Ames Research Center

Human Factors
research and technology

NASA

Studies on the Performance Impact, Discriminability and Management of Latency in Virtual Environments

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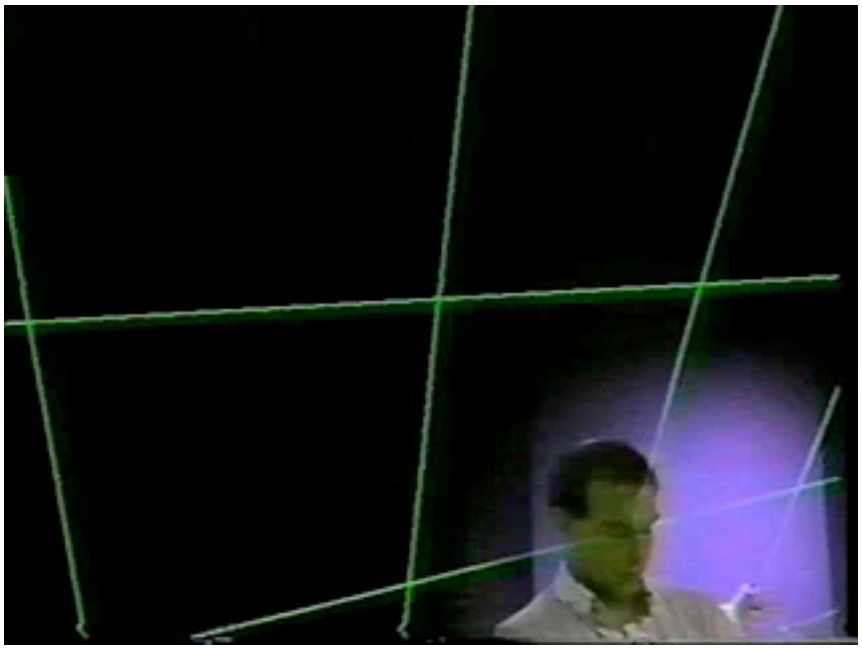
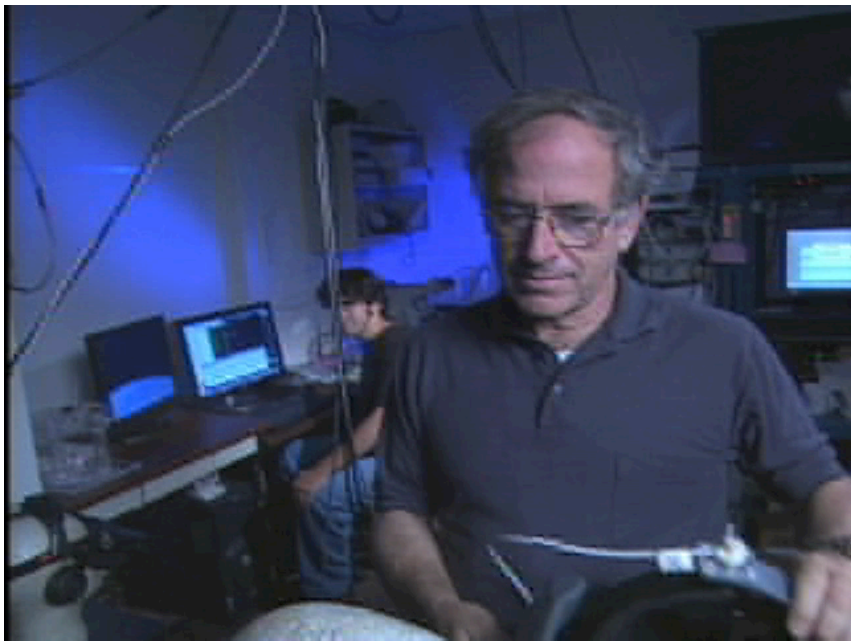
Definition of Virtual Environment

a.k.a Virtual Reality

A virtual environment is an interactive, virtual image display enhanced by special processing to convince its users that they are personally and directly immersed in an interactive space other than the one they physically inhabit.

