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
    - Etc.
- Collaborative virtual environment is a good example
  - Strong requirements
    - Users are interacting in real-time
    - Immersion requires fast multi-sensorial feedbacks
  - Lots of solutions have been proposed to overcome the technical issues

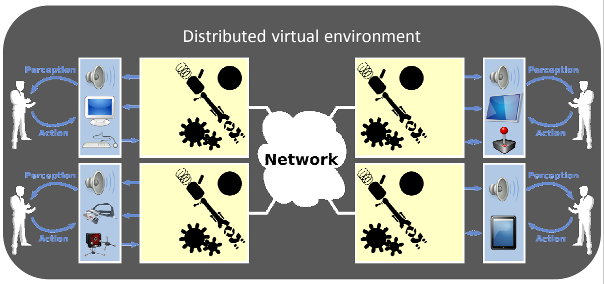
Collaborative Virtual Environments (CVE)

- 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 consistency and responsiveness

Outline

- Network Architecture
- Data Distribution
- Communication Protocols
- Consistency Management Mechanisms
- Communication Reduction Mechanisms
- Software architecture

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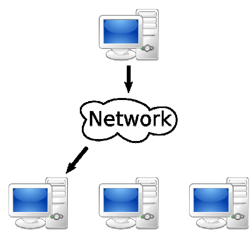
Network Architecture

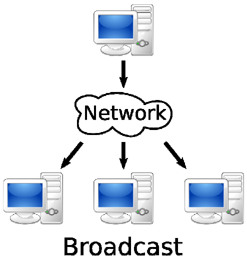
- Transmission Methods
  - Unicast



Unicast

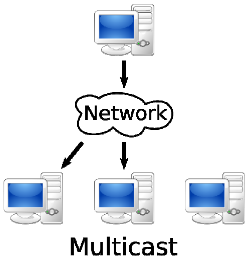
Network Architecture

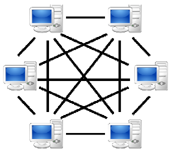
- Transmission Methods
  - Unicast
  - Broadcast



Network Architecture

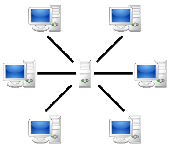
- Transmission Methods
  - Unicast
  - Broadcast
  - Multicast





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

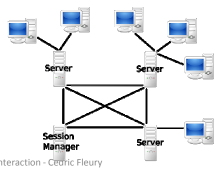


Network Architecture

- 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

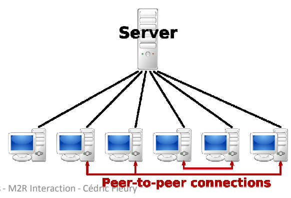
Network Architecture

- 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

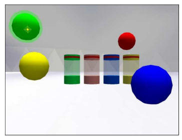


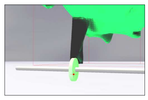
Outline

- Network Architecture
- **Data Distribution**
- Communication Protocols
- Consistency Management Mechanisms
- Communication Reduction Mechanisms
- Software architecture

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)

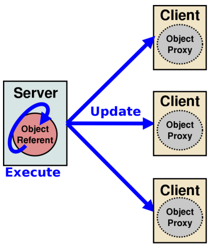




⇒ Which computers store its data ?
⇒ Which computers execute its behavior ?

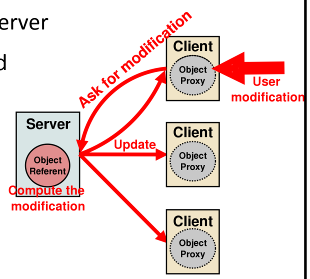
Data Distribution

- Centralized [Vistel 95]
  - Data is stored on the server
  - Behaviors are executed on the server



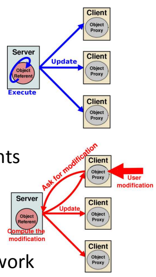
Data Distribution

- Centralized [Vistel 95]
  - Data is stored on the server
  - Behaviors are executed on the server
  - Modification requests are processed on the server



