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Groupware and Collaborative Interaction

Distributed Interactive Systems

Technical aspects

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Introduction

- Technical aspects of distributed interactive systems
  - Requirements redundant for all CSCW applications
    - Network architecture
    - Data distribution
    - Concurrency management
- Collaborative virtual environment is a good example
  - Strong requirements
    - Users are interacting in real-time
    - Immersion requires fast multi-sensorial feedbacks
  - Lots of solutions to overcome the technical issues

Collaborative Virtual Environments (CVE)

Enable users to work or have fun together

2 kinds of collaboration in virtual environment (VE)

- Co-located collaboration
- Remote collaboration

Aspects of collaboration

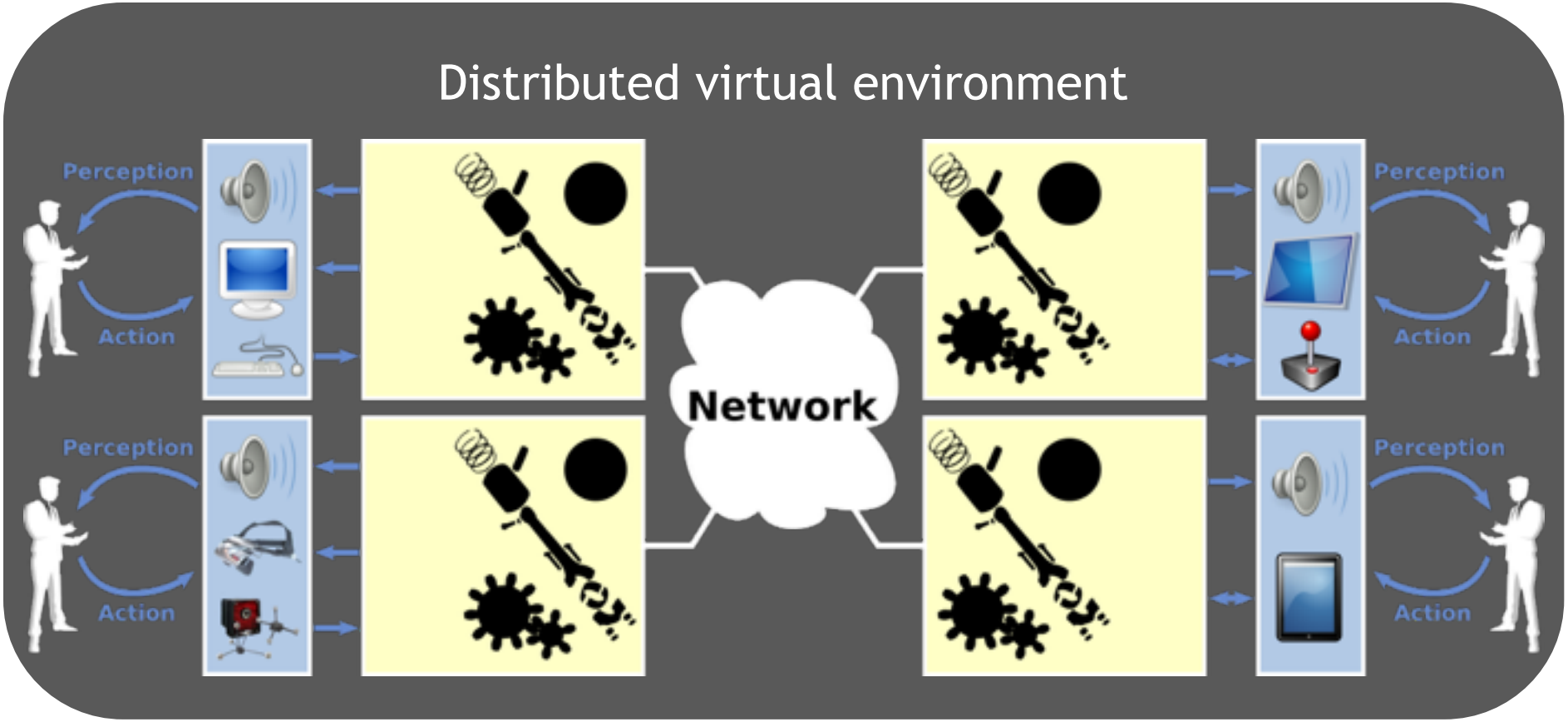
- Awareness
- Communications
- Collaborative interaction

Collaborative Virtual Environments

Users

- Share the same virtual objects
  - 3D objects (with shape, texture, color, position, etc.)
  - 3D widgets (3D objects which can be used for interaction)
  - Annotations
  - Interaction tools (virtual ray of the others, etc.)
- Need to interact together in real-time

Remote Collaboration



Collaboration requirements

For efficient collaboration, users need to:

Have the same state of the virtual environment (virtual objects) at the same time

⇒ Consistency of the VE

Modify the virtual objects in real-time

⇒ Responsiveness of the system (interactivity)

Consistency

[Delaney et al., 2006]

Distributed virtual environment

- Distributed database of virtual objects with users modifying it in real-time

Manage the consistency

- Ensure that the database is the same for all users

Inconsistencies due to:

- Concurrent modifications
- Delay to transmit modification on the network

Responsiveness

[Delaney et al., 2006]

Responsiveness of the system

- Time required to respond to users' actions (latency during users' interaction, jitter)

Due to the time required to:

- Process and send users' actions
- Transmit actions on the network (if mandatory)
- Give a feedback to the users

Between 40ms and 300ms, under 100ms is good

Distributed Virtual Environments

Find a good trade-off between consistency and responsiveness (task, application, etc.)

Technical requirements

- Connect remote computers
- Distribute data
- Share information
- Manage concurrent accesses to the data

=> Each technical choice must consider both consistency and responsiveness

Outline

Network Architecture

Data Distribution

Communication Protocols

Consistency Management Mechanisms

Communication Reduction Mechanisms

Software architecture

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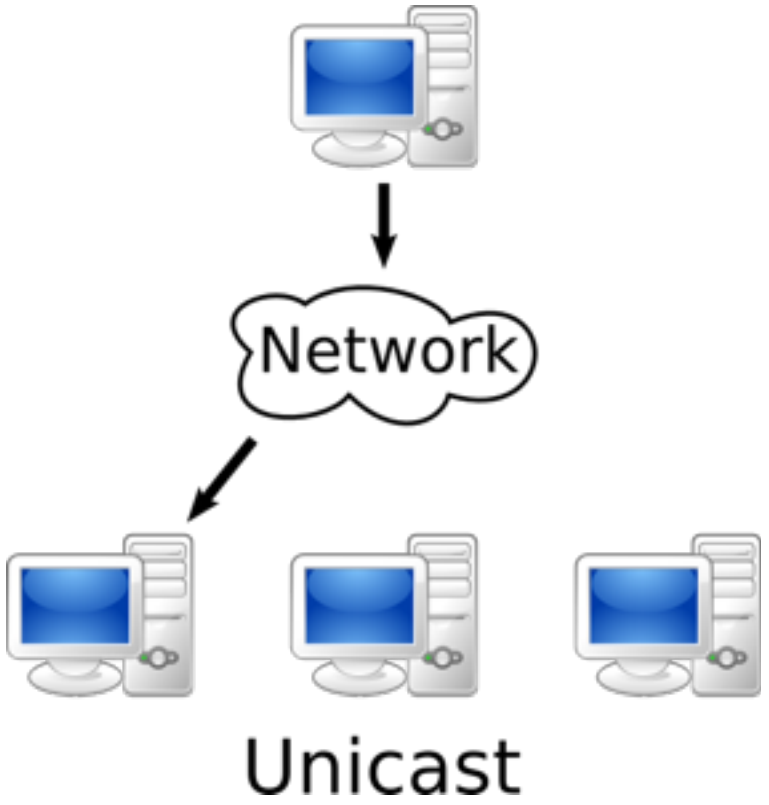
Network Architecture

