# Semantic Analysis of Mobile Eyetracking Data

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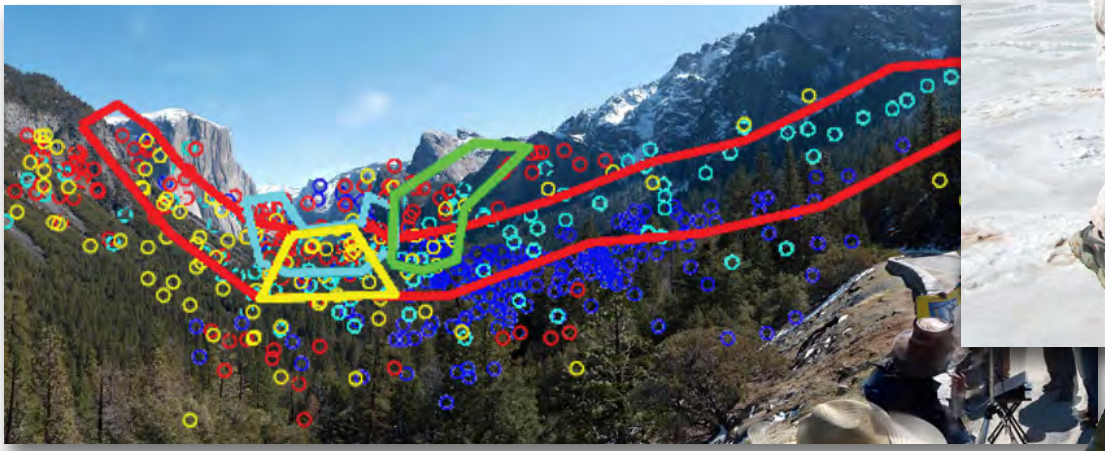


1st International Workshop on Pervasive Eye Tracking and Mobile Eye-Based Interaction

Many problems suggest themselves to the psychologist whose solution would be greatly furthered by an accurate method of recording the movements of the eye.

# A METHOD OF RECORDING EYE-MOVEMENTS.

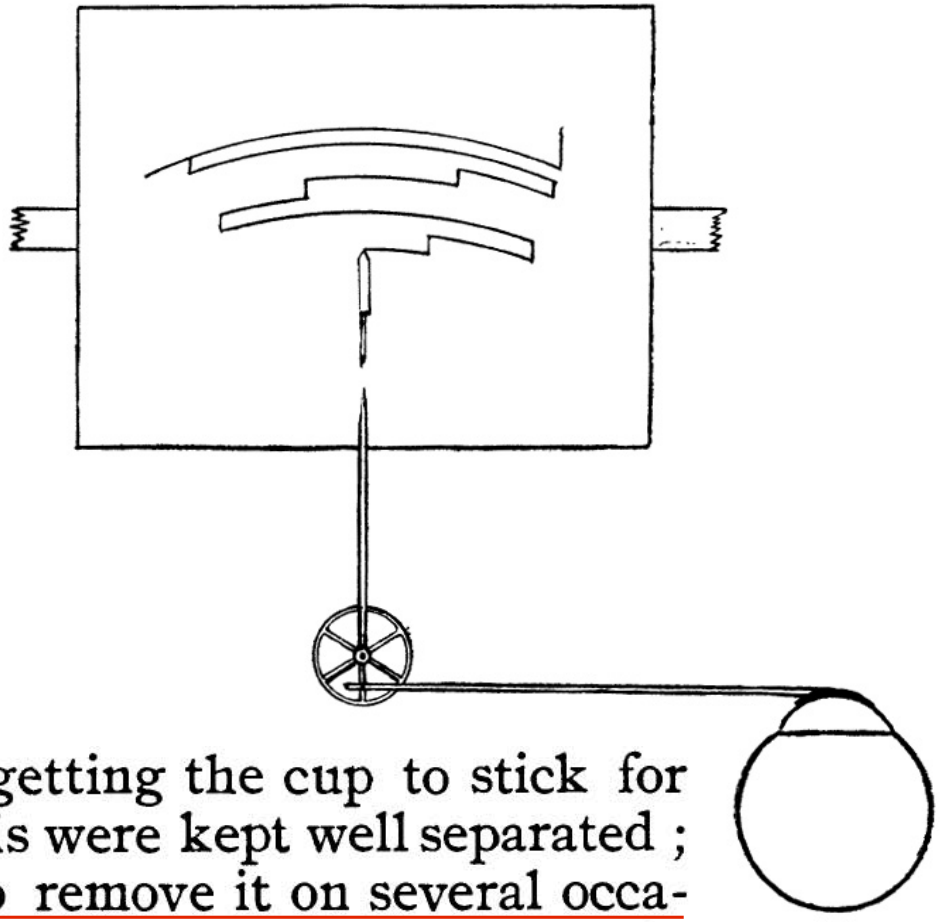
By E. B. DELABARRE, Professor of Psychology, Brown University.

Many problems suggest themselves to the psychologist whose solution would be greatly furthered by an accurate method of recording the movements of the eye.


I am indebted to Dr. Lough, my assistant last year in the laboratory at Harvard, for the suggestion that plaster-of-Paris will attach itself firmly and immovably to any moist surface. Acting on this suggestion, I made a few plaster casts over the cornea of an artificial eye. I thus produced a smooth concave surface that would fit fairly well the curvature of the cornea of a natural eye. This I trimmed with a knife to the diameter of the cornea, and to a thickness that would make it as light as possible while retaining the requisite firmness. Then I made the eyeball anæsthetic by applying two or three drops of a two to three per cent. solution of cocaine, and on fitting the cast over the cornea found that it held there perfectly, without pain or discomfort.

Delabarre (1898) *The American Journal of Psychology*

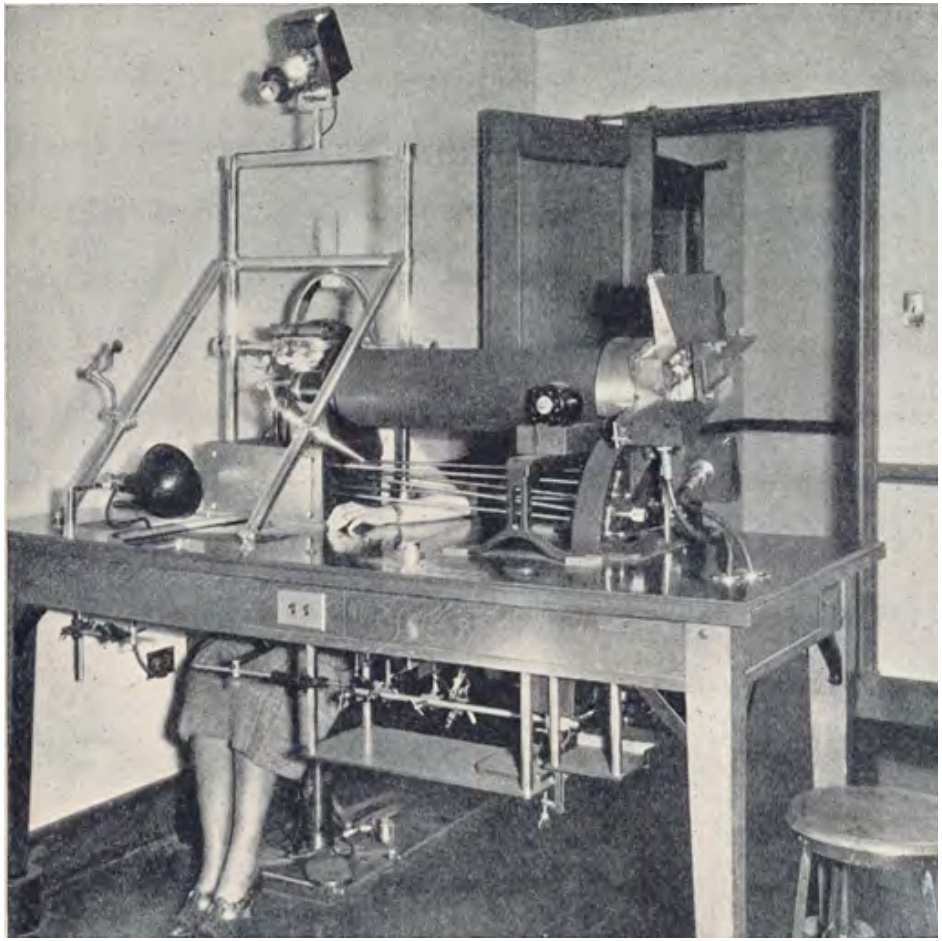
Delabarre (1898) *The American Journal of Psychology*

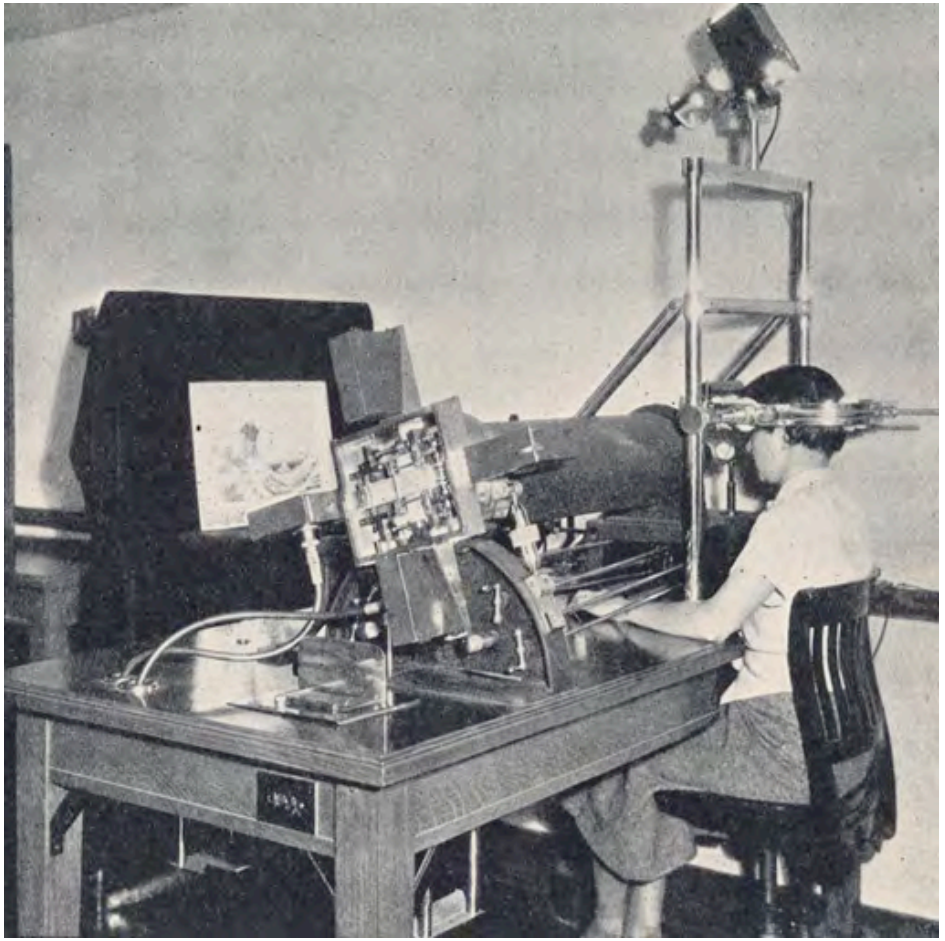


No trouble was experienced in getting the cup to stick for as long as was desired, when the lids were kept well separated ; indeed, it was somewhat difficult to remove it on several occasions. The experiments have so far been made on but two subjects — Prof. Hodge and myself. I am especially indebted to Prof. Hodge, as it has been difficult to get subjects ; partly from an exaggerated notion of the danger to the eye, partly from the defective vision of those who were otherwise available.

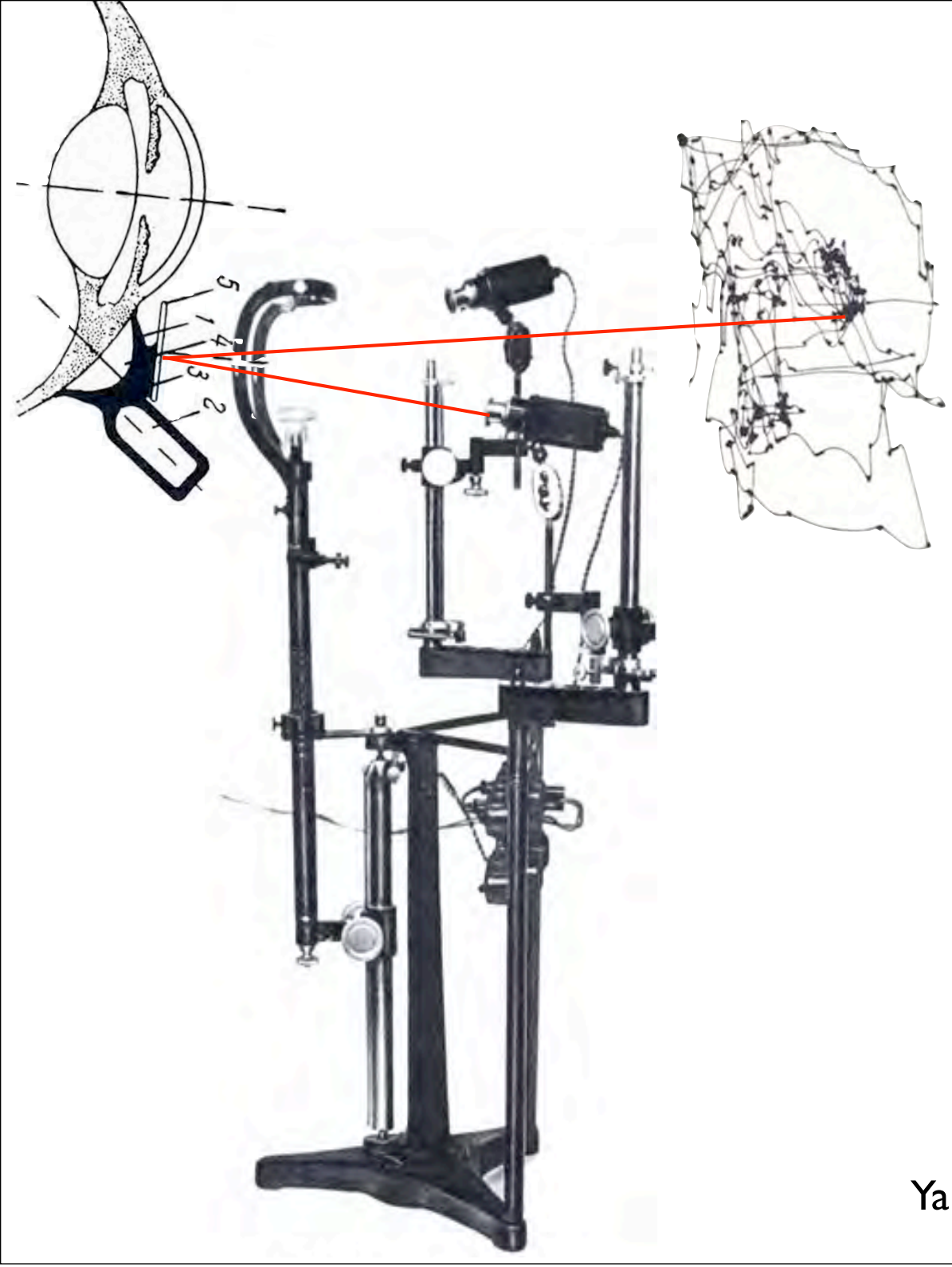
Huey (1898) *American Journal of Psychology*

# Corneal Reflection (CR) film-based eyetracker systems

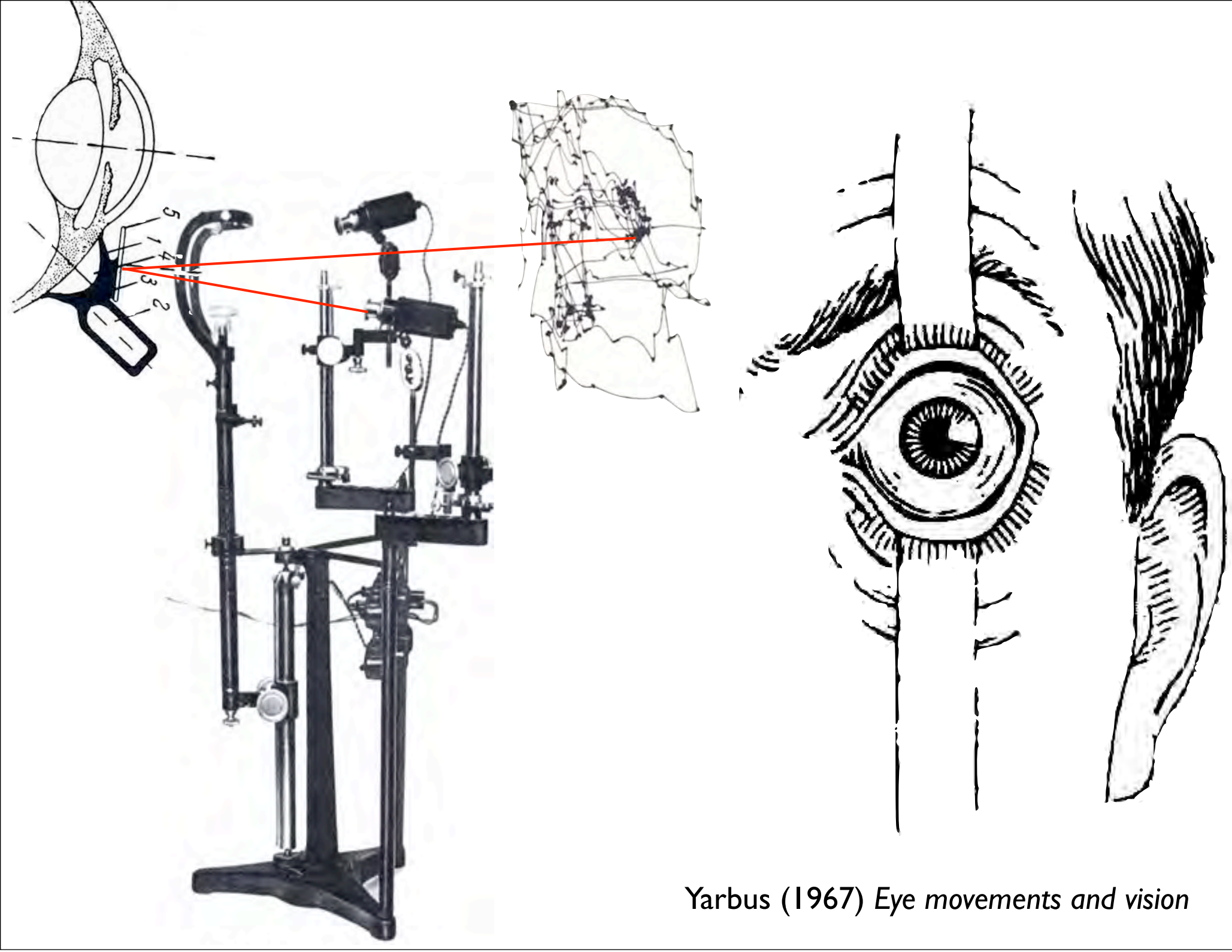




Buswell (1935) *How people look at pictures*



Yarbus (1967) *Eye movements and vision*



Yarbus (1967) *Eye movements and vision*

# Corneal Reflection (CR)
# Video-based eyetracker system

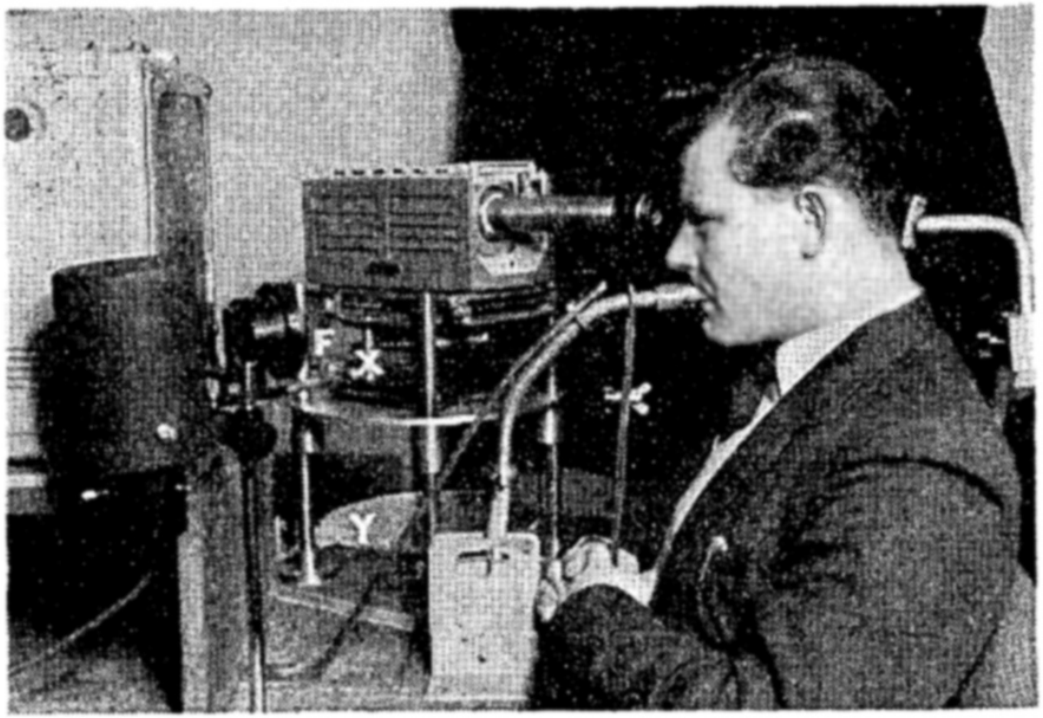


FIG. 1. General arrangement for eye camera.

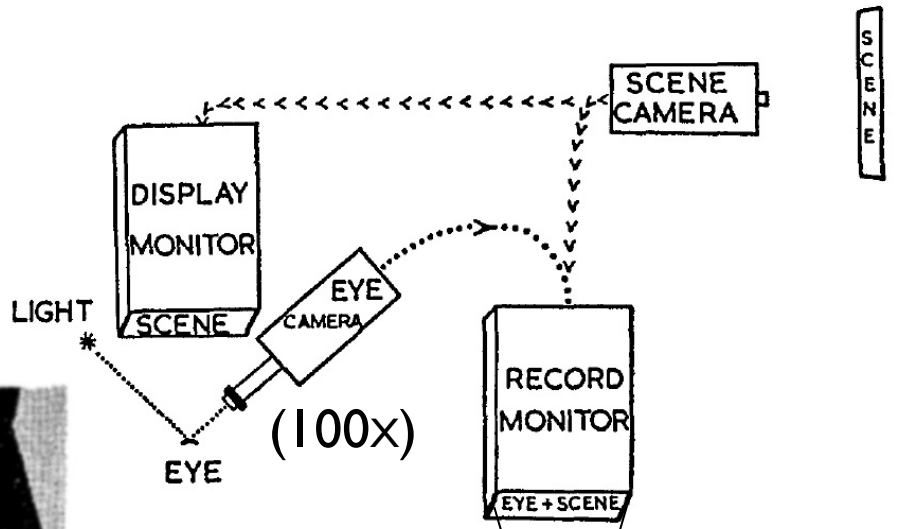



FIG. 2. Schematic vertical view.

6 fps 16mm

Mackworth & Mackworth (1958) JOSA

# Electrooculograph (EOG)
# Video-based eyetracker system

Shackel (1960) *JOSA*

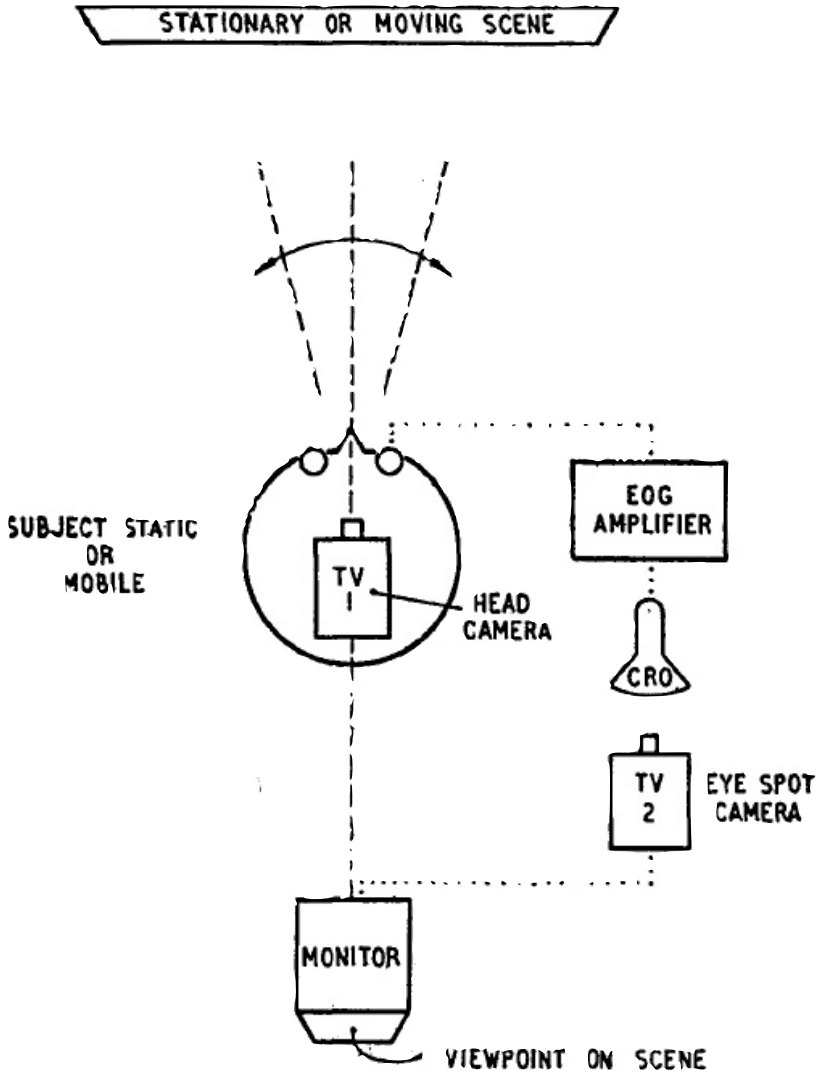



FIG. 2. Schematic diagram of method using EOG eyeball position recording.

