VIRTUAL REALITY

Virtual Reality

1. a **computer-generated environment** with scenes and objects that **appear** to be **real**, making the user feel they are immersed in their surroundings.
2. **Feeling the imaginary world** rather than real one.
3. Experiencing things through computers that really does not exist.

Three I’s of Virtual Reality

1. **Immersion :**

- Allows the user to feel the artificial environments that are created using different computer technologies.
- Perception of being physically present in the computer generated world.

Factors :

1. **Continuity of the surroundings :** able to see in all directions
2. **Freedom of movement :** able to move freely in any direction
3. **Physical interaction :** able to hold/ touch the objects.
4. **Physical feedback :** able to correct perception of object by touch and motion.
5. **Narrative feedback :** capability to decide the flow of story.
6. **3D Audio :** Able to replicate the natural sound relative to people and objects.

2. Interaction

- The user should be able to interact with the VR environment similar to the real world.
- Telepresence: Combination of sense of immersion and interactivity.

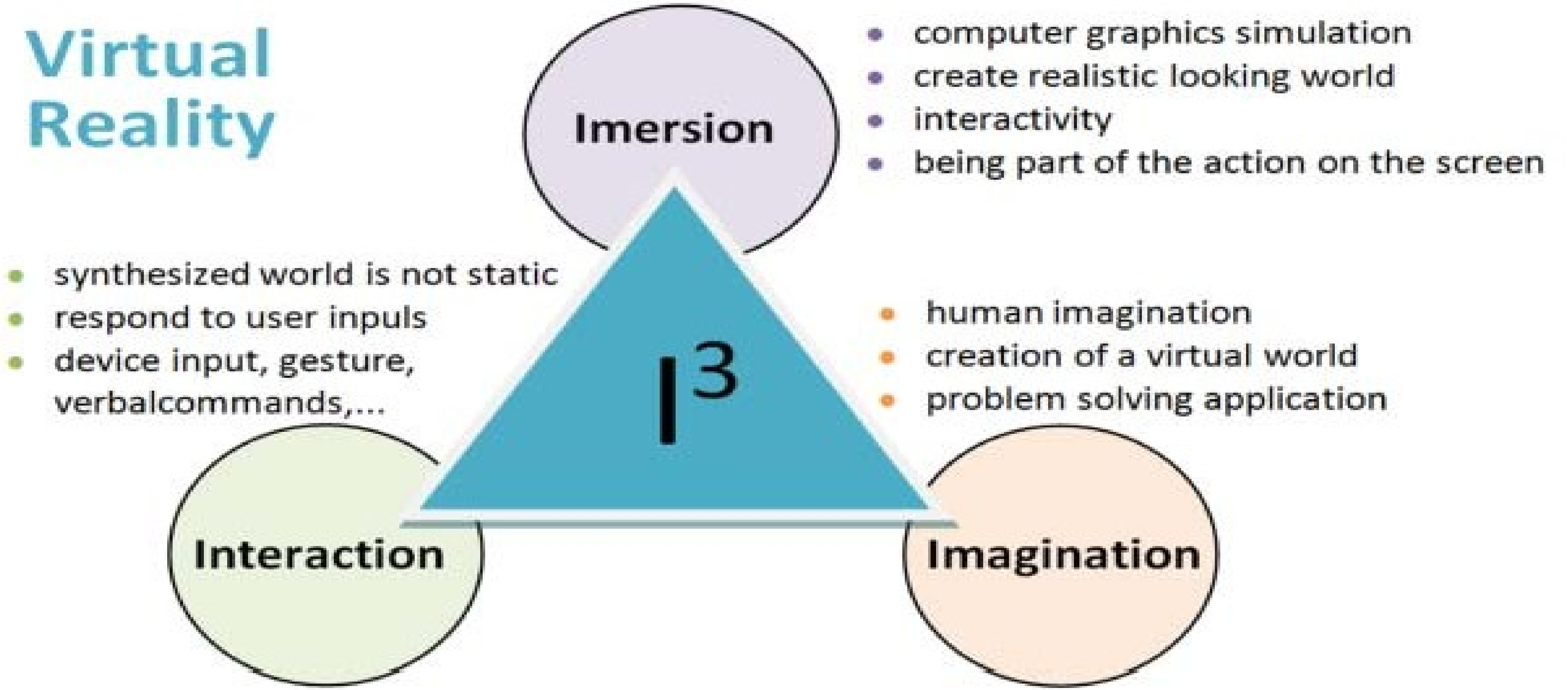
Factors :

1. **Speed :** rate at which the ation of the user is incorporated.
2. **Range :** number of possible outcomes
3. **Mapping:** the ability of system to produce natural results.
4. **Navigation :** Direction of user movement.

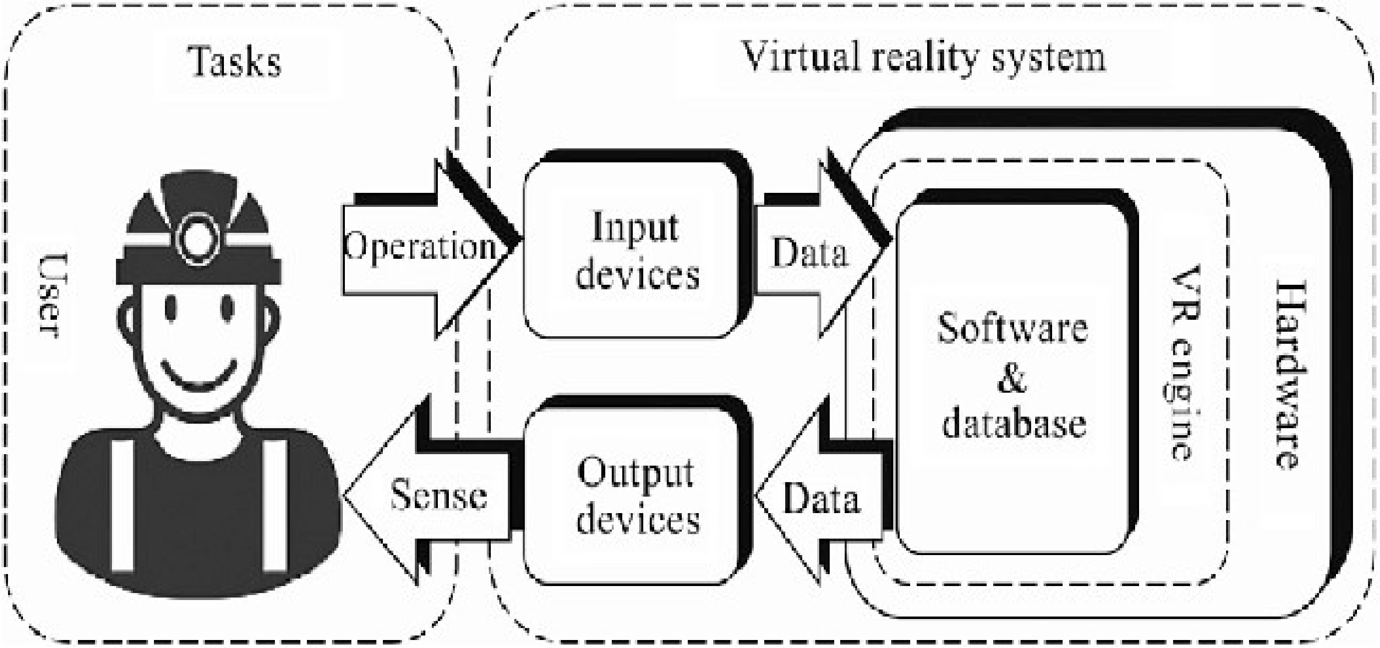
Figure. 1. Samples of Virtual Reality interaction

Imagination :

The capacity of the user's mind to create non-existent things and create illusion of their existence in real world.



Components of Virtual Reality



Input Devices:

- the user interacts with the virtual world
- send signals to the system about the action of the user
- Classified as tracking device, point input device, bio-controllers and voice device.
  - **Tracking devices :**
    - position sensors, are used in tracking the position of the user and include, electromagnetic, ultrasonic, optical, mechanical and gyroscopic sensors, data gloves, neural and bio or muscular controllers.
  - **point-input devices** include 6DOF mouse and force or space ball.
  - **Voice communication** is a common way of interaction among humans.


MANUS


3Dconnexion
ESC
CTRL
ALT

Output Devices:

- get feedback from the VR engine and pass it on to the users
- Classified as :
  - graphics (visual),
  - audio (aural),
  - haptic (contact or force),
  - smell and taste

VR Engine

- has to be selected according to the requirement of the application
- Depends on the application field, user, I/O devices, level of immersion and the graphic output required,
- responsible for calculating and generating graphical models, object rendering, lighting, mapping, texturing, simulation and display in real-time.

Virtual Reality System Software and Tools

- a collection of tools and software for designing, developing and maintaining virtual environments and the database where the information is stored.
- **Classified into**
  - **modeling tools**
    - 3ds Max, Maya and Creator
  - **development tools.**
    - virtual world authoring tools, VR
    - toolkits/software development kits (SDK) and
    - application program interfaces (APIs).

