Dynamic Shared State & Resource Management in Distributed Collaborative Environments

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Outline

- Distributed Collaborative Environments
- Brief History and Networked VR Systems Examples
- Maintaining the Dynamic Shared State
- DARE's Dynamic Shared State
- Resource Management, Scalability & Performance
- Conclusions

Distributed Collaborative Environments

- Viewpoints in designing DCE
  - Use Case Viewpoint
  - Human Computer Interaction (HCI) Viewpoint
  - Computer Science Viewpoint

- A Distributed Collaborative Environment is distinguished by 5 features:
  - a shared sense of space (or parts of space)
  - a shared sense of presence
  - a shared sense of time
  - a way to communicate
  - a way to share

DCE and Mixed Reality
- *a shared sense of space* -

1. All participants have the illusion of sharing some of (or all) the virtual components.

2. The shared components must present the same characteristics to all participants.

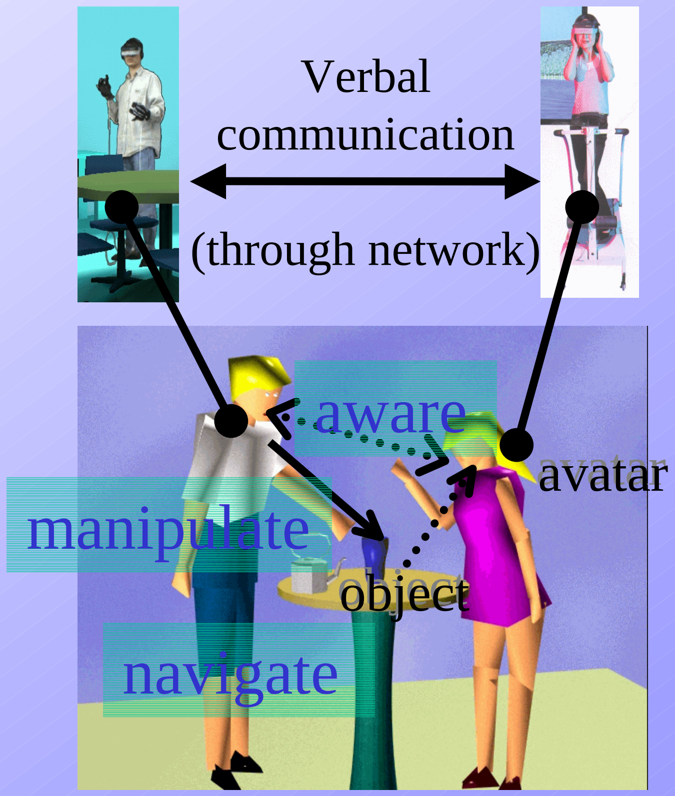
DCE and Mixed Reality
- *a shared sense of presence* -

- Each participant takes on a virtual persona (avatar)
  - representation of human
  - user interface
  - state of avatar controls view, audio, network, session
- Each participant can sense the presence of others:
  - directly: seeing, hearing, feeling others
  - indirectly: sensing the actions of others
- Avatar research:
  - Jack - U.penn, DI-Guy (http://www.bdi.com/)
  - EPFL, MIRALab (http://ligwww.epfl.ch/)
  - H-Anim (http://ece.uwaterloo.ca/~h-anim)

DCE and Mixed Reality
- *a way to communicate* -

- Communication adds a sense of realism to a partially or fully simulated environment.

- Communication & Interaction:
  - aware
  - navigation
  - object manipulation
  - verbal communication
  - gesture communication



DCE and Mixed Reality
- *a shared sense of time* -

- Participants see each other's behavior as it occurs
- Real-time interaction is possible

=> Dynamic Shared State consistency maintenance

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Network VR systems

Categorization:

1. Military industry

   Battlefield simulators: SIMNET, DIS, NPSNET => HLA …

2. Entertainment industry

   Networked games: SGI Flight, Doom, Diablo …

3. Academia

   Computer Sported Collaborative Work (CSCW): NPSNET, PARADISE, DIVE, MASSIVE 1,2,3, (Equip),dVS,VISTEL, SPLINE (at MERL Lab), COVEN, AVOCADO, ….