# Electrooculograph (EOG)
# Video-based eyetracker system

Shackel (1960) *JOSA*

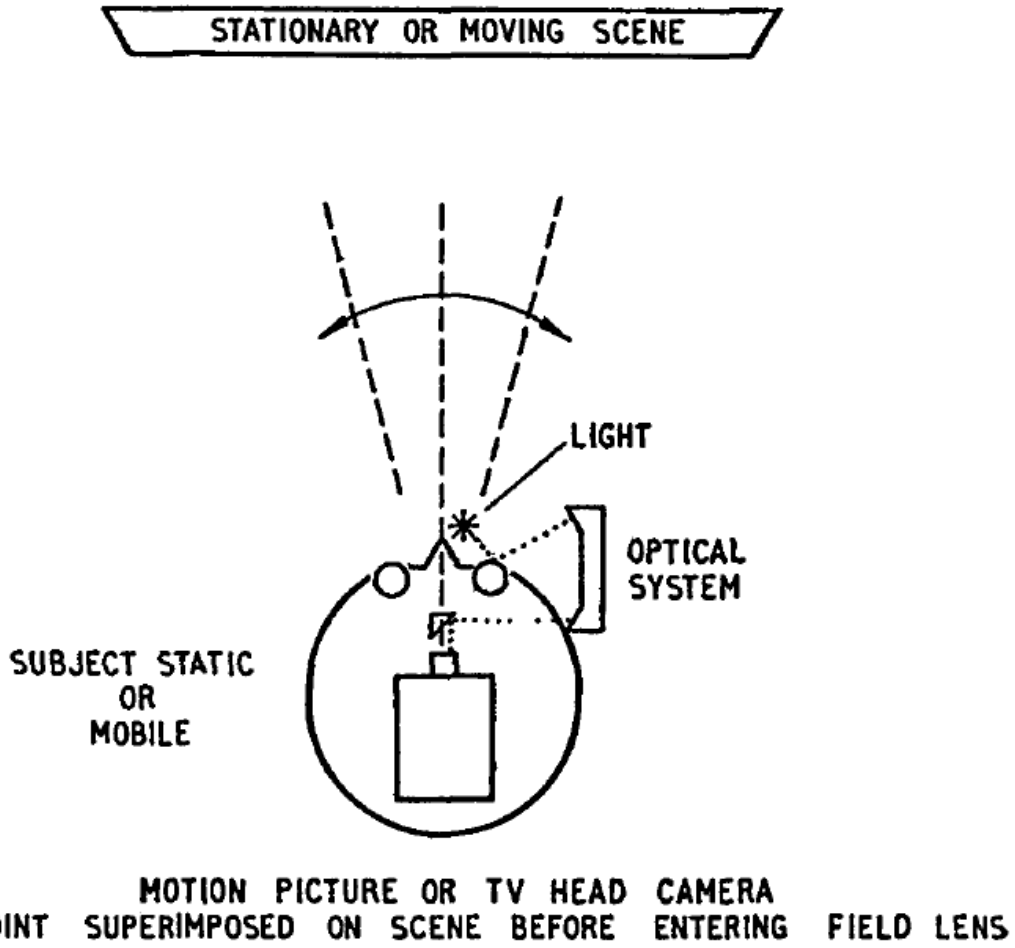



FIG. 3. Sketch of principle applied to corneal-reflection eyeball position recording.

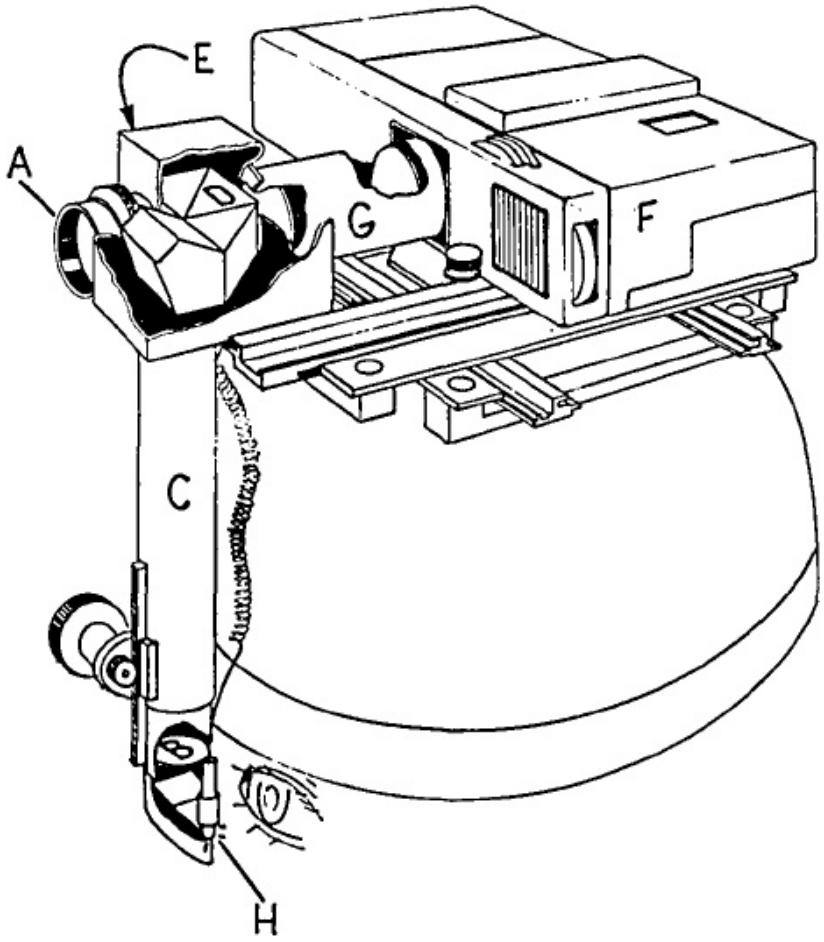



FIG. 1. Schematic diagram for head-mounted 8-mm movie camera.

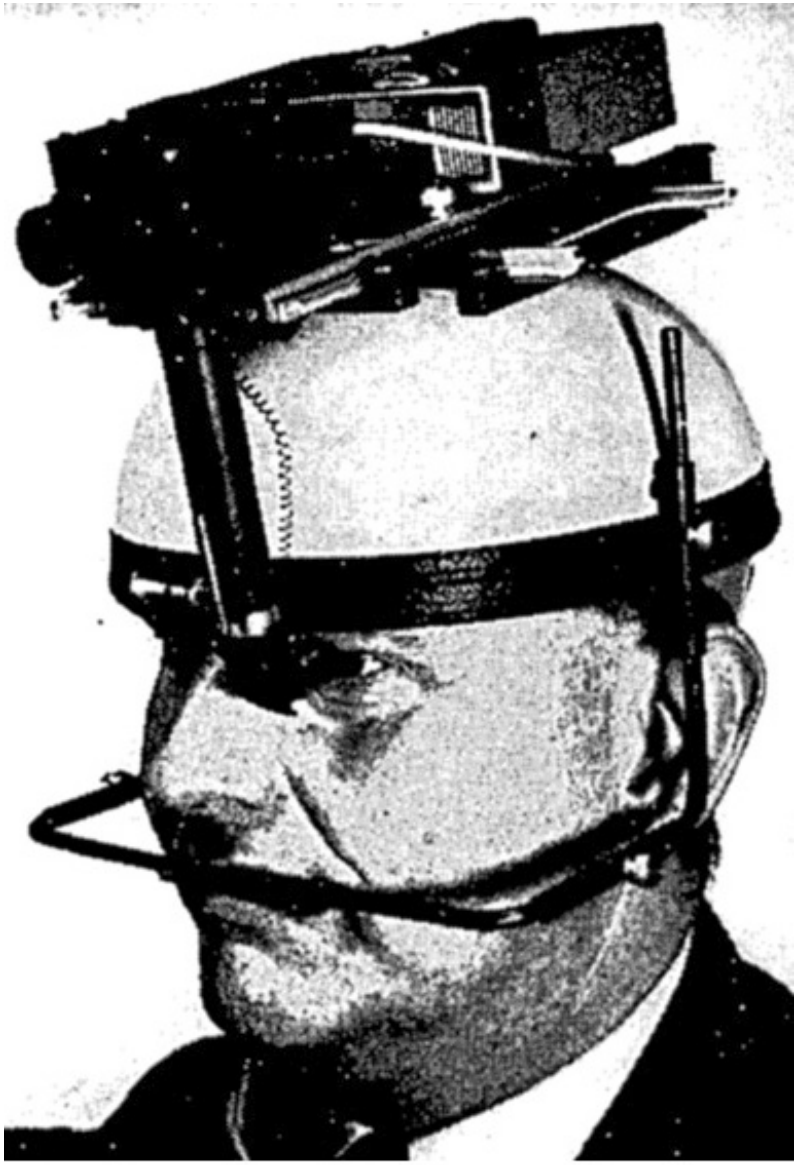
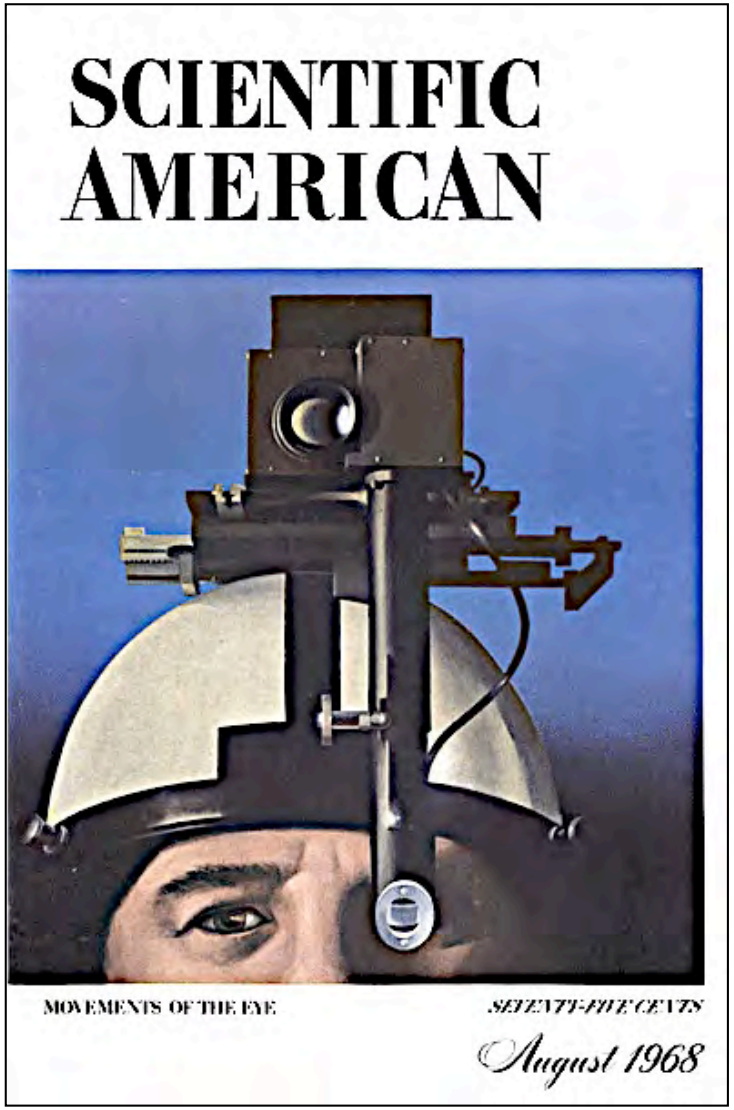
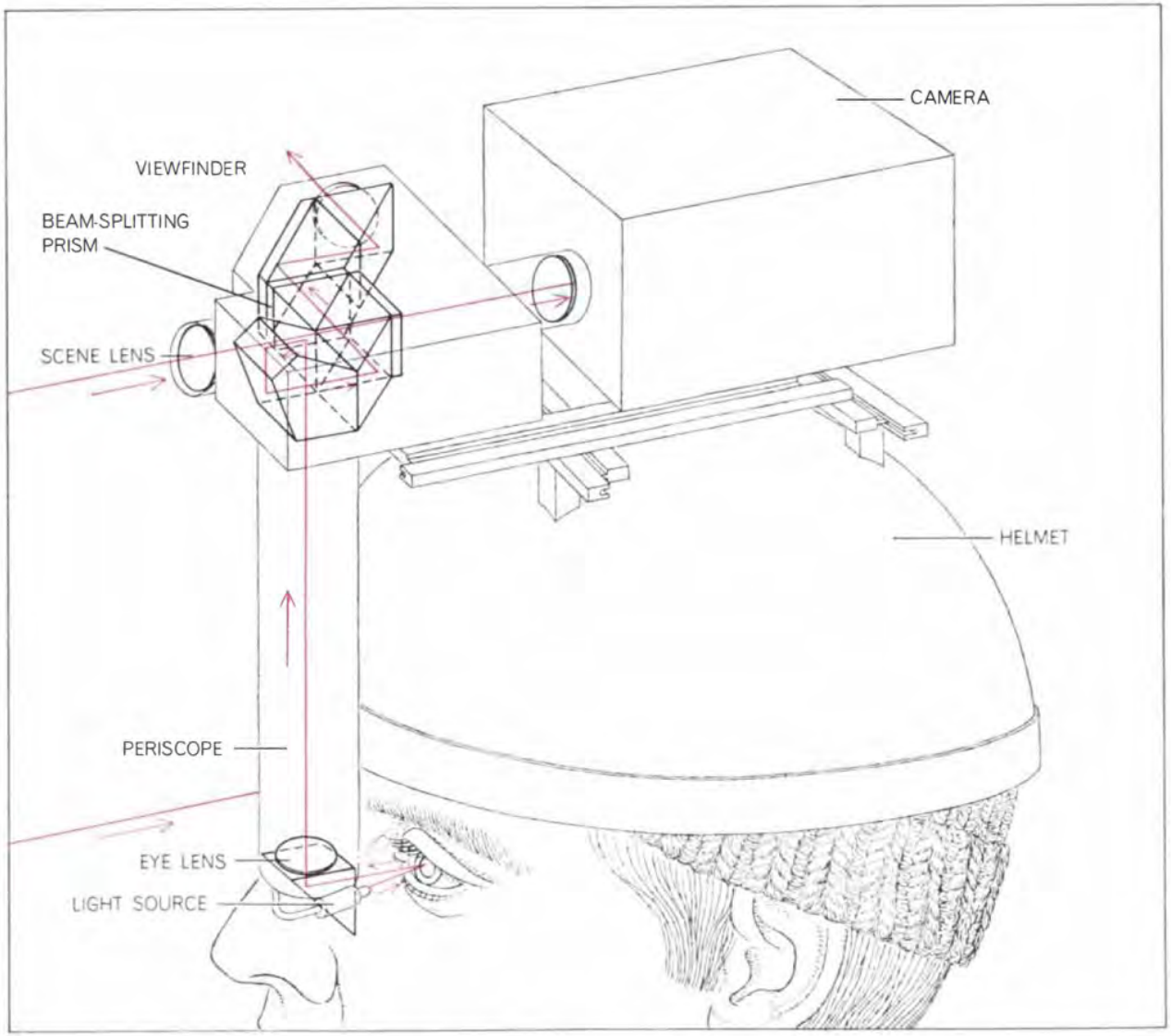


FIG. 2. Head-mounted eye-marker camera.

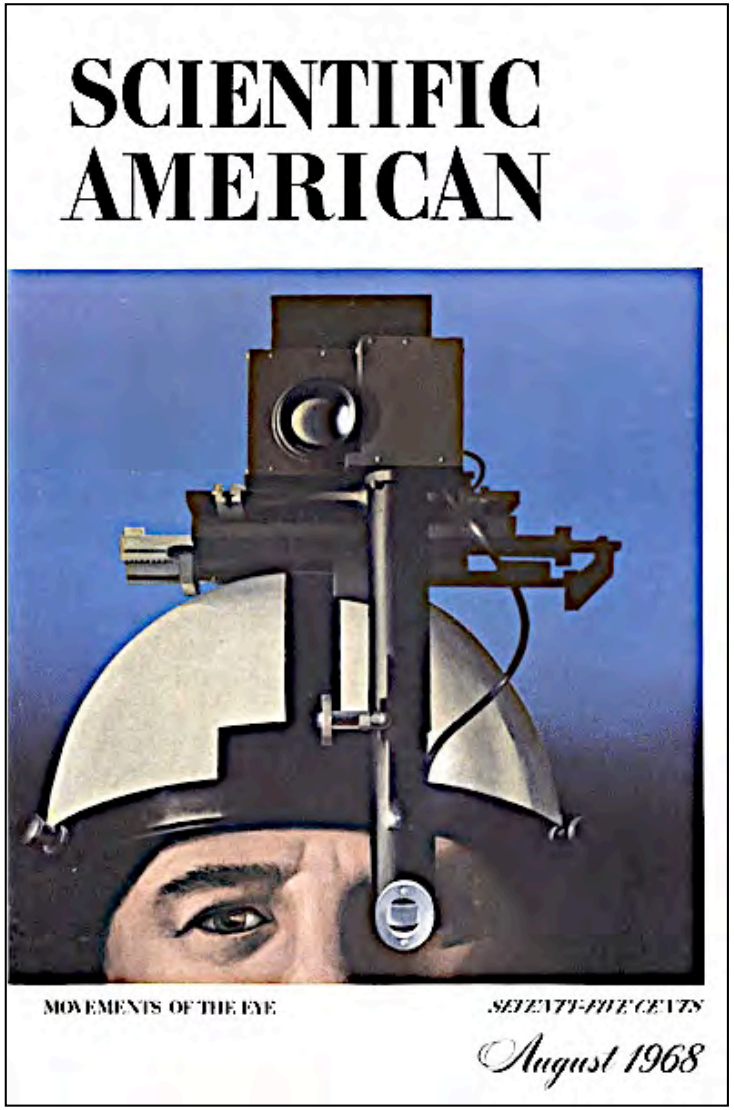
Mackworth & Thomas (1962) *JOSA*



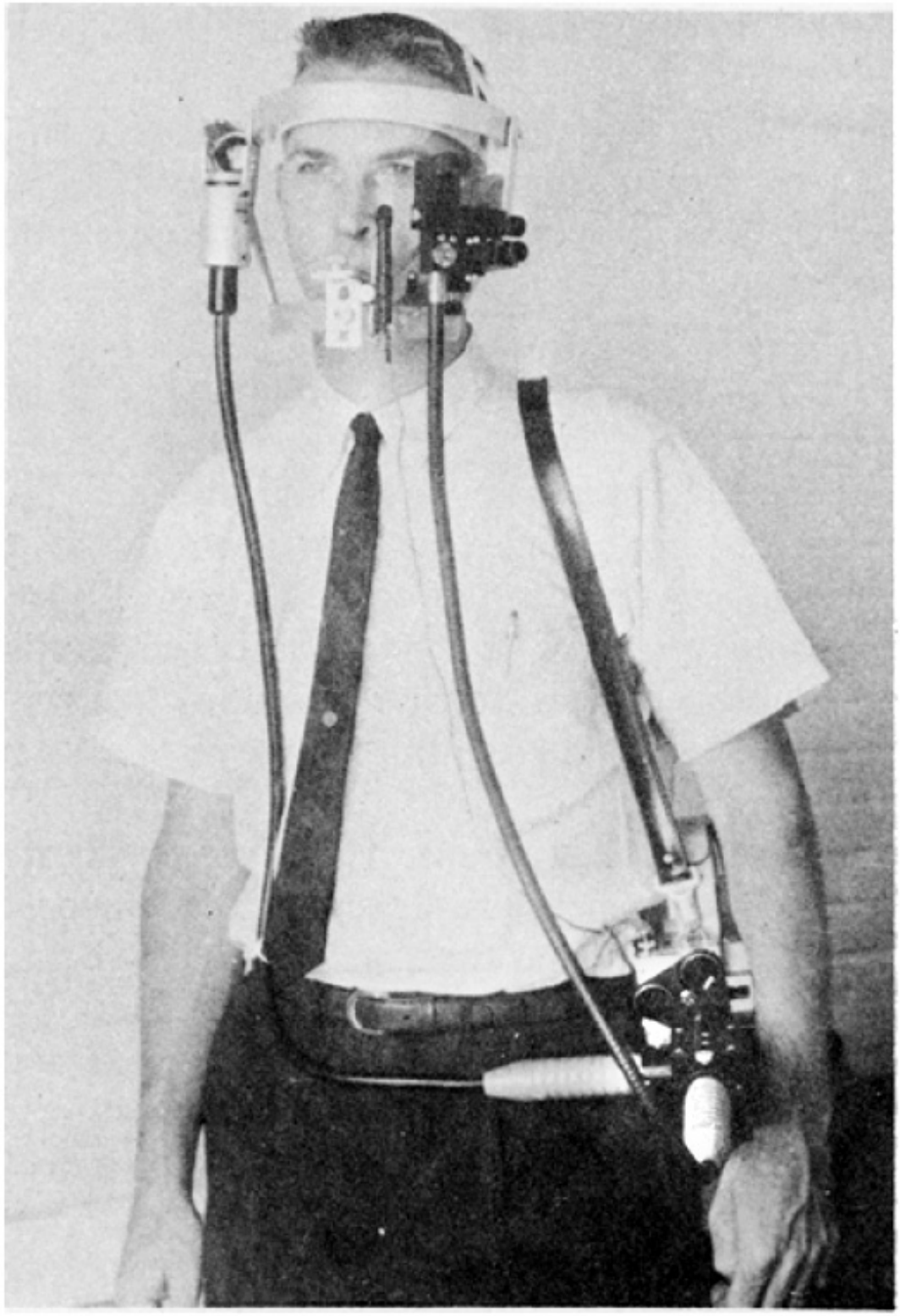

**EYE-MARKER CAMERA** tracks and records the eye's glance. The image of a spot of light, reflected from the cornea, is transmitted by an optical system in the periscope through a series of prisms. This serves to superpose the eye-marker image on the scene image. The combined image can be monitored through the viewfinder as it is photographed by the motion-picture camera.

Thomas (1968) *Scientific American*




Thomas (1968) *Scientific American*

# Corneal-reflection film system with fiber-optic coupling



Young & Shea (1975) *BRMI*

# Pupil - Corneal Reflection (P-CR) eyetracker systems

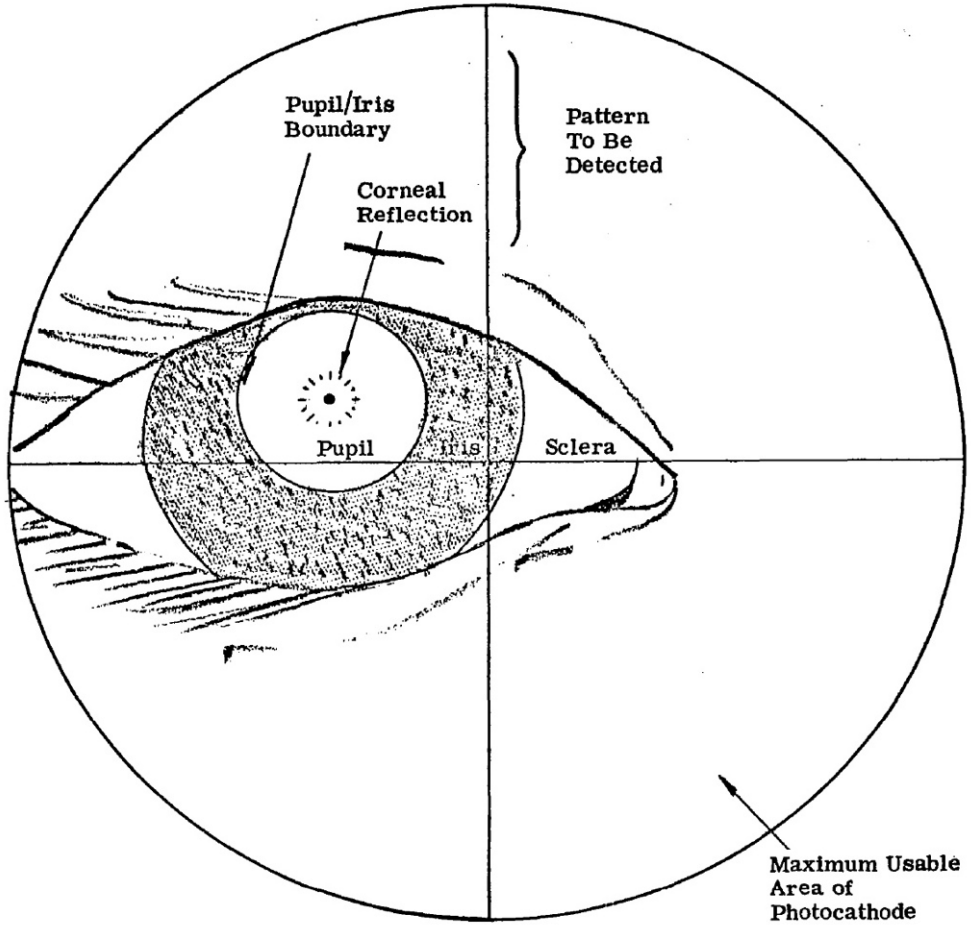



Figure 3.11 IMAGE OF EYE ON PHOTOCATHODE

Merchant (1967) *NASA Tech Report CR-805*

Figure 1 OPTOMECHANICAL UNIT

Merchant (1969) *NASA Tech Report CR-1422*

# Pupil - Corneal Reflection (P-CR) eyetracker systems

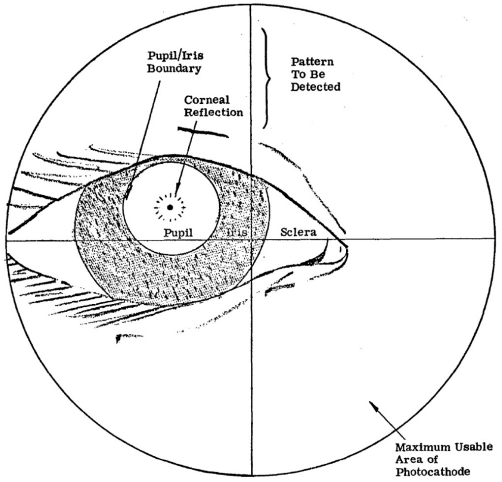
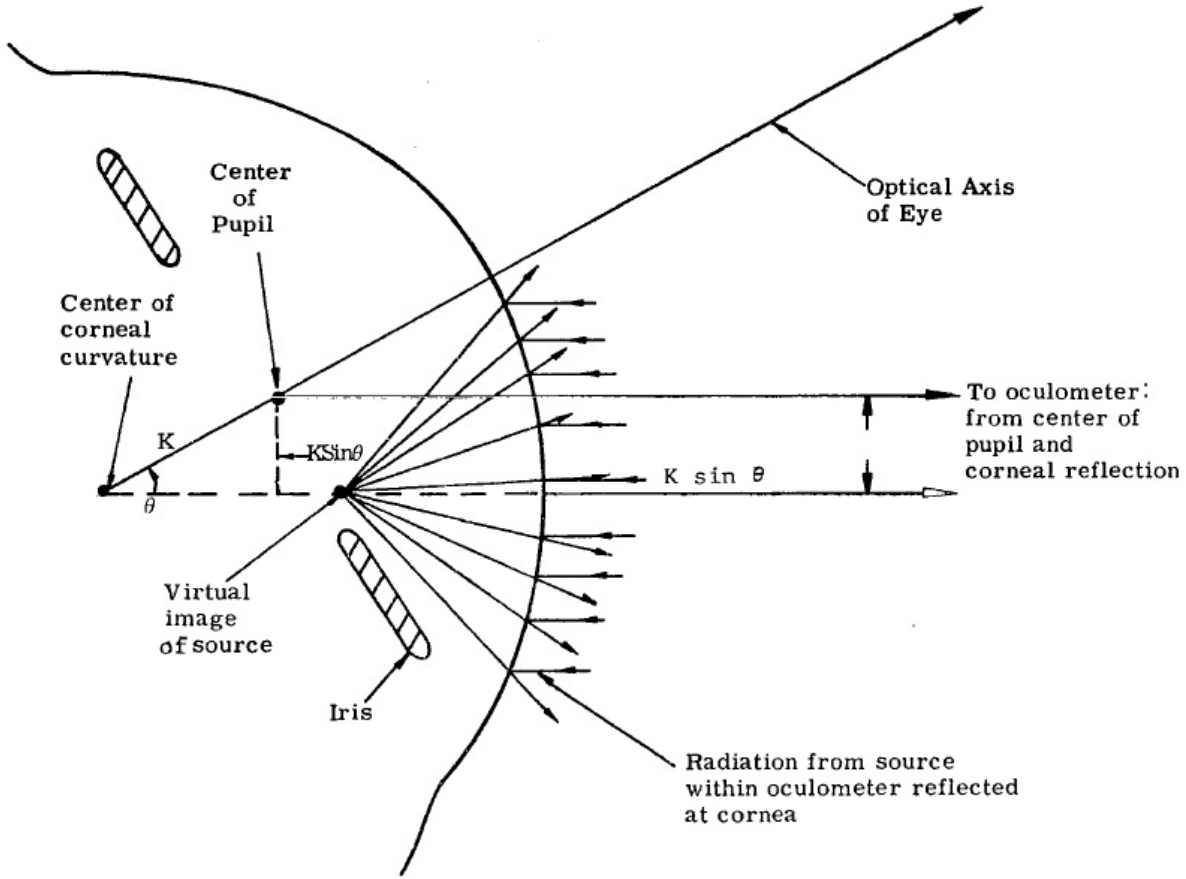


