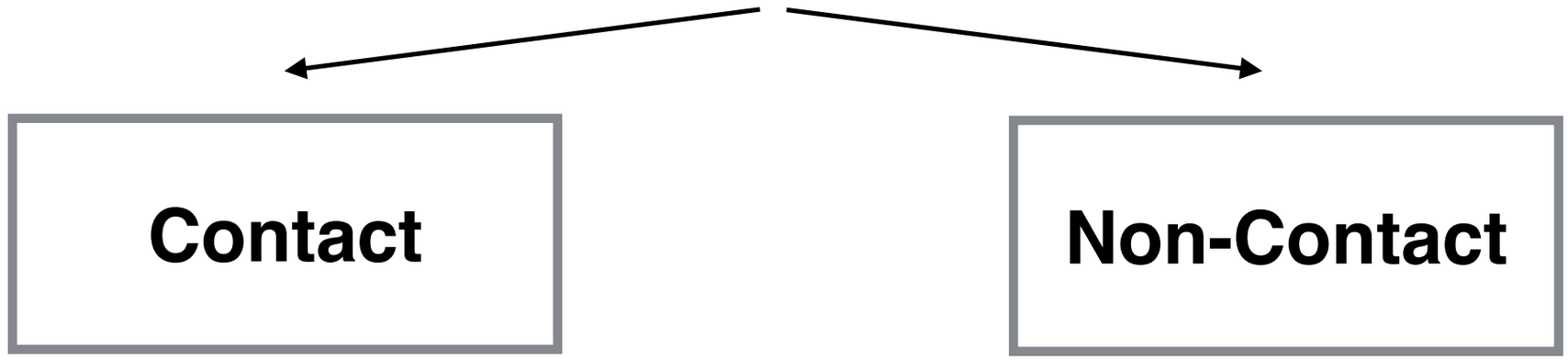
- An ***axial plane*** is an anatomical plane that divides the body into superior and inferior parts