Application

1. Healthcare
2. Entertainment
3. Education
4. Automative
5. Space & Military
6. Architecture
7. Digital Marketing
8. Occupational Safety
9. Tourism
10. Construction








Application


STRIVR

Multiple modals of i/p and o/p interfaces in virtual reality

- Provides the user many ways to communicate with physical and virtual system.
- Provides many different tools for input and output.
- Makes communication freely and naturally.

3D Position Tracker

- To monitor real time location and orientation of the user’s hand and head.
- For some applications user’s arm
- In some cases whole body.
- **Latency:**
  - Delay between the action and result.
  - Period between the change in position of an object and time taken by sensor to detect change.
- **Update Rate:**
  - No. of measurements the tracker reports every second.

Mechanical Tracker

- Earliest tracking system
  - Used by Ivan Sutherland for the Ultimate Display
- Rigid jointed chain-like structure
- Each joint provides a transformation relative to parent
  - Like a scene graph
  - Each joint has 2-3DOF
  - Position typically fixed relative to parent joint
  - Sensors at joints measure the angles
  - Concatenate translates and rotates to find position and orientation of the distal joint relative to base.

Optical Tracker

- Use light to calculate a target’s orientation along with position.
- It includes a group of infrared LEDs.
- Sensors consist of nothing but only cameras. These cameras can understand the infrared light that has been emitted.
- LEDs illuminates in a fashion known as sequential pulses.
- The pulsed signals are recorded by the camera and then the information is sent to the processing unit of the system.
- Estimates the position as well as the orientation of the target.

Electromagnetic Tracker

- Calculate magnetic fields generated by bypassing an electric current simultaneously through 3 coiled wires
- Wires are set up in a perpendicular manner to one another.
- System’s sensors calculate how its magnetic field creates an impact on the other coils.
- The measurement shows the orientation and direction of the emitter.
- The responsiveness is really good.
- They level of latency is quite low.

Acoustic Tracker

- Senses and produces ultrasonic sound waves to identify the orientation and position of a target.
- Calculate the time taken for the ultrasonic sound to travel to a sensor.
- Sensors kept stable in the environment. The user puts on ultrasonic emitters.
- Position of the target depending on the time taken by the sound to hit the sensors

3D Mouse

- A specialized pointing and control device that is designed to be used in virtual 3D environments.
- It is a hand-held device that contains a tracker sensor and few buttons.
- It is used to navigate items.
- Used to control the forward motion.
- Ex :
  - Tilting the mouse forward it can start to move forwa
  - Holding it upright stops the movement.

Gloves

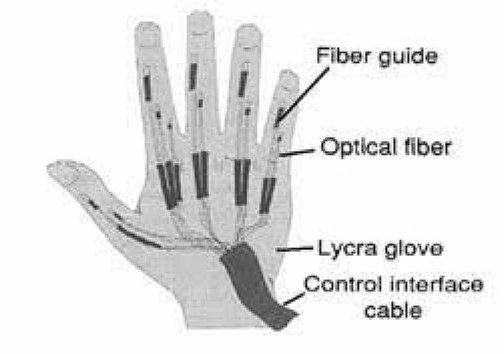
- a type of wearable technology designed to immerse the user in a VR
- experiences more natural and realistic.
- **Hand tracking feedback:**
    - Allows users to see hand movements and gestures in virtual space.
- **Vibrotactile feedback:**
    - Provides a range of sensations, from light touch to rough textures.
- **Force feedback:**
    - Allows users to feel the size and density of virtual objects
- **Contact feedback:**
    - Allows users to feel the shape of virtual objects and sur
- **Temperature feedback:**
    - Allows users to feel the temperature of virtual objects.

Infidelity

A simple interactive glove , made up of lightweight material.

Transducers are installed to measure the angles between fingers.

Used to communicate the hand gestures like pointing and holding .

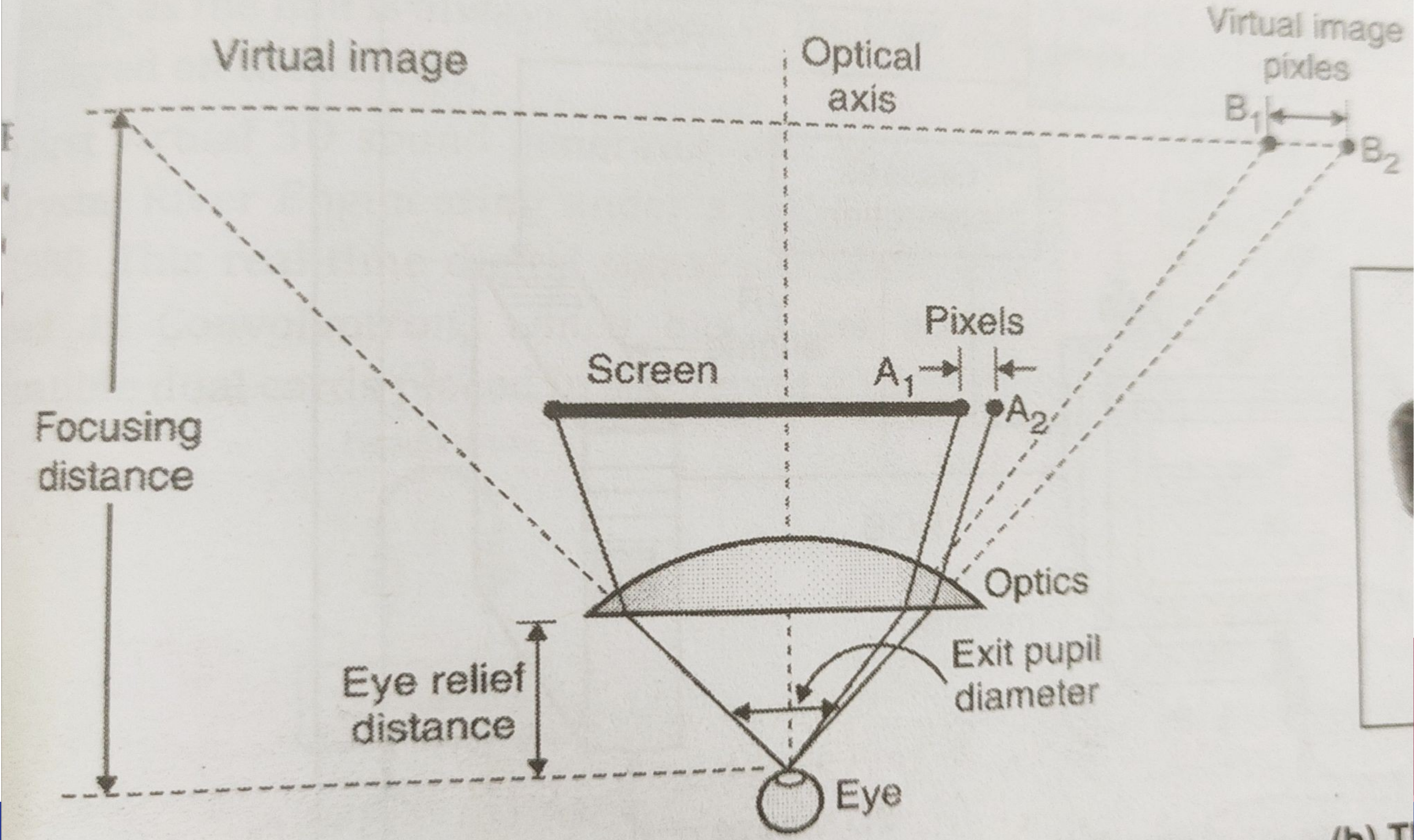


Head Mounted Display (HMD)

a type of computer display device or monitor

worn on the head or is built in as part of a helmet.

The display streams data, images and other information in front of the wearer's eye(s).



Virtual image
Optical axis
Virtual image pixles
B1
B2
Pixels
Screen
A1
A2
Focusing distance
Optics
Exit pupil diameter
Eye relief distance
Eye

Features of HMD

- **Contrast Ratio:**
  - Ratio of highest luminance to the background luminance.
  - 100:1 is normal value.
- **Field of view:**
  - A measure of the horizontal and vertical range of an optical system.
- **Exit pupil:**
  - The distance eye can deviate from the optical center of the display before image disappears.
  - Order of 1.2 cm