Virtual Environments at the NASA Ames Research Center



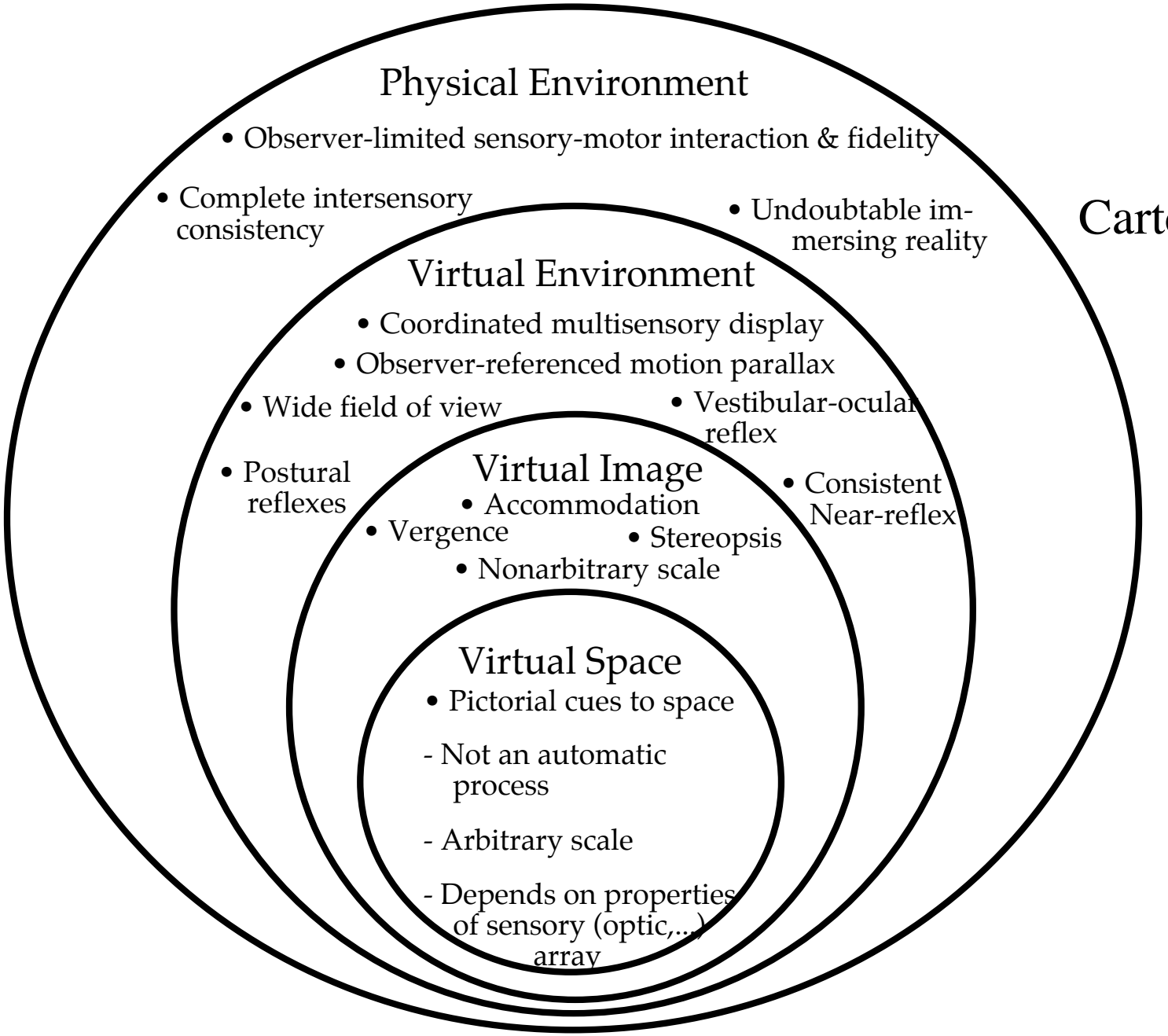


~1987 **2005**

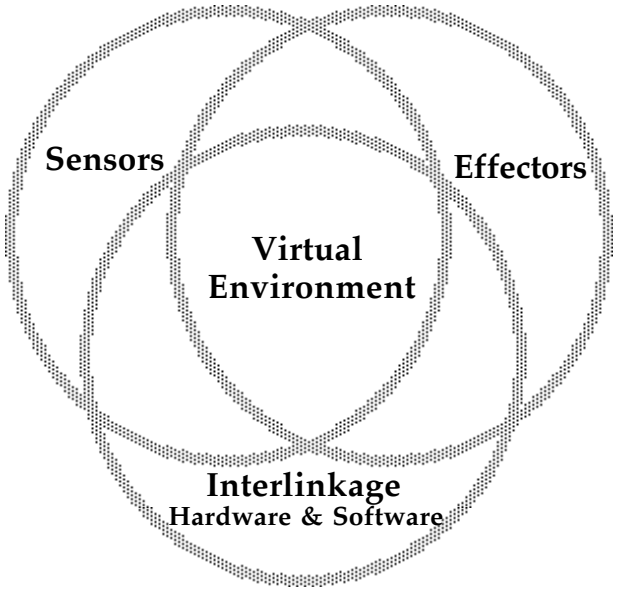
What's new?

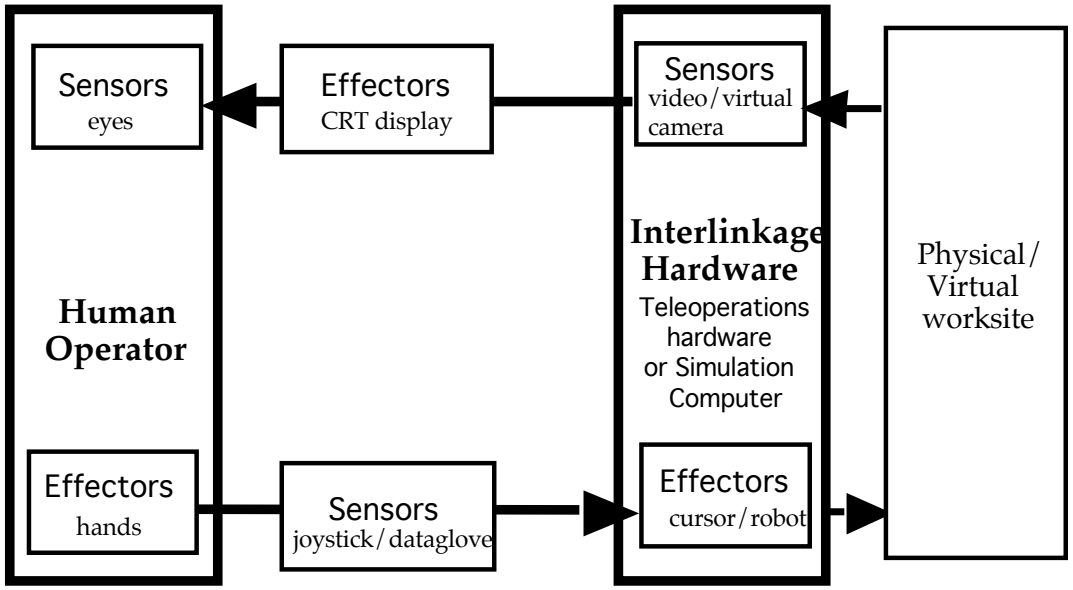
- Truth in advertising
- Much better display fidelity and databases
- Real applications

Information & Interactivity in Virtual Environments



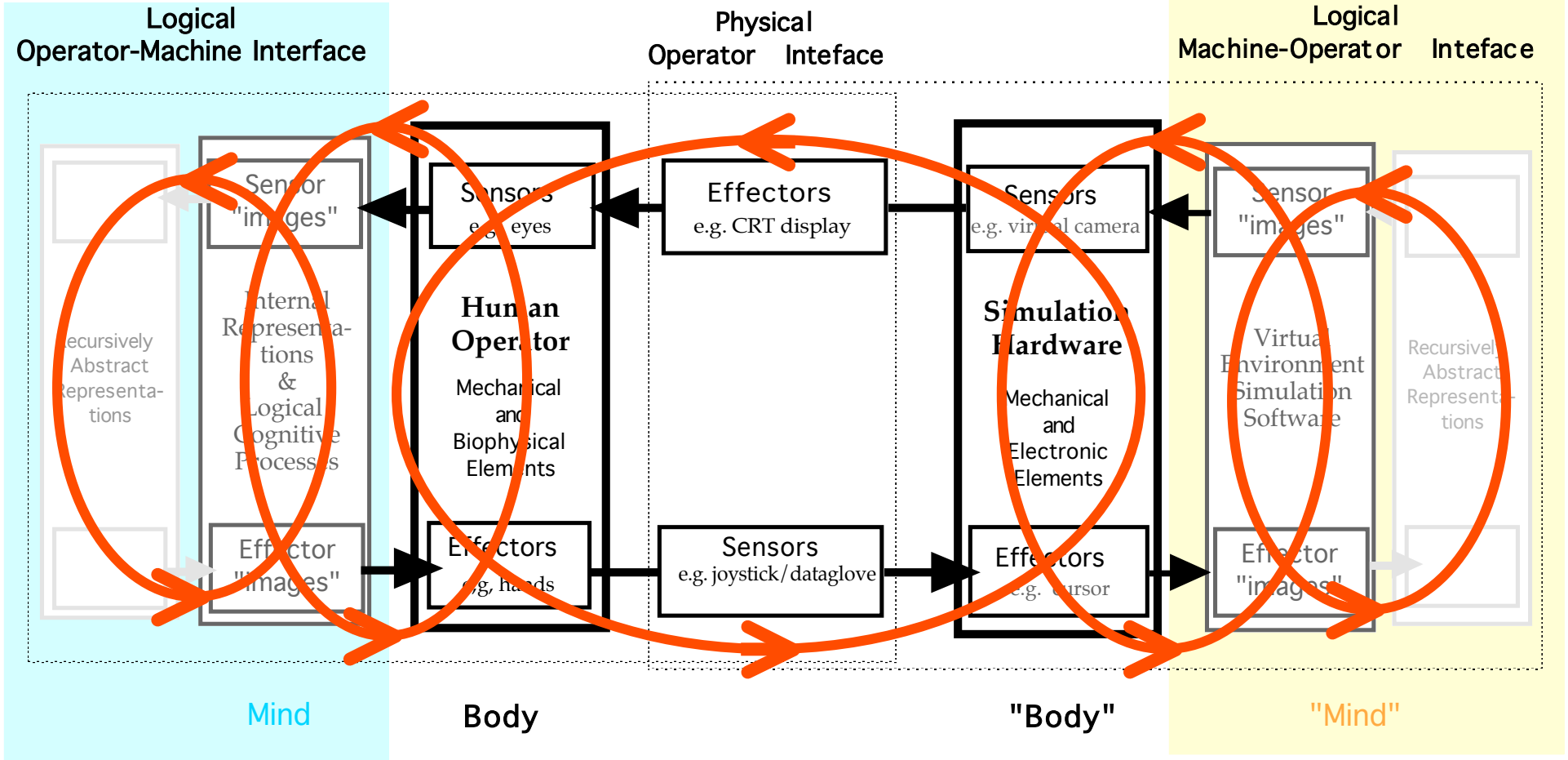
Physical Decomposition of a Virtual Environment





Ellis, S. R. (1993) What are virtual environments? *Computer Graphics and Applications, 14,* 1, 17-22.

