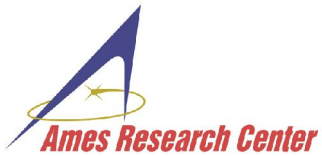


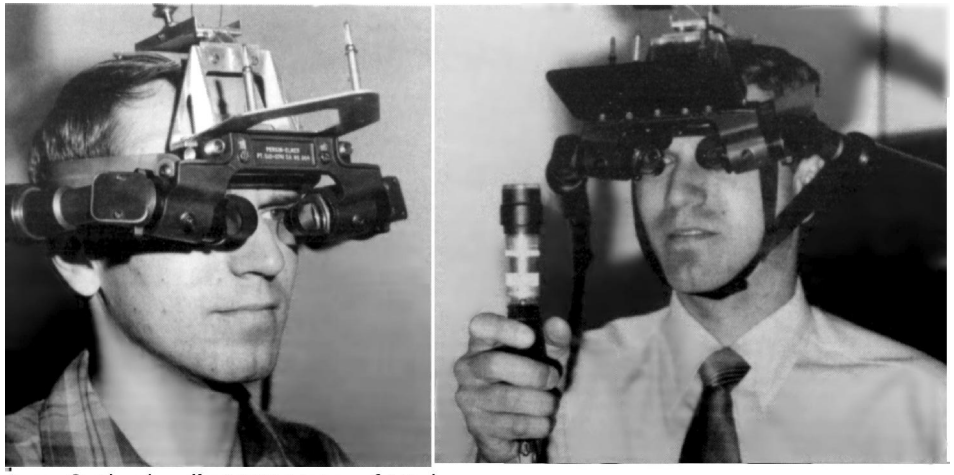
Visual Stability of Objects and Environments Viewed Through Head-Mounted Displays

Stephen R. Ellis & Bernard D. Adelstein
NASA Ames Research Center
Moffett Field, CA

1.
2.
3.
4.

