Eye Tracking in 360: Methods, Challenges, and Opportunities

Instructors:

Eakta Jain University of Florida

Olivier Le Meur, IRISA Rennes and Univ. of Rennes 1

Introduction: Eakta Jain

- PhD, Carnegie Mellon University
- Currently Assistant Professor, University of Florida
- Research Interests:
  - Compelling virtual avatars
  - Recording and understanding attention and perception

Sponsors: NSF, oculus, YouTube, FDOT

Introduction: Olivier Le Meur

- PhD, University Of Nantes (Fr)
- HDR, French post-doctoral degree, University of Rennes 1
- Associate Professor, University of Rennes 1
- Team leader: PERCEPT / IRISA
- More than 10 years at Technicolor R&D
- Research Interests:
  - Computational modelling of visual attention
  - Image processing (quality, inpainting, HDR…)

http://www-percept.irisa.fr/

Sponsors:

Special thanks to

- Brendan John
  - PhD student, University of Florida
  - NSF Graduate Research Fellow
  - Research Interests: VR, Eye tracking

Why is this topic relevant to VR/AR?

- Foveated Rendering
- Gaze as input: Objects react to being looked at, interactive narratives

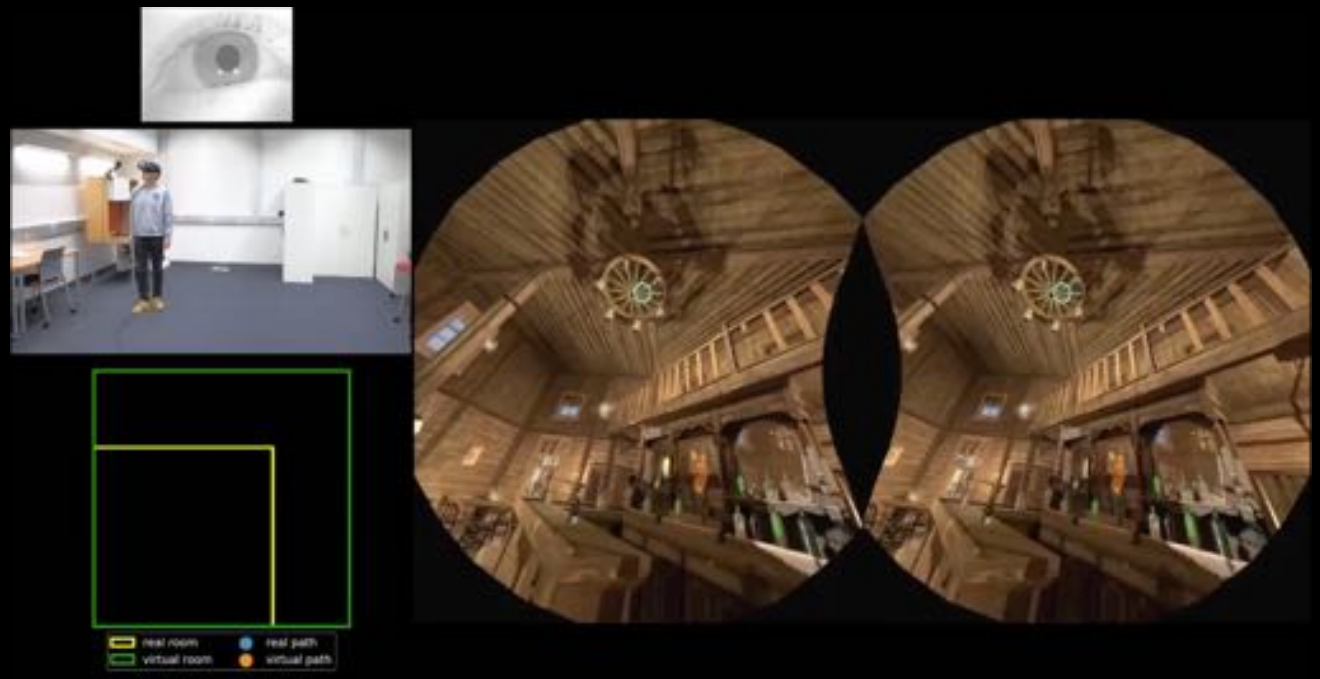
Datasets for Saliency Modeling/Head Orientation Prediction

Applications: Video Streaming
Firdose, Saeik, Pietro Lunqaro, and Konrad Tollmar. "Demonstration of Gaze-Aware Video Streaming Solutions for Mobile VR." 2018 IEEE VR, 2018.