Information Flows in Virtual Environment Simulation



Dimensions of User Interaction in a Virtual Environment

Quality (sensory modality): vision, audition, haptics

Space (location): geometry/kinematics

position, orientation, frame or reference

Time: sampling, temporal spectral content, lags and latencies

Meaning: Goals, set points, memory

Features of Temporal Interaction in a Virtual Environment

Frequency of a variable change

spectral content, predictability, trackability?

Sampling of a variable

filtering, aliasing artifacts

Latency of detection of variable change

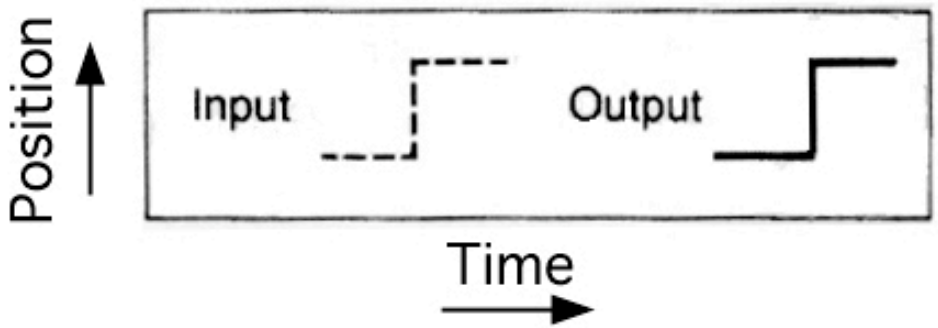
lag properties, delay time, delay variability

