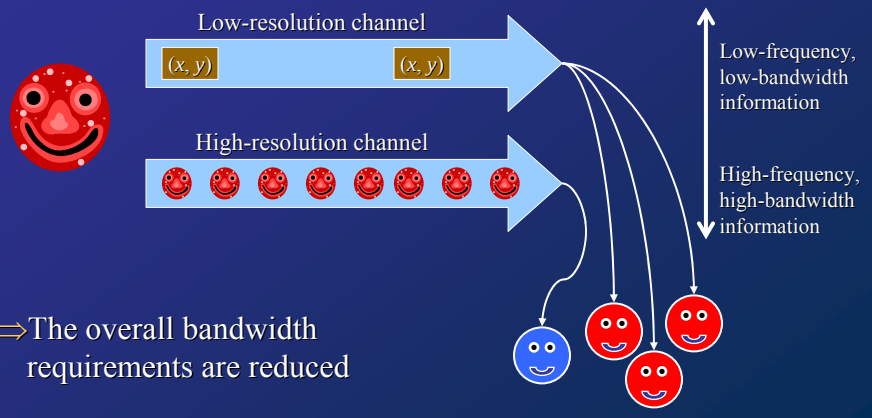
Exploiting Level-of-Detail Perception

- Nearby viewers
  - expect full graphical details
  - accurate structure, position, orientation
  - update rate → local frame rate
- Distant viewers
  - can tolerate less graphical details
  - less accurate structure, position, orientation
- User's focus is typically nearby
- Many inaccuracies cannot even be detected on a fine-resolution display

Multiple-Channel Architecture

- Multiple independent data channels for each entity



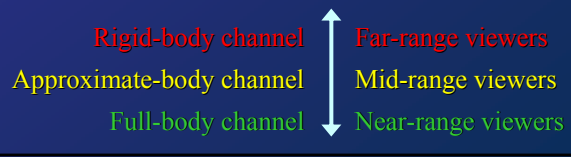
⇒The overall bandwidth requirements are reduced

Implementation Examples

- Client-server
  - each transmission identifies its channel
  - server dispatches data from channels to clients
- Multicast group for each region
  - assign multiple addresses for each region
    - one group provides all of the entities' high-resolution channels, another group provides all of the entities' low-resolution channels
- Multicast group for each entity
  - assign multiple addresses for each entity
- Different reliabilities to each channel
  - low-frequency updates are important
    - lost packets can have a significant impact

Selecting the Channels to Provide

- How many channels to provide for an entity?
  - more channels: better service for subscribers
  - each channel imposes a cost (bandwidth and computational)
- To satisfy the trade-off, three channels for each entity is typically needed
  - channels provide order-of-magnitude differences in
    - structural and positional accuracy
    - packet rate



Rigid-Body Channel

- Demands the least bandwidth and computation
- Represents the entity as a rigid body
- Ignores changes in the entity's structure
- Update types:
  - position
  - orientation
  - structure

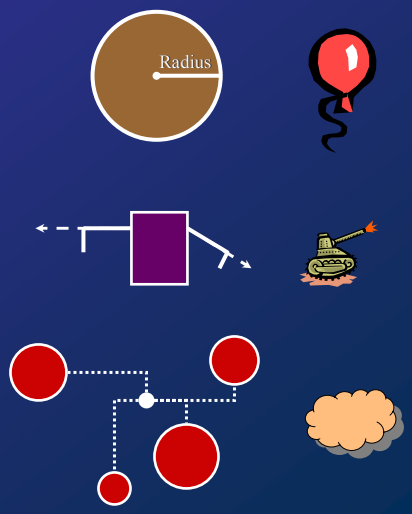


Approximate-Body Channel

- More frequent position and orientation updates
- Hosts can render a rough approximation of the entity's dynamic structure
  - appendages and other articulated parts
- Provided information is entity-specific
  - corresponds to the dominant changes of the structure

Common Approximations

- Radial length
  - motion towards and away from a centre point
  - update packets include the current radius
- Articulation vector
  - the current direction of the appendage
  - models a rotating turret, arms and legs
- Local co-ordinate system points
  - subset of the entity's significant vertices relative to the entity's local co-ordinate system
  - the entity is composed of multiple components