Transmission Methods

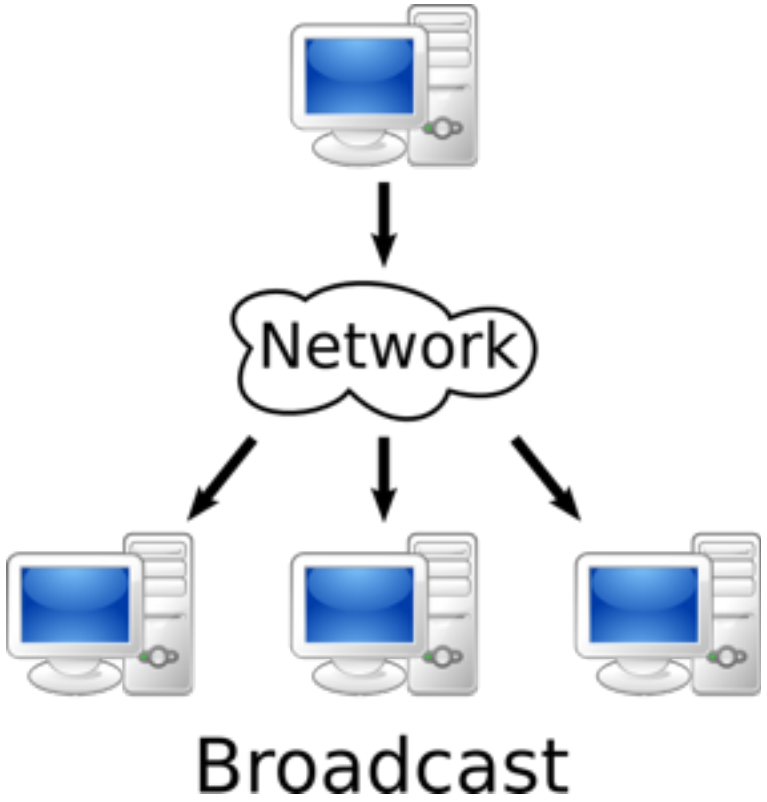
Unicast



Network Architecture

Transmission Methods

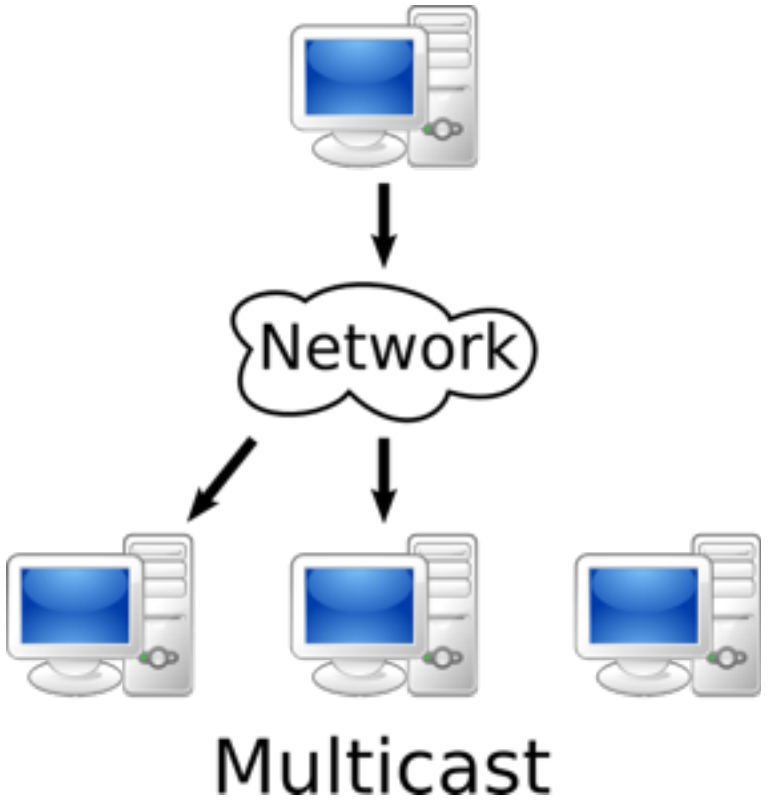
- Unicast
- Broadcast



Network Architecture

Transmission Methods

- Unicast
- Broadcast
- Multicast



Network Architecture

Peer-to-peer architecture

[Reality Build for Two 90, MR Toolkit 93, SIMNET 93, NPSNET 94]

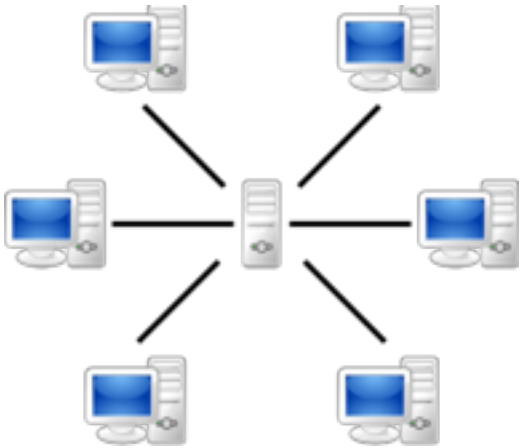
Fast communications between pairs of nodes

- Closely coupled interactions between a few users

Difficulties to contact all nodes at the same time

- Consistency and synchronization are hard to ensure
- Many messages are transmitted over the network

Network Architecture

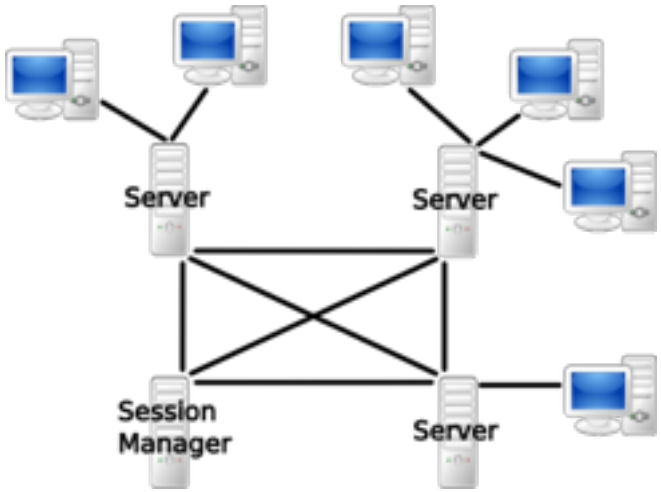


Client/server architecture
[Vistel 95, RING 95, BrickNet 95, ShareX3D 08]

- All communications pass through the server
  - latency during interactions
- All nodes can be contacted quickly
  - Consistency and synchronization are easy to ensure
- A “bottleneck” can occur on the server

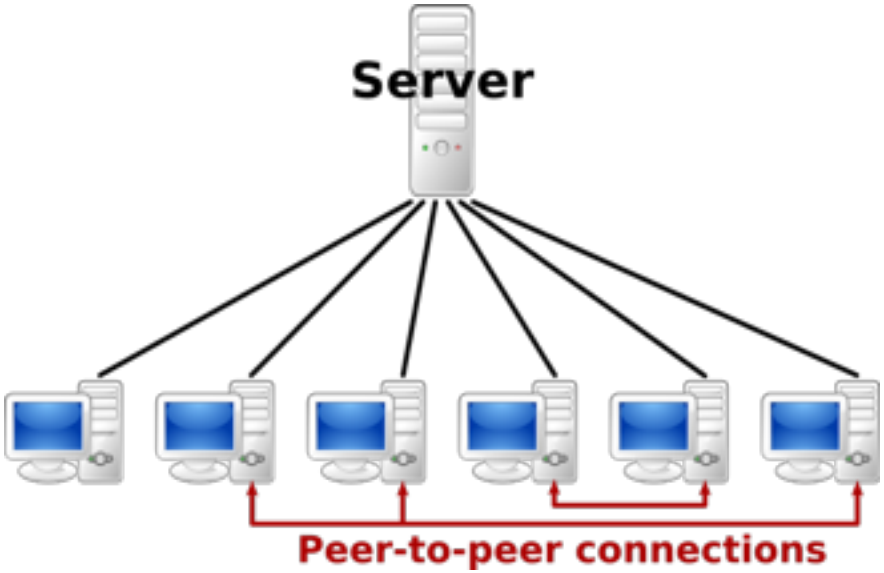
Network Architecture

- Hybrid architecture
  - Servers connected with peer-to-peer connections [SPLINE 97]
    - Avoids the “bottleneck” on a single server
    - Connects nodes with specific requirements
    - Increases system latency



Network Architecture

- Hybrid architecture
  - Temporary peer-to-peer connections [Anthes et al., 04]
    - Are established according to users' locations in the VE
    - Increase CVE consistency between nearby users



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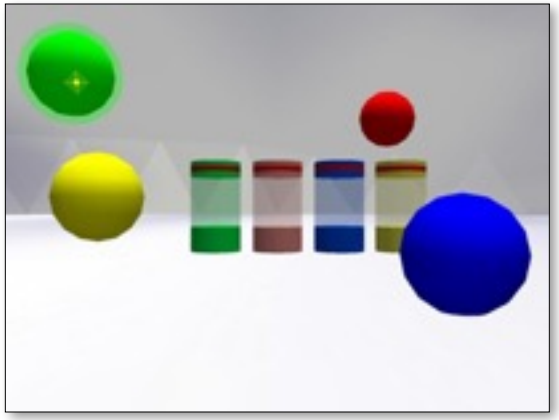
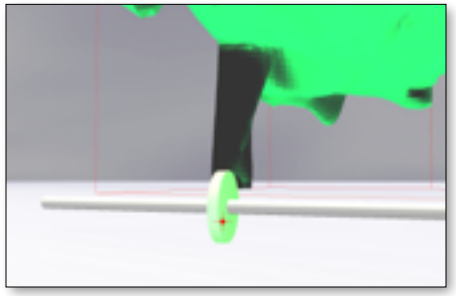
Data Distribution

A virtual object

- A set of parameters (data)
  - Identifier
  - Attributes (position, orientation, etc.)
  - User access rights
  - Geometry, and eventually textures
- A behavior
  - Only reactive (responding to user actions)
  - Continuous (evolving in the time)





⇒ Which computers store its data ?

