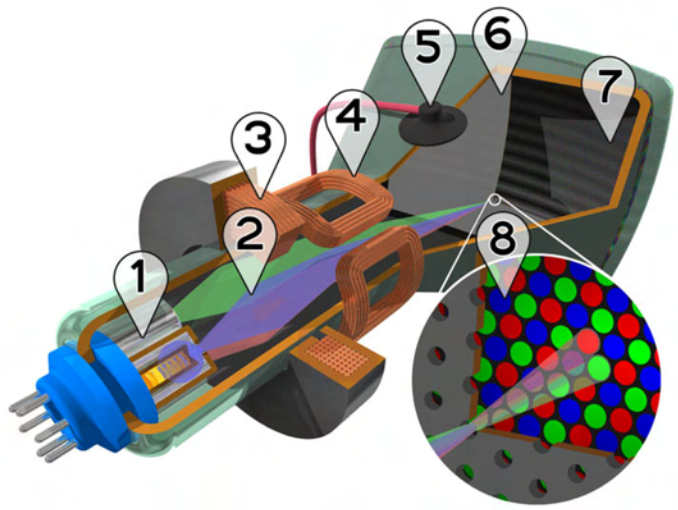
III. VR Systems

1. VR Hardware

- Vision Perception
  - Human vision allows the recognition of shapes in a 3D space with different colors and light intensities.
  - Vision is recognized as the primary source of information about the world.
    - Vision is commonly used to double check the accuracy of other senses.
      - e.g., we direct our sight toward unexpected sources of sound, such as an ambulance siren, to verify their location and evaluate potential danger.

Dr. X. Yuan (xyuan@uwindsor)

  - Graphical Display Technologies
    - The cathode-ray tubes (CRT)

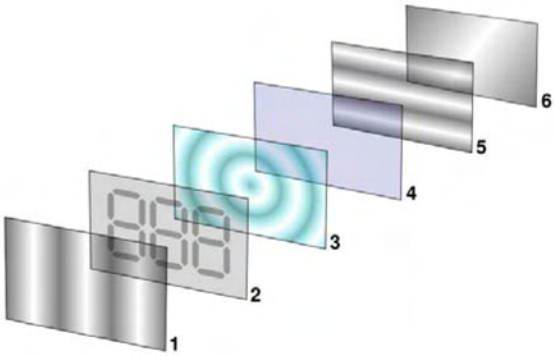


Dr. X. Yuan (xyuan@uwindsor)

- CRTs are still popular in the printing and broadcasting industries as well as in the professional video, photography, and graphics fields due to their greater color fidelity and contrast, better resolution when displaying moving images, and better view from angles.

– Liquid crystal displays (LCD) are found in many devices, including watches, handheld devices, and large computer monitors. Desktop-based applications can use this kind of display due to the limited space required by the screen, the brightness, and the flicker-free image they provide.

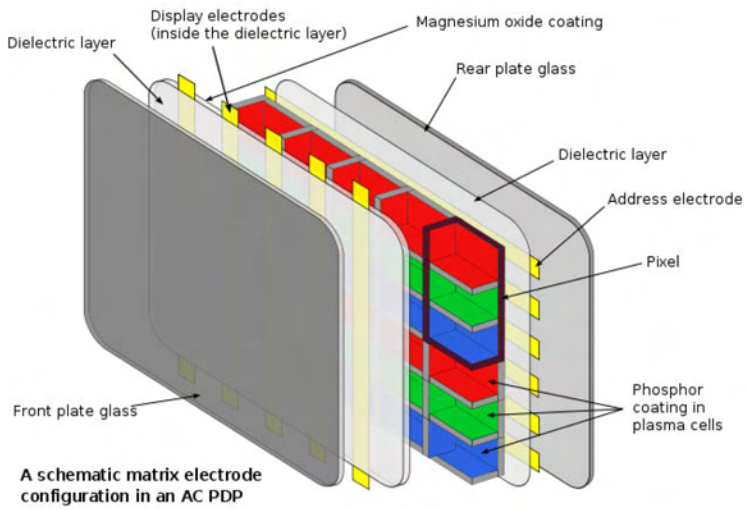
Dr. Y. Yuan (yyuan@uwindsor)



– Plasma displays usually offer superior brightness, faster response time, greater color spectrum, and wider viewing angle of color; but LCD technology has improved with advantages of lower weight,

Dr. Y. Yuan (yyuan@uwindsor)

falling prices, higher available resolution, and often lower electrical power consumption.