Definition of a Virtual Environment

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

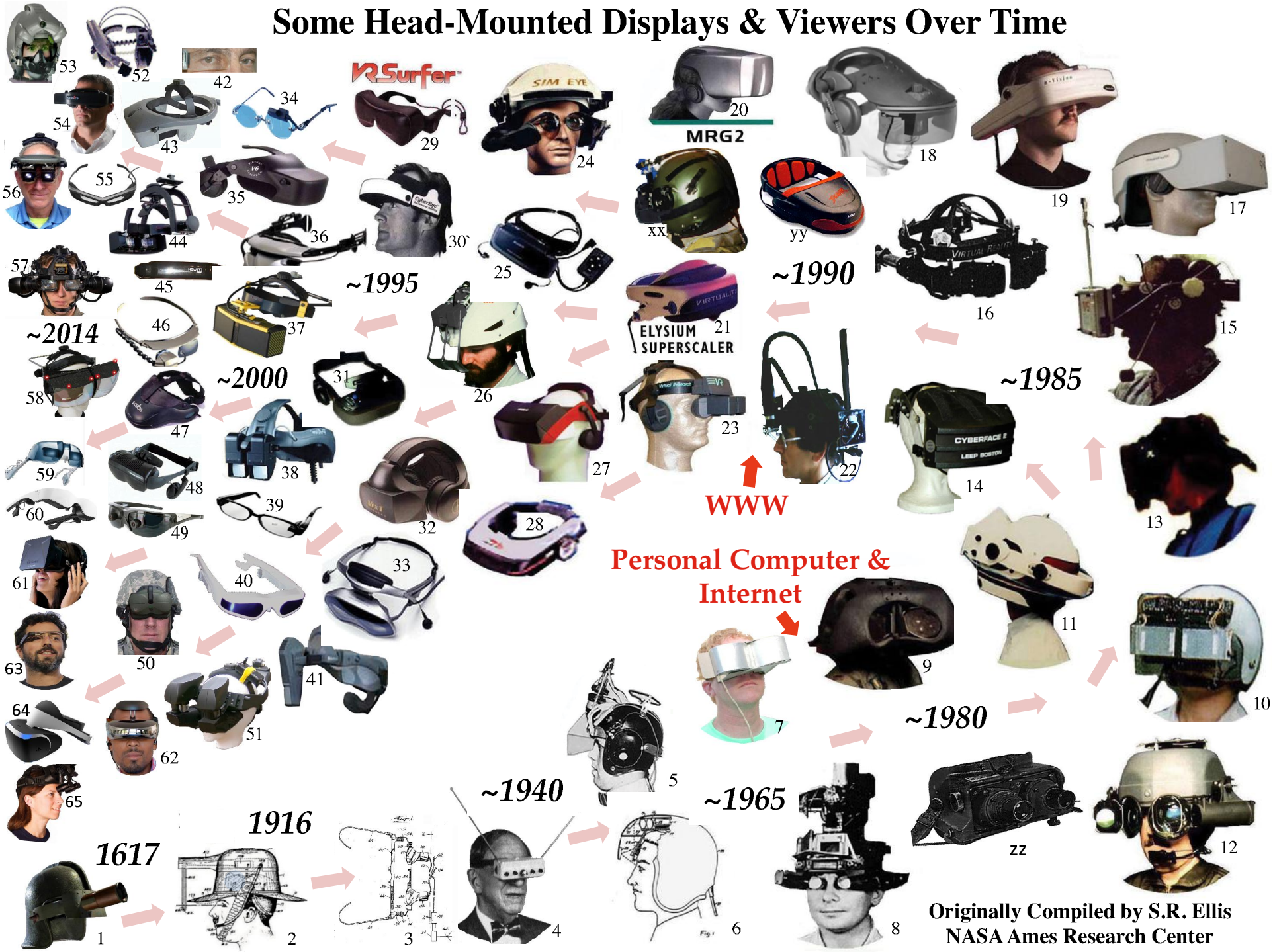


Ivan Sutherland's HMD Univ. of Utah

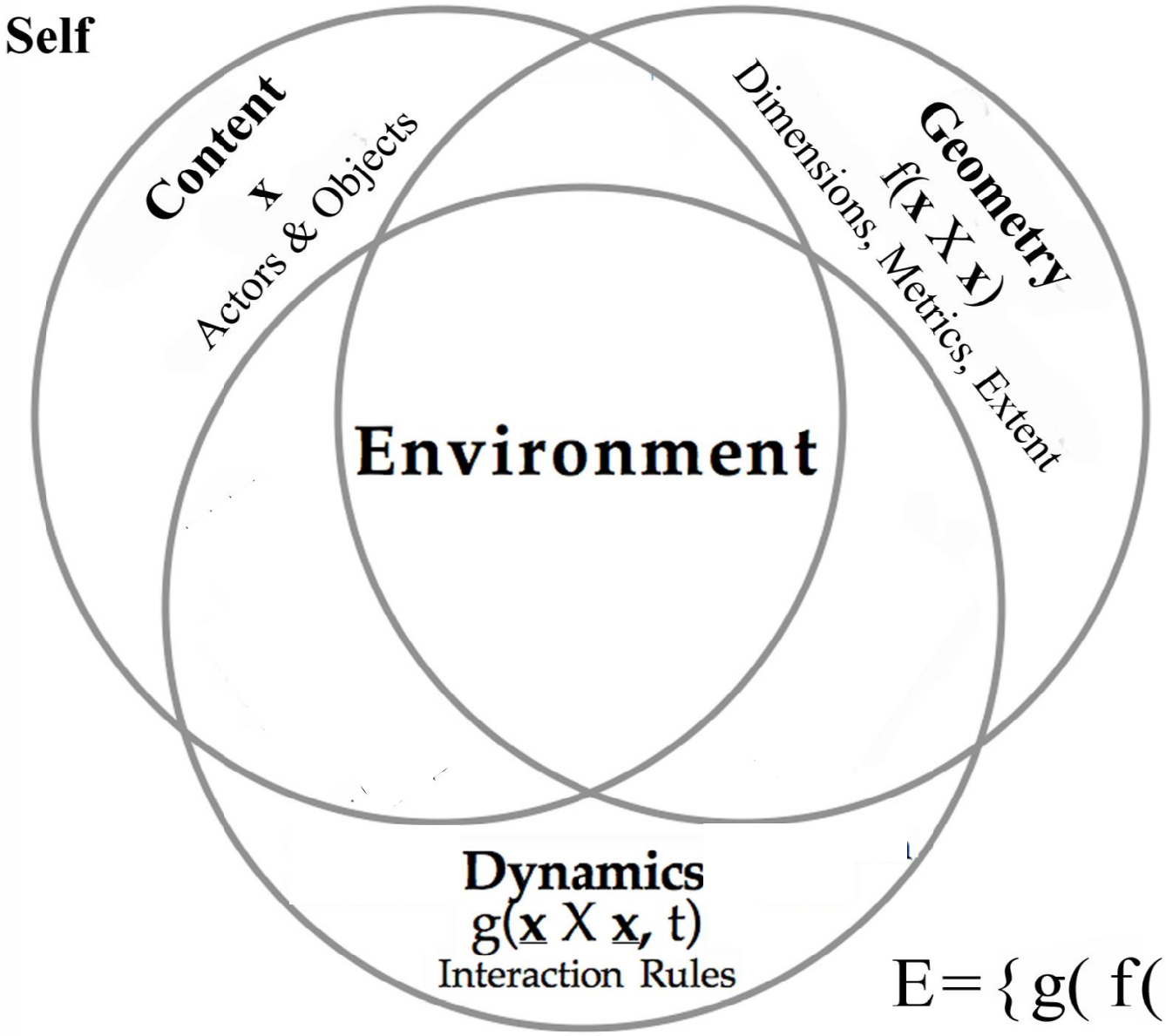
Ivan Sutherland's virtual environment *personal simulator*[1] circa 1965

[1]Haber, R. N. (1986). The simulation of high speed aircraft flight. *Scientific American, 255,*(July) 96-103.