Control of reaction to variable change

Management of dynamic disturbances

noise, predictive filters, predictive display, management artifacts

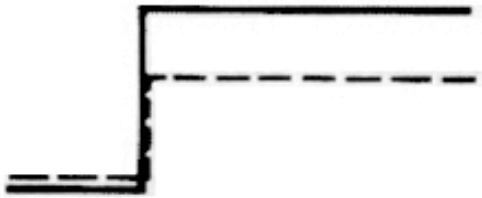
Some System Elements



(a) Pure gain

$o(t) = ki(t)$

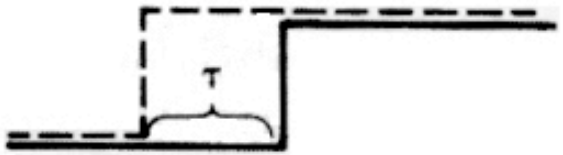
$O = kI$



(b) Pure time delay

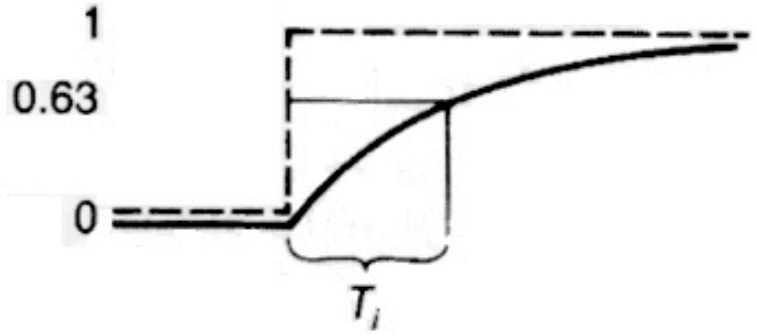
$o(t) = i(t - \tau)$

$O = e^{-\tau s} I$

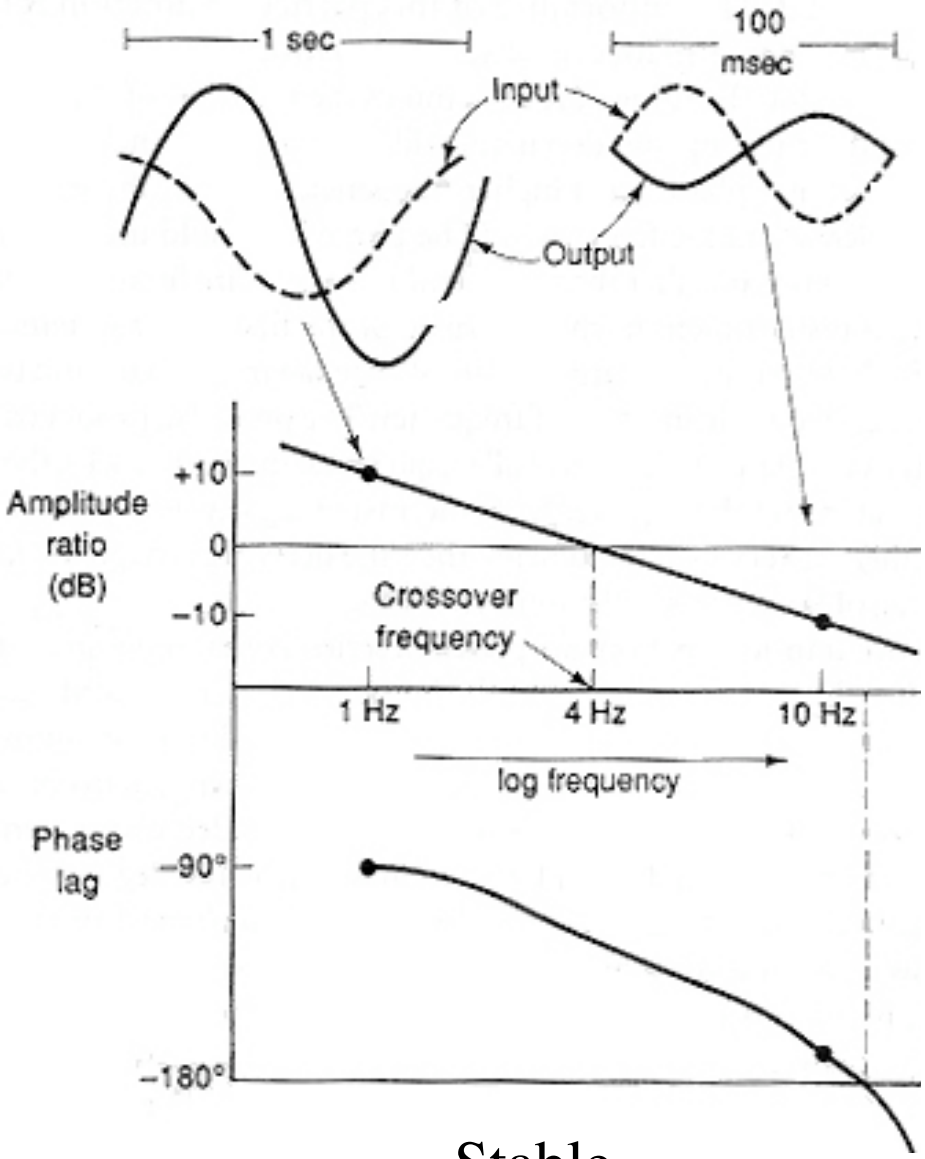


(c) Exponential lag

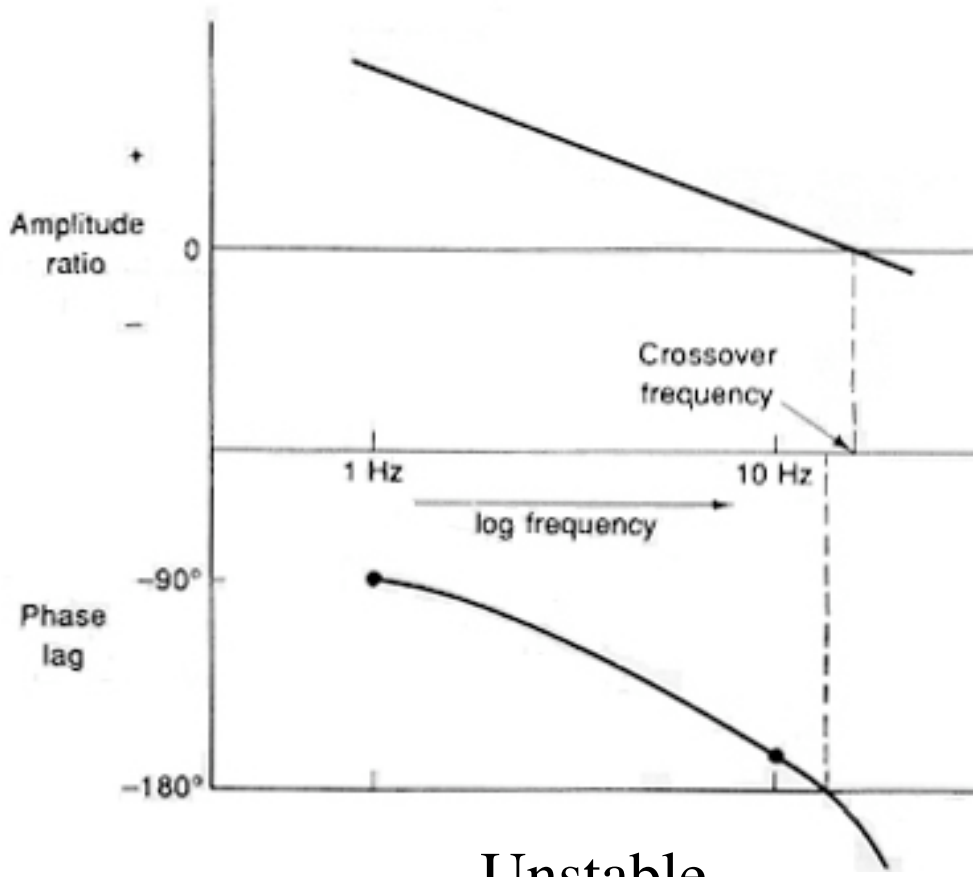
$$O = \frac{I}{T_i S + 1}$$



Lag and stability as seen in the Bode Plot of a Tracked Signal



Stable

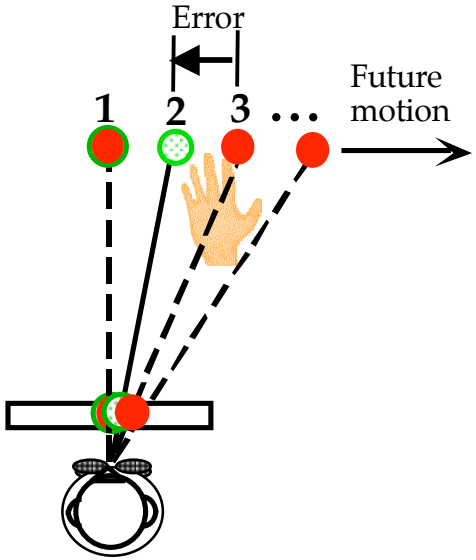


Unstable

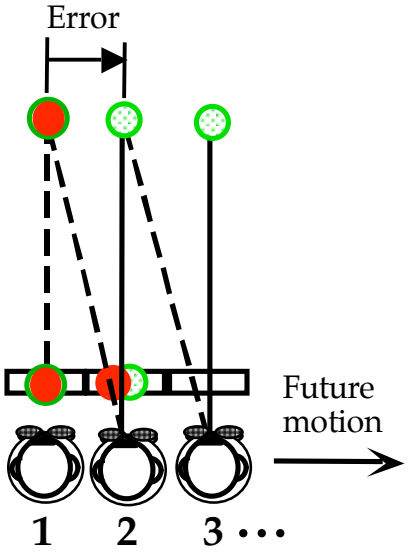
Some Effects of Rendering Latency

Presented via Head-mounted Displays

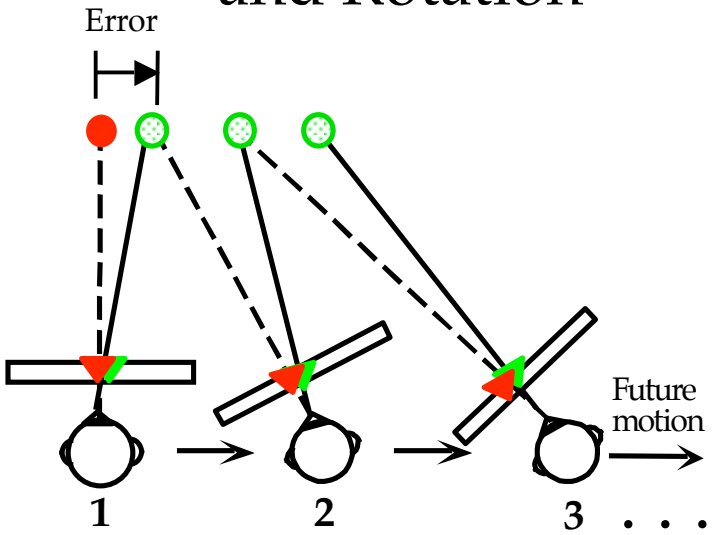
Hand Translation



Head Translation



Head Translation and Rotation

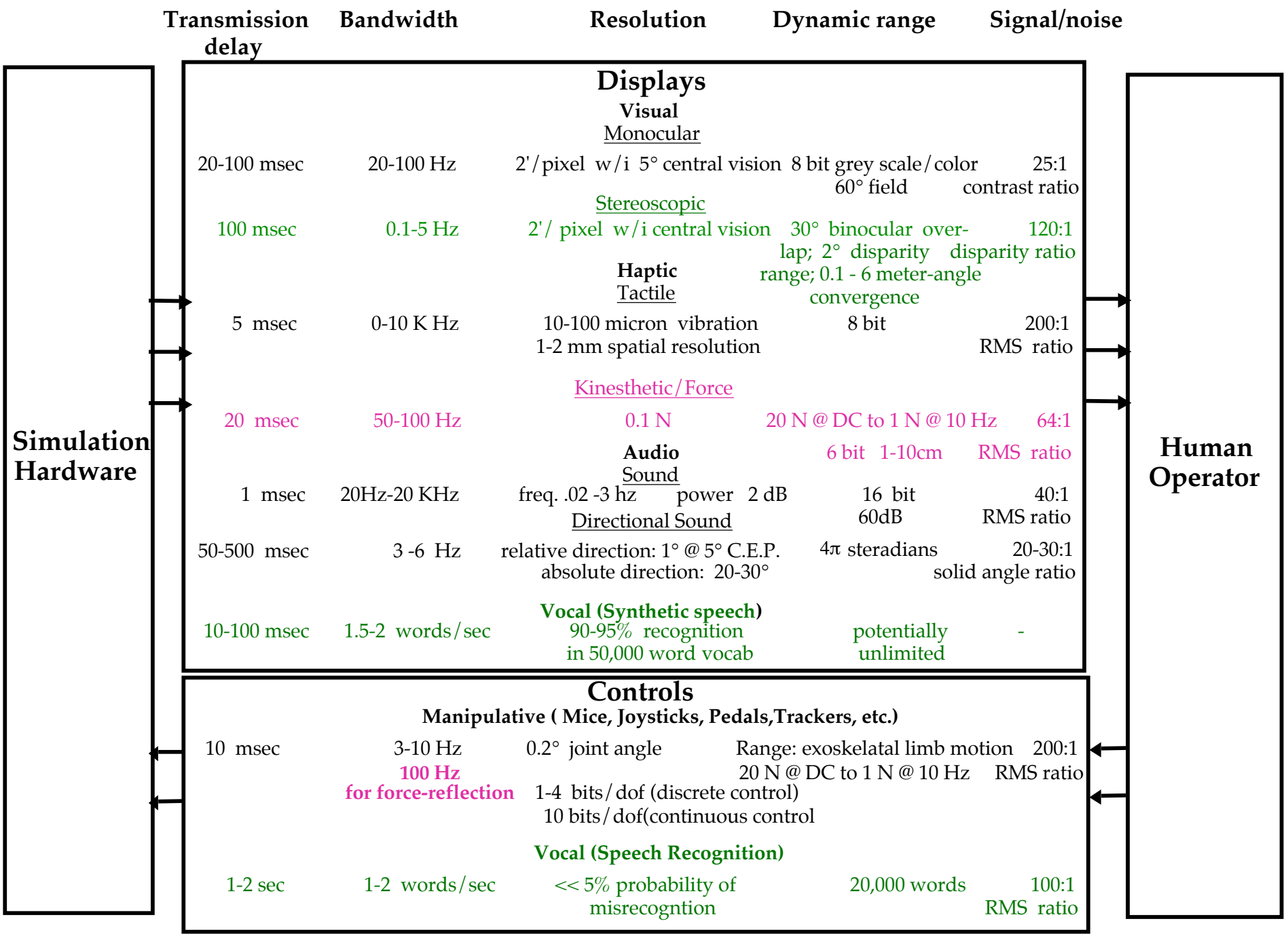