Networked Virtual Environments

- *Military industry* -

- DoD primary sponsor
  - Battlefield simulators for:
    - Training
    - Strategy evaluation
    - After hours fun …
  - Scalability
  - Real-time behavior

SIMNET

- Started 1983 - Delivered 1990
- Goals:
  - High-quality (graphics) & low-cost simulators
  - Scalability
  - Real-time behavior
- Software Architecture
  - client-server based
  - interconnection of low-end simulators
  - Ethernet broadcast : less then 200 participants
  - homogeneous platform, the simplest solution
  - an embedded set of predictive modeling algorithms "dead reckoning"

DIS

- Build after SIMNET

- Software Architecture
  - the core of the DIS network is the protocol data unit PDU.
  - (IEEE 1278) defines 27 different PDU's, only 4 (entity state, fire, detonation, collision) are used
  - heartbeats (every second) to update objects in the scene.

- Drawbacks
  - Packets are send via unreliable UDP broadcast and are sometimes lost
  - No modeling of collision among vehicles
  - Computation for dynamic terrain is very expensive, and no satisfactory solution has been found yet.

HLA

- HLA (High Level Architecture) - 1995~
  - evolved from DIS, proposal to IEEE standard
  - A general purpose architecture
  - goal : interoperability, reusability
    - DIS PDUs are specialized for special simulation.
    - general time management

- HLA Basic components
  - HLA compliance rules
  - Object model templates
  - Run time infrastructure

Networked Virtual Environments
- *Entertainment industry*-

- Demos
  - SGI Flight
  - Dogfight

- Games
  - Doom, Diablo
    - no dead reckoning,
    - flooded LANs with packets at frame rate

Networked Virtual Environments
- *Academic* -

- DoD systems major drawbacks
  - lack of generality
  - lack of availability

- Academic community
  - reinvented
  - documented the systems
  - published results

  => transition to workstation based VR

NPSNET group

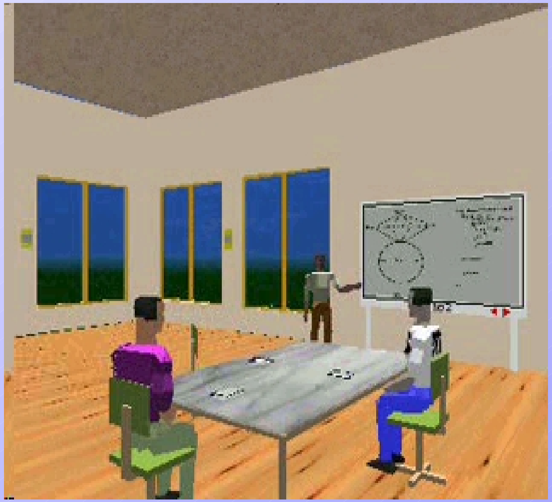
- FOG-M (fiber-optically guided missile) virtual environment *[Smith/Streyle,87]*
- VEH (target vehicle simulator), FOG and VEH were connected via a simple open socket.
- NPSNET-1 (‘90) no dead reckoning, flooding the network with packets at framerate.
- NPSNET-2,3 utilized to explore better, faster ways to do graphics and extend the size of the terrain databases.
- NPSNET-IV (‘93) , same time Performer API SGI was released. Had spatial sound and used dead-reckoning. The first virtual environment able to work on Internet across the multicast backbone (MBone)
- NPSNET-V (’02), Java-based component architecture for networked virtual environment applications: clients, servers, peers, and standalone products

PARADISE

- Reduce bandwidth throughout the system, hierarchy of Area of Interest (AOI) was introduced
- IP multicasting - to assign a different multicast address to each active object
- Position History-Based Dead Reckoning *[Singhal/Cheriton,95]* for fast moving objects.
- To support slowly changing entities - reliable multicast protocols (to eliminate the frequent heartbeat messages)
- Object oriented RPC *[Zelesko/Cheriton,96]* common interface to all network interactions.