A schematic matrix electrode configuration in an AC PDP

Dr. Yi Yuan (yuan@uwindsor)

- VR Displays
  - Displays can be roughly classified based either on the number of users that can participate in the VR experience, i.e., individual and collective displays, or the degree of visual immersion, i.e., from fully immersive systems to handheld displays.
  - While see-through HMD have applications in the maintenance of complex systems as they can provide the technician with "X-ray vision" by combining computer graphics (e.g., system diagrams) with natural vision, ordinary HMDs can be an appropriate choice for VR applications requiring frequent turns and spatial orientation, such as navigation tasks.

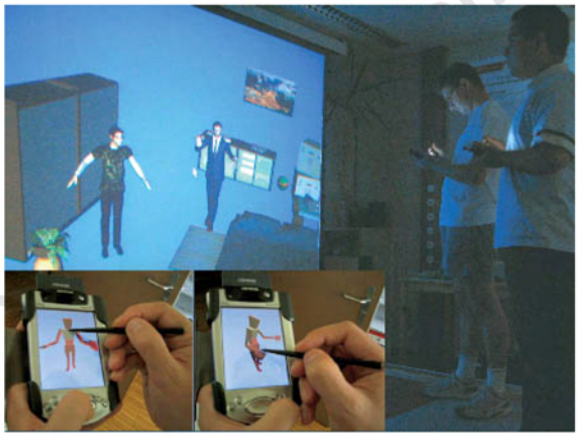
Dr. Yi Yuan (yuan@uwindsor)

– Fish Tank VR is a system using a high resolution monitor supplemented with hardware for stereoscopic viewing such as shutter glasses and a head-tracking device for adjusting the perspective transformation to a user's eye position can simulate the appear-

ance of stable 3D objects positioned behind or just in front of the screen, which is particularly for scientific visualization applications by allowing users to carefully examine complex structures.

Dr. Yuan Tian @uwindsor)

– Handheld displays represent a real alternative to head-attached devices for mobile applications, and consumer devices (e.g., PDAs and mobile phones) have the potential to bring augmented reality to a mass market.

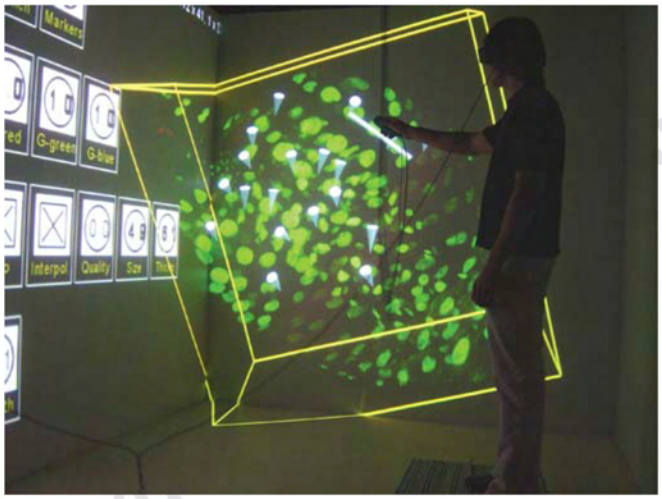


– Large Projection Screens constitute a semi-immersive approach that consists in positioning one or more users in front of a large rear-projection screen displaying the virtual world.

- To participate in the competition of a virtual game, the player has to physically run and jump during the game; wearing a simple body suit, the movements are registered by a tracking device and are instantaneously transferred to animated cartoon character on a large projection screen. The players compete from different locations.

– The CAVE project allows user to see the entire environment from the correct viewpoint, thus creating a compelling illusion of reality. Real and virtual objects are blended in the same space and the user can see her body interacting with the environment.