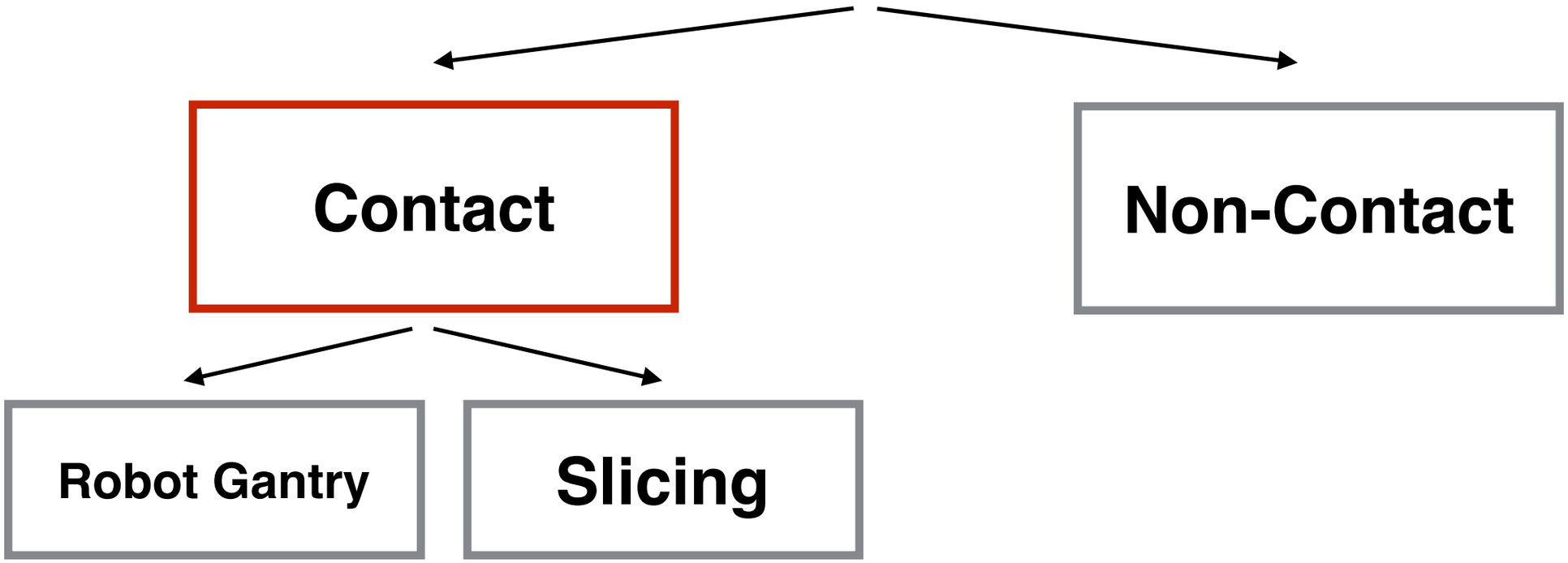


3D Scanning Taxonomy

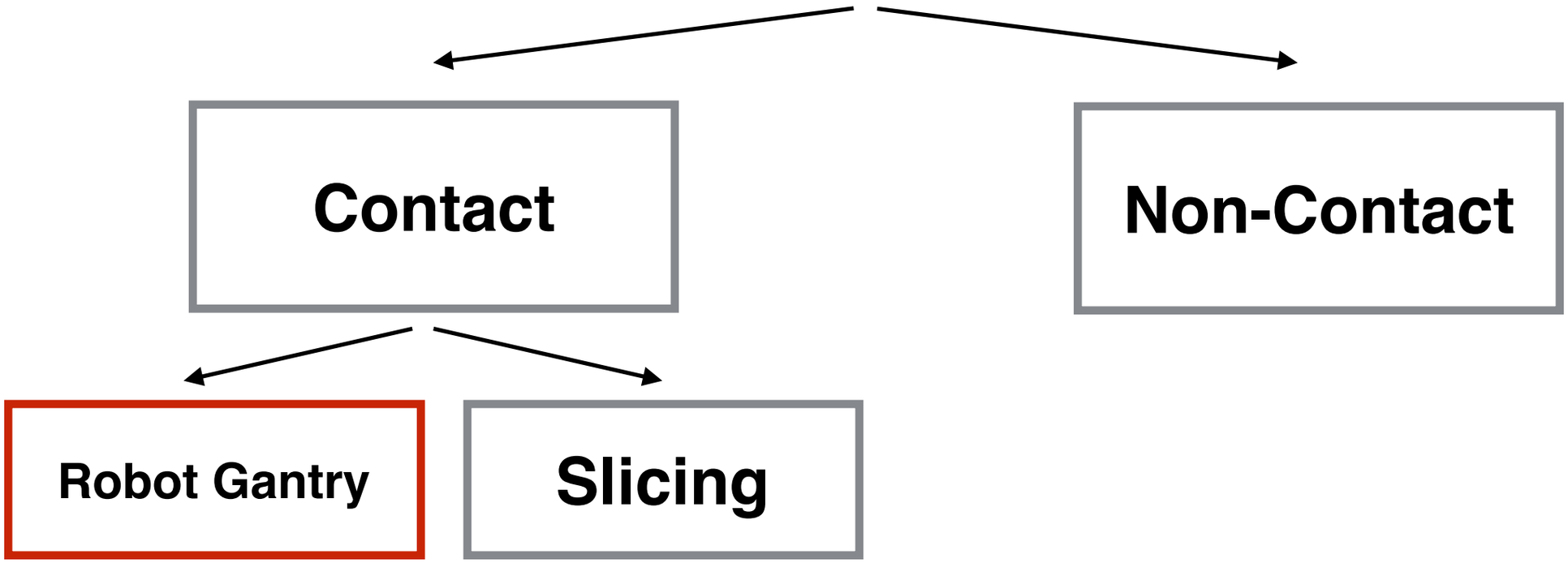
3D Scanning Taxonomy



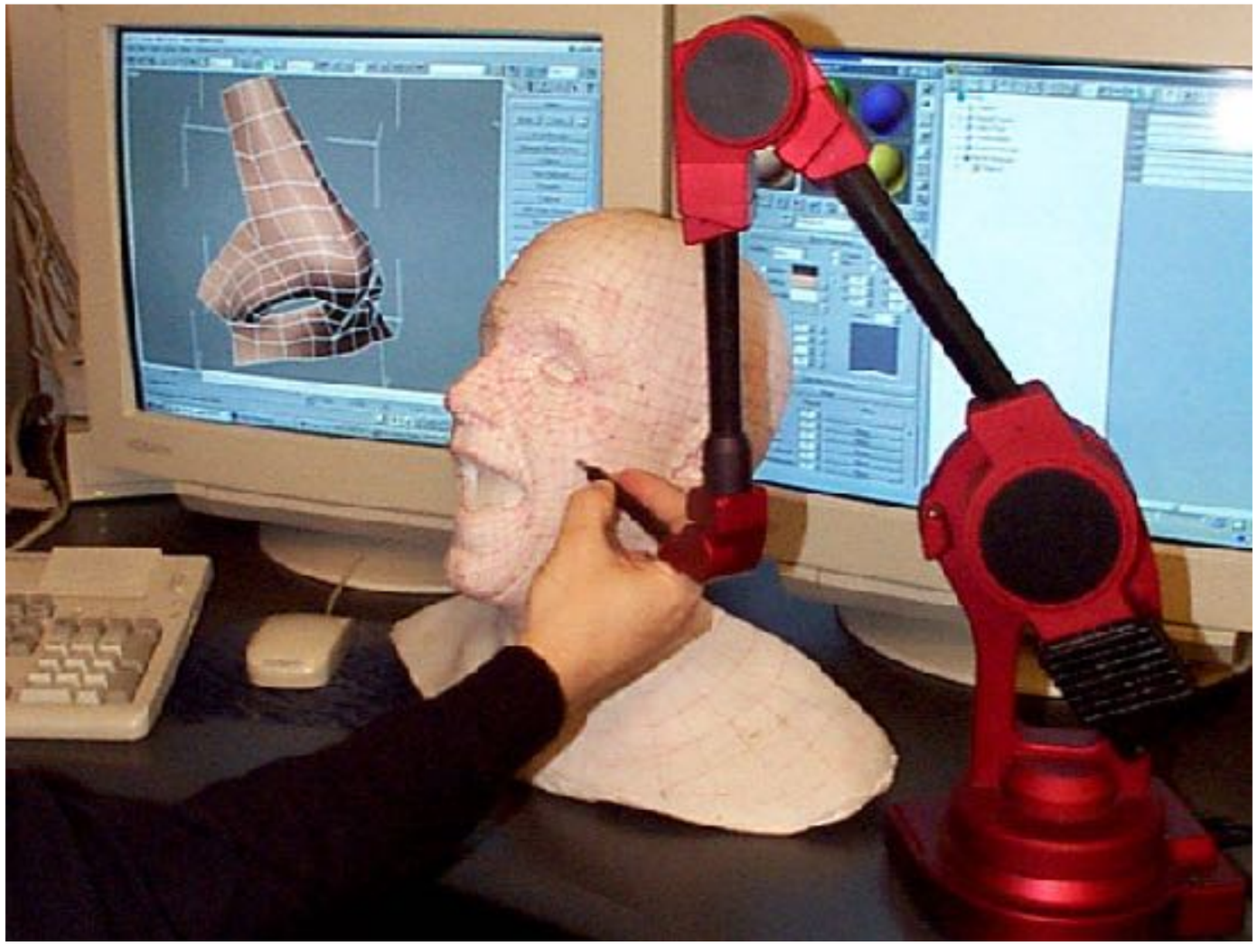
3D Scanning Taxonomy



3D Scanning Taxonomy



3D Scanning Taxonomy: Robot Gantry

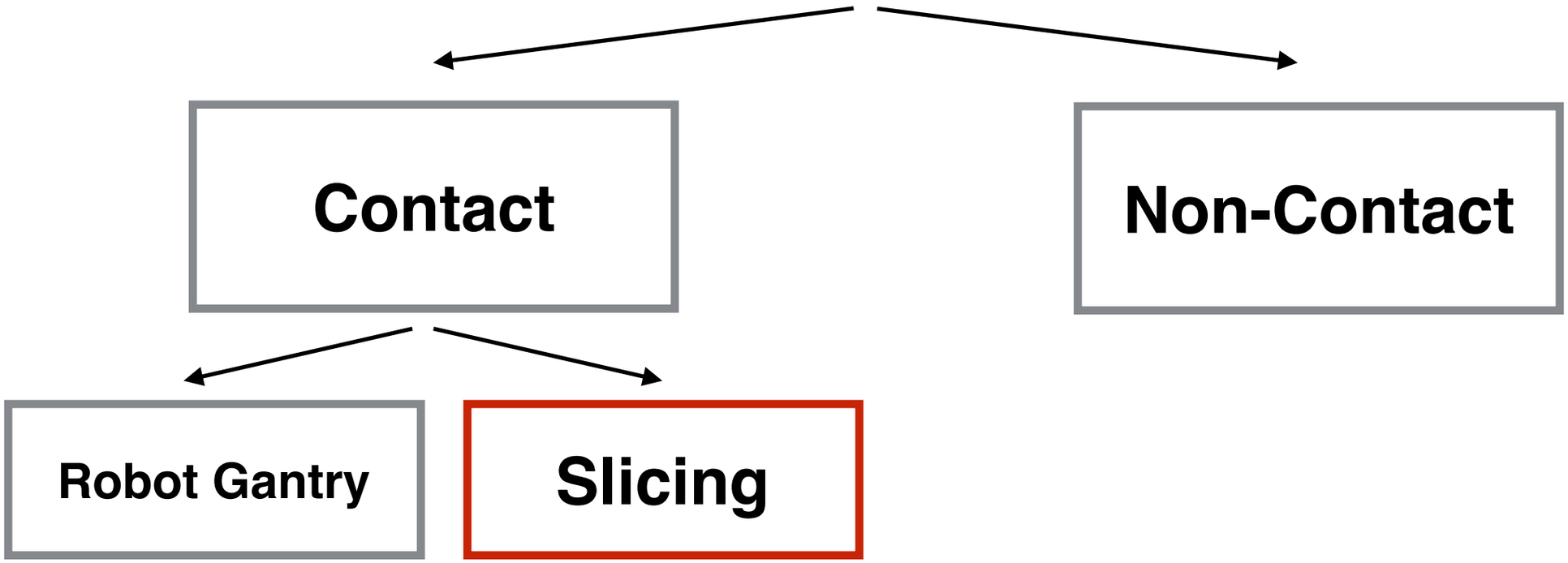


Object is “*probed*” at different locations

3D Scanning Taxonomy: Robot Gantry

- Highly accurate (micron)
- Moderate-high costs: $2,000 - $15,000
- Slow scanning; labor intensive!
- Ideal for: rigid and non-fragile objects
- Uses: manufacturing control, art/design, reverse engineering
- Output data: sparse 3D points