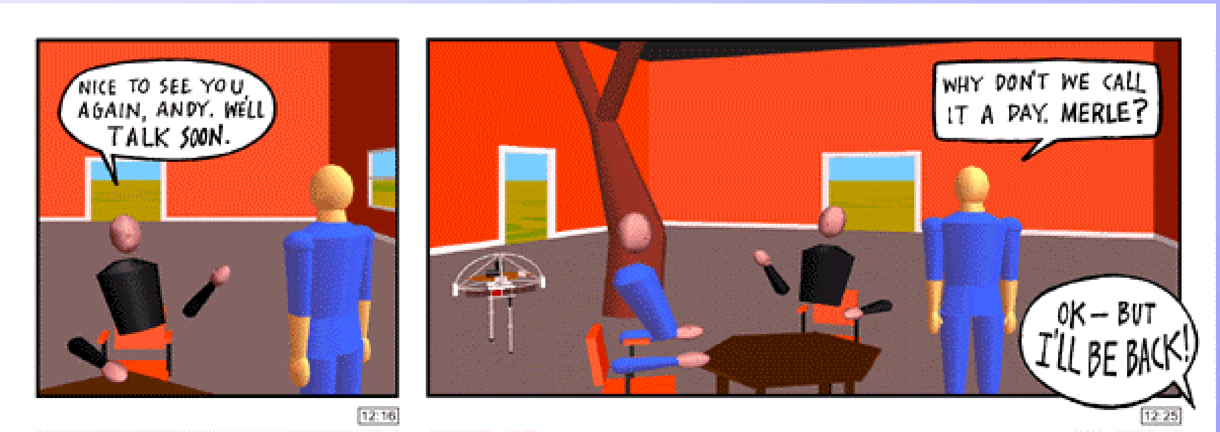
DIVE

- Swedish Institute of Computer Science
  - http://www.sics.se/dive/
- Uses ISIS toolkit concept of process groups to simulate a large shared memory over a network.
- Uses a distributed fully replicated database similar to SIMNET. The entire database is dynamic.
- DIVE 3 based on IP multicast and Scalable Reliable Multicast *[Floyd,95]* instead of ISIS, TCL code for behaviors.



SPLINE (DiamondPark)

- Mitsubishi Electric Research Laboratory (MERL)
- Electronic Meeting Place ('94)
  - 5 participants : 4 human, 1 computer-simulated robot
  - MIT, Boston Dynamics Inc., Carnegie Mellon Univ. U. Penn.