Dr. X. Yuan (xyuan@uwindsor)



- Audition Perception
  - The combination of sound and graphics enhances the sense of presence.

Dr. X. Yuan (xyuan@uwindsor)

- Spatial sound, as perceived from different spatial locations in everyday life, is a key aspect in producing realistic virtual environments.
- Sound can play different roles in a Virtual Reality system.
  - *Complementary information* — sound allows to provide additional and richer information about the simulated environment.
  - *Alternative feedback* — sound feedback can enhance user interfaces.
  - *Alternative interaction modality* — in the form of voice, sound can be an efficient communication channel.

Dr. X. Yuan (xyuan@uwindsor)

- There are three main methods for sound recording:
  - A monaural sound recording uses a single microphone, thus there is no sense of sound positioning.
  - Recorded with two microphones, stereo sound gives a sense of the sound position.
  - Using microphones embedded in a dummy head, binaural recordings sound closer to what humans hear in the real world.
- Spatial sound synthesis consists in processing sound signals to produce realistic audio, taking into account individual sound signals and parameters describing the sound scene: position and orientation of each source and acoustic characterization of the room or space.

Dr. X. Yuan (xyuan@uwindsor)

- Sound rendering creates spatial sound by attaching a characteristic sound to each object in a scene.
- Head-related transfer function (HRTF) measures body's effect on the sound signal arriving from a given direction. With the support of special hardware, it can be used to synthesize accurate binaural signals from a monaural source.
- The 3D sound imaging technique consists in approximating binaural spatial audio through the interaction of a 3D environment simulation
- By focusing on attaching sampled sounds to objects in 3D space, loudspeaker location can be used for less-expensive real-time spatial sound systems.

Dr. X. Yuan (xyuan@uwindsor)

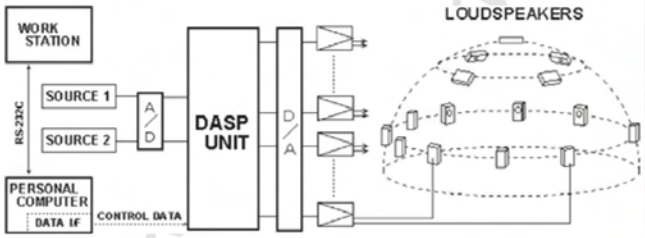
- Sound Systems for VR
  - VR requirements
    - The perceived position of the sound source should match the spatial location of the associated object in the virtual environment.
    - Acoustic room simulation is essential to perceive spatial properties such as size of the room and reflection properties of the walls.
    - There is a trade-off between accurately simulating the physical properties of spatial sound and the efficient generation of sound in real time.
    - Realistic virtual environments require a certain number of simultaneous virtual sound sources.

Dr. X. Yuan (xyuan@uwindsor)

– Sound Hardware

. Headphones allow more precise control of the spatial cues.

. Panning between multiple pairs of loudspeakers arrayed in front of and behind the listener is often used to produce "surround-sound".



Dr. X. Yuan (xyuan@uwindsor)

. Professional hardware includes special sound cards for custom multichannel sounds.

– Sound engines are software components that allow software developers to interface with the sound card and/or implement 3D sound generation in software.

- Touch Perception

  ◦ Touch is one of the most important human senses.

  – Touch can be divided into cutaneous, kinesthetic, and haptic systems.

  . The cutaneous system is composed of mechanoreceptors embedded in the skin. It constitutes the tactile sense, which process any stimulation on the body surface, the skin.

Dr. X. Yuan (xyuan@uwindsor)

- The kinesthetic system is composed of receptors located in the muscles, tendons, and joints. It constitutes the kinesthetic sense, which allows us to be aware of our limb positions and movements and muscle tensions.
- The haptic sensory system can be considered the combination of both cutaneous and kinesthetic systems.

– Haptic feedback has different modalities: force, tactile, and proprioceptive feedback.

- Force-feedback integrated in a VR simulation helps the user estimate the hardness, weight, and inertia of virtual objects.