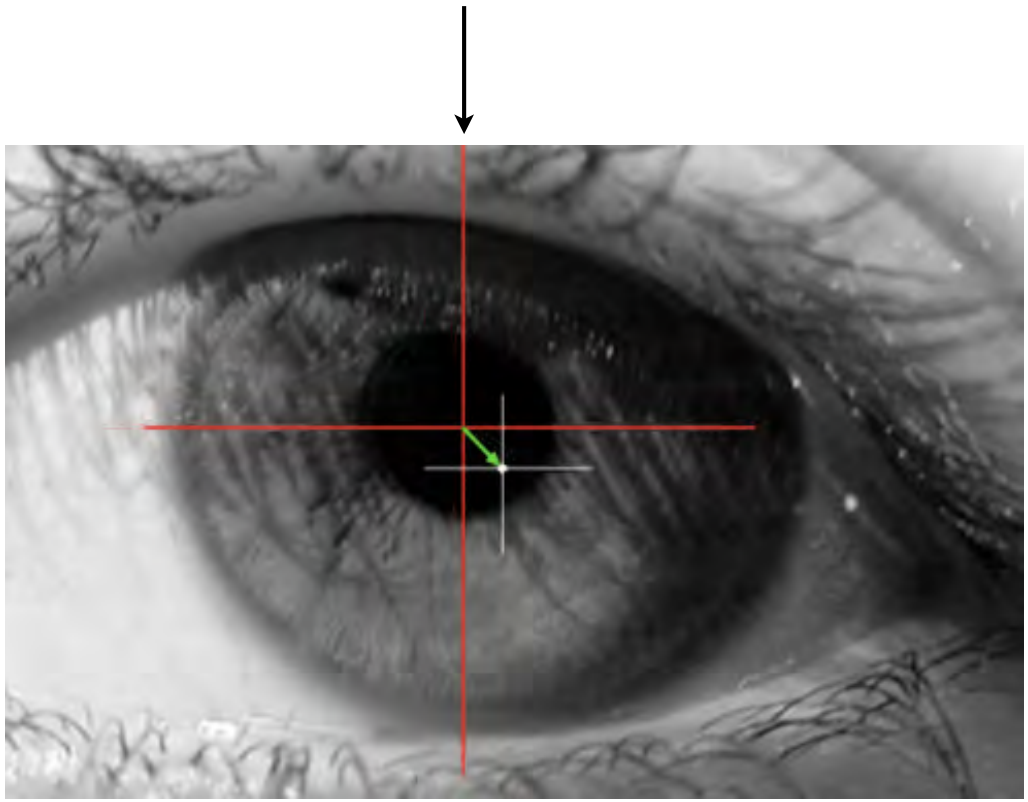

Figure 3.11 IMAGE OF EYE ON PHOTOCATHODE

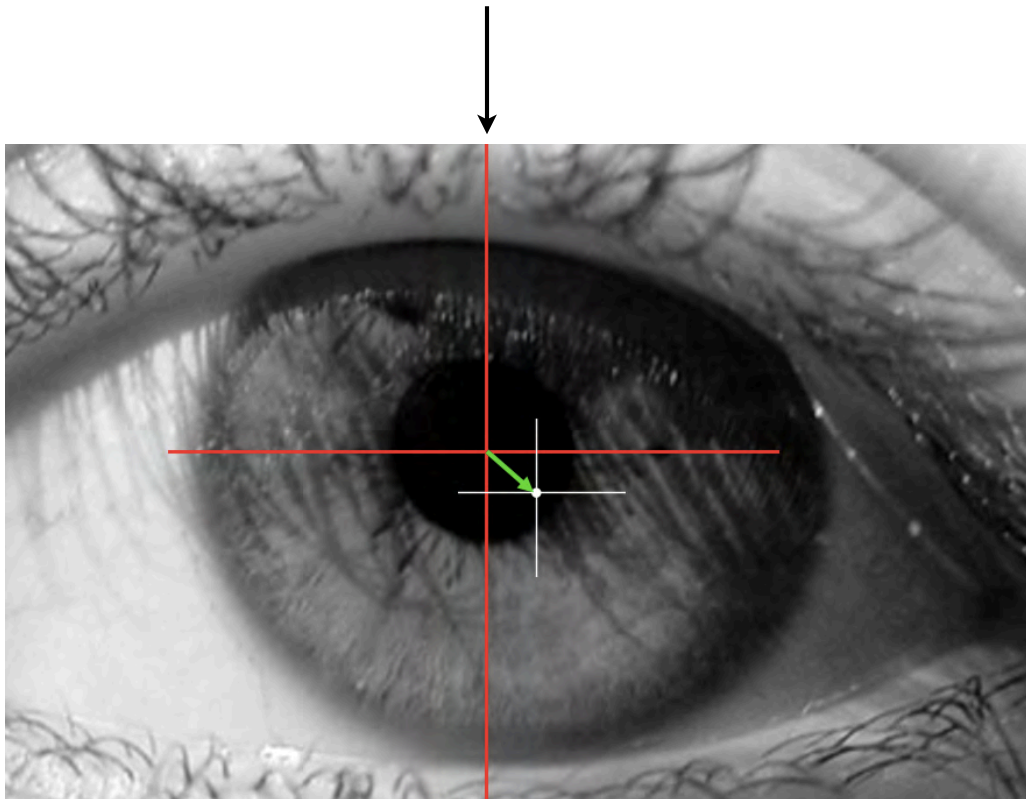



Displacement of corneal reflection from center of pupil, K Sin θ, is proportional to the angular direction, θ, of the eye, and is independent of the position of the eye.

Merchant (1969) *NASA Tech Report CR-1422*

# Pupil - Corneal Reflection (CR) eyetracker systems

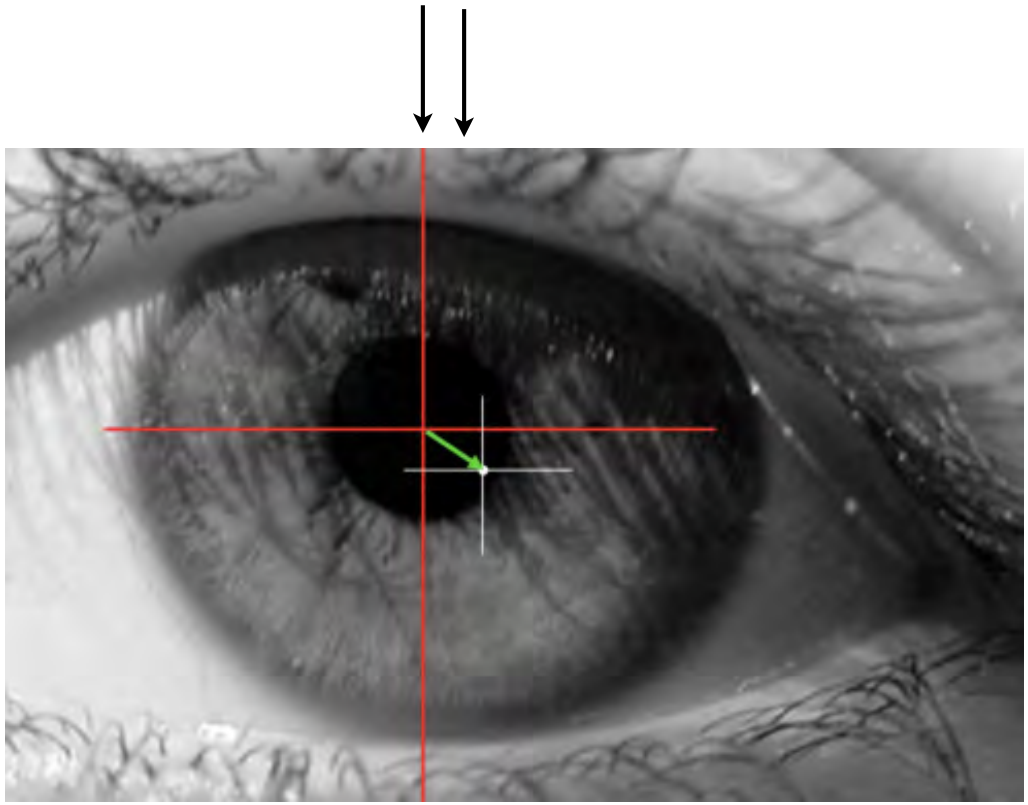




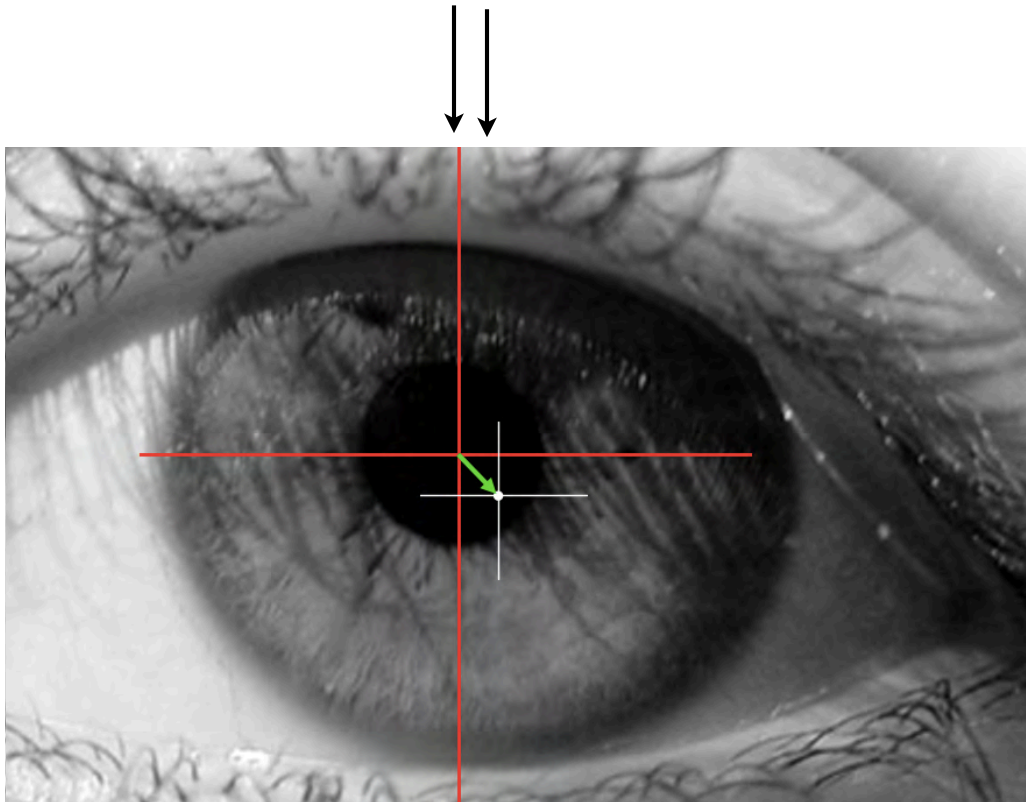
Eye movement (rotation)

Camera movement (translation)

# Pupil - Corneal Reflection (CR) eyetracker systems

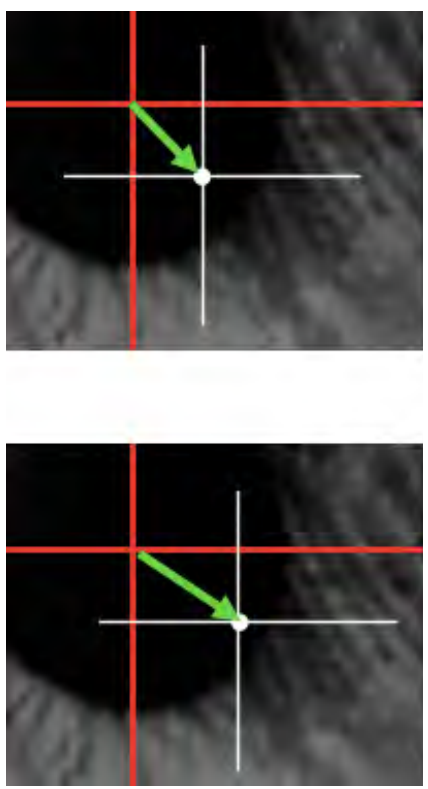


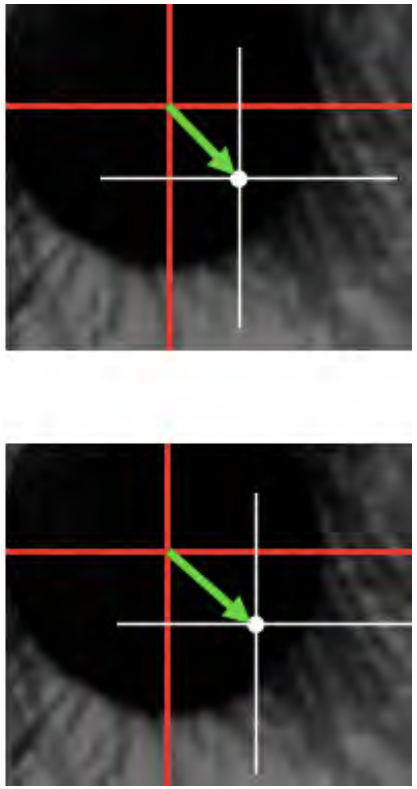
Eye movement
(rotation)



Camera movement
(translation)

# Pupil - Corneal Reflection (CR) eyetracker systems





Eye movement (rotation)

Camera movement (translation)

# Pupil - Corneal Reflection (CR) eyetracker systems

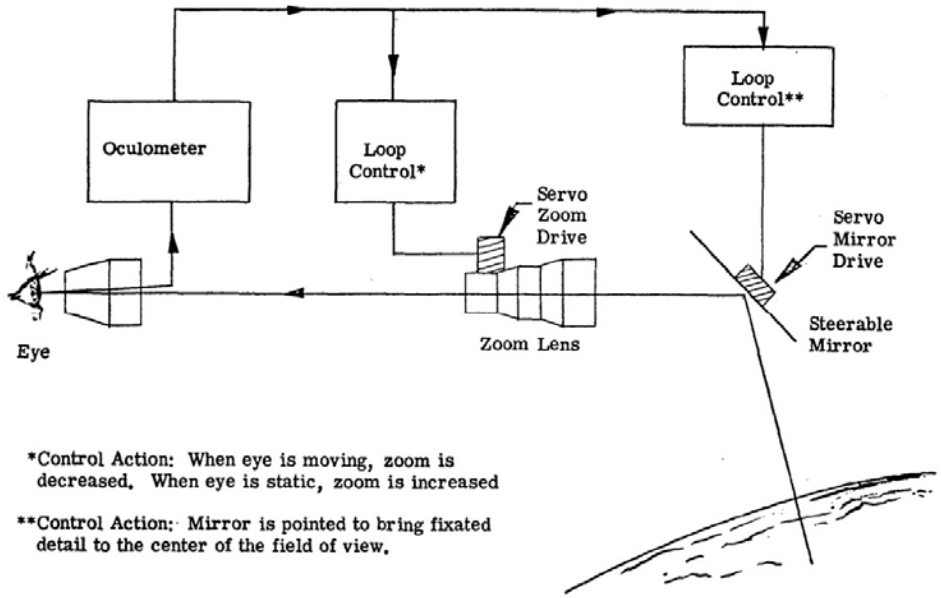



Figure A.2 ASTRONAUT'S EYE-CONTROLLED TRACKING TELESCOPE

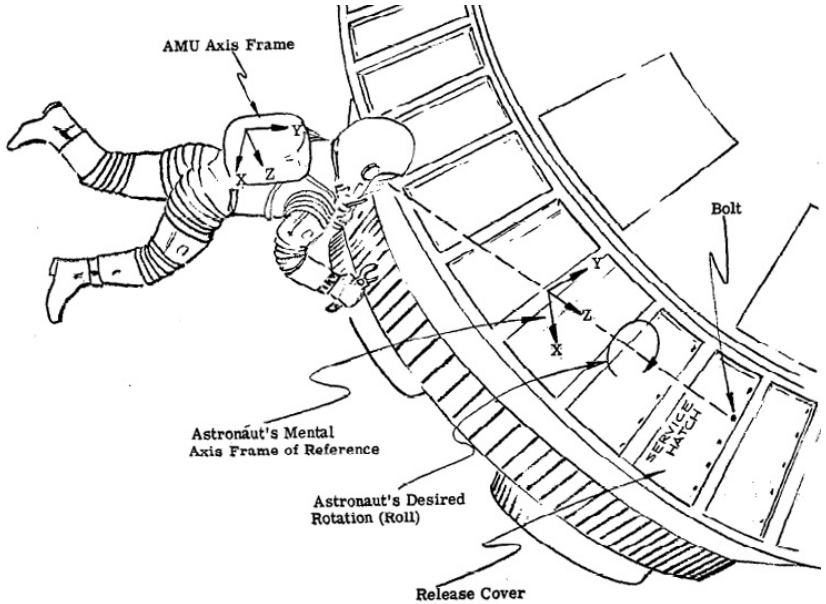



Figure A.11 ASTRONAUT DESIRES TO ROLL IN HIS OWN AXIS FRAME

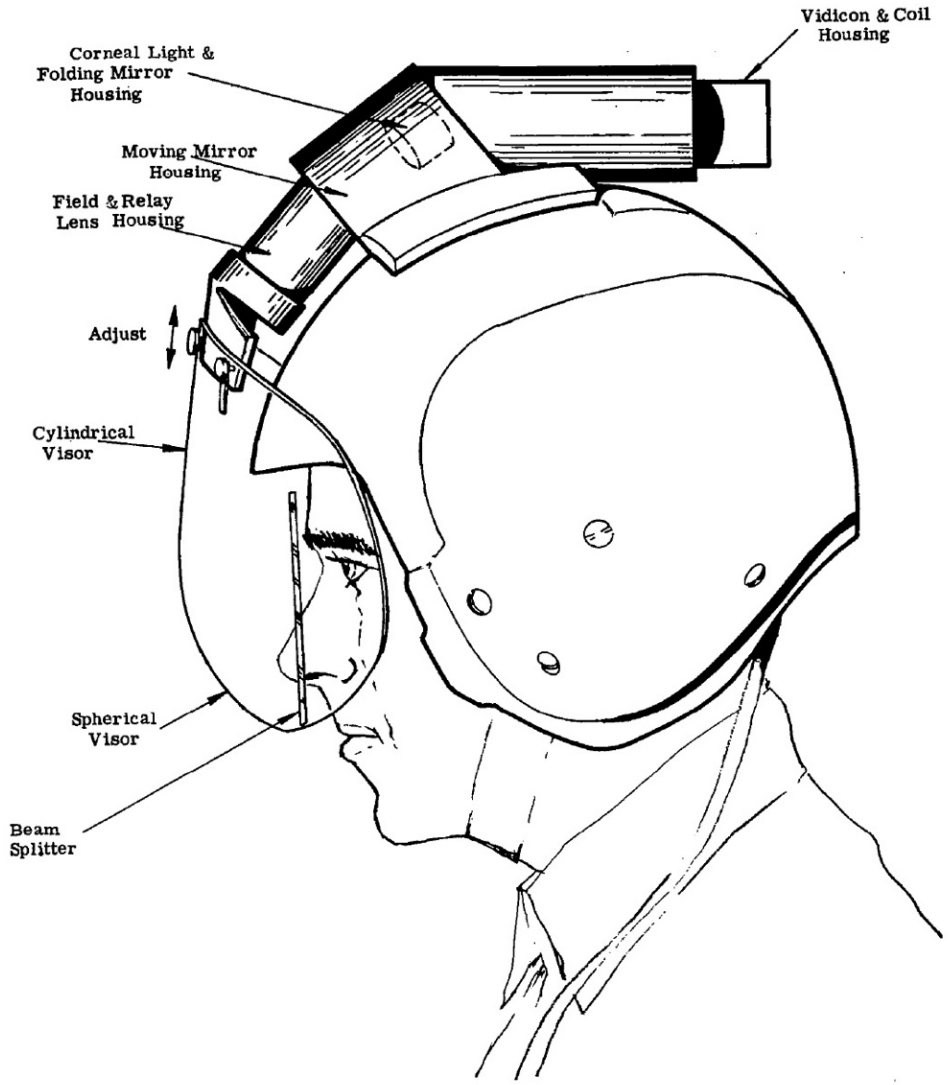



Figure A.1 CONFIGURATION OF HELMET-MOUNTED OCULOMETER

Merchant (1967) *NASA Tech Report CR-805*

# Pupil - Corneal Reflection (CR) Video-based eyetracker systems (Merchant - 1974)



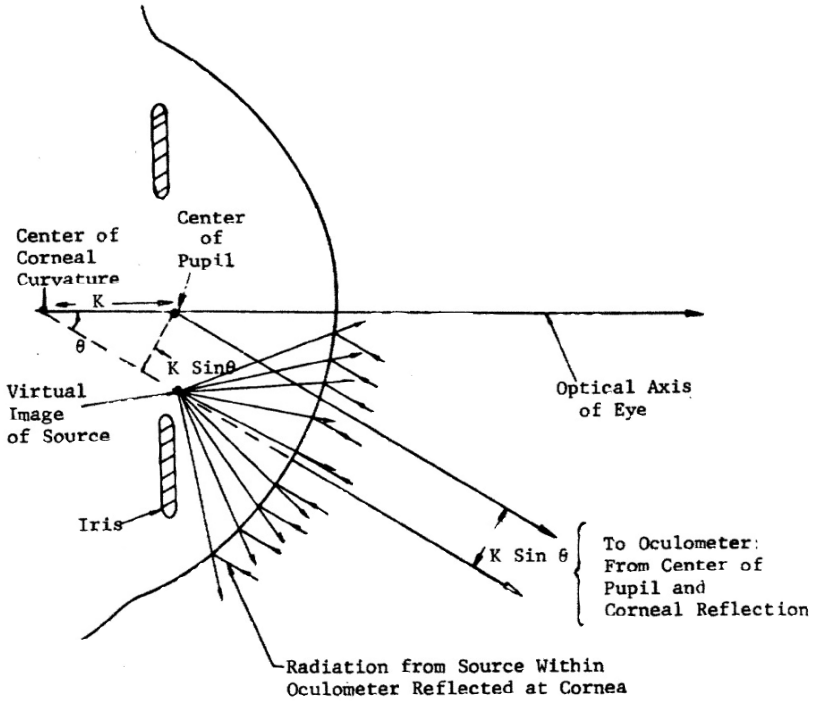
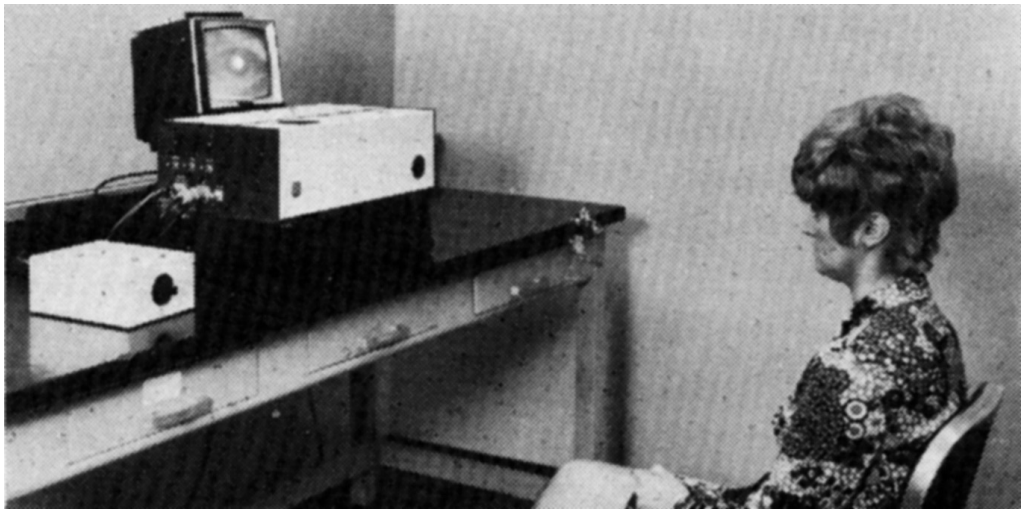



Fig. 5. Basic sensing principle. Displacement of the corneal reflection from the center of the pupil by $K \sin \theta$ is proportional to the angular direction $\theta$ of the eye, and is independent of the position of the eye.



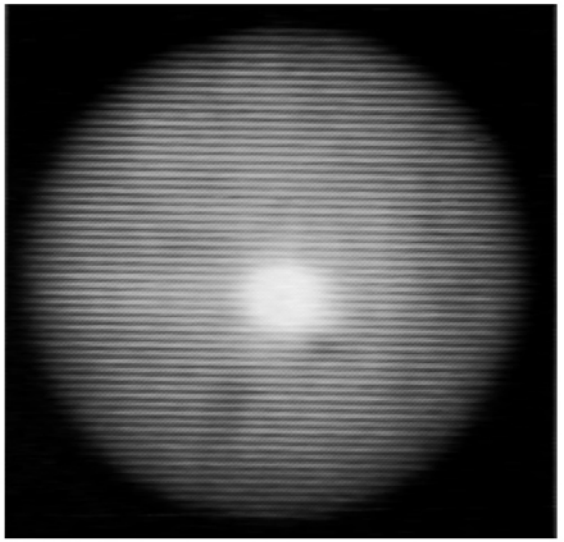


Fig. 7. TV picture of the eye.

