Adaptive Scene Synchronization for Virtual and Mixed Reality Environments

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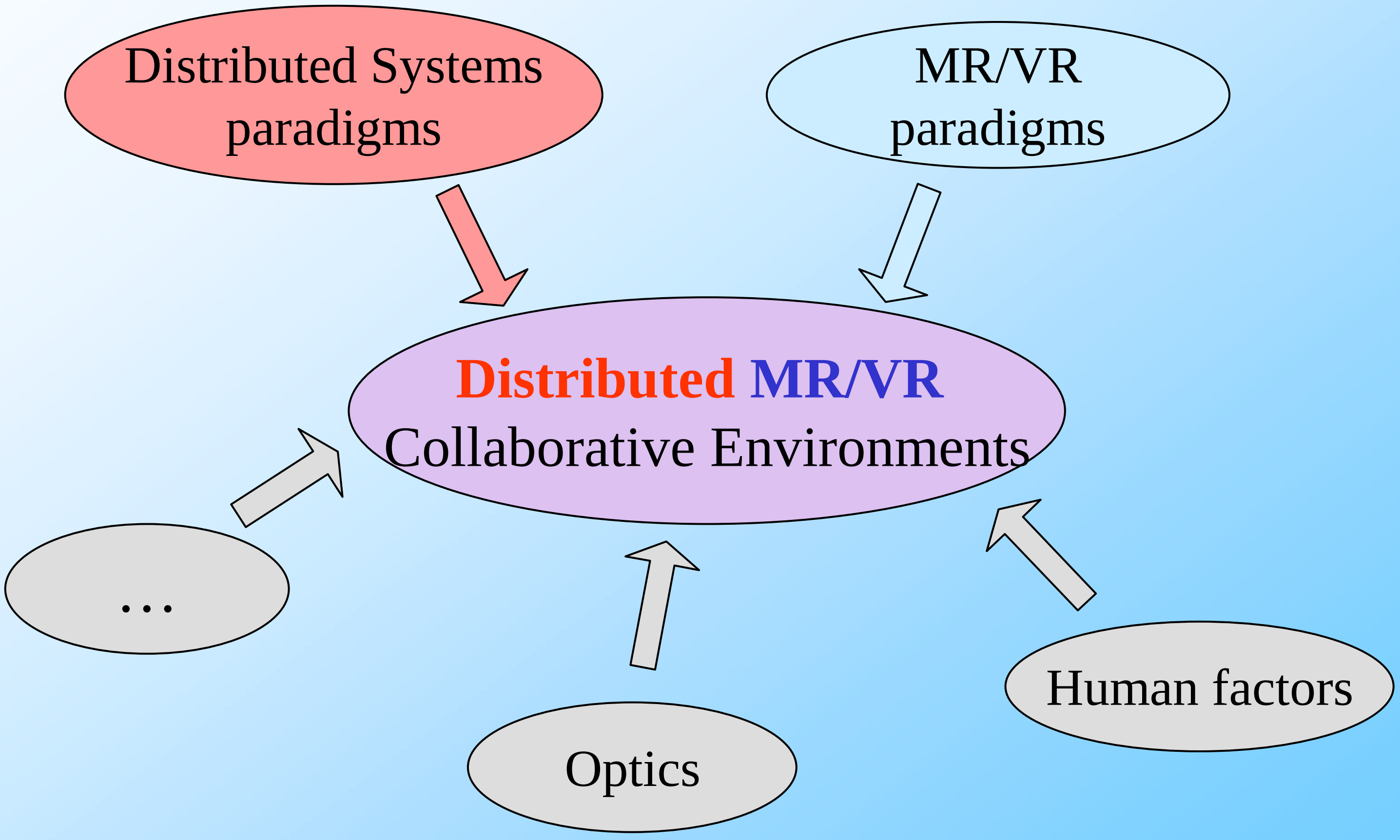
Outline

- Distributed Collaborative Environments (DCE)
  - Mixed + Virtual Reality (MR/VR), Distributed Systems
  - Examples of MR/VR based DCE & Trend
  - Dynamic Shared State
- Adaptive Scene Synchronization Algorithm
  - Drift Value, Drift Matrix
  - Fixed vs. Adaptive Threshold
  - Quantitative Assessment
- Experimental Results
  - Scenario one – 2 nodes
  - Scenario two – 5 nodes
- Conclusions and Future Work
- Acknowledgments

Distributed Collaborative Environments

- MR/VR & DS paradigms

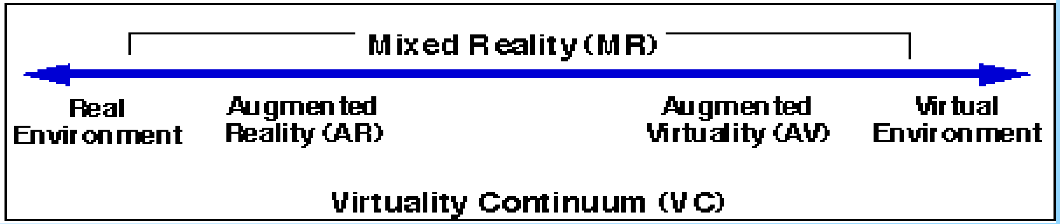


Distributed Collaborative Environments
- Examples of MR/VR based DCE & Trend

- DCE application
  - Information/knowledge dissemination
  - Reduced costs, time and risks
  - Increased efficiency through team work
- Examples & Trend
  - Industry
    - Military simulations: (VR) SIMNET, NPSNET, (MR) MOUT …
    - Entertainment: (VR) networked games, (MR) Project (ISMR'99) …
    - Medicine: (AR) training tools (MMVR'03) …
  - Academia: (VR) MASSIVE, DIVE, DEVA, (AR) Studierstube, Coterie…
  - Trend toward Mixed Reality (focus on AR)

Distributed Collaborative Environments
- Dynamic Shared State

"The dynamic shared state constitutes the changing information that multiple machines must maintain about the networked Virtual Environment" ("Networked Virtual Environments – design and implementation", S. Singhal, M. Zyda)



The cause for inconsistency

- ➢network latency (propagation, transmission, routing)
- ➢computer system latency (rendering, buffering, etc.)

Dynamic Shared State
- Related Work

- Approaches:
  - centralized information repositories (pull/push architectures)
  - dead-reckoning algorithms (convergence & prediction)
  - frequent state regeneration (blind broadcasts, applications that do not require absolute consistency)

- Other techniques for resource management:
  - Communication protocol optimization (packet compression)
  - Visibility of data management (AOI)
  - Human perceptual limitations (LOD)
  - System Architecture

"Networked Virtual Environments – design and implementation", S. Singhal, M. Zyda.