Dr. X. Yuan (xyuan@uwindsor)

- Tactile feedback provides a feel of object's surface contact geometry, smoothness, temperature, etc.
- Proprioceptive feedback helps to estimate the relative position of body limbs body posture within the virtual environment.

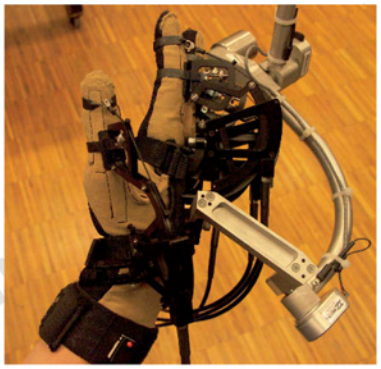
○ Data Gloves

– The whole body is able to receive and process haptic feedback, but our hands are the main interface to touch and manipulate our external environment.

– One of the first interaction devices created to take advantage of hand gestures was the data glove.

- Various sensor technologies are used to capture physical data such as bending of fingers.

Dr. X. Yuan (xyuan@uwindsor)



- Often a motion tracker (magnetic or inertial) is attached to capture the global position/rotation data of the glove.
- Some devices can also provide vibrotactile and force-feedback.

Dr. X. Yuan (xyuan@uwindsor)

- Postures and gestures can be categorized into useful information.
  - e.g., recognizing sign language or hand-based interaction

- Haptic interfaces generate mechanical signals that stimulate human kinesthetic and touch channels.
  - Two types of haptic interfaces:
    - Passive haptic interfaces can only exert resistance forces against the user's movement.
    - Active haptic interfaces utilize actuators that are capable of supplying energy.
  - Haptic rendering algorithms to generate forces in response to interaction with virtual objects

Dr. X. Yuan (xyuan@uwindsor)

- 3-DOF haptic rendering: only the position in 3D space can be modified as it considers touching virtual objects with a single contact point, which has only 3 DOF.
- 6-DOF haptic rendering: the feedback consists of 3D force and torque as it is designed to render the forces and torques arising from the interaction of two virtual objects.

– Three types of feedback

- Vibrotactile displays are composed of a single vibrating component used to encode information in temporal parameters of the vibration signal, such as frequency, amplitude, waveform, or duration.

Dr. X. Yuan (xyuan@uwindsor)

- Tactile displays may create touch sensations by passing a small *electric* current through the skin, simulate the thermal cues associated with making contact with materials with different *thermal* properties, or *mechanically* reproduce the small-scale skin deformations that occur during fingertip interactions with real objects.
- Kinesthetic feedback can be provided by devices exerting forces to simulate the texture and other high-spatial-frequency details of virtual objects. Various types of force-feedback devices have been designed: single-point interaction, exoskeletons, and haptic surfaces.

Dr. X. Yuan (xyuan@uwindsor)

- Smell/Taste Perception
  - It is known that smells influence action and feeling.
    - The sense of smell can stimulate the memorization of concepts or experiences.
      - e.g., the use of olfactory stimuli for cuing memories during sleep is useful for memory consolidation
    - Studies show that olfactory stimuli can enhance the sense of presence by recalling previous experiences and modifying the emotional state of the user.
  - Taste perception serves as a primary gatekeeper controlling voluntary ingestion of substances.
    - Humans can distinguish five major taste classes: sweet, sour, bitter, salty, and umami.

Dr. X. Yuan (xyuan@uwindsor)

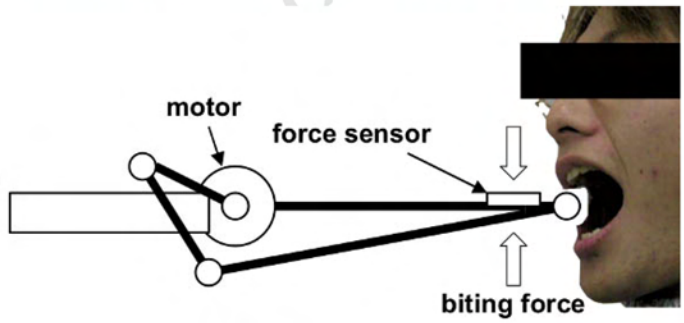
    - Each individual has different sensitivity to many different substances.
      - Some of this variation is known to be genetic in origin.
      - Other factors such as age, sex, and exposure to different diets and foods are also known to affect some taste abilities.
      - Anxiety or depression are also associated with taste disturbances.
    - The sense of taste plays a very important role in perceiving the real world, but is is still an open research question whether it can be used as an interaction modality in virtual worlds.