Positional uncertainty due to latency & low update rate makes it difficult for the subject to keep the tetrahedron w/i the randomly moving cube

Higher frame rate and reduced latency improve tracking

3D Tracking of moving cube nominal 20 Hz & base + 6 frames latency

3D Tracking of Moving Cube Nominal 20 Hz & Base Latency



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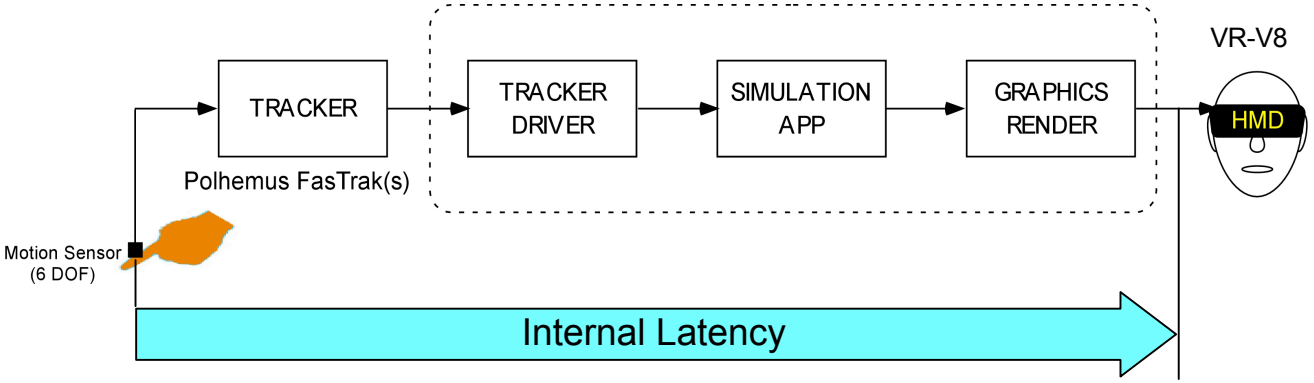
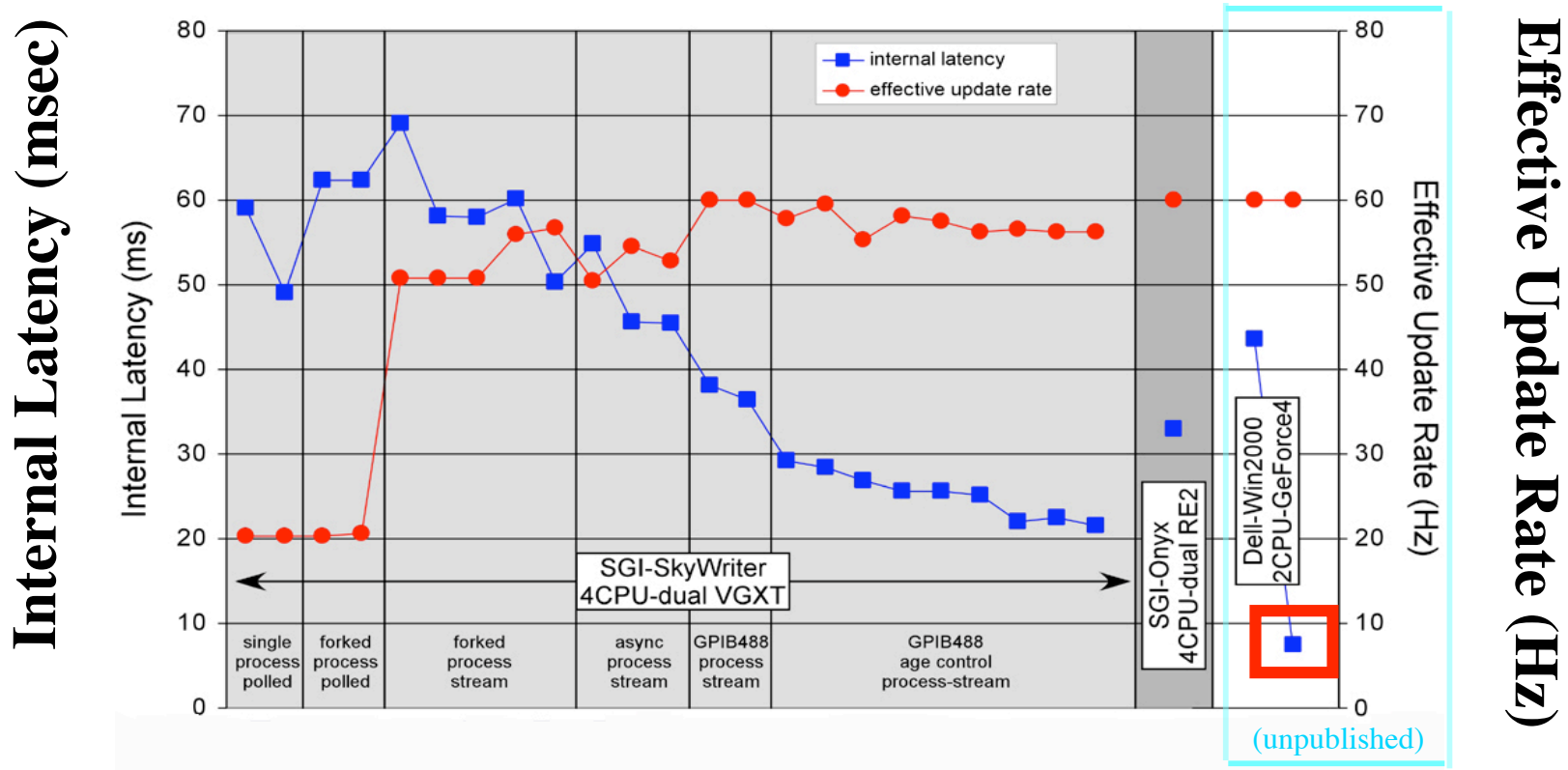
System Latency with various Polhemus Installation Environments



$$E(\tau_{end-to-end}) = \sum_{i=1}^{N} E(\tau_i)$$

$$\sigma^2_{end-to-end} = \sum_{i=1}^{N} \sigma_i^2$$

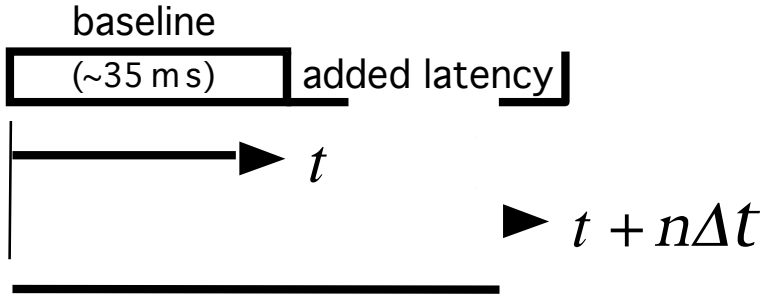
Measure and Model



Jacoby, R. H., Adelstein, B. D., Ellis, S. R. (1996) Improved temporal response in virtual environments through system hardware and software reorganization. Proc. of the SPIE 2653, Stereoscopic displays and virtual reality systems III Feb., 1996. pp. 271-284.