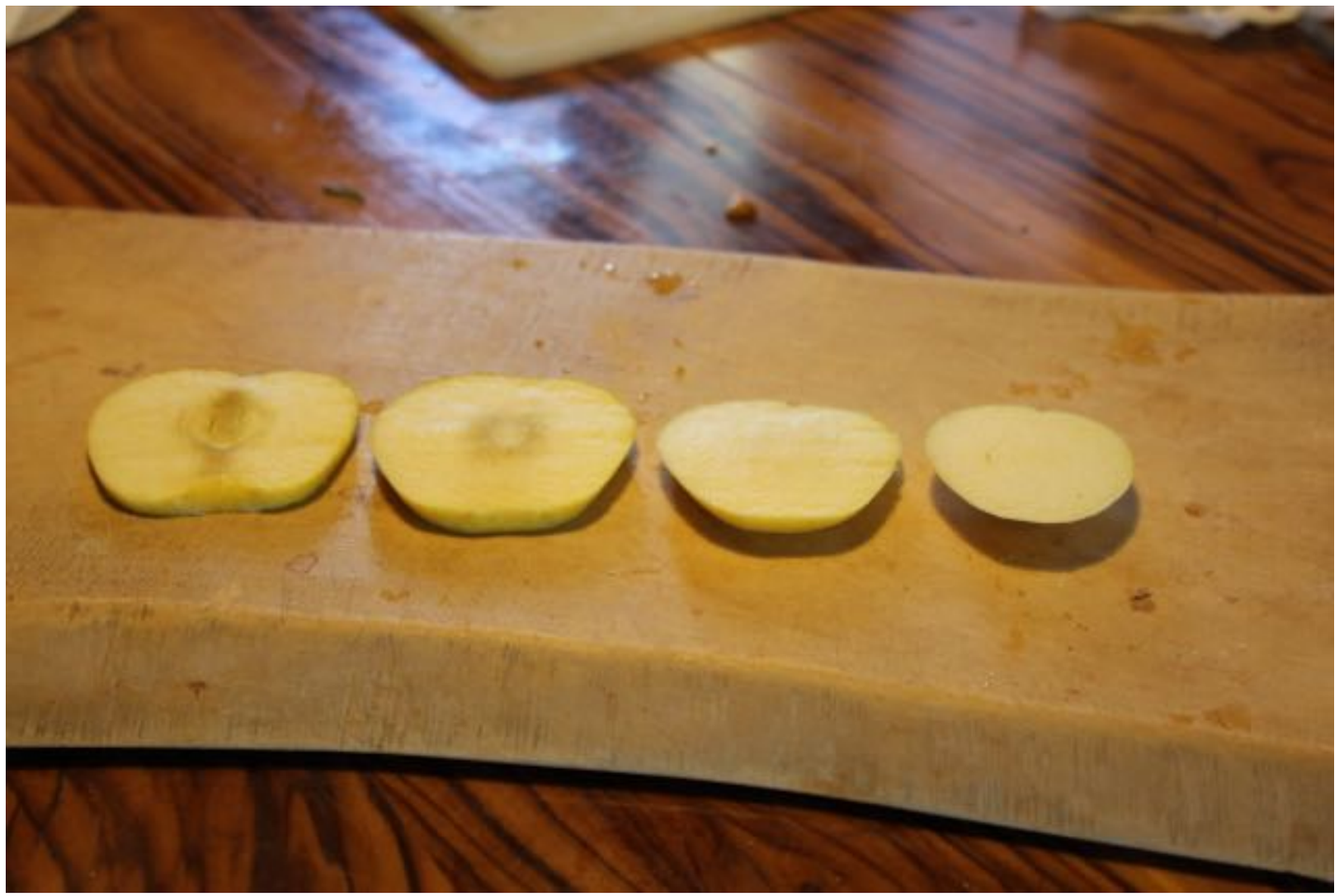
3D Scanning Taxonomy



3D Scanning Taxonomy: Slicing

3D Scanning Taxonomy: Slicing

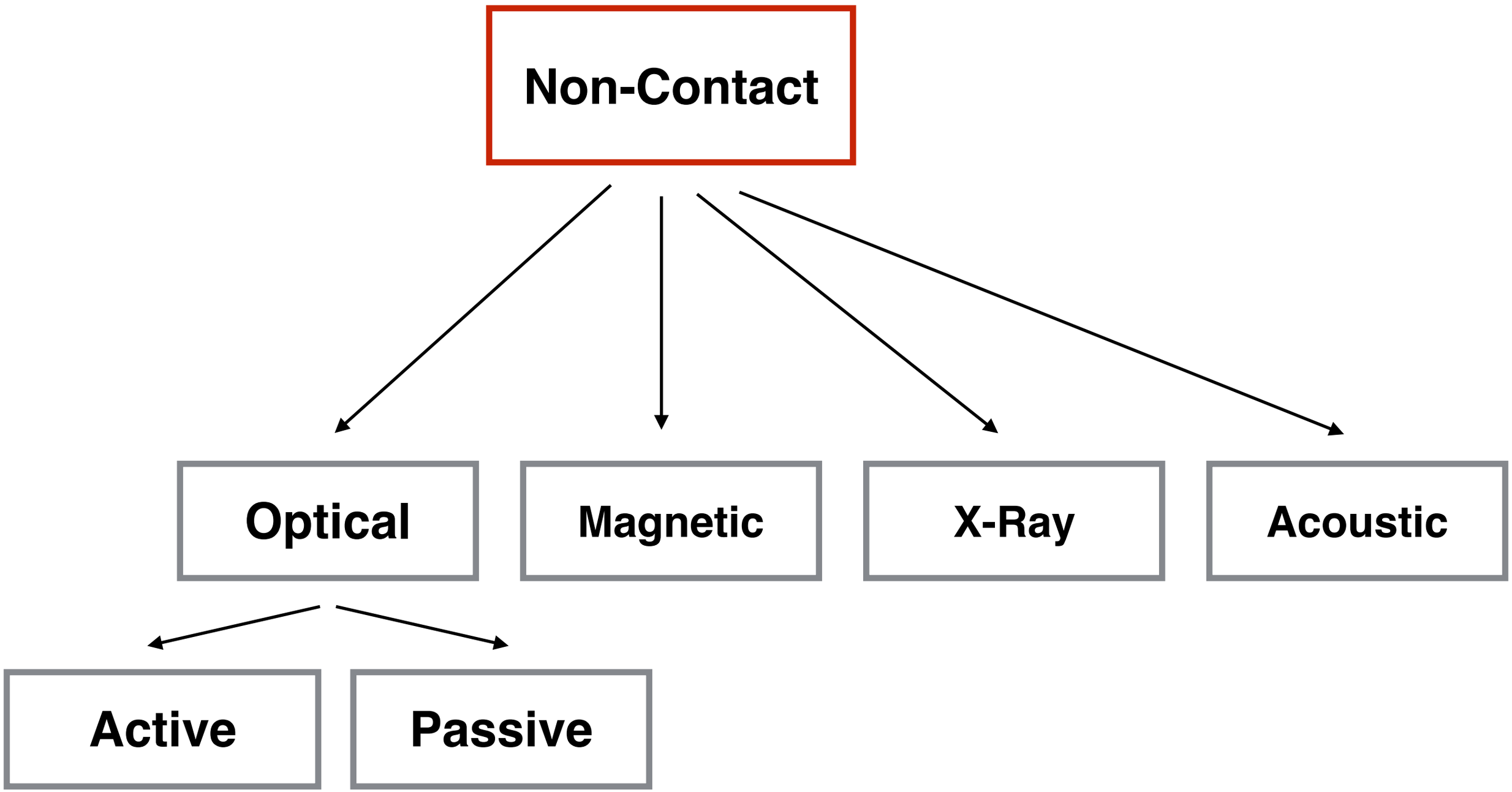
3D Scanning Taxonomy: Slicing



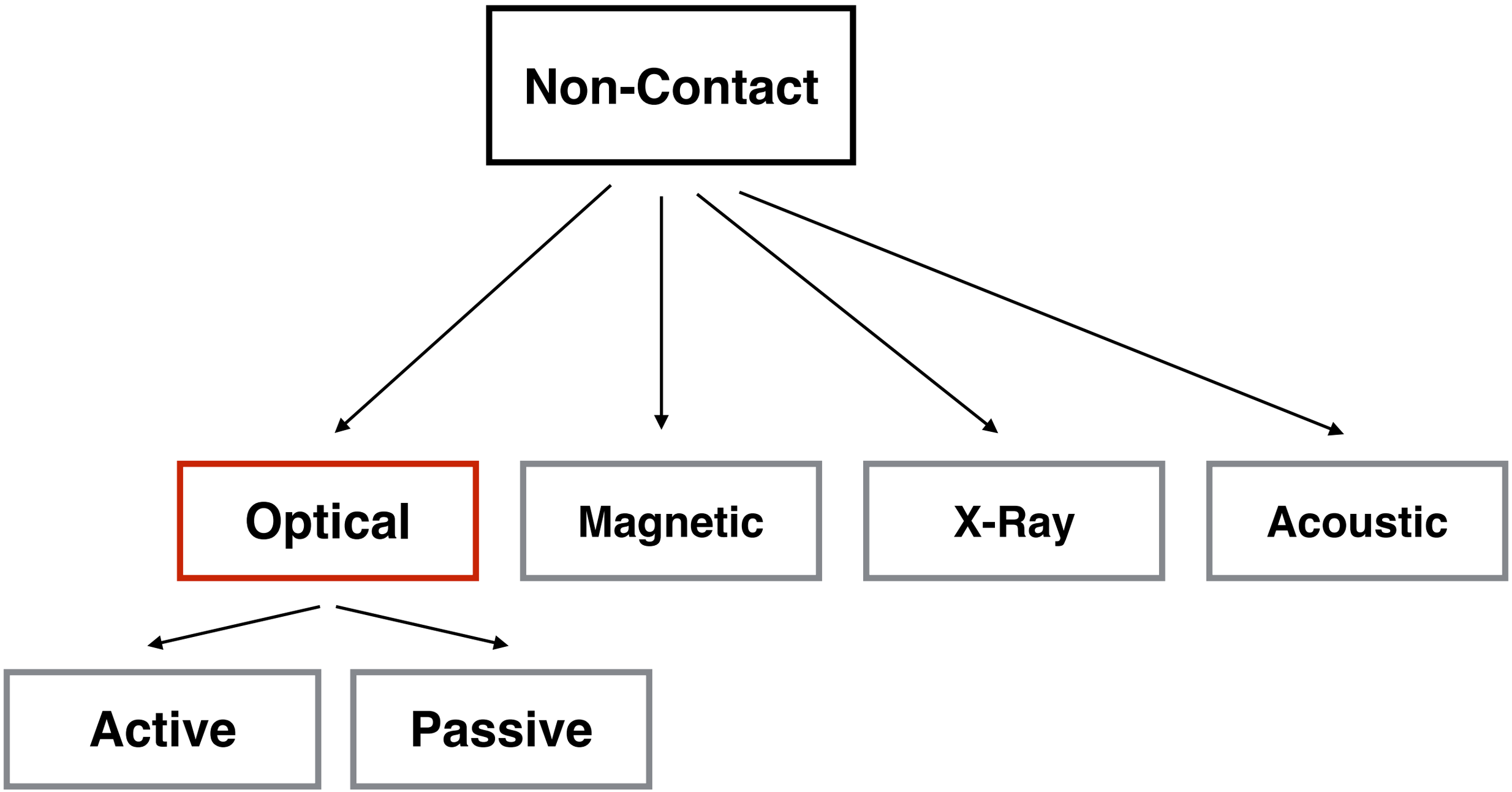
3D Scanning Taxonomy: Slicing

- It can be accurate and precise; if slicing is automatic
- Slow scanning
- Ideal for:
  - rigid and non-deformable objects
  - breakable objects
- Uses: biology, reverse engineering
- Output data: a 3D volume (in this case we can have a per voxel color)

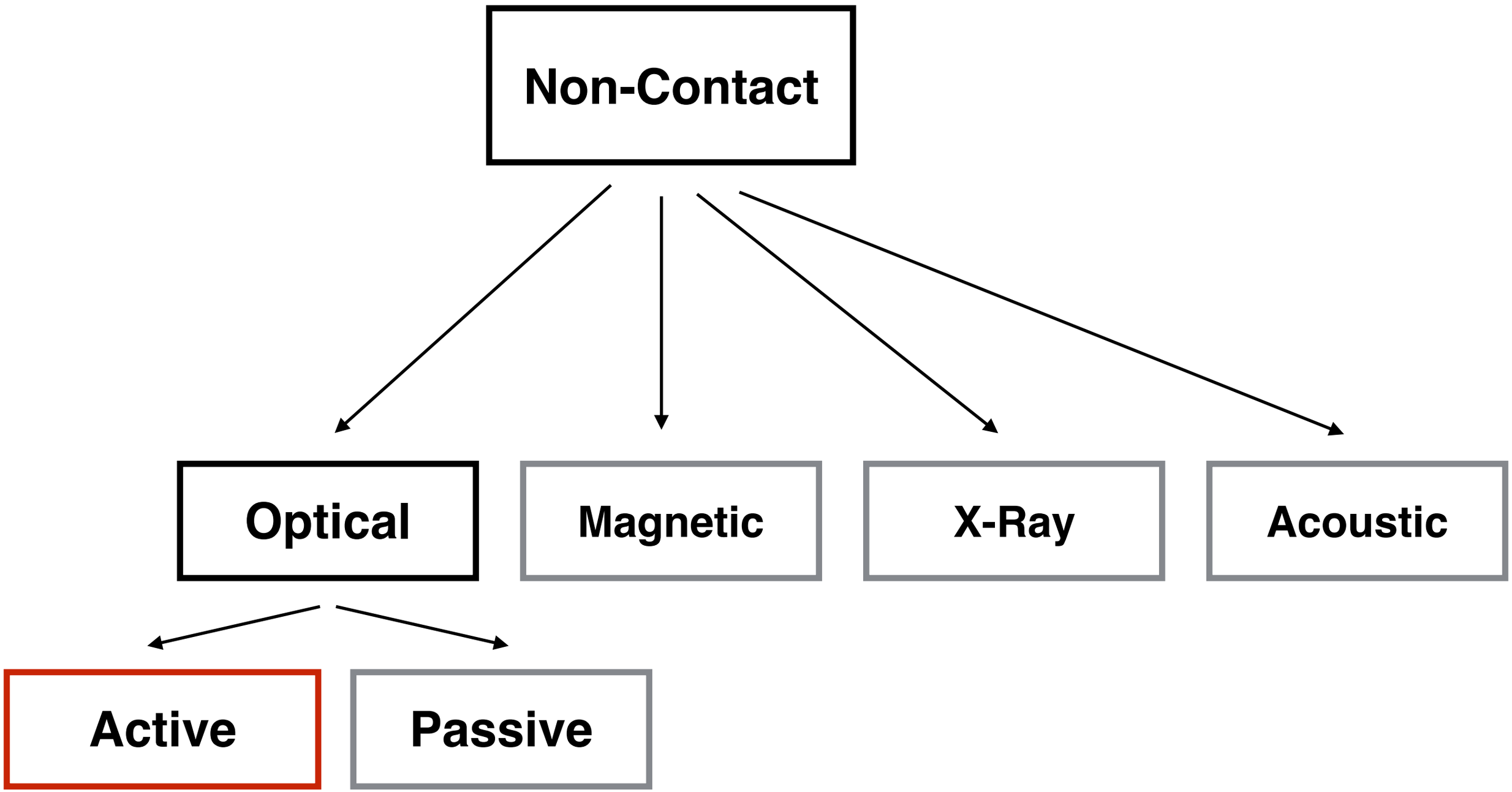
3D Scanning Taxonomy



3D Scanning Taxonomy



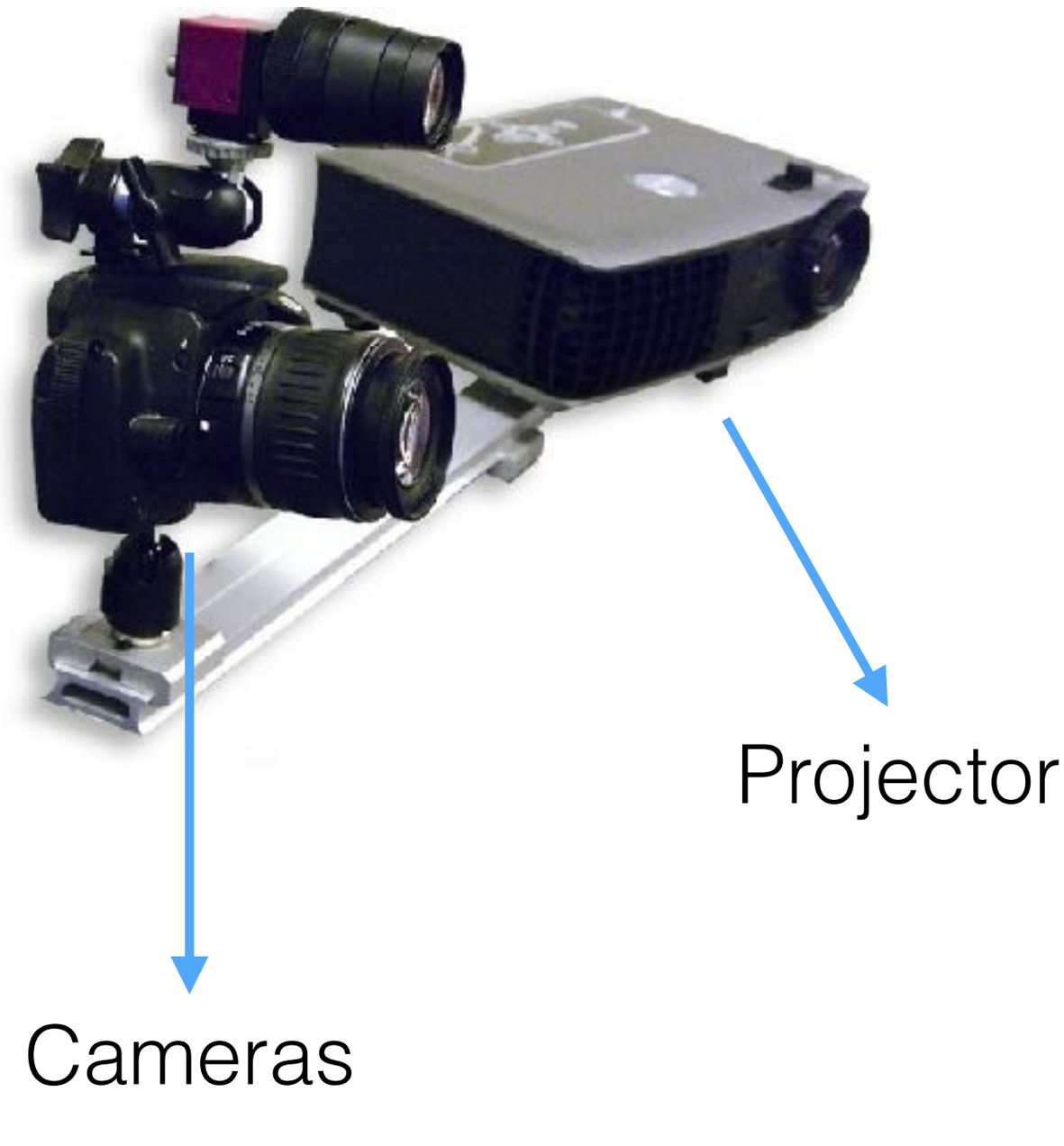
3D Scanning Taxonomy



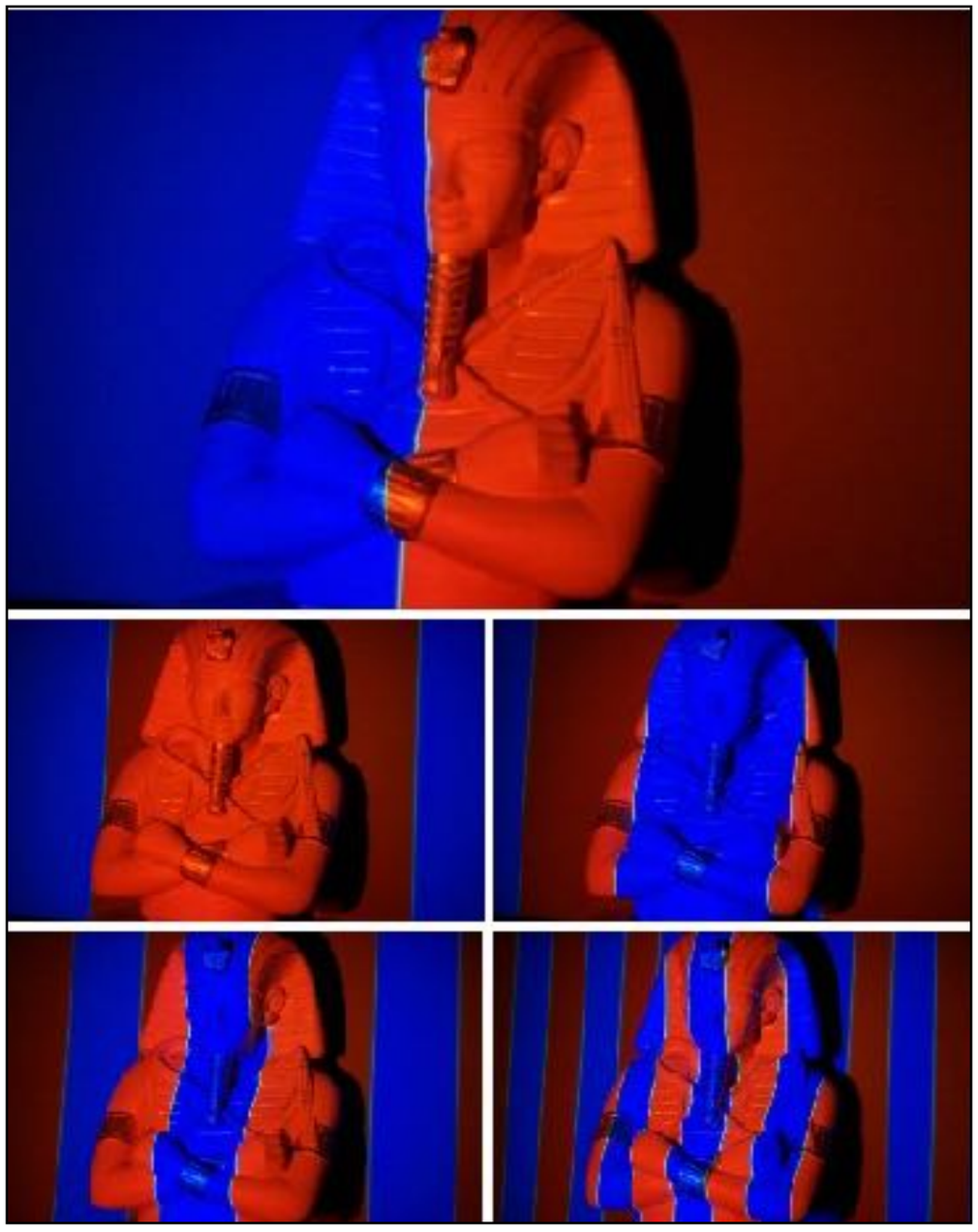
3D Scanning Taxonomy: Optical - Active

- Main blocks:
  - A calibrated camera
  - A light source —> that's why it's *active*!