Dr. X. Yuan (xyuan@uwindsor)

- Smell Interfaces, also called olfactory displays, have been mainly used to provide alerts and notifications.
  - An olfactory display consists of a palette of odorants, a flow-delivery system, and a control algorithm that determines the mixing ratios, concentration, and timing of the stimulus.
  - There are two types of olfactory displays:
    - Multiuser olfactory displays are used in special rooms, e.g., a CAVE system with computer-controlled fragrance dispensers and careful air control.
    - Individual olfactory displays may use an air cannon that tracks the user's nose to present smells.
  - The use of olfactory displays is not fully explored.

Dr. X. Yuan (xyuan@uwindsor)

- Very few investigations were reported that explored the sense of taste as "taste interfaces" in VR systems.
  - A "food texture display" simulates the action of chewing different kinds of food by releasing flavoring chemicals onto the tongue and playing back the prerecorded sound of a chewing jawbone corresponding to the food being simulated.



Dr. X. Yuan (xyuan@uwindsor)

- The drink simulator is a straw-like user interface that simulates the sensations of drinking by reproducing pressure, vibration, and sound.
- The *tasteScreen* contains 20 small plastic cartridges filled with flavoring agents that can be mixed together and dripped down the front of the monitor. When a user touches his tongue to the computer screen, certain combinations of flavoring agents recreate a flavor appropriate to the user's task.

2. System Architectures

- The creation of VR systems to support virtual environments (VE) is a challenging problem requiring diverse areas of expertise, ranging from networks to psychology.

Dr. X. Yuan (xyuan@uwindsor)

- Developing VEs is a very expensive task in terms of time and financial and human resources.
  - VEs can be applied in a broad range of areas, such as scientific visualization, socializing, training, psychological therapy, and gaming.
  - Such a diversity of applications produces a set of requirements that make it very difficult, if not impossible, to build a single system that fits all needs.
  - The result has been the creation of monolithic systems that are highly optimized to a particular application, with very limited reusability of components for other purposes.
- Scene Graph-Based Systems

Dr. X. Yuan (xyuan@uwindsor)

- A scene graph is an abstract logical access structure, a "tree".
  - It is used to represent objects comprising the environment and the relationships between them.
  - Scene graphs are used to connect game rules, physics, animation, and AI systems to the graphics engine.
- The scene graph consists of parent nodes, child nodes, and data objects.
  - The parent nodes, also called group nodes, organize and, in some cases, control how to interpret their descendants.
  - Group nodes serve as the glue that holds a scene graph together.

Dr. X. Yuan (xyuan@uwindsor)

  - Child nodes can be either group nodes or leaf nodes.
  - Leaf nodes have no children.
    - They encode the core semantic elements of a scene graph, for example, what to draw (geometry), what to play (audio), how to illuminate objects (lights), or what code to execute (behavior).
    - They refer to data objects. These objects are not scene graph nodes, but they contain the data that leaf nodes require, such as the geometry to draw or the sound sample to play.
- Popular implementations of scene graph programming interfaces include: Cosmo3D (SGI), Vega Scene Graph, Java3D, OpenSceneGraph, and OpenGL Performer.