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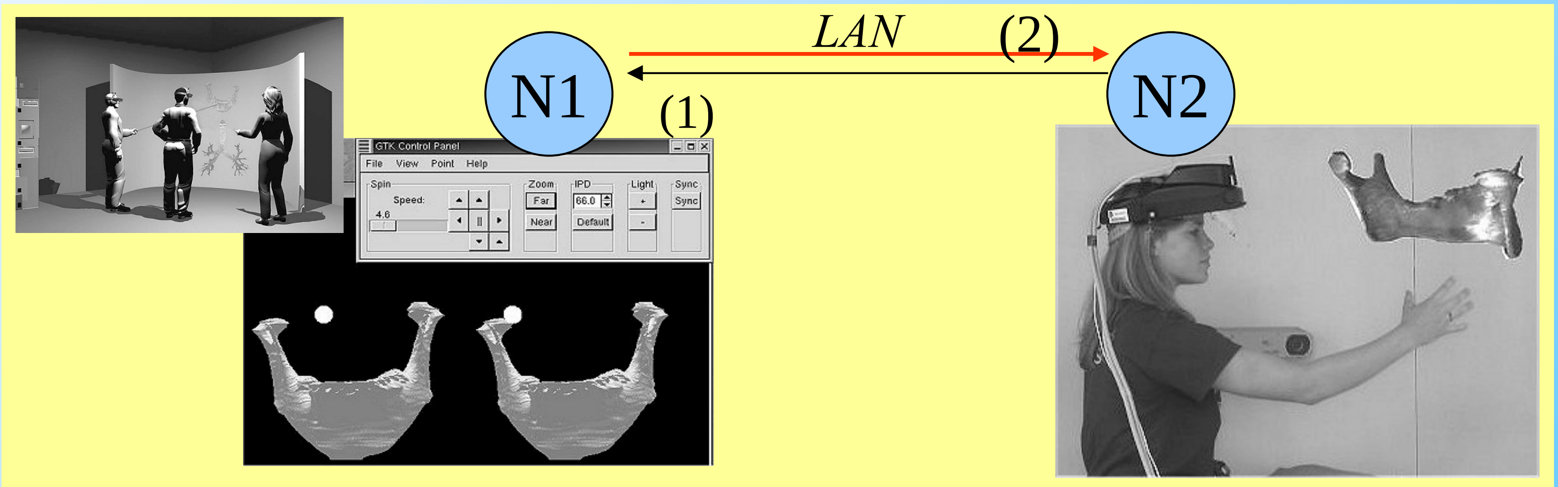
Adaptive Scene Synchronization Algorithm

- Motivation
  - distributed algorithm for shared state maintenance that compensates for the ***network latency***
  - takes into account the network infrastructure behavior
  - provides distributed computation combined with distributed system monitoring



Adaptive Scene Synchronization Algorithm
- Overview

- DCE is seen as
  - A distributed system of “n” nodes
  - Each node:
    - runs a set of threads: rendering, interaction, monitoring.
    - has access to a local library of 3D models
    - data is exchanged through software objects (each shared virtual 3D object has a software object associated)
- Two types of nodes
  - “server” nodes (produce/broadcast interaction data, software objects)
  - “client” nodes (consume interaction data, compute delay)
- Each node adjusts the local scene attributes based on
  - delay (between each producer and consumer)
  - information carried in the software objects (e.g. interaction speed)

Adaptive Scene Synchronization Algorithm
- Drift Value, Drift Matrix

- *Drift value* at *(N2)* - is the product between the action velocity and the network delay

- For a DCE of "N" nodes sharing "M" virtual objects
  - Velocities matrix, $S = [s_i]$, where $i \in [1, M_\tau]$
  - Delays matrix, $T = [t_j]$, where $j \in [1, N_\tau]$

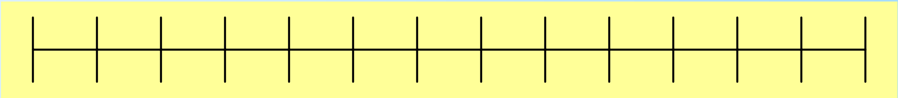
- *Drift matrix*
  - $\boldsymbol{D}(M_\tau, N_\tau) = \boldsymbol{ST}^t$

Adaptive Scene Synchronization Algorithm

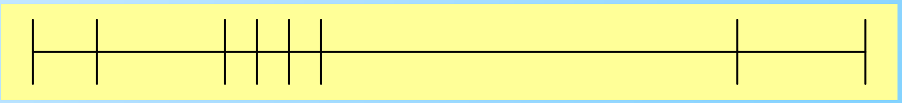
```
Client side:
        Initialization:
                Tn ← ComputeNodeDelay()
                Sn ← UpdateAction();
                Dn ← UpdateDrift()
                UpdateLocalScene();
        Main:
                if (trigger)
                        Tn ← ComputeNodeDelay()
                        Dn ← UpdateDrift()
                end if
                if (changedScene)
                        Sn← ReceiveChanges()
                        Dn ← UpdateDrift()
                end if
Server side:
        for ever listen
                if (newClientRequest)
                        SendToClient(Sn);
                end if
                if (changedScene)
                        BroadcastChanges();
                end if
        end for
```

Delay Measurements
- Fixed vs. Adaptive Threshold

- When do we trigger the delay computation ?
- Delay measurements must be triggered whenever significant variations in the network delay appear
  - Fixed Threshold – delay measurements are triggered at regular intervals

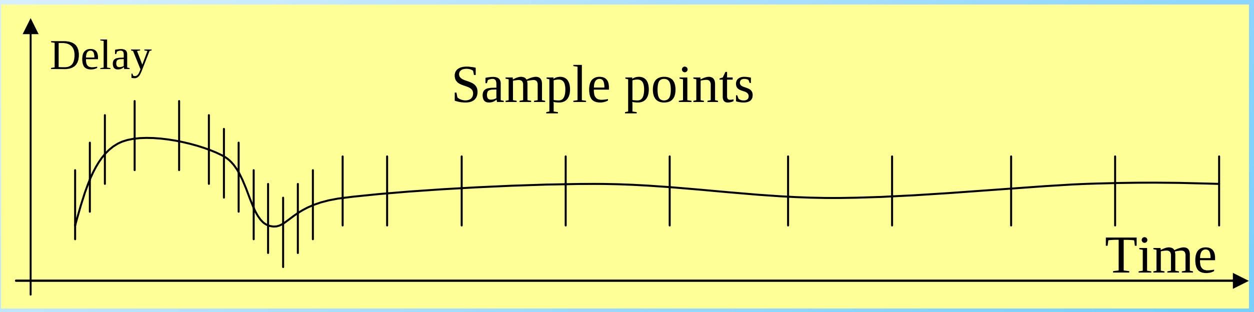


  - We propose an *Adaptive Threshold* - delay measurements are triggered based on the delay history - better characterizes the network jitter and the users interaction



Delay Measurements
- Adaptive Threshold

- Let:
  – H_p the delay history
  – σ and h_{mean} be the standard dev. and the mean of H_p
  – h_0 be the most recent delay, i.e. the last entry in H_p
  – γ_0 the current frequency of delay measurements, (*expressed as the number of measurements per second*)
- Adaptive approach:
  – decrease γ_0 , if $h_0 \in [\, h_{mean} - \sigma,\, h_{mean} + \sigma\,]$
  – increase γ_0 , if $h_0 \notin [\, h_{mean} - \sigma,\, h_{mean} + \sigma\,]$