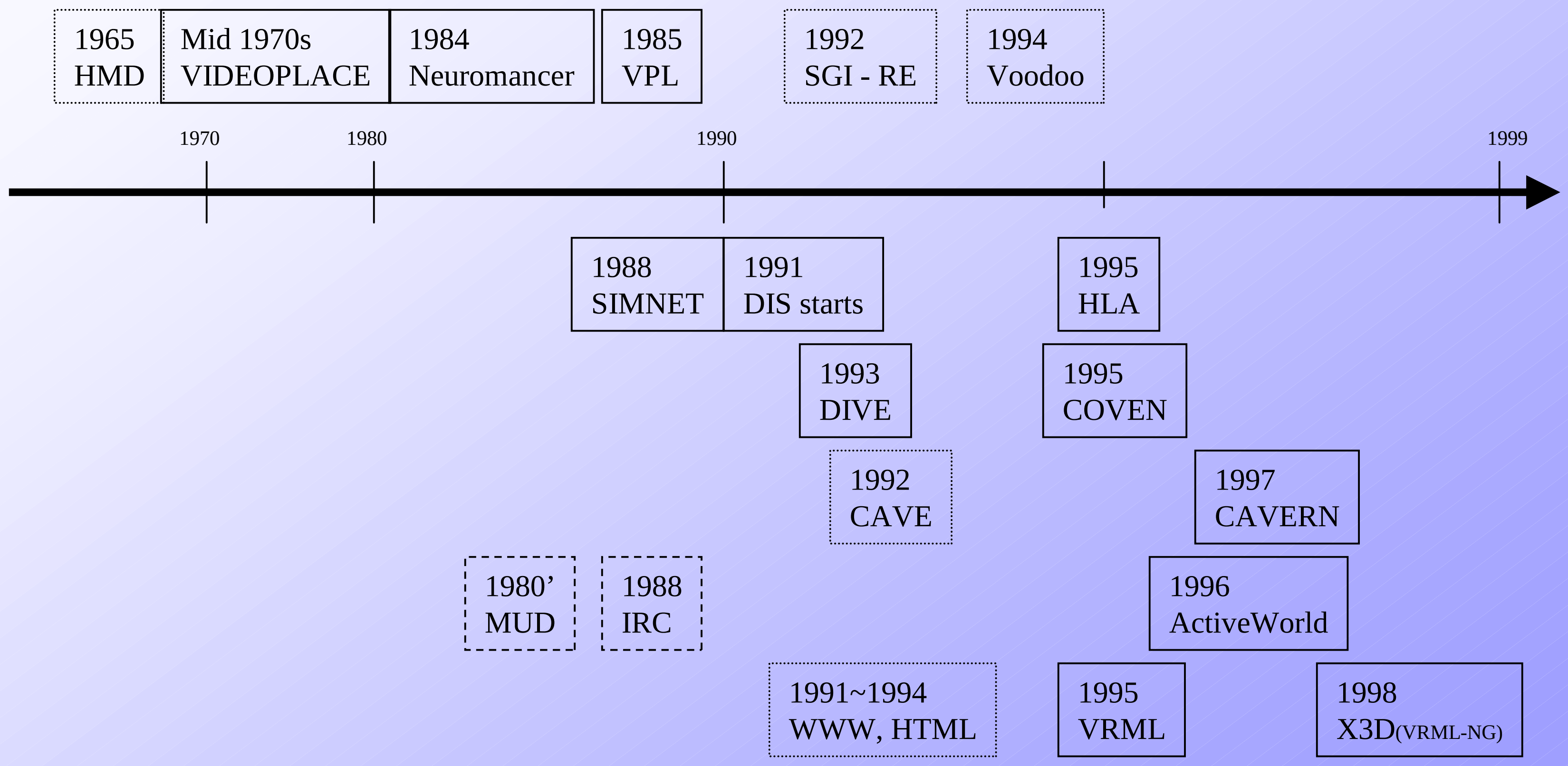
CAVE, CAVERNsoft

- CAVE(1992), ImmersaDesk(1995)
- CAVERN (CAVE Research Network)
  - alliance of industrial and research institutions
    - CAVE, ImmersaDesk
    - supercomputer
    - interconnected by (very) high-speed networks
- CAVERNUS (CAVERN) Users Society

COVEN Project

- 1995~1999 : European Project Consortium
  - http://chinon.thomson-csf.fr/projects/coven/
- Application : Citizen and business applications
  - citizen-oriented scenario - large virtual travel agency
  - professional scenarios - virtual conferencing, business game
- System (COVEN platform) : enhancement of the
  - development system : dVS(DIVISION) http://www.division.com/
  - research system : DIVE(SICS), MASSIVE(Nottingham Univ.)
- Network
  - Europe-wide ISDN and ATM network
  - network performance - trial and experimentation
- Usability study
  - human factors - trial and experimentation

Networked VR systems - Overview



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Dynamic Shared State in DCE

- Consistency-Throughput Tradeoff

"It is impossible to allow dynamic shared state to change frequently and guarantee that all hosts simultaneously access identical versions of the state." - M.Zyda

Dynamic Shared State in DCE

1. Centralized information repositories
   (shared repositories)

2. Dead reckoning algorithms
   (state prediction)

3. Frequent state regeneration
   (frequent broadcast)

Centralized Repositories

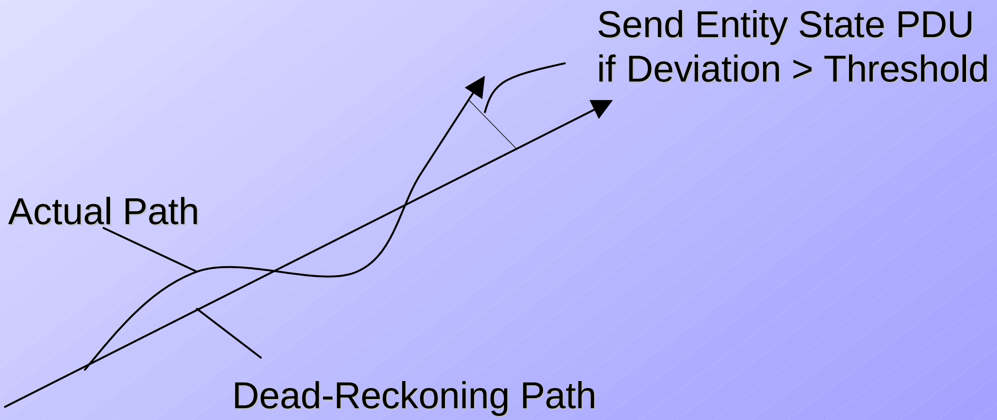
- Pull architecture
  - file repository using a shared file system NFS, AFS *[Campbell,98]*
  - repository in Server Memory *[Nakamura,94]*

- Push architecture
  - the server updates the client local cache when it has new data e.g. Shastra *[Anupam,94]*
  - virtual repositories

(!) Participants must explicitly request and obtain a lock on the particular entity before updating it.