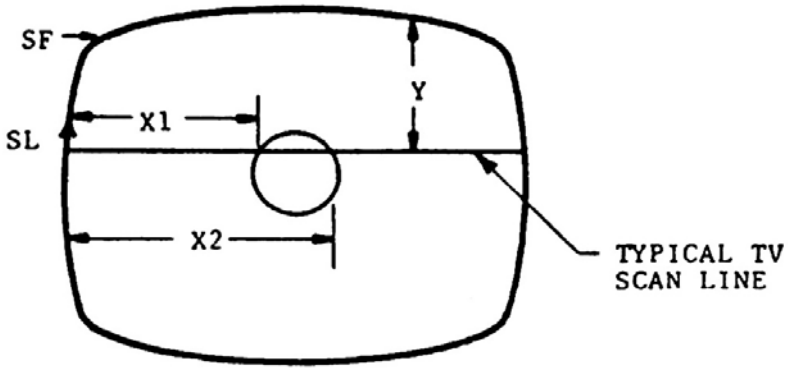
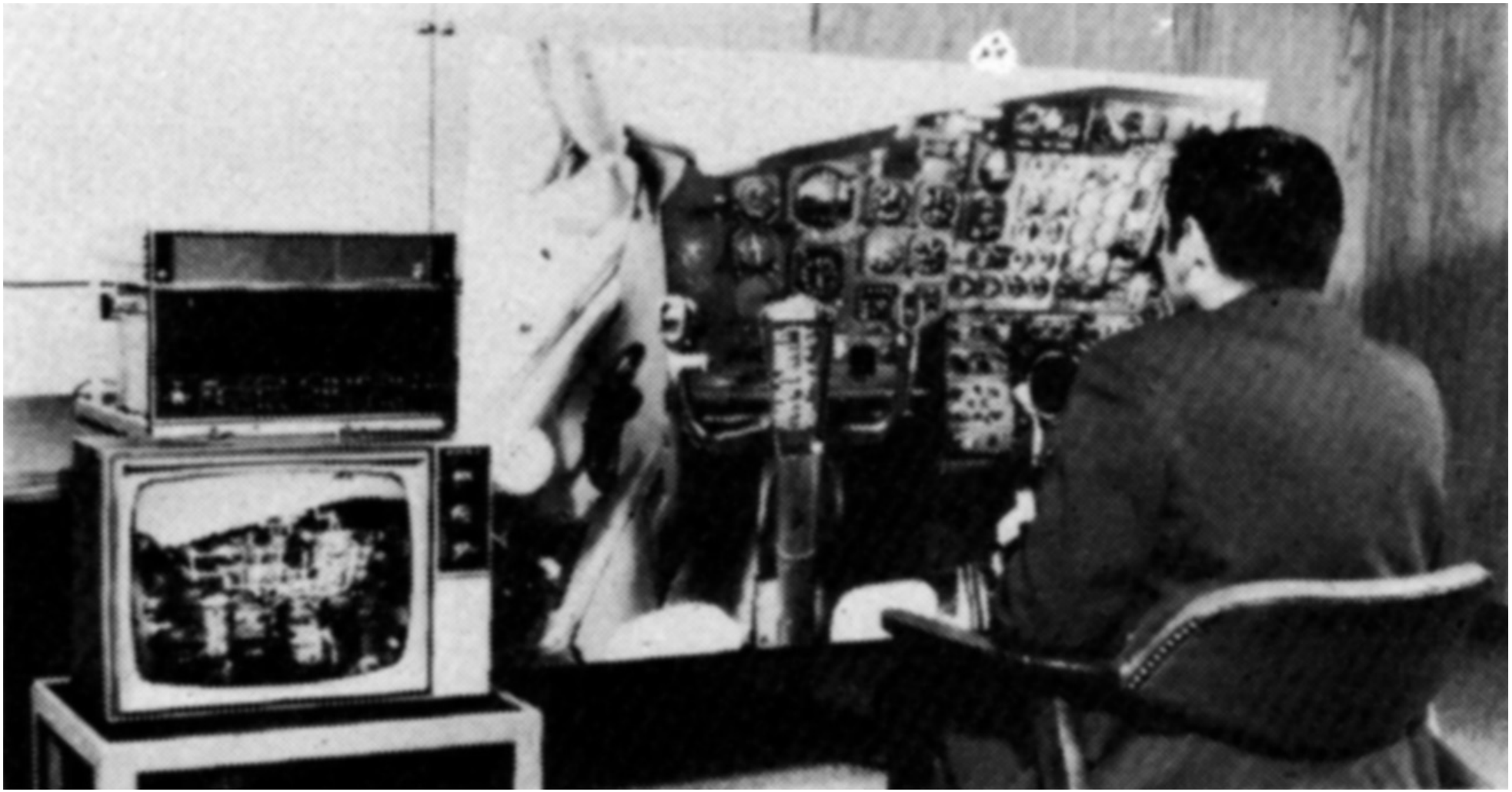



Fig. 8. Digital eye coordinates.

Merchant, Morrissette, & Porterfield (1974) *IEEE Trans Biomed Eng*

# Pupil - Corneal Reflection (CR) Video-based eyetracker systems (Merchant - 1974)



Merchant, Morrissette, & Porterfield (1974) *IEEE Trans Biomed Eng*

# Pupil - Corneal Reflection (CR)
# Video-based eyetracker systems

Arrington

ASL

Dikablis

EyeLink

Positive Science

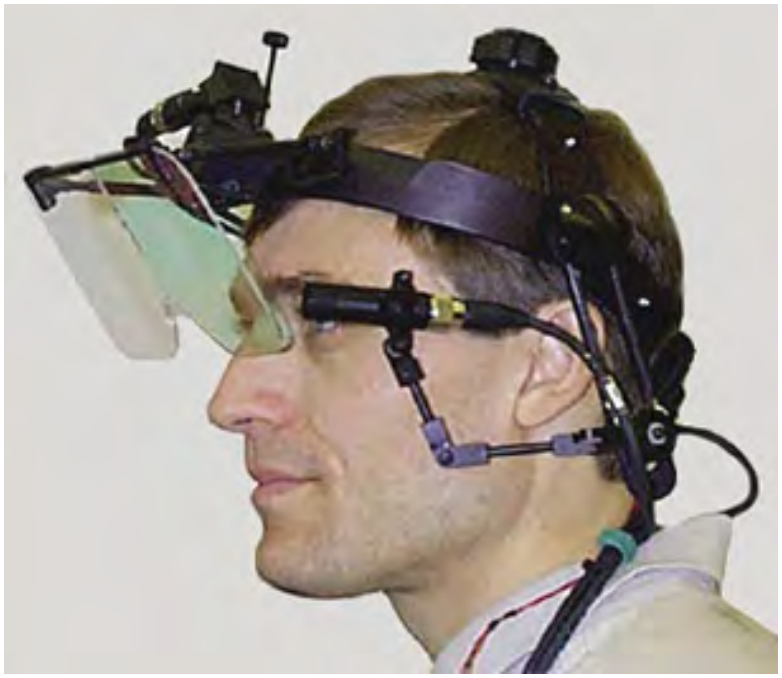
FaceLab

mirametrix

SMI


Tobii


DELL
ASL
Applied
Science
Laboratories
EYE
SCENE
POWER
Series 4000
Eye Tracking System
MODEL 4000 SU CONTROL UNIT



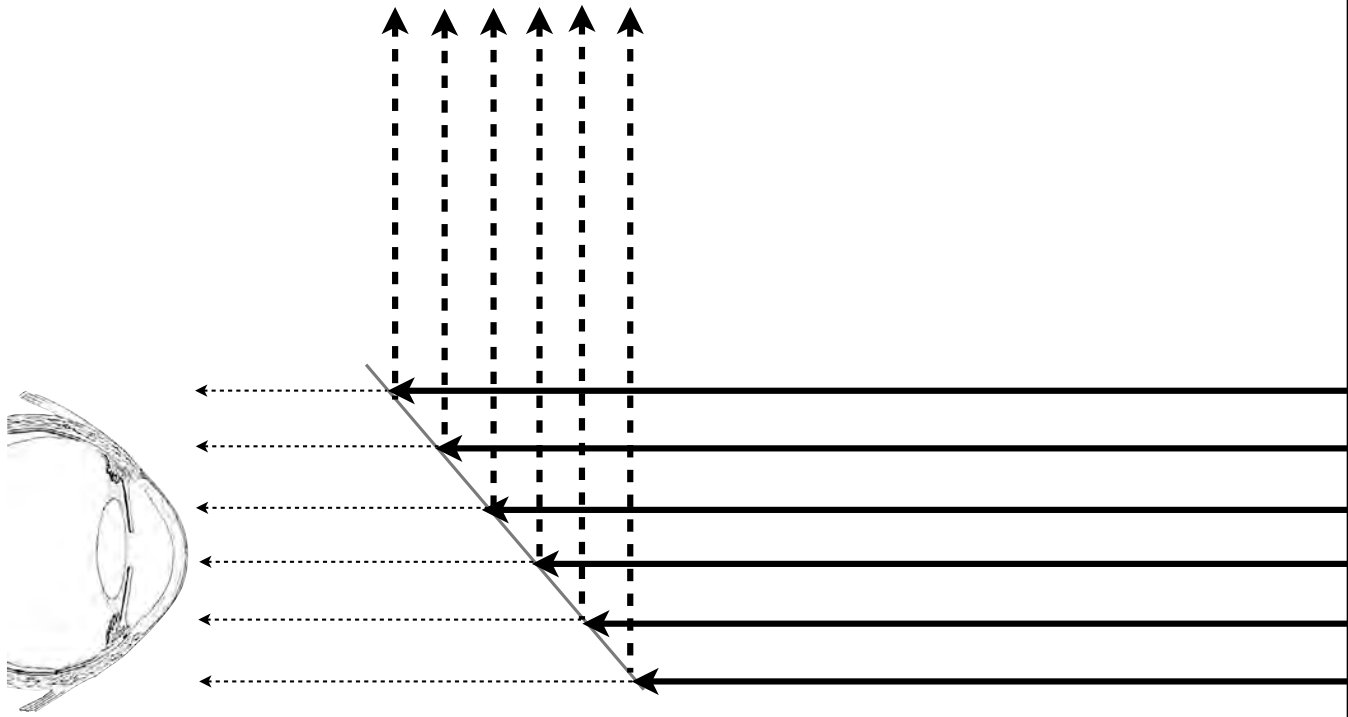
# Michael Land

Sussex

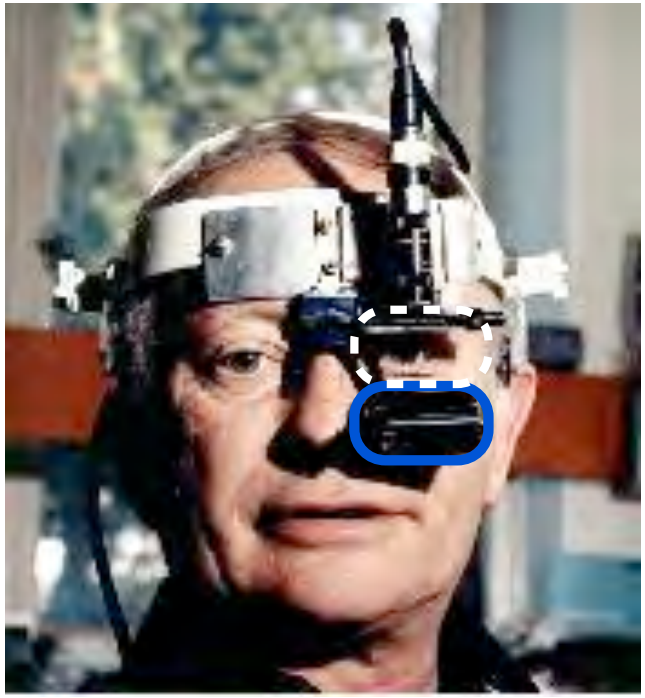
Vision Laboratory

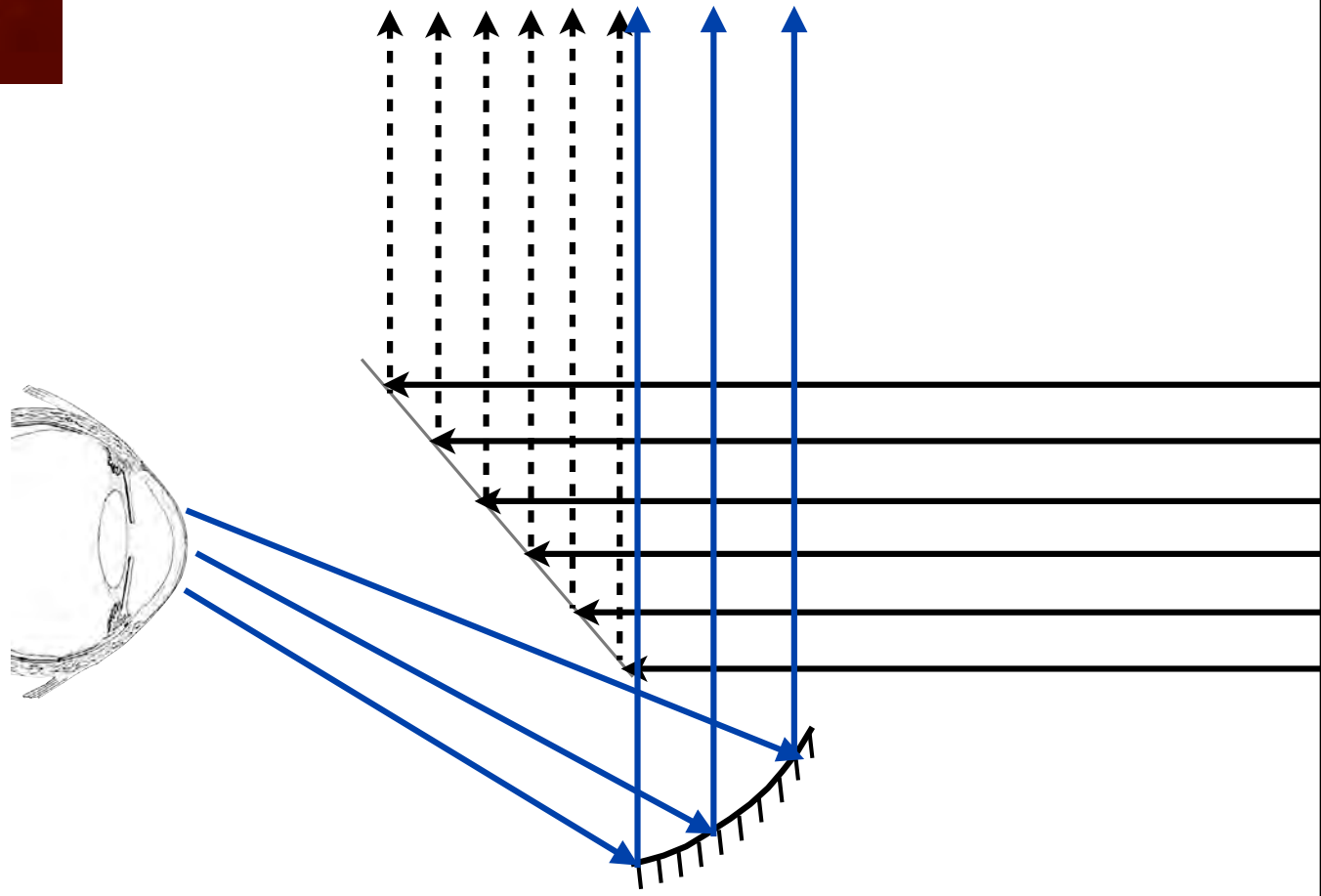
*Sussex Centre for Neuroscience*
*University of Sussex, Brighton, BN1 9QG, UK*


camera
(eye & scene)

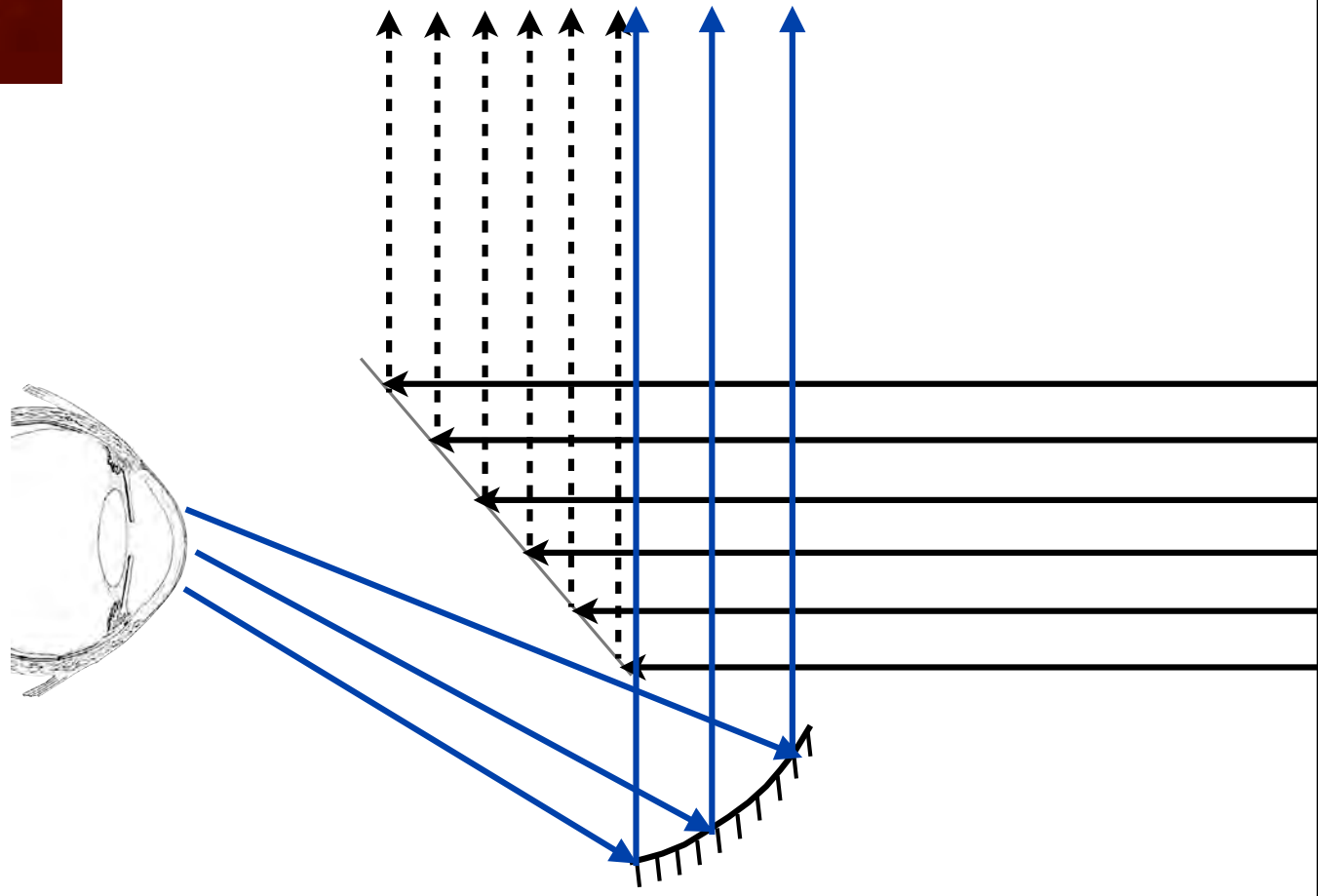


camera
(eye & scene)





camera
(eye & scene)

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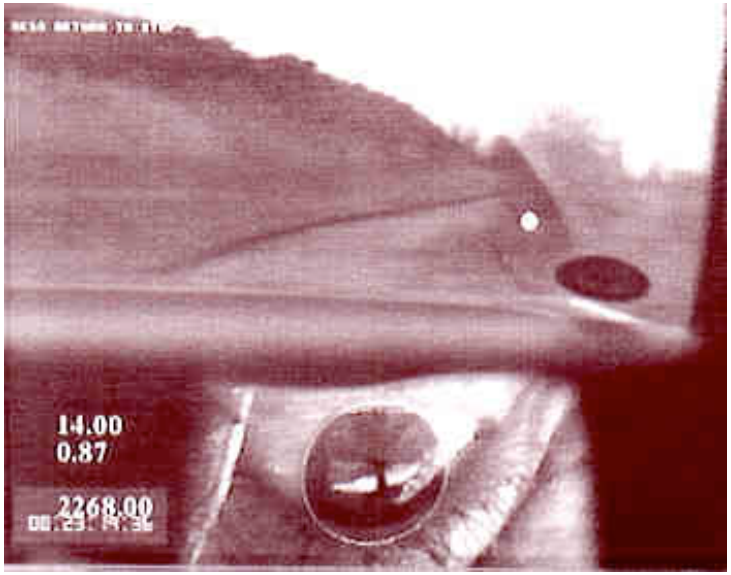
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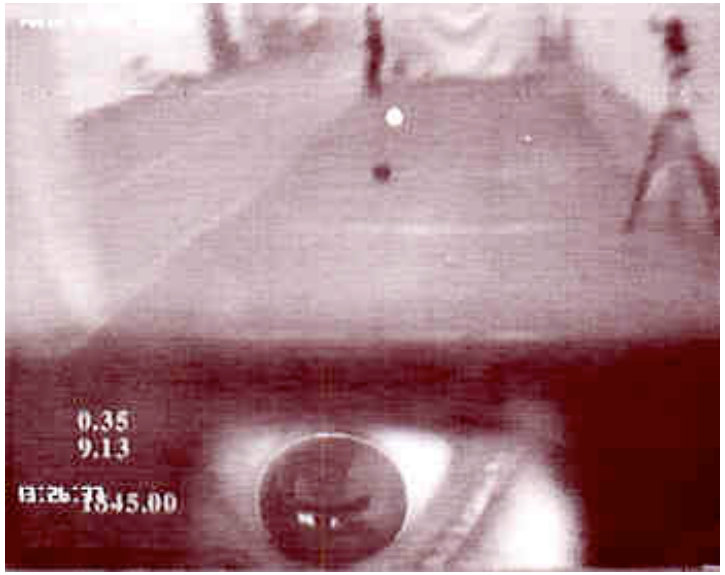
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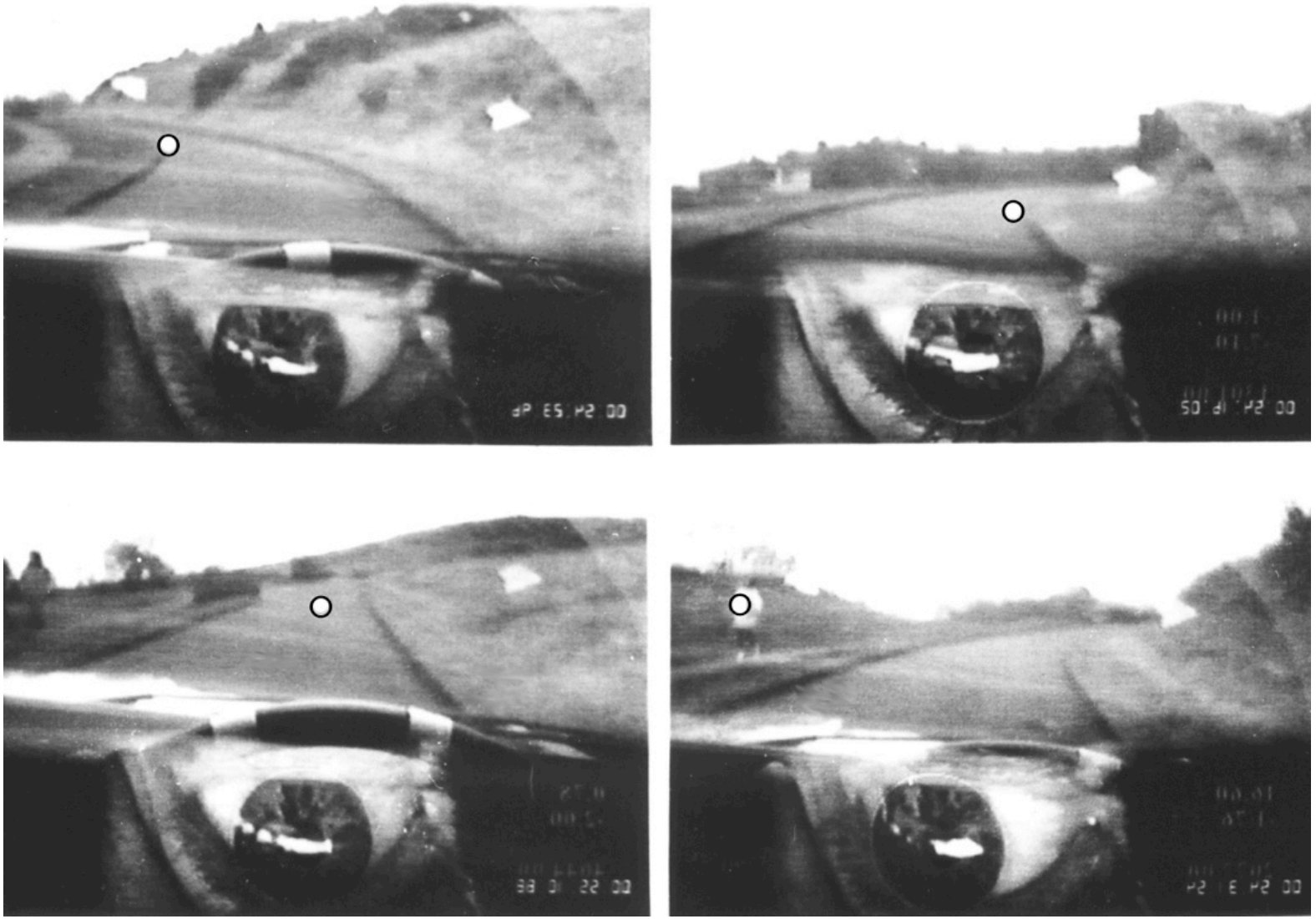
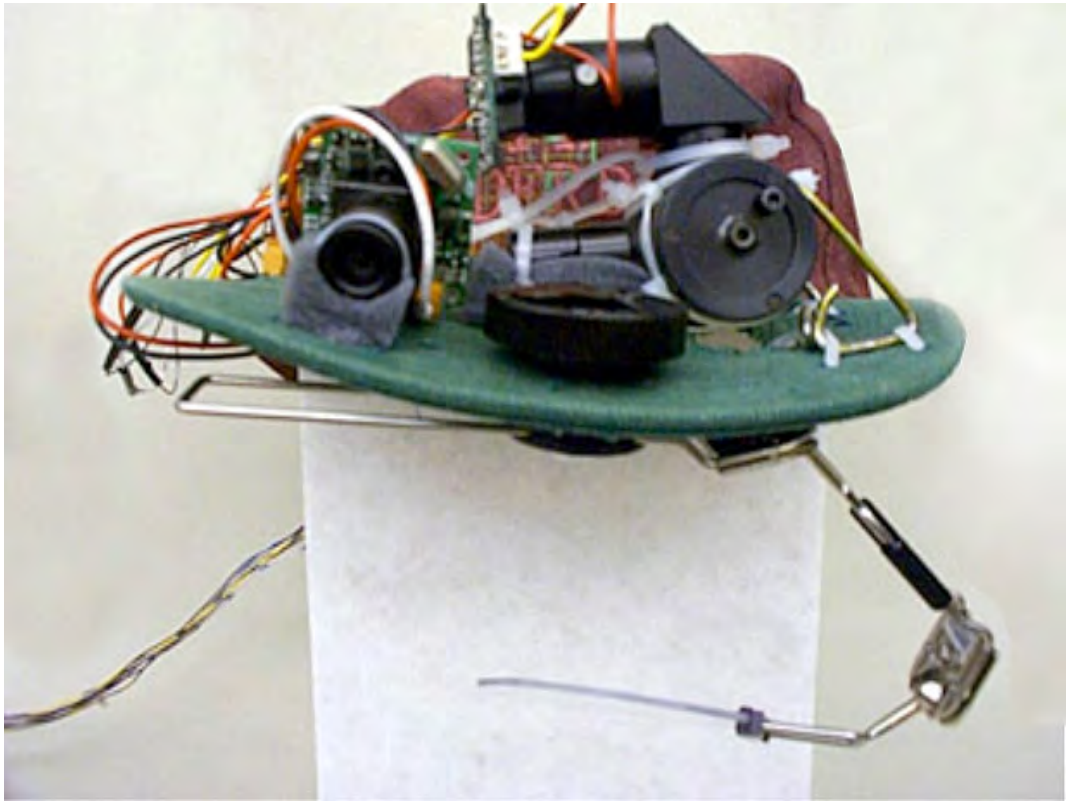


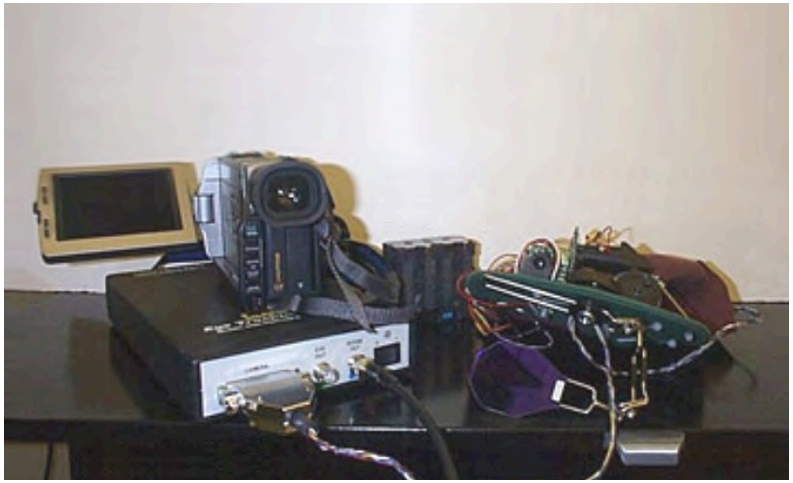
# RIT Wearable Eyetracker


"0th Generation" (1996)