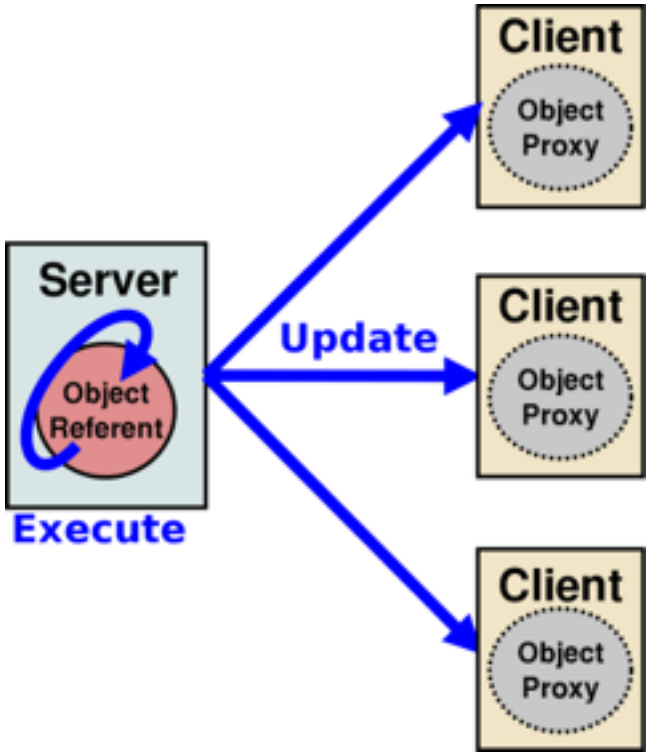
⇒ Which computers execute its behavior ?

Data Distribution

Centralized [Vistel 95]

Data is stored on the server

Behaviors are executed on the server



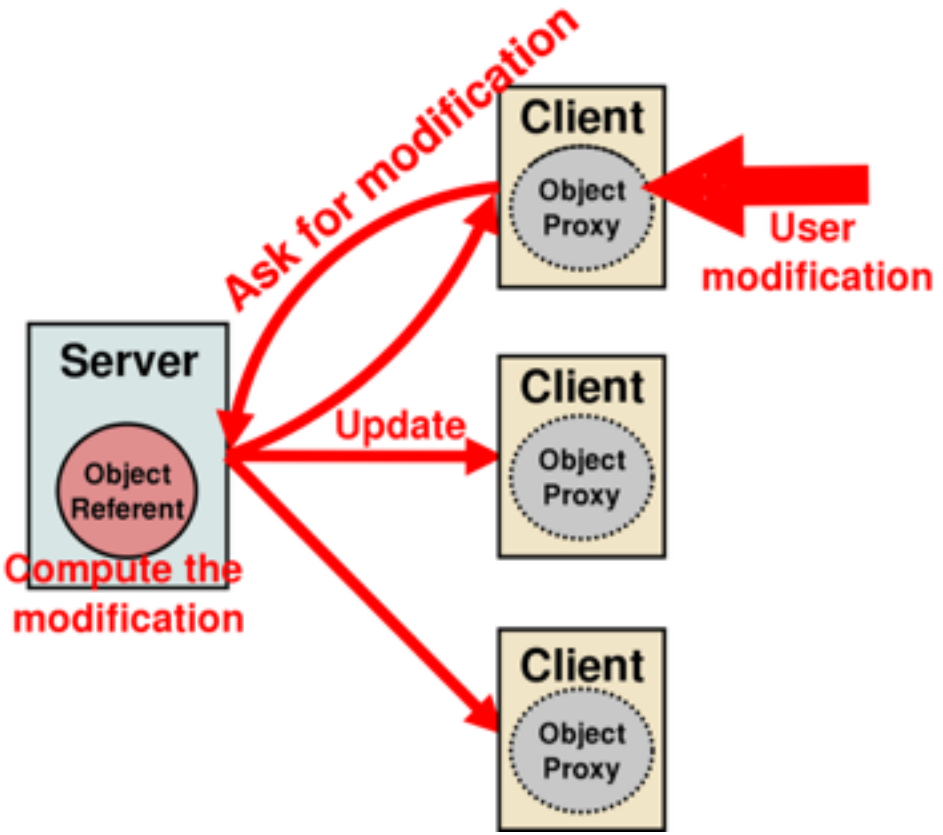
Data Distribution

Centralized [Vistel 95]

Data is stored on the server

Behaviors are executed on the server

Modification requests are processed on the server



Data Distribution

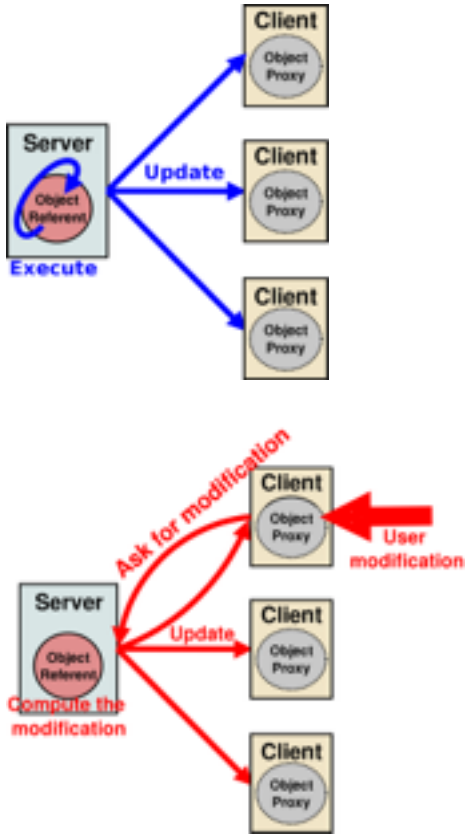
Centralized [Vistel 95]

Advantages

- Ensures a global consistency
- Avoids data replication
- Avoids behaviors processing on the clients

Drawbacks

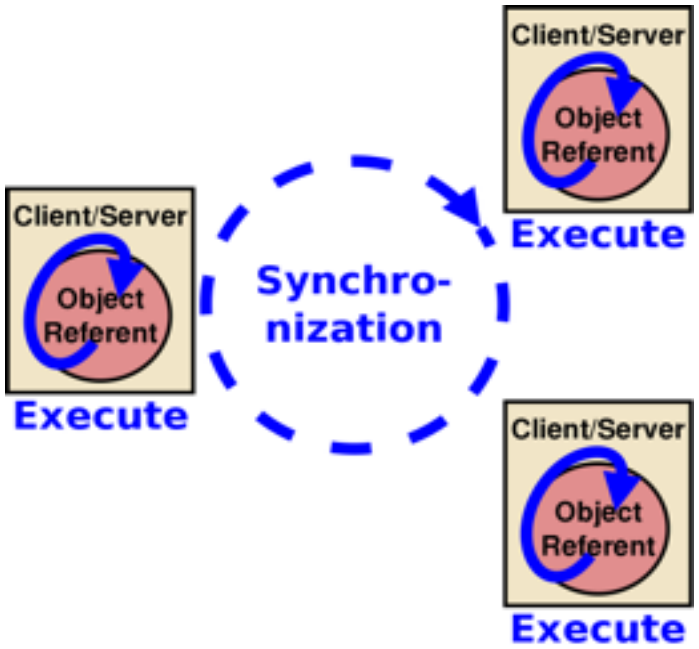
- Introduces latency during interactions
- Transmits many messages over the network



Data Distribution

Replicated [SIMNET 93, MR Toolkit 93]

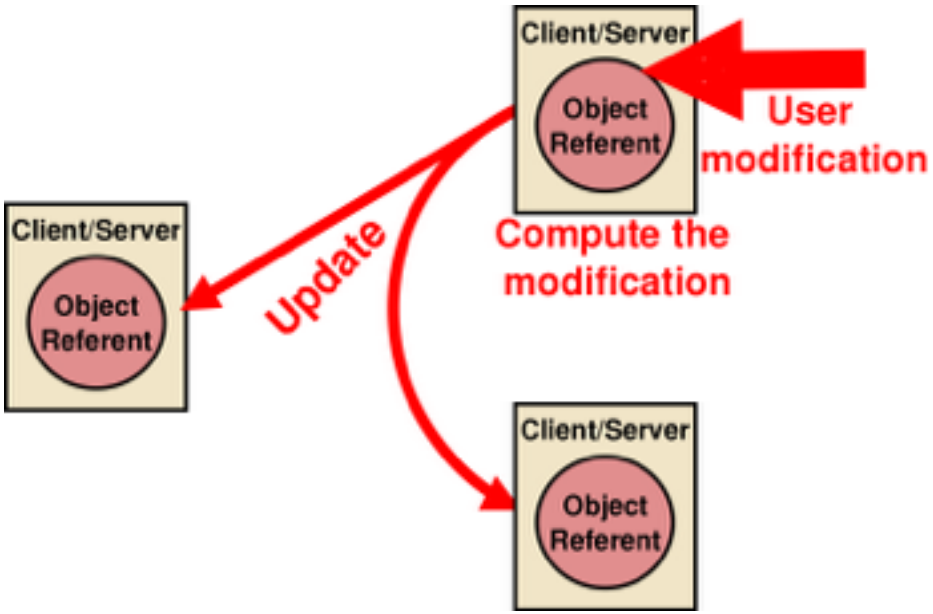
- Data is replicated on each node
- Synchronization between nodes can be achieved
- Behaviors are executed on each node



Data Distribution

Replicated [SIMNET 93, MR Toolkit 93]

- Data is replicated on each node
- Synchronization between nodes can be achieved
- Behaviors are executed on each node
- Modification requests are processed locally