Ngyugen, Yan and Nahrstedt.
Your Attention is Unique, ACM Multimedia 2018

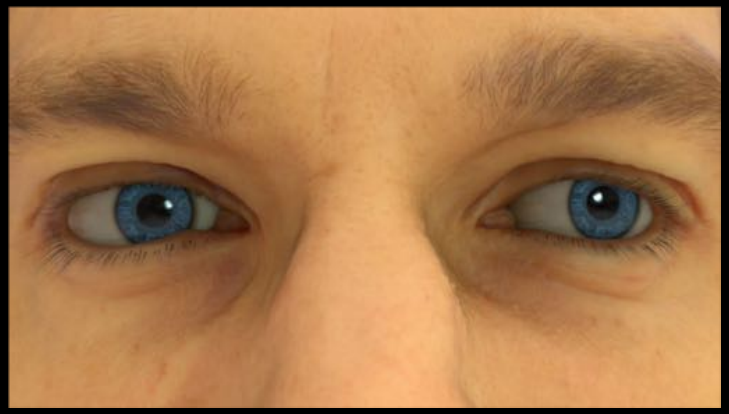
More on this in Part 3

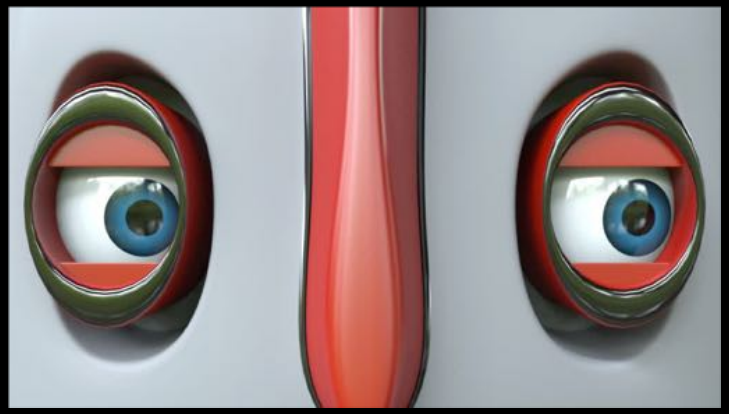
Redirected Walking



Towards Virtual Reality Infinite Walking: Dynamic Saccadic Redirection
Patney et al. ACM SIGGRAPH 2018

Social VR: Eye movements for Avatars

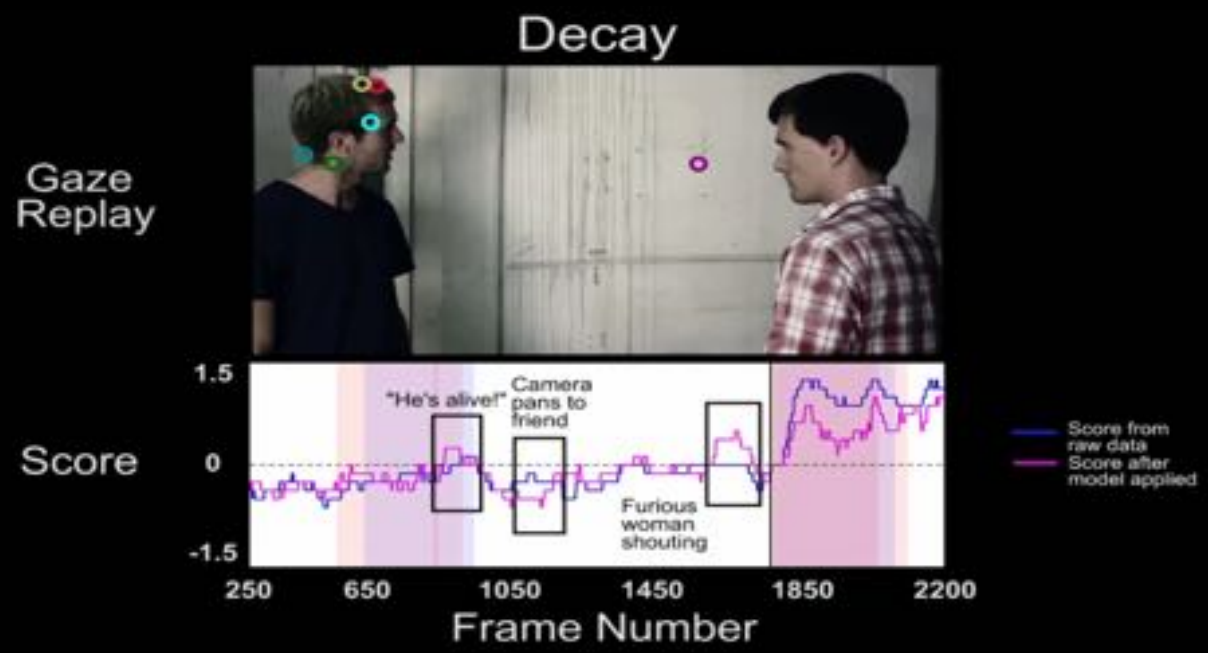




Perceptual Adjustment of Eyeball Rotation and Pupil Size Jitter for Virtual Characters.
Sophie Jörg, Andrew Duchowski, Krzysztof Krejtz, and Anna Niedzielska. 2018.
ACM Trans. Appl. Percept. 15, 4, Article 24 (October 2018)

Guiding Gaze: Experssive Models of Reading and Face Scanning,
Andrew Duchowski, Sophie Jörg, Jaret Screws, Nina Gehrer, Michael Schoenenberg,
Krzysztof Krejtz, ETRA 2019, Denver, CO, to appear.

User Engagement



Raiturkar et al. Decoupling Light Reflex from Pupillary Dilation to Measure Emotional Arousal in Videos ACM SAP 2016

John et al. An Evaluation of Pupillary Light Response Models for 2D Screens and VR HMDs,ACM VRST 2018

IEEE VR Recent Activity!

- Chen, Shu-Yu, et al. "Real-time 3D Face Reconstruction and Gaze Tracking for Virtual Reality." 2018.
- S. Grogorick, G. Albuquerque and M. Maqnor, "Gaze Guidance in Immersive Environments," 2018.
- Mei, Chao, et al. "Towards Joint Attention Training for Children with ASD-a VR Game Approach and Eye Gaze Exploration." 2018.
- Volonte, Matias, et al. "Empirical Evaluation of Virtual Human Conversational and Affective Animations on Visual Attention in Inter-Personal Simulations." 2018.
- Alghofaili *Rawan et al.* Optimizing Visual Element Placement in Virtual Environments via Visual Attention Analysis, *2019*
- Hu et al., SGaze: A Data-Driven Eye-Head Coordination Model for Realtime Gaze Prediction 2019
- Mardanbegi et al. EyeSeeThrough: Unifying Tool Selection and Application in Virtual Environments 2019

