Università di Genova | DIBRIS DIPARTIMENTO
DI INFORMATICA, BIOINGEGNERIA,
ROBOTICA E INGEGNERIA DEI SISTEMI

Augmented Reality

Lecture 7 – spatial display model and sensors for tracking

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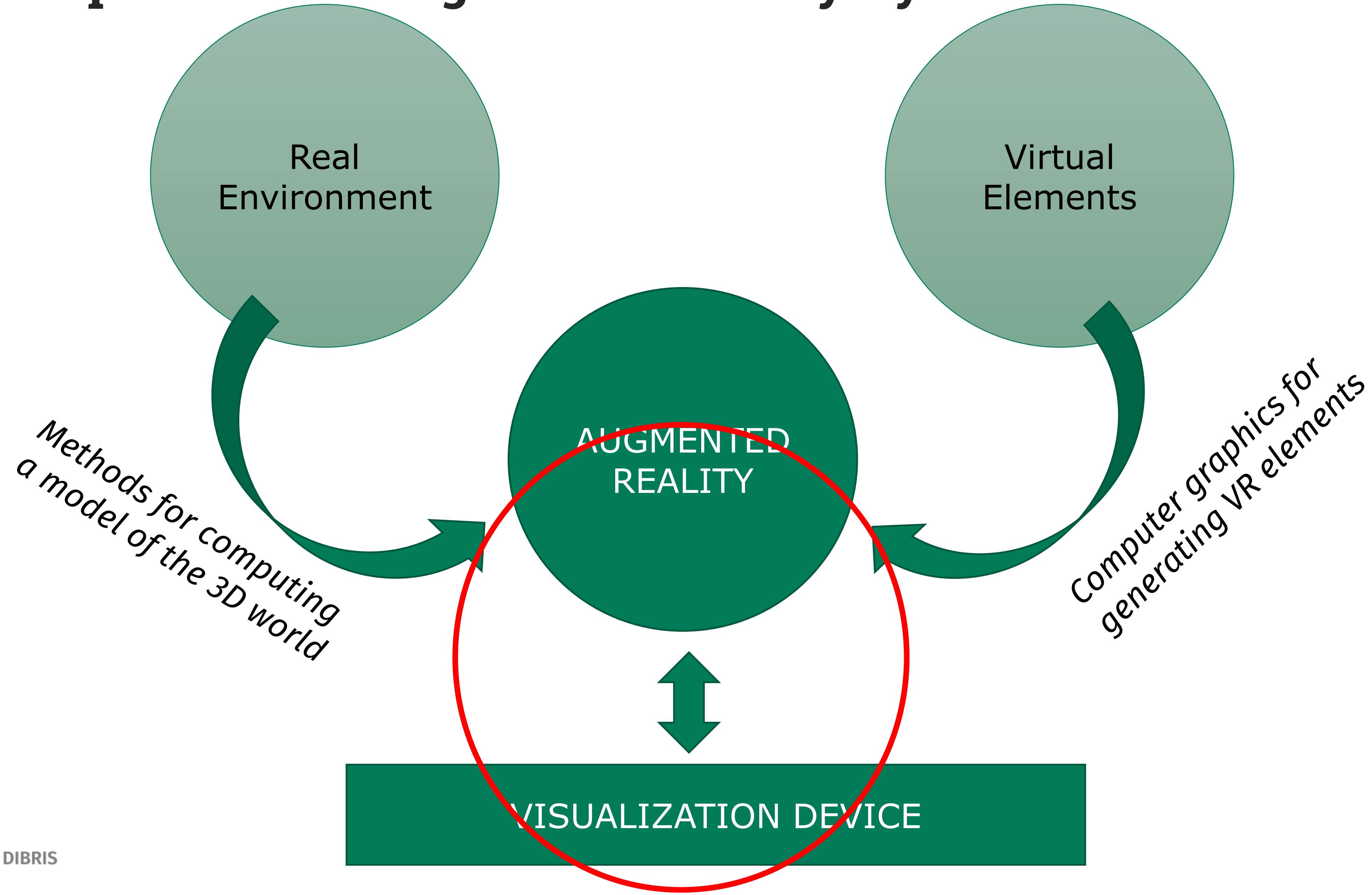
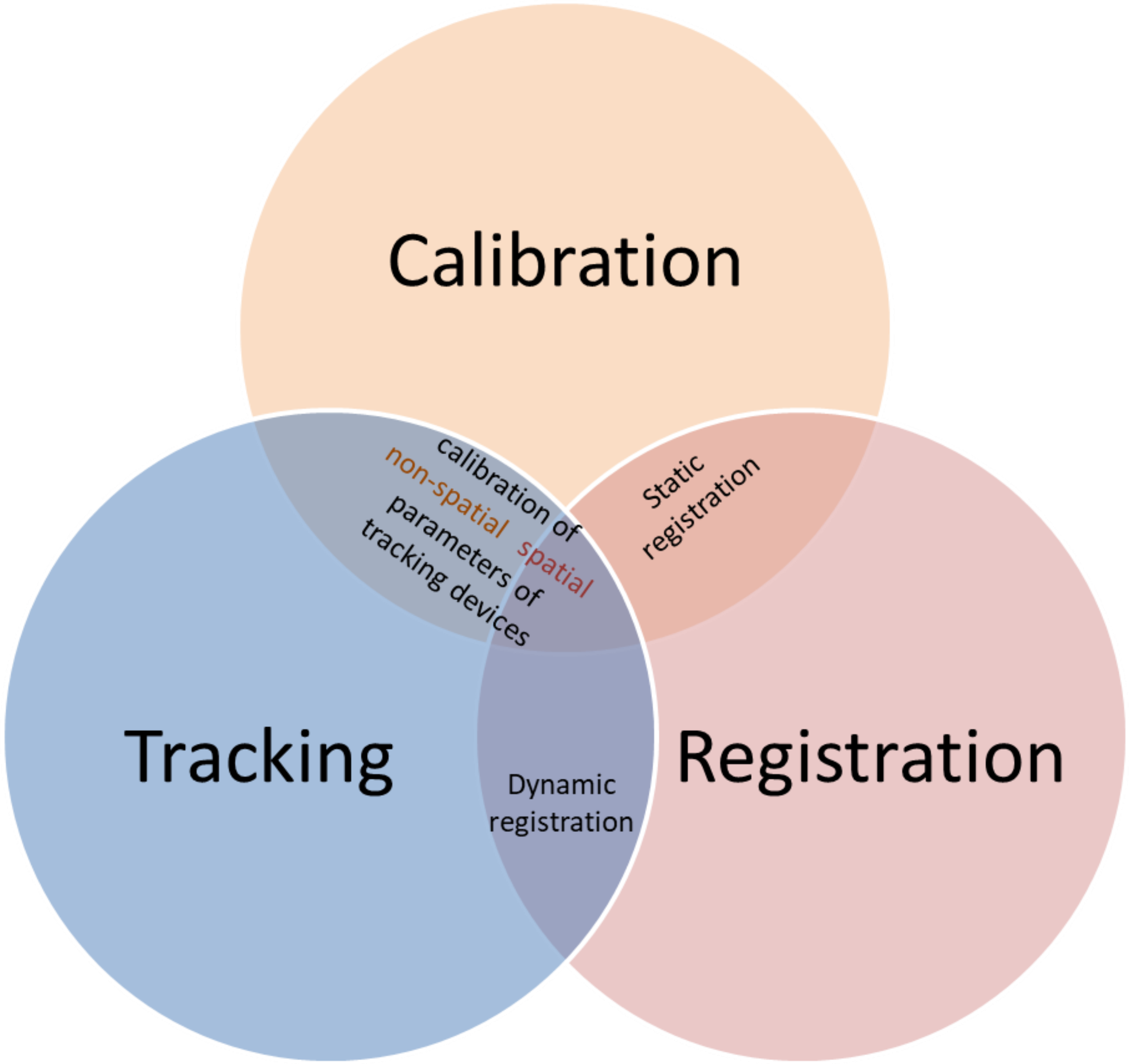
Description of an Augmented Reality System



Spatial Display Model

Calibration, tracking and registration



Calibration

- **Calibration** is the process of comparing measurements made with *two different devices*, a reference device and a device to be calibrated.
- The reference device can be replaced with a known reference value or, for geometric measurements, with a *known coordinate system*.
- The objective is to **determine parameters** for using the **device** to be calibrated to deliver **measurements** on the **known scale**.
- **For AR,** we need to calibrate the components of the AR system, especially the devices used for tracking.

Tracking

- **Tracking** is a term used to describe *dynamic sensing and measuring* of AR systems.
- To display virtual objects *registered* to real objects in three-dimensional space, we must know at least the *relative pose*.
- Because AR operates in real time, pose measurements must be continuously updated (**tracked over time**).
- In the field of AR, “tracking” is generally synonymous with “3D tracking” of the 3D position or the **six-dimensional pose** (*position and orientation*) of **real entities**, as opposed to the idea of tracking 2D features in image space, which is common in traditional computer vision.

Registration

- **Registration** in AR refers to the *alignment of coordinate systems* between virtual and real objects.
- Specifically, see-through displays should show computer graphics elements such that they align with real-world objects.
- Obtaining **static registration**, when the user or the camera is *not* moving, **requires calibration** of the tracking system to establish a common coordinate system between virtual and real object.
- Obtaining **dynamic registration**, when the user or the camera is moving, **requires tracking**.

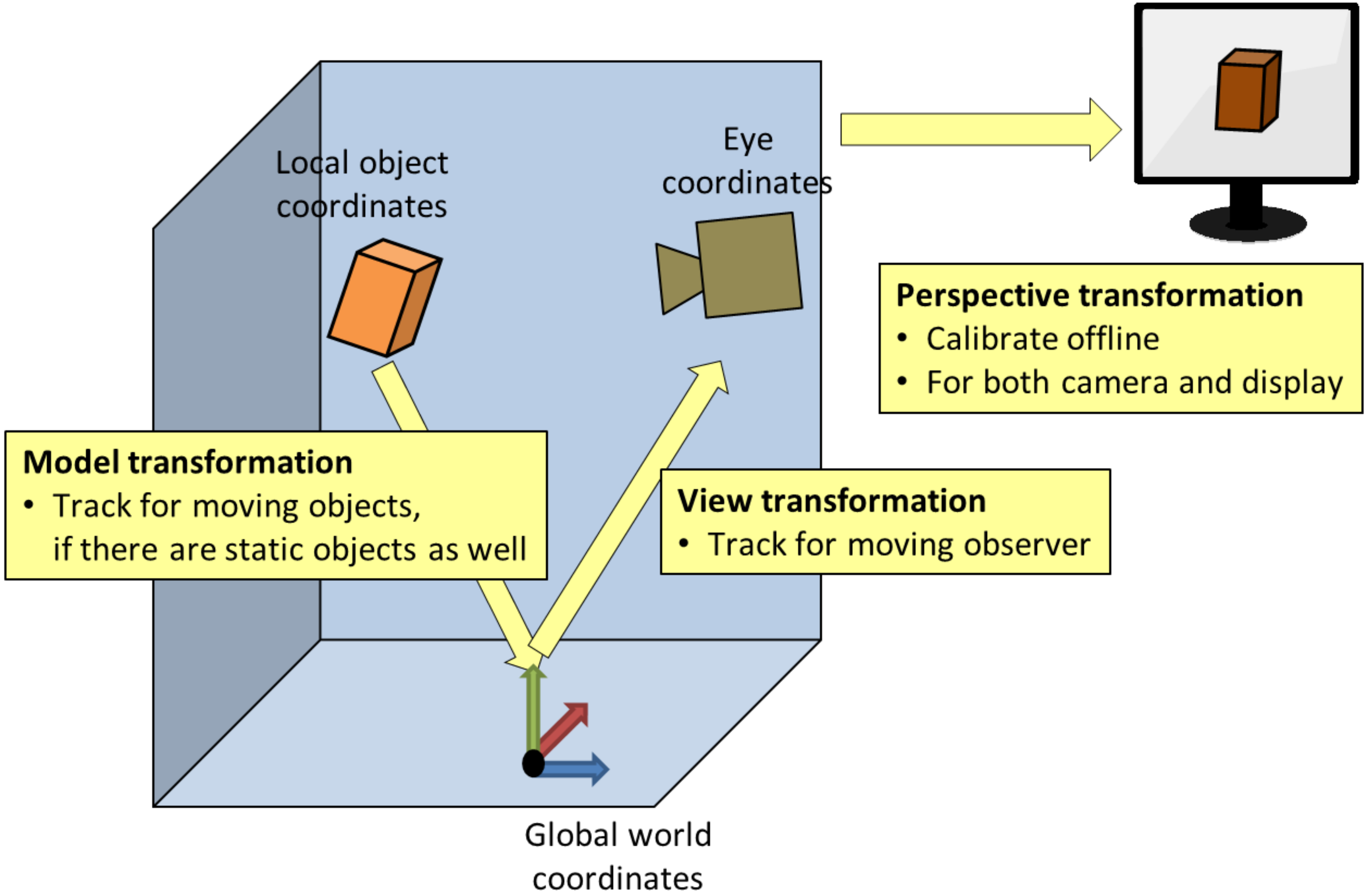
Spatial Display Model

- Process of AR information display through the interplay of various **coordinate transformations**.
- We rely on a **standard computer graphics pipeline** to produce overlays on the real world:
  - model transformation,
  - view transformation,
  - projective transformation.