Data Distribution

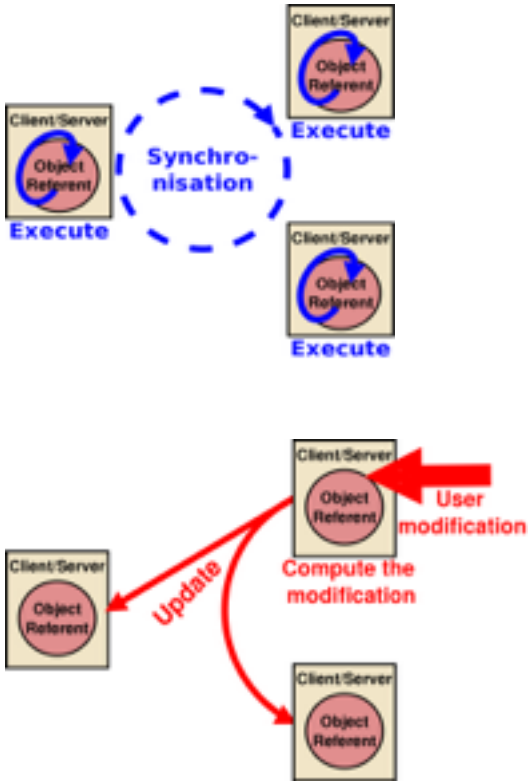
Replicated [SIMNET 93, MR Toolkit 93]

Advantages

- Low-latency interactions
- Few messages transmitted

Drawbacks

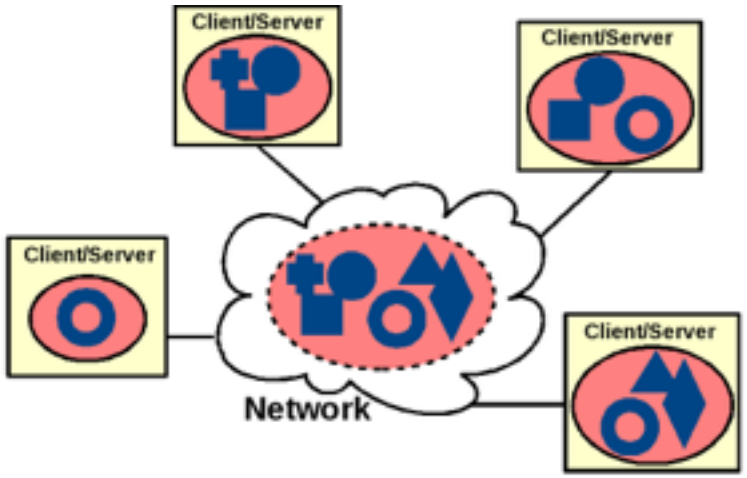
- Data replication
- Behaviors processed on each node
- Inconsistencies due to transmission delay of update messages
- Additional mechanisms for managing concurrent accesses



Data Distribution

Hybrid [DIVE 98] [BrickNet 98]

- Only the necessary objects are replicated
- A server saves the whole VE state
- Advantages
  - Reduction of data replication
  - Less processing on each node
- Drawbacks
  - Difficulties to ensure consistency and manage concurrency
  - Many messages transmitted over the network
  - Dynamic downloads of additional objects



Data Distribution

Hybrid: Referent/proxy paradigm

[OpenMASK 02][Schmalstieg et al 03][Fleury et al 10]

On a node each virtual object is represented by

- A referent
  - Stores data
  - Defines behavior
  - Processes modification requests

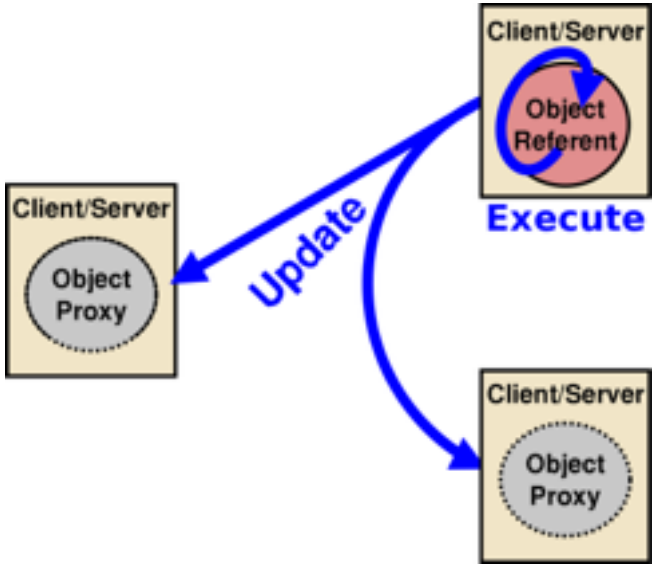
or

- A proxy
  - Receives updates from referents
  - Updates object representation in the CVE
  - Can store copy of the data (for easy migration)

Data Distribution

Hybrid: Referent/proxy paradigm
[OpenMASK 02][Schmalstieg et al 03][Fleury et al 10]

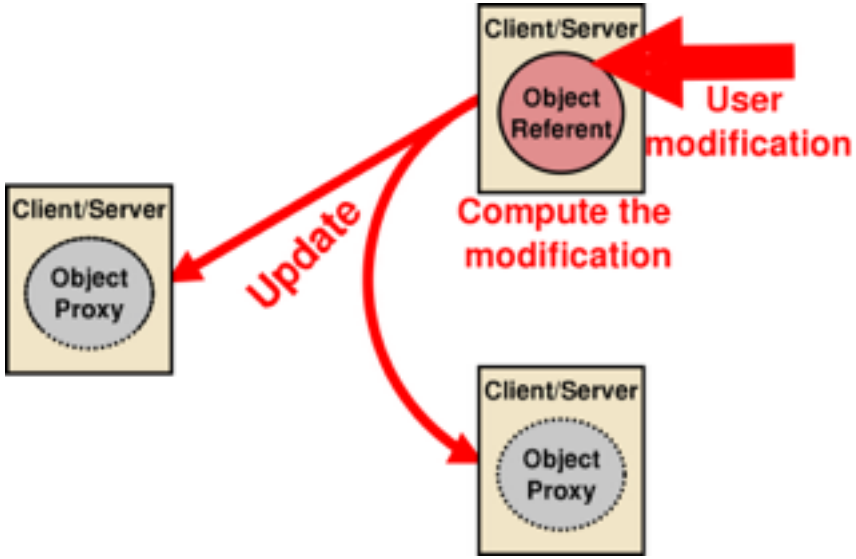
Behaviors are executed only on one node



Data Distribution

Hybrid: Referent/proxy paradigm
[OpenMASK 02][Schmalstieg et al 03][Fleury et al 10]

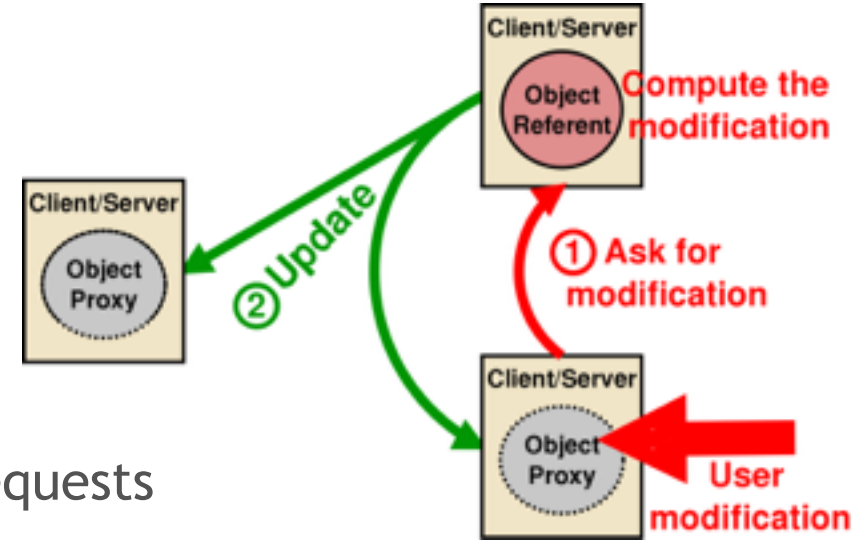
- Behaviors are executed only on one node
- Referent modification
  - Modification requests are processed locally



Data Distribution

Hybrid: Referent/proxy paradigm
[OpenMASK 02][Schmalstieg et al 03][Fleury et al 10]

- Behaviors are executed only on one node
- Referent modification
  - Modification requests are processed locally
- Proxy modification
  - Modification requests are transmitted to the referent
  - The referent processes the requests



Data Distribution

Hybrid: Referent/proxy paradigm

[OpenMASK 02][Schmalstieg et al 03][Fleury et al 10]

Advantages

- Ensures global consistency
- Implicitly manages the concurrent access
- Combines the processing power of nodes
- Reduces latency when users interact with the referent

Drawbacks

- Transmits many messages over the network
- Increases latency when users interact with a proxy (but migration mechanisms can be used)

Synthesis

Existing data distribution solutions [Fleury et al 10]

- Make a trade-off between consistency and responsiveness
- Meet particular requirements

Combine the advantages of each solution

- Dynamically adapt data distribution of each object
  - Application requirements, network capabilities
  - Tasks performed by users
  - Functions that objects fulfill in the VE