3D Scanning Taxonomy:
Optical - Active: Structured Light



3D Scanning Taxonomy:
Optical - Active: Structured Light

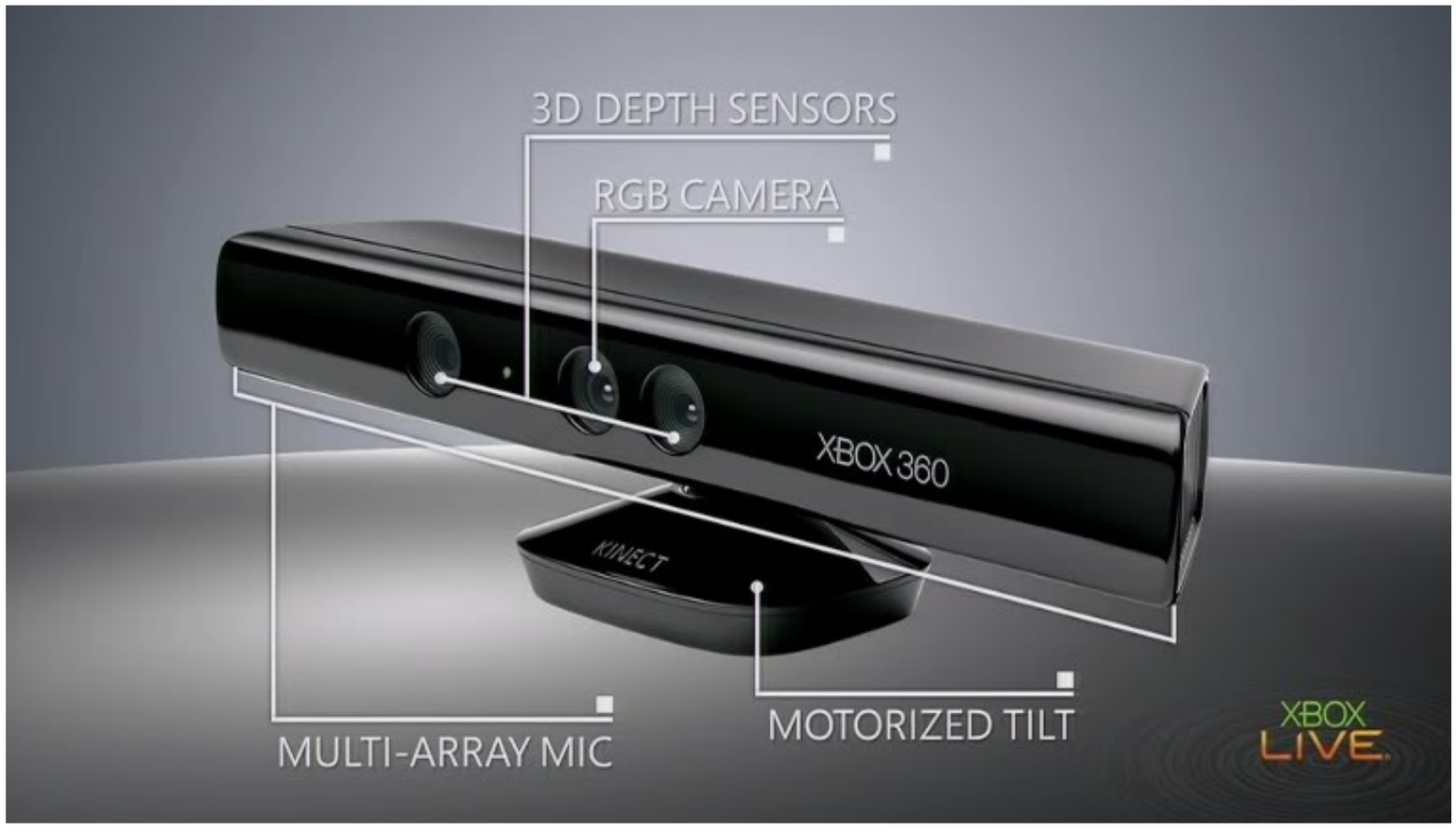


3D Scanning Taxonomy: Optical - Active: Structured Light

Breuckmann GmbH

Cost: €70,000-80,000
Accuracy: 0.1 mm

3D Scanning Taxonomy:
Optical - Active: Structured Light



Microsoft Kinect v1

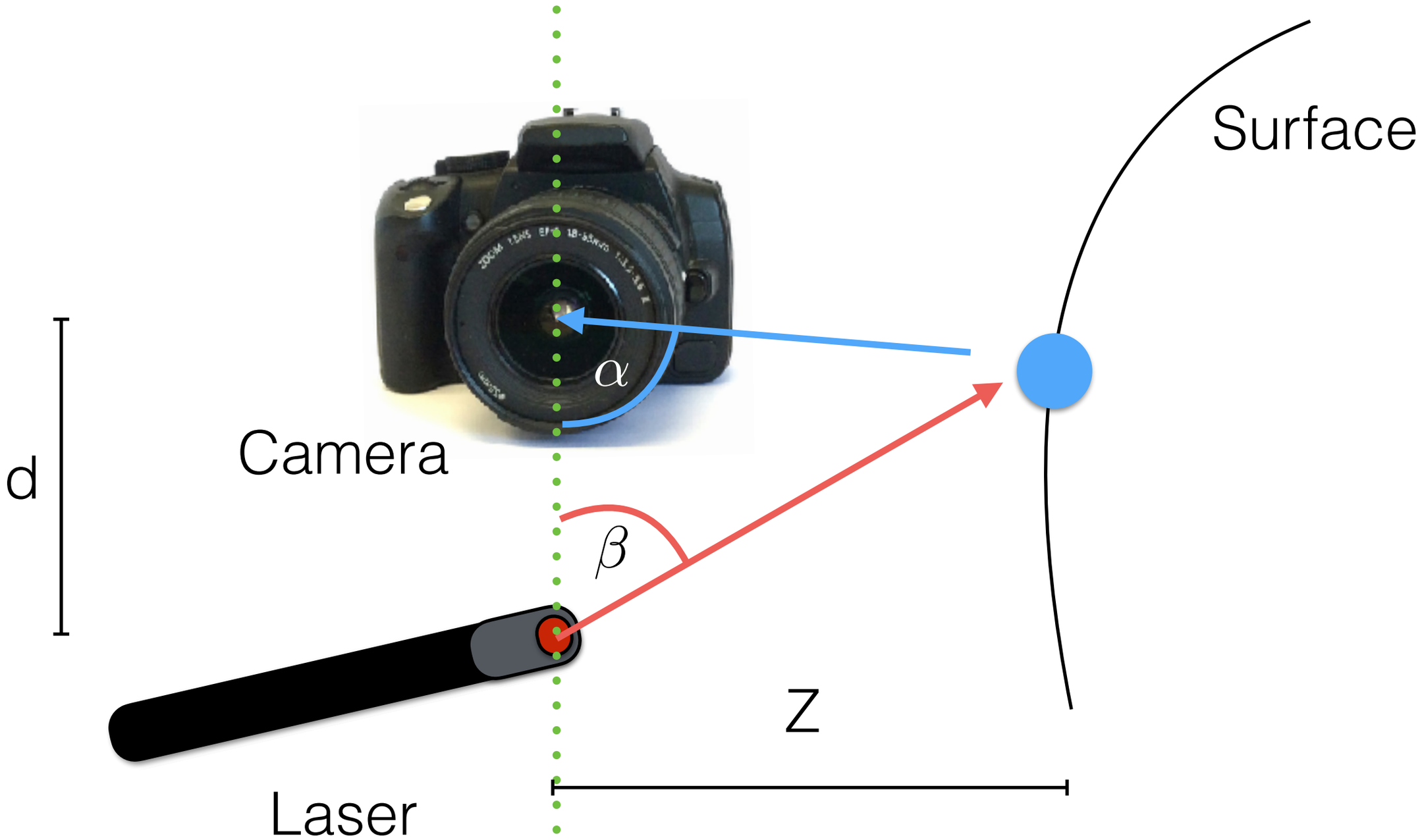
Cost: €100
Accuracy: 2-5 mm

3D Scanning Taxonomy: Optical - Active: Laser-based

Laser Line

Camera

3D Scanning Taxonomy: Optical - Active: Laser-based



3D Scanning Taxonomy: Optical - Active: Laser-based

Konica Minolta Range 7

Cost: $80,000
Accuracy: 40 micron

3D Scanning Taxonomy: Optical - Active: Laser-based

Konica Minolta Vivid 910

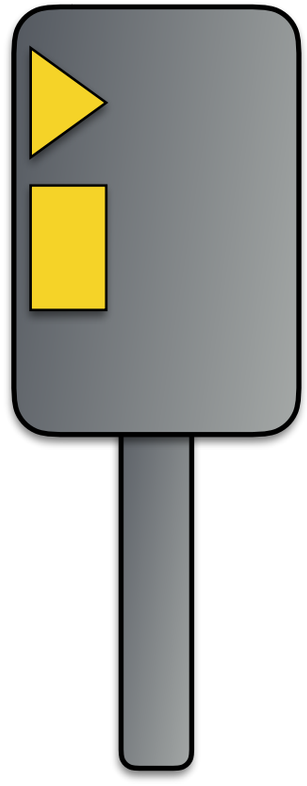
Cost: $15,000 (second hand)
Accuracy: 0.2-0.3mm