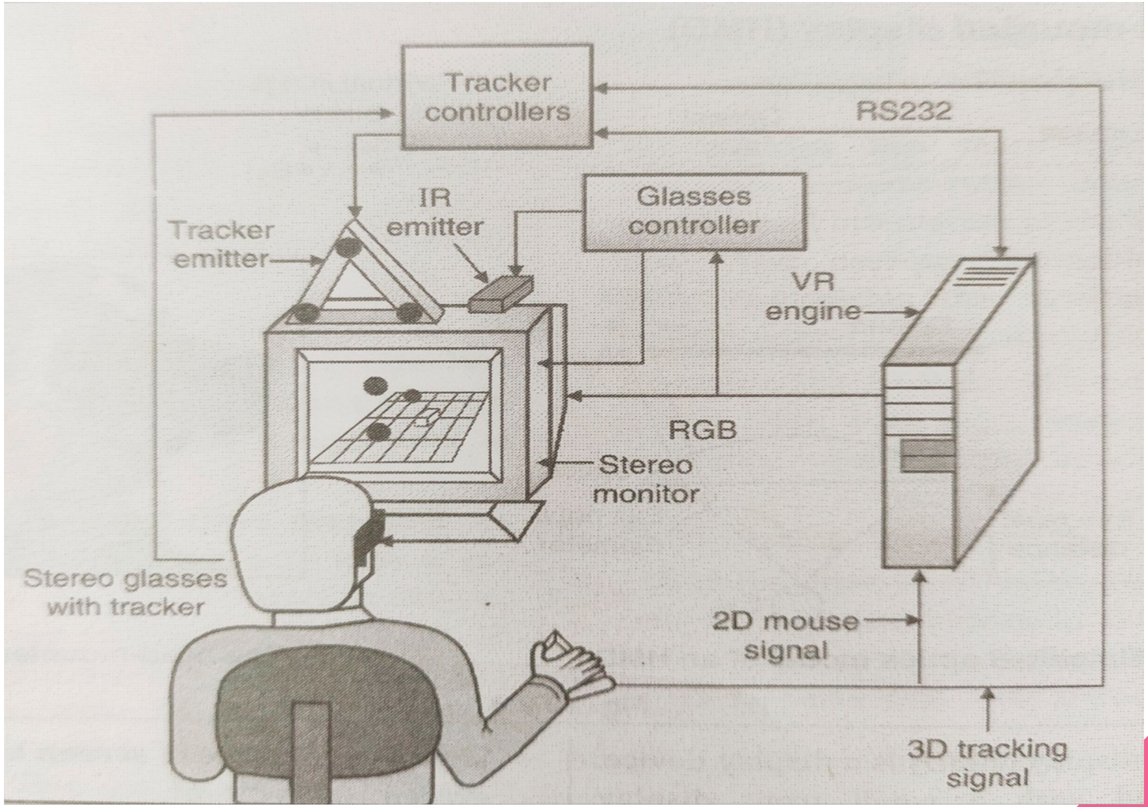
Features of HMD

- **Eye Relief**
  - A measure the distance between HMDs optical system and the face of the user.
  - Order of 2 cm.
- A standard HMD contains two LCD elements
- Resolution is usually 640 X 480 pixels.

Cave Automatic Virtual Environment

- A virtual reality (VR) environment consisting of a **cube-shaped VR room** or
- a **room-scale area** in which the **walls, floors and ceilings** are **projection screens.**
- A CAVE is contained within a **larger room** that is **completely dark** when in use.
- **(3D) images** within the VR CAVE appear to **float in mid-air.**
- The viewer's headgear is synchronized with the projectors, and they **can walk around an image to study it from all angles.**
- **Sensors** within the room provide a **tracking system** to **monitor the viewer's position** and align the perspective correctly.
- The surrounding projection consists of three active stereo screens
    - Left, Right and Front

Cave Automatic Virtual Environment



Sound Display

The computer interfaces that provide synthetic sound feedback to users when interacting with virtual world.

Monoaural : Both ear hears same sound

Binaural : each ear hears different sound

Haptic Feedback

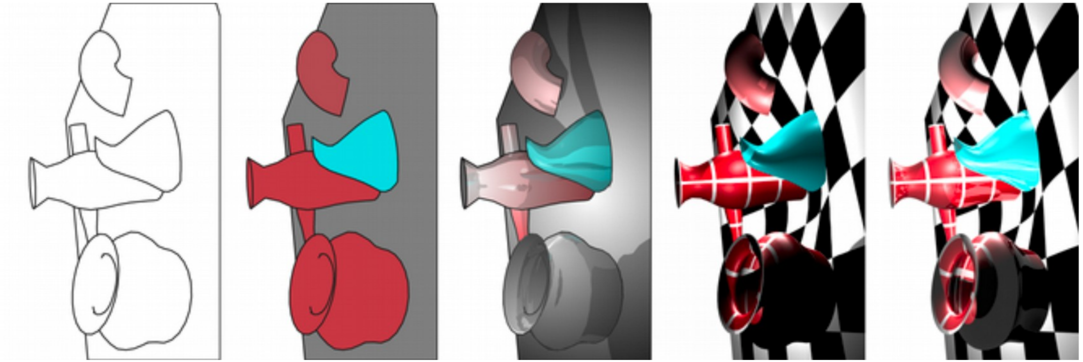
The use of touch to communicate with users.

Greek term Hapthai : Convey important sensorial information that helps.

Classified as touch and force feedback.

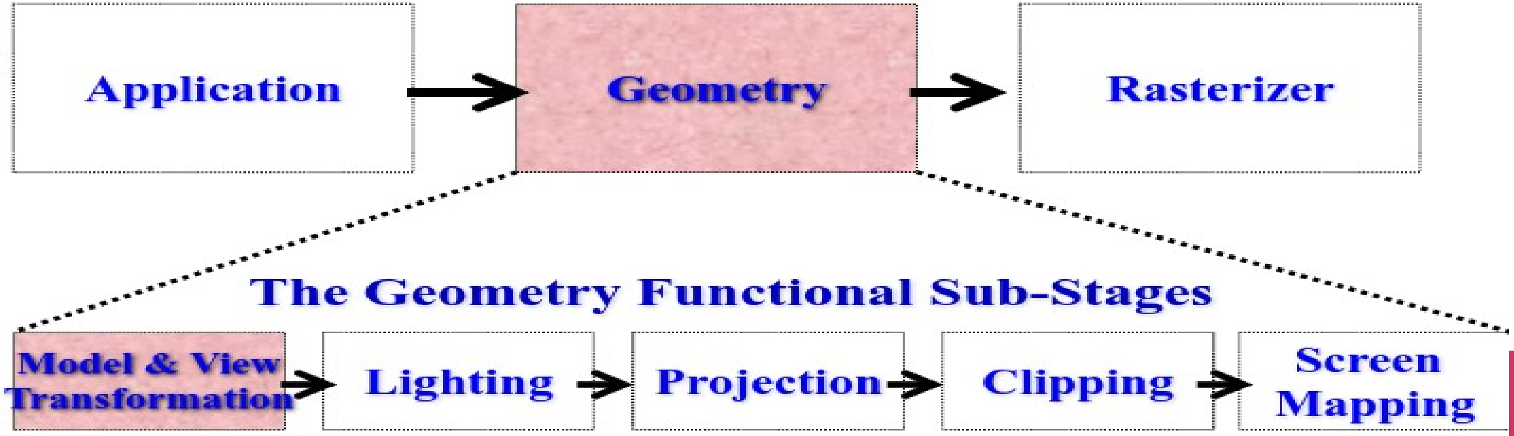
Rendering Pipeline

The process of converting 3D geometrical models populating a virtual world into 2D scene presented to the user.



Graphics Rendering Pipeline

A conceptual model that describes what steps a graphics system needs to perform to render a 3D scene to a 2D screen.

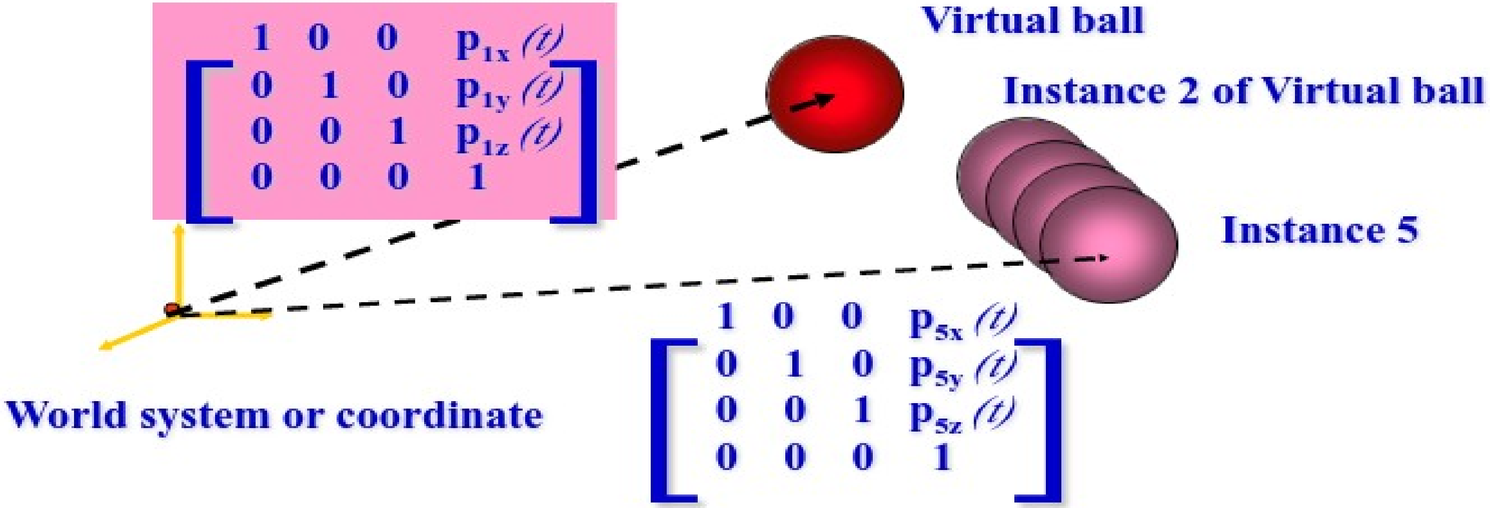


Graphics Rendering Pipeline

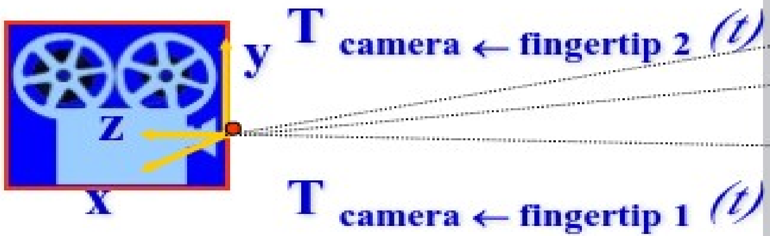
1. **Application Phase:**
   a. Performed entirely on the software by the CPU.
   b. Read a geometry database with user inputs controlled by devices.
   c. Responding to the user input, application can change the view or orientation of an object.
2. **Geometric Phase**
   a. Results of application phase are given to it.
   b. Installed in software / hardware.
   c. Contains model transformations, lighting calculations, cutting etc.
   d. **Lighting :** counts more color based on type and no. of light sources.