Dead-Reckoning Algorithms

- Convergence
  - correct inaccuracies in the predicted state for transition smoothness – curve-fitting techniques
- Prediction
  - current state is computed based on previously received updates
  - each host runs dead-reckoning on its own object (player) and other hosts’ objects (ghosts)
  - periodically sends Entity State PDU to correct its object’s state in other hosts



Dead-Reckoning Algorithms (cont.)

- Prediction
  - Derivative Polynomial Prediction
    - first order polynomials
    - second order polynomials
  - Hybrid Polynomial Prediction
    - Alternate first/second order
    - Position History-Based Dead Reckoning *[Singhal,95]*
  - Object-Specialized Prediction
    - Dead reckoning alg. for ground –based vehicles *[Pratt,93]*

Frequent State Regeneration

- For applications that do not require absolute accuracy
- Blind broadcasts are sent asynchronously and unreliably at some regular interval to all participants.
- Ownership is assigned to each state component. (similar to locks)

Examples: Doom, Diablo.

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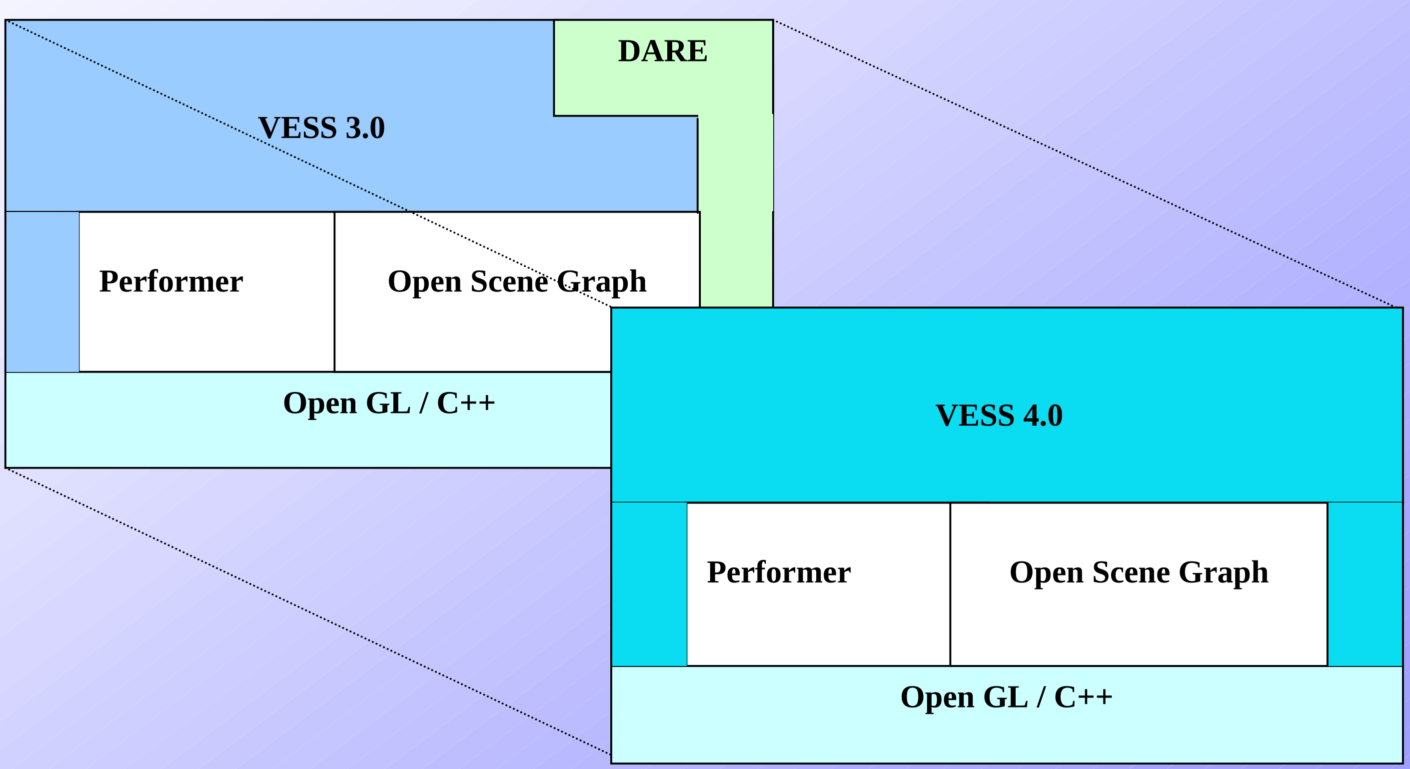
DARE's project