Quantitative Assessment

- Assess *orientation drift* of a shared 3D virtual object

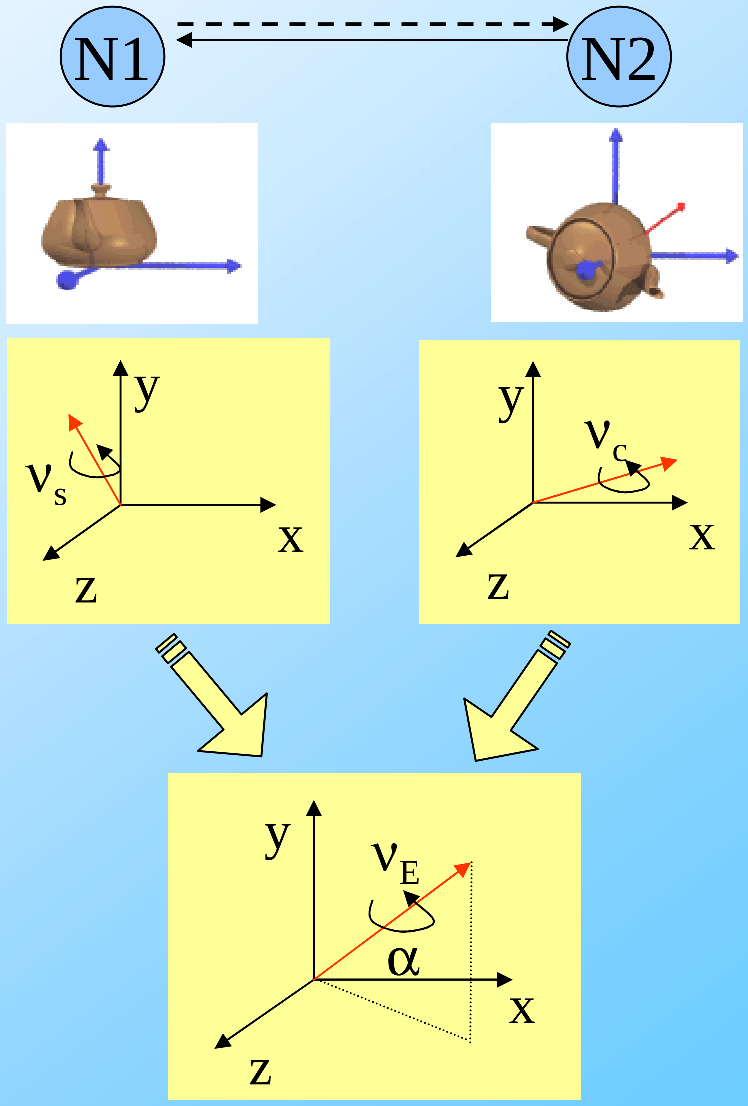
- Let
  - q_s - rotation of an object at N1
  - q_c - rotation of the same object at N2

- Correction quaternion (q_E) - expresses the error between the actual orientation of the object and the desired orientation

$$q_s = q_E q_c$$

$$q_E = (\omega_E, v_E)$$

$$\alpha = 2\cos^{-1}(\omega_E)$$



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  - Continuous vs. Discrete Interaction/Updates
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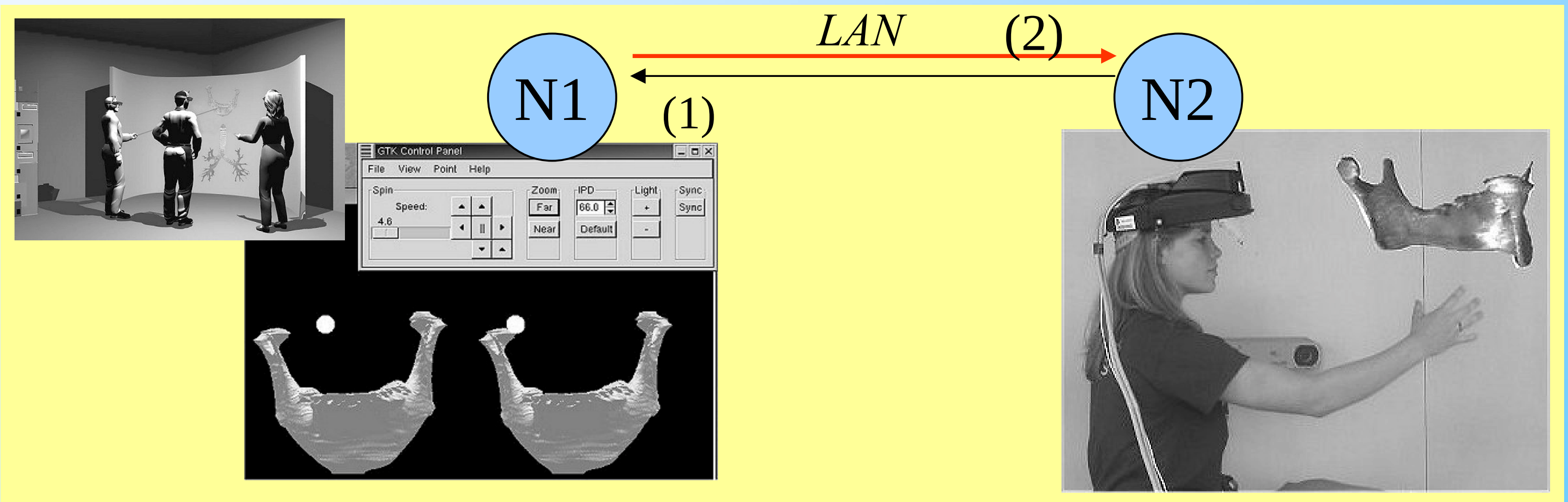
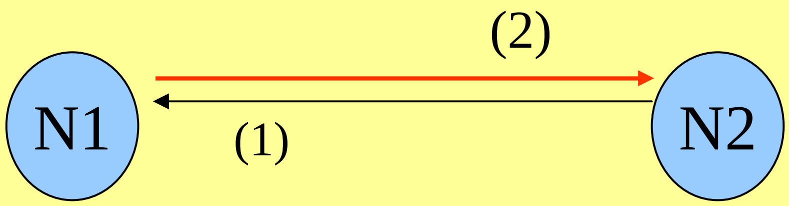
Experimental Results

- Prototype

- Distributed Artificial Reality Environment (DARE)
  - set of OO libraries for 3D rendering, communication, node monitoring, assessment (http://odalab.creol.ucf.edu/dare)
- User interacts through a GUI by applying a set of consecutive actions (rotations) on the object