Latency Discrimination in Virtual Environments

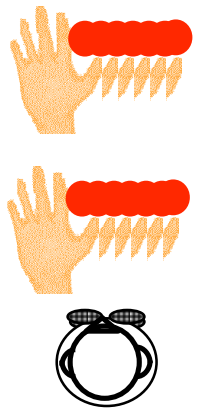
Two-Alternative Forced Choice Discrimination



t = {35, 101, 205}, Δt = 16.7 ms
n = {0,1,2,3,4,5,6}

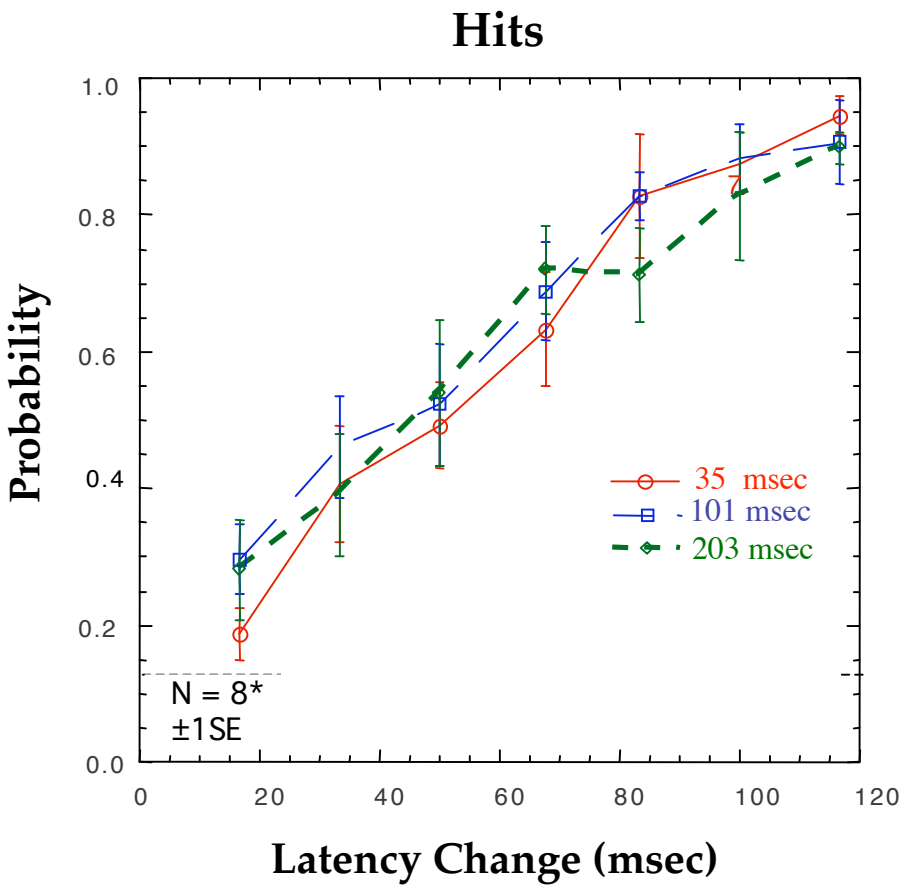
1st Condition \ 2nd Condition	T	$T+\Delta t$
$T+\Delta t$	.125 S	.375 N
T	.375 N	.125 S

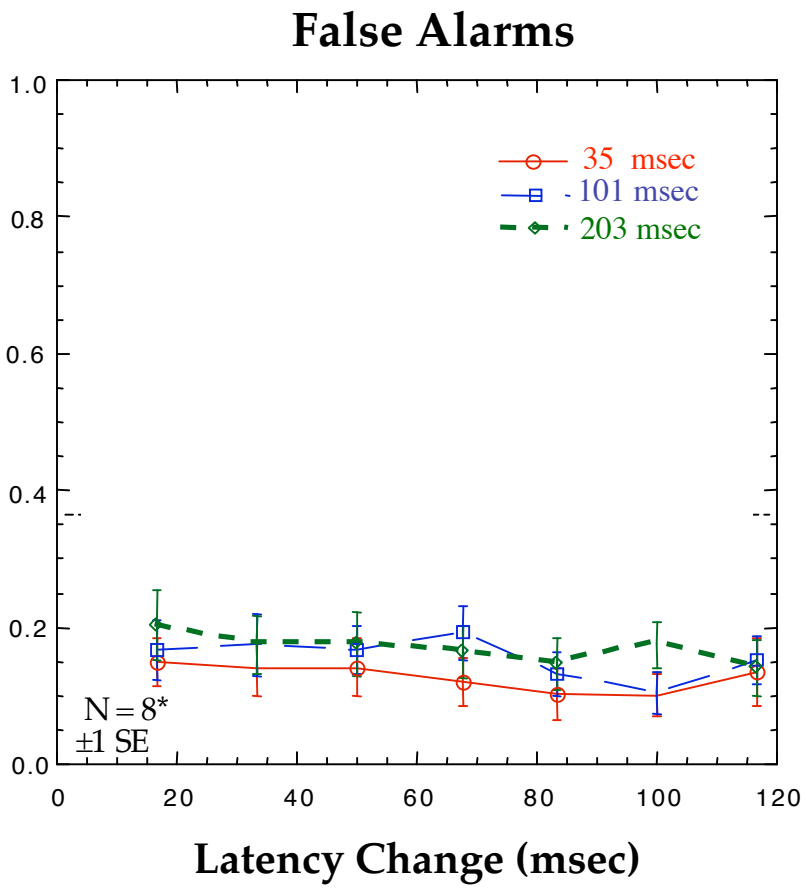
Randomized Stimulus Block



- Randomized blocks each base t (224 judgments)
- Sub-blocks each increment Δt (32 judgments)
- 3 repetitions per subject
- metronome-paced movement