Spatial Display Model

- **Model transformation:** The model transformation describes the relationship of 3D local object coordinates and 3D global world coordinates. *The model transformation describes how objects are positioned in the real world*.
- **View transformation:** The view transformation describes the relationship of 3D global world coordinates and 3D view (*observer* or camera) coordinates. *It may involve tracking techniques to determine the camera and user pose*.
- **Projective transformation:** The projective transformation describes the relationship of 3D view coordinates and 2D device (*screen*) coordinates (*usually static, not when camera parameters, e.g. FOV, change*).

Spatial Display Model: coordinate systems



Spatial Display Model: frames of reference

World-stabilized

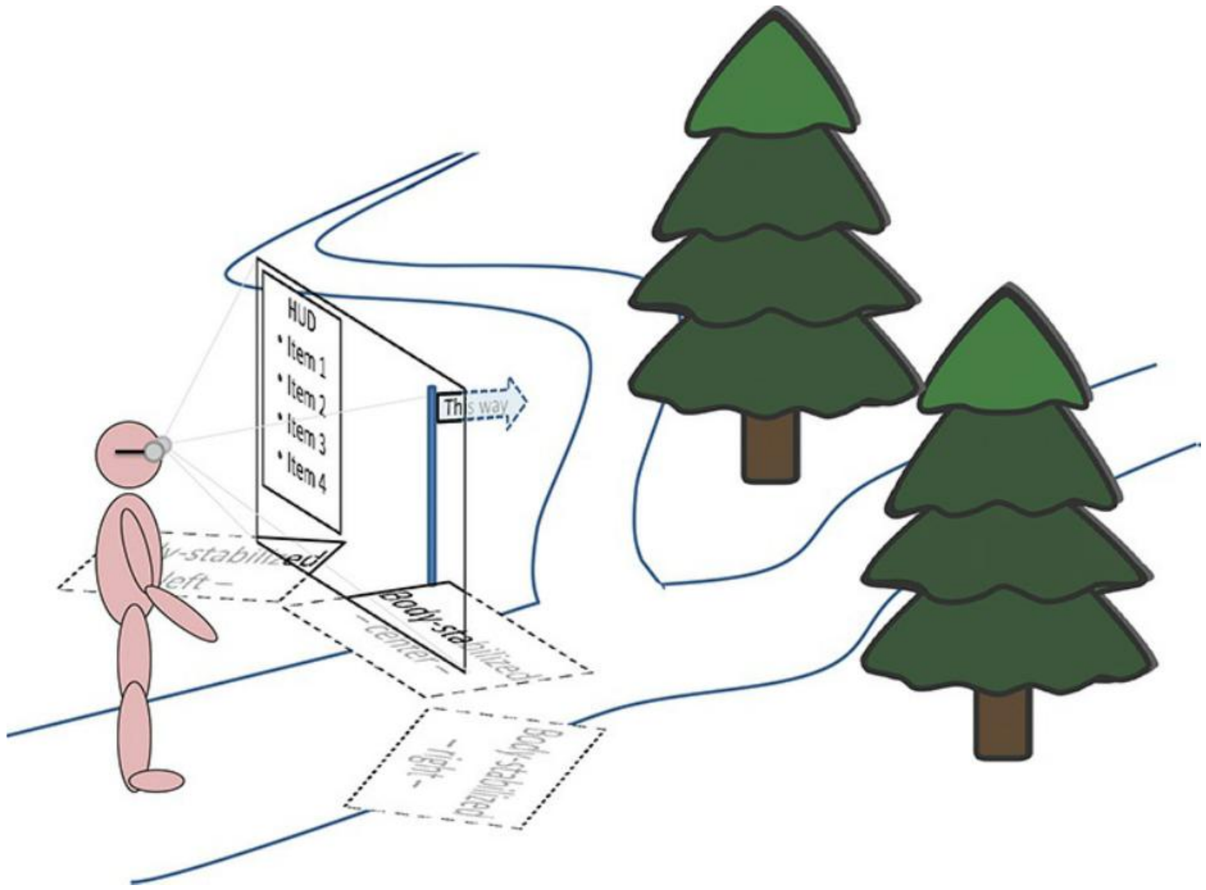
- e.g., billboard or signpost

Body-stabilized

- e.g., virtual tool-belt

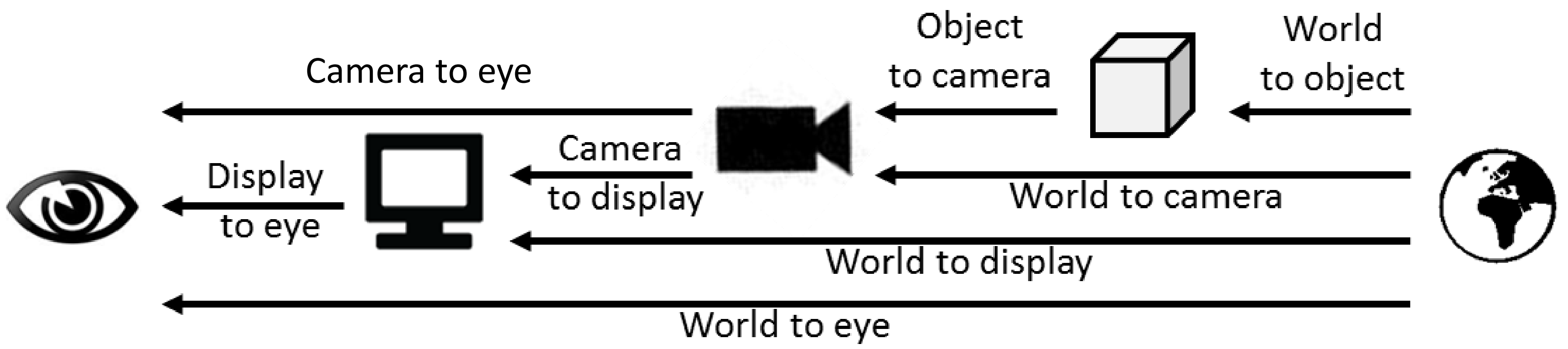
Screen-stabilized

- Heads-up display



Spatial Display Model: components

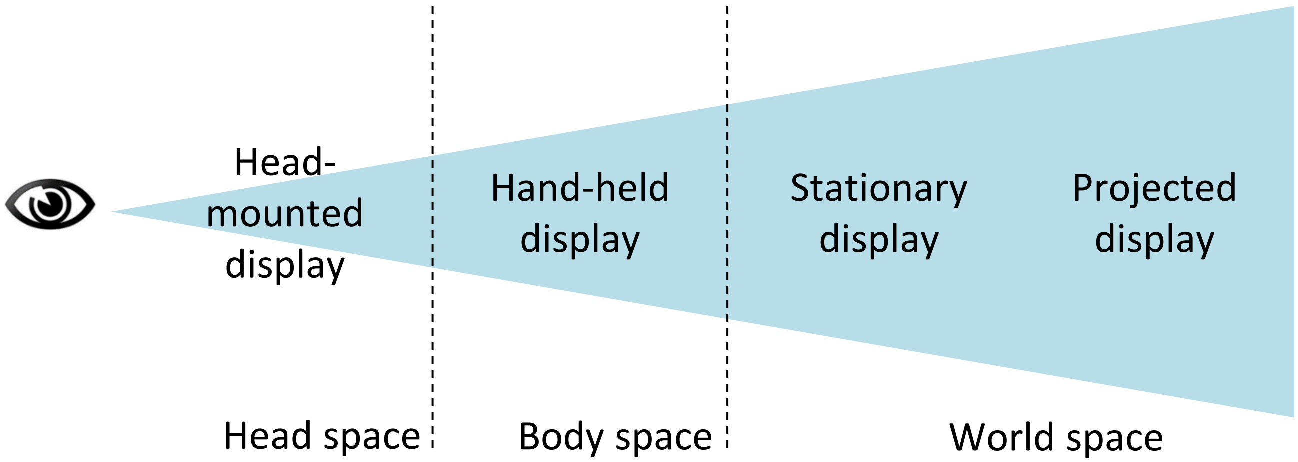
- The spatial model of most AR displays can be defined as the **spatial relationship** of up to *five components*:
  - the user's eye,
  - the display,
  - the camera,
  - an object to be augmented,
  - and the world.



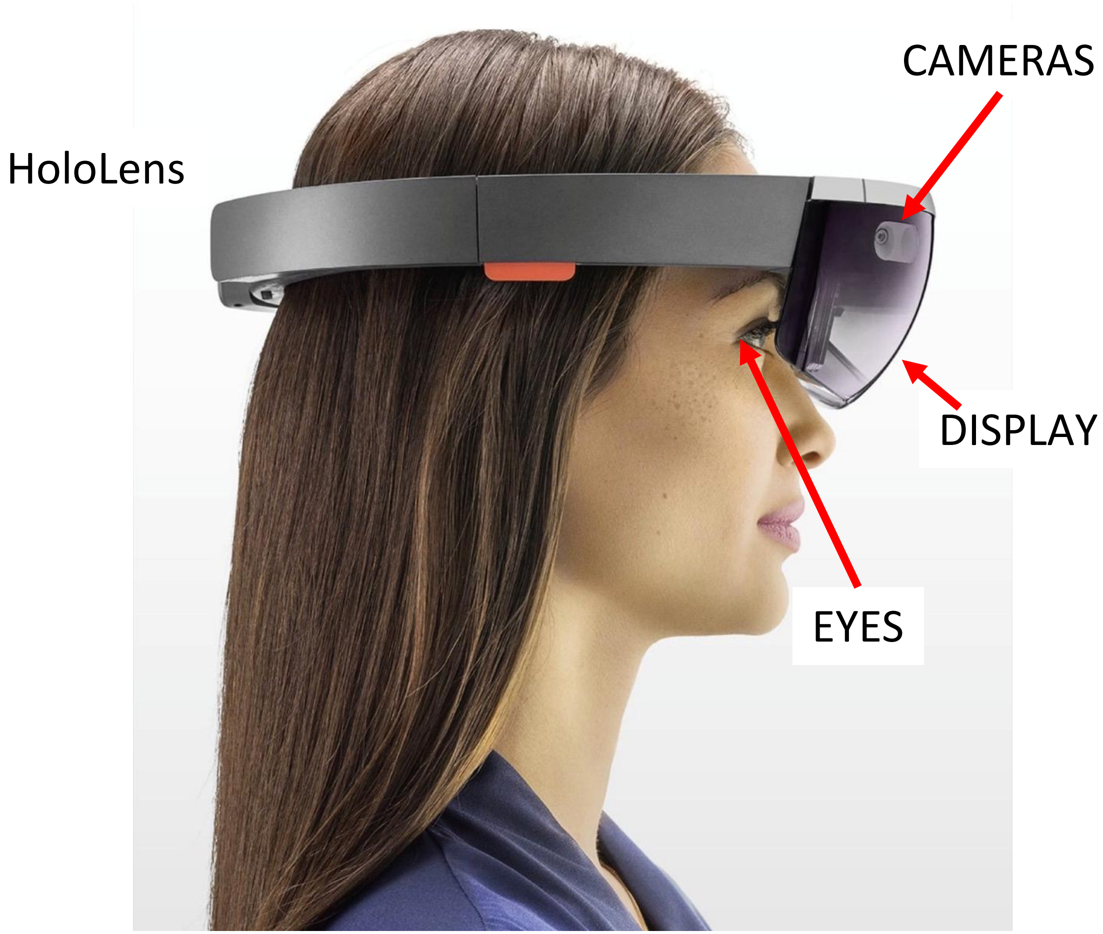
- Each **coordinate transformation** can be *fixed and calibrated*, *tracked dynamically*, or left *unconstrained*.