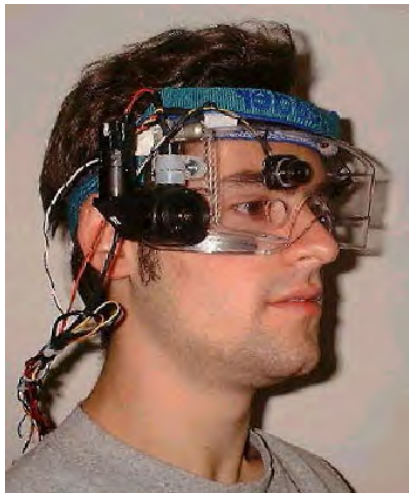
# RIT Wearable Eyetracker


1st Generation (1998)



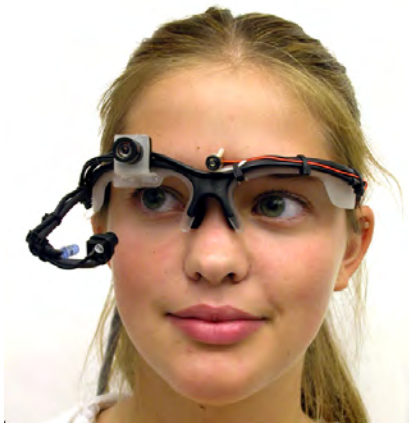


# RIT Wearable Eyetracker



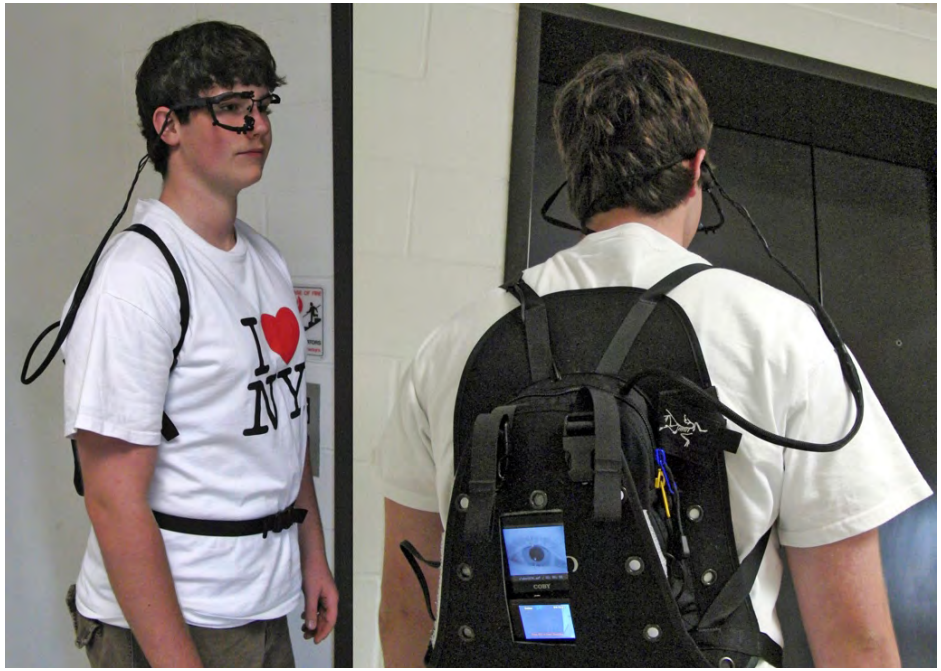
2nd (2000)

3rd (2003)



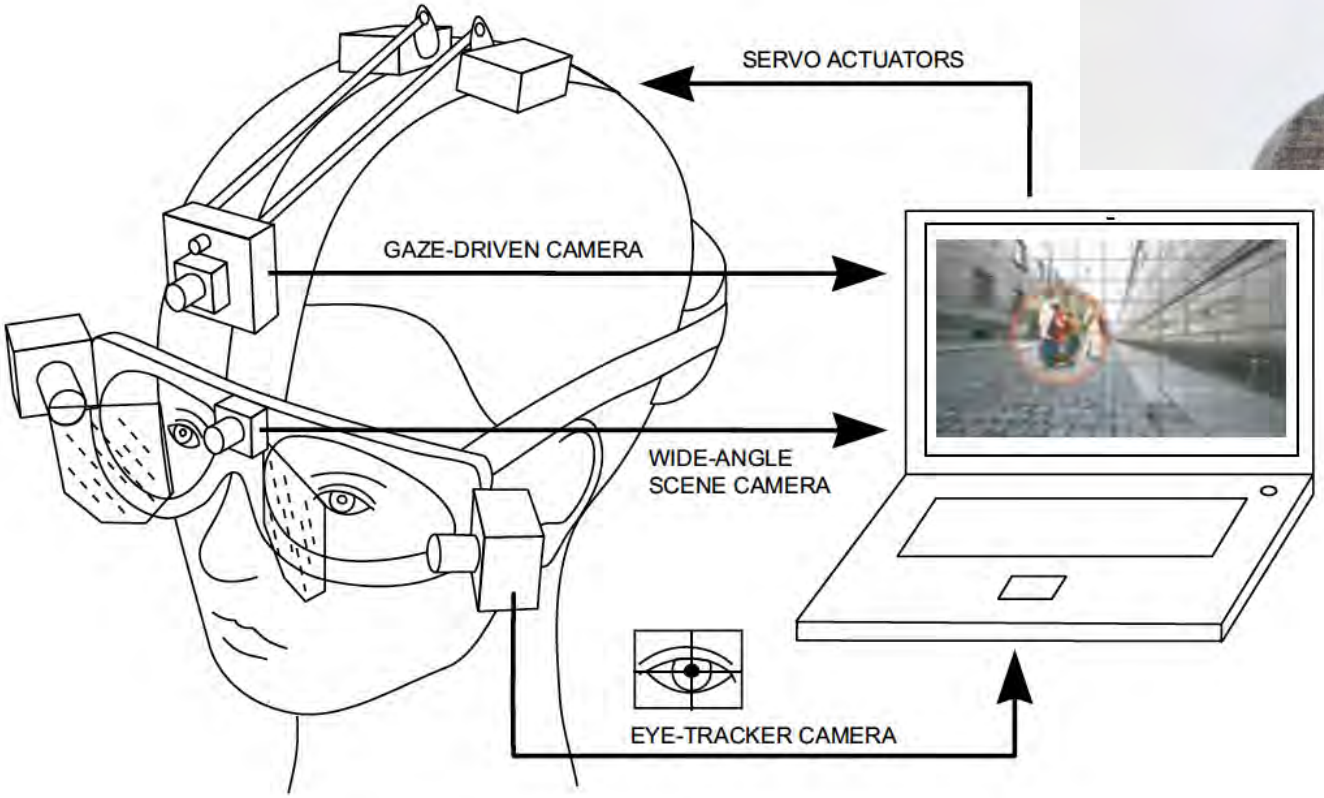
4th (2004)

5th (2006)



6th (2008)

# Positive Science™ Wearable Eyetracker


SERVO ACTUATORS
GAZE-DRIVEN CAMERA
WIDE-ANGLE
SCENE CAMERA
EYE-TRACKER CAMERA

# EyeSeeCam


Tobii Glasses
(IR markers)

SMI IView X


SMI Glasses

ASL MobileEye XG

Dong & Luo, PETMEI 2011

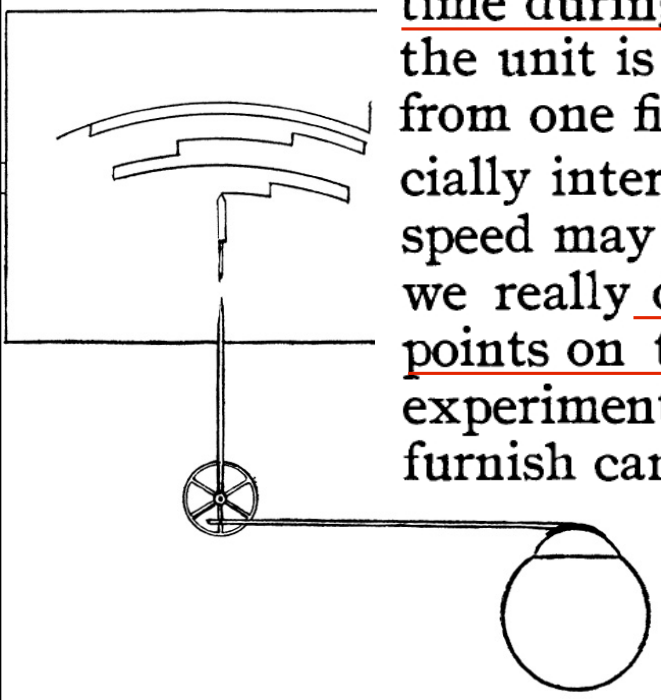
# WearCam

# Data Analysis:

Besides, the most casual observation showed that the eye moved along the line by little jerks and not with a continuous steady movement. I tried to record these jerks by direct observation, but finally decided that my simple reaction to sight stimuli was not qnick enough to keep up with them when the subject read at normal speed.

...

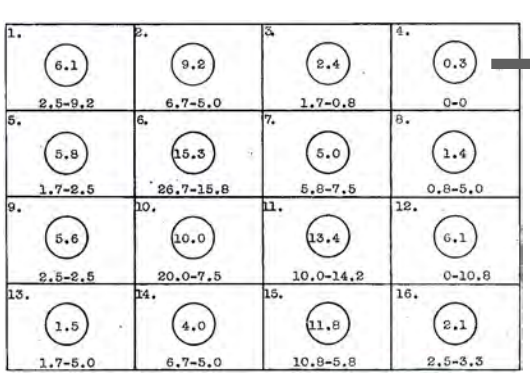
By the help of the quarter-second record written on the margin of the paper, it is possible to measure approximately the time during which the eye remains fixated at each point, but the unit is too large for getting the speed with which it moves from one fixation point to another.[1] The latter point is especially interesting, as it would seem from the curves that the speed may be so great that the retinal impressions fuse and that we really do not see foveally what we read except at the few points on the ordinary line at which the eye pauses. These experiments are as yet incomplete; and the data which they furnish cannot be arranged in time for this report.

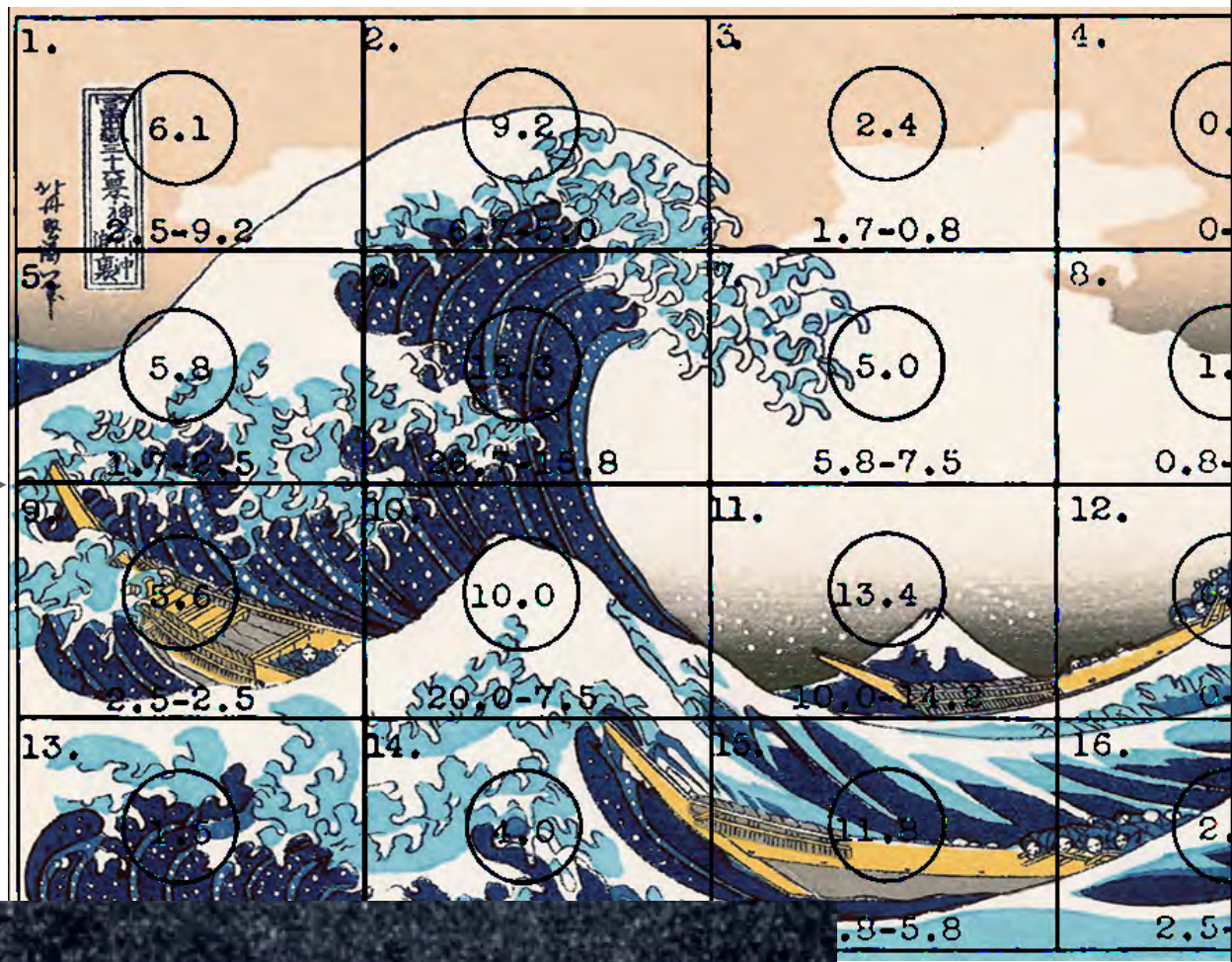


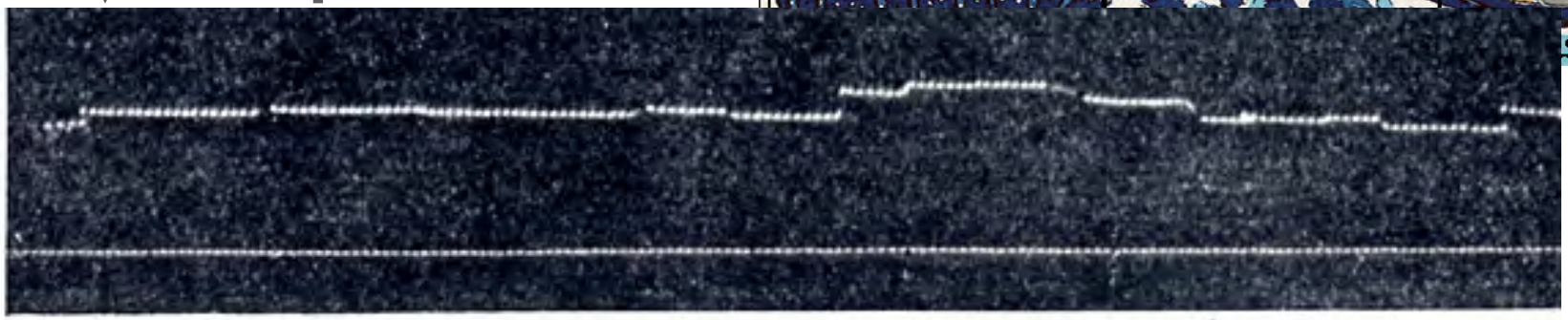
Huey (1898) *American Journal of Psychology*

# Analysis
# Buswell, 1935





# Data Analysis:

The main purpose and usefulness of this head camera technique is to give an immediate picture of on what the subject is fixating, whatever his body, head, and eye movements may be, without the need for analysis and computation to reconstruct his pattern of movements with respect to the scene before him. The film record can also be analyzed in detail in the usual way to study the relative movement of head, eyes, and scene; from examining the behavior of a few subjects and analyzing their performance in this way fruitful hypotheses may well result which can then be tested on a larger number of subjects with simpler experimental methods.

Shackel (1960) *JOSA*

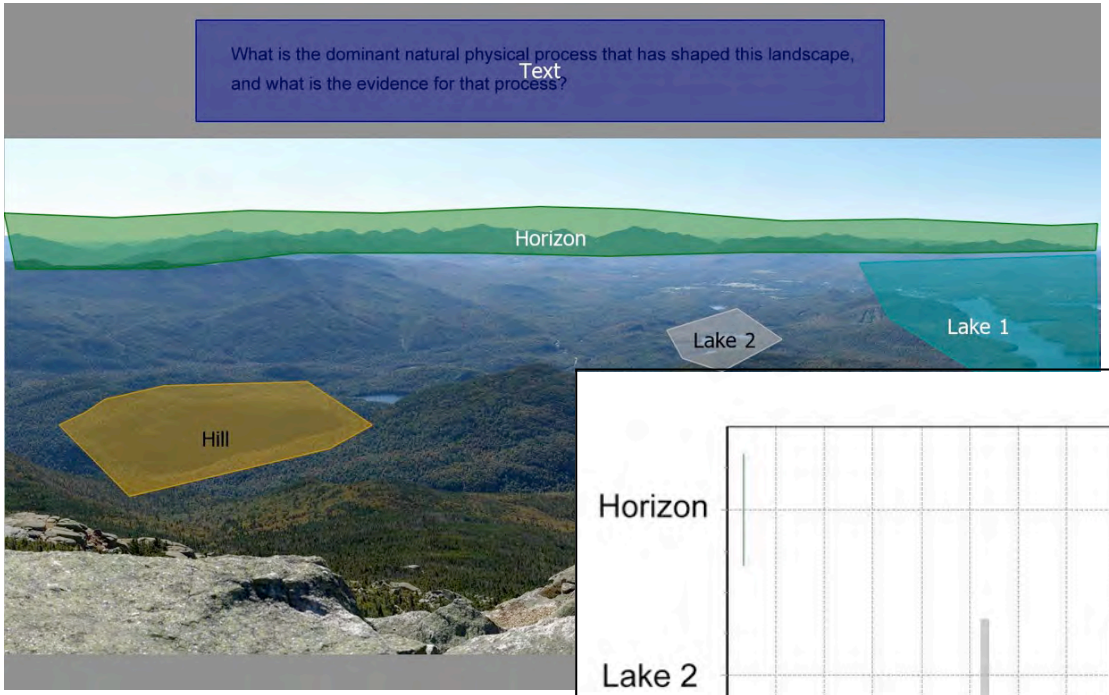
# Analyzing lab-based gaze data

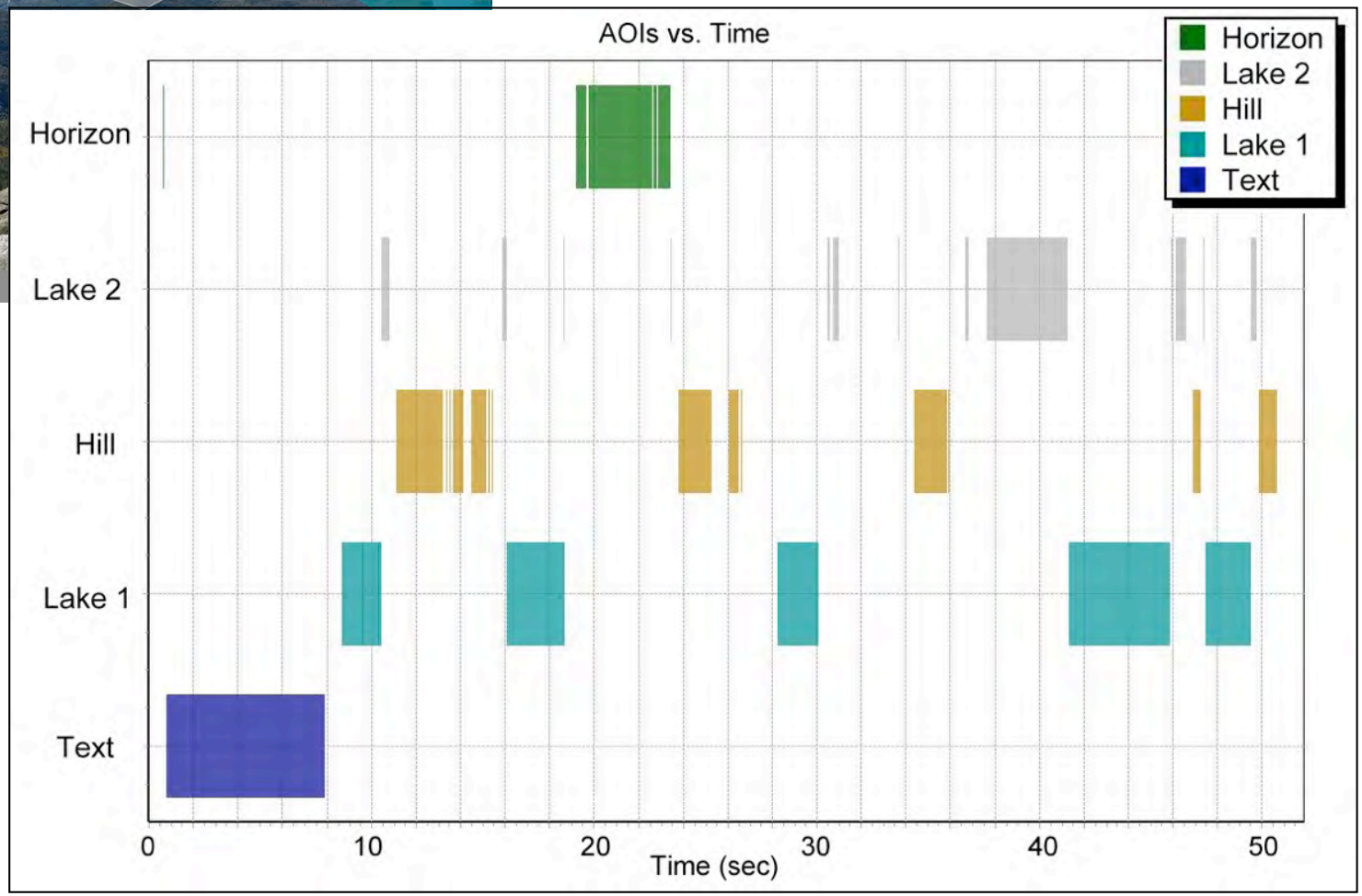
# Analyzing Video-based Gaze Data

What is the dominant natural physical process that has shaped this landscape, and what is the evidence for that process?

# Analyzing Video-based Gaze Data

# Analyzing Video-based Gaze Data



# Analyzing Video-based Gaze Data

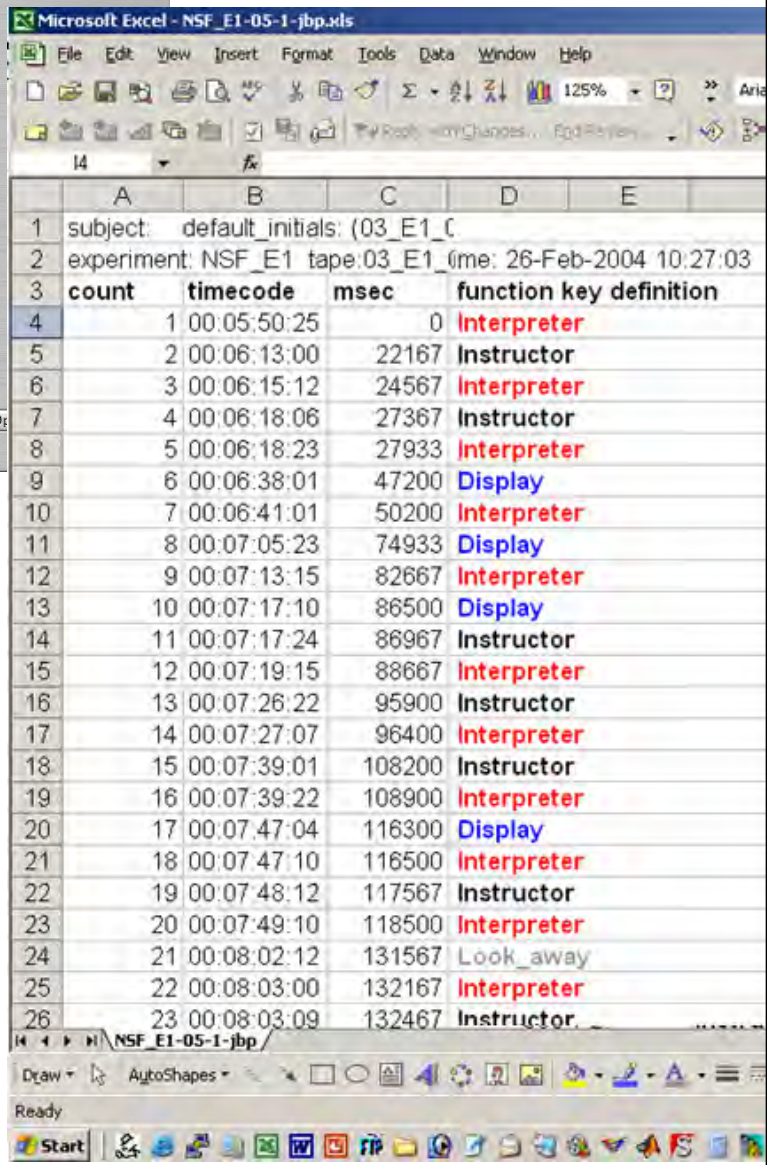

LINE
COUNT 0:14:55:22

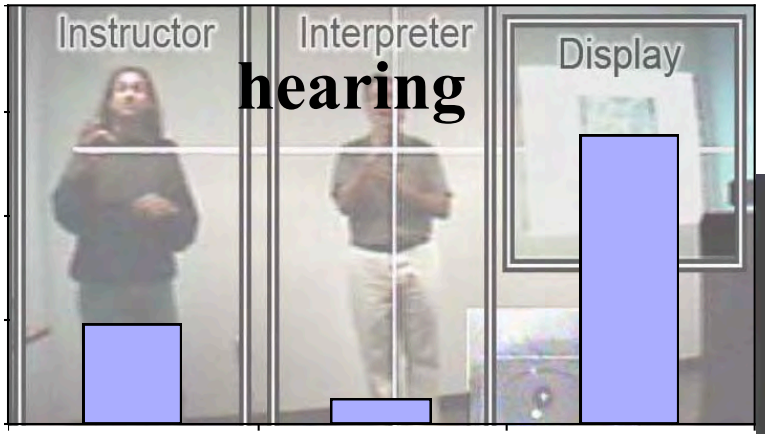

LINE
COUNT 0:14:58:02

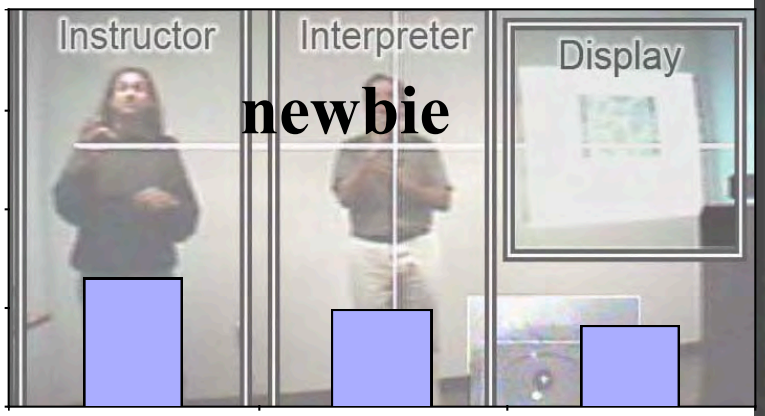

LINE
COUNT 0:15:08:20

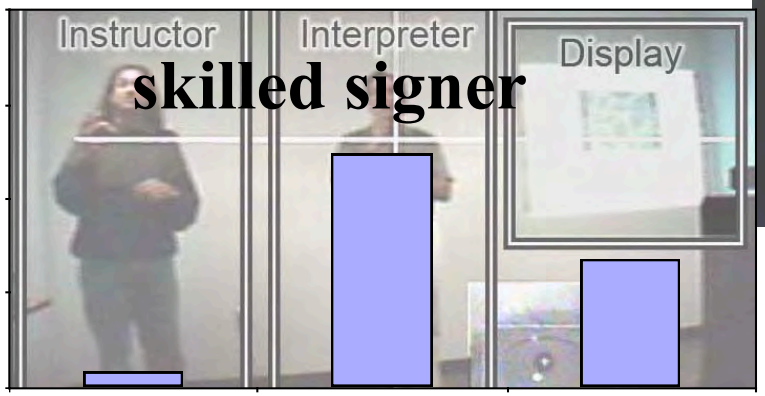

NTID_03_E1_05
Restore Keyboard
0 Enter text in "0 Note" below...
F1 Instructor
F2 Interpreter
F3 Display
F4 Track Loss
F5 Look Away
D:058 H:327 V:169 00:02:26:35
0:00:00:00.00/600
1/4 1/2 play 2x 3x 5x 10x pause
begin end
scan back back 00:00:00:00 next scan fwd
Subject: 05
Initials:
Trial: 01_A0_01
Experiment: NSF_E1
Tape: NTID_03_E1_05
Coder: MEA
Observation Playback Settings 0 Note Log