Expected Value to Audience

- Intended for a VR audience unfamiliar with eye tracking
- Who want to quickly have a working understanding of eye tracking
- Towards goals such as
  - Should they invest in an eye tracker
  - Should they propose to collect eye tracking data in their next proposal
  - Collecting eye tracking data for the very first time because their adviser got funded for it (or asked them to collect some pilot data so they could get funding for it)

Organization and Learning Objectives

Topic	Learning Objectives
Part 1: Basic understanding of the eye (focus on parameters relevant to eye tracking in VR) [Jain]	1. Define the basic eye movements 2. Define vergence accommodation conflict 3. Explain the difference between foveation and perception 4. Explain the difference between gaze in head, head in world, and gaze in world data

Organization and Learning Objectives

Topic	Learning Objectives
Part 2: Methods for collecting eye tracking data, including sample protocols and pitfalls to avoid [Jain]	1. Compare and contrast classes of eye trackers 2. Design a data collection protocol 3. Report the relevant parameters for the eye tracker, calibration and validation in the Methods section of a paper

Organization and Learning Objectives

Topic	Learning Objectives
Part 3: Methods to generate saliency maps from eye tracking data [Le Meur]	1. Explain why 2D saliency map methods need to be generalized for omnidirectional viewing 2. Discuss the pros and cons of the selected methods 3. Compare the performance of different methods using standard metrics 4. Computational saliency models for 360 images

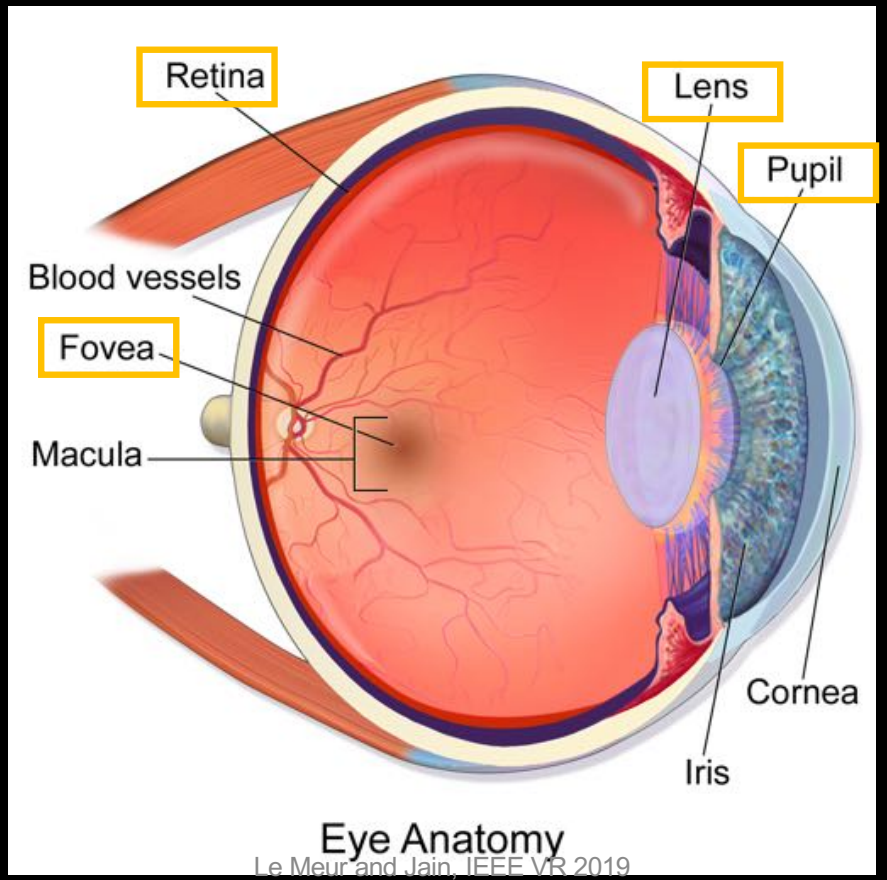
Let’s begin!

Topic	Learning Objectives
Part 1: Basic understanding of the eye (focus on parameters relevant to eye tracking in VR) [Jain]	1. Define the basic eye movements 2. Define vergence accommodation conflict 3. Explain the difference between foveation and perception 4. Explain the difference between gaze in head, head in world, and gaze in world data

Anatomy of the Eye

A Series of Anatomical Plates The Structure of the Different Parts of The Human Body. by Jones Quain, M.D. 1854