- What is DARE ?
  - Distributed Artificial Reality Environment developed by the team at ODALab
  - Software framework which implements Mixed Reality (MR) and Distributed Systems (DS) paradigms to:
    - improve development time for collaborative MR applications
    - provide a test-bed for research in DS, MR and 3D displays (e.g. data distribution, registration, calibration, virtual environment parameters assessment)
  - See: http://odalab.creol.ucf.edu/dare

DARE's project

- Possible evolution



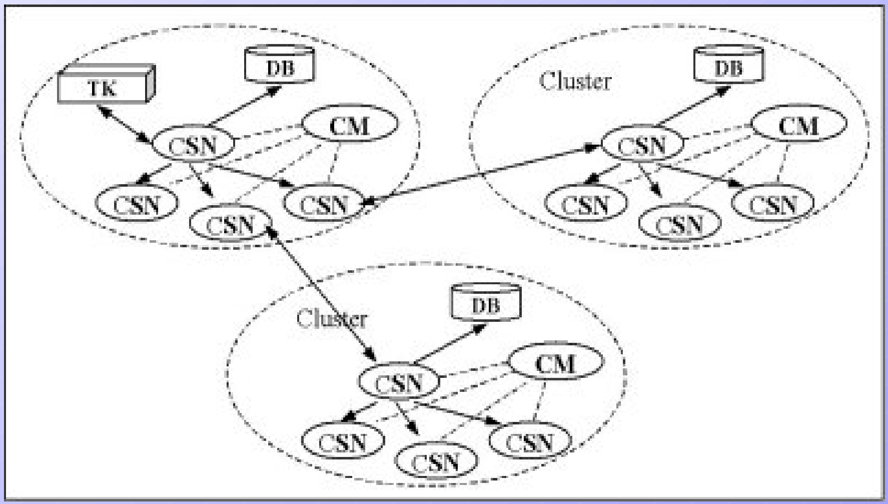
DARE's Dynamic Shared State

- The *ControlPackage* class allows instantiation of *ControlPackage* software objects

- The software objects contain information about the objects in the shared scene:
  - 3D objects position
  - 3D objects orientation
  - actions type (rotation/translation) applied on the objects
  - actions velocity
  - etc (open for sub-classing or aggregation)

DARE's Dynamic Shared State

- Objects can be transmitted through LAN using:
  - multicasting, broadcasting employing the client-server paradigm
  - tcp, Unicast (udp) employing peer-to-peer paradigm



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Resource Management for S&P

- Information Principle [*Zyda,99*]:

$$\text{Resources} \approx M * H * B * T * P$$

  - M = number of messages transmitted in the MR env.
  - H = average no. of destination hosts for each message
  - B = average amount of network bandwidth required for a message to each destination
  - T = timeliness
  - P = no. of processor cycles req. to receive and process each message