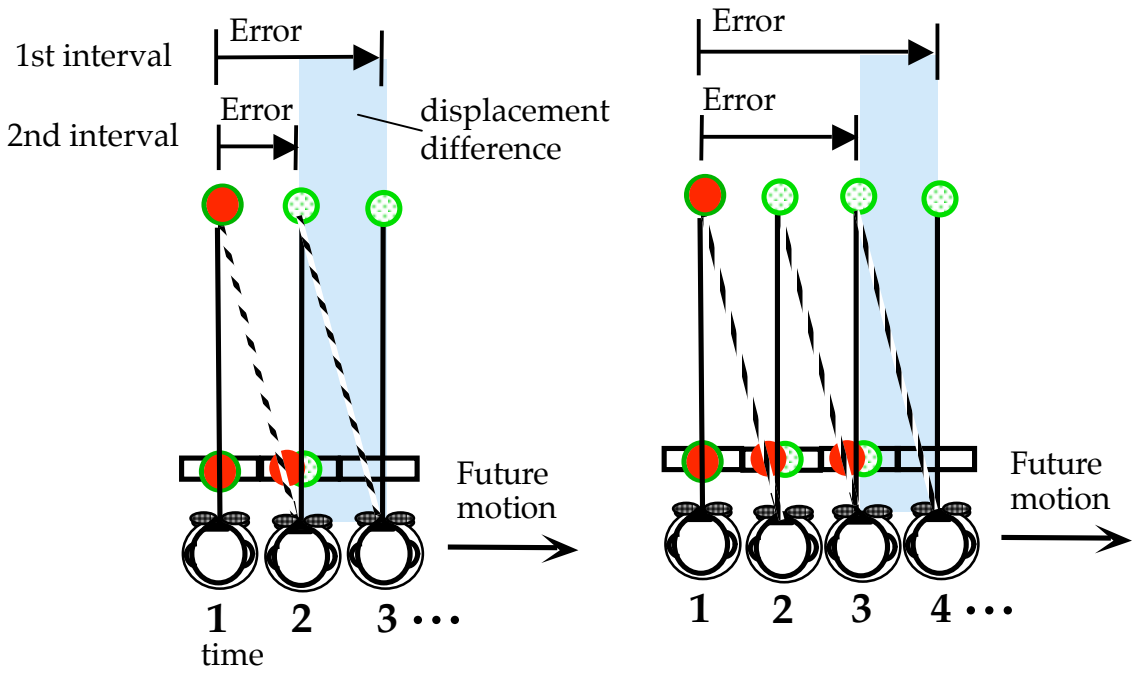
Observer Detection of Changes of Latency during Paced Hand Movement of Virtual Objects



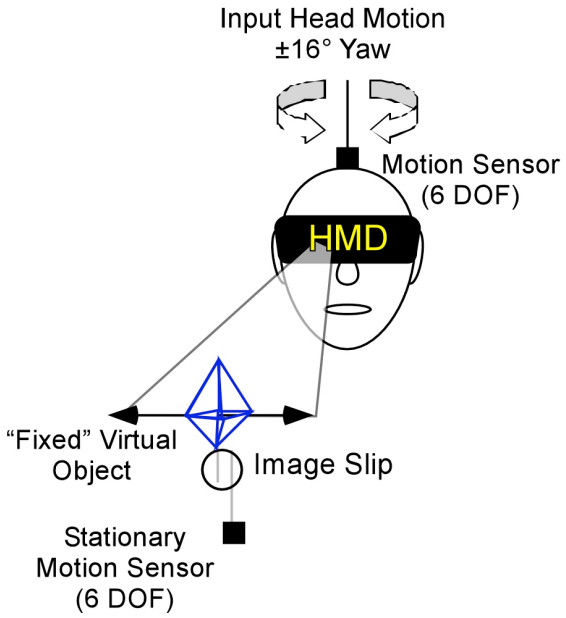


*Practiced observers in occluding HMD

Position Errors for Differing Base Latencies but Equal Increments during Head Movement

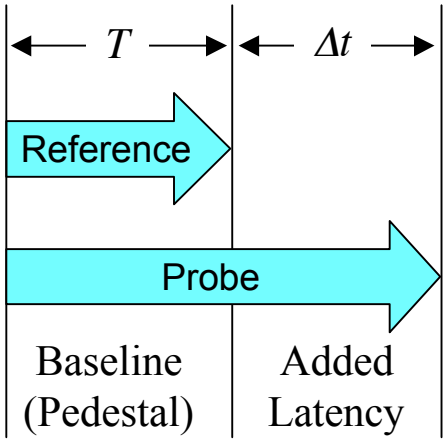


Latency During Head Movement



Factors

1. Reference latency T = {33, 100, 200}ms
2. Head pacing {Constant, Random}
   1 s ~30° side-to-side



Q (2AFC): Same or different?

Method of Limits (non-adaptive staircase)

Staircases start either

LOW

Δt = 0 ms (randomly 1 to 3 times)

and increase until "different"

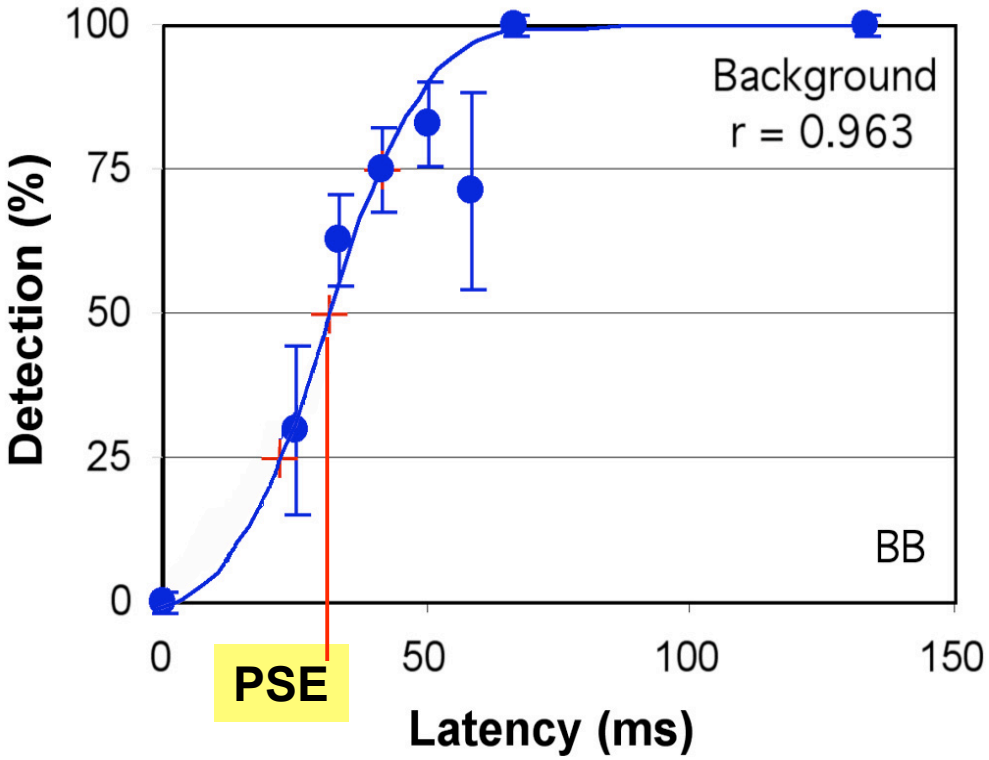
or

HIGH

Δt = {116.7,133.3,150.0} ms (randomly selected)

and decrease until "not different"