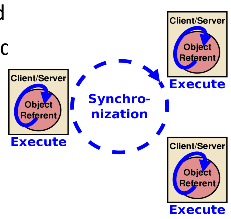
Data Distribution

- 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



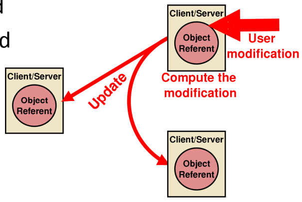
Data Distribution

- Replicated [SIMNET 93, MR Toolkit 93]
  - Data is replicated on each node
  - Synchronization between nodes can be achieved
  - Behaviors are executed on each node



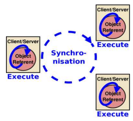
Data Distribution

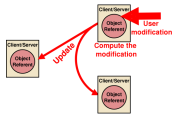
- Replicated [SIMNET 93, MR Toolkit 93]
  - Data is replicated on each node
  - Synchronization between nodes can be achieved
  - Behaviors are executed on each node
  - Modification requests are processed locally



Data Distribution

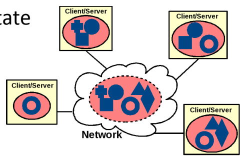
- Replicated [SIMNET 93, MR Toolkit 93]
  - Advantages
    - Low-latency interactions
    - Few messages transmitted
  - Drawbacks
    - Data replication
    - Behaviors processed on each node
    - Inconsistencies due to transmission delay of update messages
    - Additional mechanisms for managing 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

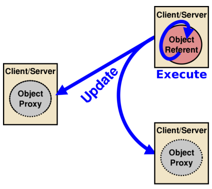


Data Distribution

- 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)

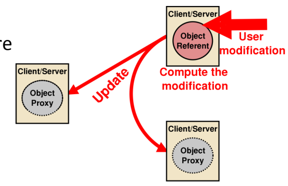
Data Distribution

- Hybrid: Referent/proxy paradigm
  [OpenMASK 02][Schmalstieg et al 03][Fleury et al 10]
  - Behaviors are executed only on one node



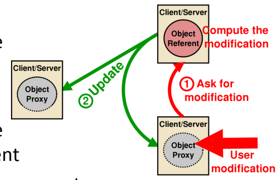
Data Distribution

- 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



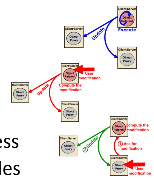
Data Distribution

- 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

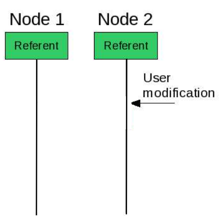
An adaptive data distribution

[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

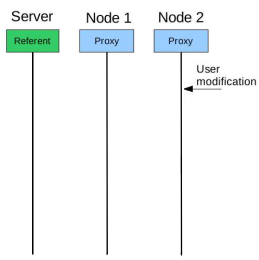
- Replicated Mode
  - Referents on all nodes
  - Interaction latency (IL)
  - Gap in consistency (GC)



⇒ Advantage: good responsiveness

3 Modes of Distribution

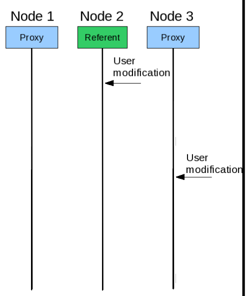
- Centralized Mode
  - 1 referent on the server
  - Proxies on other nodes
  - Interaction latency (IL)
  - Gap in consistency (GC)



⇒ 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
  - OCS (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

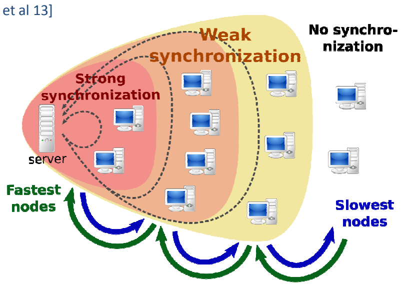
- Ensure that each user have the same state of the virtual environment at the same
- Time is a fundamental element of CVE
  - Absolute time: synchronized clock (UTC)
  - Logical or virtual time: logical clock
    - Ordered sequence of events
    - Use timestamp