Resource Management for S&P
- *approaches* -

1. Optimizing the communication protocol
   – packet compression
   – packet aggregation

3. Human perceptual limitations
   – visual perception - reduced LOD
   – temporal perception – temporal contour

2. Visibility of data management
   – multicasting
   – area-of-interest (AOI) filtering

4. System architecture
   – server clusters
   – peer-server communication

1. Optimizing the communication protocol

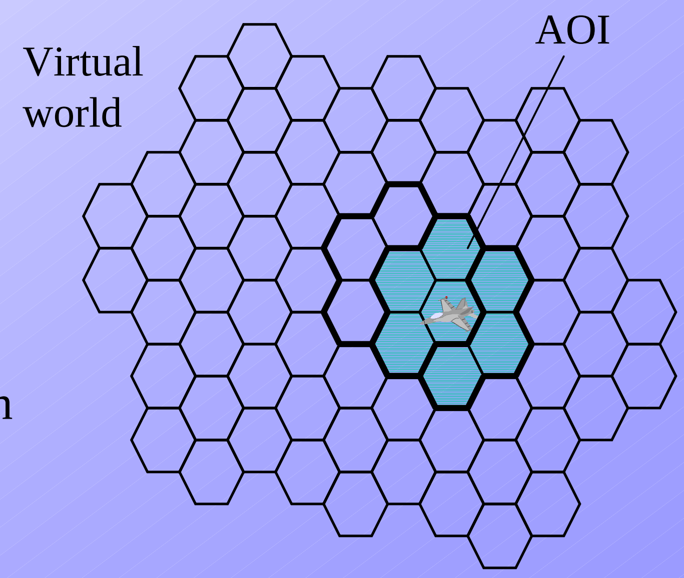
- Compression:
  - Lossless compression vs Lossy compression
  - Internal compression vs External compression
  - Application Gateways *[Calvin,95]*
    - e.g.: Strategic Theater of War (STOW)

- Aggregation:
  - Reduce the number of packets by merging info from multiple packets
  - Tradeoff – bandwidth savings vs. data delay

2. Visibility of data management

- Data flow management
    1. Area-of-Interest filtering
    2. Multicasting
    3. Subscription-based aggregation (hybrid between 1&2)

- Example
    – ***Aura-Nimbus*** information model *[Greenhalgh,97]* Aims at reducing the average number of hosts that receive each message



3. Human perceptual limitations

- Level-of Detail (LOD) perception
  - Multiple Channel Architecture
    - Rigid, Approximate, Full body channel

- Temporal perception
  - Temporal Contour *[Sharkey,98]*
    - Active entity- takes actions, generates update notifications
    - Passive entity – reacts to events, doesn't generate its own actions
    - Radial basis functions for contour blending

$$\Delta = \frac{-r_i}{v_i}\,{}^{\mathrm{L}}\Delta_{\mathrm{Ri}}\; e^{\frac{-r_i^2}{2v_i}}$$

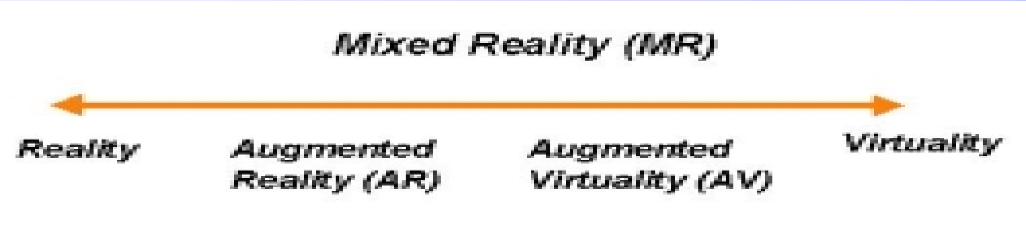
$$\Delta = \Phi\left(r_{\mathrm{L}}\right) \times \sum_{i=1}^{n} {}^{\mathrm{L}}\Delta_{\mathrm{Ri}}\; e^{\frac{-r_i^2}{2v_i}}$$

4. System architecture

- Server clusters
  - Multiple servers reduce the workload on each server
  - Drawbacks: more updates => higher latency
- Server hierarchies
  - The servers themselves act as clients for other servers (it is still Client-Server)
  - Drawback: sensitive to topology changes
- Hybrid Systems
  - Client –Server + Peer-to-Peer = Peer-Server *[Singhal,97]*
  - Hybrid Behavior *[Hamza,03]*

Conclusions

- Dynamic Shared State maintenance is an important problem for distributed systems spanning the virtuality continuum



- Research frontiers:
  - Scalability
  - Enhanced realism
  - Reliability (e.g. graceful degradation)
  - Composability

Acknowledgements

- Charles Hughes & Jannick P. Rolland (Ph.D. Advisors)
- ODALab team members for participation in DARE Dev.
- Link Foundation for 2003-2004 Fellowship