3D Scanning Taxonomy: Optical - Active: Laser-based

NextEngine

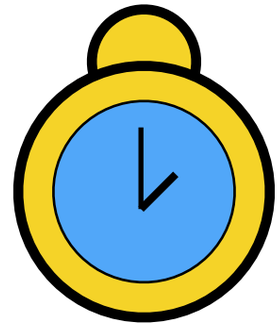
Cost: $2,000
Accuracy: 0.2-0.5mm

3D Scanning Taxonomy: Optical - Active: Time-of-flight



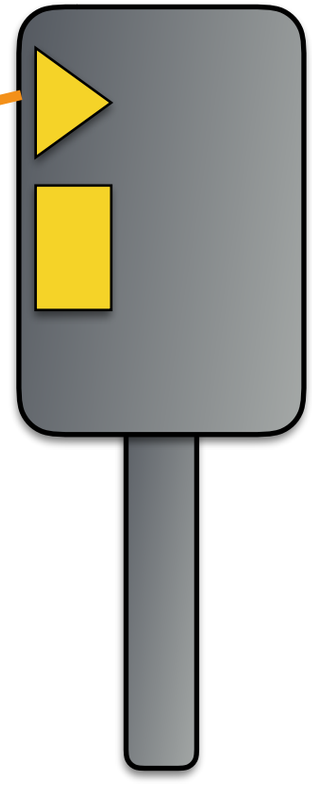
Transmitter

Detector



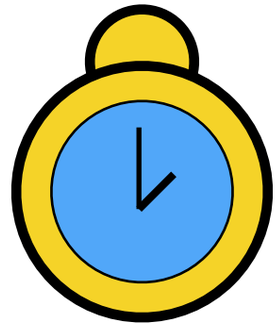
Clock

3D Scanning Taxonomy: Optical - Active: Time-of-flight



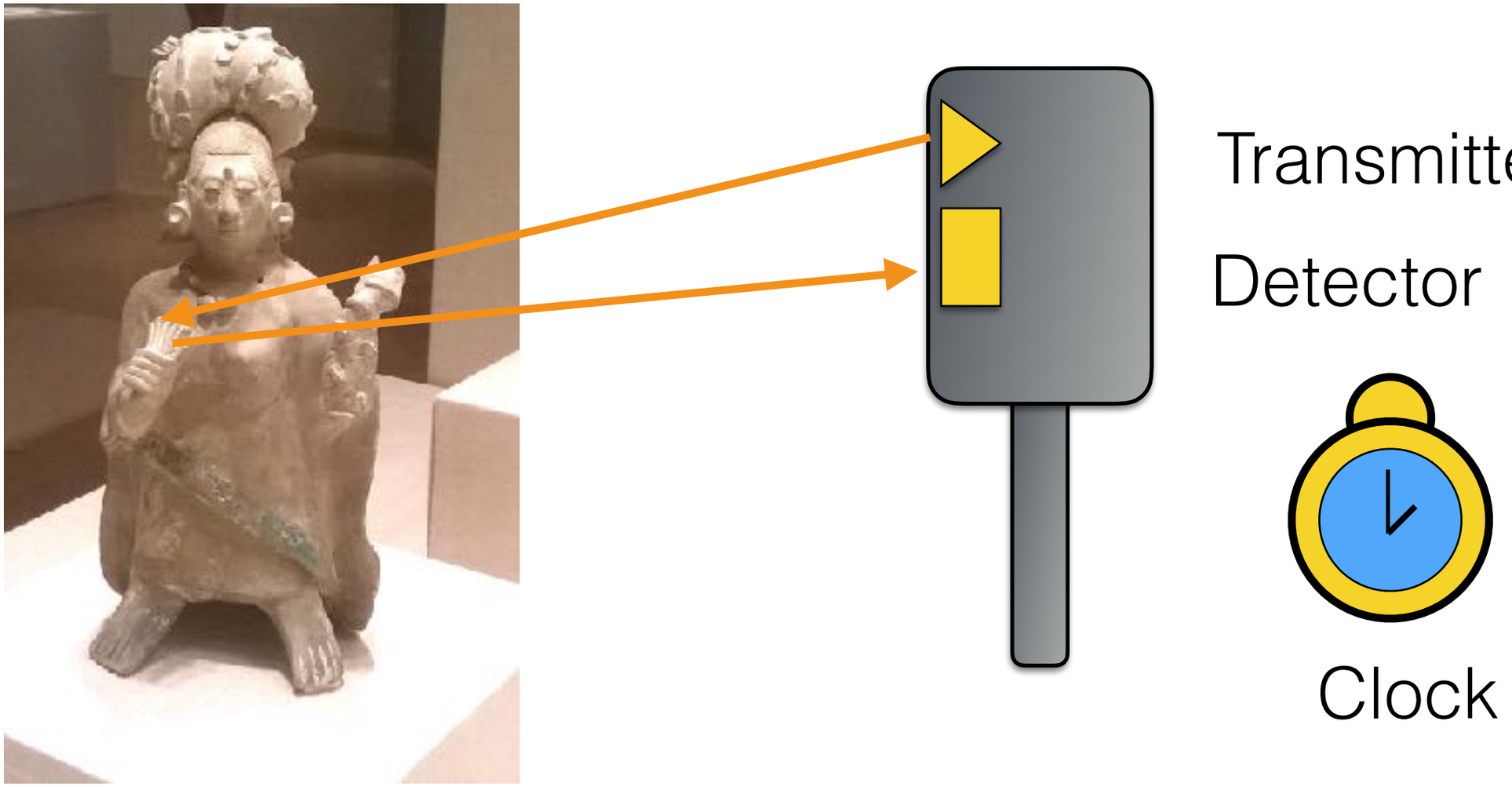
Transmitter

Detector



Clock

3D Scanning Taxonomy: Optical - Active: Time-of-flight



3D Scanning Taxonomy: Optical - Active: Time-of-flight

Microsoft Kinect v2

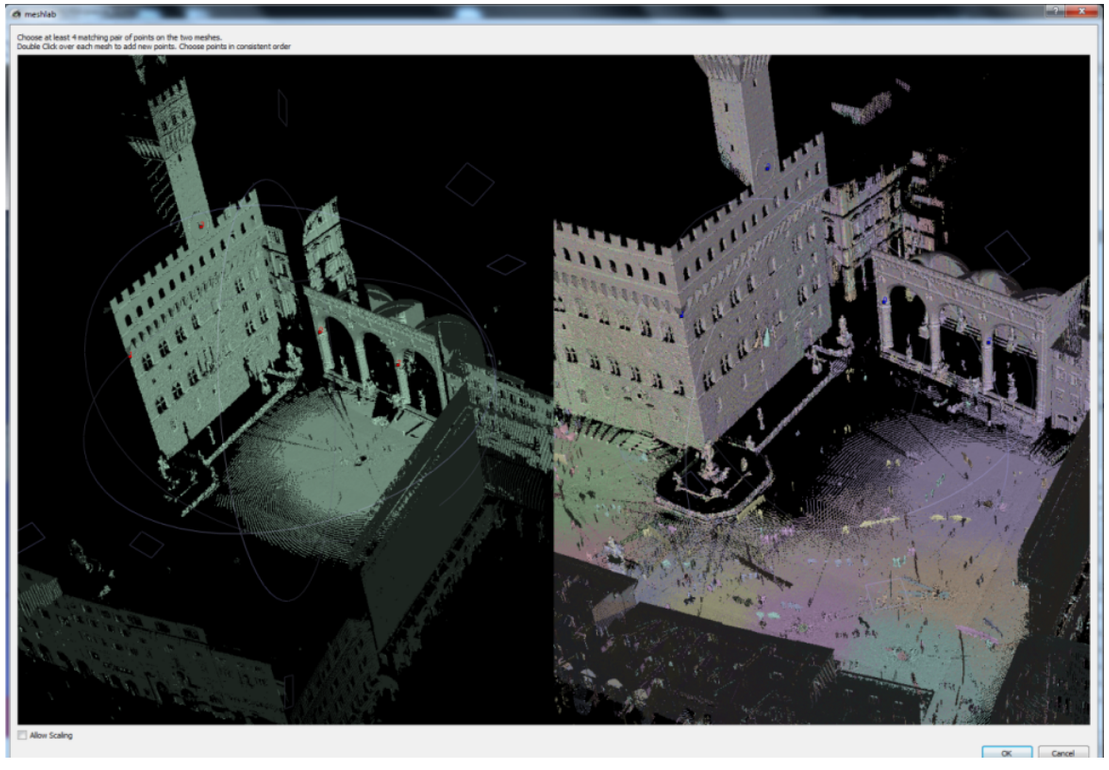
Cost: €200

Accuracy: 2-5 mm

It is meant for ***small*** environments: 2-3m radius

3D Scanning Taxonomy: Optical - Active: Time-of-flight

Cost: €50,000 - 100,000
Accuracy: 5-10 mm

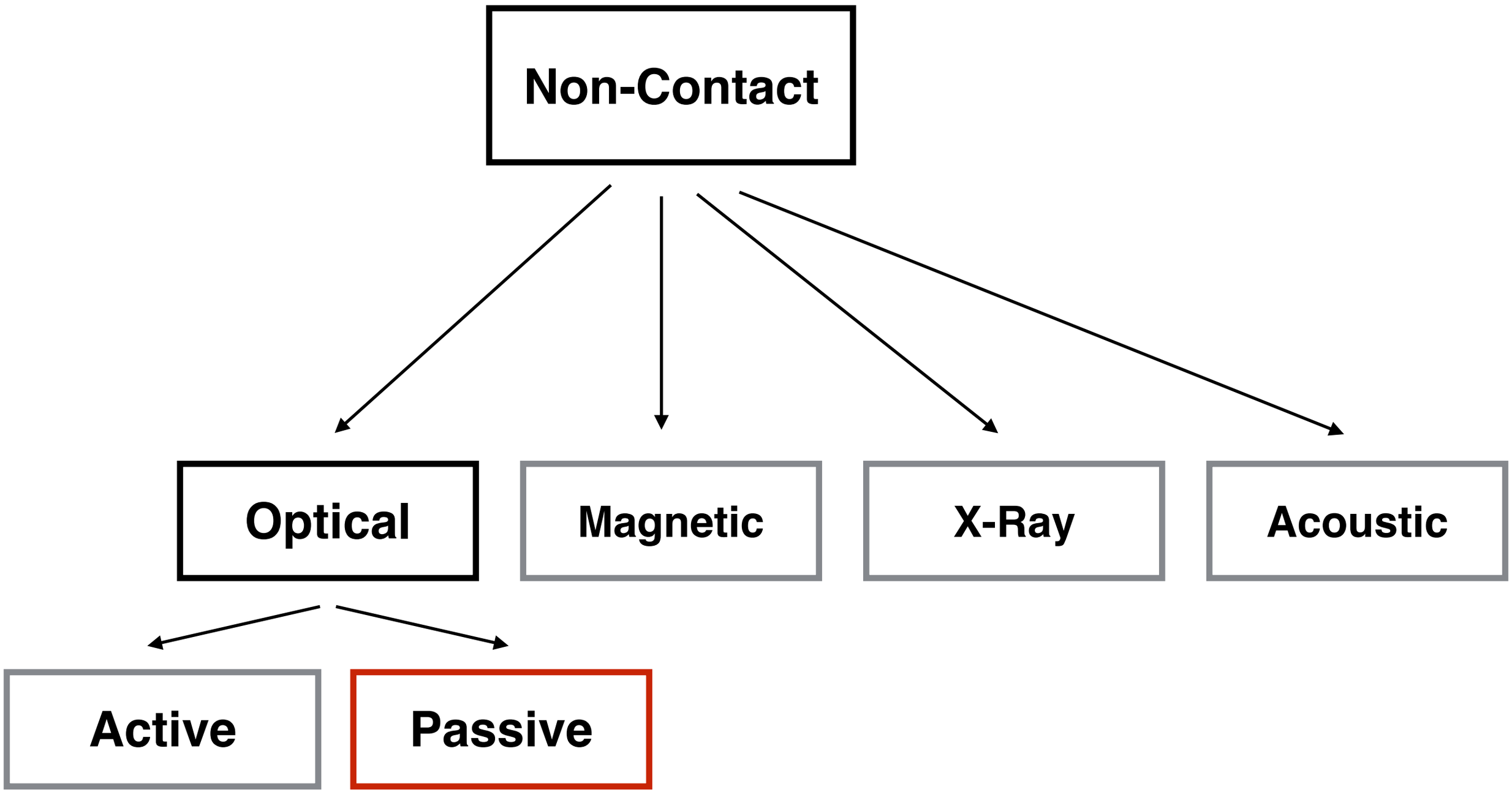


It is meant for ***large*** environments: 1-30m radius

3D Scanning Taxonomy: Optical - Active

- It can be accurate and precise
- Ideal for: rigid object with diffuse optical properties; i.e., it does not work well for specular surfaces and dark materials
- Uses: reverse engineering, cultural heritage, metrology (if calibrated), body scanning, etc.
- Costs: from $200 to $100,000
- Output data: a range map