An adaptive data distribution

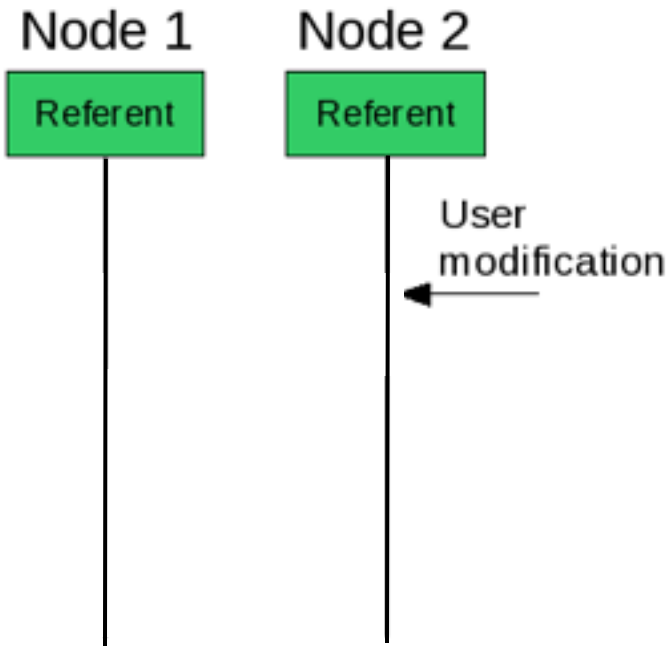
[Fleury et al., 2010]

- Based on a referent/proxy paradigm
  - Three modes of data distribution
    - Centralized
    - Replicated
    - Hybrid
  - Chosen independently for each object
  - Changed dynamically during a working session

3 Modes of Distribution

Replicated Mode

- Referents on all nodes
- Interaction latency (IL)
- Gap in consistency (GC)



⇒ Advantage: good responsiveness

3 Modes of Distribution

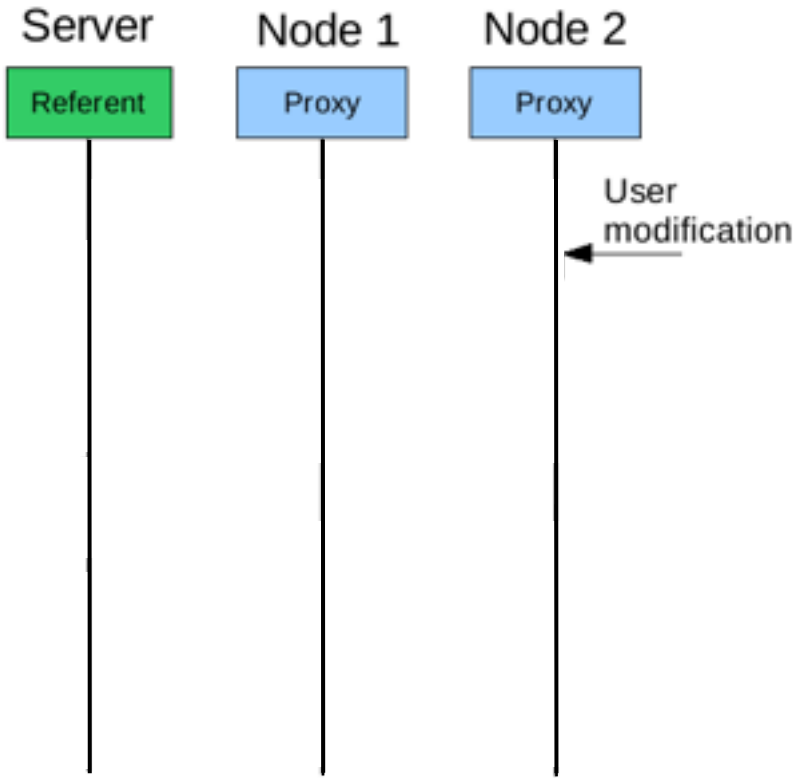
Centralized Mode

1 referent on the server

Proxies on other nodes

Interaction latency (IL)

Gap in consistency (GC)

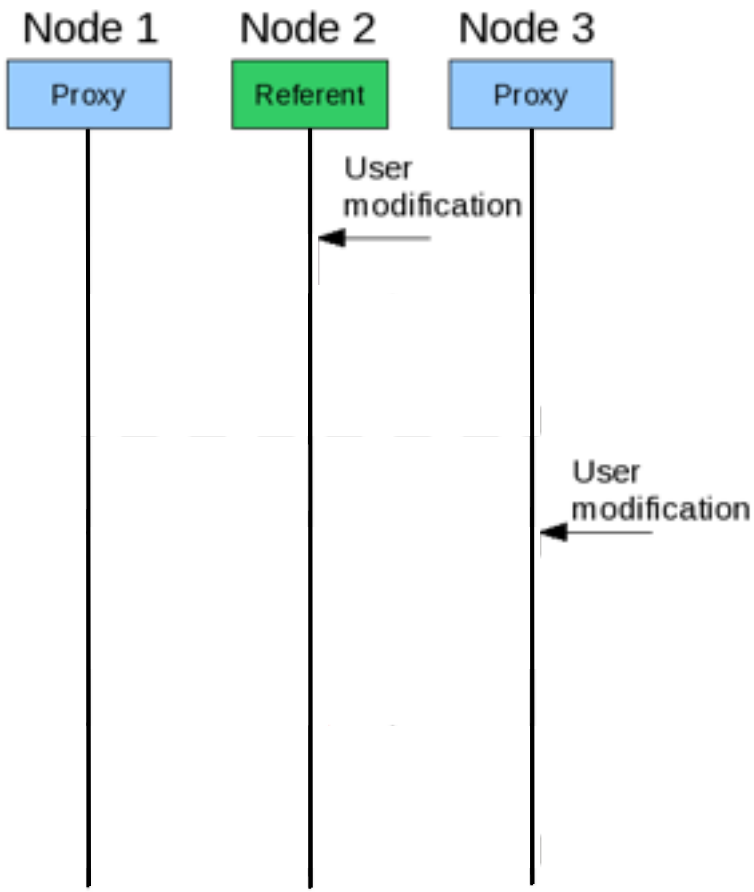


⇒ Advantage: strong consistency

3 Modes of Distribution

Hybrid Mode

- 1 referent on a node
- Proxies on the other nodes
- Interaction latency (IL)



- Gap in consistency

⇒ Advantage: good tradeoff between responsiveness and consistency

Choice at object level

- Motivations:
  - Different consistency/responsiveness requirements for each virtual object
    - Function fulfilled by objects
    - Precision requires to manipulate objects
- Solution:
  - Choose the distribution mode at the object level
    - Each node can independently have
      - Referents for some objects
      - Proxies for some others
    - Each object can have a particular data distribution

Dynamical Modification

Motivations:

- Adapt data distribution during a working session
  - Tasks that users perform in the VE
  - Network troubles

Solution:

- Dynamically change the distribution mode
  - Dynamically migrate the referent
    - Move the referent from one node to another (hybrid mode)
    - Put the referent on the server (centralized mode)
    - Duplicate the referent on all nodes (replicated mode)

Outline

Network Architecture

Data Distribution

Communication Protocols

Consistency Management Mechanisms

Communication Reduction Mechanisms

Software architecture

Communication Protocols

Classical protocols (TCP, UDP)

Multicast oriented protocols

- Difficult to achieve over large network
- Use additional network layers
  - "MBone" [DIVE 94, NPSNET 98]

Virtual Reality dedicated protocols

- [RTP\I 99]: adapt RTP for interaction
- [VRTP 97]: support VRML (virtual reality modeling language)
- Some others [DWTP 98, DIS 93, HLA 97, ISTP 97]

Communication Protocols

Specific protocols in industrial environment

- Deal with:
  - Standard Internet access
  - Firewalls that support only HTTP and HTTPS protocols
- Use “long polling” technique [ShareX3D 08]

More generic standards start to be used

- VRPN (Virtual-Reality Peripheral Network)
- OSC (Open Sound Control)
- Html5 (WebGL based on OpenGL ES 2.0)

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Consistency Management Mechanisms