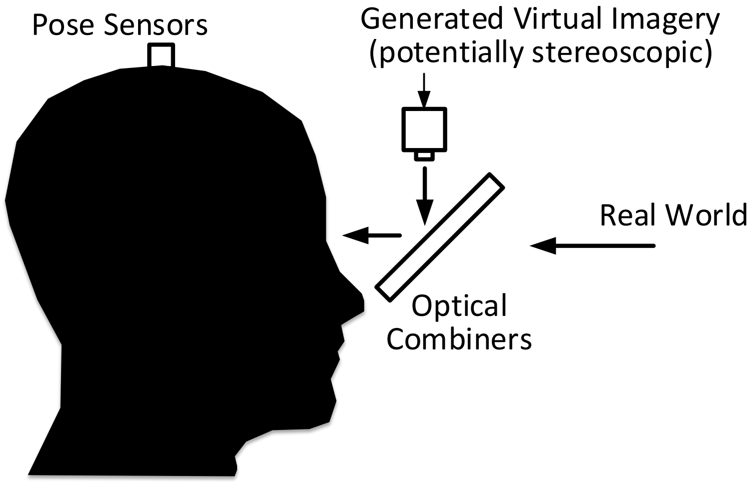
Spatial Display Model

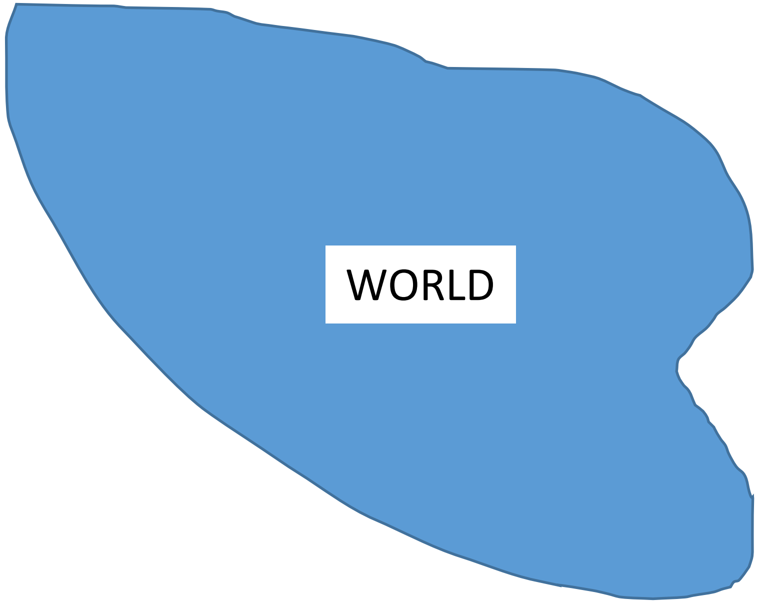
AR displays can be categorized according to the distance from eye to display.



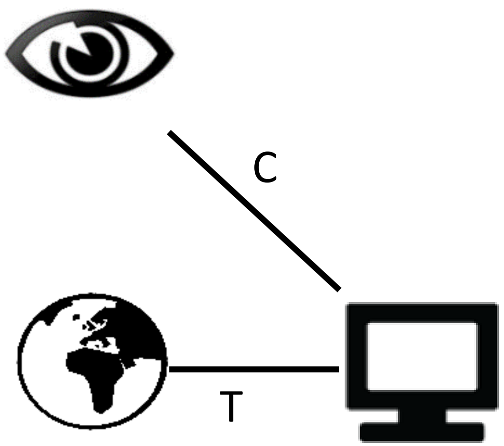
Spatial Display Model: OST HMD



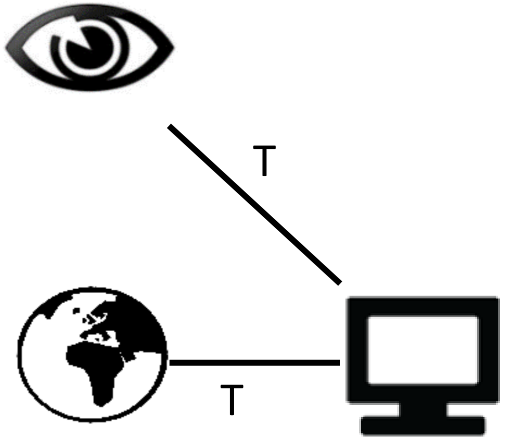




Spatial Display Model: OST HMD



Without eye tracking

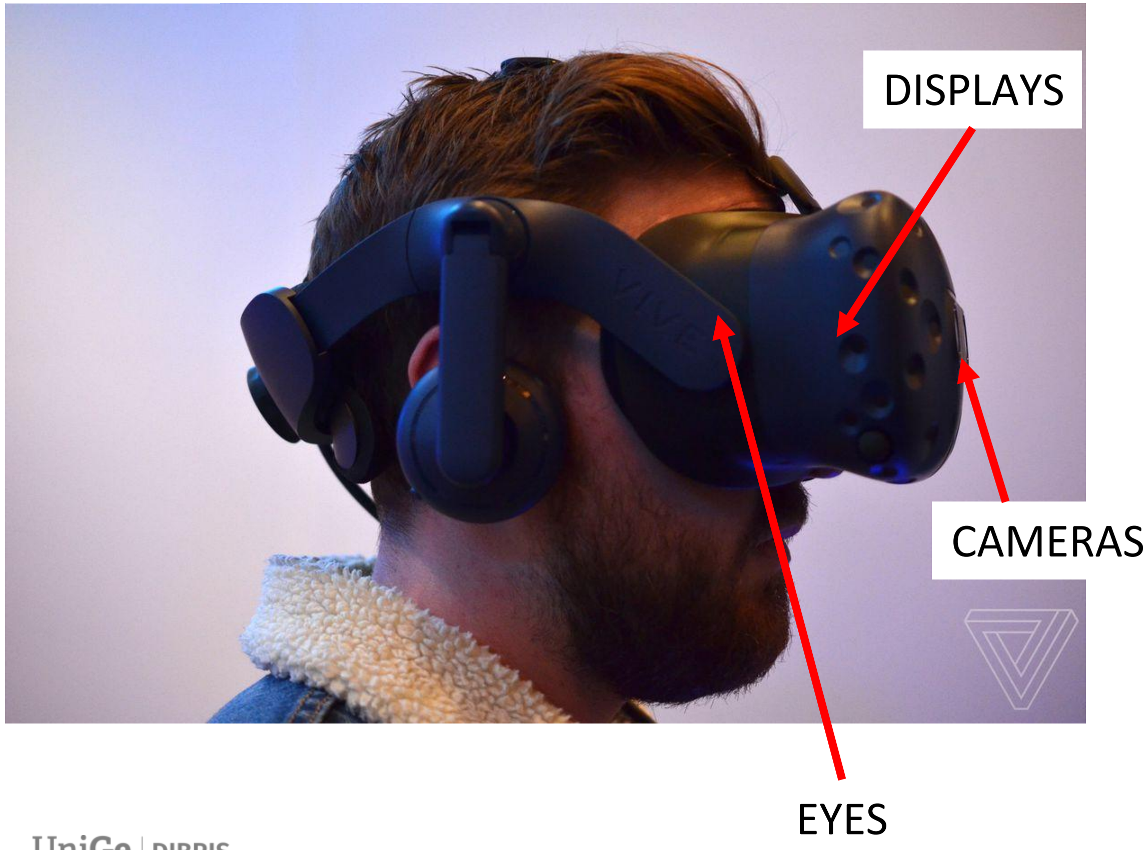


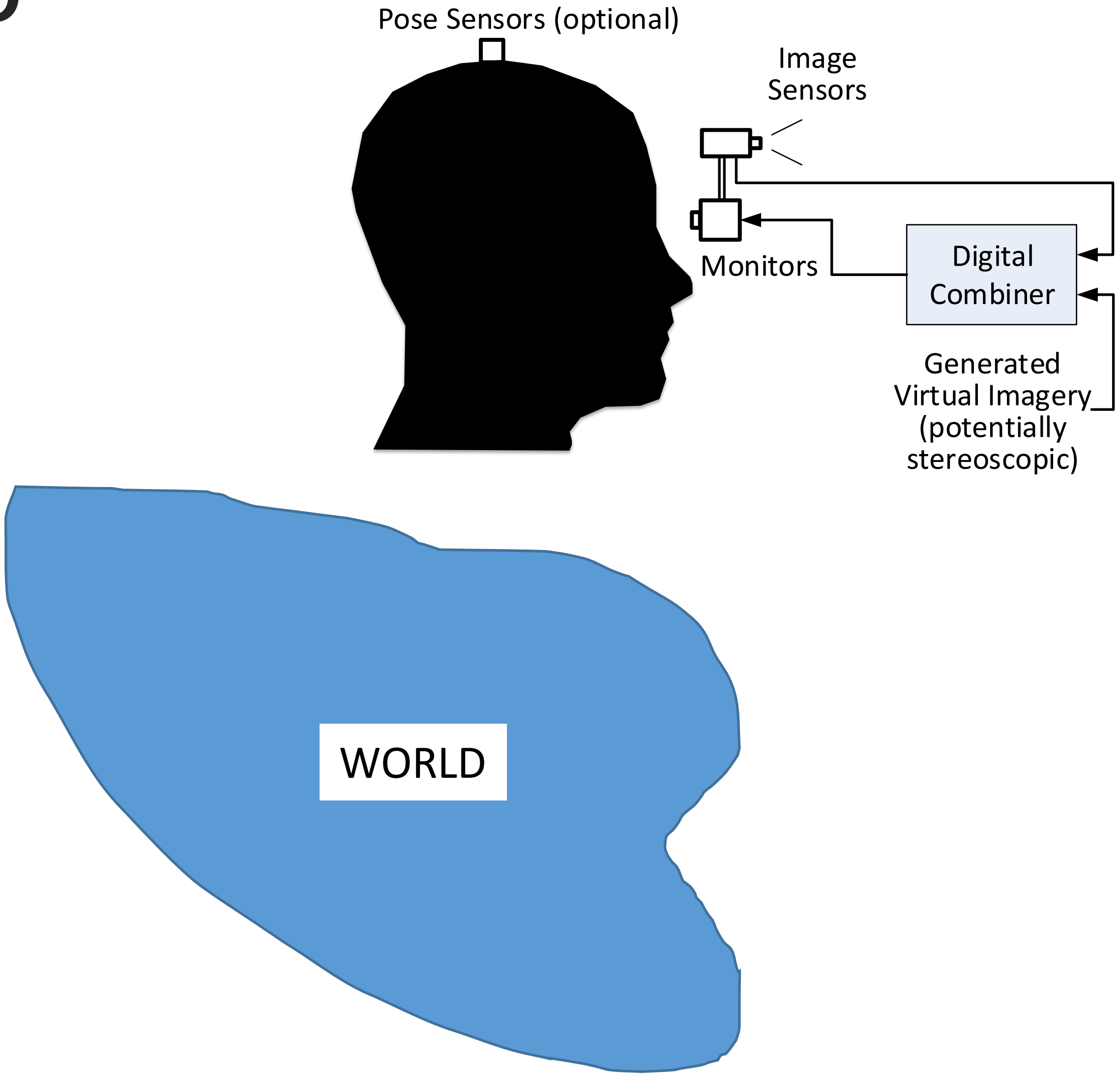
With eye tracking

C – **Calibrated** (*constant*) transformation
T – **Tracked** (*dynamic*) transformation