3D Scanning Taxonomy



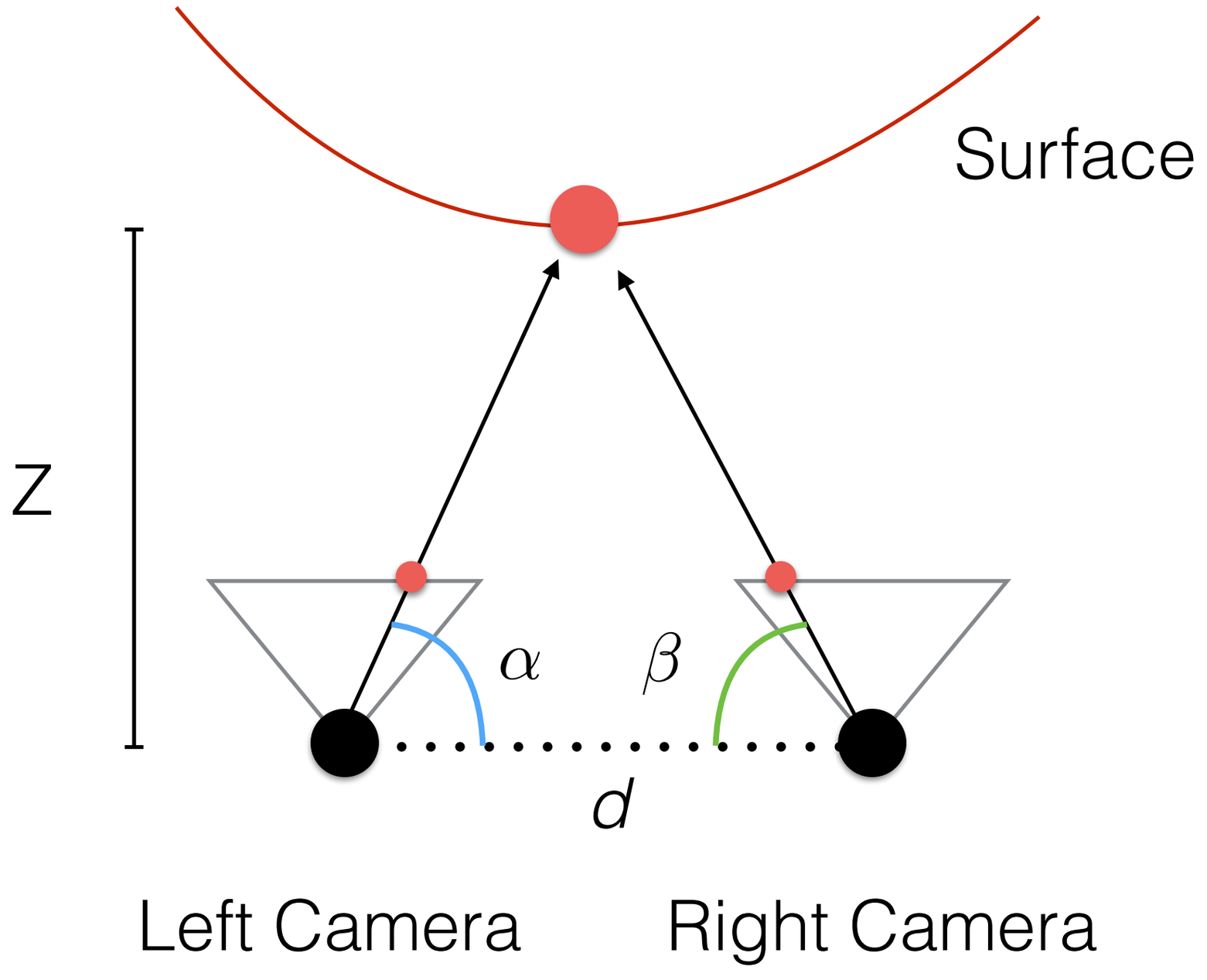
3D Scanning Taxonomy: Optical - Passive

- Main blocks:
  - One ore more calibrated camera(s)
  - No control on lighting —> that's why it's *passive*!

3D Scanning Taxonomy: Optical - Passive: Stereo

- It is based on the same principle of human stereo vision:
    - two cameras that captures the real-world from two slightly different positions
- Our brains does it automatically though