Dr. X. Yuan (xyuan@uwindsor)

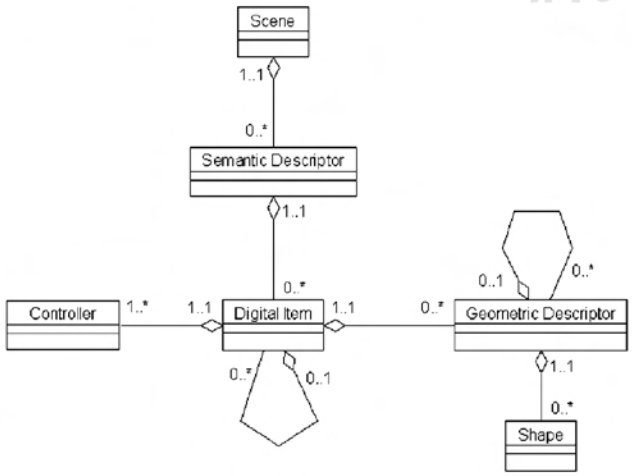
- OpenGL Performer is evolved from Open Inventor, and Open Inventor is an open-source project that provides a higher layer of programming for OpenGL with a scene graph library.
- Java 3D gained popularity as the main scene graph-based API for developing 3D applications with Java. It is frequently used for developing Web-based applications enhanced with real-time 3D graphics.

• Semantic Virtual Environments (SVE)

◦ Its main idea is to develop a higher-level semantic representation of virtual environments that can enhance the reusability and adaptation capabilities of the virtual entities participating in a VE.

Dr. X. Yuan (xyuan@uwindsor)

◦ The semantics-based representation is built on the concept of a scene graph, with the difference that it does not focus on visual or spatial relationships between entities but on higher-level semantics.



Dr. X. Yuan (xyuan@uwindsor)

- A general class diagram of the semantic model for the VE
  - The scene is the data repository used by digital items and other software tools such as viewers or interaction devices.
  - The semantic descriptor is the placeholder for any information describing how the digital item is to be used and how it is related to other items in the scene.
  - Digital items can be not only virtual objects to be rendered as part of the scene, but also independent user interfaces and controls for animation or interaction.

Dr. X. Yuan (xyuan@uwindsor)

  - The geometric descriptor of a digital item specifies the type of shape associated with the entity.
- A controller specifies the interaction possibilities: predefined object behaviors that react to human intervention and the way to provide access to them.
  - Usually, digital items in a VE are animated in either an autonomous or an event-triggered way.
- The objective to maximize the reusability of software and data while maximizing the variety of VR applications can also be achieved by developing a generic system architecture with three main layers:
  - An application layer creates the VR user interface.
  - The graphics layer deals with 3D object models.

Dr. X. Yuan (xyuan@uwindsor)

- The rendering layer allows plugging adapters for different rendering technologies.

- A distributed virtual environment (DVE) uses the following approaches to improve its scalability while allowing users in a network to interact with each other.
  - Architecture for communication coordination.
    - client-server model — server is the bottleneck as it needs to synchronize and distribute all messages to all or some of the users.
    - peer-to-peer model — each user has to assume all the responsibility of message filtering and synchronization as users are allows to directly exchange messages.

Dr. X. Yuan (xyuan@uwindsor)

    - peer-to-server model — consistency management is done by a server and communication among users is performed using multicast.
  - Interest management overcomes the limitations of network resources by focusing on users' interests.
  - Concurrency control is required to maintain synchronization among replicas of shared information.
    - The pessimistic scheme allows a user to manipulate an object only when a lock request for an object is granted, causing deteriorated performance.
    - The optimistic scheme enables natural interactions by allowing object updates without conflict checks, increasing the complexity to repair conflicts.

Dr. X. Yuan (xyuan@uwindsor)

- The prediction-based concurrency control uses the basis of the position, orientation, and navigation speed of the users to predict the next owner before users request ownership of the object.

- Data replication of the virtual world from the server at the client is necessary to support real-time interaction as it requires only updates with local changes or notification of remote changes.
  - Prioritized transfer maximizes the graphical fidelity of world objects as well as interactive performance by mediating the graphical detail and the transmission overhead of the objects.

Dr. X. Yuan (xyuan@uwindsor)

  - Caching and prefetching exploit the spatial relationship based on the distance between a user and objects to make the demanded data immediately available in a timely manner.

- Partitioning a virtual world into multiple regions and distributing the responsibilities for managing the regions across multiple servers can significantly reduce the workloads of individual servers.

Dr. X. Yuan (xyuan@uwindsor)