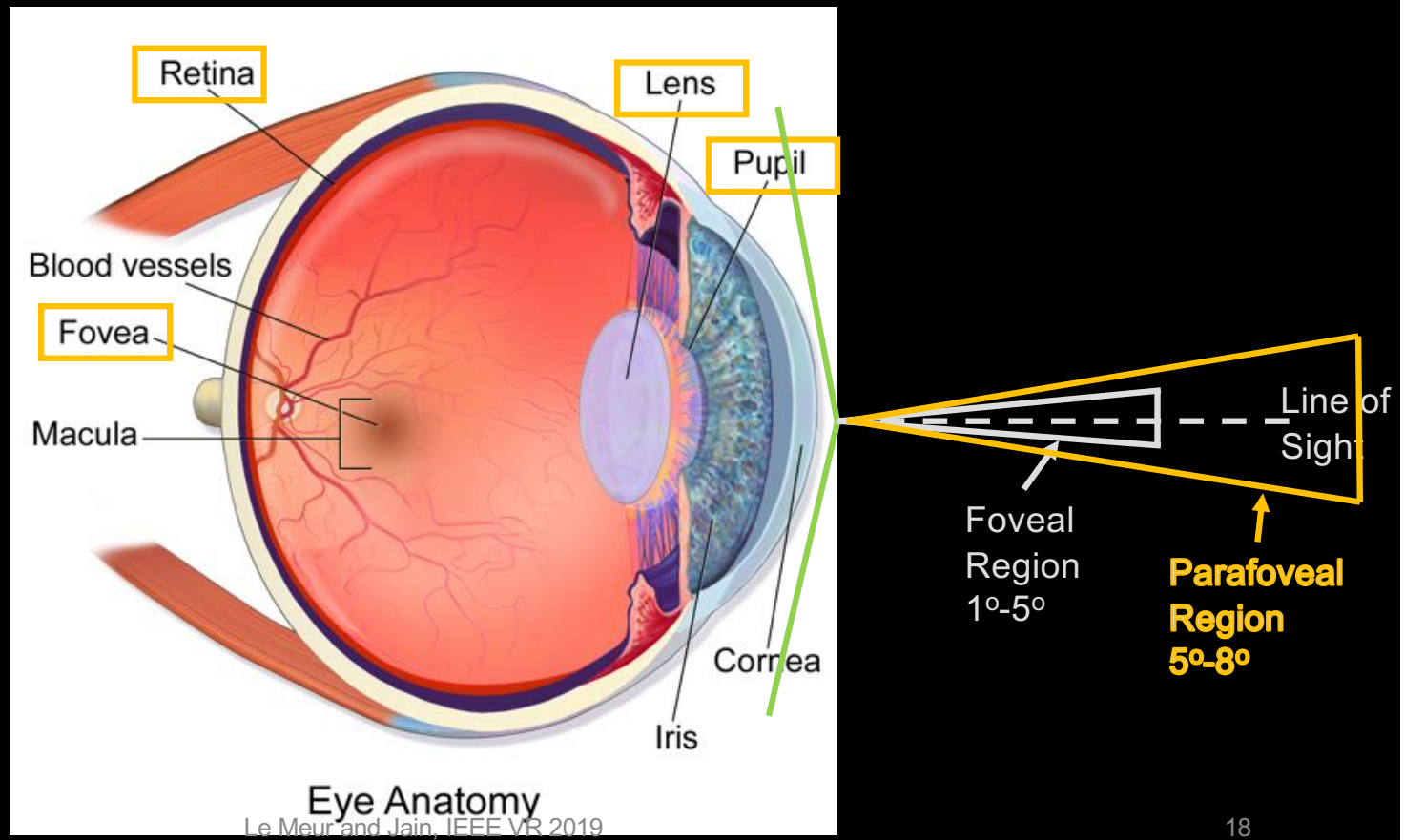
Anatomy of the Eye



Le Meur and Jain, IEEE VR 2019

Image Credit: Wikimedia

Anatomy of the Eye



Le Meur and Jain, IEEE VR 2019

Eye Movements

- **Saccades**
  - Rapid, ballistic eye movements that shift the fovea (30-50ms)
  - Perception is attenuated during saccade
  - Fixations (between saccades) are when the eye is “stationary” (~200ms)
  - Patterns of saccades and fixations are typical of tasks, e.g., reading, search
- **Vergence**
  - Eyes converge so that object is on the fovea for each eye
  - May be initiated by disparity cues (object not in fovea for one of the eyes) or accommodation cues (presence of blur in one of the eyes)

Vision Science by Palmer (1991)

Eye Movements

- **Smooth Pursuit**
  - Track a moving object
  - If moving object not tracked, its image would be ”smeared” across retina … poor evolutionary choice!
  - [Hold head still and move finger]
- **Physiological Nystagamus**
  - Tiny tremors that cause the retinal image to never be still
  - If removed, then retinal image “fades away”
- **Vestibular Ocular Reflex**
  - Eye moves to keep fixated on an object when head or body is rotated
  - Initiated by the vestibular system
  - [Hold finger still and move head]
  - VOR much quicker and accurate than pursuit movements

Vision Science by Palmer (1991)

Eye Movements

- **Other parts of the eye move too**
  - Pupil
  - Eye lids
- Pupil diameter changes recorded by eye trackers
- Eye lid movement – we can think of this as blinks – identified as points where pupil is not fully visible rather than eye lid tracking

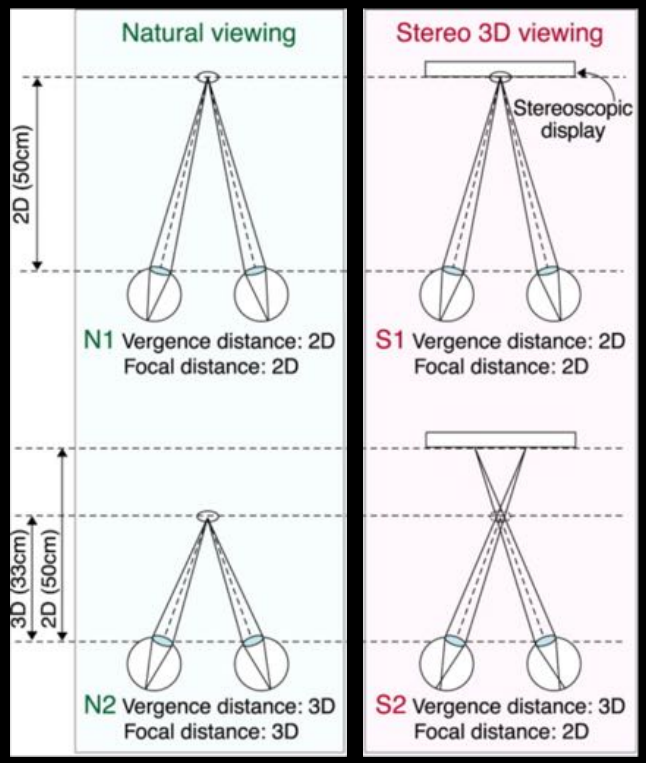
Pop Quiz!