Inconsistencies due to

- Network delay
- Concurrent modifications

2 kind of techniques

- Synchronization
- Concurrency control

Synchronization

Ensure that each user have the same state of the virtual environment at the same

Time is a fundamental element of CVE

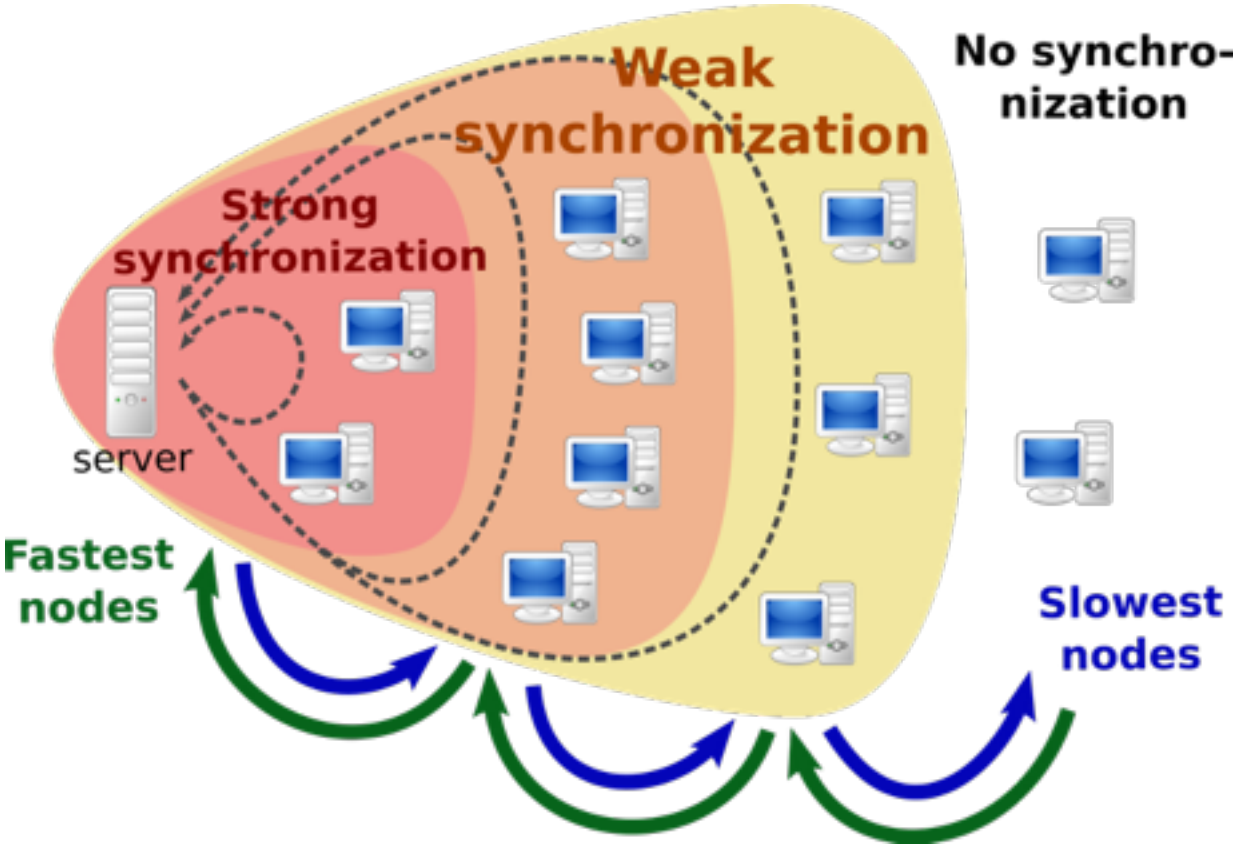
- Absolute time: synchronized clock (UTC)
- Logical or virtual time: logical clock
  - Ordered sequence of events
  - Use timestamp

Synchronization

- Lockstep synchronization [Ring 95, OpenMASK 02]
  - Waits all nodes before computes the next simulation step
    - Each node send acknowledgements to the system
    - Then, the system allows nodes to process the next step
  - Advantages
    - Perfect synchronization
    - Events are processed in the correct order
  - Drawbacks
    - Real-time is not guaranteed
    - One node can slow down all the others

Synchronization

Lockstep synchronization for several groups [Fleury et al 13]



Synchronization

Imposed global consistency [Delaney et al 06]

- Delays the processing of local and remote events
  - Use a pre-defined value (max. of the network latency)
  - Use an absolute clock
- Advantage
  - Strong synchronization
- Drawback
  - Introduce latency during interactions

Synchronization

Delayed global consistency [Delaney et al 06]

- Mark events with a timestamp using a logical clock
  - Execute events following the correct timestamp order
- Advantage
  - Causality is ensured
- Drawback
  - No time synchronization

Synchronization

Server synchronization [ShareX3D 08]

- Server manages a “state number” for each object
  - Increments the “state number” for each modification
- Server sends the last received update to nodes if they are not up-to-date
- Advantages
  - Ensures that nodes are up-to-date
  - Reduce the number of sent messages
- Drawback
  - No causality and no time synchronization

Synchronization

Time warp synchronization [Jefferson 85]

- Events are marked with a timestamp
- Events are processed as soon as they arrive
- “Rollbacks” are used to solve causality errors
  - Incoming event older than the event already processed
- Advantage
  - No Latency during interactions
- Drawback
  - “Rollbacks” are very annoying for the users (feedbacks)
  - “Rollback propagation”

Synchronization

Predictive Time Management [PARADE 97]

- Events are predicted before they occur and send on the network
- Events are sent just in time to avoid bad prediction by estimating the latency (RTT)
- Advantage
  - Good synchronization
- Drawback
  - Only for predictable objects (object behaviors, collision detection, etc.)

Concurrency control

Centralized mode or hybrid mode (with 1 referent)

- Server/referent can handle concurrent modification requests

Replicated mode or hybrid mode (with several referents)

- Virtual objects can be modified locally on several node at the same time
- Concurrency control is required

Concurrency Control

3 main modes of concurrency control

- Pessimistic mode [BrickNet 98]
  - Only one user can modify an object at the same time
- Optimistic mode [Delaney et al 06]
  - No concurrency control during interactions
  - A correction is necessary when conflicts occur
- Prediction based mode [PARADE 97, ATLAS 07]
  - Predict which users will probably modify an object
  - Give priority to the users according to the prediction

Users' Access Rights

Give different access rights to users

- Protect virtual objects (confidential data, no modifiable objects, etc.)
- Assign some role to users

3 criteria

- Right to see an object
- Right to modify its parameters
- Right to create/delete objects

Use a scale of access level from 0 to N
(0 is the most restrictive)

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Communication Reduction Mechanisms

Avoid to overload the network

- Big number of users
- Low bandwidth network

Reduce the number of messages transmitted on the network without:

- Reducing the consistency
- Increasing the latency during interactions

Dead-Reckoning

[SIMNET 93][NPSNET 94]

Based on a prediction method

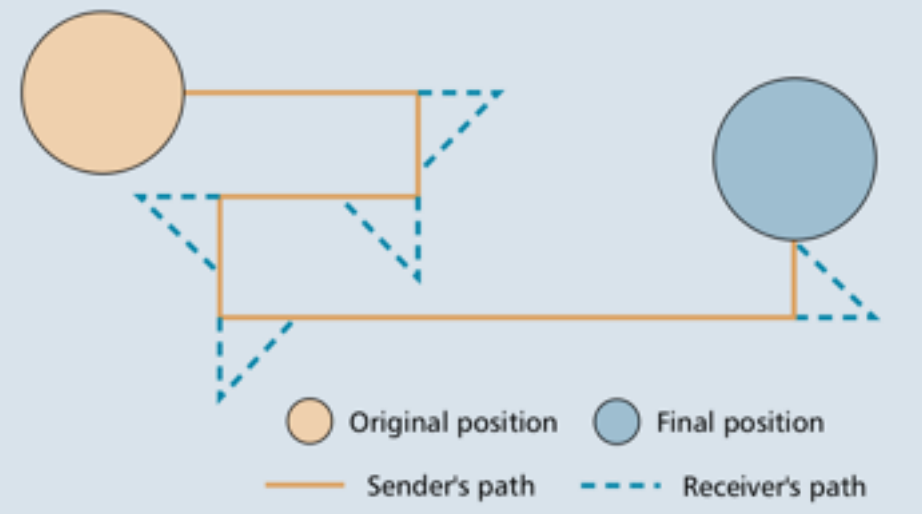
- Prediction formula
- Error threshold
- Convergence formula

The node in charge of the object compute

- The object behavior
- The prediction formula
- This node does not send any update message

Dead-Reckoning

[SIMNET 93][NPSNET 94]



When the error threshold is reached

- Bad prediction
- Action of the user

The node send an update message

The correct state of the object is recovered using the convergence formula

Message filtering

Send only the updates to the concerned users

- Avoid overloading the network
- Reduce the processing time of the messages

Reduce the nb of shared objects between users

Filter according the area of interest of users

- Objects close to a user [Waters et al., 1997]
- Objects in the field of view of a user [Funkhouser, 1995]

Technical aspects: server and multicast

Migration

[Duval et Zammar, 2006]

Referent/proxy paradigm

- Move the referent to a node to another

Goals:

- Balance the processing load
- Move the referent on the node of the user who interacts

Technical aspects:

- Upload object data on the new referent node
- Delete object data on the old referent node

Compression & Aggregation

- Compression
  - Not relevant for position/orientation [Joslin et al., 2004]
  - But when data start to be complicated
    - Joints of a virtual avatar, physical simulation data
  - Migration
  - Load new virtual objects (geometry, level of details)
- Aggregation
  - Send all the object updates in one message
  - Can introduce delay in message transmission