ID	Title	Year	Application Fields	Image Acquisition System	Vision	Hearing	Touch	Smell	Mixing Realities System	Display System 1	Display System 2
1	Architectural Anatomy	1996	Maintenance, Architecture	Human Eye	True	True	False	False	Optical	Optical Mono HMD	-
2	Spaceframe Construction	1996	Construction, Architecture	Stereo Video Camera	True	True	False	False	Electronic: depth based	Video Stereo HMD	-
3	Mixed Reality 3D Conference Application	1999	Collaborative Work, Video Conferencing	Video Camera	True	True	False	False	Electronic: depth based	Optical Mono HMD	Desktop Monitor
4	Calibration Free AR	1998	Methodology, Calibration Free	Stereo Video Camera	True	False	False	False	Electronic: depth based	Video Stereo HMD	-
5	Calibration Free AR in Perspective	2000	Methodology	Video Camera	True	False	False	False	Electronic: depth based	Video Stereo HMD	-
11	Virtual Fashion Simulator	2000	Methodology, Merging CG Cloth & Humans, Fashion	Video Camera	True	False	False	False	Electronic: depth based	Desktop Monitor	-
12	Augmented Surfaces	1999	Collaborative Work, Interchange of Digital Information	Human Eye	True	True	False	False	Real World	Projector to Special Device	Projector to Special Device
13	TransVision	1996	Collaborative Work, Design	Video Camera	True	False	False	False	Electronic: chromakeyng	Other	-
14	GRASP	1994	AR Development Platform	Video Camera	True	False	False	False	Electronic: chromakeyng	Desktop Monitor	Pointer
15	ARCHEOGUIDE	2001	Mobile AR, Outdoor's AR Guided Tours	Stereo Video Camera	True	True	False	False	-	Video Stereo HMD	-
16	RV-Border Guards	1999	Entertainment, Video Games	Stereo Video Camera	True	True	False	False	-	Video Stereo HMD	Virtual Reality Glove
17	Device Diagnostics with AR and 3D Audio	1999	Maintenance	Video Camera	True	True	False	False	Electronic: chromakeyng	Desktop Monitor	-
18	MCAR - Mobile Collaborative AR	2001	Mobile AR, Collaborative work, Studierstube Based	-	False	False	False	False	-	-	-
19	MARS - Mobile Augmented	1999	Development Platform, Interactive AR	Human Eye	True	True	False	False	Optical	Video Stereo HMD	-

ID	Title	Year	Application Fields	Image Acquisition System	Vision	Hearing	Touch	Smell	Mixing Realities System	Display System 1	Display System 2
20	ARToolkit	2000	Development Software Package, Image Recognition	-	False	False	False	False	-	-	-
21	ARGOS	1993	Telerobotics, Human telerobot interaction	Stereo Video Camera	True	False	False	False	-	Video Stereo HMD	-
22	ARTEMIS	1996	Teleoperation, Telerobotics	-	False	False	False	False	-	-	-
23	Studierstube	2001	AR Development Platform Multi Display Systems	-	False	False	False	False	-	-	-
24	ARAS - Augmented Reality Aided Surgery	2002	Image Guided Surgery, AR Aided Surgery, Studierstube Based	-	False	False	False	False	-	-	-
25	Nähstube: Simulating Cloth	1998	Textile Design, Fashion, Studierstube Based	-	False	False	False	False	-	-	-
26	SignPost - Mobile AR Navigation System	2002	Mobile AR, Guided Walk, Studierstube Based	-	False	False	False	False	-	-	-
29	3DK - The Virtual Studio	1994	Entertainment, AR Blue Room, Television	-	False	False	False	False	-	-	-
30	Two-Handed direct interaction with ARToolkit	2002	Mobile AR, Interactive AR, ARToolkit based	-	False	False	False	False	-	-	-
31	Wearable Augmented Reality System	2002	Mobile AR, Guided Tours, MARS Based	Human Eye	True	False	False	False	-	-	-
32	Touring Machine	1999	Mobile AR, Guided Tours MARS Based	-	False	False	False	False	-	-	-
33	Situated Documentaries	1999	Mobile AR, Guided Tours, MARS Based		False	False	False	False			
34	Distributed Artificial Reality Environment	2001	Distributed , Visualization, Medical Diagnostics	-							