Full-Body Channel

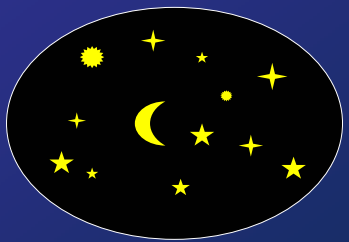
- Highest level of detail
- High bandwidth and computational requirements
  - viewer can subscribe to a limited number of full-body channels
- Frequent transmissions
- Position and orientation
- Accurate structure information

Exploiting Temporal Perception

- Render the entity in an accurate location — albeit slightly out-of-date
- As long as the local user does not interact, small temporal inaccuracies can be allowed
- Advantages:
  - works on WANs having great latency
  - can enhance packet aggregation
  - can enhance dead reckoning

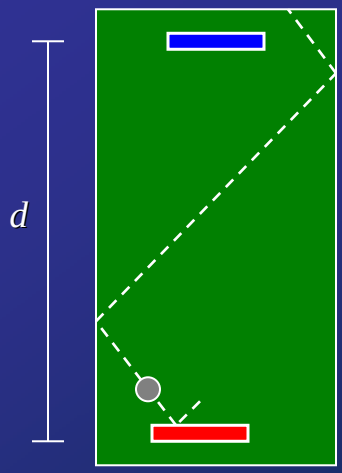
Active and Passive Entities

- An active entity
  - takes actions on its own
  - generates updates
  - human participants, computer-controlled entities
  - cannot be predicted typically
  - rendered using state updates adjusted for the latency



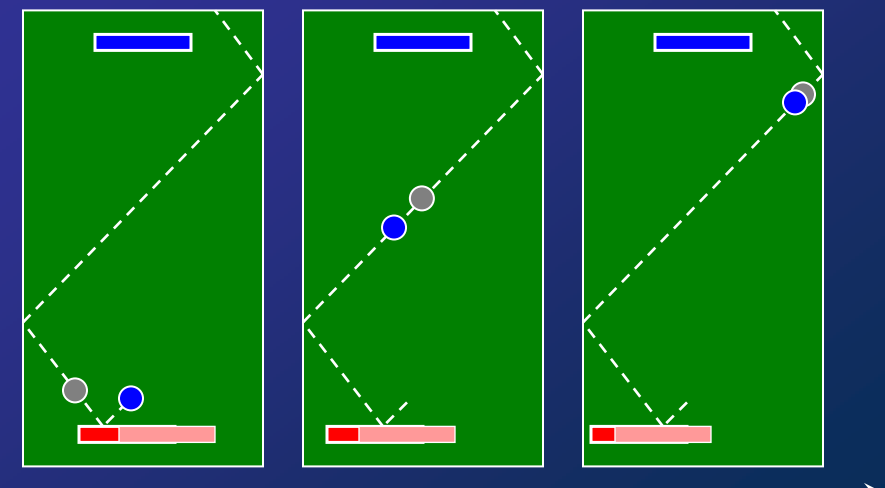
- A passive entity
  - reacts to events from the environment, does not generate its own actions
  - inanimate objects (e.g., rocks, balls, books)
  - active entities interact with passive entities
  - rendered according to the latency of its nearest active entity
  - reacts instantaneously to the actions of a nearby active entity

Example: Pong

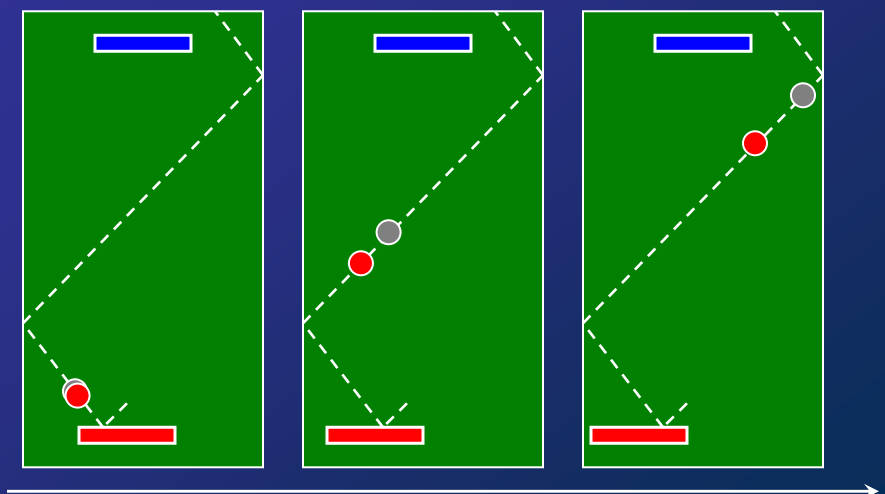


- Two active entities: paddles
  - movement unpredictable
- One passive entity: ball
  - movement predictable
- Latency of *d* seconds