Some Head-Mounted Displays & Viewers Over Time



Abstract Decomposition of an Environment

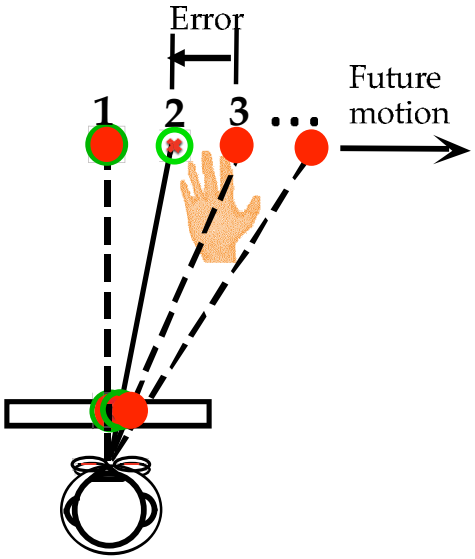


$$E = \{ g(f(\mathbf{x} X \mathbf{x}), t \}$$

Example of Path Following
Latency ~380 ms

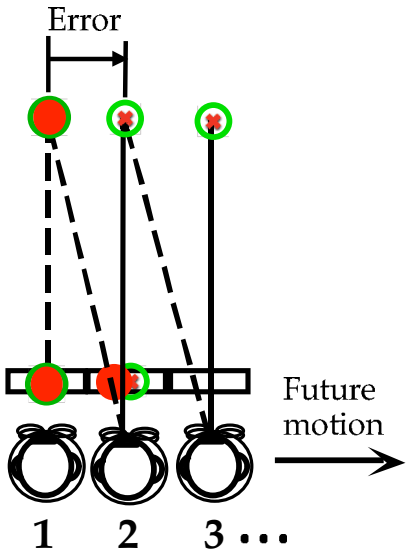
Intersensory Performance Effects
of Latency in A Virtual Environment

Hand Translation



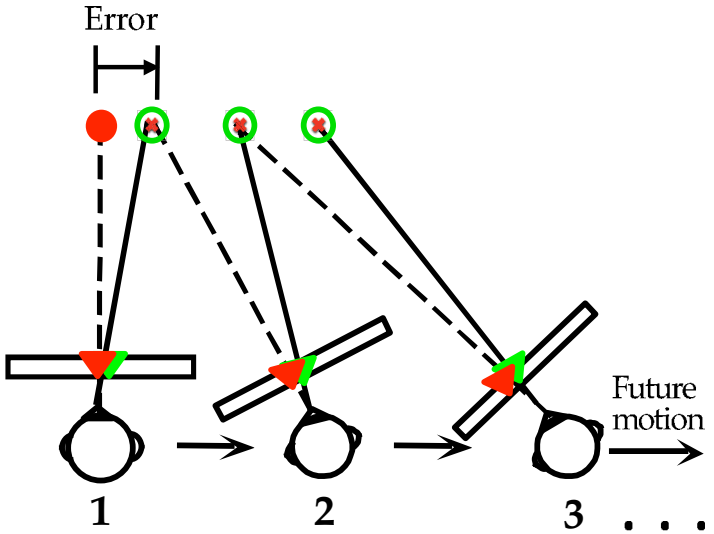
Error in the direction of motion

Head Translation



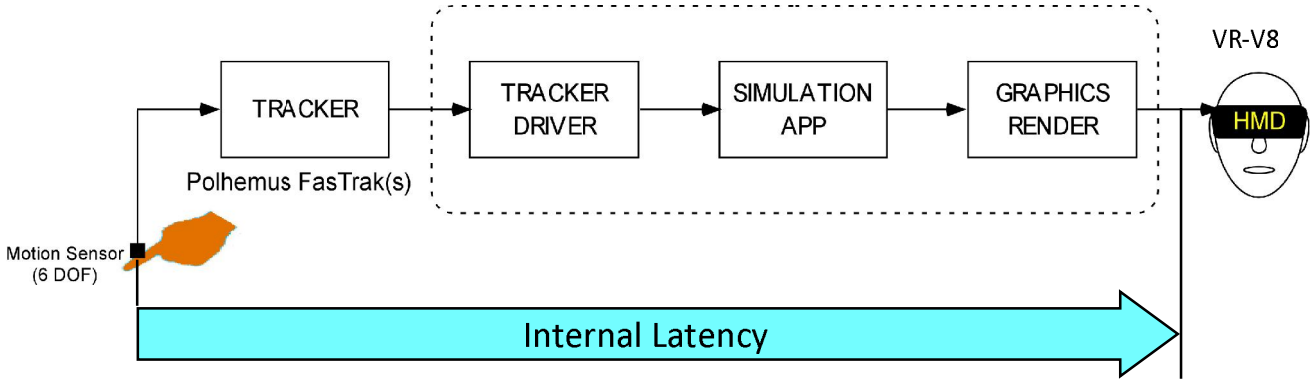
Error against the direction of motion

Head Translation and Rotation



Superposition of errors both in and against the direction of motion for translation and rotation