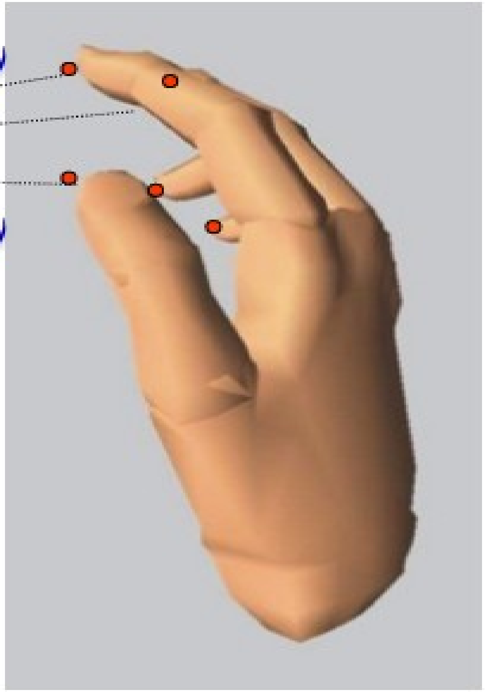
Model and Viewing Transformations:

✓ Model transforms link object coordinates to world coordinates. By changing the model transform, the same object can appear several times in the scene. We call these ***instances***.



Camera system of coordinates

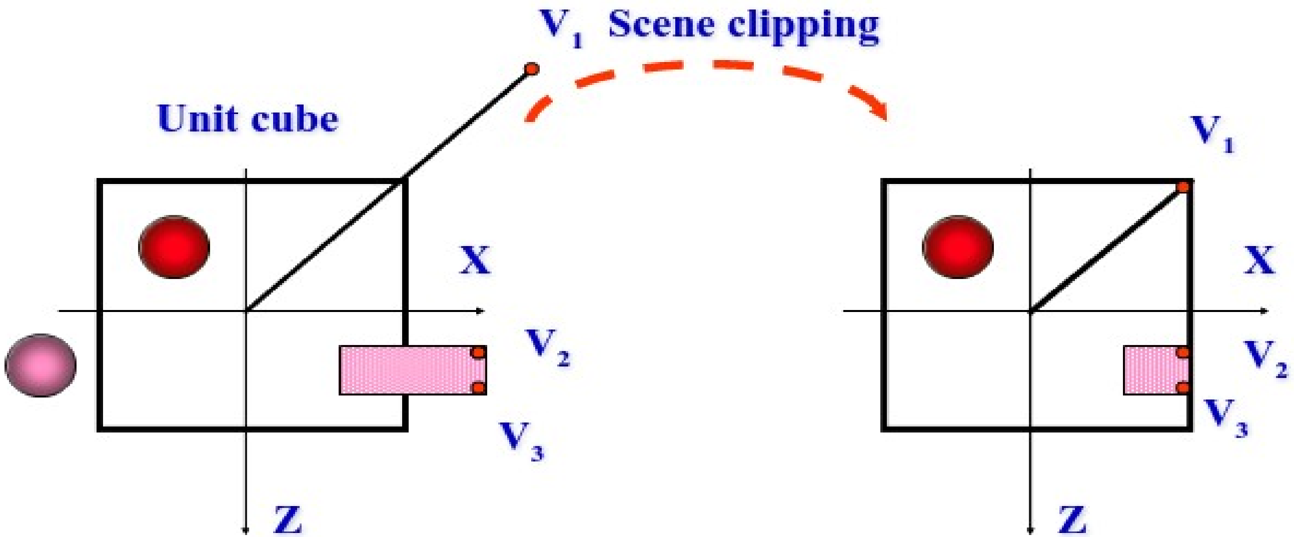




- The *View Transform* matrix captures the position and orientation of the virtual camera in the virtual world;
- It maps world coordinates to camera space (also called "eye space");
- The camera is located at the origin of the camera coordinate system, looking in the negative Z axis, with Y pointing upwards, and X to the right.

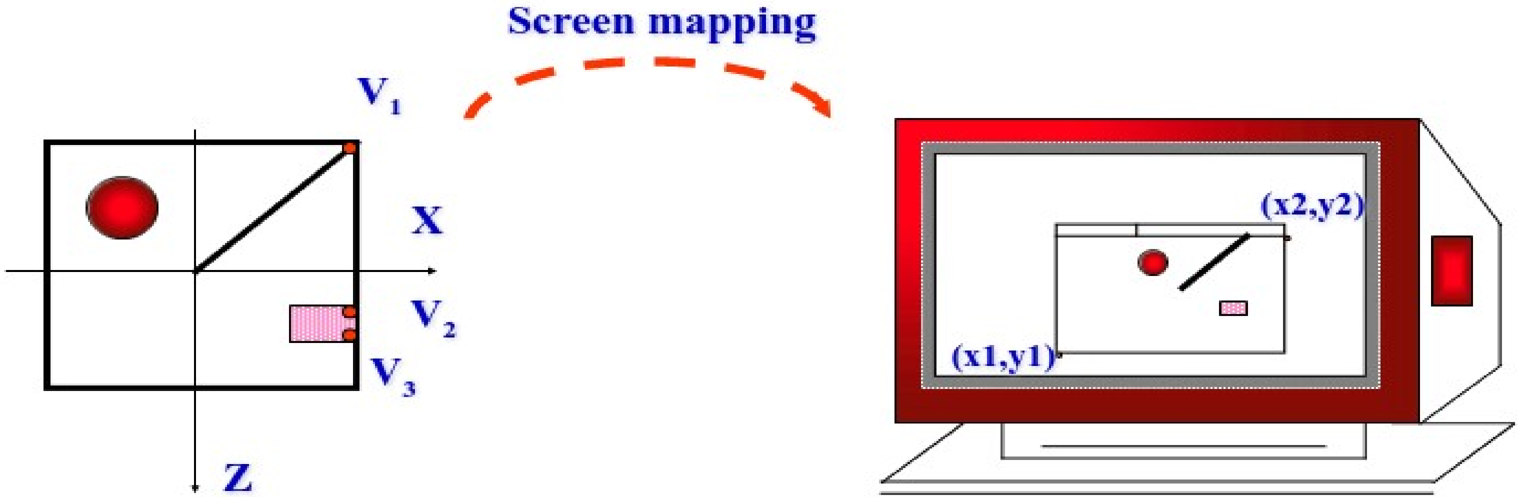
Clipping Transformation:

✓ Since the fulcrum maps to the unit cube, only objects inside it will be rendered. Some objects are partly inside the unit cube (ex. the line and the rectangle). Then they need to be "clipped". The vertex V_1 is replaced by new one at the intersection between the line and the viewing cone, etc.



Screen Mapping (Viewport Transformation):

- The scene is rendered into a window with corners (x_1,y_1), (x_2,y_2)
- Screen mapping is a translation followed by a scaling that affects the **x** and **y** coordinates of the primitives (objects), but not their z coordinates. Screen coordinates plus $z \in [-1,1]$ are passed to the rasterizer stage of the pipeline.



Graphics Rendering Pipeline

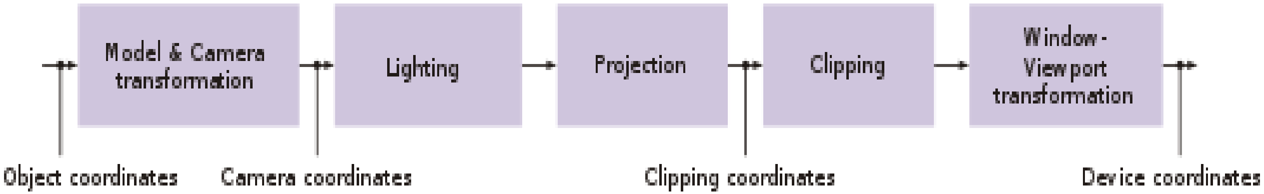


Fig : Geometric Phase

3. Rasterizing Phase

a. Made up of hardware for speed.
b. Converts vertex information output in pixel details required for video
c. Performs antialiasing.