Experimental Results - Scenario 1

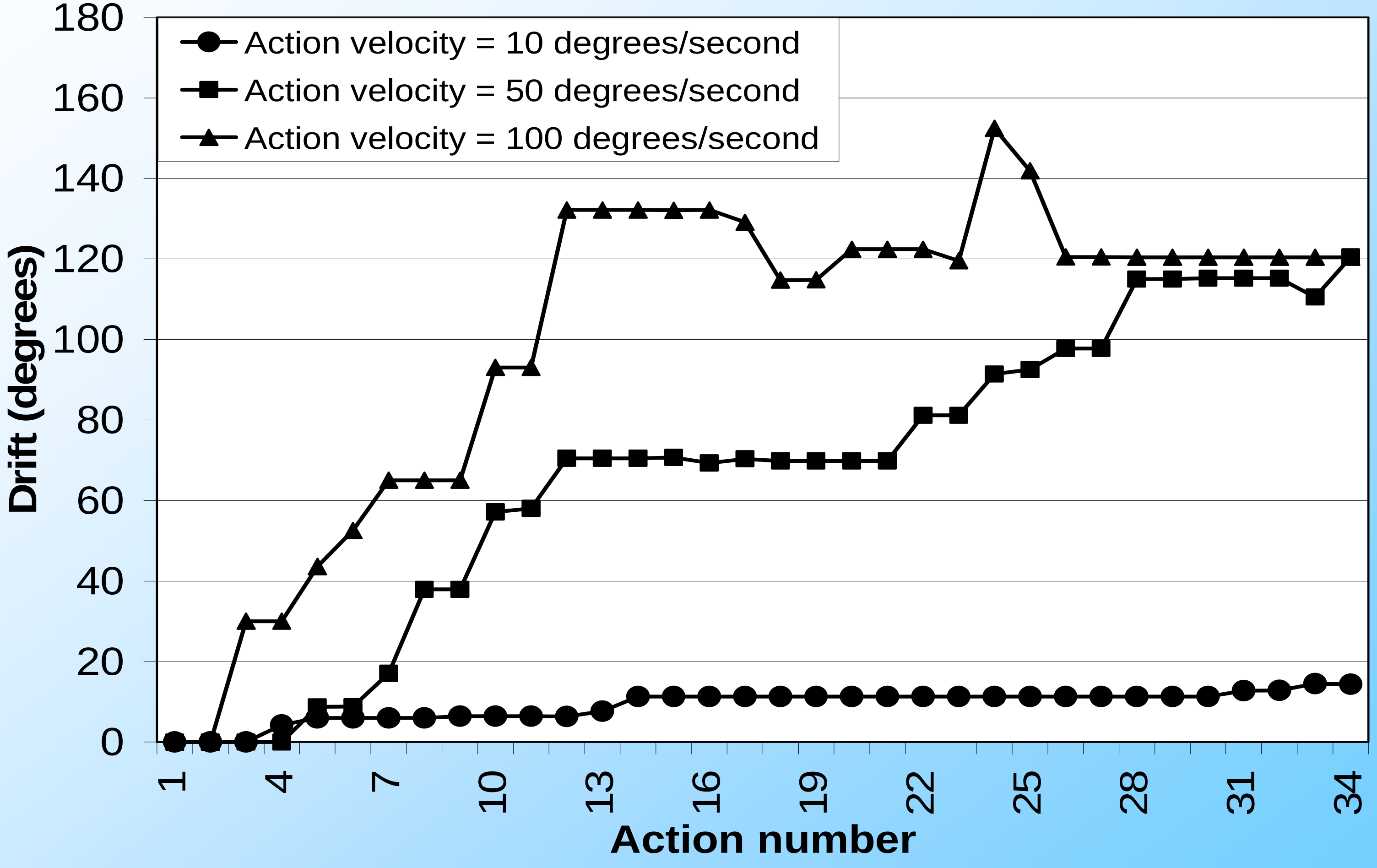


User at N1 rotates the shared object around axes with different velocities (e.g. 10, 50, 100 degrees/second)

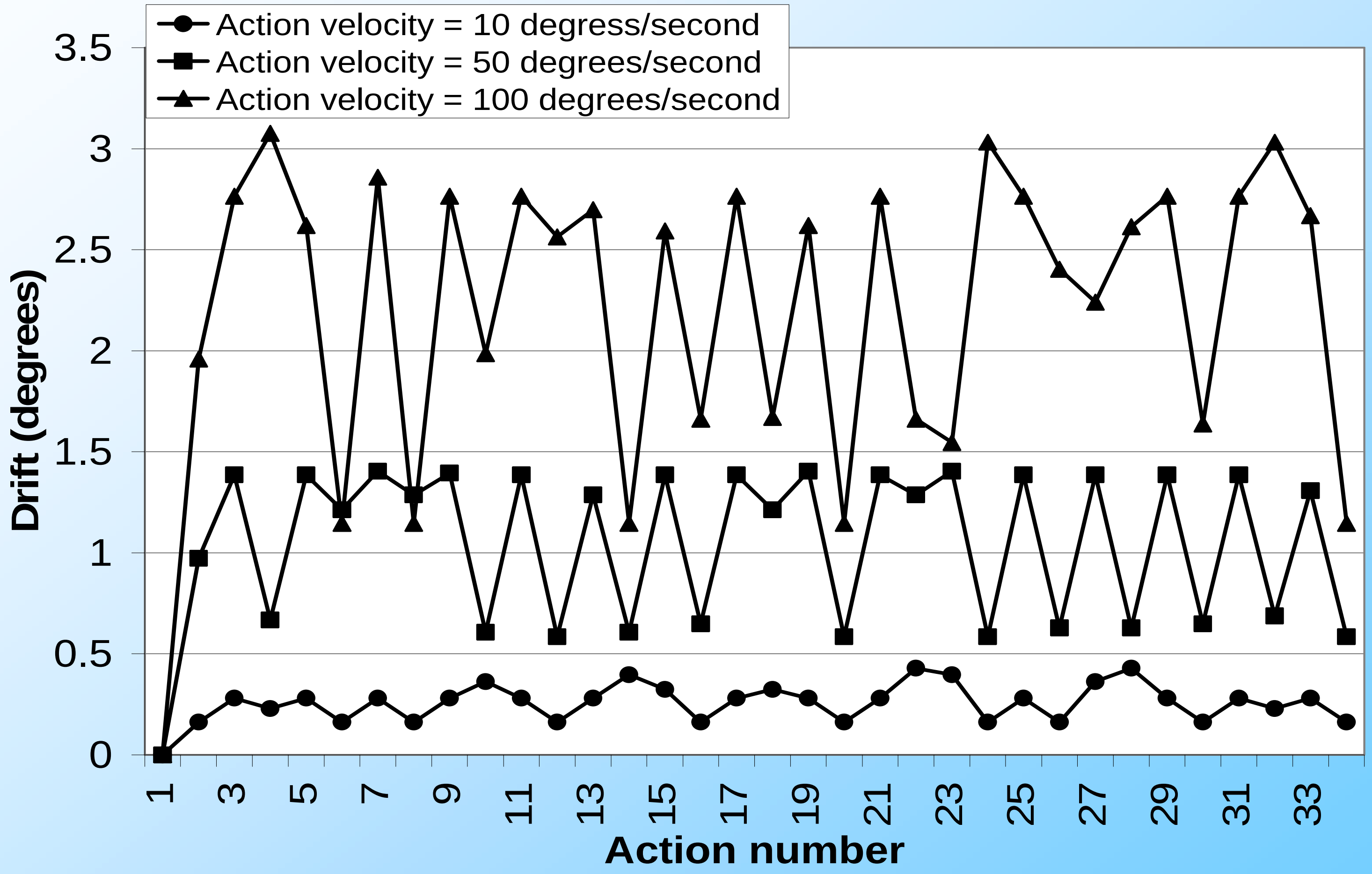
(1) N2 computes the inter-node delay.