Topic	Learning Objectives
Part 1: Basic understanding of the eye (focus on parameters relevant to eye tracking in VR)	Define the basic eye movements

Humans are effectively blind during this type of eye movement:
(a) Fixation
(b) Saccade

Answer:
(b) Saccade

Vergence



Adapted from Shibata et al (2011) The Zone of Discomfort: Predicting Visual Discomfort with Stereo Displays, Journal of Vision

Vergence Accommodation Conflict

Koulieris et al (2017) SIGGRAPH. Accommodation and Comfort in Head Mounted Displays

Pop Quiz!

Topic	Learning Objectives
Part 1: Basic understanding of the eye (focus on parameters relevant to eye tracking in VR)	Define vergence accommodation conflict

Vergence accommodation conflict occurs when:
(a) The stereo depth of the object being looked at is further than the screen
(b) The stereo depth of the object being looked at is the same as the screen

Answer:
(a)

Looking versus Seeing

Rubin's Vase

Looking != Understanding

- I can be looking at a math equation for a long time without understanding it

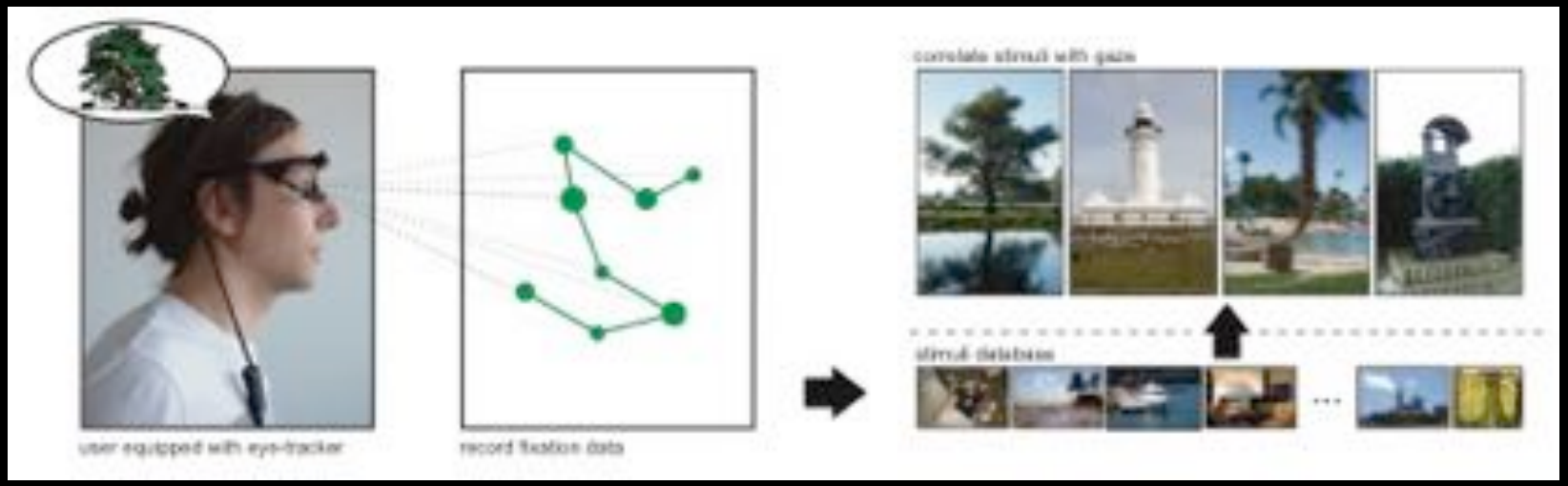
$$E = mc^2$$

It’s an eye tracker not a mind reader…

-- Andrew Duchowski

(I said that in the context of marketing studies... but I've been wrong before---we now have the notion of user intent)

Though…

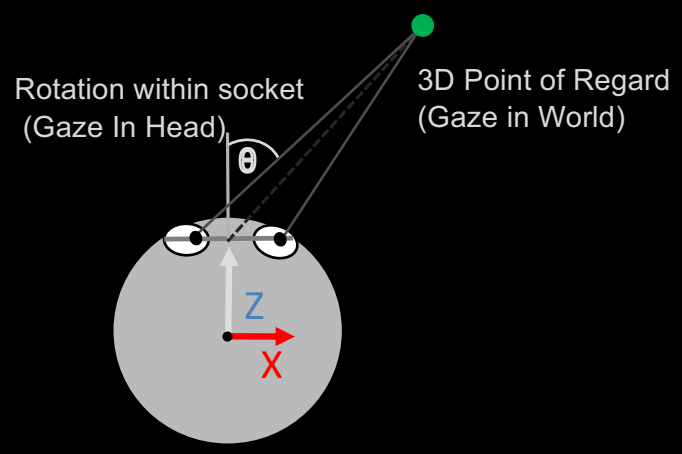


User being eye tracked while recalling an image

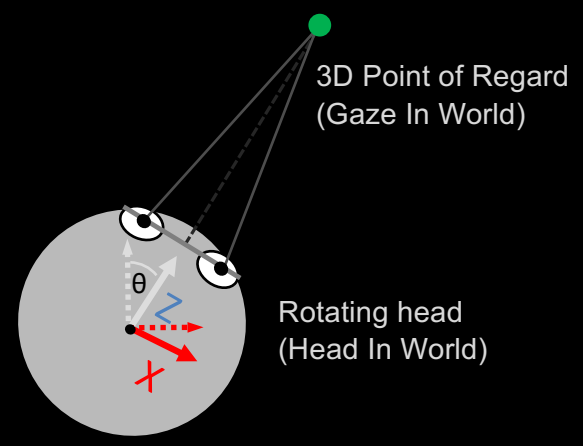
Retrieve image from a dataset of matching images

Wang et al. The Mental Image Revealed by Gaze Tracking. CHI 2019

VR Relevant Parameters



(Eyes rotated within the head's coordinate frame)



(Head rotated within the global coordinate frame)

Pop Quiz!