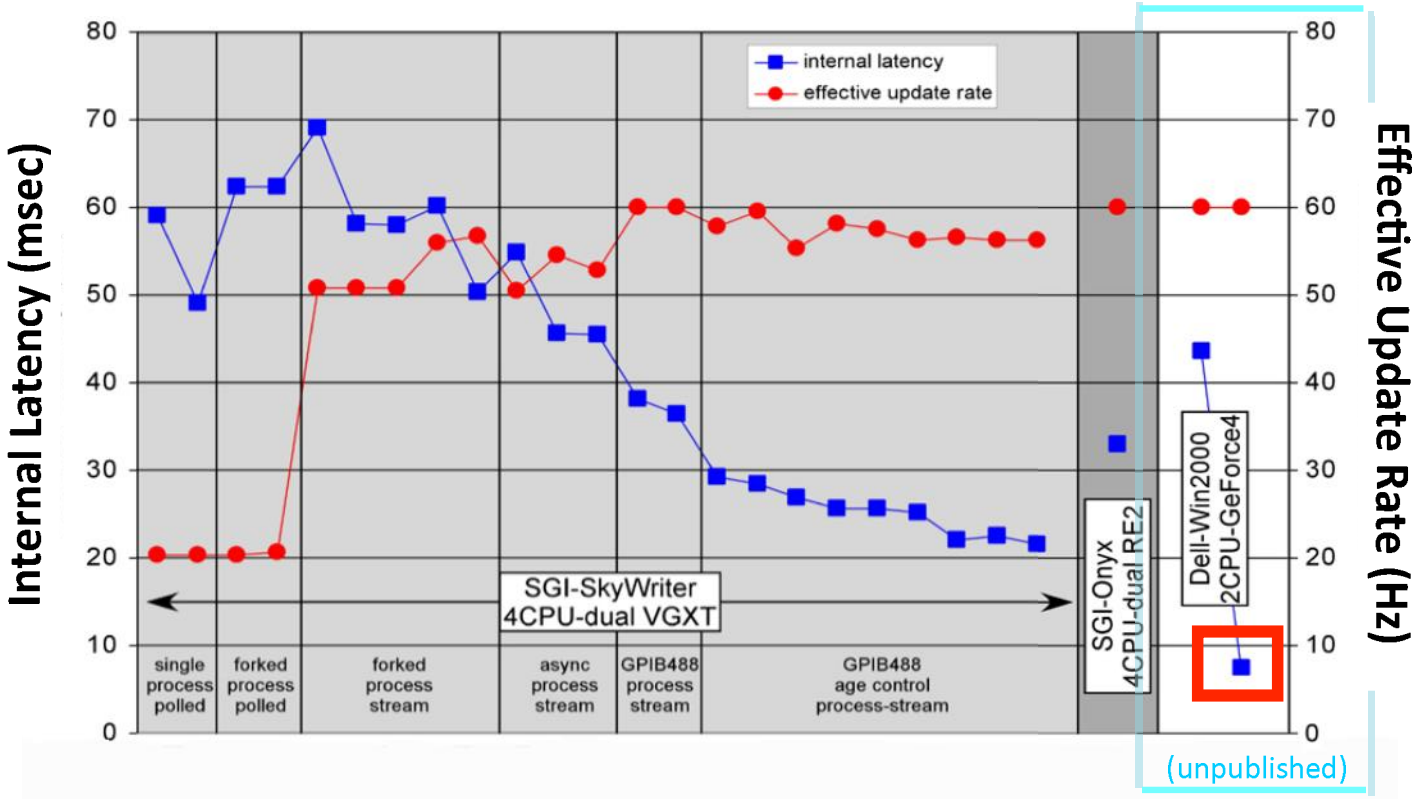
System Latency with some Polhemus-based Systems



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

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

Measure and Model



Jacoby, et al . (1996). Proc. of the SPIE 2653, Stereoscopic displays and virtual reality systems III Feb., 1996. pp. 271-284.

Example of Path Following
Low Latency ~1994

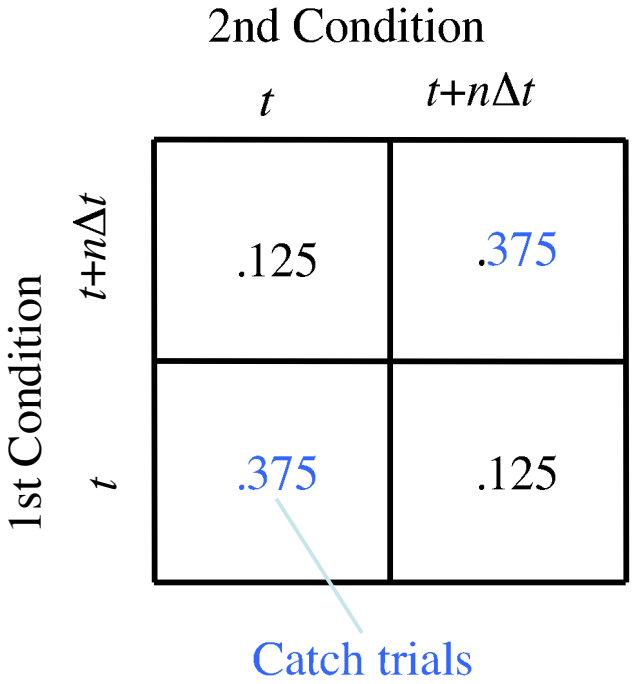
Some Characteristics of the Head Mounted Display System Used Or Where We Were ~ 1990? (at least some of us)