3D Scanning Taxonomy: Optical - Passive: Stereo



3D Scanning Taxonomy: Optical - Passive: Stereo

Left Camera

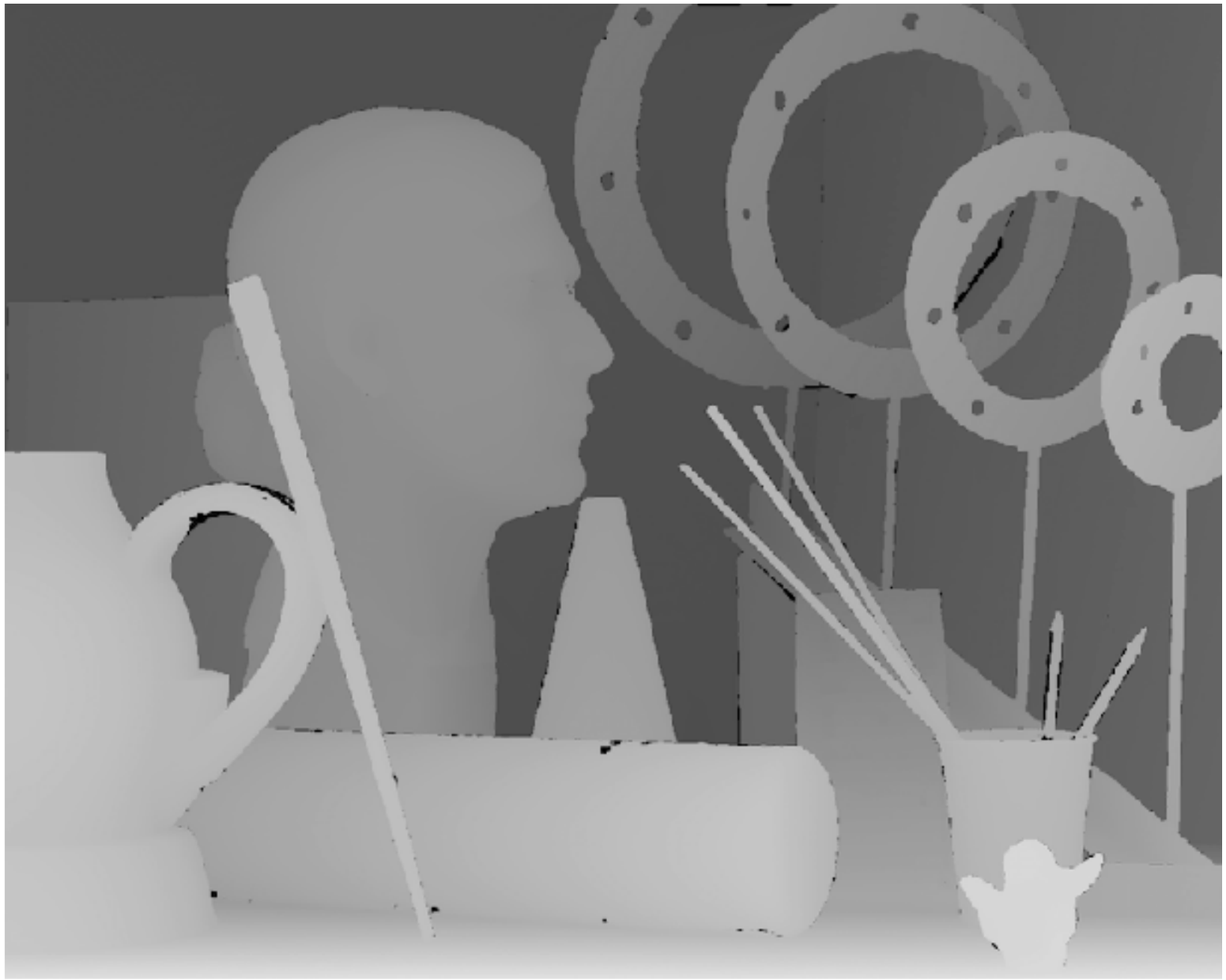
Right Camera

3D Scanning Taxonomy: Optical - Passive: Stereo

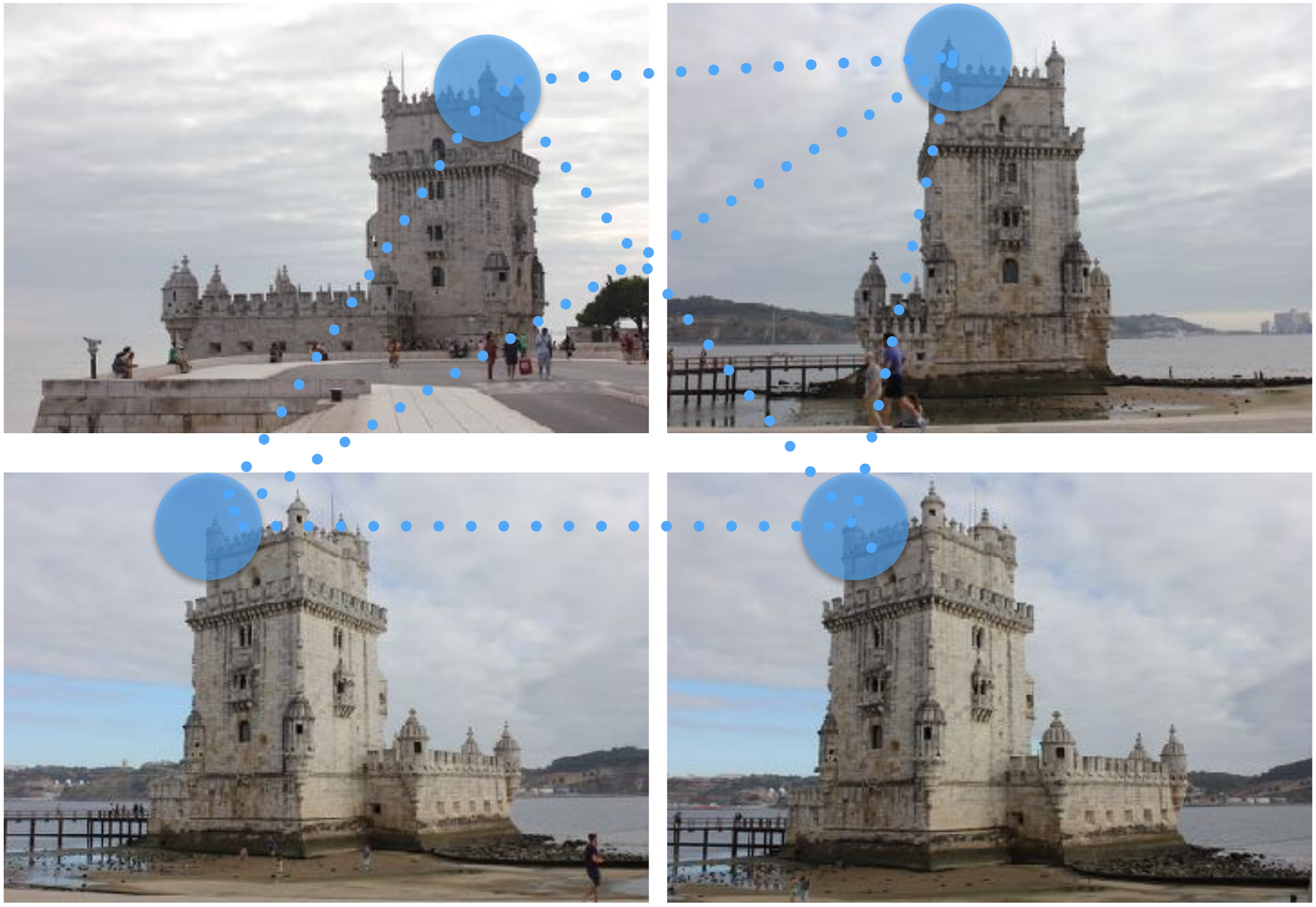
Left Camera

Right Camera

3D Scanning Taxonomy: Optical - Passive: Stereo



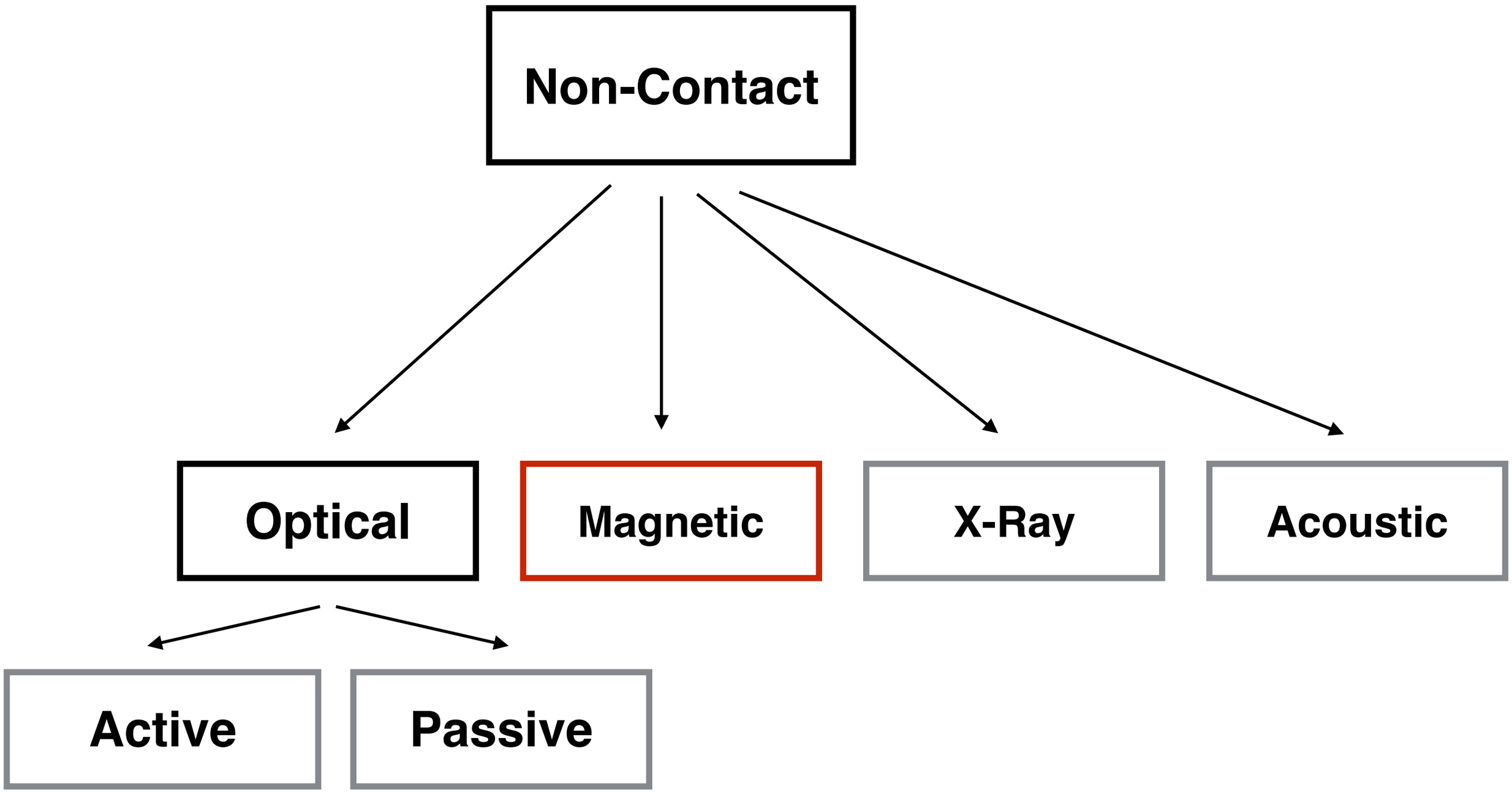
3D Scanning Taxonomy: Optical - Passive: Stereo



3D Scanning Taxonomy: Optical - Passive

- It can be accurate and precise
- Many images are required
- Ideal for: objects with diffuse optical properties
- Uses: reverse engineering, cultural heritage, body capturing, metrology (if calibrated)
- Output data: sparse 3D points or range maps

3D Scanning Taxonomy



3D Scanning Taxonomy:
Magnetic - Magnetic Resonance Imaging (MRI)

Philips MRI Scanner

Hydrogen atoms in our body are made to emit a radio signal (using a magnetic field) that is detected by the scanner.

3D Scanning Taxonomy: Magnetic - MRI

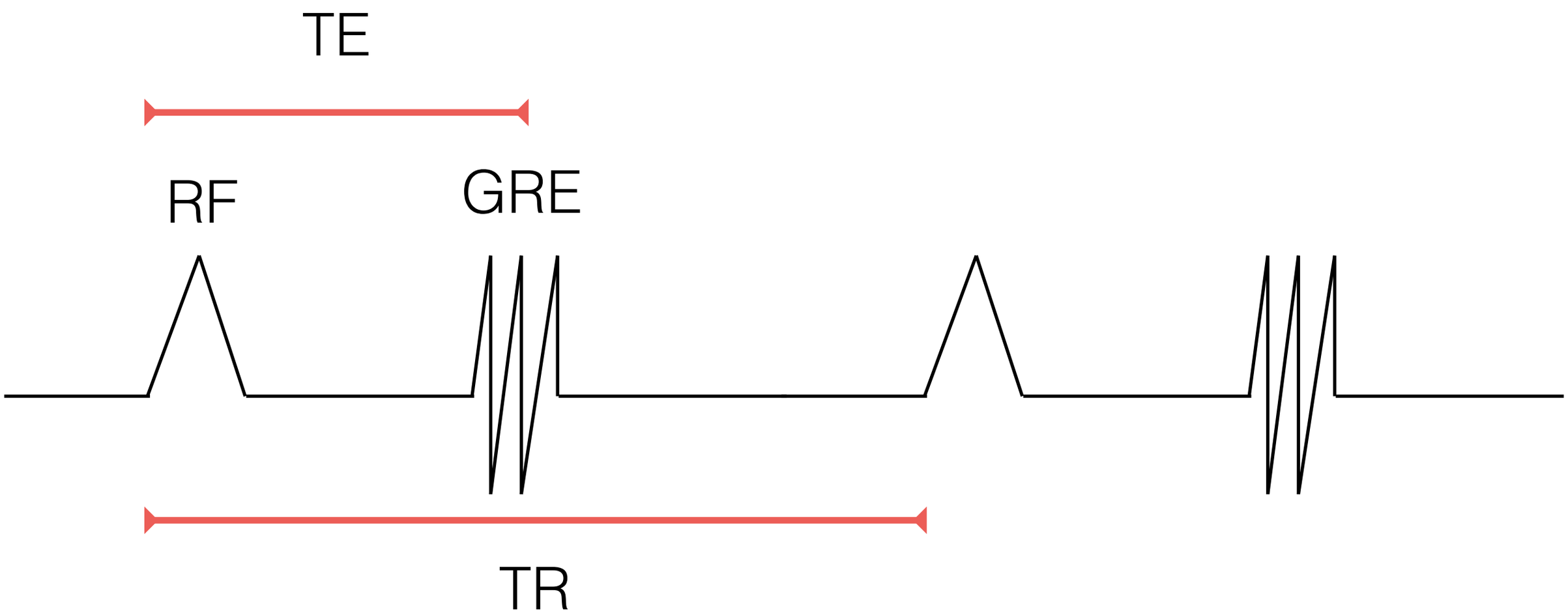
- T1 weighted images are generated by using short (15ms and 500ms) **time to echo** (TE) and **time of repetition** (TR)

- T2 weighted images are generated by using long (>80ms and >2000ms) TE and TR (also less noise than T1)

- TE is the time between the initial pulse and the echo

- TR is the time between two excitation pulse

3D Scanning Taxonomy: Magnetic - MRI



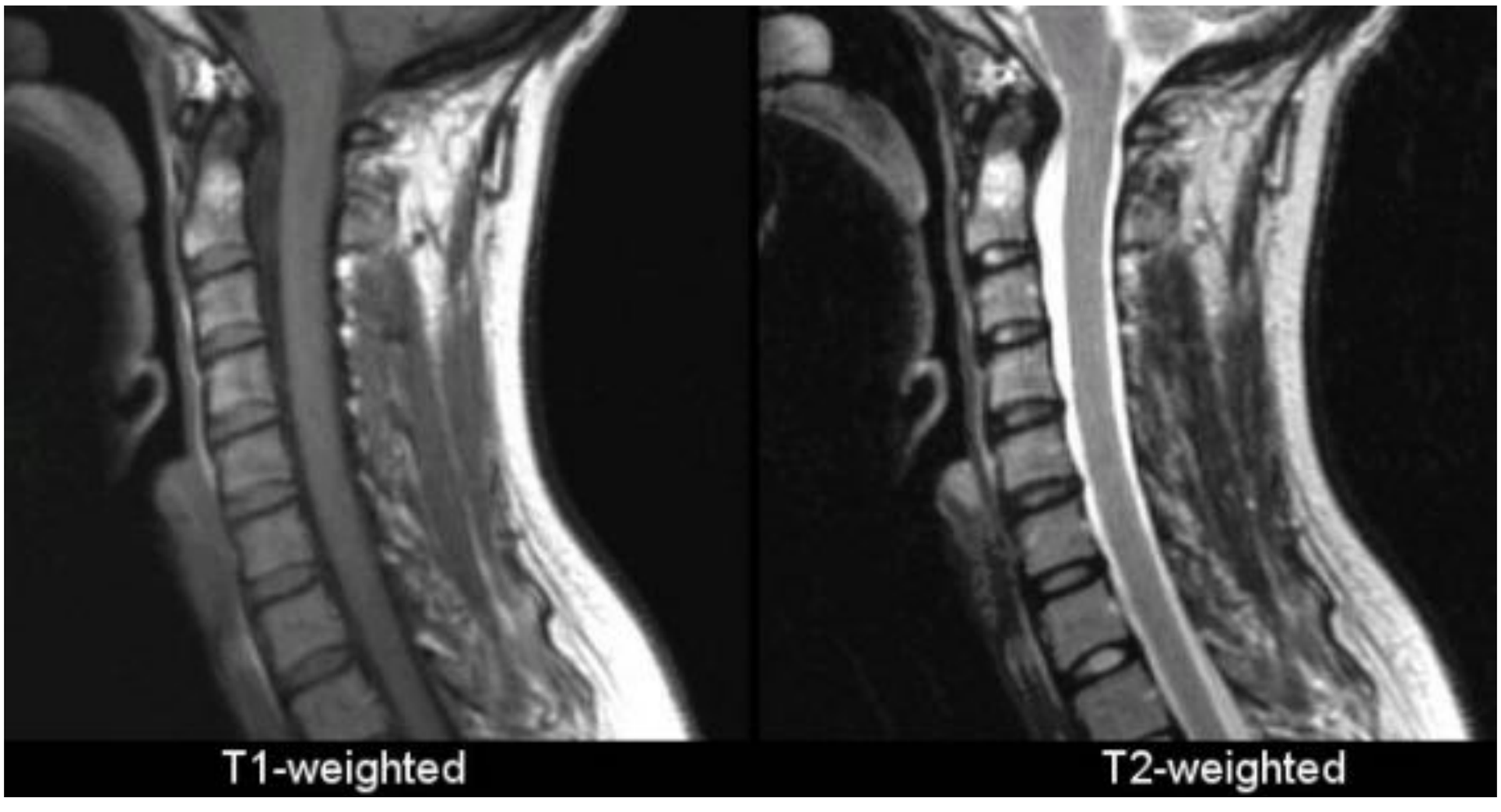
3D Scanning Taxonomy: Magnetic - MRI

- T1: tissues with high fat content (e.g., white matter) appear bright and compartments filled with water appears dark:
    - ideal for showing anatomy features

- T2: compartments filled with water (e.g. cerebrospinal fluids) appear bright and tissues with high fat content (e.g. white matter) appear dark:

    - ideal for highlighting pathologies (more water!)