Spatial Display Model: VST HMD

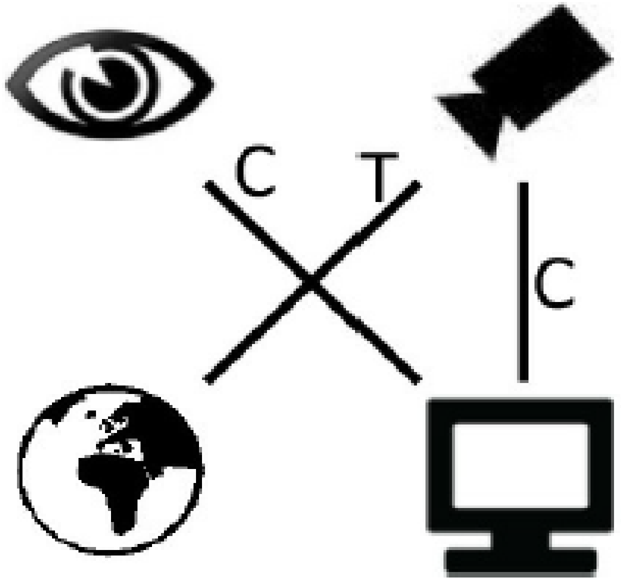
HTC Vive



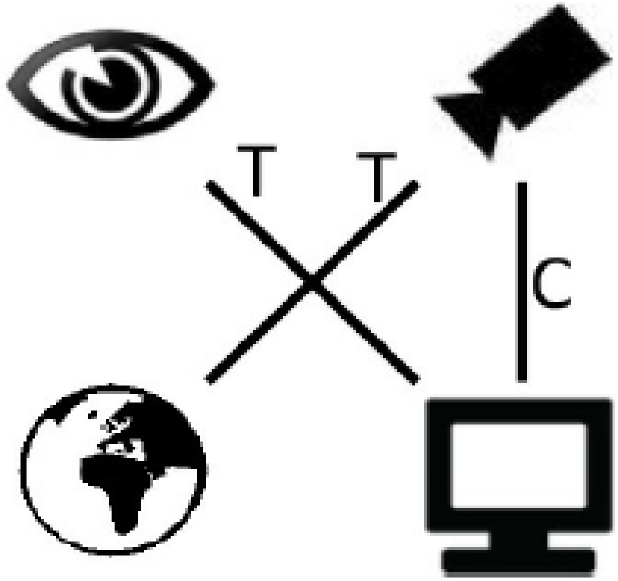


Spatial Display Model: VST HMD

A VST HMD adds *one or more video cameras* to a non-see-through HMD. With this technology, three components are organized in a *rigid configuration*: the user's eye, the display, and the camera (*calibrated*)

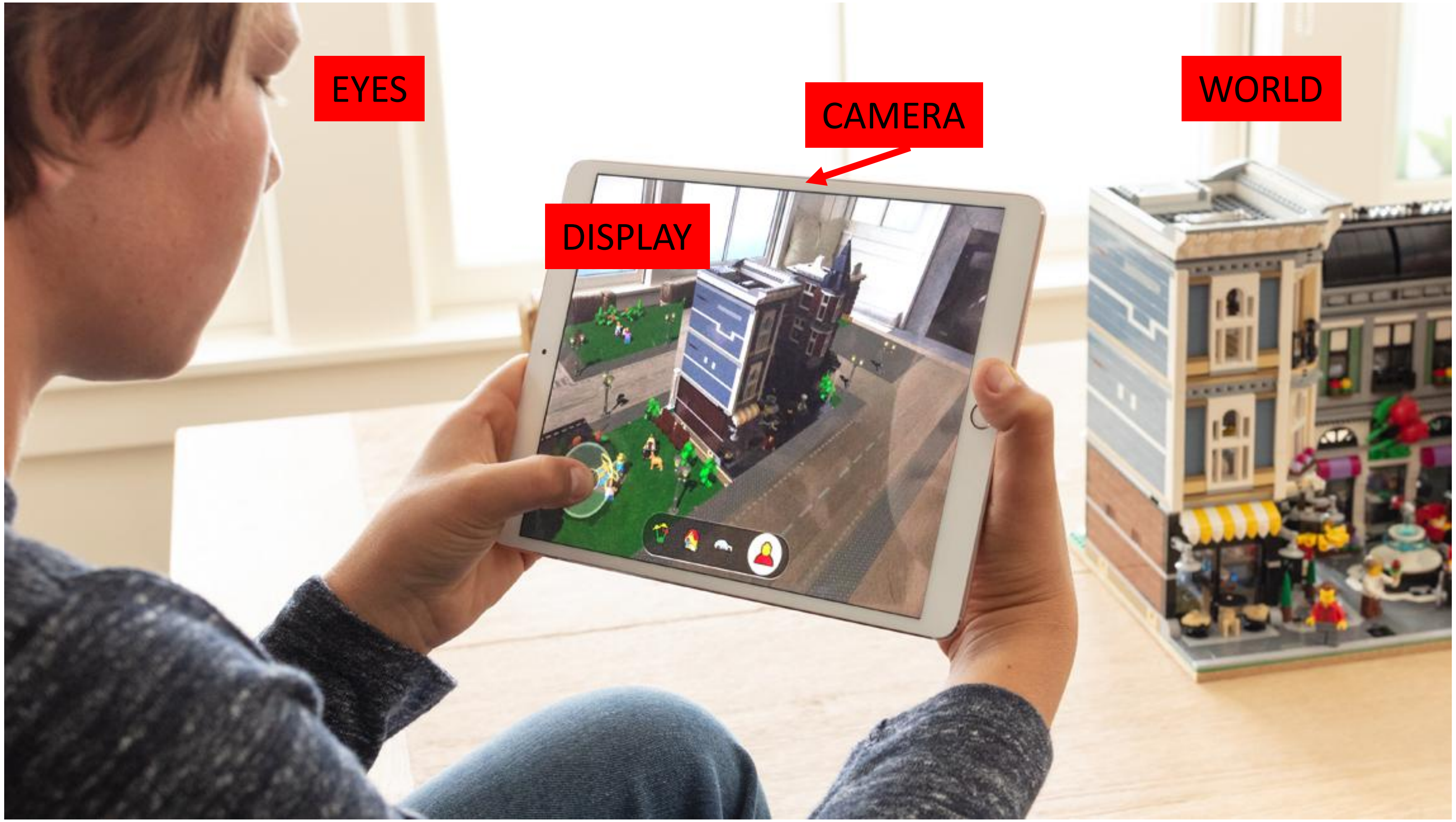


Without eye tracking



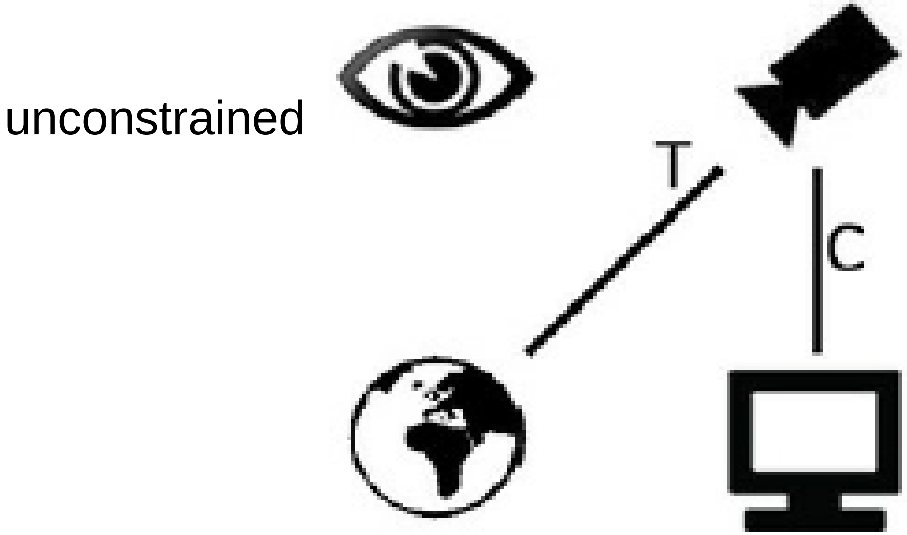
with eye tracking

Spatial Display Model: handled display



Spatial Display Model: handled display

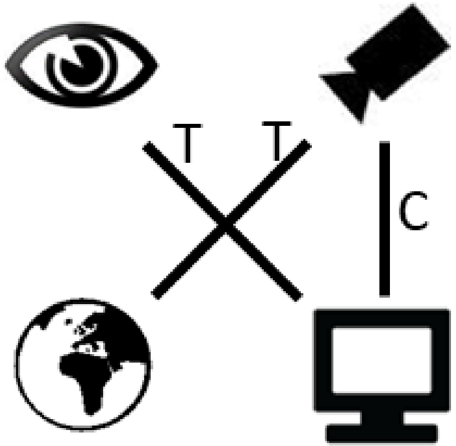
A handheld display houses both the actual display, and the camera *rigidly mounted* in a casing. The transformation from display to camera can be *calibrated*. Tracking of the device's pose in the world will be performed through the camera in most cases, but other tracking modalities could also be used.



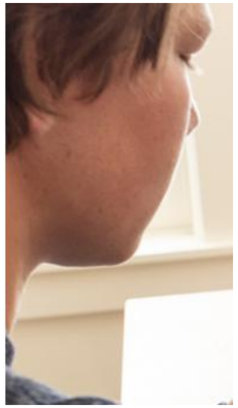
Spatial Display Model: handled display

Handheld display with
device perspective

Handheld display with
user perspective



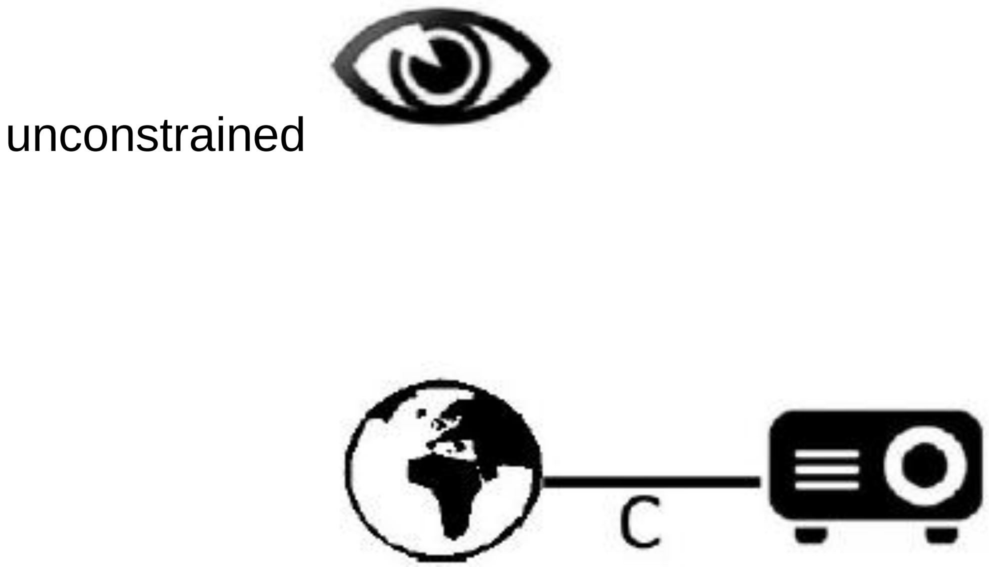
Spatial Display Model: projected display



EYES

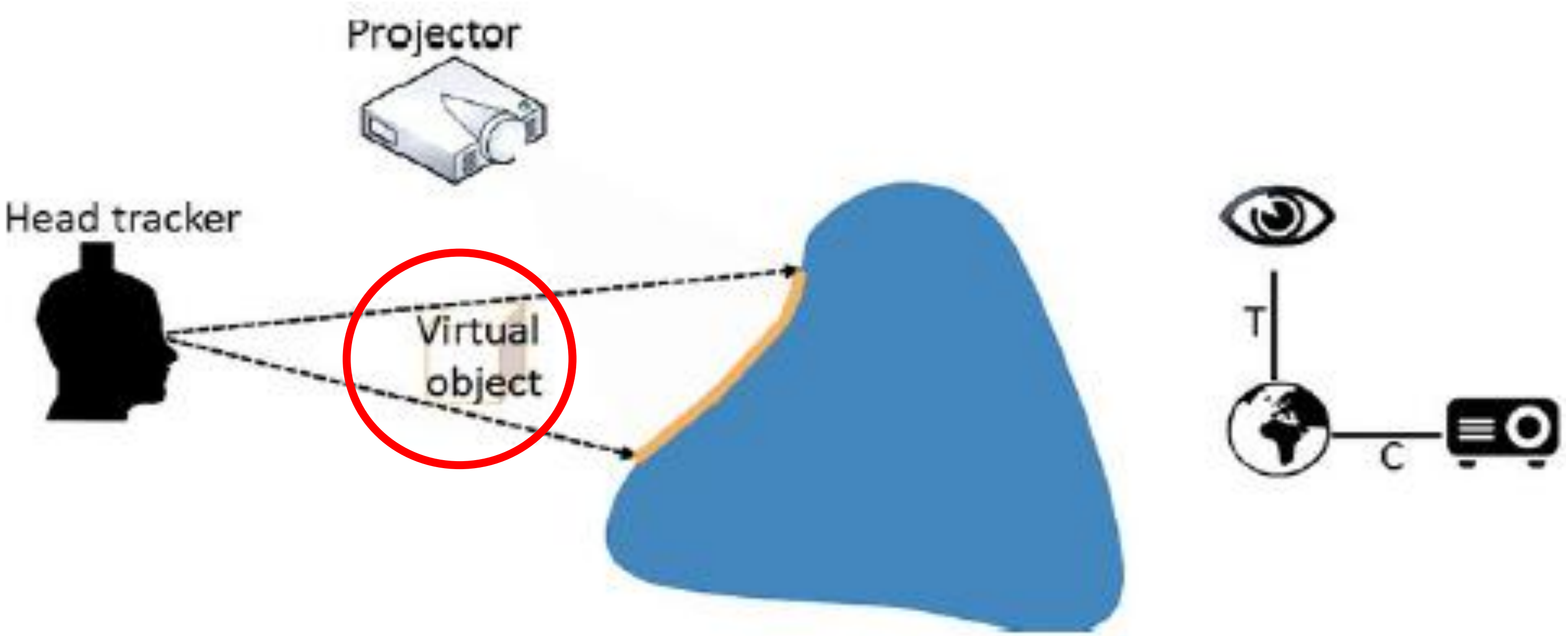
Spatial Display Model: projected display

Simple **spatial AR** does not require any tracking, *as long as the augmented scene is static*.