Weight		0.77 – 1.1 kg Thank you Sony !
Visual		
Resolution 1024 X 768	→	~700 X 525 **check VIEW hardware**
Brightness min/max		6/68 cd/m^2 ~ w/r see-thru background
FOV		20°-32° diameter
Contrast(Michelson)		0.6 – 0.8 ~ w/r see-thru background
Color		Monochrome
Accommodative Demand		1 diopter (adjustable)
Stereo resolution		~2-3 arcmin
Stereo overlap		100%
IPD		60 -78 mm
Tracking & Rendering		Polhemus Fastrak/vairous SGI/PCs
Accuracy		~ ±5 mm, 1-2°
Resolution		< 1 mm, < 0.24°
Position sensing:		120 Hz
Frame (Update) rate:		60 Hz
Latency		~45 ms (now 8-25 ms)
User Interface		
None: voice to computer operator/HMD assistant		

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}

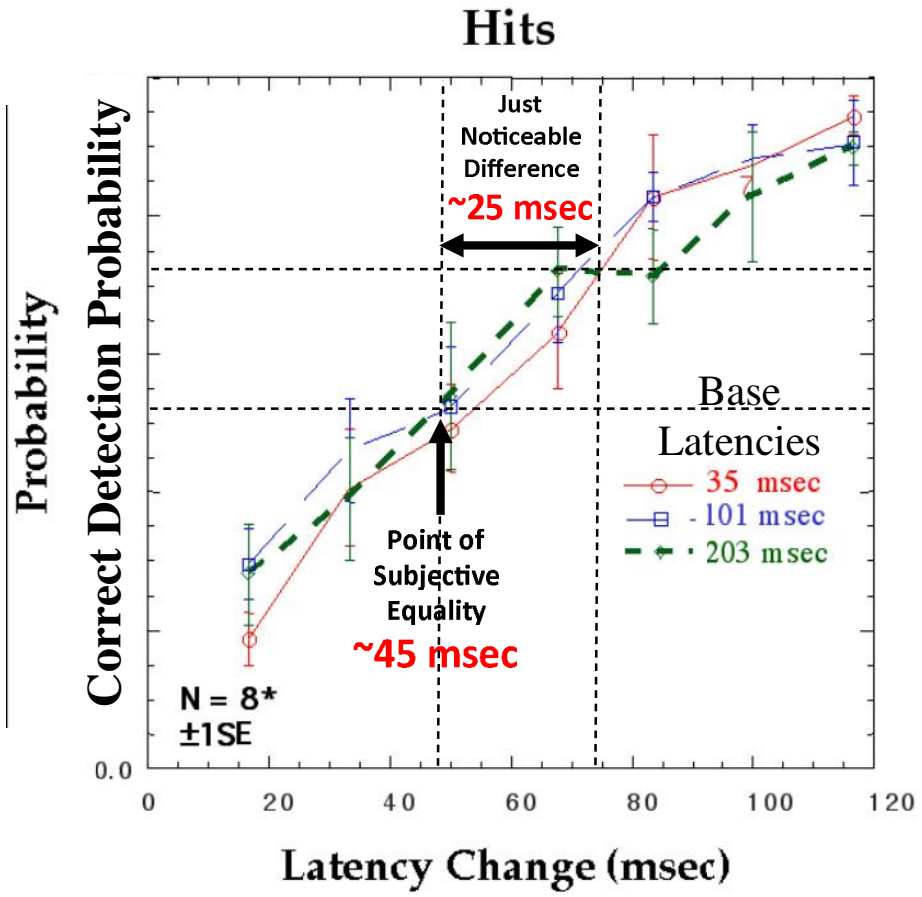


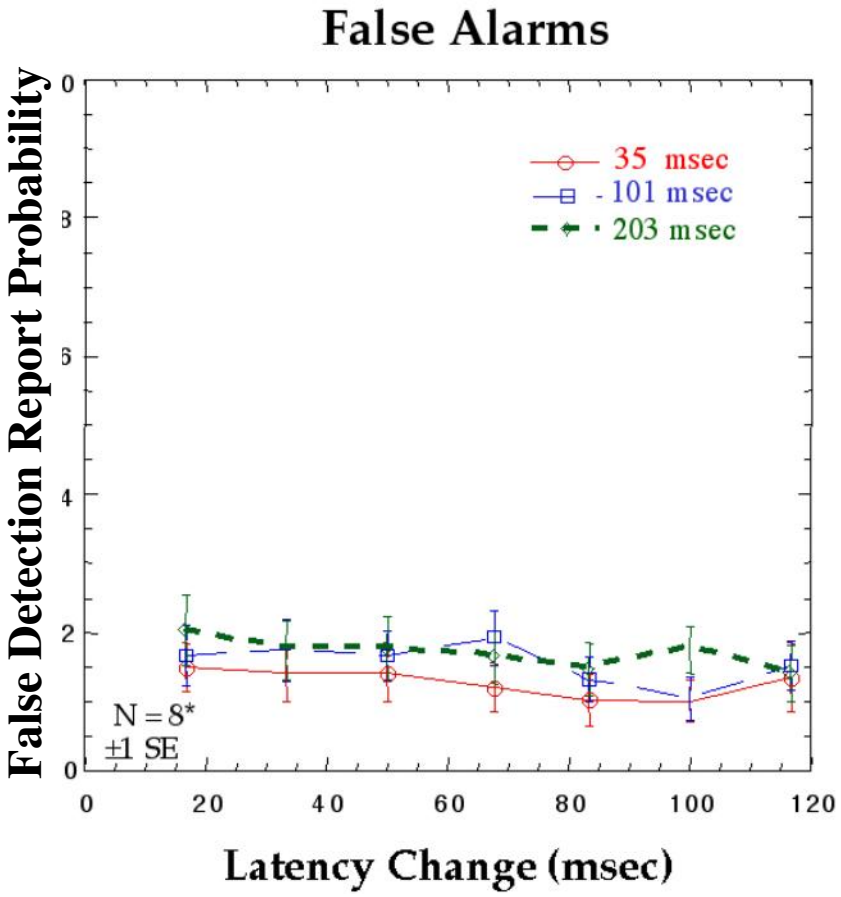
- Method of constant stimuli
- Randomized blocks each base *t* (224 judgments)
- Sub-blocks each increment Δt (32 judgments)
- 3 repetitions per subject
- Metronome-paced movement 0.5 Hz

(Ellis, Young, Ehrlich , & Adelstein, 1999)

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

No Webers Law: $\Delta t_l / t_l$ not constant!