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 cock
  - 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 them 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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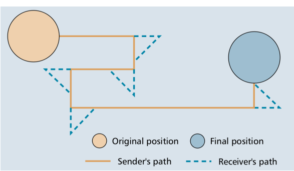
Communication Reduction Mechanisms

- 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 data start to be complicated
    - Joints of a virtual avatar, physical simulation data
  - Migration
  - Load new virtual objects (level of details)
- Aggregation
  - Send all the object updates in one message
  - Can introduce delay in message transmission

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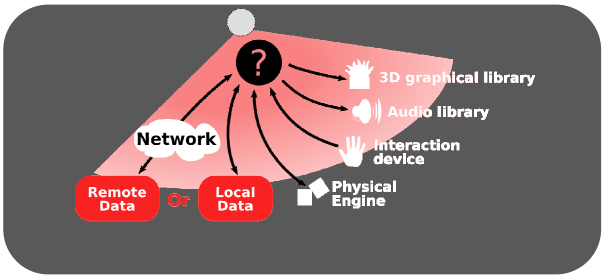
Software Architecture



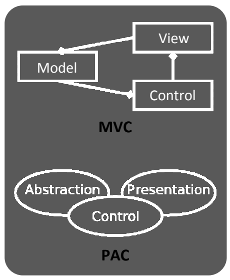
⇒ How to design virtual objects in order to insure a good separation between data distribution and multiple representations?

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

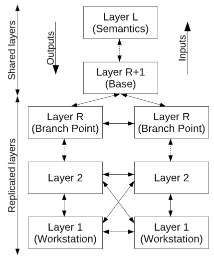
Models for Interactive System

- 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

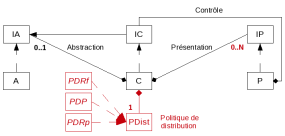
Synthesis

- 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

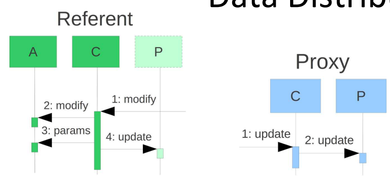
PAC-C3D Model

[Duval et Fleury, 2011]



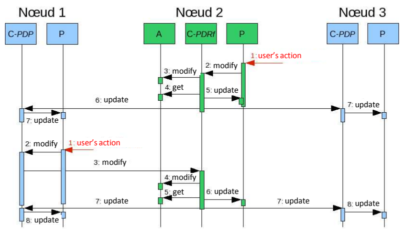
- Extend the PAC model to the CVE
  - Each virtual object is modeled by a PAC agent on each node
  - The Control manages the network distribution
    - Maintains the consistency between all the nodes
      - Several distribution policy (one for each data distribution mode)
    - Provides generalized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

Data Distribution



- Easy implementation of referent/proxy paradigm
- Interoperability between all the 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



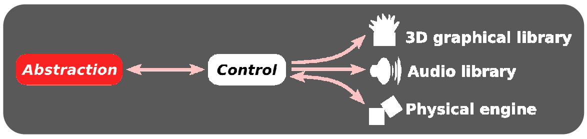
- All modification requests are sent to the Control
- The Control:
  - Chooses where the requests should be processed
  - Manages updates of the remote versions of the objects

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

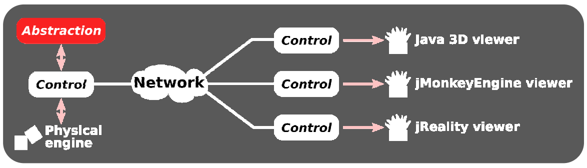
Multiple representations

- Several Presentations of an object on the same node
  - Multi-sensorial representation of the object
  - Add of some “active” Presentations
    - Ex: physical instance of the object 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