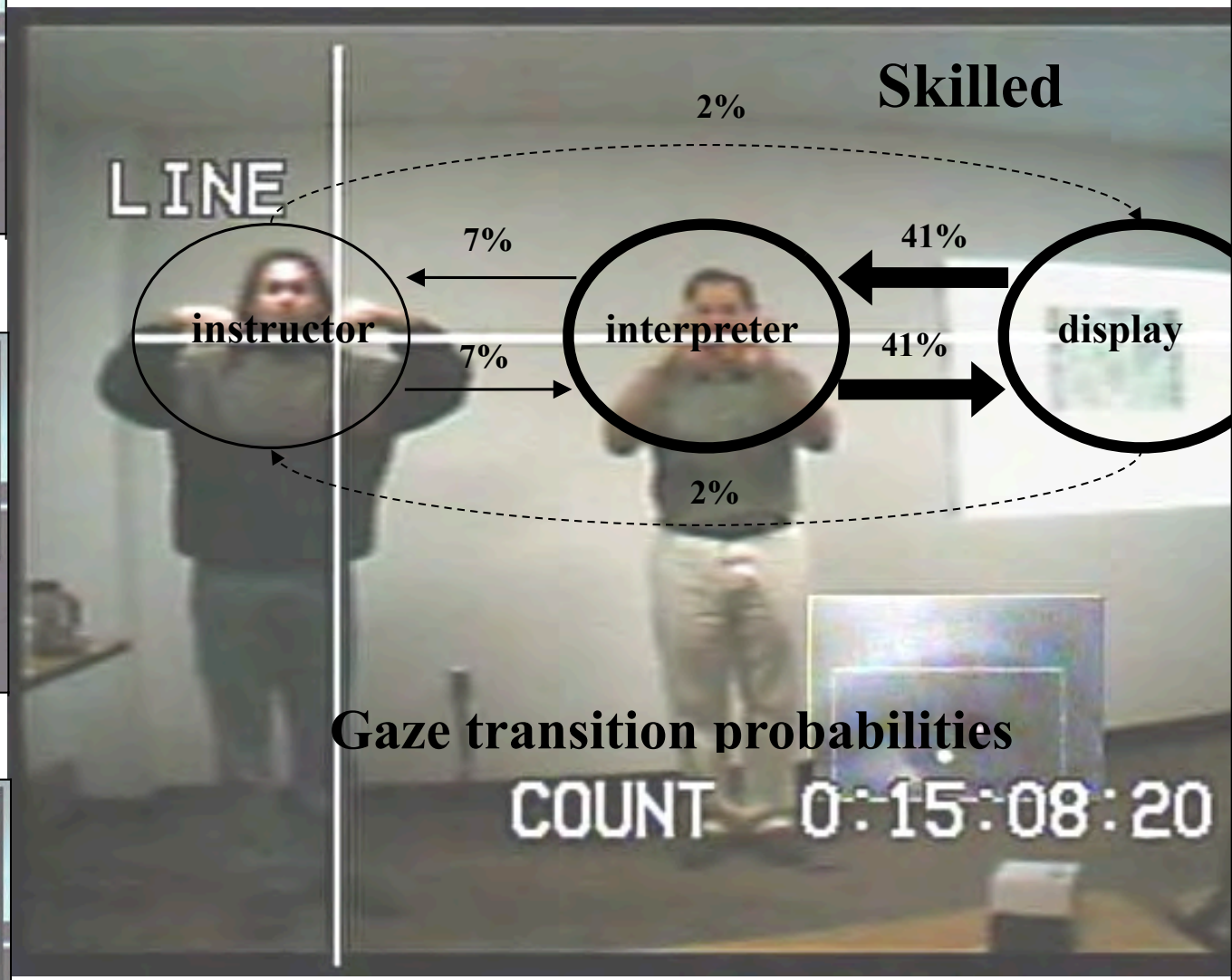
# RITCode

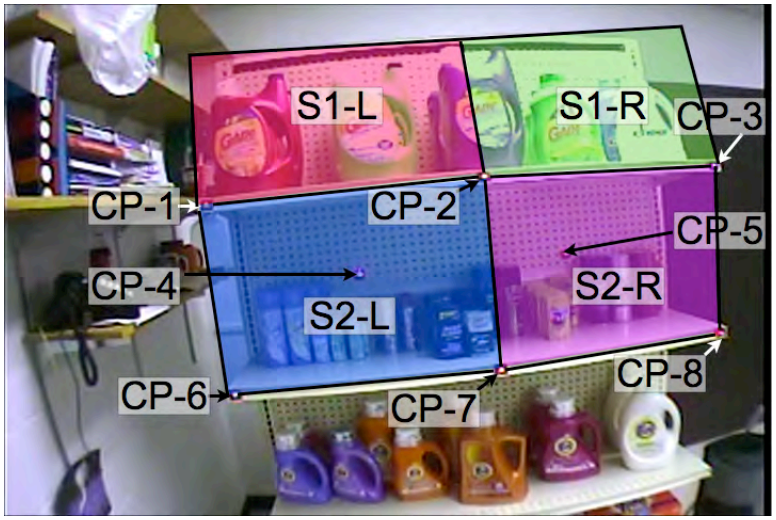

Microsoft Excel - NSF_E1-05-1-jbp.xls
File Edit View Insert Format Tools Data Window Help
subject: default_initials: (03_E1_(
experiment: NSF_E1 tape:03_E1_(me: 26-Feb-2004 10:27:03
count timecode msec function key definition
1 00:05:50:25 0 Interpreter
2 00:06:13:00 22167 Instructor
3 00:06:15:12 24567 Interpreter
4 00:06:18:06 27367 Instructor
5 00:06:18:23 27933 Interpreter
6 00:06:38:01 47200 Display
7 00:06:41:01 50200 Interpreter
8 00:07:05:23 74933 Display
9 00:07:13:15 82667 Interpreter
10 00:07:17:10 86500 Display
11 00:07:17:24 86967 Instructor
12 00:07:19:15 88667 Interpreter
13 00:07:26:22 95900 Instructor
14 00:07:27:07 96400 Interpreter
15 00:07:39:01 108200 Instructor
16 00:07:39:22 108900 Interpreter
17 00:07:47:04 116300 Display
18 00:07:47:10 116500 Interpreter
19 00:07:48:12 117567 Instructor
20 00:07:49:10 118500 Interpreter
21 00:08:02:12 131567 Look_away
22 00:08:03:00 132167 Interpreter
23 00:08:03:09 132467 Instructor
NSF_E1-05-1-jbp
Draw AutoShapes
Ready
Start

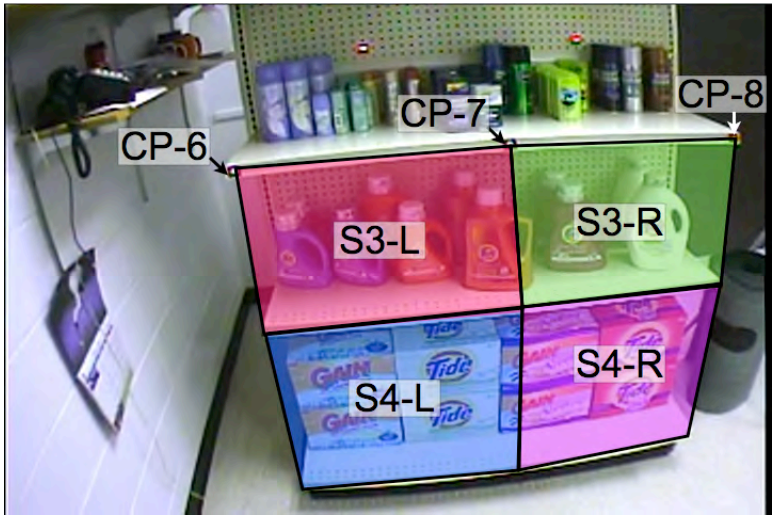

Instructor
Interpreter
Display
hearing


Instructor
Interpreter
Display
newbie


Instructor
Interpreter
Display
skilled signer


Skilled
2%
LINE
7%
41%
instructor
interpreter
display
7%
41%
2%
Gaze transition probabilities
COUNT 0:15:08:20

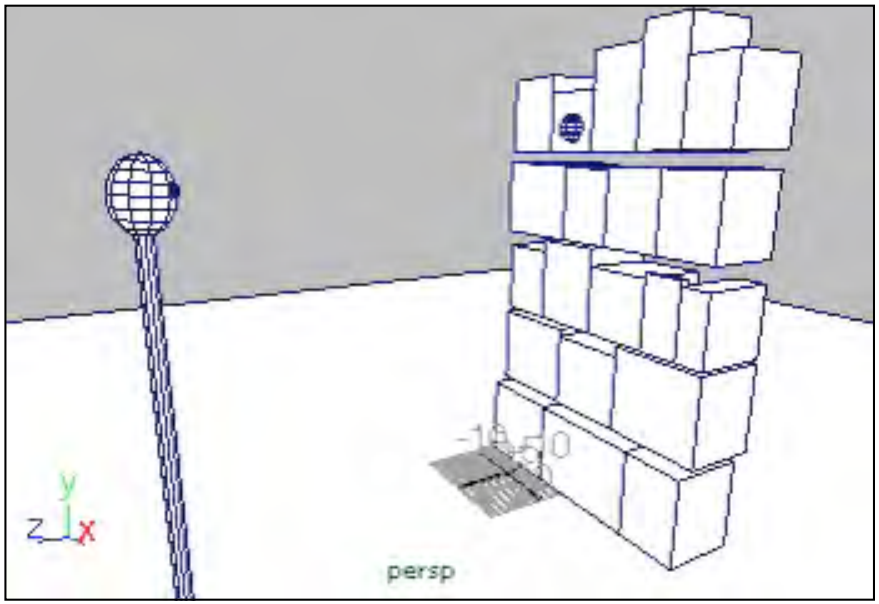

S1-L
S1-R
CP-3
CP-1
CP-2
CP-5
CP-4
S2-L
S2-R
CP-6
CP-7
CP-8


CP-7
CP-8
CP-6
S3-L
S3-R
S4-R
S4-L


S1-L
S1-R
CP-3
CP-1
CP-2
CP-5
CP-4
S2-R
S2-L
CP-8
CP-6
CP-7
S3-L
S3-R
S4-R
S4-L


Subject 1
PG 1/09/09

# Susan Munn: FixTracer




2D POR

3D model

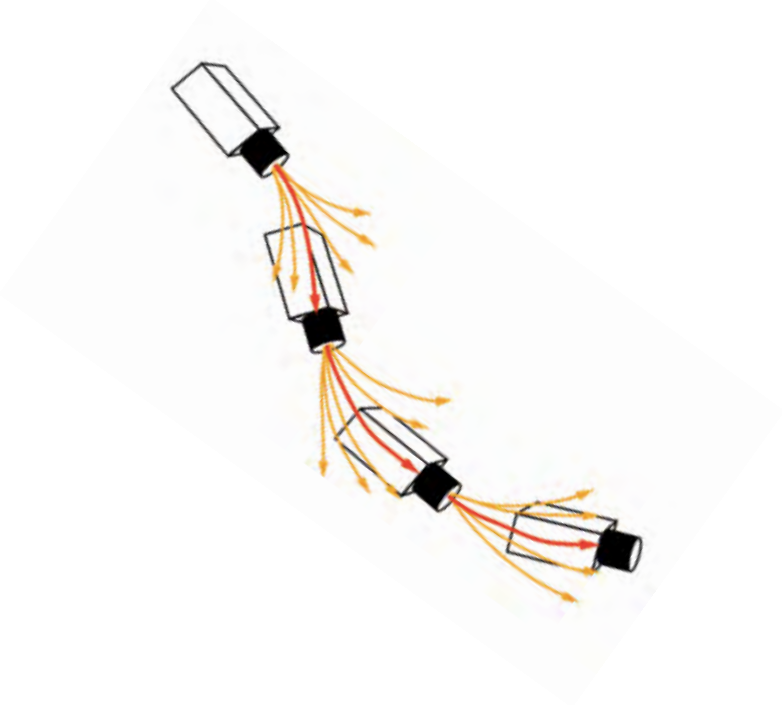
Susan Munn
RIT PhD,
now at ASL

Support: P&G


Object ID

# SLAM

MonoSLAM: Davison et al., *IEEE Trans PAMI* 2007
Visual SLAM: Takemura et al., *ETRA* 2010



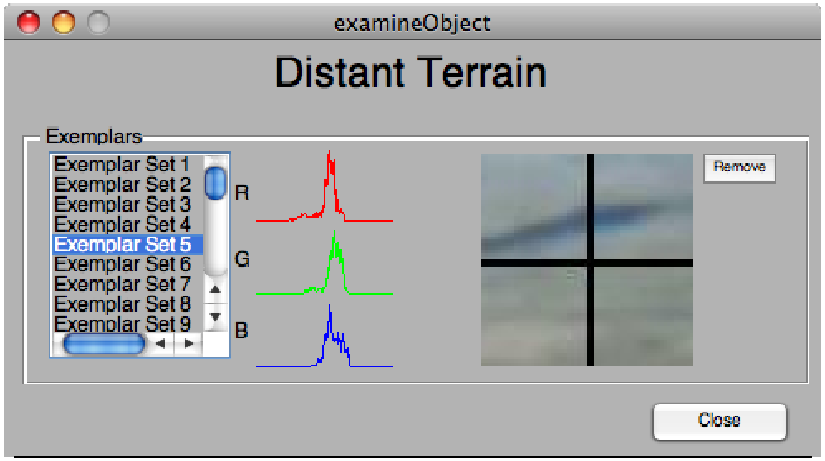
# Object recognition


**Figure 2. Object recognition illustration in shopping setting**

Brône, Oben, & Goedemé, PETMEI 2011

# SemantiCode

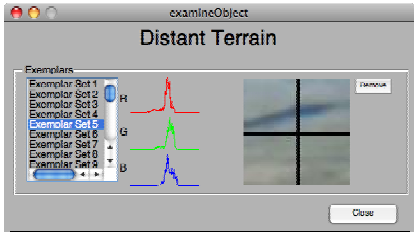
# SemantiCode

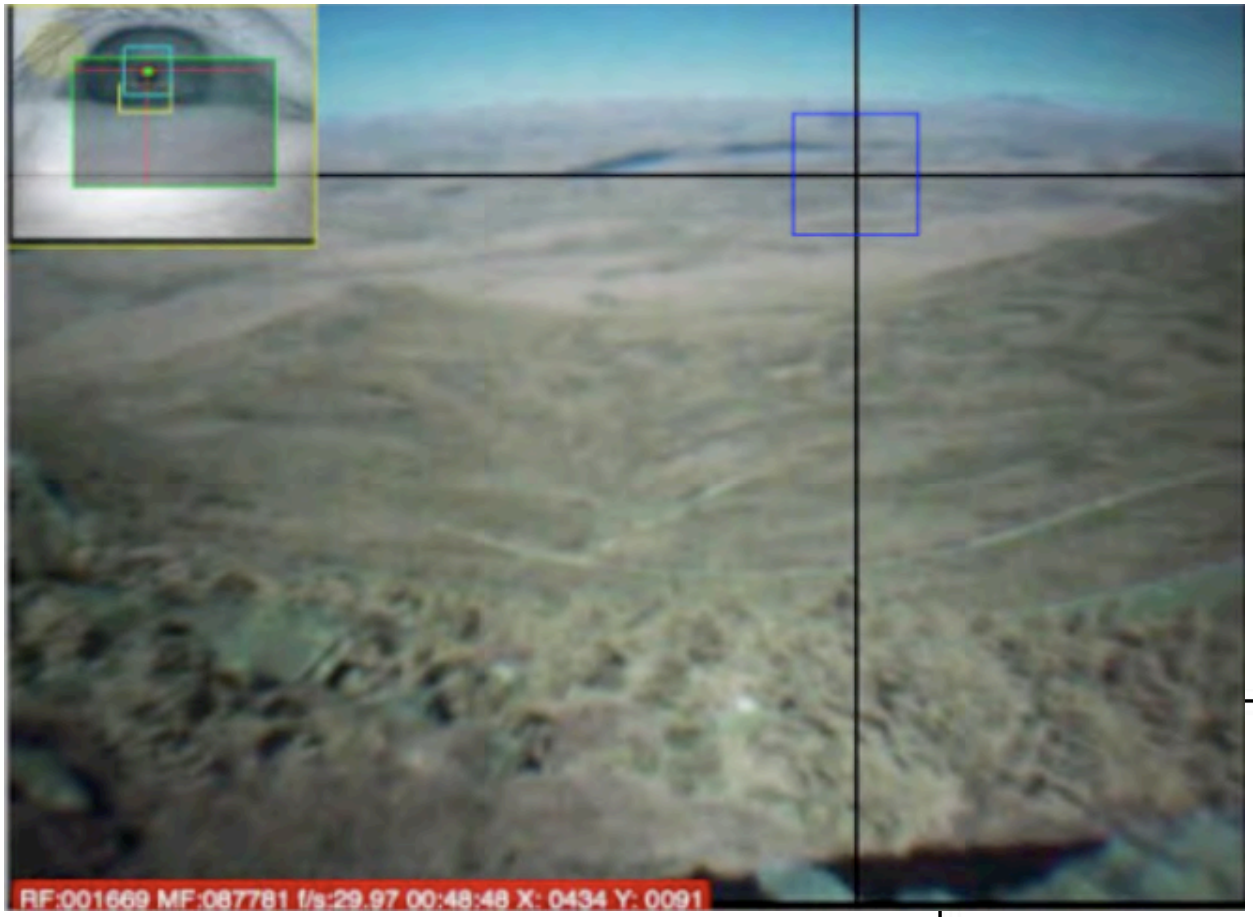



Fixations can be 'tagged' as class exemplars

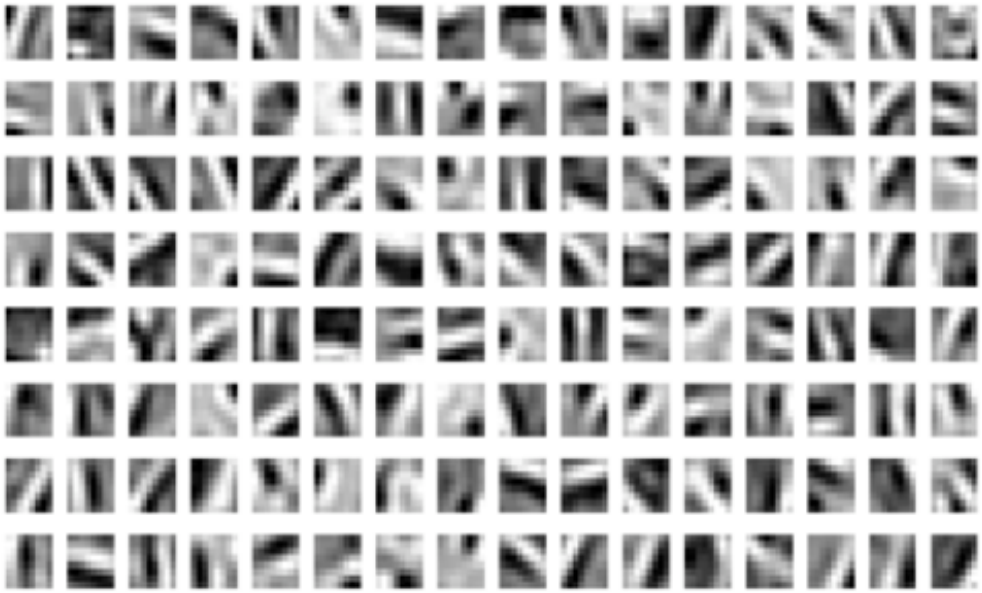
Color histogram intersections
(Swain & Ballard, '90)

# Using only RGB color histograms:



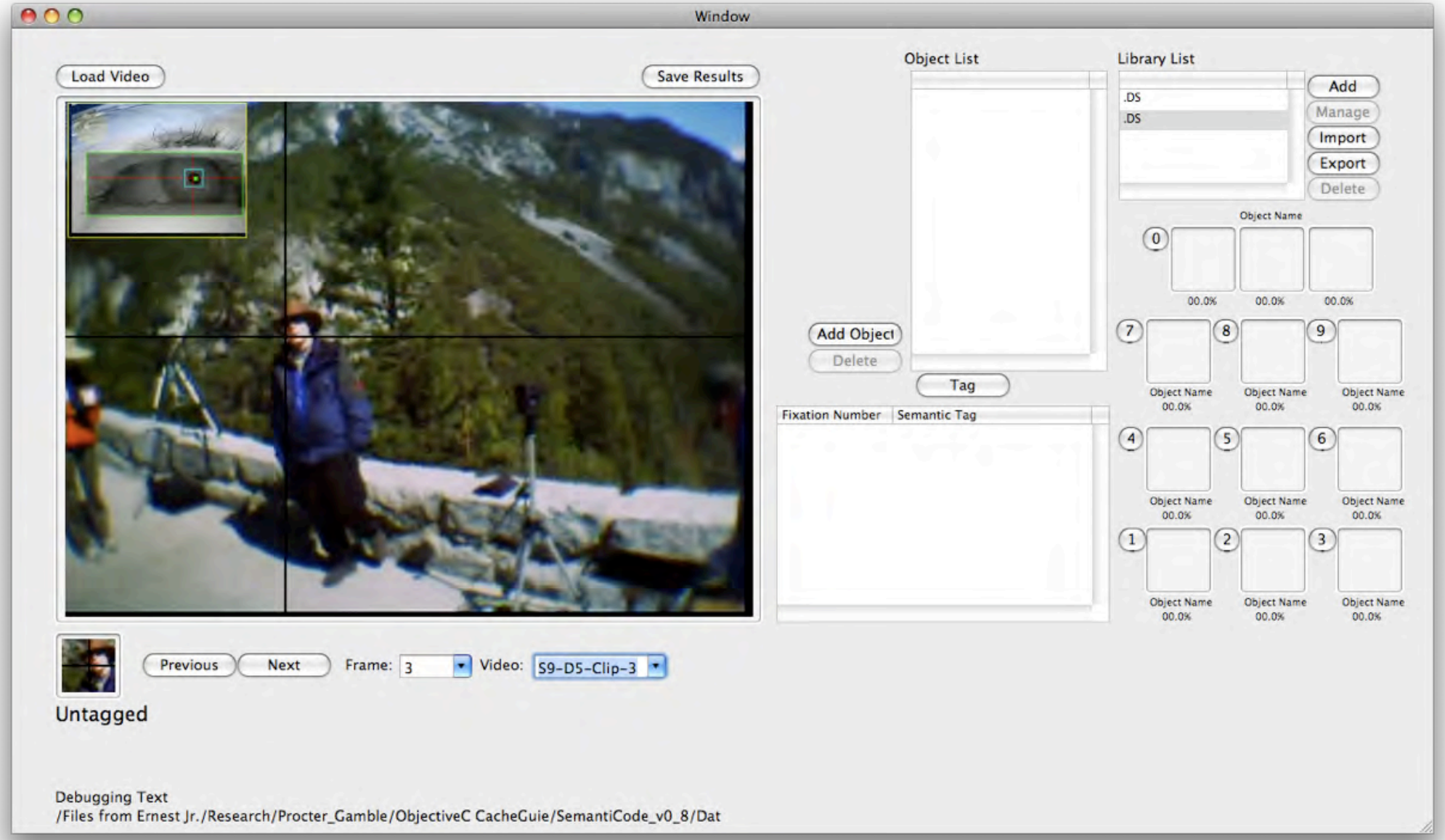




| | Midground | Lighter terrain | Distant terrain | Horizon | Lake |
|---|---|---|---|---|---|
| Midground terrain | 81% | 52% | 26% | 38% | 55% |
| Lighter terrain | 34% | 77% | 72% | 54% | 65% |
| Distant terrain | 45% | 65% | 82% | 58% | 71% |
| Horizon | 14% | 30% | 39% | 60% | 55% |
| Lake | 14% | 61% | 72% | 65% | 81% |



Other features (spectral, spatial, temporal) can be used to identify exemplars.