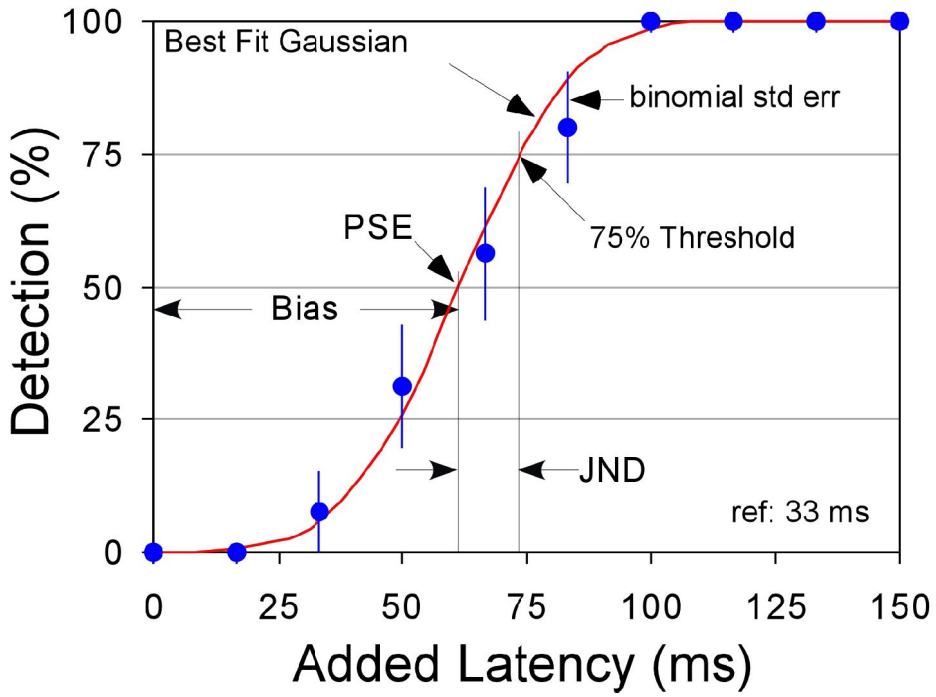




*Practiced observers using an occluding HMD

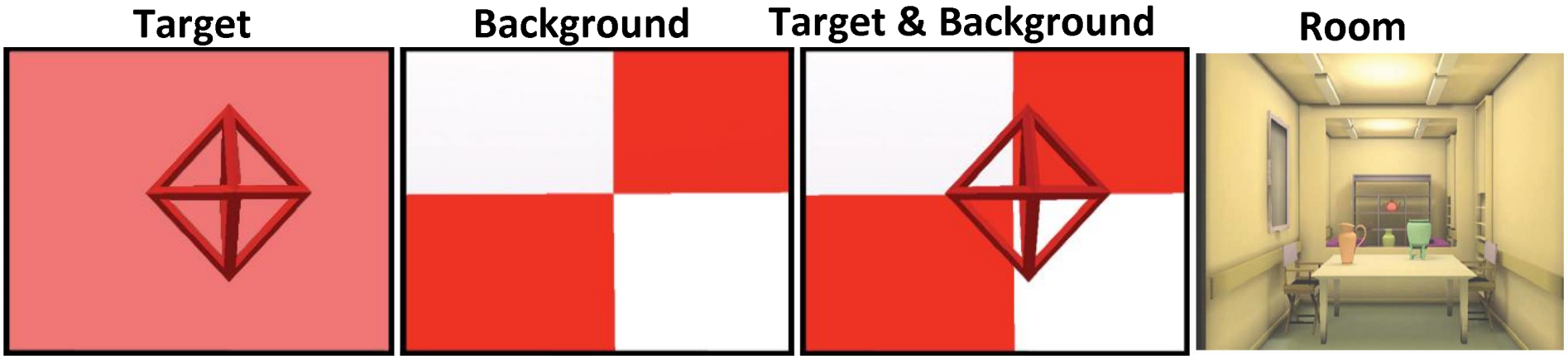
Ellis, Stephen R. , Young, Mark J. , Ehrlich, Sheryl M., and Adelstein, Bernard D. (1999) Discrimination of changes of latency during voluntary hand movement of virtual objects. Proceedings of HFES. pp. 1182-1186.

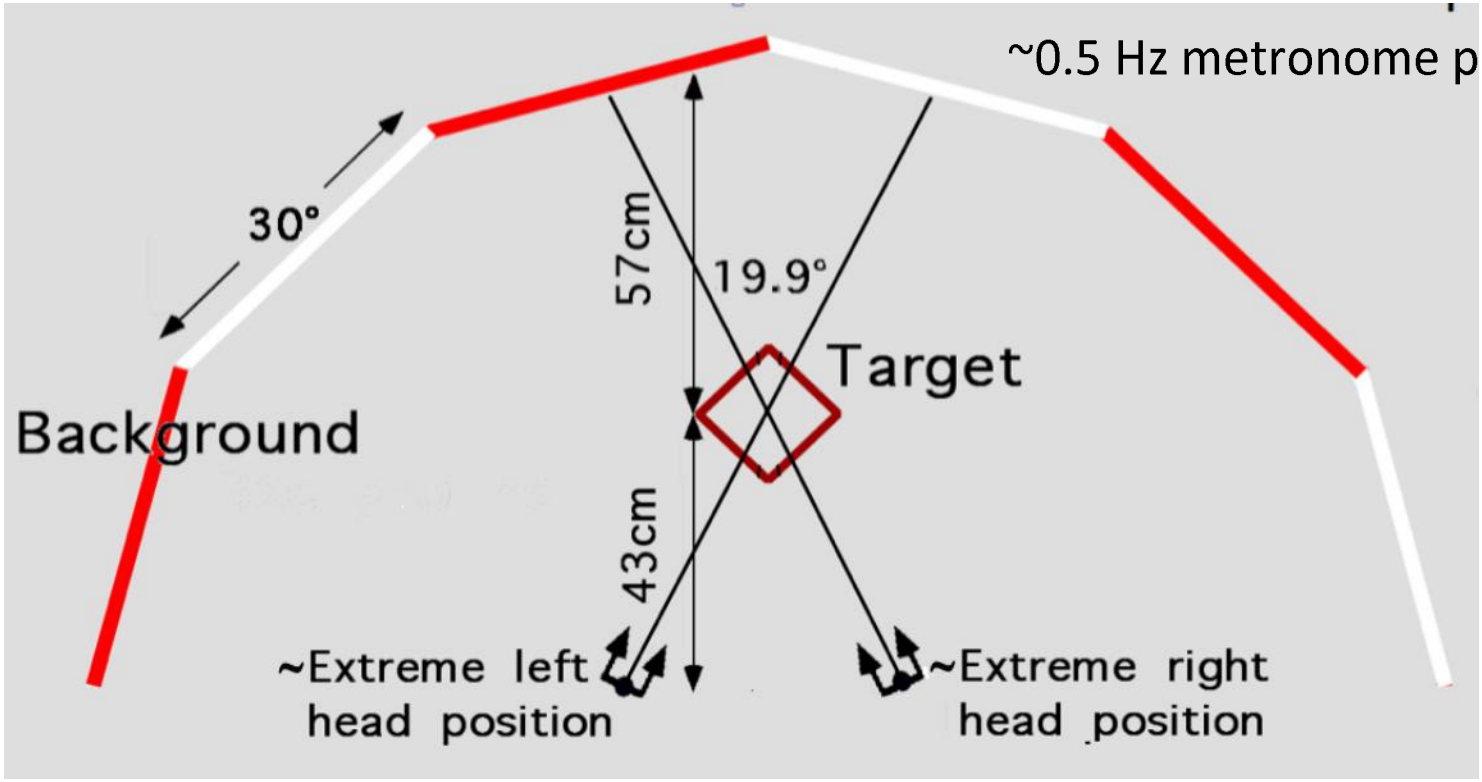
Latency Detection One Subject Making Head Rotations Data Analysis Procedure