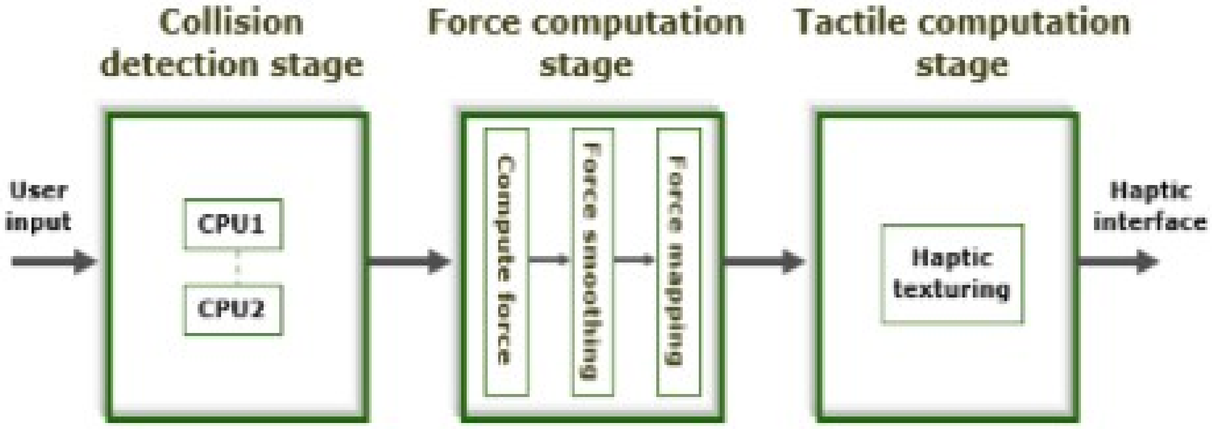
Haptics Rendering Pipeline

1. **Collision detection stage:**
    a. Gives the visual features of 3D objects.
    b. Includes smoothness, weight, surface temperature etc
    c. Determines which objects are in conflict.
2. **Force computation stage:**
    a. Compute the collision forces.
    b. Simpler force models are used.
    c. Includes force smoothing and mapping.
    d. Force smoothing: Regulates the direction of force vector to avoid sharp transitions.
    e. Force mapping : project the designed force to the characteristics.

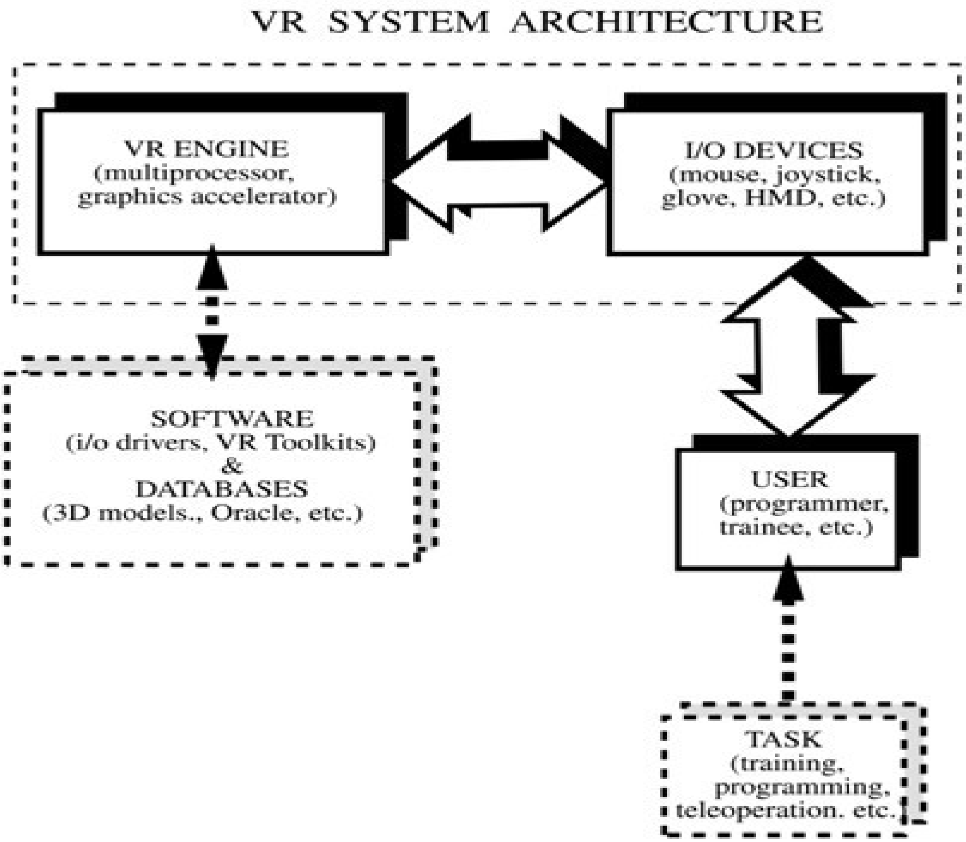
Haptics Rendering Pipeline

Tactile computation stage

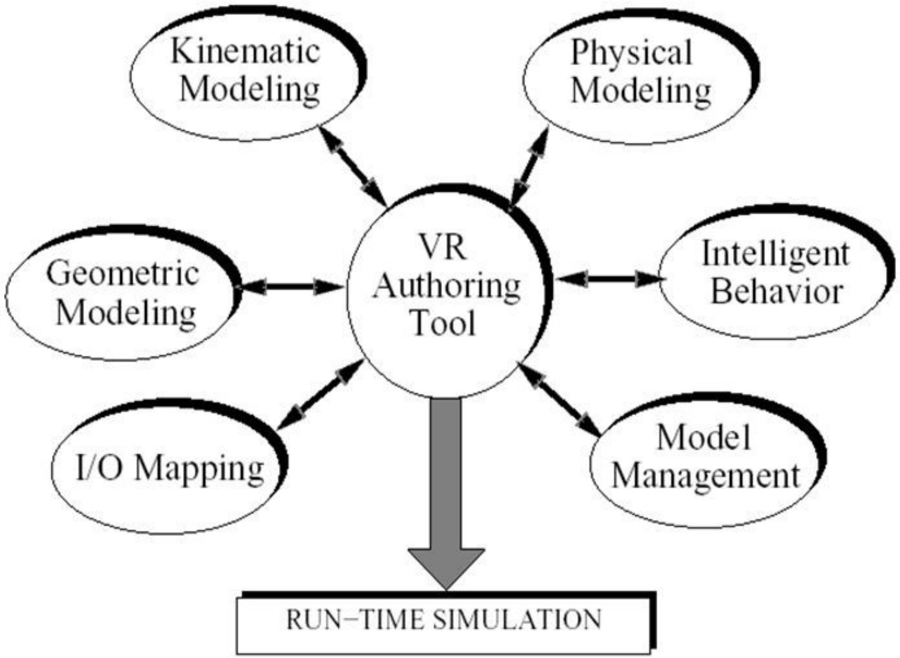
- Render the touch feedback component of the simulation
- The computed effects are added to the force vector send to the haptics output display



Modeling in Virtual Reality



The VR modeling cycle

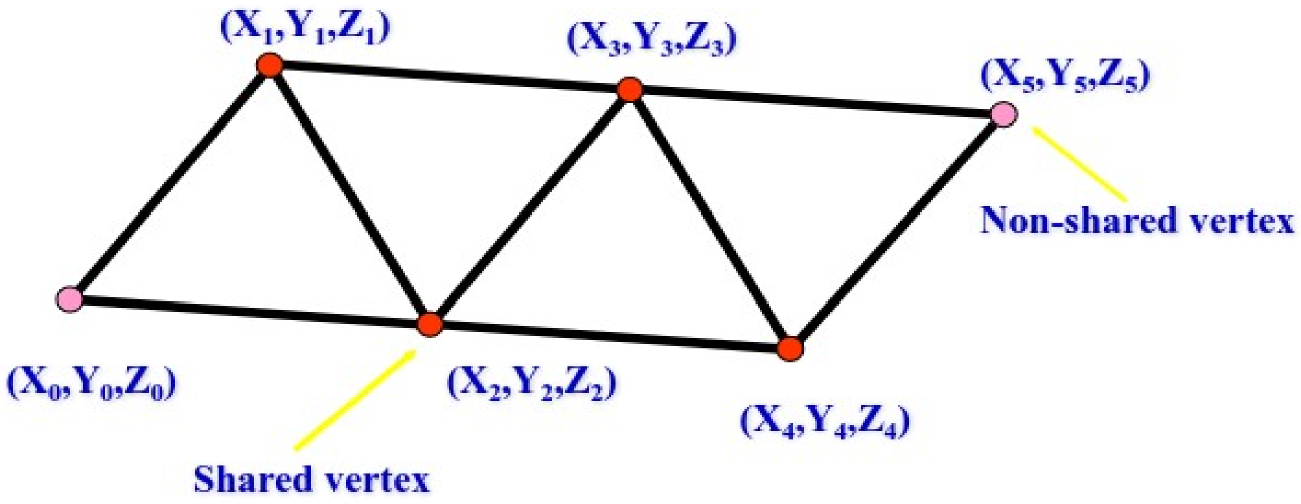


Geometric Modelling

- Defines the shape of virtual objects.
- Defines their appearance like surface texture, illumination, color e