# SemantiCode



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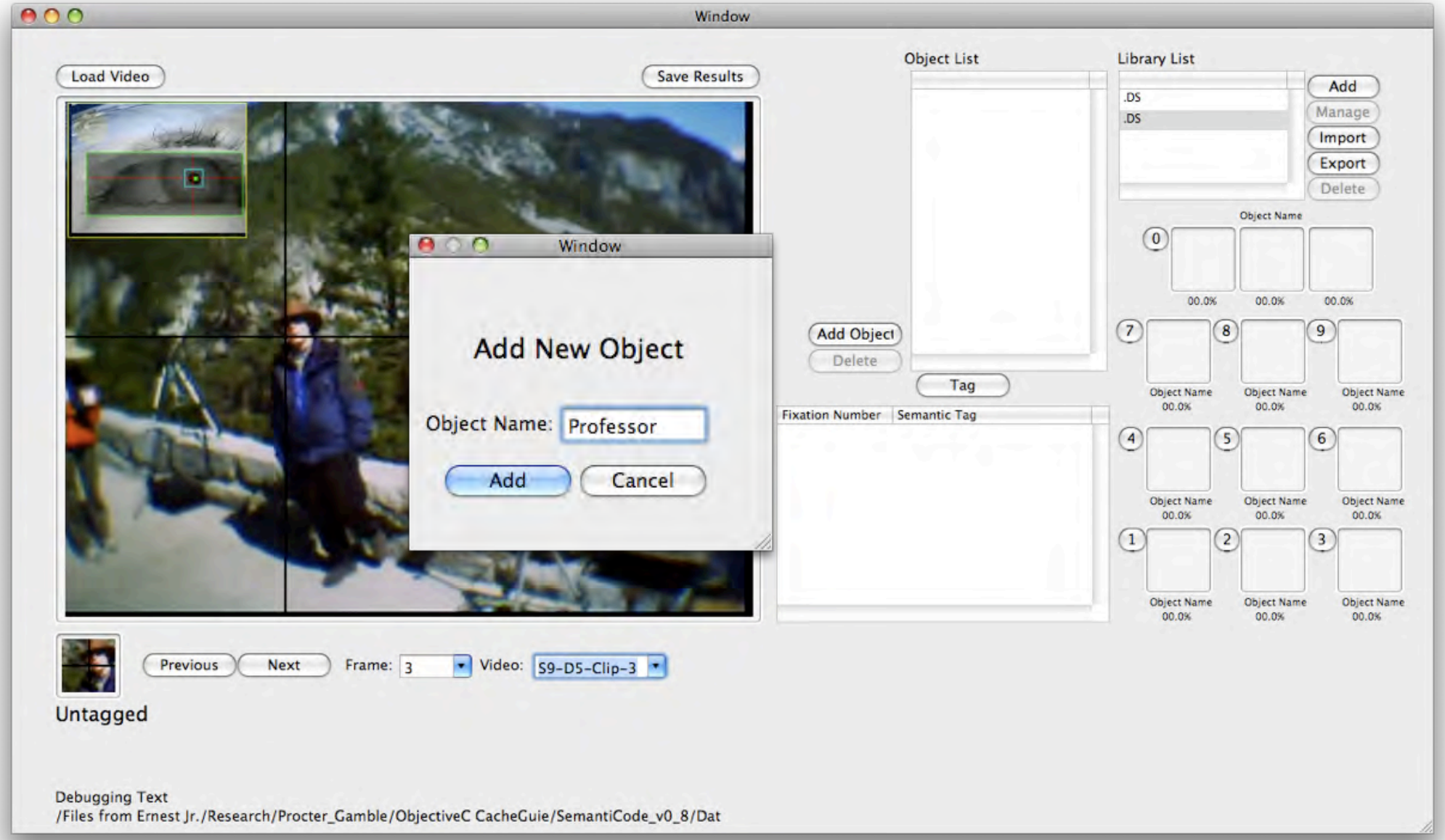

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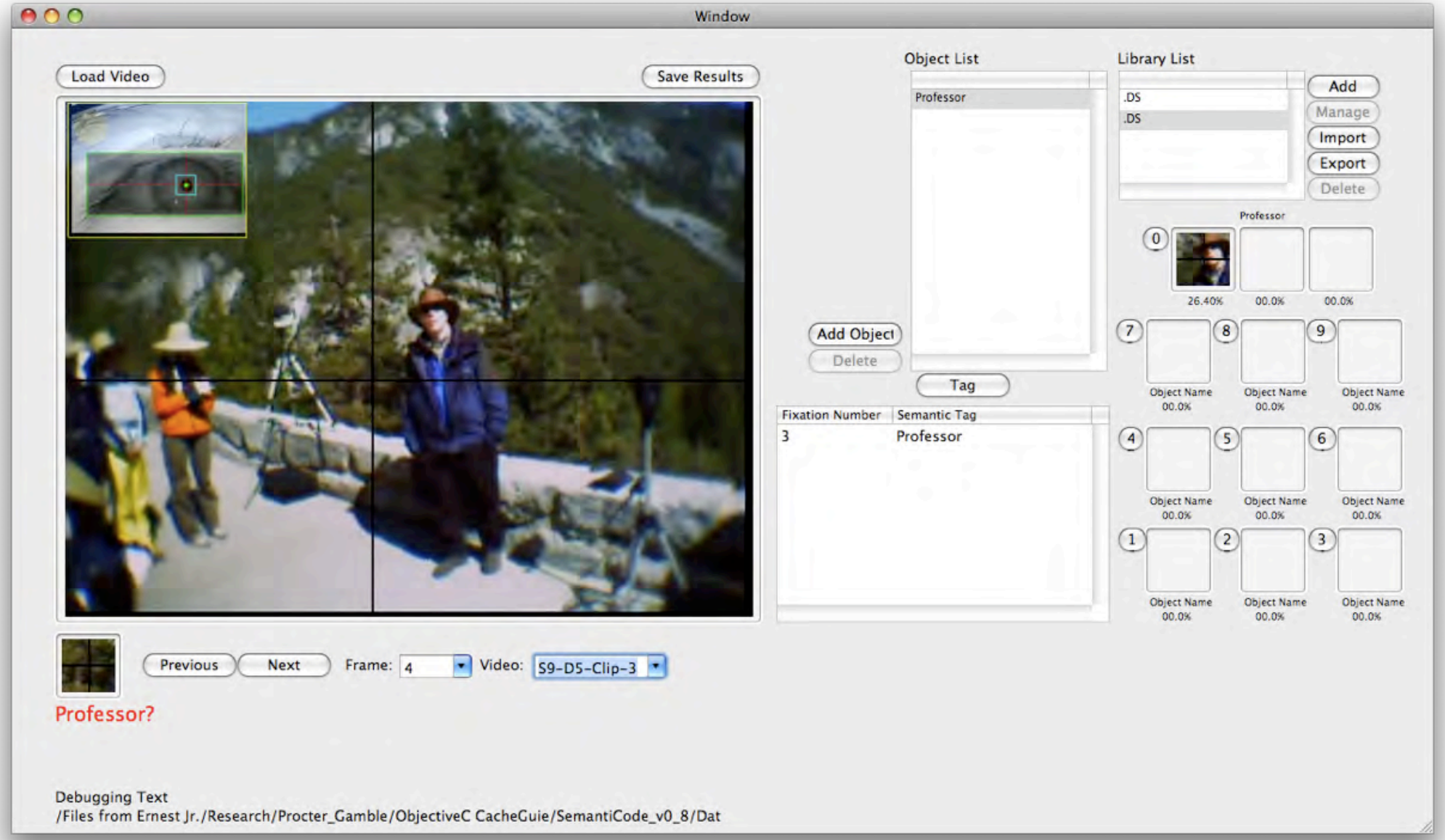

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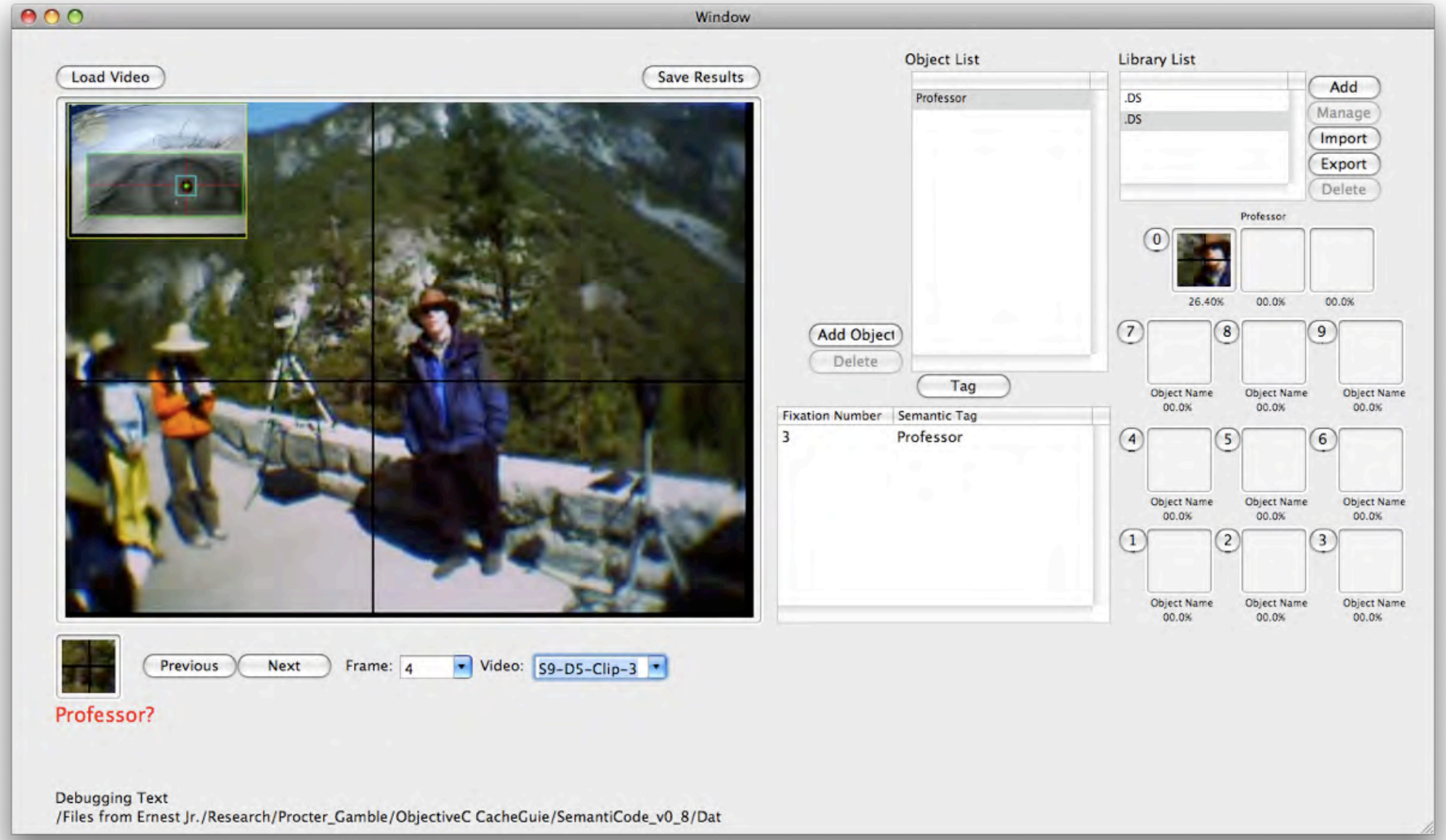

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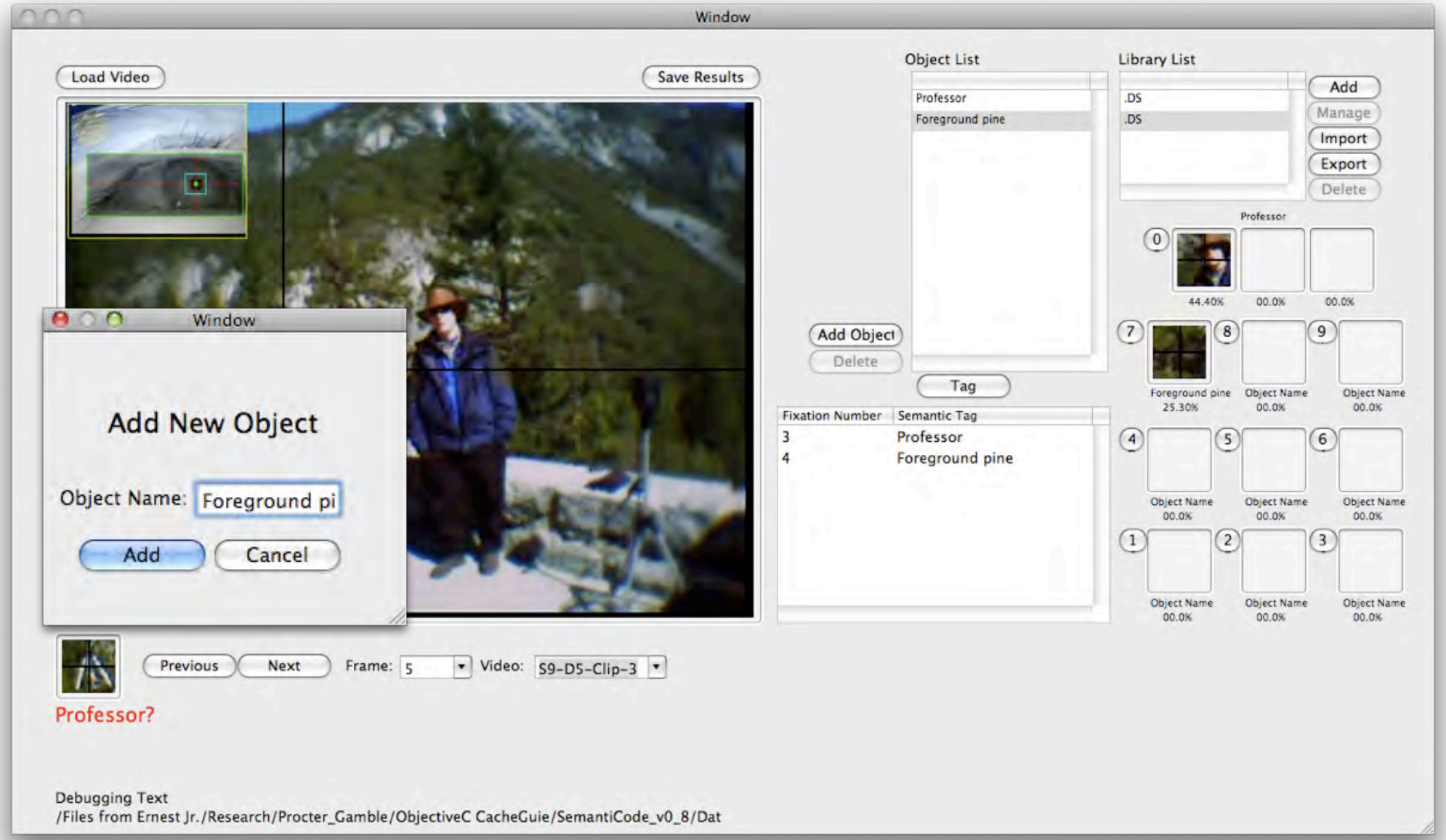

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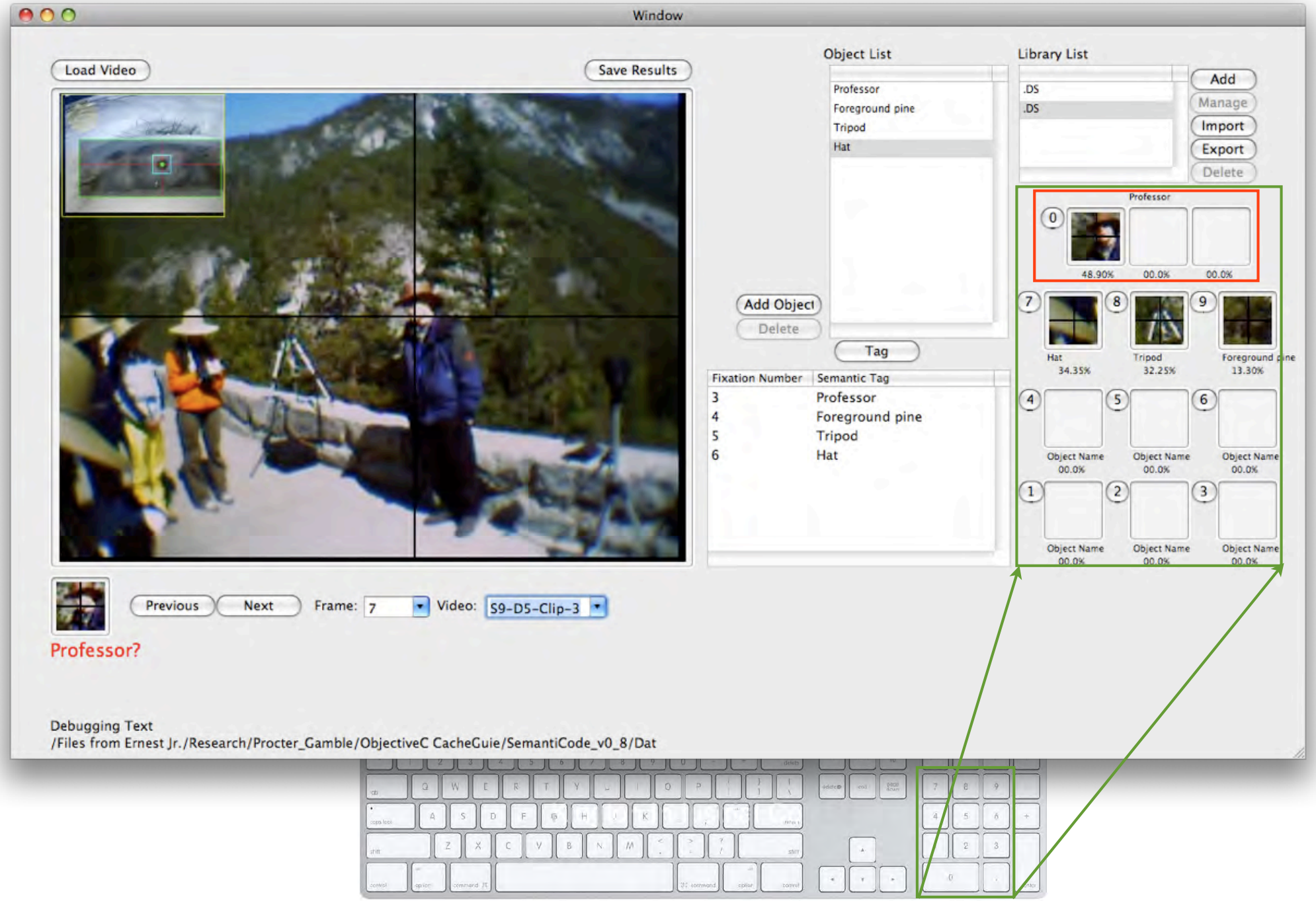

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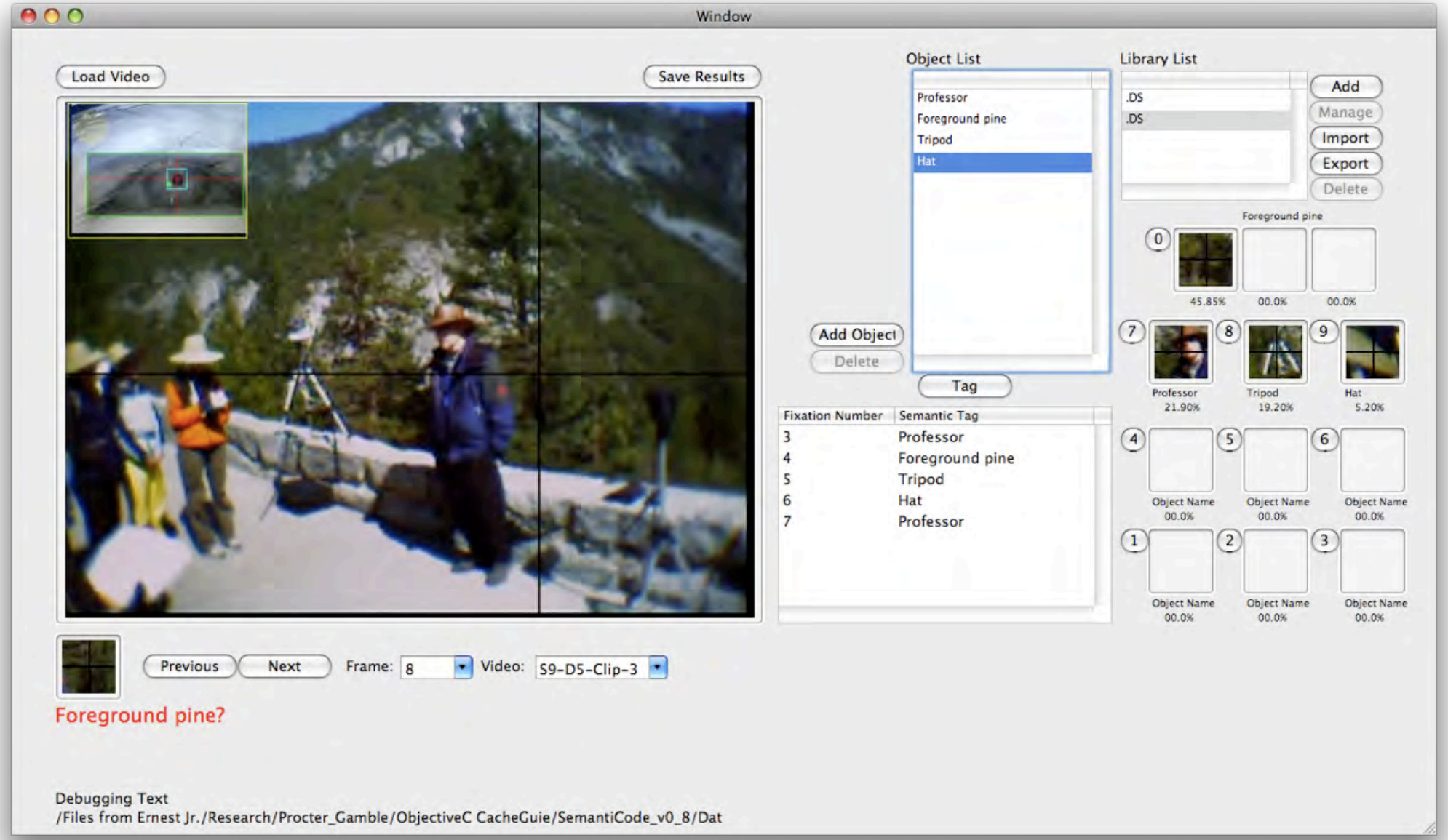

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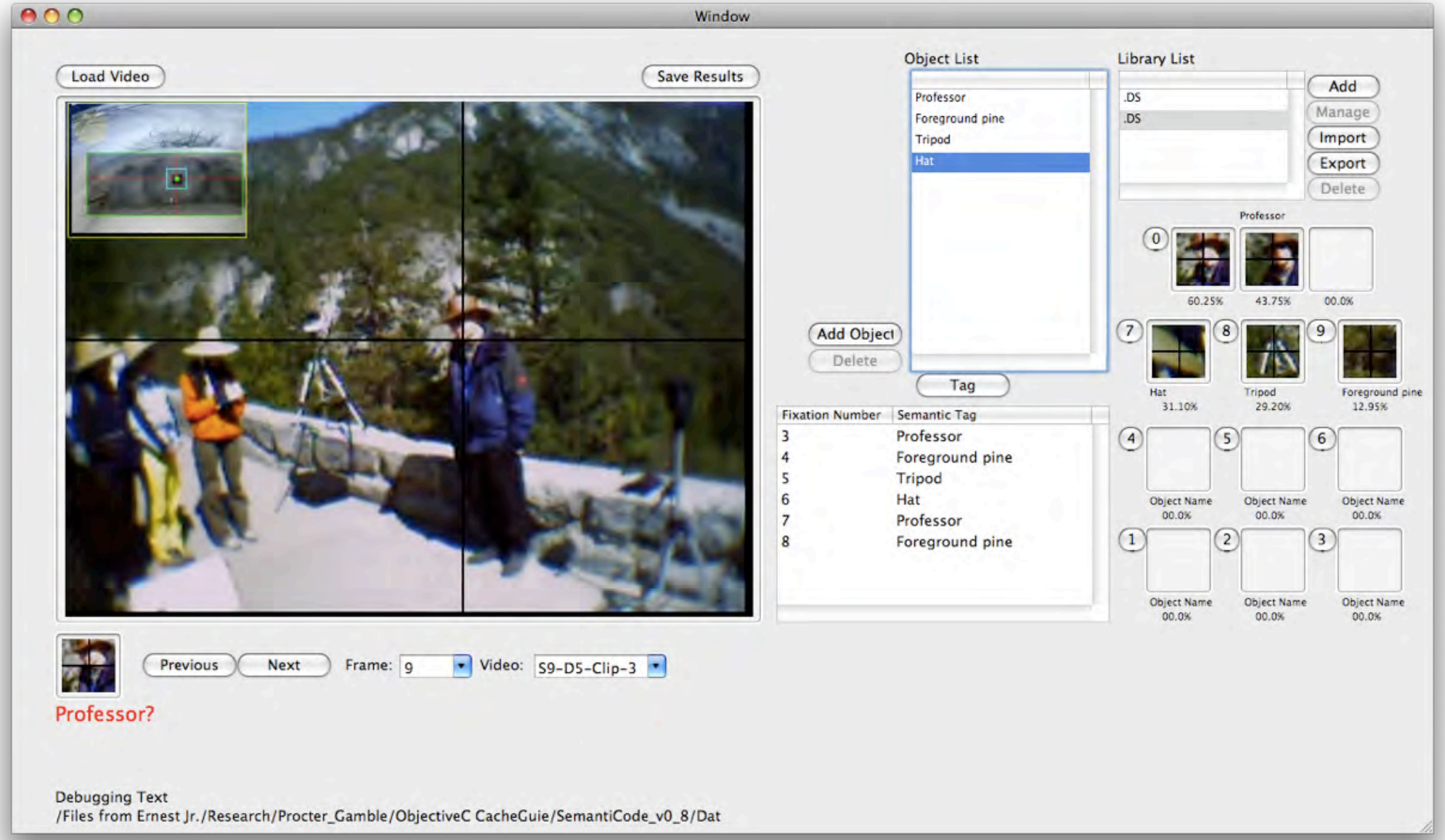

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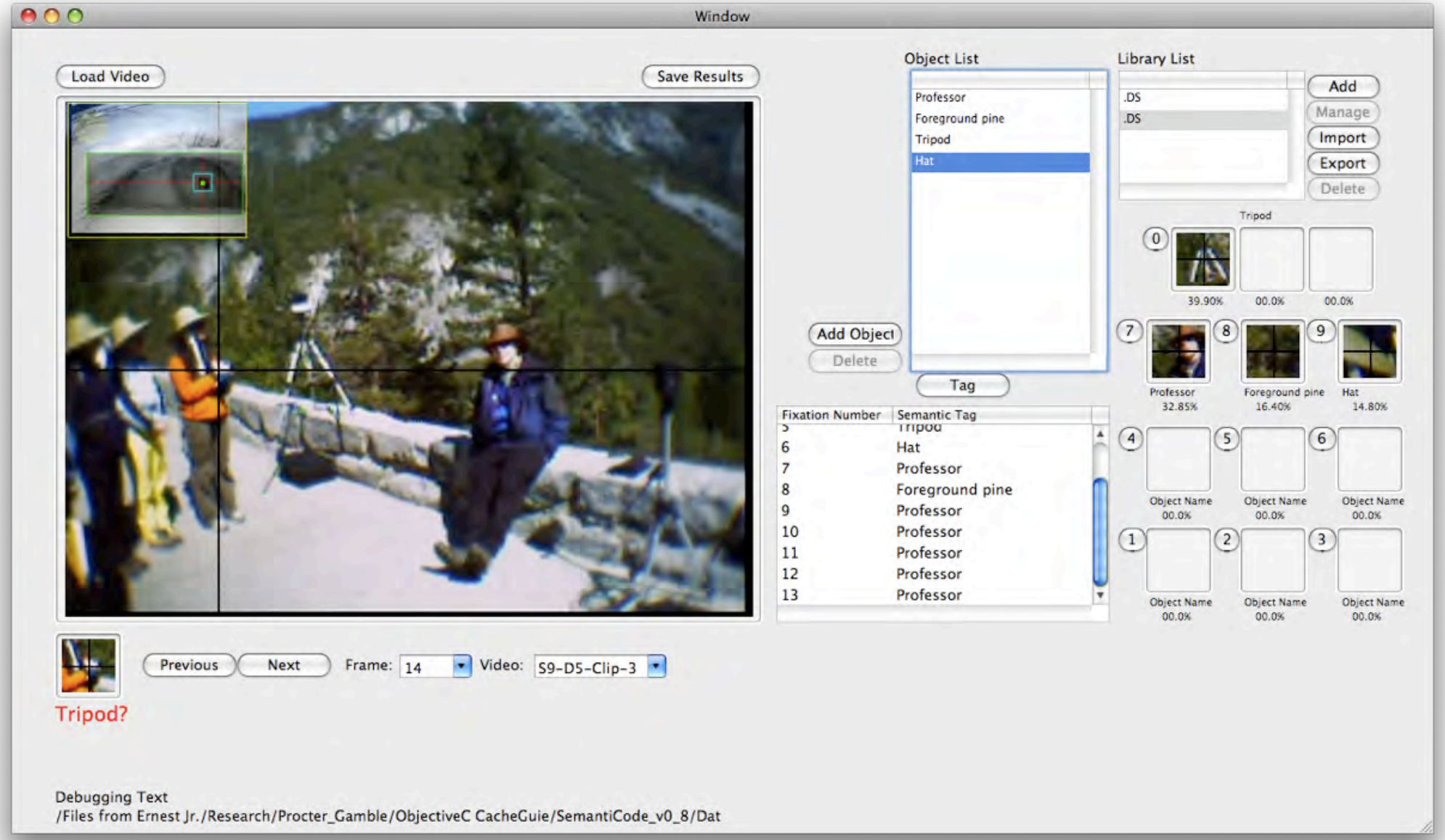