(2) N1 broadcasts updates as the user at N1 interacts with the object.

Angular Drift at N2, Synch. OFF

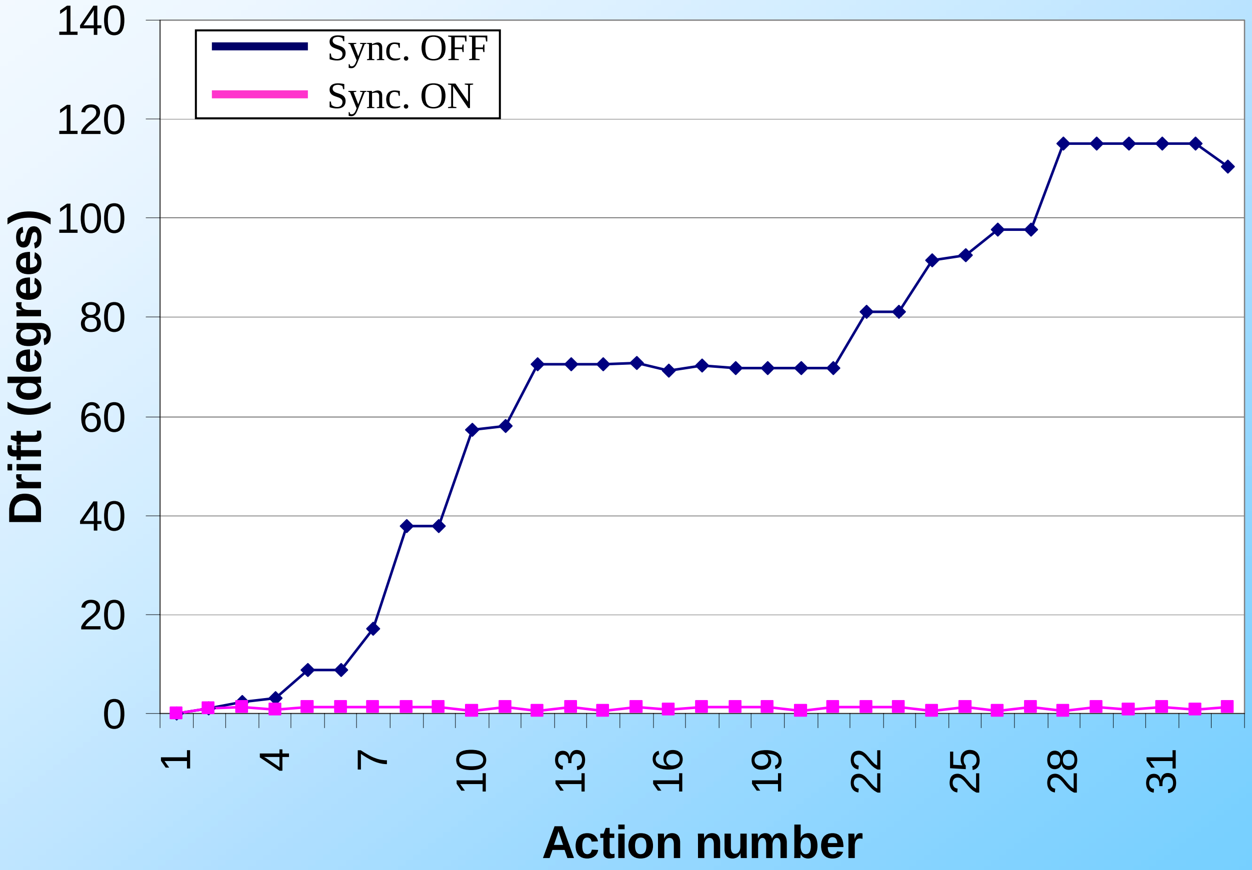


Angular Drift at N2, Synch. ON

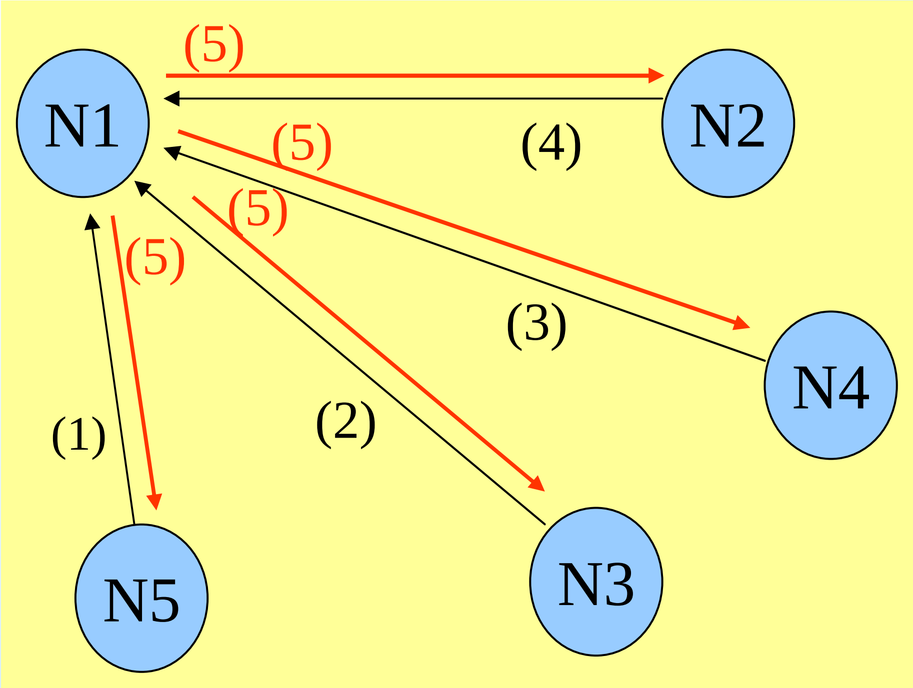


Comparison Synch. ON/OFF

Drift on N2, action speed 50 degrees/sec



Experimental Results – Scenario 2
- Investigation of Scalability



(1) node 5 joins and uses the ***delay probe*** to compute the latency between him and the server.