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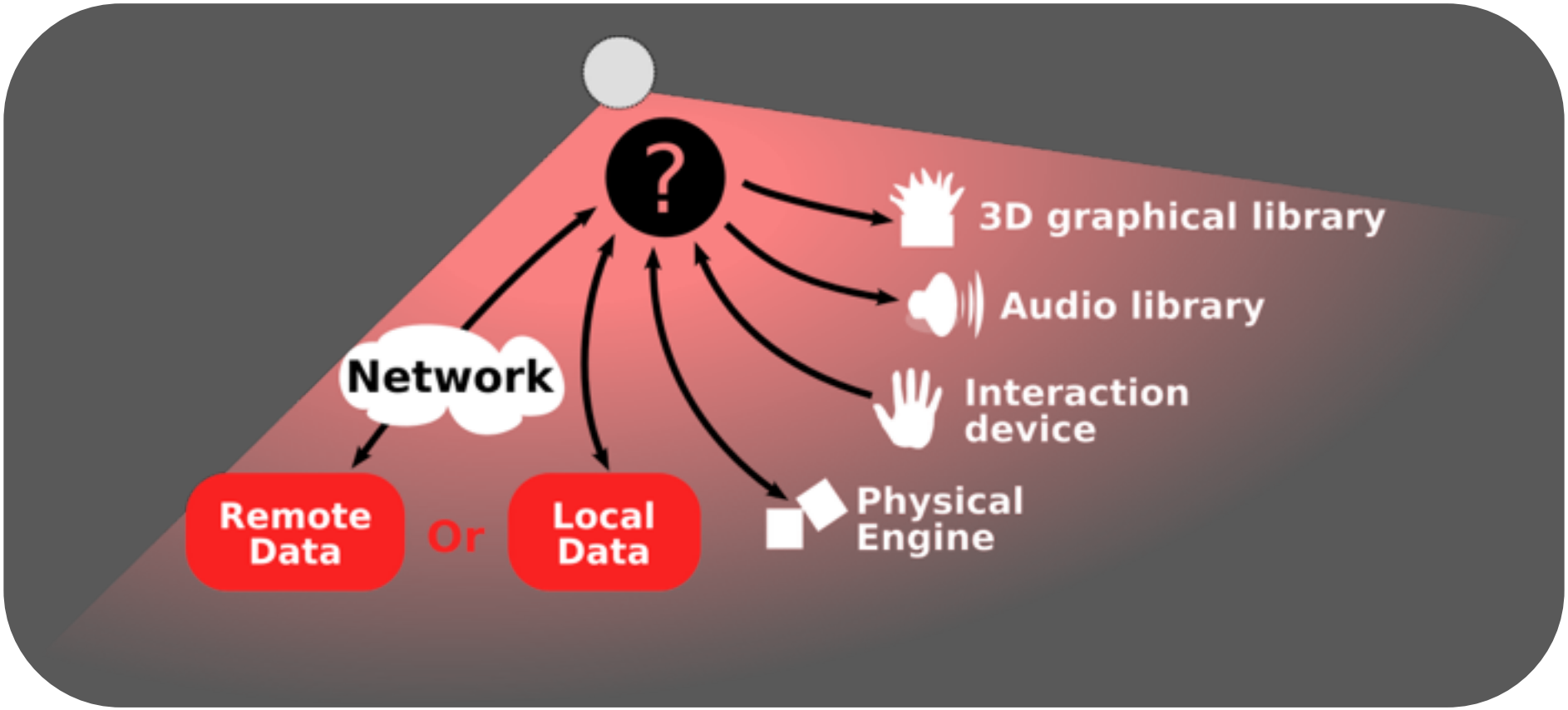


⇒ How to design virtual objects in order to insure a good separation between data distribution and multiple representations?

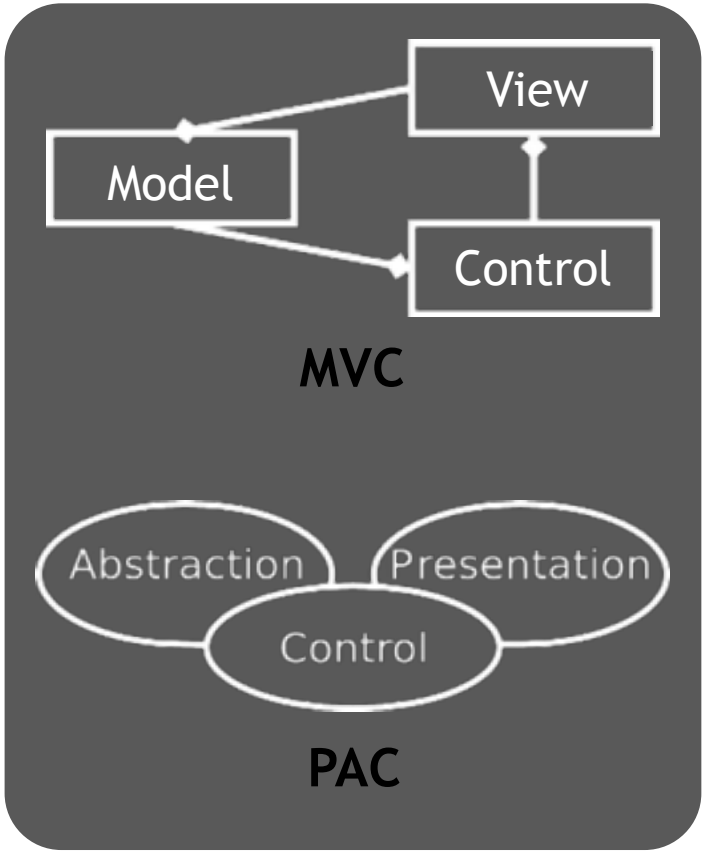
Models for Interactive System

- Application can be decomposed in 3 parts
  - Core component
    - Store data
    - Execute behavior
    - Process users' modification requests
  - Interface component
    - Make the link with the users
      - Display the object
      - Register the action of the users
  - A link between the Two components

Models for Interactive System

Existing models

- Functional decomposition
  - Arch [UIMS 92]
- Multi-agents
  - MVC [Reenshaug 79][Eckstein 07]
  - PAC [Coutaz 87][Duval et Tarby 06]
- Hybrid [Nigay et Coutaz 91]



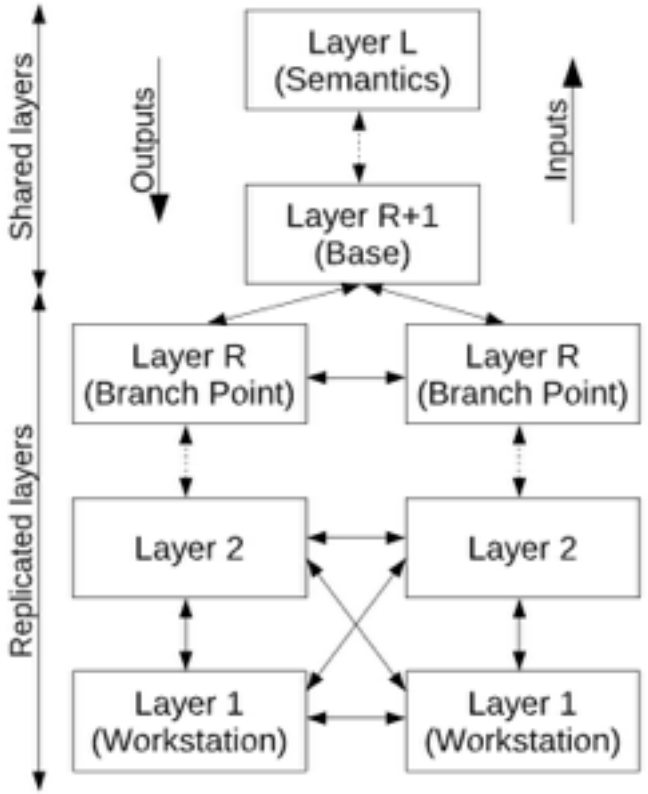
Models for Collaborative System

Distributed data on remote computer

Manage communications

Existing models

- Abstraction layers [Dewan 99]
- Multi-agents
  - ALV [Hill 92]: shared abstraction
  - CoPAC [Salber 95]: Additional communication component
- Functional description of collaboration [Calvary et al. 97][Laurillau et Nigay 02]



Dewan

Synthesis

Multi-agents models are well adapted for VE

- A virtual object = an agent
- Particular data distribution for each virtual object

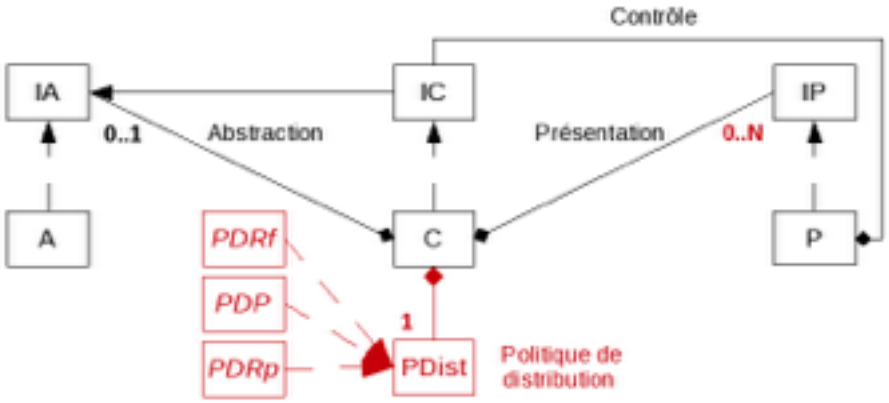
However existing models for collaborative system do not fit these requirements

- ALV proposes only a centralized data distribution
- CoPAC does not specify the data distribution

⇒ Extend PAC model for the CVE

PAC-C3D Model

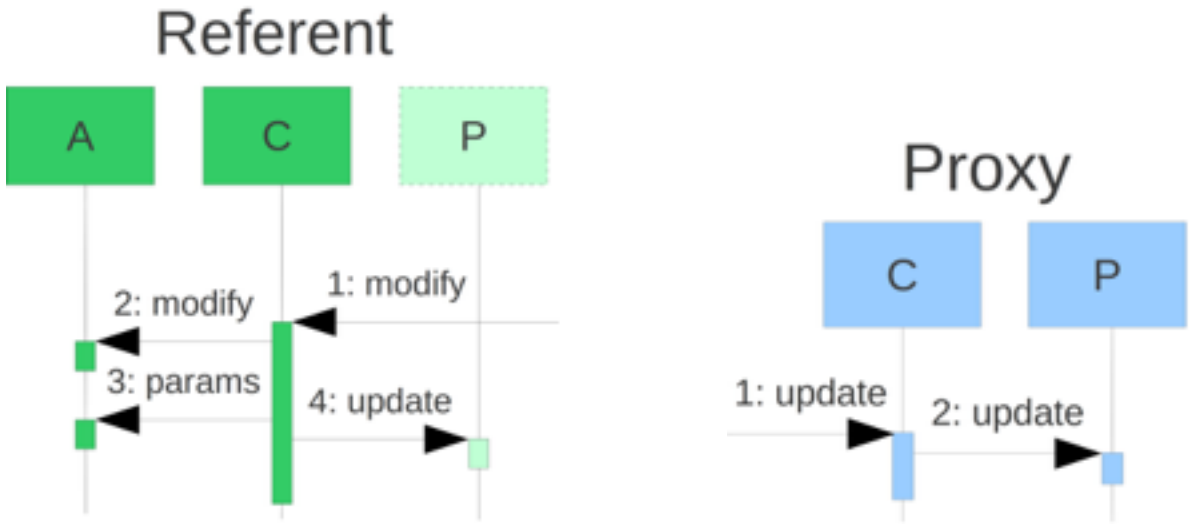
[Duval et Fleury, 2011]