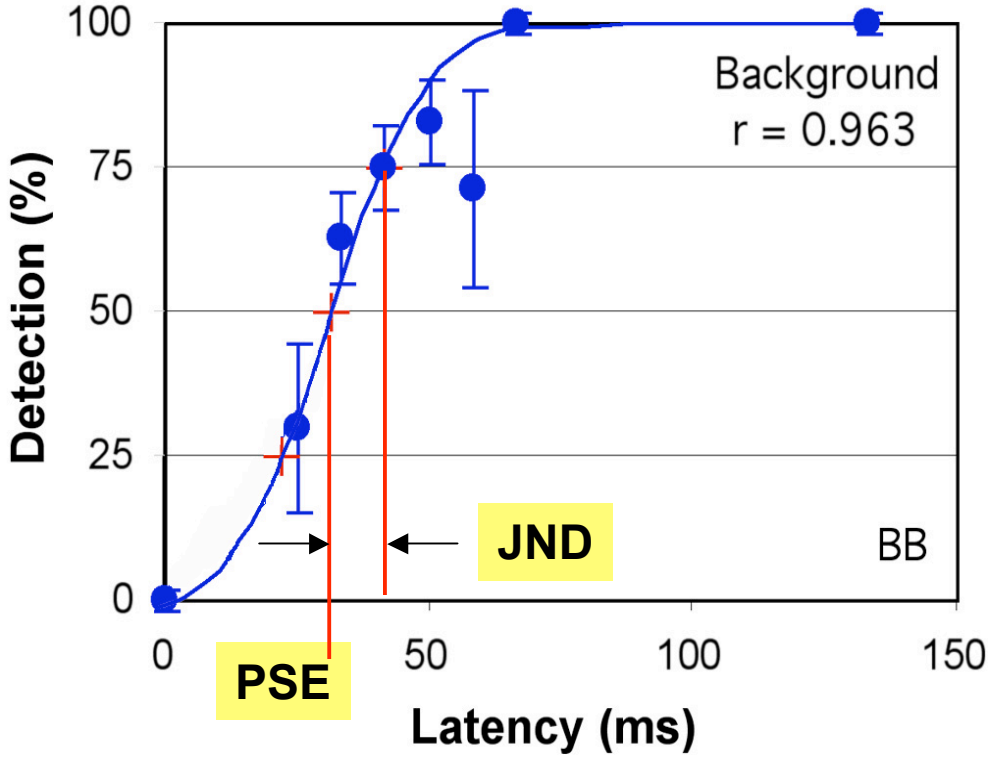
Data Analysis Procedure



- Individual observer's 2AFC responses are accumulated
  from 3 staircase pairs (6 staircases)
  for each display condition

- Probit Analysis → Psychometric Function
  → Gaussian Quartiles → PSE & JND

Psychometric Functions by Staircase



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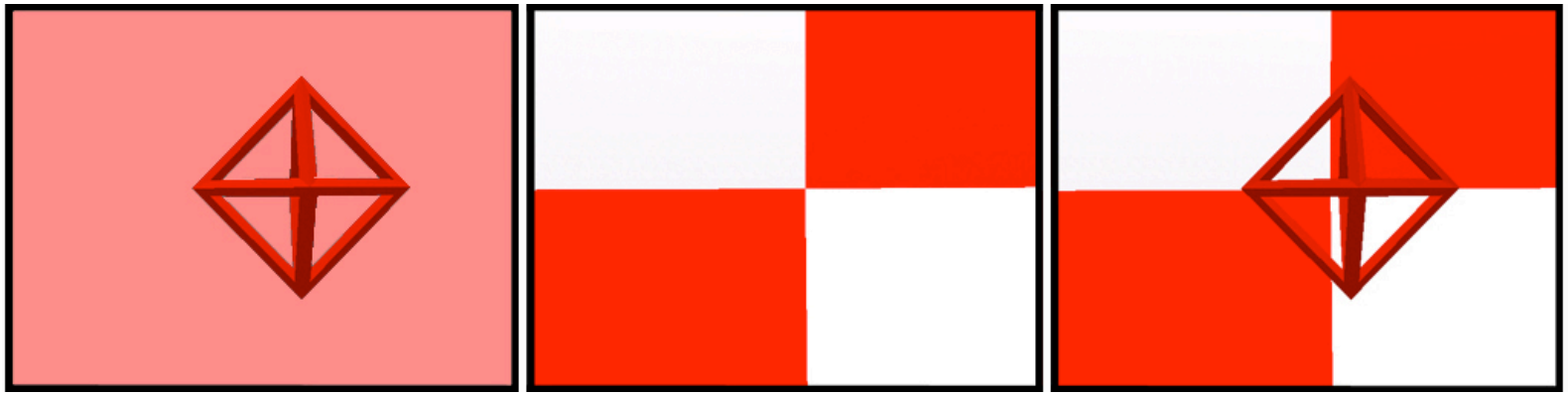
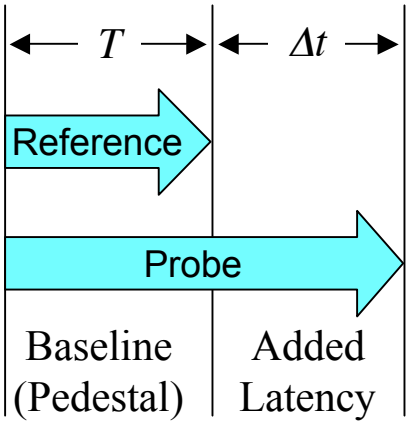
Latency Detection w/ Multiple Depths



Object
Octahedron at 0.43 m
(~ 20°)

Background
Sphere surface at 1 m
(30° per patch)

Both

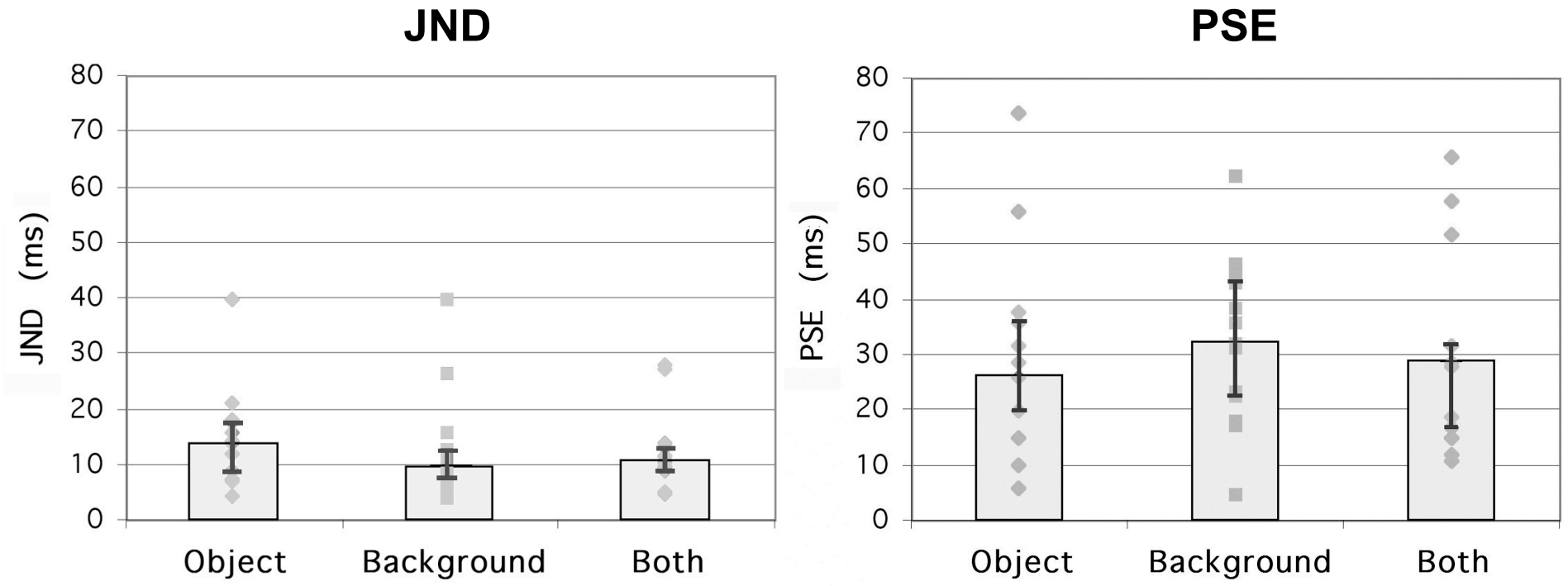


Q (2AFC): Same or different?

- Scene: 3 Levels pictured above
- Fully balanced for all 6 sequences of 3 stimulus levels
- Adaptive 2 Down, 1 Up staircases (71% threshold)
  _"Different" _ "Same" (8.3 ms step size)
- Interleaved pairs of staircases to prevent tracking
- Blocks of 3 consecutive staircase pairs

- Constant: 1 s audible pacing
- 30° side-to-side cued by 58% darkening

Latency Detection w/ Multiple Depths



Error Bars: Interquartile Range (13 observers)

Effects and Interactions for scene and sequence were not significant

Both parametric and nonparametric tests