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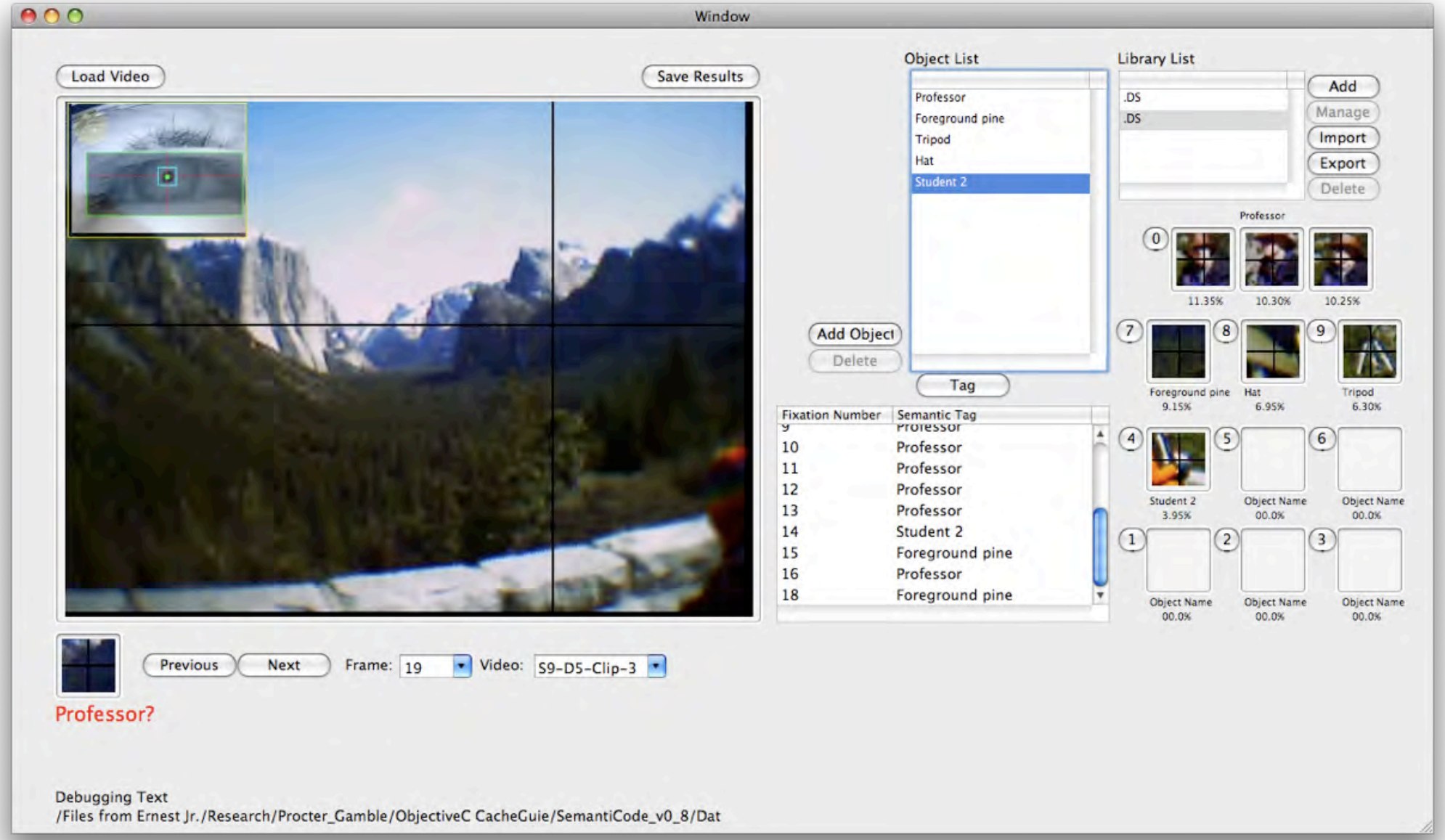

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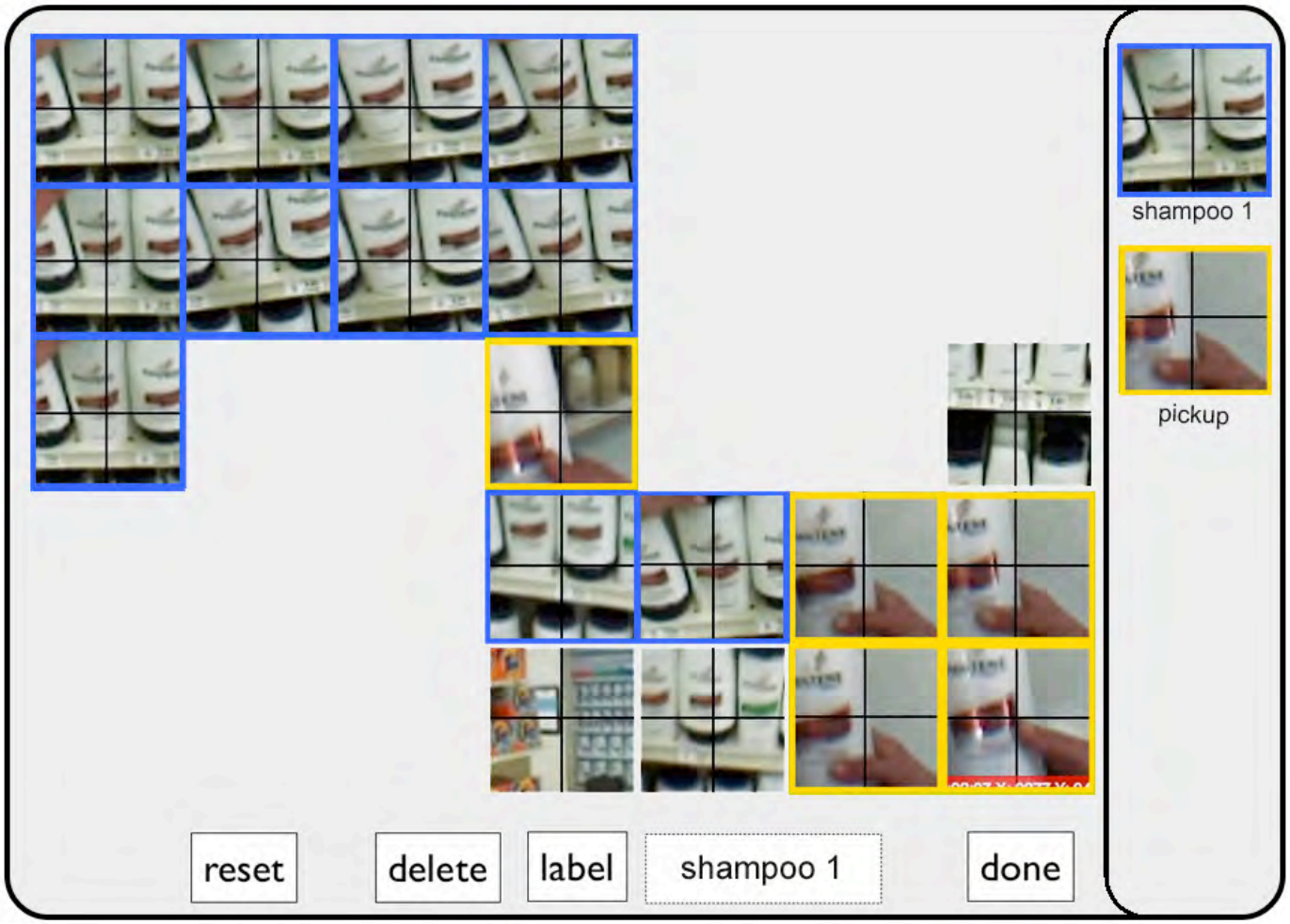
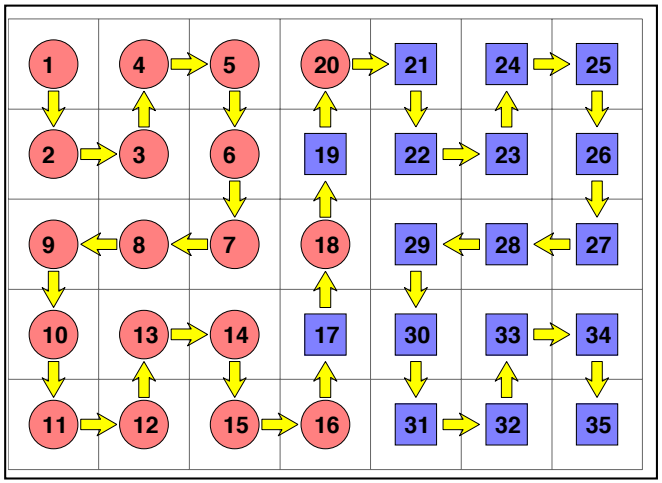
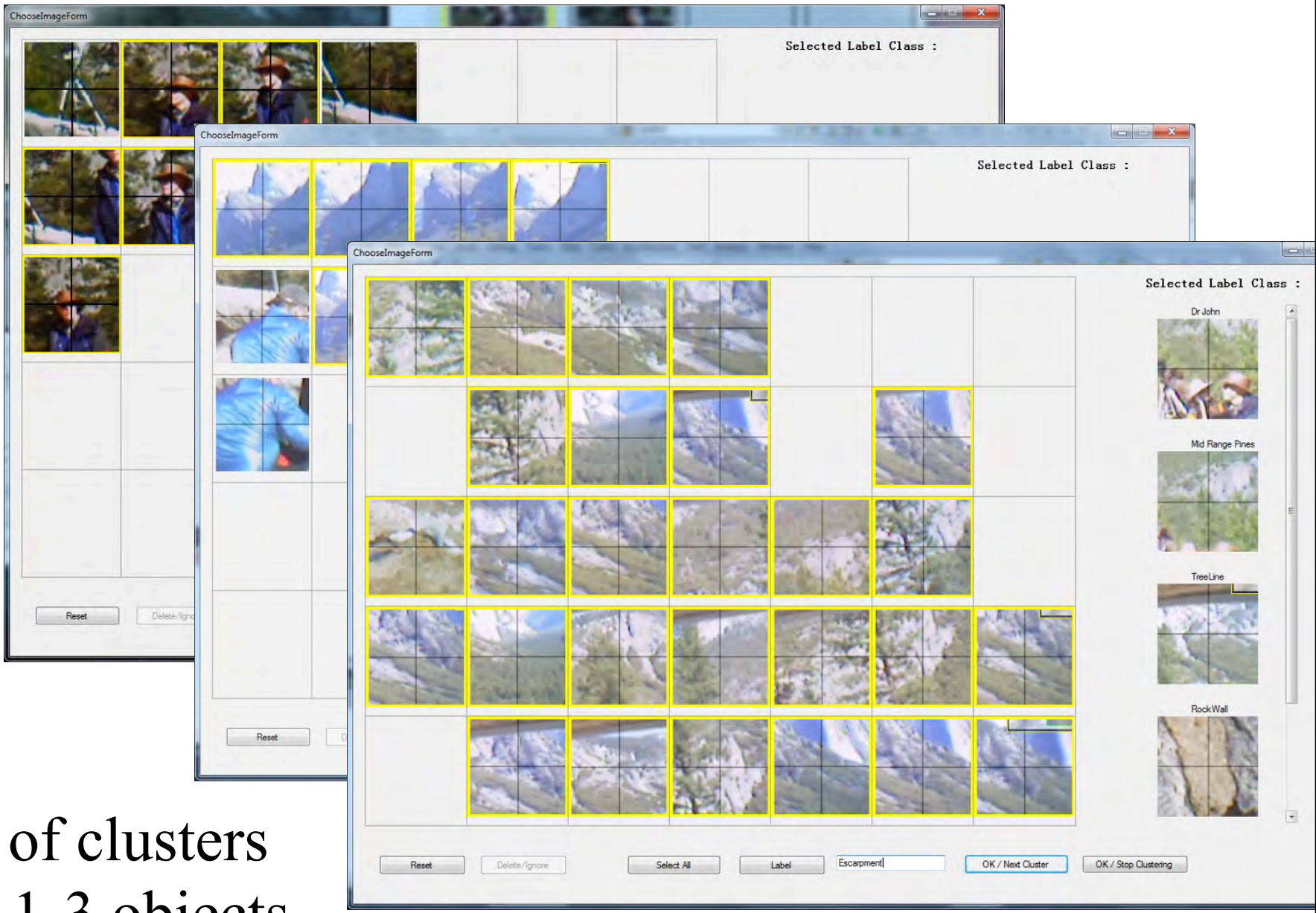


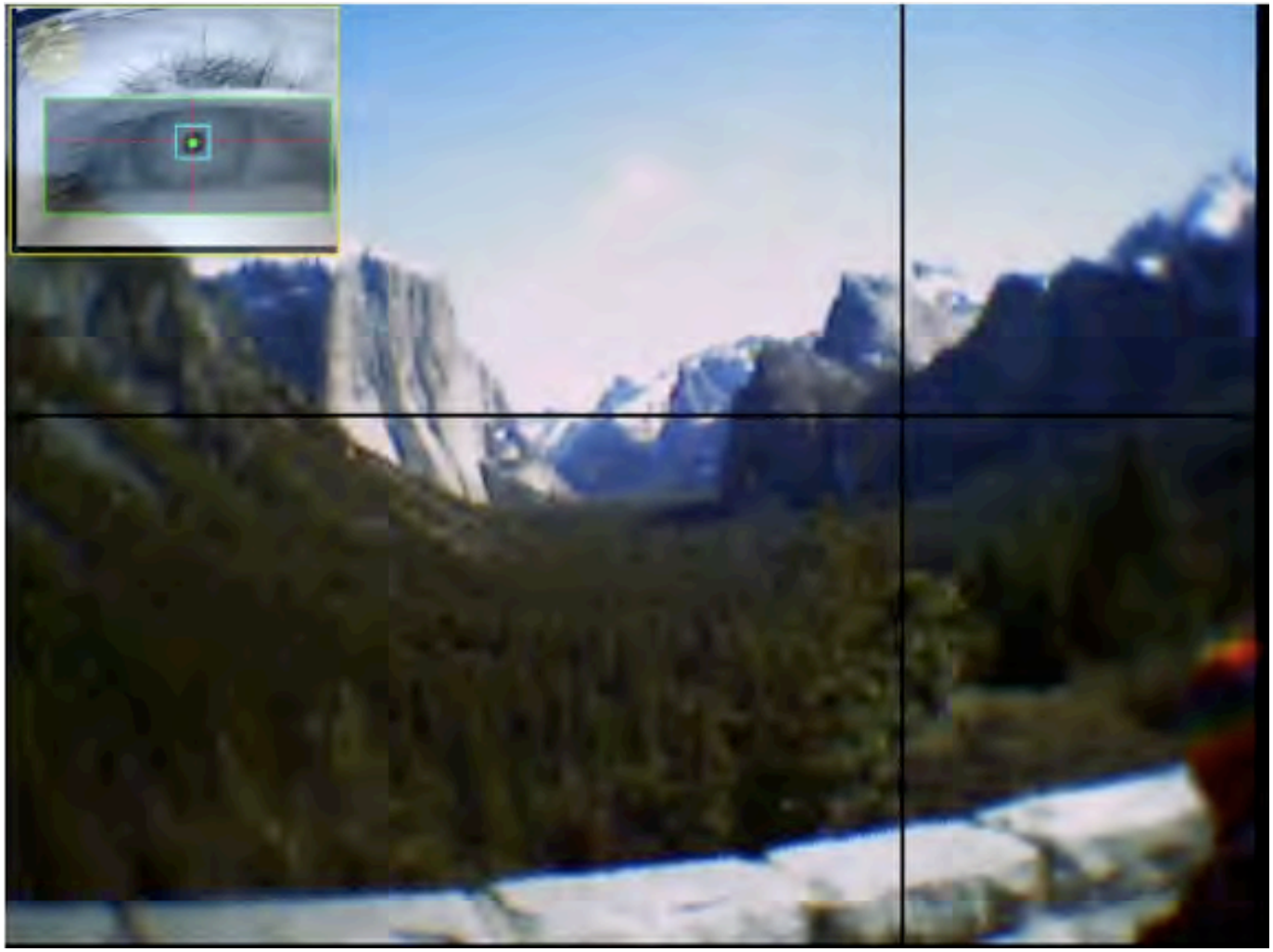



# Analyzing Video-based Gaze Data




50% of clusters
have 1-3 objects

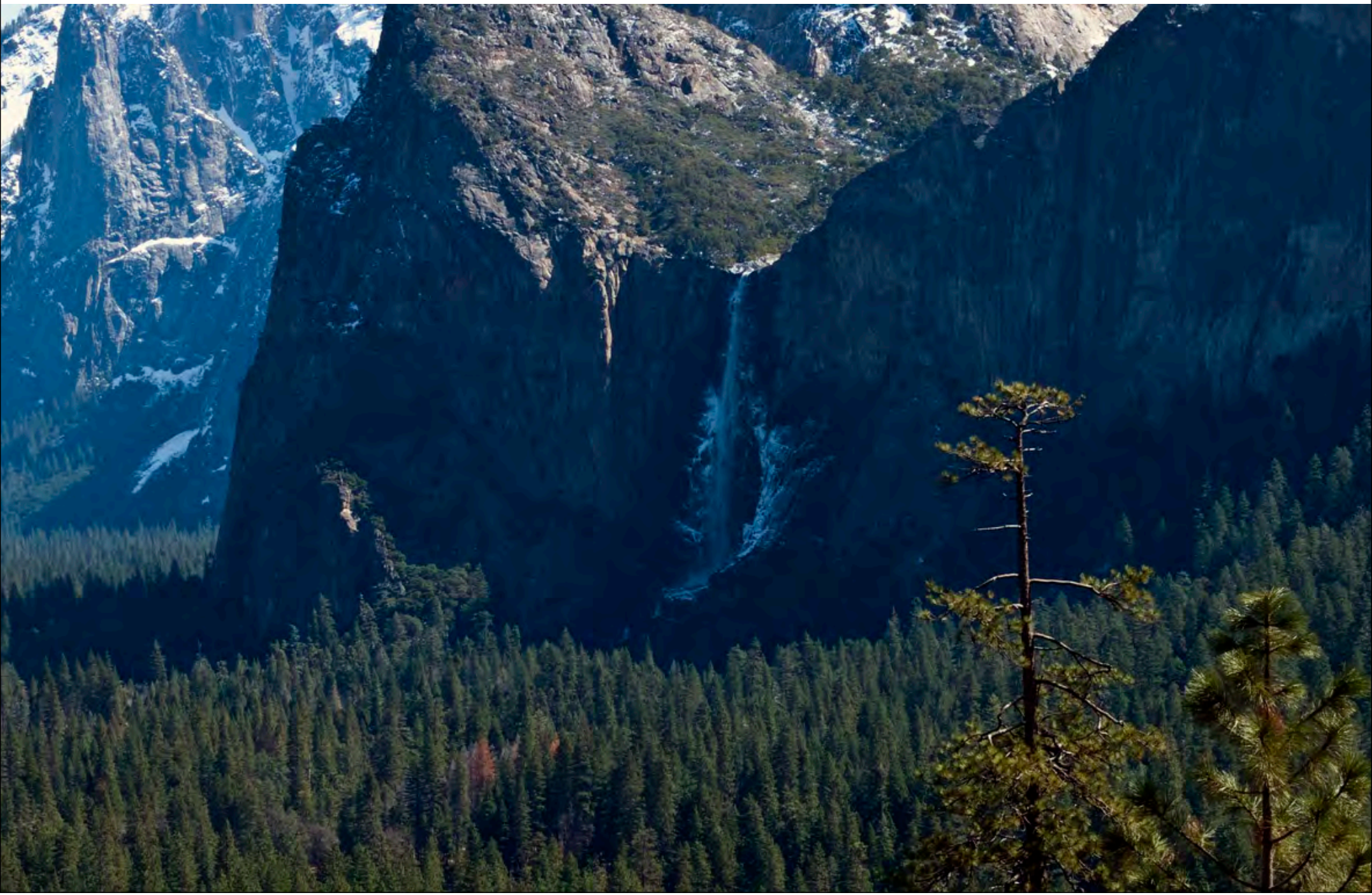
# Limited resolution of scene video

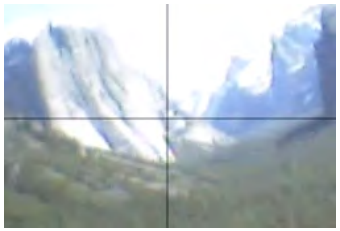


# Panoramic image capture

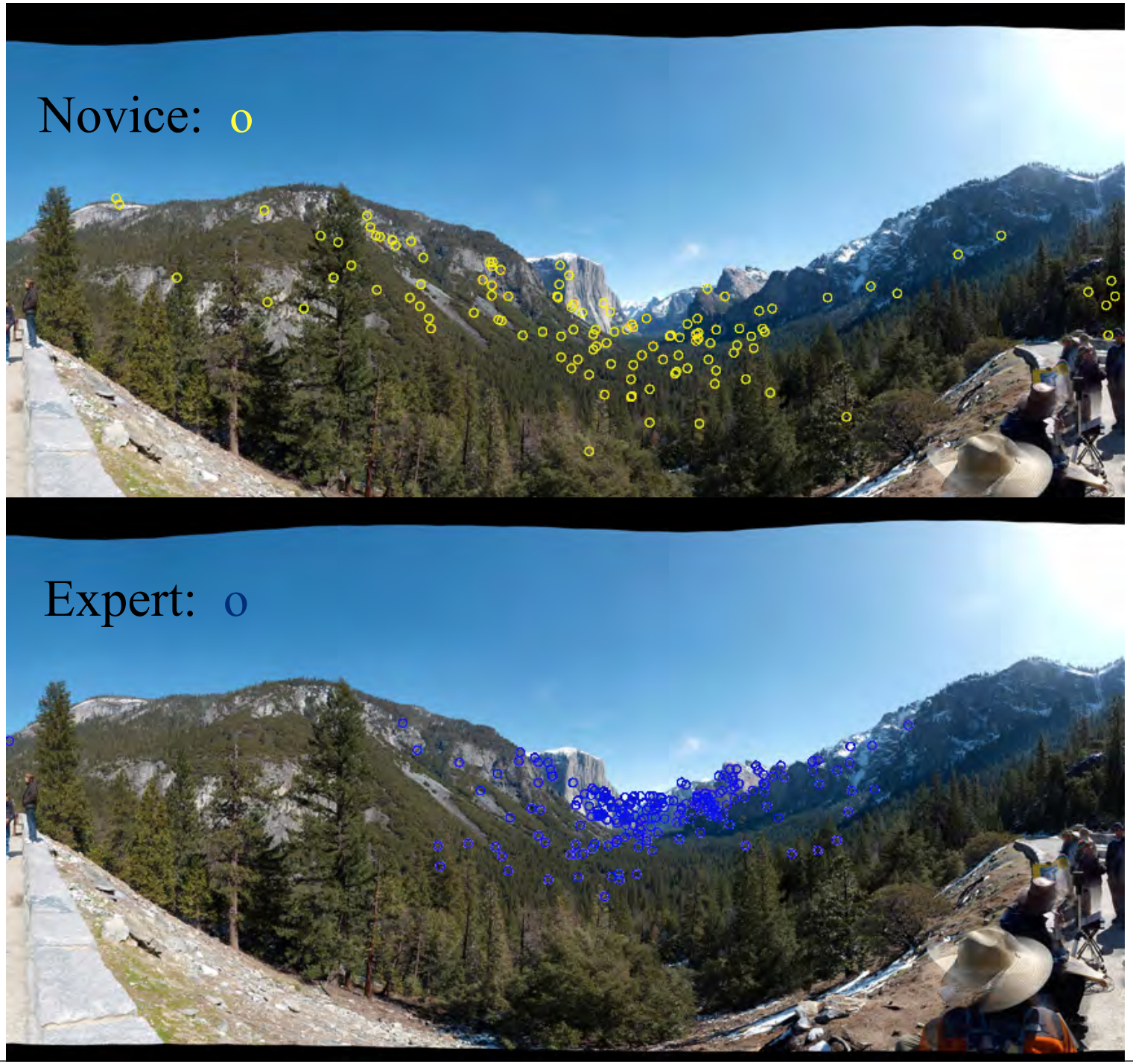
# Panoramic image capture

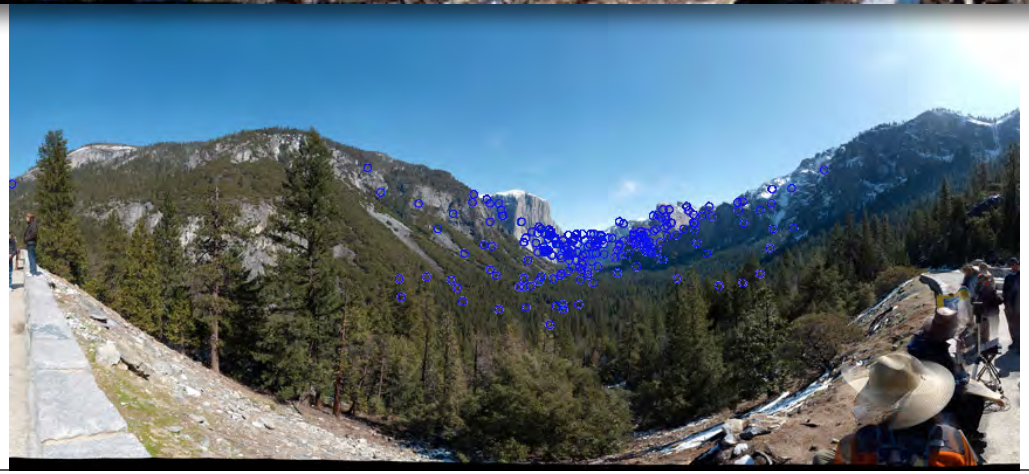
# Panoramic image capture





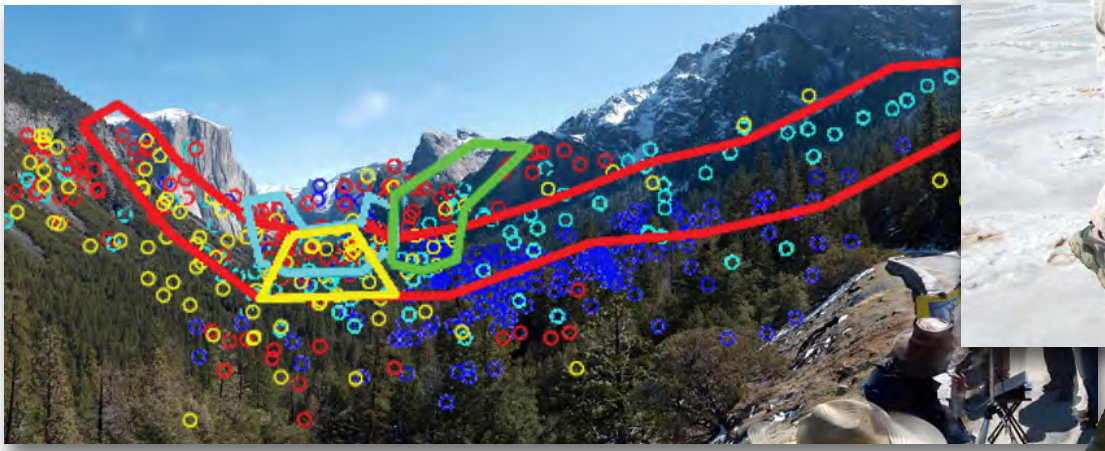
# Common reference frame





# Semantic Analysis of Mobile Eyetracking Data

**Jeff B. Pelz**
Rochester Institute of Technology
Rochester, NY, USA



**1st International Workshop on Pervasive Eye Tracking and Mobile Eye-Based Interaction**