Topic	Learning Objectives
Part 1: Basic understanding of the eye (focus on parameters relevant to eye tracking in VR)	Explain the difference between gaze in head, head in world, and gaze in world data

What is the difference between gaze in head and gaze in world orientations?

(a) The coordinate frame with respect to which it is measured

(b) Gaze in head is always larger

Answer:

(a) Coordinate frame

Break

Organization and Learning Objectives

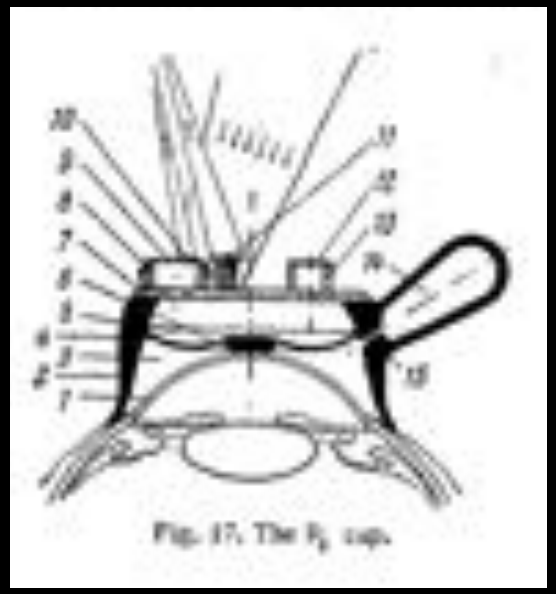
Topic	Learning Objectives
Part 2: Methods for collecting eye tracking data, including sample protocols and pitfalls to avoid [Jain]	1. Compare and contrast classes of eye trackers 2. Design a data collection protocol 3. Report the relevant parameters for the eye tracker, calibration and validation in the Methods section of a paper

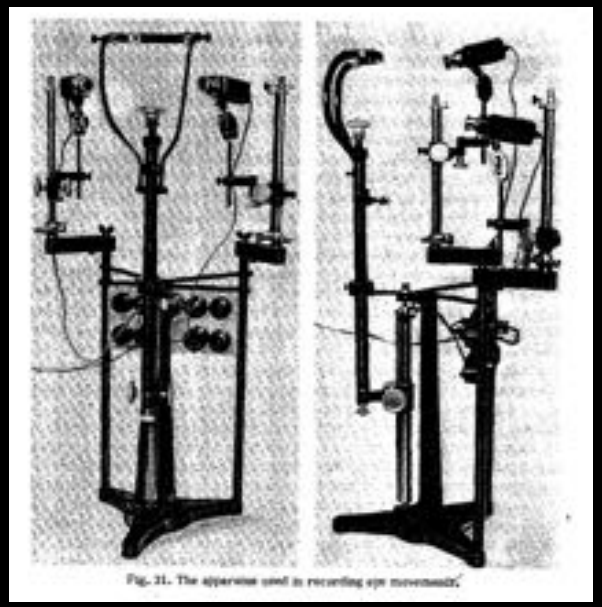
What is an eye tracker

“A device that measures eye position and eye movements”

What is an eye tracker

- Then: caps inside the eye





Yarbus, 1967

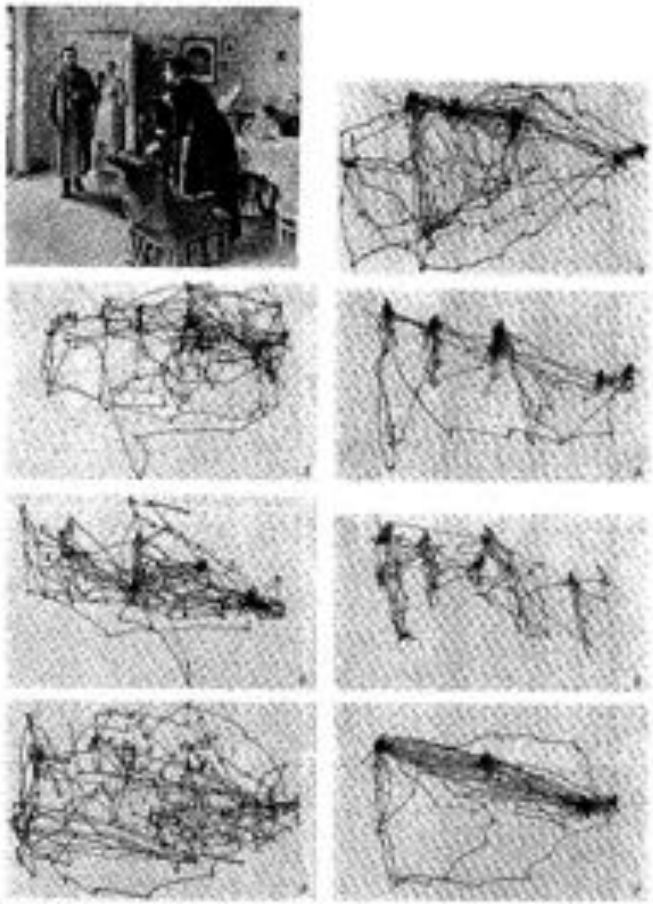
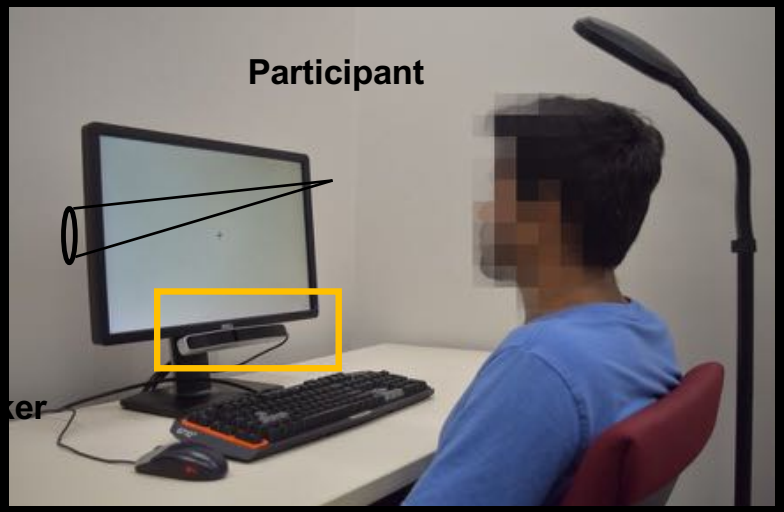