View of the Blue Player



View of the Red Player

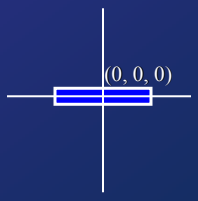


Pong: A Summary

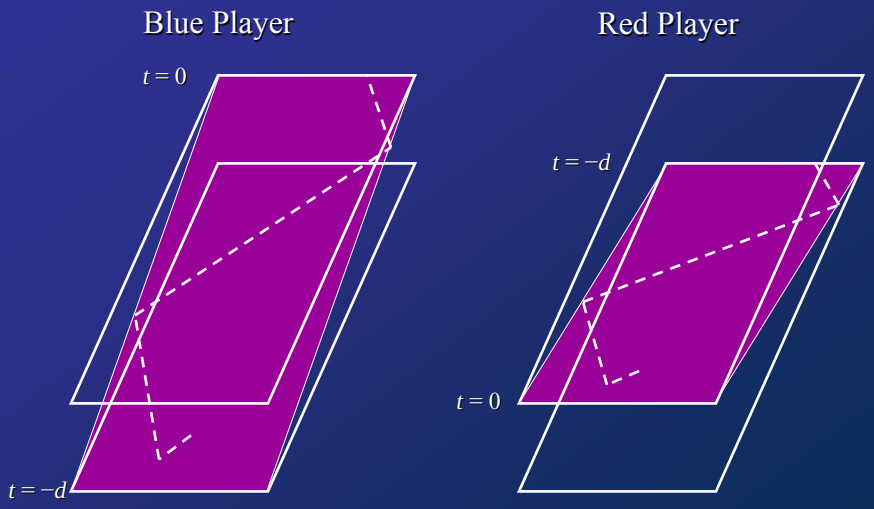
- Each player sees a different representation of the same playing field
- The ball accelerates as it approaches the local player's paddle
- The ball decelerates as it approaches the remote player's paddle
- The ball's rendered position alternates between
  - the current time
    - meaningful interaction for local player
  - a past time reference
    - network latency
    - observing meaningful interaction for remote player

3½-Dimensional Playing Field

- Represent each player's perception as a four-dimensional co-ordinate system (x, y, z, t)
  - x, y, z: the spatial position relative to the local player's current position
    - local player at (0, 0, 0)
  - t: the time associated with rendered information from that position
    - local player rendered at current time: $t = 0$
    - opposing player: $t = -d$

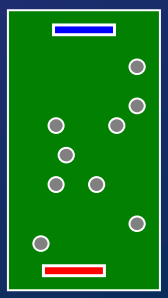


Co-ordinate Systems



Properties of the Co-ordinate System

- The co-ordinate system is defined independently for each player
- Depends on the player's current position and the delay of arriving information
- Changes dynamically as the player moves or as the network properties change
- Defines how a passive object should be rendered
- Two interacting objects are rendered at the same time reference point
- Each user perceives all collisions correctly
- Objects that approach the local user are rendered in the user's time
- Smooth movement

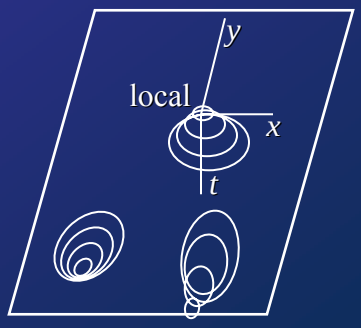


Generalizing the Local Temporal Contour

- Limitations:
  - players are capable of moving along a single axis only
  - supports two active objects only
- Generalization to a 4D co-ordinate system requires preserving for the local user:
  - interacting naturally with passive objects in vicinity
  - seeing remote interactions (passive-to-passive, passive-to-active) naturally
  - perceiving smooth motion of remote objects