Virtual object shape

The surface polygonal (triangle) mesh



Disadvantage :
Highly curved and bumpy surfaces

Triangle meshes are preferred since they are memory and computationally efficient (shared vertices)

Object spline-based shape:

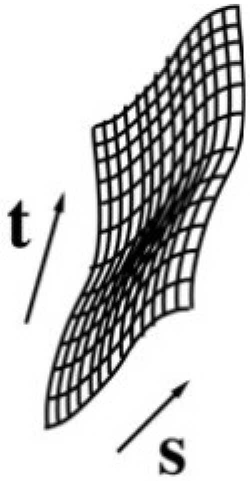
- ✓ Another way of representing virtual objects;
- ✓ Functions are of higher degree than linear functions describing a polygon – use less storage and provide increased surface smoothness.
- ✓ Parametric splines are represented by points x(t), y(t), z(t), t=[0,1] and a, b, c are constant coefficients.

$$x(t) = a_x \cdot t^3 + b_x \cdot t^2 + c_x \cdot t + d_x,$$
$$y(t) = a_y \cdot t^3 + b_y \cdot t^2 + c_y \cdot t + d_y,$$
$$z(t) = a_z \cdot t^3 + b_z \cdot t^2 + c_z \cdot t + d_z,$$

Object spline-based shape:

✓ Parametric surfaces are extension of parametric splines with point coordinates given by x(s,t), y(s,t), z(s,t), with s=[0,1] and t=[0,1].

β-Splines are controlled indirectly through four control points

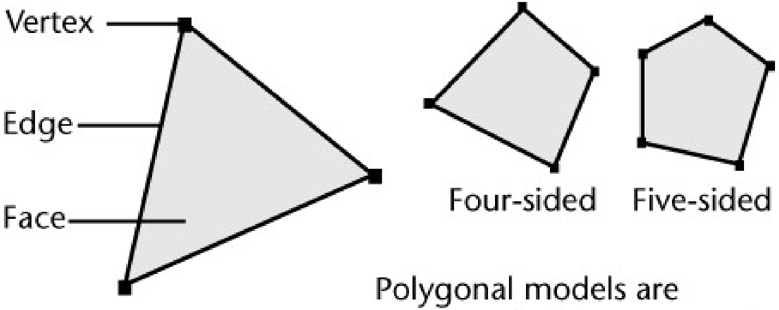


Object polygonal shape:

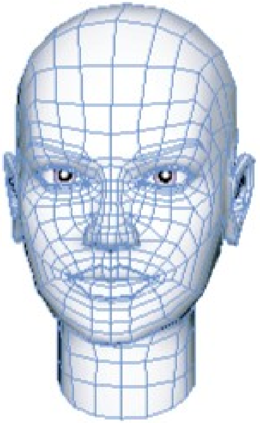
- ✓ Can be programmed from scratch using OpenGL or other toolkit editor; it is tedious and requires skill;
- ✓ Can be obtained from CAD files;
- ✓ Can be created using a 3-D digitizer (stylus), or a 3-D scanner (tracker, cameras and laser);
- ✓ Can be purchased from existing online databases (Viewpoint database). Files have vertex location and connectivity information, but are *static*.

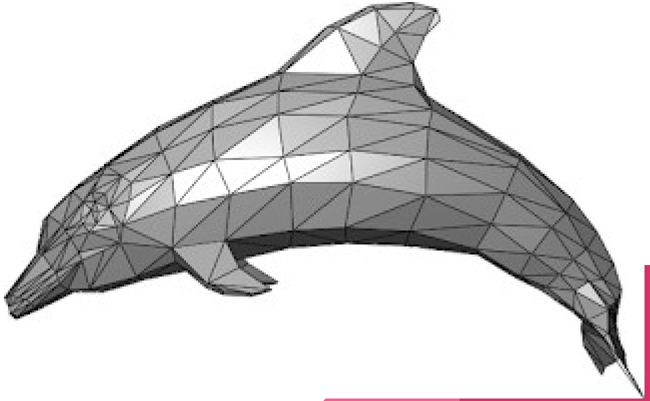
Geometric Modeling

Venus de Milo created using the HyperSpace 3D digitizer, 4200 textured polygons using NuGraph toolkit



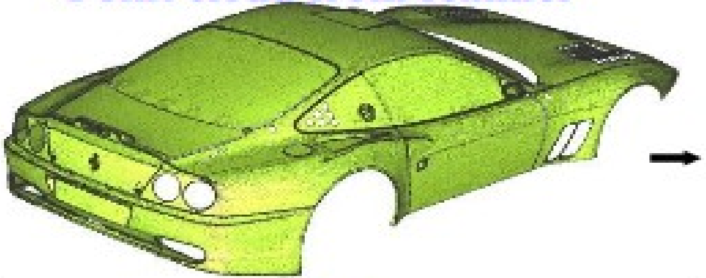
Polygonal models are composed of many separate polygons combined into a polygon mesh.





Case example: Ferrari down-force rear wing

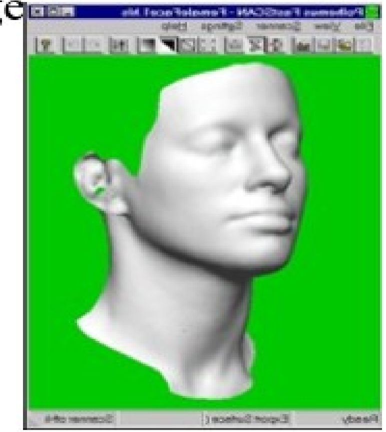
Point cloud from scanner



Polygonal mesh

Polhemus 3-D scanners:

- ✓ Eliminate direct contact with object.
- ✓ uses two cameras, a laser, and magnetic trackers (if movable objects are scanned)
- ✓ Scanning resolution 0.5 mm at 200 mm range;
- ✓ Scanning speed is 50 lines/sec;
- ✓ Range is 75-680 mm scanner-object range



Object Visual Appearance

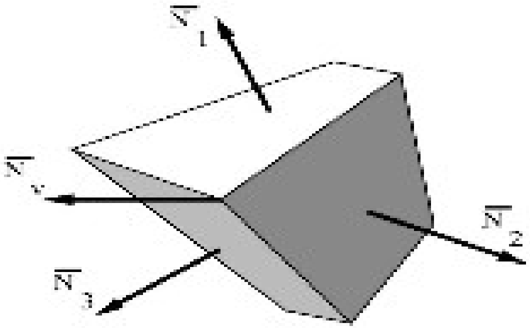
- To create a realistic- modelling of the geometry of a virtual object is the first step.
- Next step is to illuminate the scene such that object become visible.
- **Scene Illumination :**
  - The appearance of object depends on the type and placement of virtual light.
  - Determines the light intensities on the object surface.
- **Classified as :**
  - Local Illumination
  - Global Illumination

Scene illumination

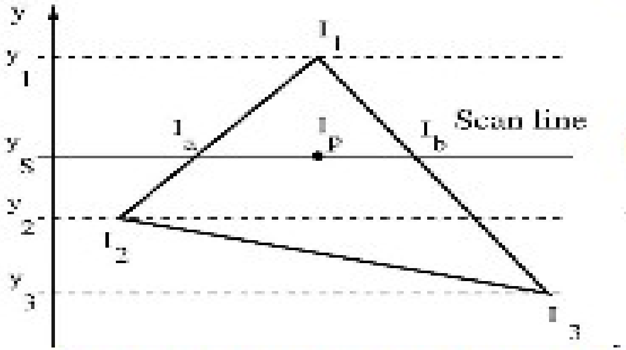
- ✓ Local methods (Flat shaded, Gouraud shaded, Phong shaded) treat objects in *isolation*. They are computationally faster than global illumination methods;

- ✓ Global illumination treats the *influence of one object on another* object's appearance. It is more demanding from a computation point of view but produces more realistic scenes.