Extend the PAC model to the CVE

- Each virtual object is modeled by a PAC agent on each node
- The Control manages the network distribution
  - Maintains the consistency between all the nodes
    - Several distribution policy (one for each data distribution mode)
  - Provides generalized interface to access to the object
- Multiple Presentations of a same virtual object

Data Distribution



Easy implementation of referent/proxy paradigm

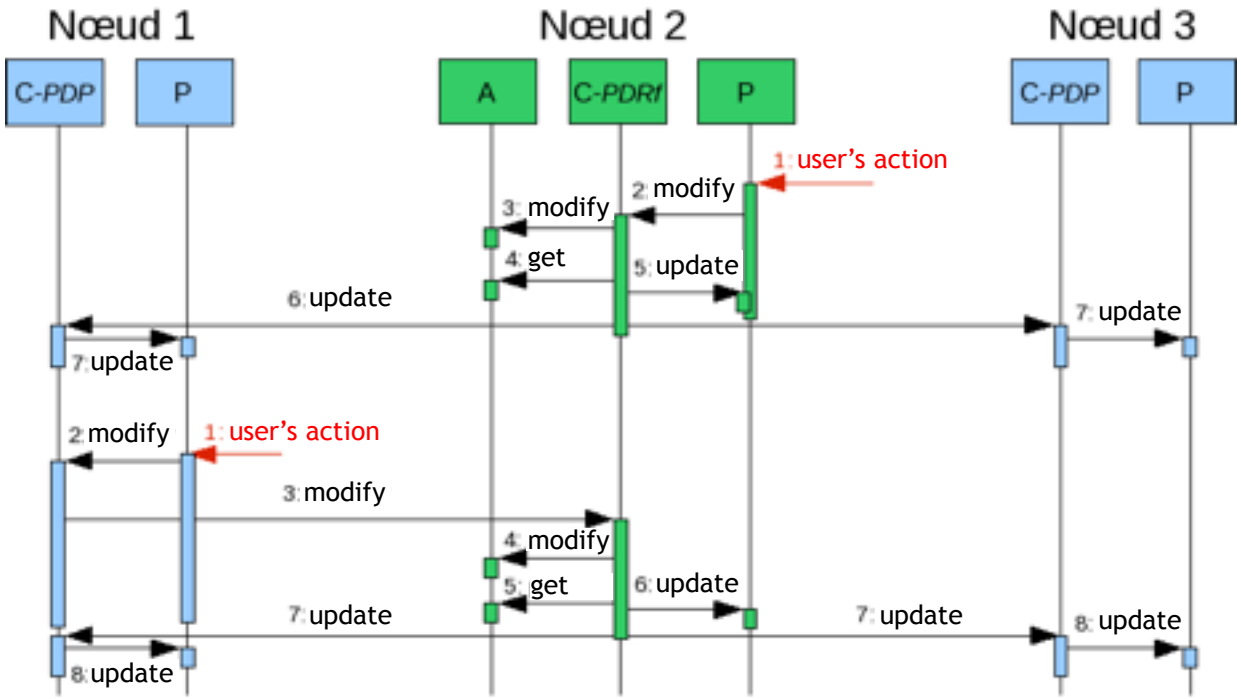
Interoperability between virtual objects

(even if they don’t use the same data distribution mode)

All accesses to objects are managed by the Control

Dynamic migration of the referent

Example for the hybrid mode



All modification requests are sent to the Control

The Control:

- Chooses where the requests should be processed
- Manages updates of the remote versions of the objects

Advantages for data distribution

« Interoperability » between objects using different data distribution modes on the network

- All the accesses go through the Control

Easy migration of the referent

- Change the distribution policy of the Controls
- Create an updated Abstraction for the new referent
- Delete the Abstraction of the old referent

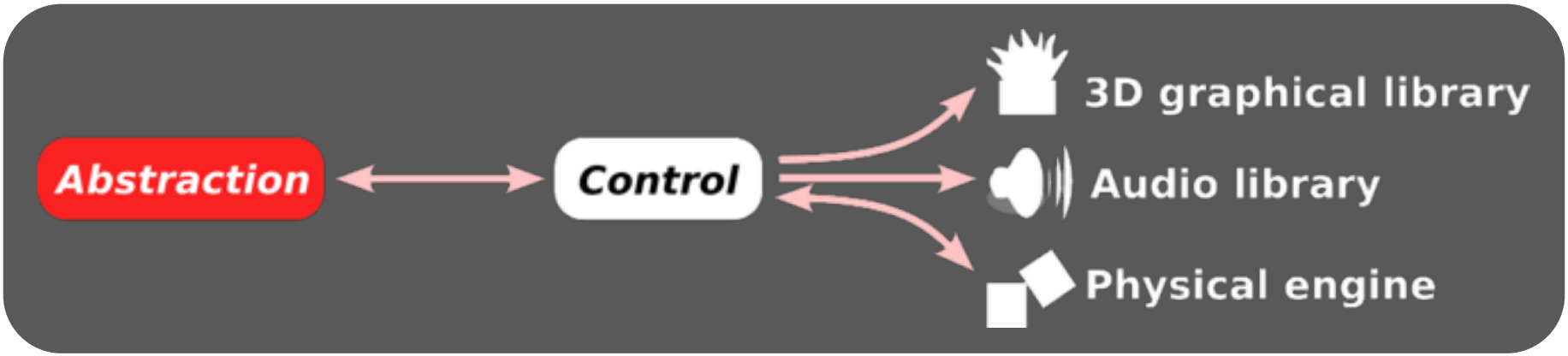
Developer do not have to deal data distribution

- They just have to heritage from basically components

Multiple representations

Several Presentations of an object on the same node

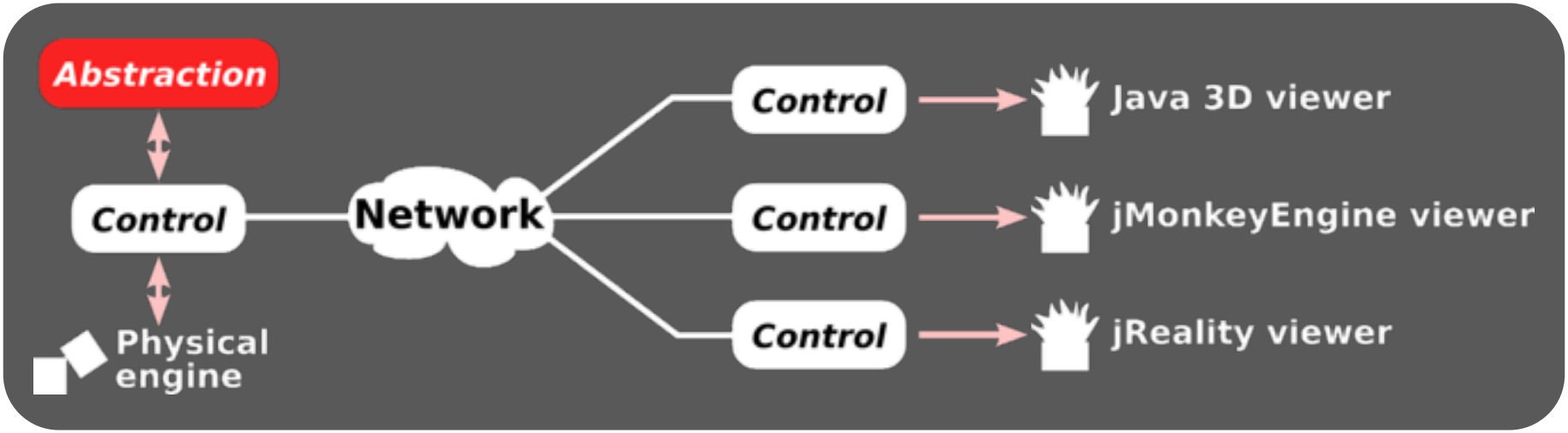
- Multi-sensorial representation of the object
- Add of some “active” Presentations
  - Ex: physical instance of objects in a physical engine



Multiple representations

Several Presentations of an object on different nodes

- No duplication of data and behavior processing in each software libraries
- Interoperability between several software libraries



Conclusion

Common issues of CSCW applications

- Trade-off between consistency and responsiveness
  - Network architecture and data distribution
  - Consistency management mechanisms

⇒ No solution which fits all application requirements, so an adaptive solution might be a good solution

- Software architecture has to deal with
  - Data distribution over the network
  - Various software libraries and materiel devices

⇒ Make a clear separation between core application part, data distribution part, interface with the users