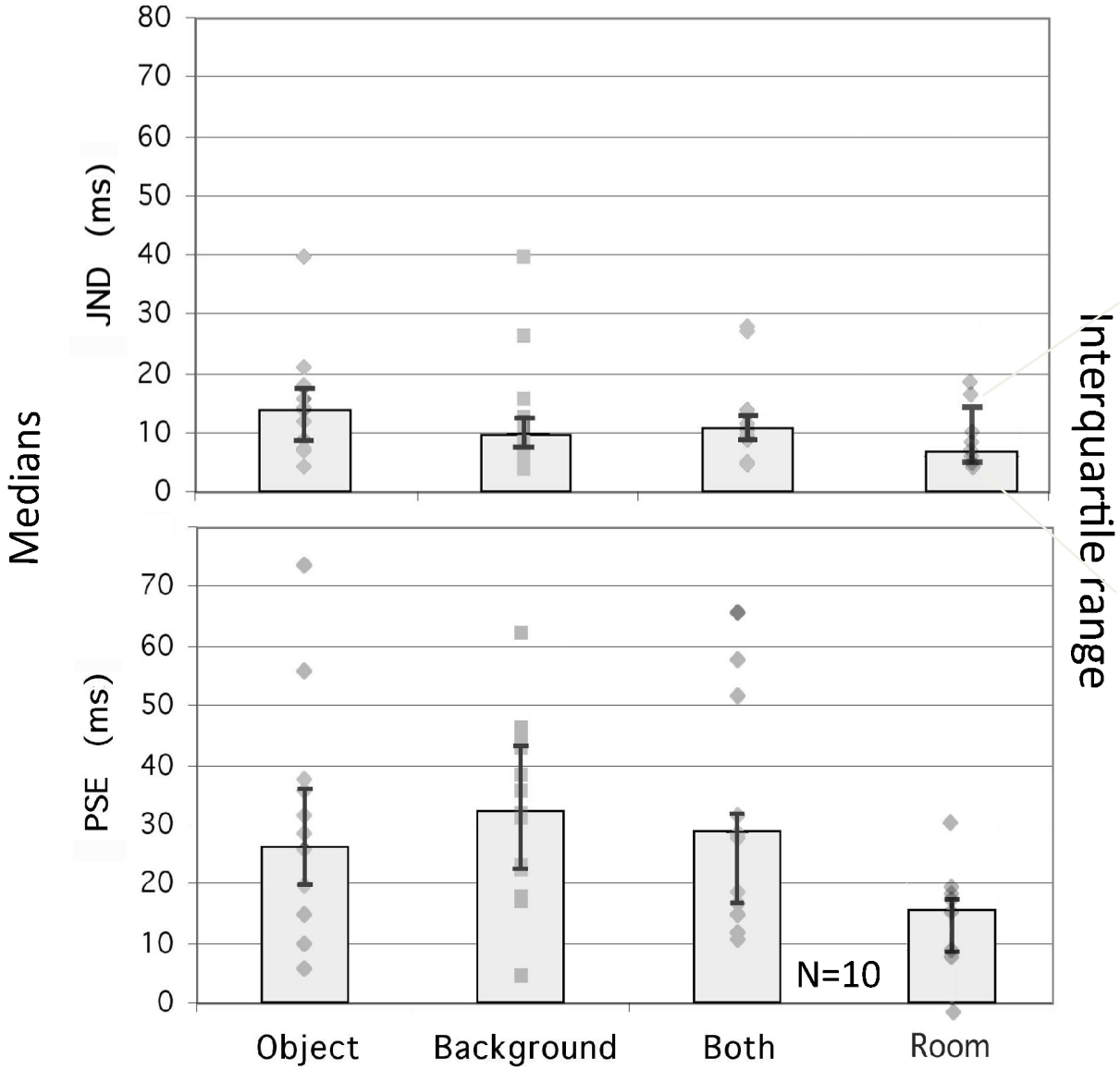
- Accumulated responses from 10 ascending 10 descending runs
- Probit Analysis→ Gaussian Quartiles→PSE & JND

Latency Discrimination During Head Movement: Graphic Models





Latency Discrimination during Head Movement



cf
Hand
Movement
JND ~25 msec

cf
Hand
Movement
PSE ~45 msec

Ellis et al (2004) Proc. of the Human Factors and Ergonomics Society pp. 1836-1841.


HIGH RESOLUTION: WHERE ARE WE?
DK1 100% overlap
640x480 @ 110 degrees
~6 pixels / degree
DK2
960x1080 @ 100 degrees
~10 pixels / degree
100% overlap Vive
1080x1200 @ 105 degrees
~10 pixels / degree
VRelia Pro G1
1920x1080 @ 123 degrees
~15 pixels / degree
Sony Morpheus
Courtesy and after Mark Miné, Dir. Disney, Disney Research

Some Imagined Performance Specs for HMDs but especially for dream Augmented Reality