Local illumination methods

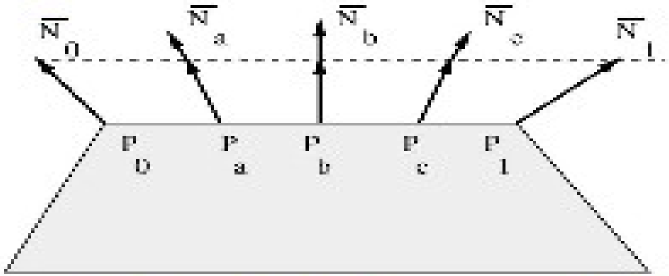


Flat shading model

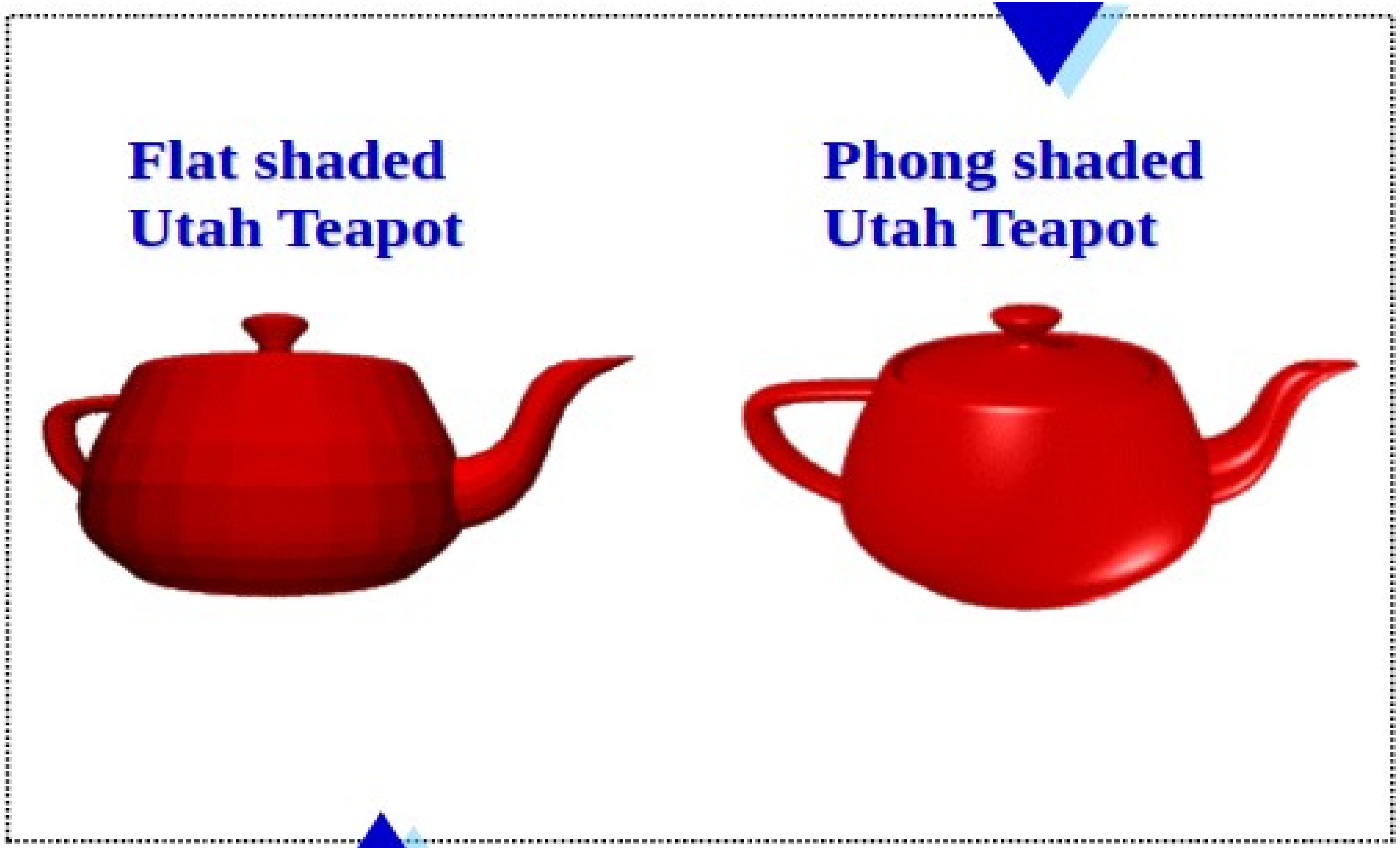


$$I_p = I_b - (I_b - I_a)\,\frac{x_b - x_p}{x_b - x_a}$$

Gouraud shading model



Phong shading model


Flat shaded
Utah Teapot
Phong shaded
Utah Teapot

Global scene illumination

- ✓ The inter-reflections and shadows cast by objects on each other.

Texture mapping

- It is done in the rasterizer phase of the graphics pipeline, by mapping texture space coordinates to polygon vertices (or splines), then mapping these to pixel coordinates;
- Texture ***increase scene realism***;
- Texture provide better 3-D spatial cues (they are perspective transformed);
- They reduce the number of polygons in the scene – increased frame rate (example – tree models).

How to create textures:

- ✓ Models are available on line in texture "libraries" of cars, people, construction materials, etc

- ✓ Custom textures from scanned photographs or
- ✓ Using an interactive paint program to create bitmaps

Kinematics Modeling

1. Homogeneous transformation matrices;
2. Object position;
3. Transformation invariants;
4. Object hierarchies;
5. Viewing the 3D world.

Homogeneous Transformations:

- ✓ Homogeneous system of coordinates is a right-hand Cartesian system of coordinates with ***orthonormal*** unit vector triads;
- ✓ Such **(i, j, k)** triads have the property that their norms $|\mathbf{i}| = |\mathbf{j}| = |\mathbf{k}| = 1$ and their dot product is $\mathbf{i} \bullet \mathbf{j} = \mathbf{i} \bullet \mathbf{k} = \mathbf{j} \bullet \mathbf{k} = 0$;
- ✓ Homogeneous transformation matrices relate two such systems through a 4×4 matrix.

Homogeneous Transformations:

- Have the general format:

$$T_{A \leftarrow B} = \begin{bmatrix} & R_{3x3} & & P_{3x1} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where $\mathbf{R_{3x3}}$ is the ***rotation submatrix*** expressing the orientation of the system of coordinates **B** vs. system of coordinates **A**;

$\mathbf{P_{3x1}}$ is the ***position vector*** of the origin of system **B** vs. the origin of system of coordinates **A**.

Homogeneous Transformations:

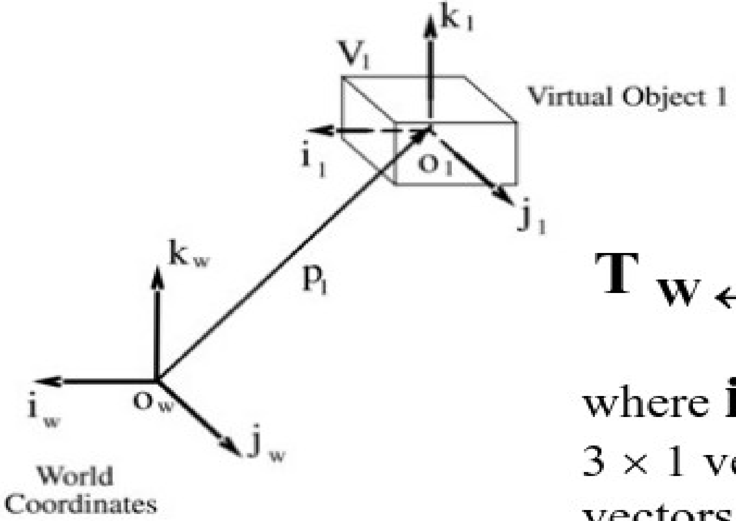
✓ Have many advantages:

- treat object translation and rotation mathematically in the same way;
- are easily invertible;

$$\mathbf{T}_{\mathbf{B}\leftarrow\mathbf{A}} = (\mathbf{T}_{\mathbf{A}\leftarrow\mathbf{B}})^{-1} = \begin{bmatrix} & \mathbf{R}^{T} & & -\mathbf{R}^{T}\bullet\mathbf{P} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Object Position/Orientation (static):

- given by homogeneous transformation matrix that relates the object system of coordinates to world system of coordinates.



$$T_{W\leftarrow 1} = \begin{bmatrix} \mathbf{i}_{w\leftarrow 1} & \mathbf{j}_{w\leftarrow 1} & \mathbf{k}_{w\leftarrow 1} & \mathbf{P}_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where $\mathbf{i}_{w\leftarrow 1}$, $\mathbf{j}_{w\leftarrow 1}$, $\mathbf{k}_{w\leftarrow 1}$ are 3×1 vectors projecting the object unit vectors into word system of coordinates

Object Position/Orientation (moving):

- ✓ If the virtual object moves, then the transformation matrix becomes a function of time