Fig. 109. Seven records of eye movements by the same subject. Each record lasted 3 minutes. The subject examined the reproduction with both eyes. 1) Free examination of the picture. Before the subsequent recording sessions, the subject was asked to: 2) estimate the material circumstances of the family in the picture; 3) give the ages of the people; 4) surmise what the family had been doing before the arrival of the "unexpected visitor"; 5) remember the clothes worn by the people; 6) remember the positions of the people and objects in the room; 7) estimate how long the "unexpected visitor" had been away from the family.

Le Meur and Jain, IEEE VR 2019

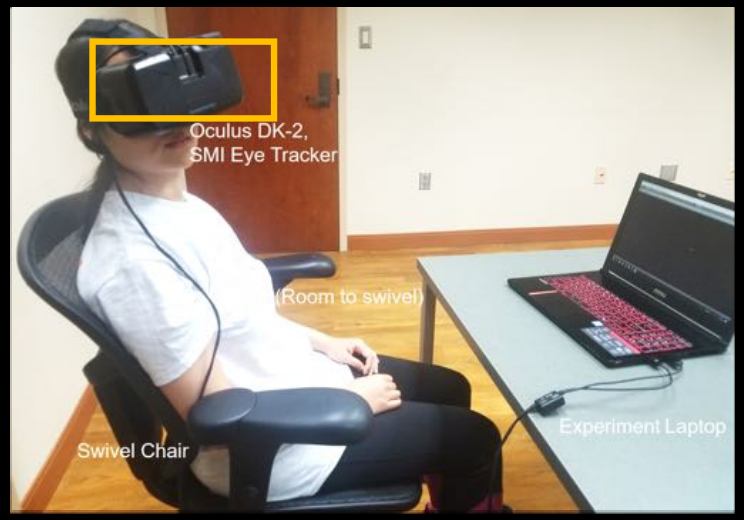
What is an eye tracker

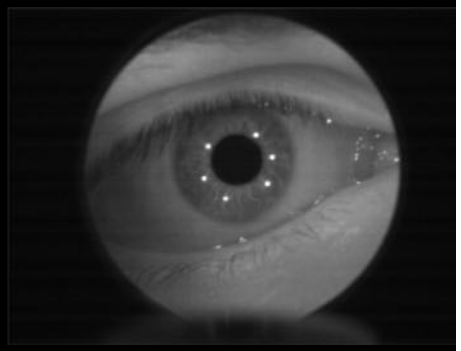
- Now: optical tracking using IR cameras



What is an eye tracker

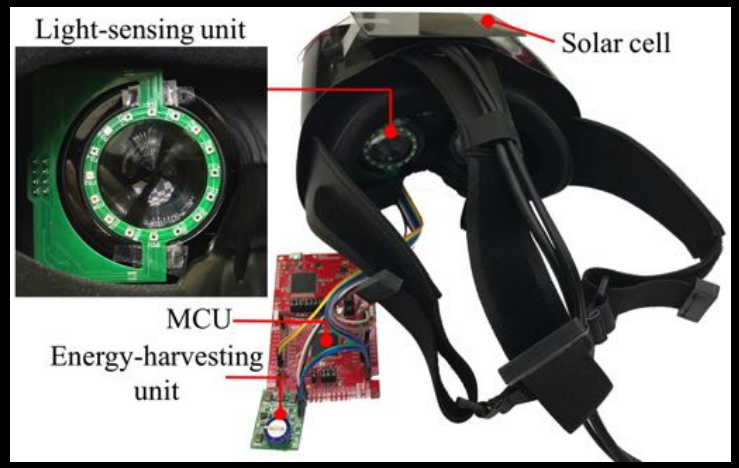
- Now: optical tracking using IR cameras