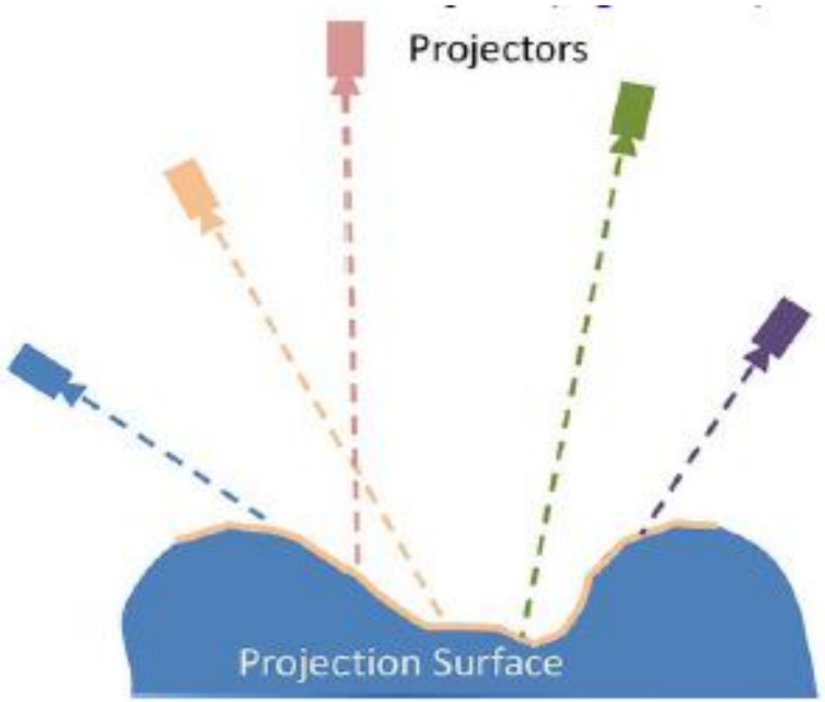
Spatial Display Model: projected display

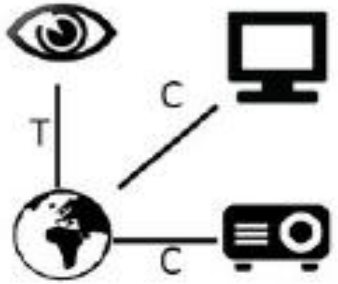
View-dependent **spatial AR** requires tracking the user but can present free-space 3D objects (not only on real objects).



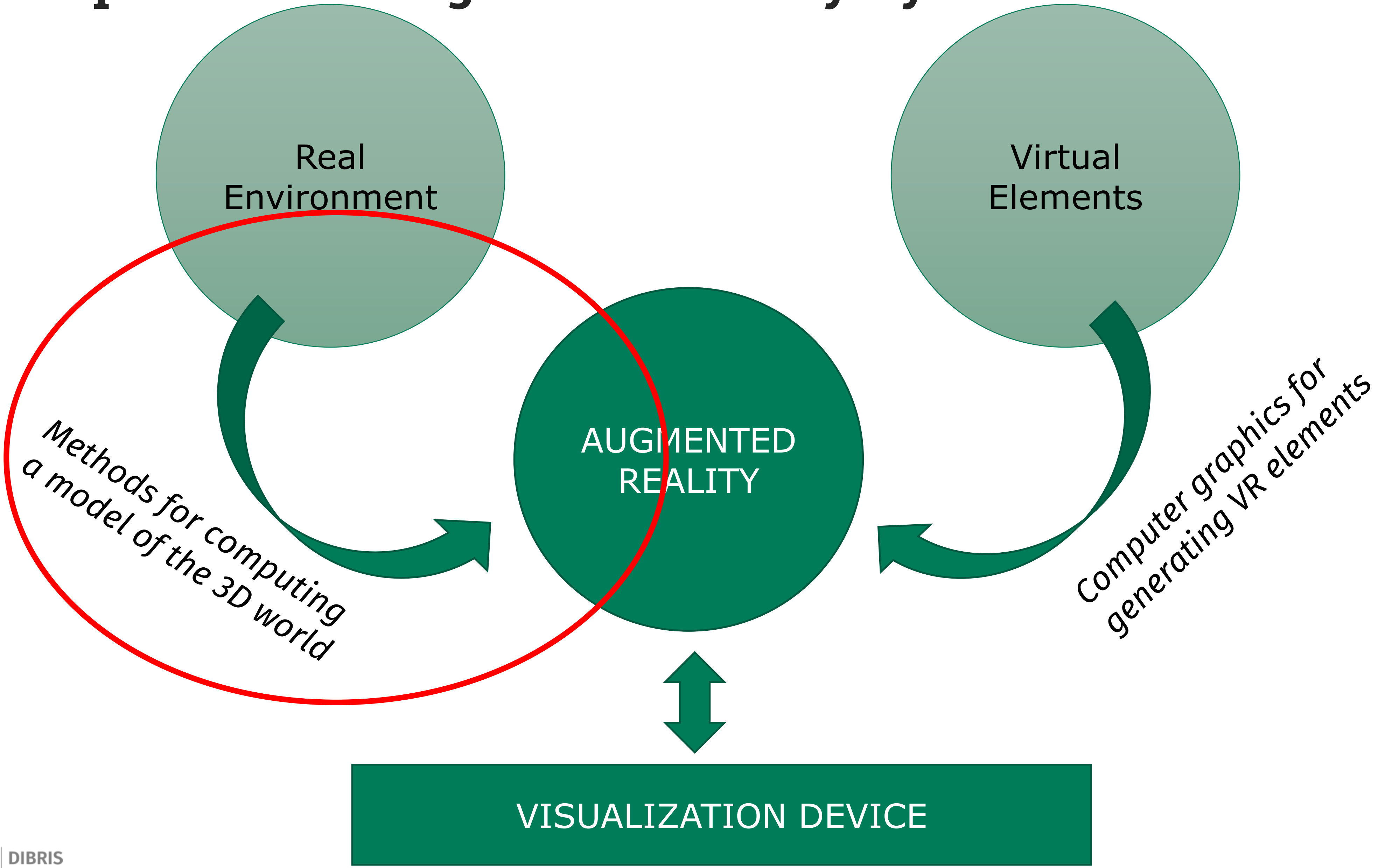
Spatial Display Model: projected display

Multiple projectors can be combined *to minimize pixels projected out of focus*. The geometry of the projection surface needs to be known. It is represented here as a *display calibrated to the world.*





Description of an Augmented Reality System



Tracking and sensors

Tracking

- In the previous section, we established ***what* to track**.
- Now, we will examine ***how* to track**.

- **Measurement systems** used in tracking can employ a variety of *physical phenomena* and arrangement options.
- These choices determine which *coordinate systems* are being measured and affect the temporal and spatial properties of the tracking.

Tracking

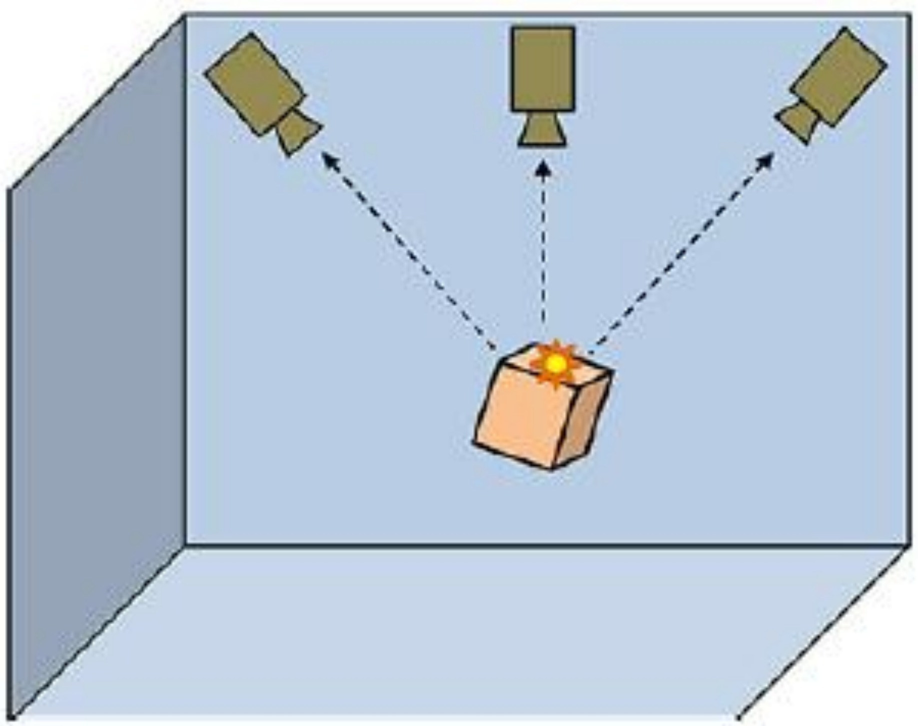
- **Physical Phenomena:** Measurements can exploit electromagnetic radiation (including visible light, infrared light, laser light, radio signals, and magnetic flux), sound, physical linkage, gravity, and inertia, with the specialized sensors.

- **Measurement Principle:** We can measure signal strength, signal direction, and time of flight (both absolute time and phase of a periodic signal). We can measure electromechanical properties.

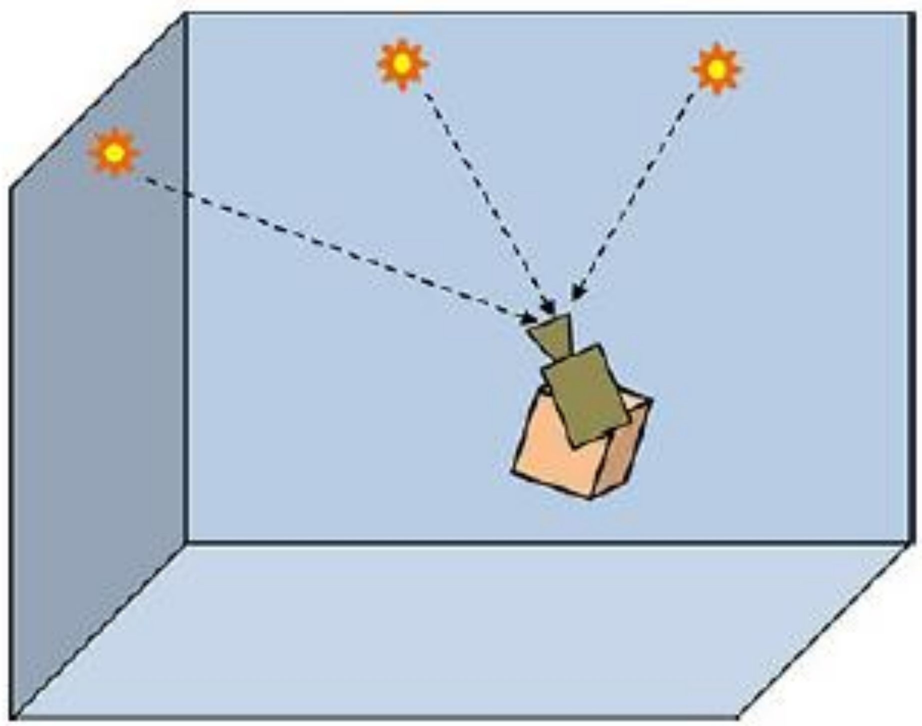
Sensor Arrangement

- A common approach is to use **multiple sensors** together in *a known rigid geometric configuration*, such as a stereo camera rig.
- Sometimes, it is important to arrange *three sensors orthogonally* to measure *vector-valued quantities*, such as acceleration in three fundamental directions.
- If multiple sensor configurations are used, then either we need **sensor synchronization** to ensure simultaneous acquisition of measurements, or we need to deal with the fact that measurements from two sensors are taken at slightly different times.
- The process of **combining** *multiple sensor* **inputs** to obtain a more complete or more accurate measurement is referred to as **sensor fusion**

Spatial Sensor Arrangement



Outside-in tracking: sensors are mounted stationary in the environment and observe a moving target, such as a head-worn display.