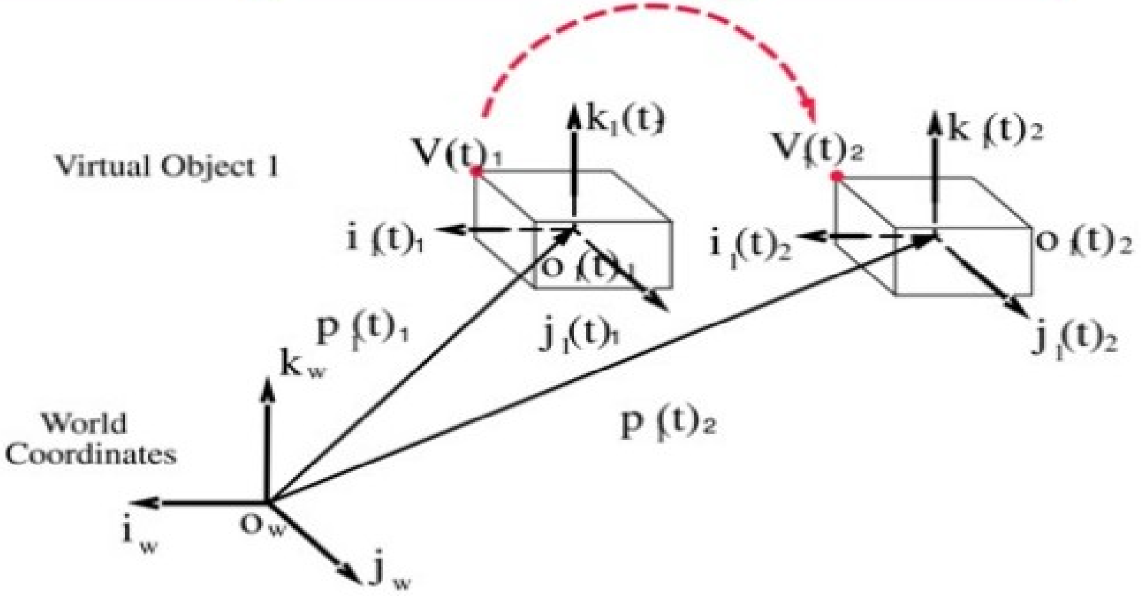
$$\mathbf{T}_{\mathbf{W}\leftarrow \mathbf{1}}(t) = \begin{bmatrix} \mathbf{i}_{\mathbf{w}\leftarrow \mathbf{1}}(t) & \mathbf{j}_{\mathbf{w}\leftarrow \mathbf{1}}(t) & \mathbf{k}_{\mathbf{w}\leftarrow \mathbf{1}}(t) & \mathbf{P}_{\mathbf{1}}(t) \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \end{bmatrix}$$

- ✓ The position of an object vertex $\mathbf{V}_i$ in word coordinates versus its position in object coordinates

$$\mathbf{V}_i^{(\mathbf{W})}(t) = \mathbf{T}_{\mathbf{W}\leftarrow \mathbf{1}}(t)\,\mathbf{V}_i^{(\mathbf{object})}$$

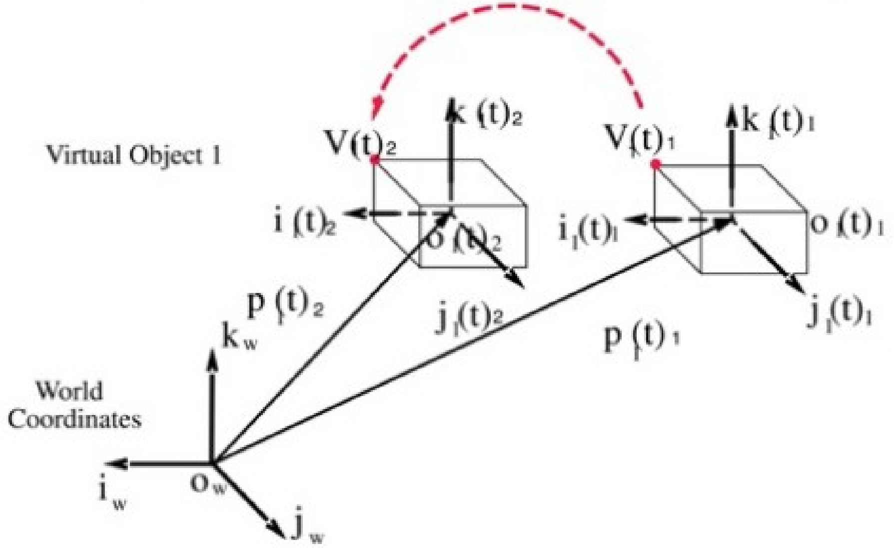
If the virtual object translates, all vertices translate

$$\mathbf{V}_i^{(W)}(t) = \begin{bmatrix} 1 & 0 & 0 & p_{1x}(t) \\ 0 & 1 & 0 & p_{1y}(t) \\ 0 & 0 & 1 & p_{1z}(t) \\ 0 & 0 & 0 & 1 \end{bmatrix} \mathbf{V}_i^{(object)}$$



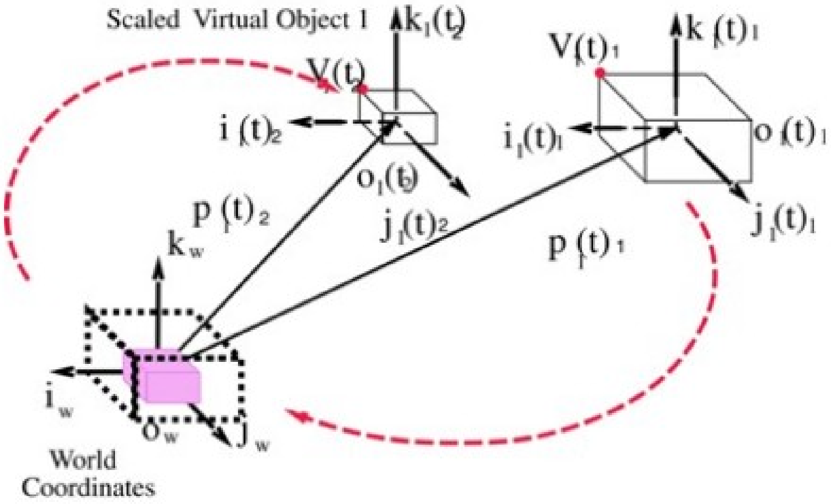
If the virtual object translates back to its initial position, all its vertices translate by an equal but negative amount.

$$\mathbf{V}_i^{(W)}(t) = \begin{bmatrix} 1 & 0 & 0 & -p_{1x}(t) \\ 0 & 1 & 0 & -p_{1y}(t) \\ 0 & 0 & 1 & -p_{1z}(t) \\ 0 & 0 & 0 & 1 \end{bmatrix} \mathbf{V}_i^{(object)}$$

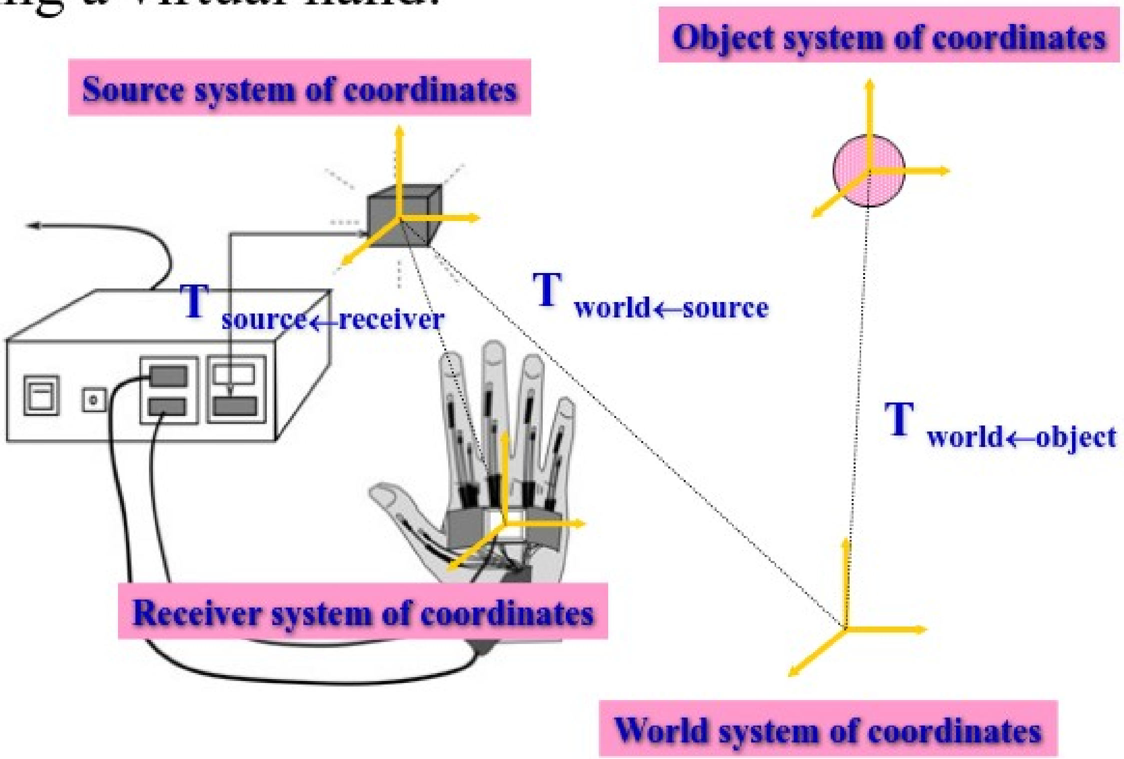


If the virtual object needs to be scaled, it is translated back, scaled, then translated to a new position

$$V_i^{(W)}(t) = T_{W \leftarrow 2} \begin{bmatrix} s_x & 0 & 0 & 0 \\ 0 & s_y & 0 & 0 \\ 0 & 0 & s_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} T_{W \leftarrow 1} V_i^{(object)}$$



Tracking a virtual hand:



Object Hierarchies:

- ✓ Allows models to be partitioned into a hierarchy, and become dynamic;
- ✓ Segments are either parents (higher level object) or children (lower level objects).
- ✓ The motion of a parent is replicated by its children but not the other way around.
- ✓ Example – the virtual human and the virtual hand;
- ✓ At the top of the hierarchy is the “world global transformation” that determines the view to the scene.