(2), (3), (4) Same

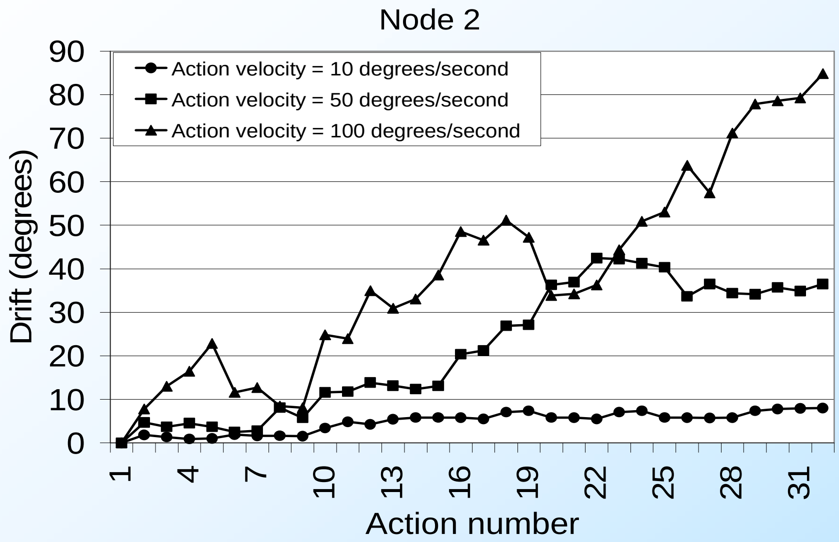
(5) The server (N1) broadcasts data to all participants (as they join the environment)

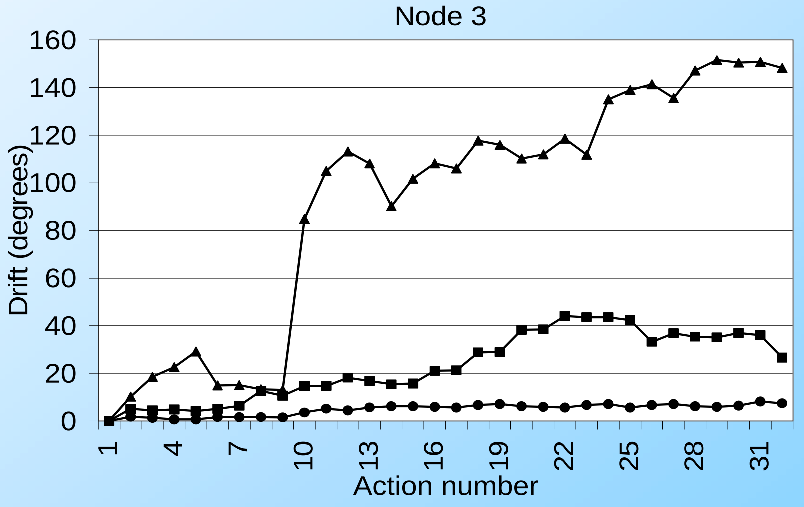
Experimental Results – Scenario 2

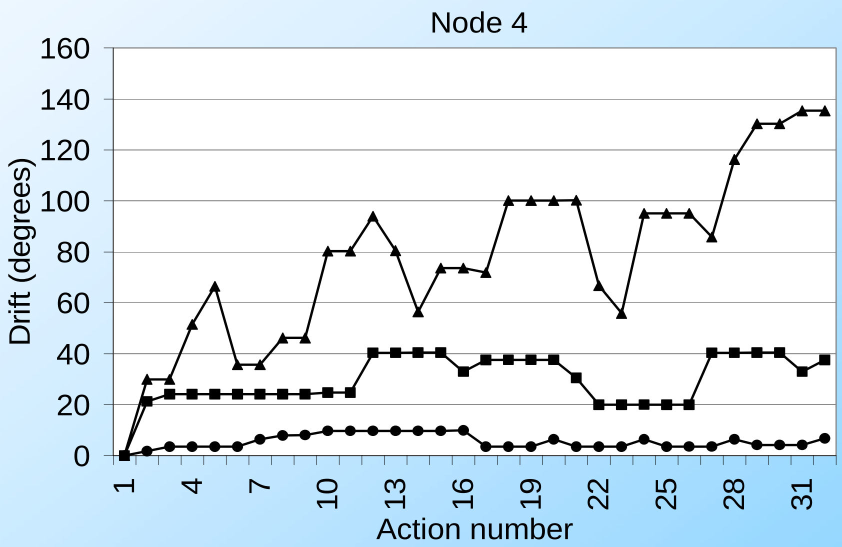
- Hardware

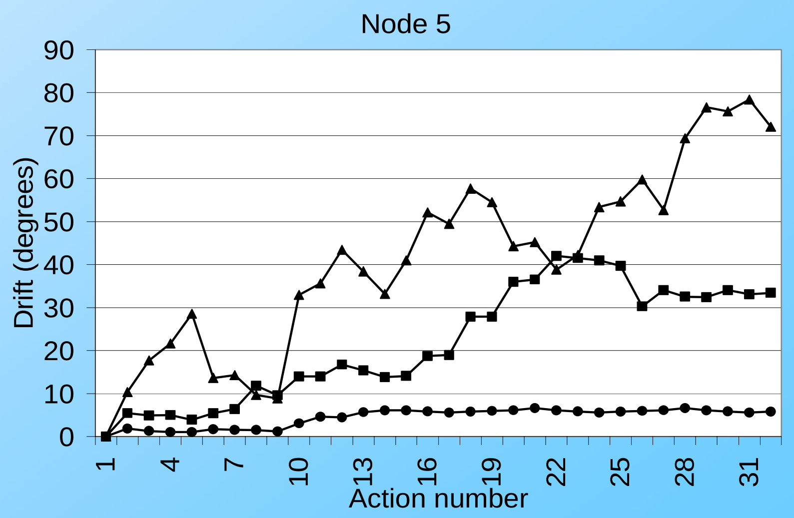
Node no.	Arch	CPU (GHz)	RAM (MB)	Video card
1	Desktop	1.5 AMD	1024	4 Ti4600
2	Desktop	1 P3	1024	2 Mx
3	Desktop	1.7 P4	512	4 Mx 440
4	Desktop	1.7 AMD	1024	4 Ti4600
5	Laptop	2 P4	1024	4 Go440