Inside-out tracking: sensors move with the tracked object and observe stationary references in the environment.

Degrees of Freedom (DOF)

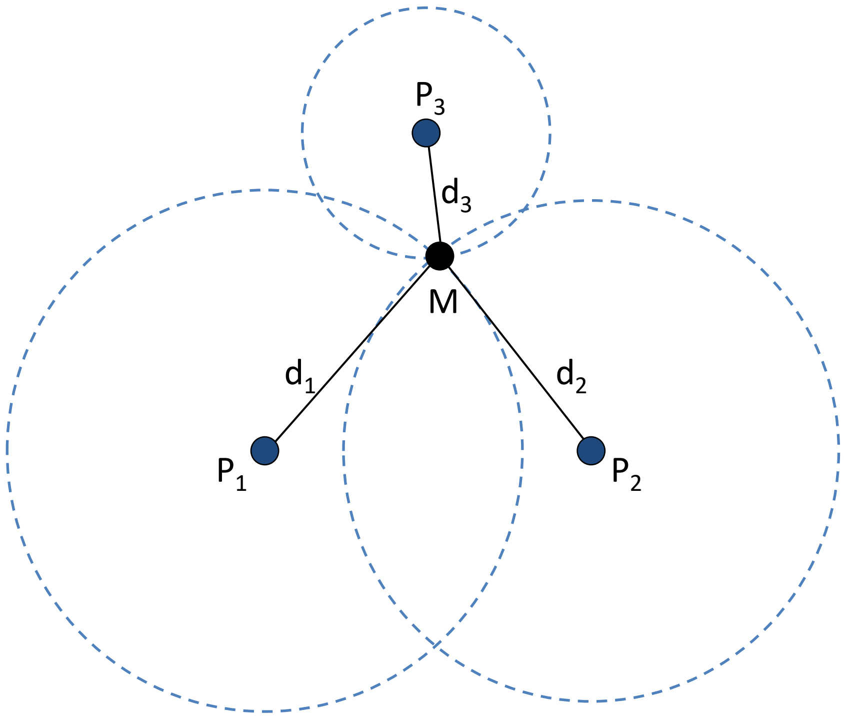
- DOF → independent dimension of measurement
- **Full tracking** requires 6DOF
  - 3DOF position (x, y, z)
  - 3DOF orientation (roll, pitch, yaw)
- Some sensors deliver only a subset
  - e.g., gyroscope → 3DOF orientation only
  - e.g., tracked LED → 3DOF position only
  - e.g., mouse → 2DOF position only

Signal Sources

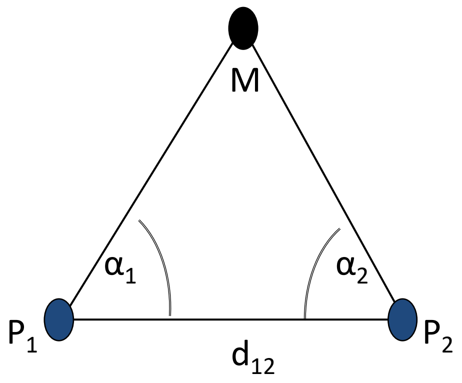
- Sources provide the signal that is picked up by the sensors. Like sensors, sources must be positioned in a **known geometric configuration**.
- Sources can be:
  - **Passive**: rely on *natural signals* present in the environment, such as natural light or the Earth's magnetic field. When no external source is apparent, such as in inertial sensing, the signaling method is described as **sourceless sensing**
  - **Active**: rely on some form of electronics to *produce a physical signal*. Most types of active sources, such as acoustic, optical, and certain radiowave sources, require an open line of sight for the signal to travel to the sensor unperturbed.

Measured Geometric Property

- **Trilateration**: 3 distances



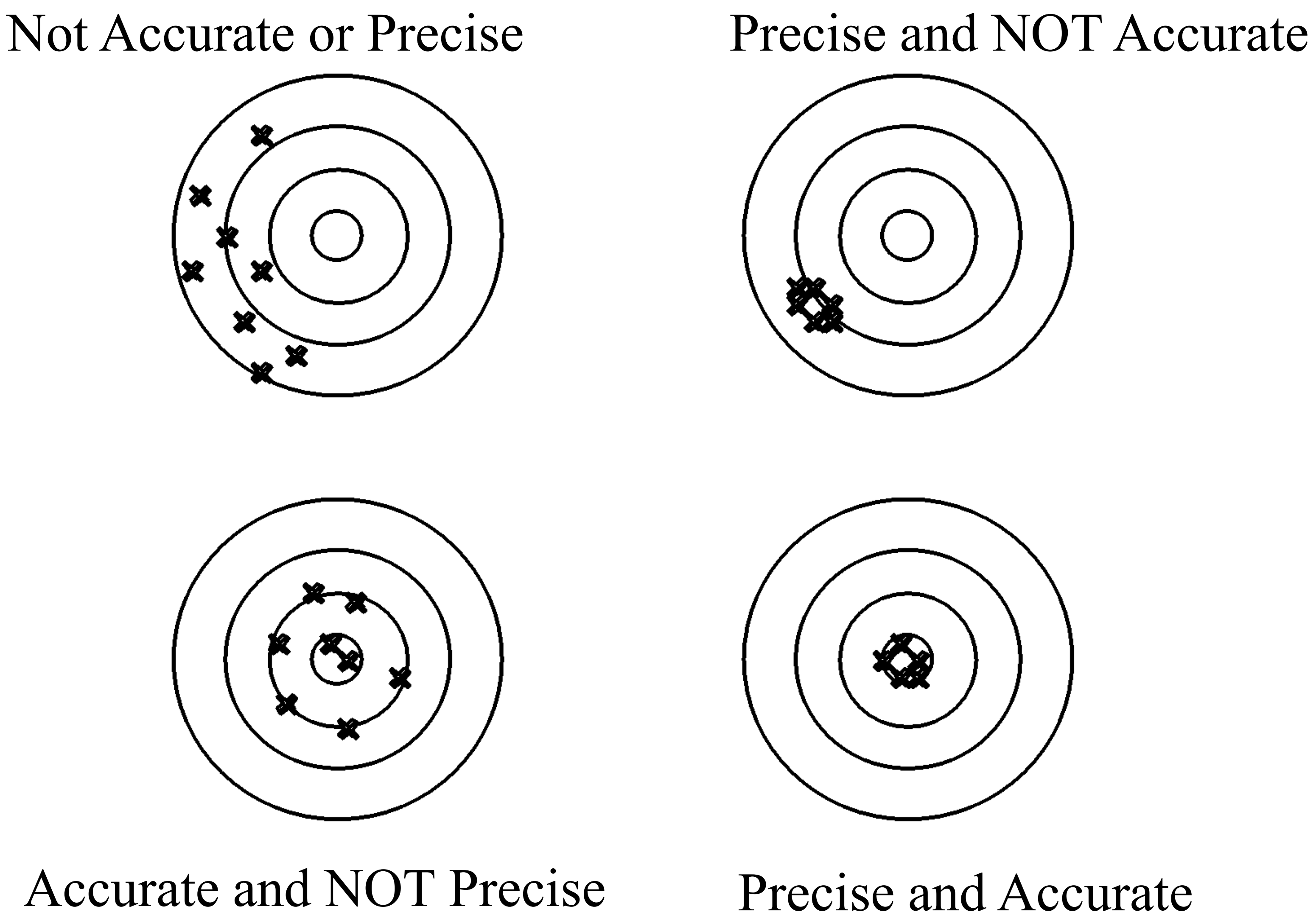
- **Triangulation**: 2 angles, 1 distance



Measurement error

- **Accuracy**
  - How close is measurement to true value
  - Affected by systematic errors
  - Can be improved with better calibration
- **Precision**
  - How closely do multiple measurements agree (random error, noise)
  - Varies per type of sensor
  - Varies per degree of freedom
  - Can be improved with filtering (more computation, more latency)
- **Resolution**
  - Minimum difference that can be discriminated between two measurements
  - Cannot be reached in practice because of noise

Measurement error

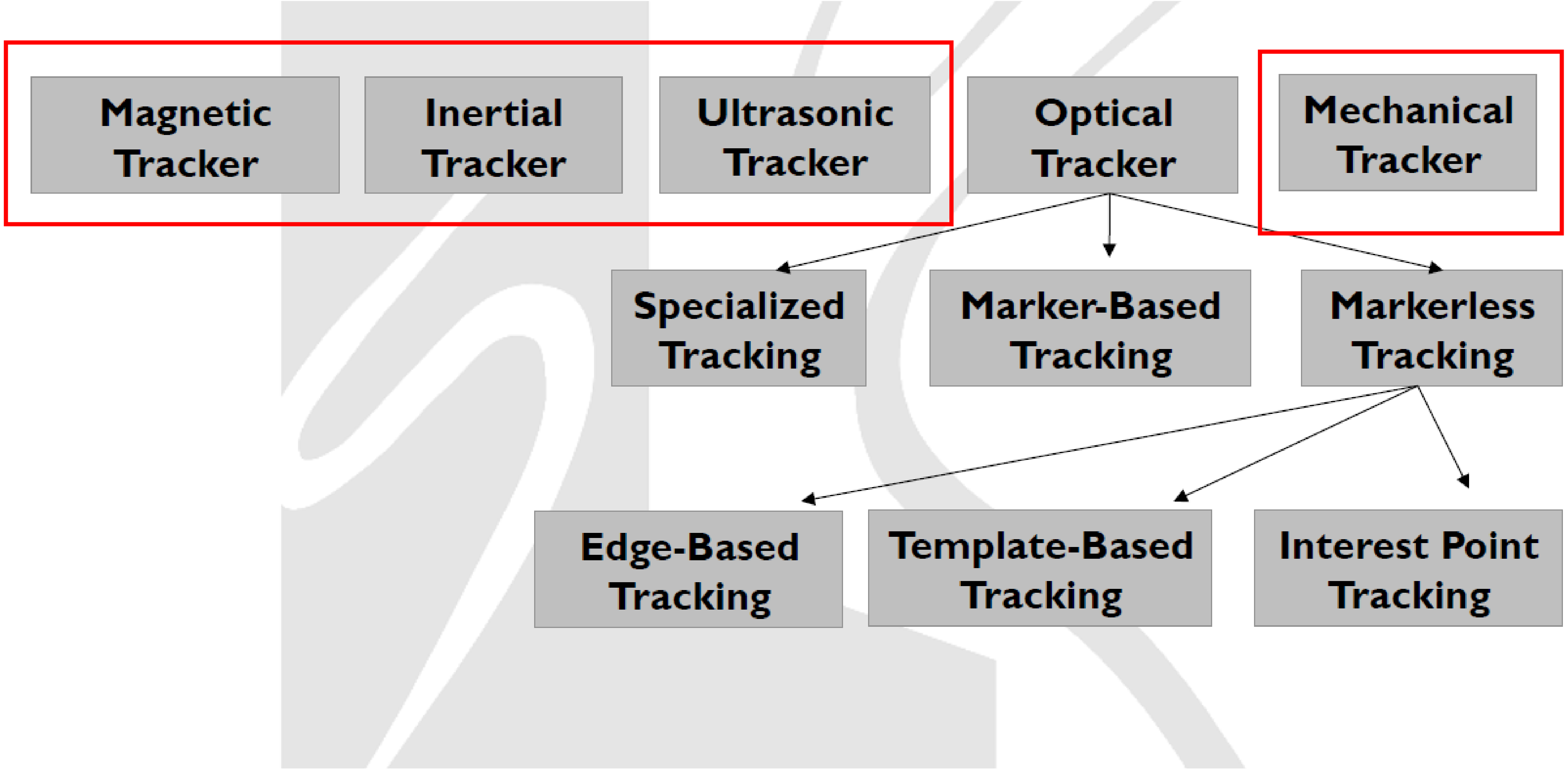


Temporal Characteristics

- Update rate:
  – Number of measurements per time interval

- Measurement latency
  – Time it takes from occurrence of physical event to data becoming available (*important in AR*)
- End-to-end latency
  – Time it takes from occurrence of physical event to presentation of a stimulus (*important in AR*)