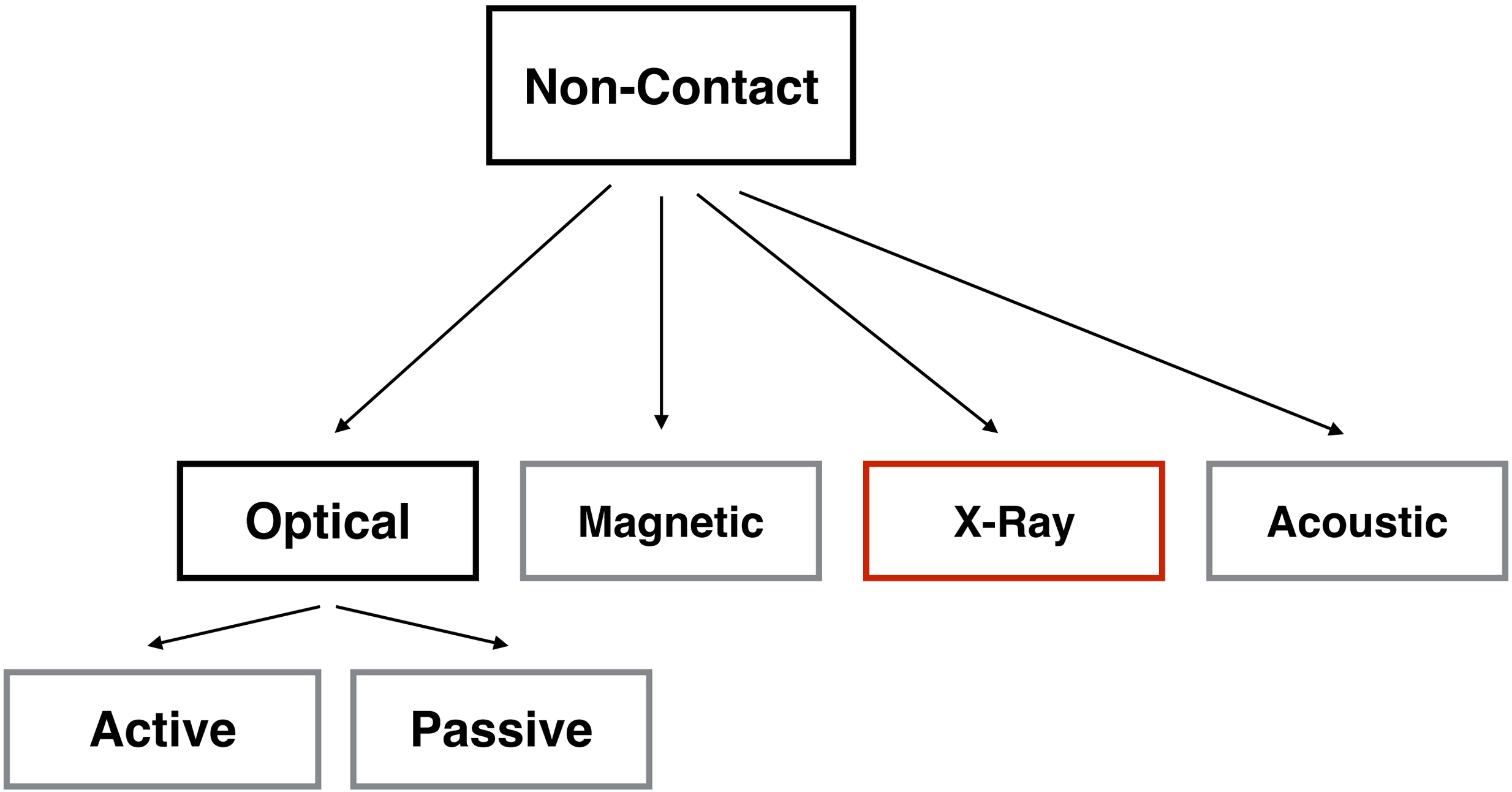
3D Scanning Taxonomy: Magnetic - MRI



3D Scanning Taxonomy: Magnetic - MRI

- No hazard, but it requires no metal implant in the patient's body
- It takes long time for a scan; e.g., 15-30 mins
- Costs: they start at $1 million
- Ideal for: soft tissues, ligaments, tendons, etc.
- Uses: medical imaging, and cultural heritage
- Output data: a 3D volume

3D Scanning Taxonomy



3D Scanning Taxonomy:
X-Ray - Computer Tomography (CT)

GE LightSpeed CT scanner

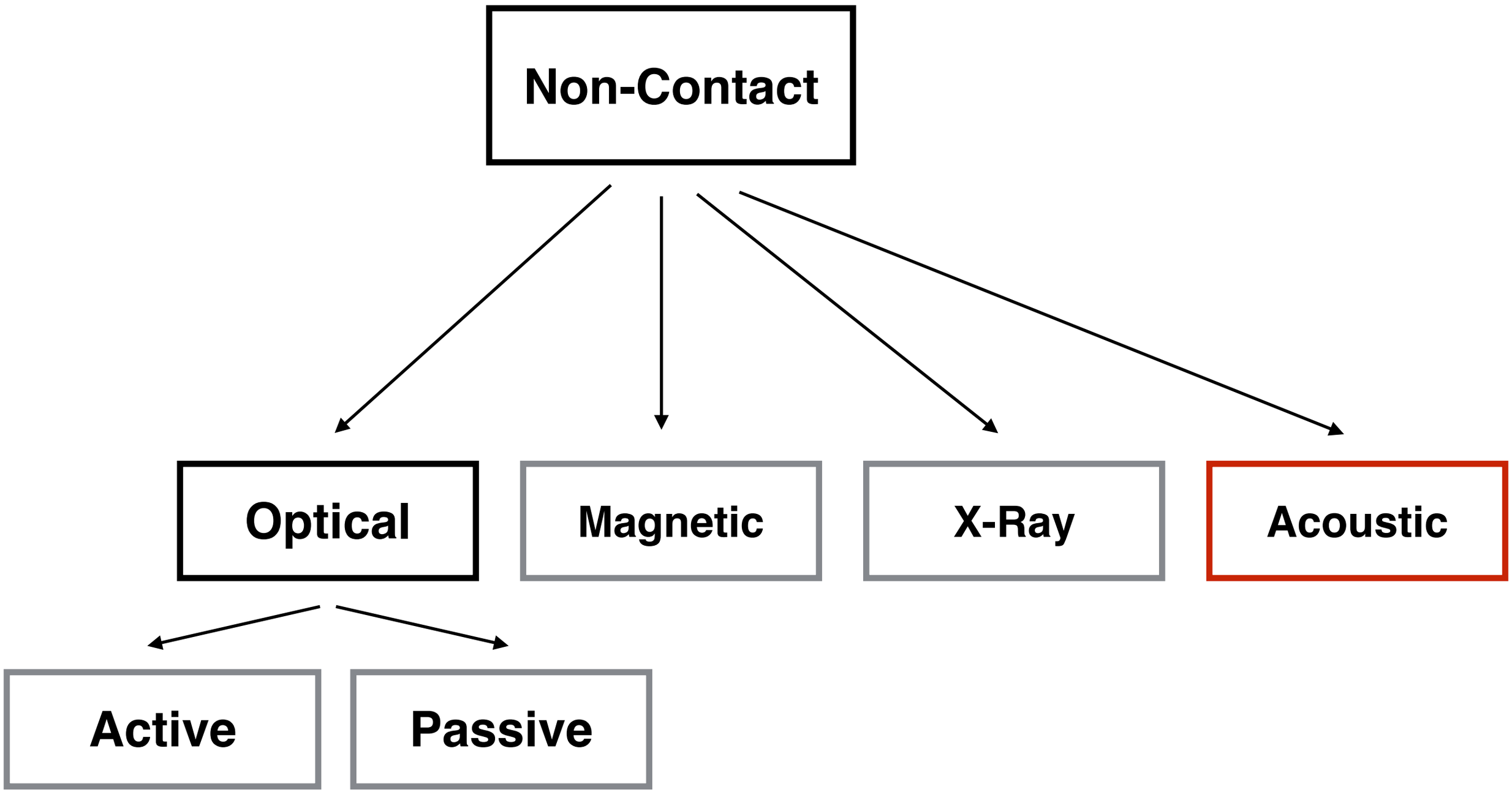
CT works by taking X-ray images from different angles to produce cross-sectional images

3D Scanning Taxonomy: X-Ray - CT

- Hazard for the patient
- It takes long time; e.g., 30 secs - 5 mins
- Costs: they start at $85,000 - $500,000
- Ideal for: bones (Ca absorbs X-rays), lungs (contain gas; lower absorption than tissues), chest, and ER (for time)
- Uses: medical imaging, and cultural heritage
- Output data: a 3D volume

3D Scanning Taxonomy: X-Ray - CT

3D Scanning Taxonomy

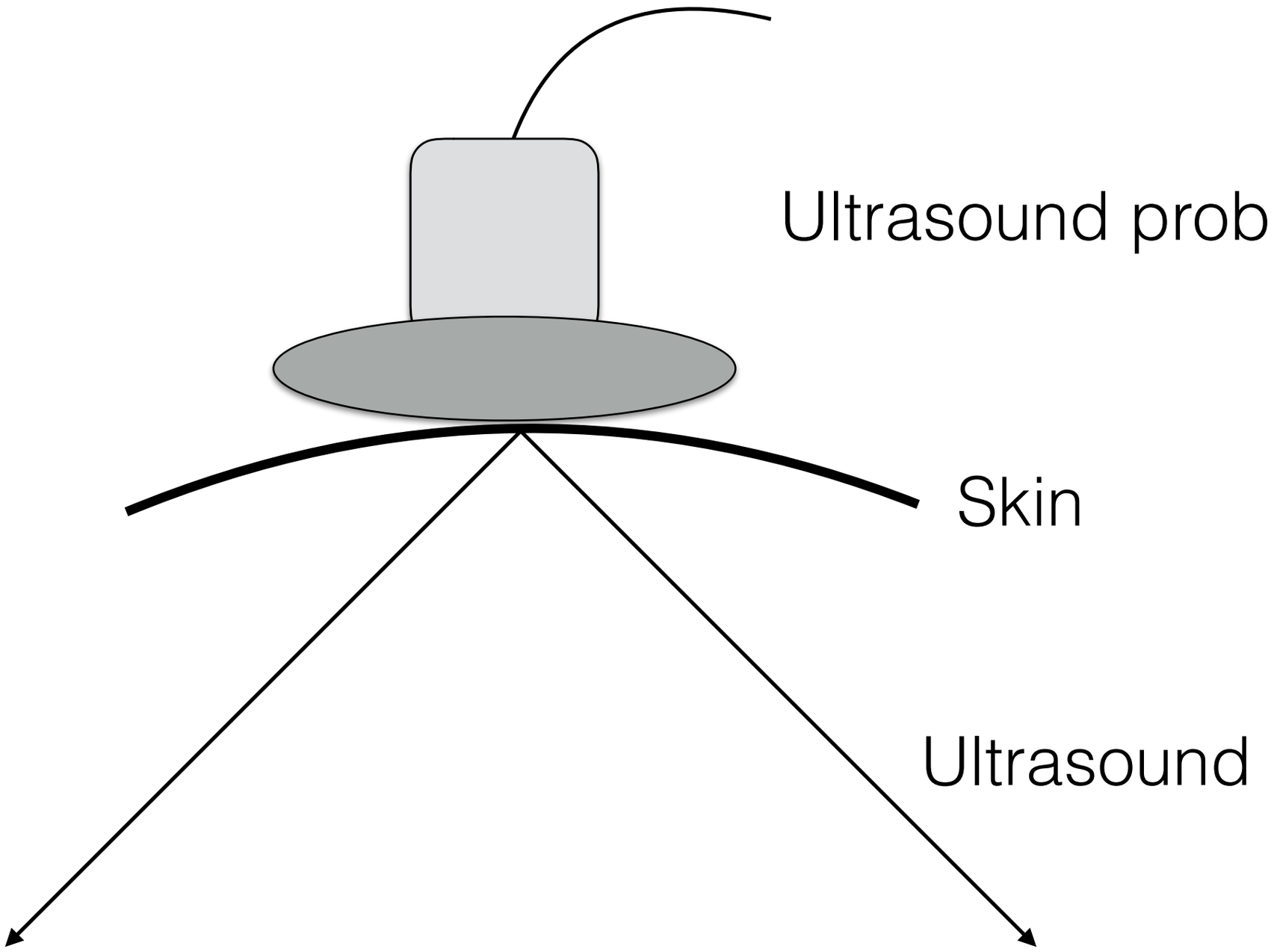


3D Scanning Taxonomy: Acoustic: Medical Ultrasound

A probe sends pulses of ultrasounds (>20,000Hz)

The sound echoes off the tissue; with different tissues reflecting varying degrees of sound

3D Scanning Taxonomy: Acoustic: Medical Ultrasound



3D Scanning Taxonomy: Acoustic

- It is real-time!
- Quality-wise it can have speckle; i.e., granular noise
- Ideal for: medical imaging of soft tissues (tendons, muscles, joints, internal organs, etc.); especially during pregnancy. It can not penetrate bones
- Output data: a 3D volume (limited to a pyramid)

Acknowledgements

- Some images and text are based on work by:
  - Dr. Matteo Dellepiane:
    - http://vcg.isti.cnr.it/~dellepiane/
  - Dr. Marco Callieri:
    - vcg.isti.cnr.it/~callieri/
  - Wikipedia

Acknowledgements

- Some images and text are based on work by:
  - Dr. Matteo Dellepiane:
    - http://vcg.isti.cnr.it/~dellepiane/
  - Dr. Marco Callieri:
    - vcg.isti.cnr.it/~callieri/
  - Wikipedia

Extra

3D Scanning Taxonomy: Magnetic - MRI

- Time of Repetition (TR) is the time between successive radio frequency (RF) pulses:
  - A long TR —> protons in all tissues relax back into alignment with the main magnetic field
  - A short TR —> protons from some tissues will be not fully relaxed back before the next measurement

3D Scanning Taxonomy: Magnetic - MRI

- Time of Echo (TE) is the time at which the electrical signal induced by the spinning protons is measured:
  - A long TE —> to reduce the signal for some tissues such as gray matter (protons go out of phase)
  - A short TE —> to reduce dephasing