Drift between client nodes and N1 – Synch. OFF

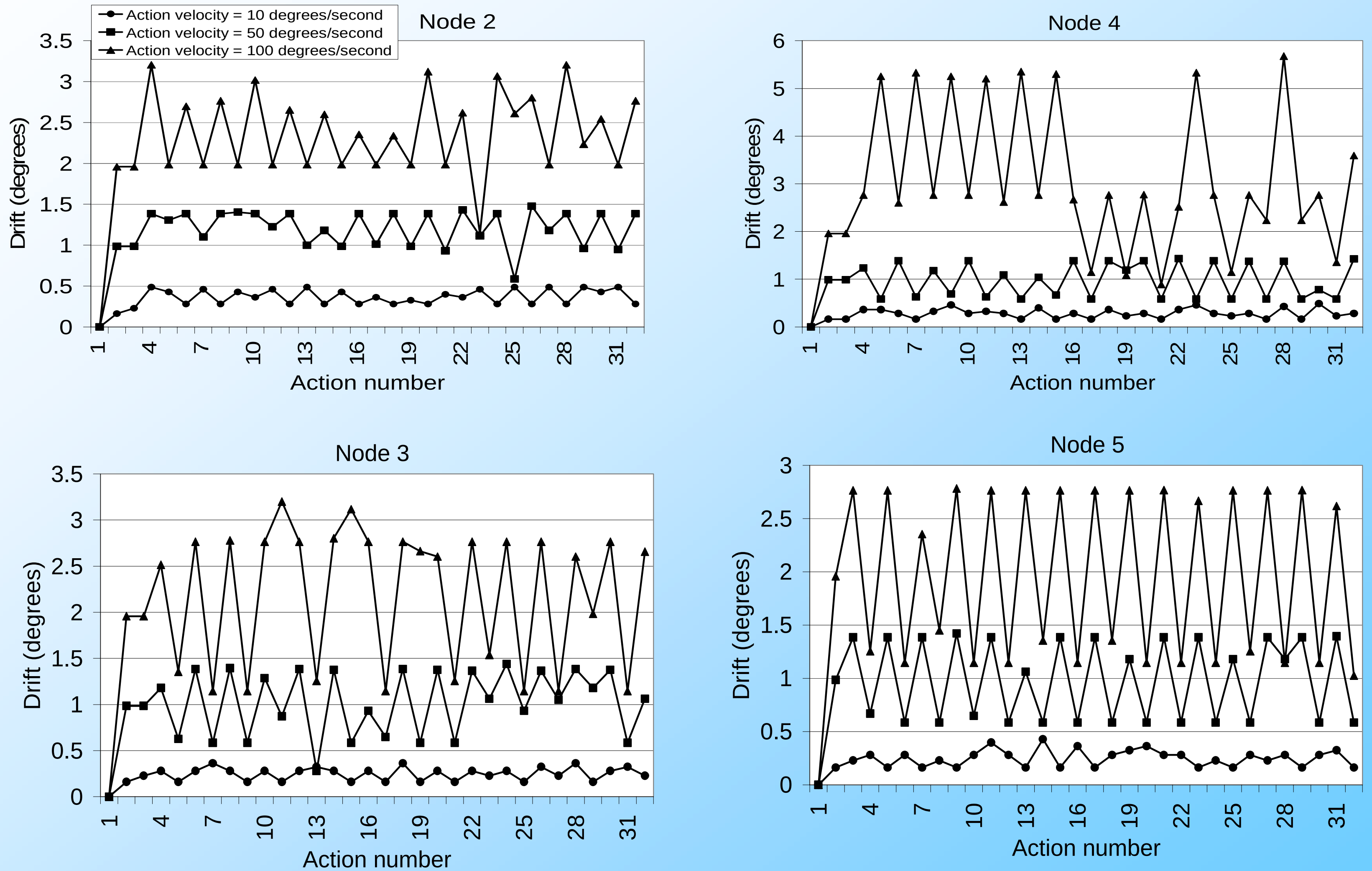






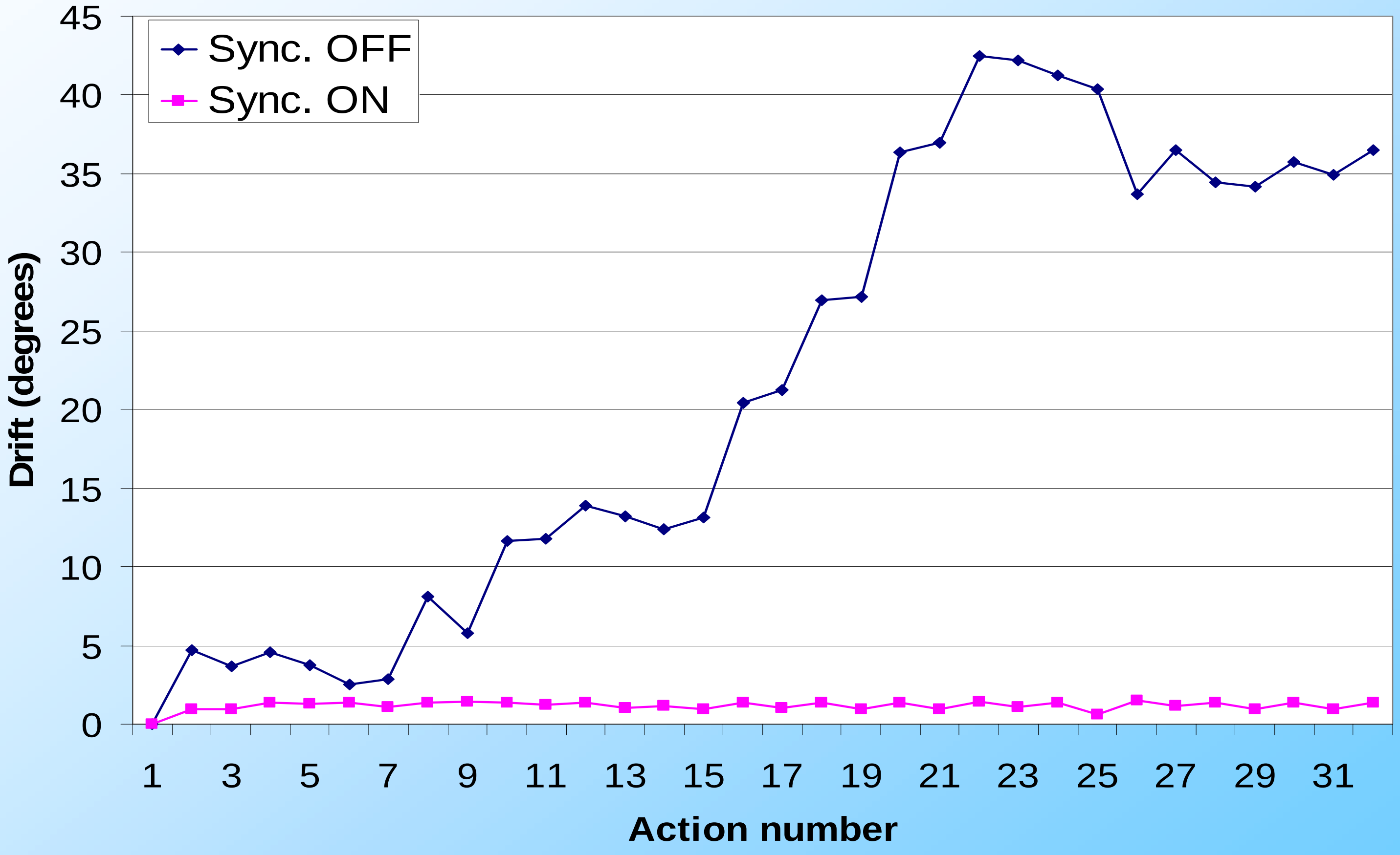


Drift between client nodes and N1 – Synch. ON



Comparison Synch. ON/OFF

Drift on N2 at action velocity 50 degrees/sec



Summary of Results

- Maintains a low and constant drift level
  - 100 degrees/sec, synch OFF, after 34 actions => $\sigma_{drift} = 22.59$
  - 100 degrees/sec, synch. ON, after 34 actions => $\sigma_{drift} = 0.48$
- Scalability regarding the number of nodes (ψ average drift)
  - $\psi_n = n\,\psi_1$ linear increase, low scalability
  - $\psi_n \approx \psi_1$ i.e. good scalability
  - experimental results:
    - $\psi_1 = 2.4$ (2 nodes setup)
    - $\psi_4 = 2.9$ (4 nodes setup)