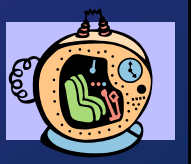
Local Temporal Contour

- The local user at (0, 0, 0)
- Each active object is assigned a *t* value corresponding to its latency
- Interpolate the contour over all active objects including local
- Contour defines a suitable *t* value for each spatial point



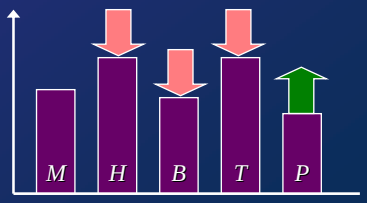
Limitations

- Varying latency can cause entities to (unnaturally) jump forward or backward in time
  - use averaged latency to dampen the effect
- What if an update packet is delayed considerably?
  - predict entity's past position, dead reckoning
- Computational requirements
  - compute the contour using only the nearest active entities

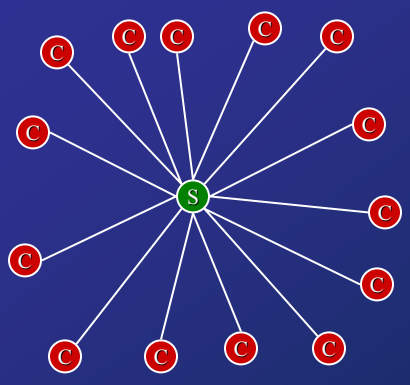


§6.4 Enhancing the System Architecture

- Change the network software architecture
- Basic structures: client-server and peer-to-peer
- Augment and combine basic structures
  - server clusters
    - partition clients across multiple servers
    - partition the NVE across multiple servers
  - server hierarchies
  - peer-server systems



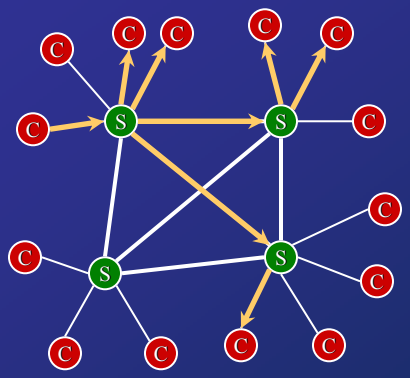
Traditional Client-Server



- Server may act as
  - broadcast reflector
  - filtering reflector
  - packet aggregation server
- Scalability problems
  - all traffic goes through the server

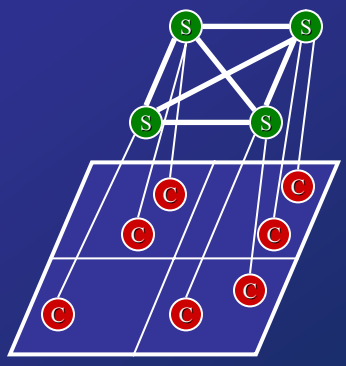
⇒Server clusters

Partitioning Clients across Multiple Servers



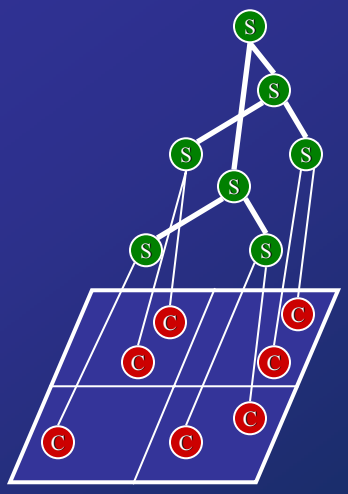
- The servers exchange control messages among themselves
  - inform the interests of their clients
- Reduces the workload on each server
- Incurs a greater latency
- The total processing and bandwidth requirements are greater

Partitioning the NVE across Multiple Servers



- Each server manages clients located within a certain region
- Client communicates with different serves as it moves
- Eliminates a lot of network traffic
- Requires advanced configuration
- Is a region visible from another region?
- Aggregation servers are a special case of NVE server partitioning

Server Hierarchies



- Servers themselves act as clients
- Packet from an upstream server:
  - deliver to the interested downstream clients
- Packet from a downstream client:
  - deliver to the interested downstream clients
  - if other regions are interested in the packet then deliver it to the upstream server