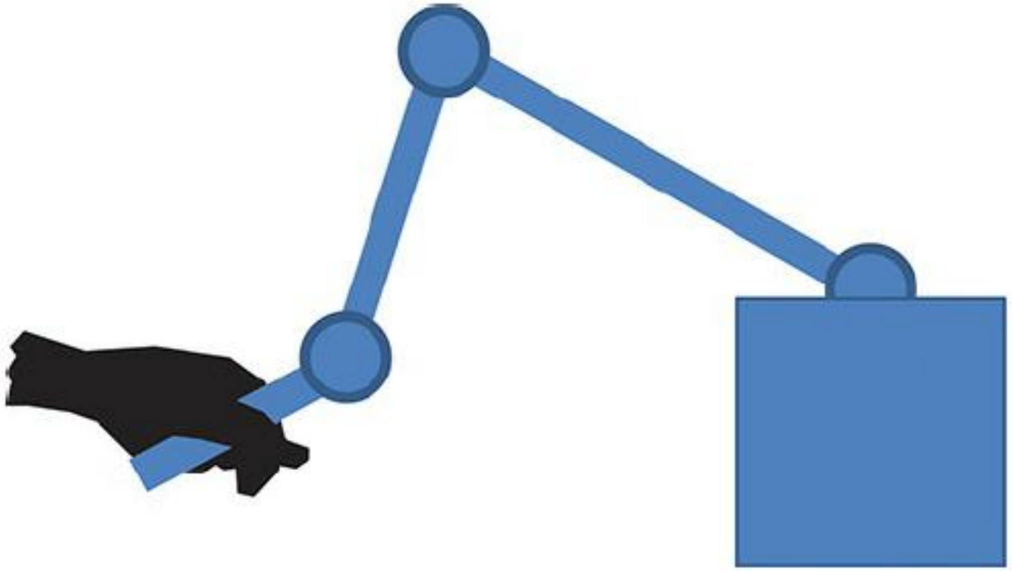
Tracking types



Mechanical Tracking

- Mechanical tracking, which is probably the *oldest technique*, builds on mechanical engineering methods that are very well understood.
- Usually, the *end-effector* of an articulated arm with two to four limbs is *tracked.*

The **angles** at the **joints** are **sensed**.
Such a setup can also provide *force feedback.*



Mechanical Tracking

- This approach delivers *high precision* and a *fast update* rate,
- but the *freedom* of operation is severely *limited* by the mechanical structure.
- Most mechanical tracking systems can provide *measurements* only for a *single point*.
- Outside-in setup.
- For AR, it is *undesirable* to have the articulated arm in the field of view, where virtual or real objects should be placed.

Mechanical Tracking

HITLabNZ
Human Interface Technology Laboratory New Zealand
www.hitlabnz.org

unlocking the power of HUMAN INTELLIGENCE

Mechanical Tracker

- Idea: mechanical arms with joint sensors

Microscribe

- ++: high accuracy, haptic feedback
- -- : cumbersome, expensive

Electromagnetic Tracking

- Electromagnetic tracking uses a *stationary source* producing *three orthogonal magnetic fields.*
- Position and orientation are measured simultaneously from *magnetic field strength and direction* using small *tethered sensors* equipped with three orthogonal coils.
- Decreasing field strength with distance and tether length of the sensors typically limit the operating range to a hemisphere of 1–3 m diameter.
- Inside-out tracking approach
- it does not require an open line of sight; consequently, it can handle occlusions.
- Overall, magnetic tracking approaches are *rarely used for AR* today.

Electromagnetic Tracking

HITLabNZ
Human Interface Technology Laboratory New Zealand
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Magnetic Tracker

- Idea: difference between a magnetic transmitter and a receiver

Flock of Birds (Ascension)

- ++: 6DOF, robust
- -- : wired, sensible to metal, noisy, expensive

Mobile sensors

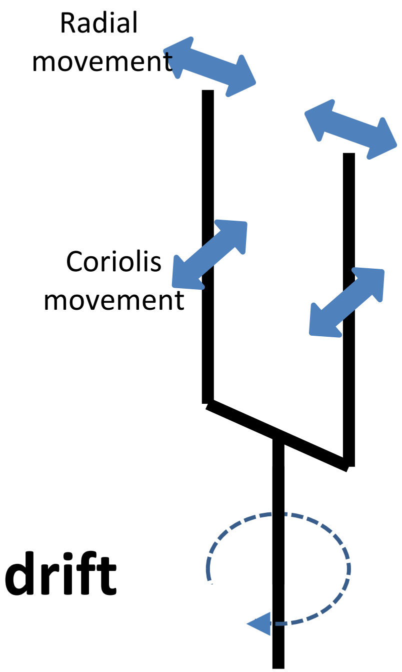
- While stationary tracking systems are suitable for certain types of VR applications that do not require a user to move much, **tracking systems for AR should be mobile**.
- Outdoor users cannot rely on constant quality of wireless services.
- Both **sensing** and **computation** for tracking must be performed **locally** on the **mobile device**, usually without the aid of infrastructure in the environment.
- **Modern mobile devices such as smartphones or tablets are equipped with an array of sensors.**

Mobile sensors

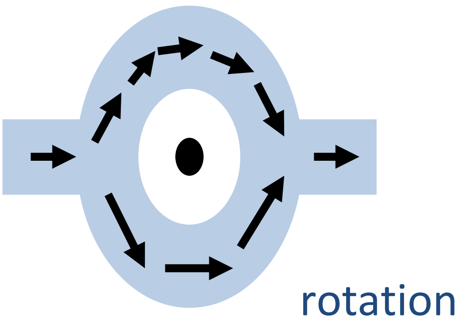
- Compass
  - Earth’s magnetic field
  - Measures **absolute orientation**

Gyroscope

- Determines **rotational velocity**
- **Electronic gyro**
  - Measures Coriolis force of small vibrating object
  - Micro-electromechanical system (**MEMS**)
  - High update rate (1KHz)
  - Only **relative measurements**
  - Must **integrate** once to determine **orientation** → can **drift**

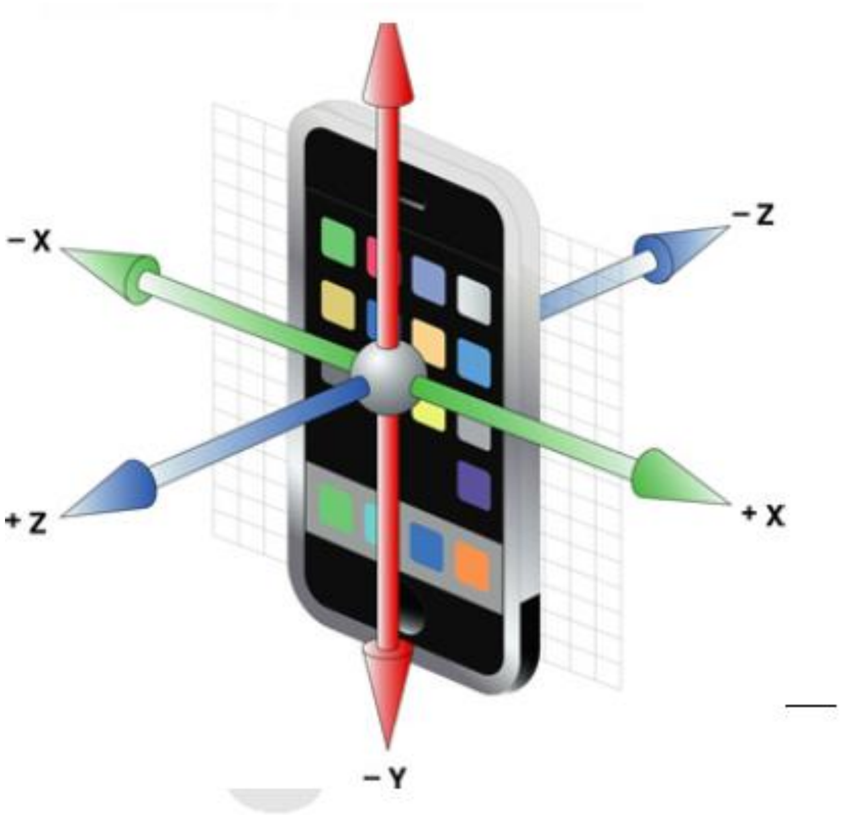


- Laser gyro (fiber-optic gyro)
  - Measures angular acceleration based on light interference
  - Large, expensive, used in aviation *not in AR*



Mobile sensors

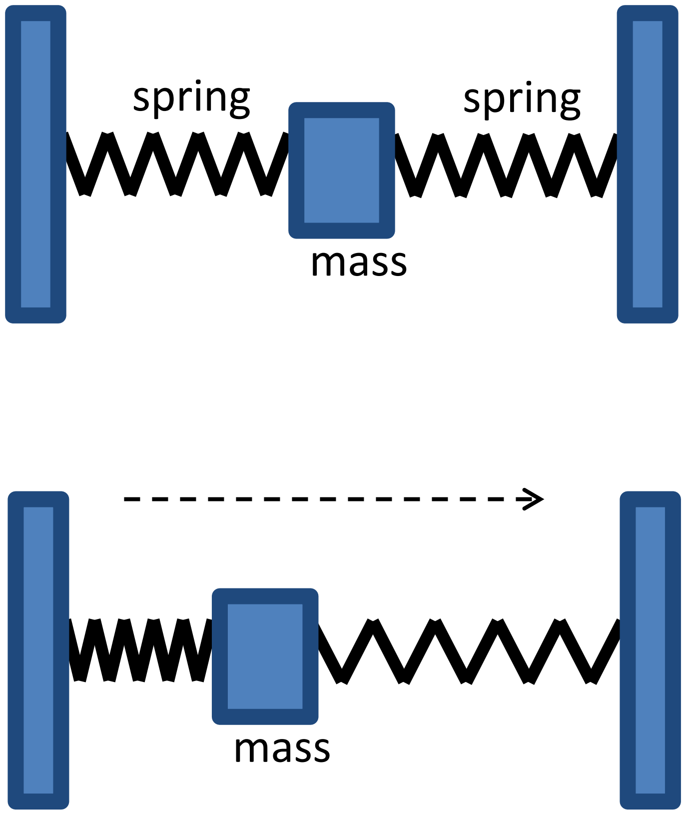
- Accelerometers
  - Measures acceleration about axis
  - Used for **tilt**, relative **rotation**
  - Can drift over time



Linear accelerometer

- **MEMS** device
- **Displacement** of small **mass**
- Measures
  - **Change of electric capacity**, or
  - Piezoresistive effect of bending
- Subtract gravity + Integrate twice numerically to get **position**
- Drift problems
- Examples: (i) pedometers often use accelerometers to count a user's steps to infer walking distance. This is done by mounting an accelerometer to the body and analyzing maxima of the measured acceleration over time. (ii) To estimate the gravity vector, along which a known constant acceleration of approximately 9.81 m/s2 occurs, if the device is not moving.