$\Rightarrow$ $\psi_4 \approx \psi_1$

Conclusions and Future Work

- Distributed algorithm for dynamic shared state maintenance
  - takes into account network latency
  - reduces intrusiveness through an adaptive threshold
  - decentralized delay and drift computation approach

- Extend the system infrastructure to multiple interacting nodes:

  Hamza-Lup, F. J. Rolland, C. Hughes: "*Hybrid Nodes with Sensors - Architecture for Interactive Distributed Mixed and Virtual Reality Environments*" in press, SCI 2004, July 18-21 Orlando Florida.

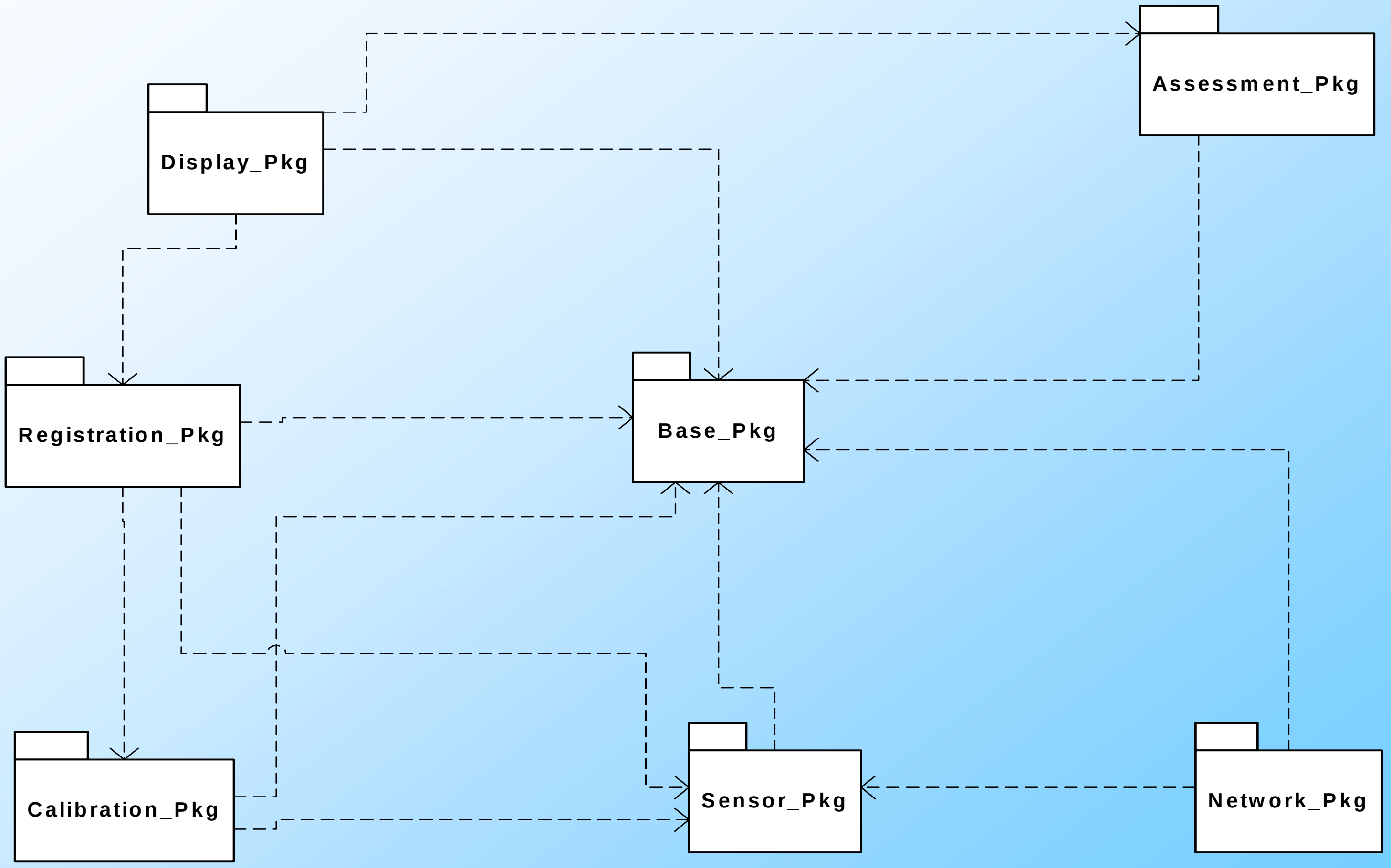
Acknowledgments

- NSF/ITR: IIS-00-820-16
- The Link Foundation
- ODALab team
- Prof. Charles Hughes

Thank you.

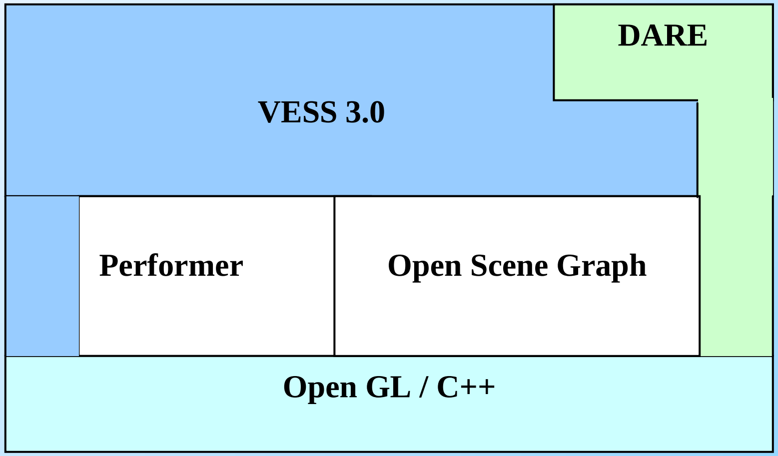
Questions please …

DARE packages



Distributed AR Environment

- DARE and other VR libraries



Continuous vs. Discrete

- Distributed System
  - Continuous data flow
  - Intermittent (“Discrete” data flow)
- Interaction in MR/VR
  - Continuous (e.g. a sensor feeding data)
  - Discrete (e.g. a user interacting through a GUI)
- System Updates
  - Continuous
  - Discrete

Continuous vs. Discrete

Interaction / Update	Continuous	Discrete
Continuous	(-) scalability (+) consistency	(-) scalability (+) consistency
Discrete	(+) scalability (-) consistency	(+) scalability (+) consistency