- Combine lin.acc., gyro + compass into ***inertial measurement unit*** (**IMU**)

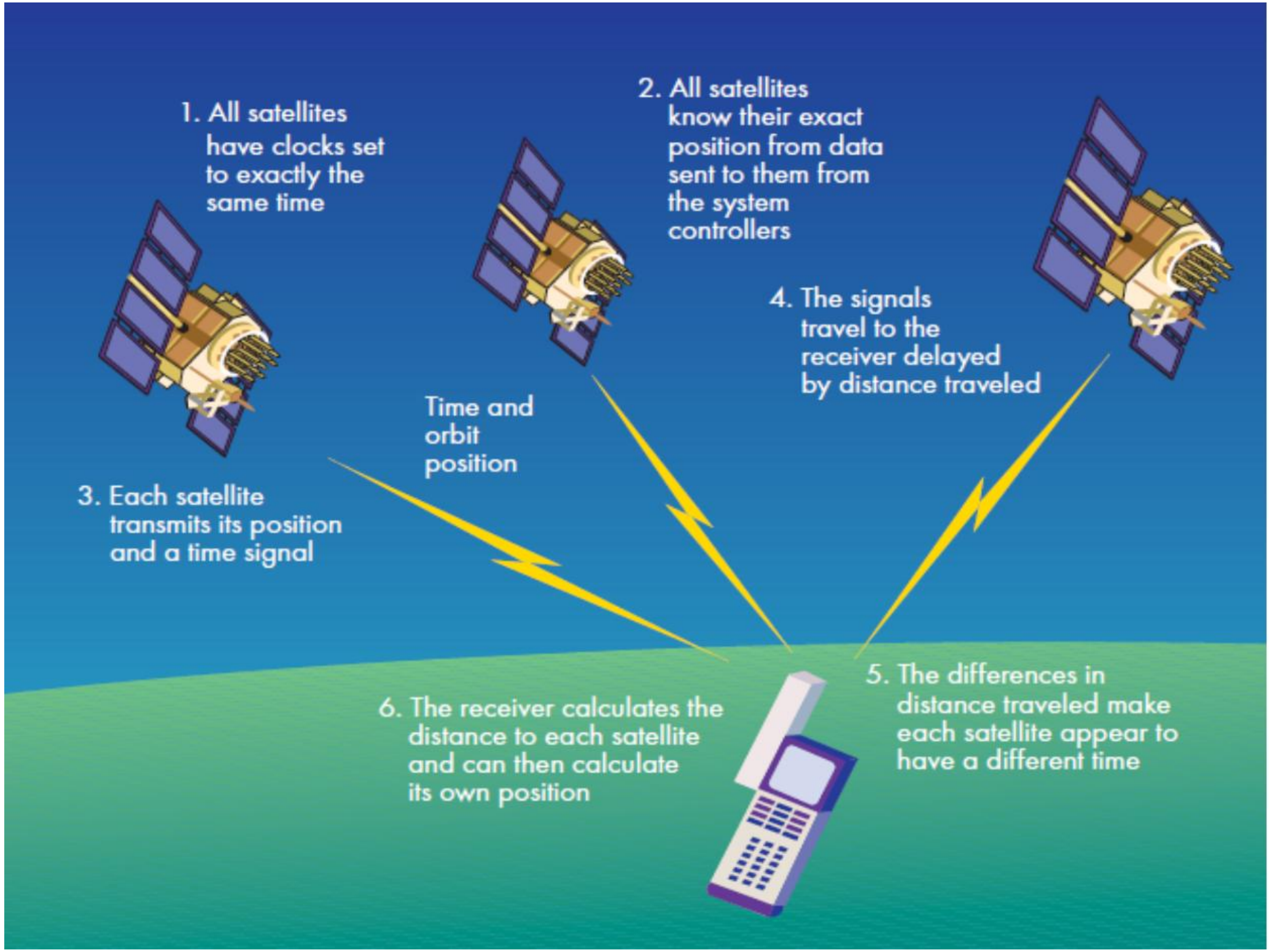


Inertial sensors (accelerometers and gyroscopes)

- PROs:
  - No transmitter
  - Small
  - Cheap
  - High frequency
  - Wireless

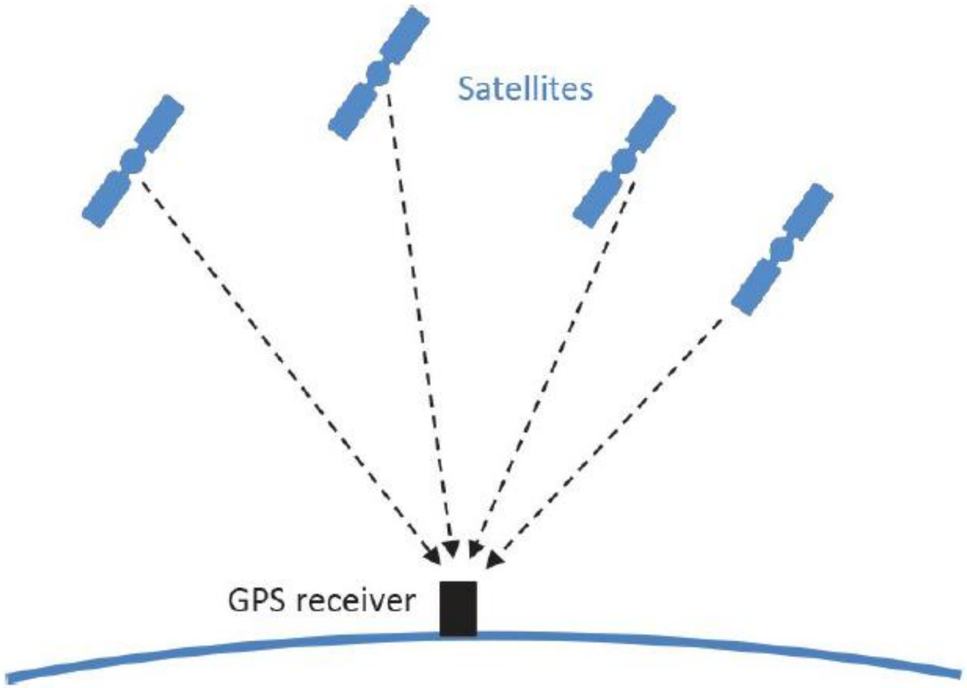
- CONs:
  - Drift
  - hysteresis

Global Positiong System (GPS)



Global Positiong System (GPS)

- GPS measures the *time of flight* of coded radio signals emitted by satellites in Earth orbit, essentially representing a *planet-sized inside-out system.*
- GPS measures the time of flight of signals received from multiple orbital satellites and determine the **position** of a **mobile** receiver through **trilateration**.

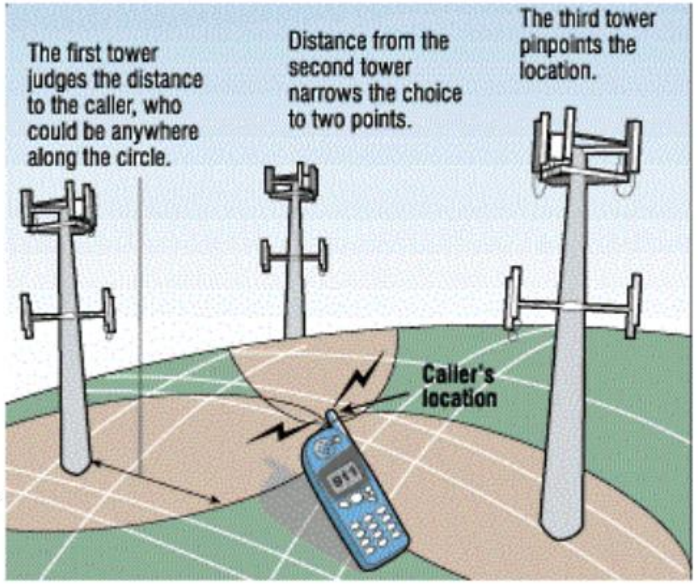


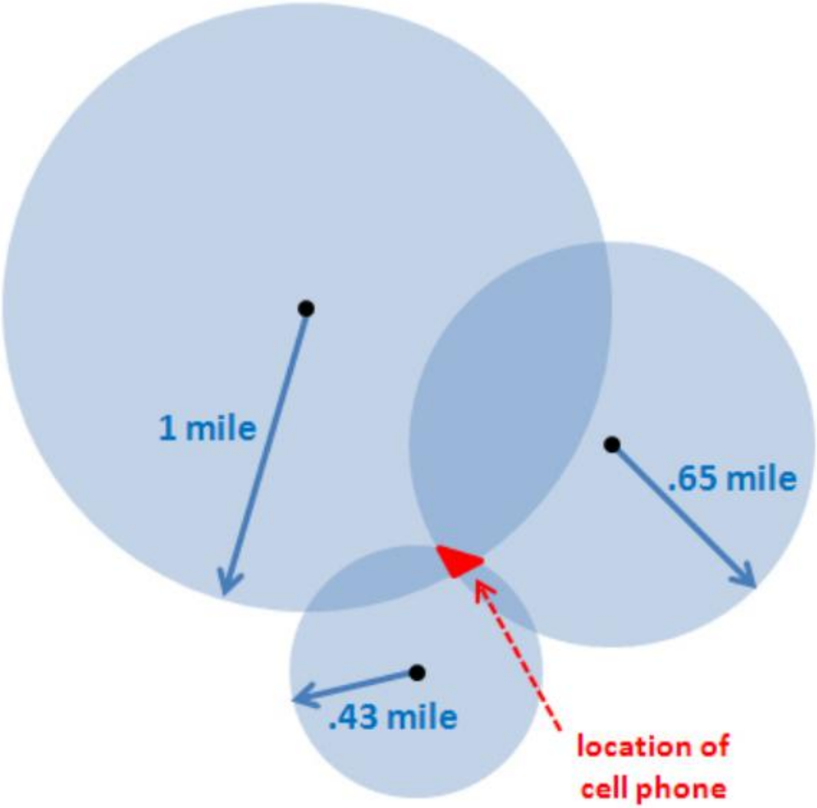
Global Positiong System (GPS)

- A 3D position can be estimated, but often only longitude and latitude are used, while height, which is more significantly affected by measurement error, is occasionally considered.
- Reliable indoor reception is usually not possible.
- Orientation cannot be determined with GPS, but rather must be obtained from other sensors.
- GPS is popular in current consumer location-based service applications, but by itself is *not fit for high-accuracy tracking*, like that required for very precise registration in AR.
- Accuracy 5-10 m in urban canyon, 0.5-1m in open areas

Cell Tower trilateration

- Calculate phone positio
from signal strength
- < 50 m in cities
- > 1 km in rural





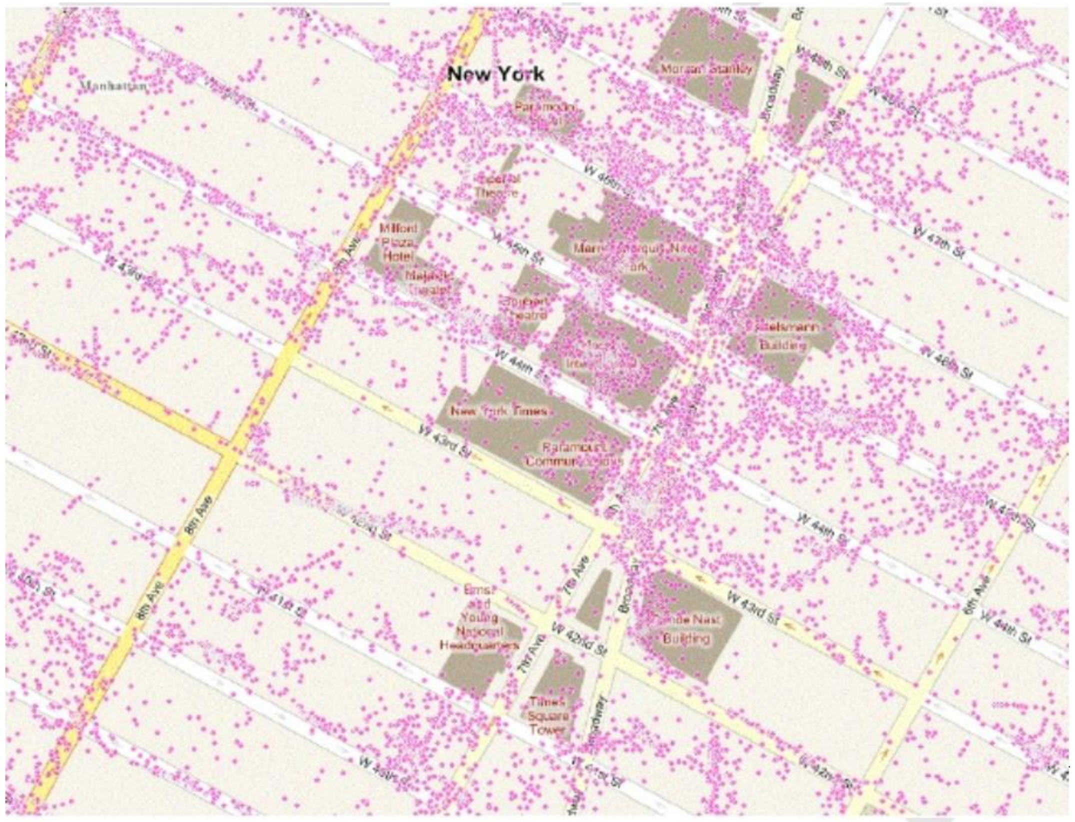
Trilateration - cell phone detected within a certain radius of each of 3 cell towers – the area where each cell tower overlaps the phone is where it is pinpointed.

Wireless Networks

- Existing wireless network infrastructures, such as WiFi, Bluetooth, and mobile
- Every *base station* offering wireless networking broadcasts a unique identifier (ID with a position on a map), phone networks, can be used to determine one’s position
- The simplest approach to positioning uses only the ID of observed base stations (accuracy several meters).
- Low-power, low-cost beacons based on Bluetooth are a possible dedicated infrastructure for indoor positioning—for example, in retail applications.

WiFi Positioning

- Estimate Location by using WiFi access points
  - Can use known location of access points
  - *Trilateration through signal strength*
- Accuracy
  - 5 – 100 m (depend on WiFi density)



Indoor localization sensing

- Asset, people tracking
- WiFi + RFID
- WiFi + led tracking
- Beacon (Bluetooth radio transmitters)