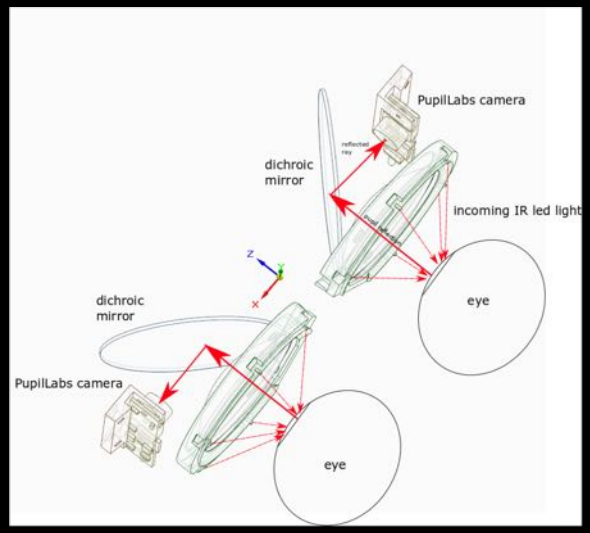
Exploratory alternatives

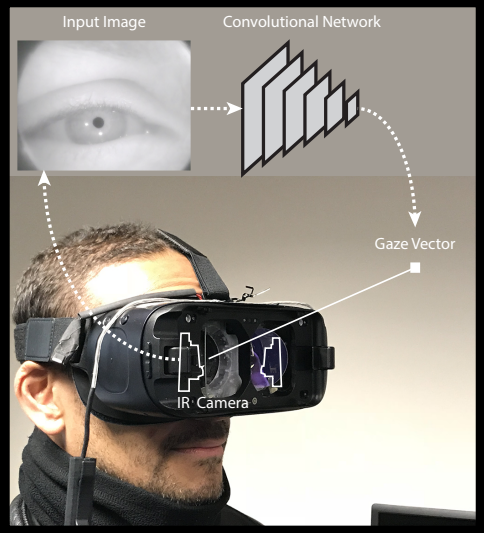
Whitmire et al. EyeContact: Scleral coil eye tracking for virtual reality. ACM International Symposium on Wearable Computers 2016



Li, et al. Ultra-Low Power Gaze Tracking for Virtual Reality. *ACM Conference on Embedded Network Sensor Systems 2017*

Exploratory Alternatives





NVGaze: Anatomy-aware Augmentation for Low-Latency, Near-Eye Gaze Estimation

Stengel, Kim, Majercik, De Mello, McGuire, Laine, Luebke (2019)

Compare and Contrast

Device	Eye Image Resolution	Sample Rate (Hz)	Cost (USD)
7invensun	-	120	$200
FOVE VR HMD	320 x 240	120	$599
aGlass and aSee	-	120-380	-
Pupil Labs VR (VIVE USB)	320 x 240	30	$1,572*
Pupil Labs VR (Dedicated USB)	640 x 480	120	$1,572*
Pupil Labs AR (Hololens)	640 x 480	120	$1,965*
Pupil Pro Glasses	800 x 600	200	$2,066?*
Pupil Pro Glasses	800 x 600	200	$2,066?*
Looxid Labs	-	-	$2999
Hololens v2	-	-	$3500
Tobii Pro Glasses 2	240 x 960	100	$10,000

*Without academic discount

Pop Quiz!

Topic	Learning Objectives
Part 2: Methods for collecting eye tracking data, including sample protocols and pitfalls to avoid	Compare and contrast classes of eye trackers

You want to use an eye tracker to study where people look during a public speaking study. In particular you are studying pre-service and experienced teachers in a classroom.
What type of eye tracker should you use?

(a) Eye tracking glasses
(b) Table mounted eye tracker

Answer:
(a) Eye tracking glasses

Pop Quiz!

Topic	Learning Objectives
Part 2: Methods for collecting eye tracking data, including sample protocols and pitfalls to avoid	Compare and contrast classes of eye trackers

You want to get a HMD fitted with an eye tracker to study where people look during a VR public speaking study. What spec should consider?
(a) Sample rate, because bigger is better
(b) Calibration accuracy, because 30-60Hz is sufficient for attentional research

Answer:
(b) Calibration accuracy

Pop Quiz!

Topic	Learning Objectives
Part 2: Methods for collecting eye tracking data, including sample protocols and pitfalls to avoid	Compare and contrast classes of eye trackers

You want to get a HMD fitted with an eye tracker to study foveated rendering. What spec should consider?

(a) Sample rate, because bigger is better

(b) Calibration accuracy, because 30-60Hz is sufficient for attentional research

Answer:
Both!

What does an eye tracker measure

- Gaze location (L,R)
- Pupil diameter

2D Eye Tracking Data

Gaze driven Video Re-editing. Eakta Jain, Yaser Sheikh, Ariel Shamir, Jessica Hodgins. ACM Transactions on Graphics. 2015

Overlaid gaze data

Gaze driven Video Re-editing. Eakta Jain, Yaser Sheikh, Ariel Shamir, Jessica Hodgins. ACM Transactions on Graphics. 2015

What does it tell you

- If an AOI was attended
- How long was it looked at (Dwell times)
- How many times was it revisited
- What order were they looked at
- Patterns across individuals (e.g. center bias, spatio-temporal consistency)

Mobile Eye Tracking Glasses

- Glasses based eye tracking – gaze position on scene camera feed

VR-HMD Eye Tracking

- VR eye tracking – gaze direction, gaze in world

John, Raiturkar, Le Meur, Jain. A Benchmark of Four Methods for Generating 360 degree Saliency Maps from Eye Tracking Data, AIVR 2018

VR Relevant Parameters

- Is head a good enough approximation of eye?
- People assume this for ease of data collection
- Depends on the application

Break

Design Choices in an Eye Tracking Study

- Apparatus
- Task

Apparatus: How to select an eye tracker

- Remote or head mounted
- Glasses or VR-HMD
- Built in or retrofitted

Design Choices in an Eye Tracking Study

- Apparatus
- Task

Task Components: General

Component	Explanation
Informed Consent	Purpose of study, Risks/Benefits, Compensation, Data, Opt out, Agree?

Task Components: General

Component	Explanation
Informed Consent	Purpose of study, Risks/Benefits, Data, Opt out, Agree?
Instructions	What participant is asked to do, depends on research question

Task Components: General

Component	Explanation
Informed Consent	Purpose of study, Risks/Benefits, Data, Opt out, Agree?
Instructions	What participant is asked to do, depends on research question
Calibration	Map eye image to gaze coordinates

Calibration

- Participants look at known targets
- Design choices: Number and form factor of calibration targets
- Usually fixed for commodity devices

Task Components: General

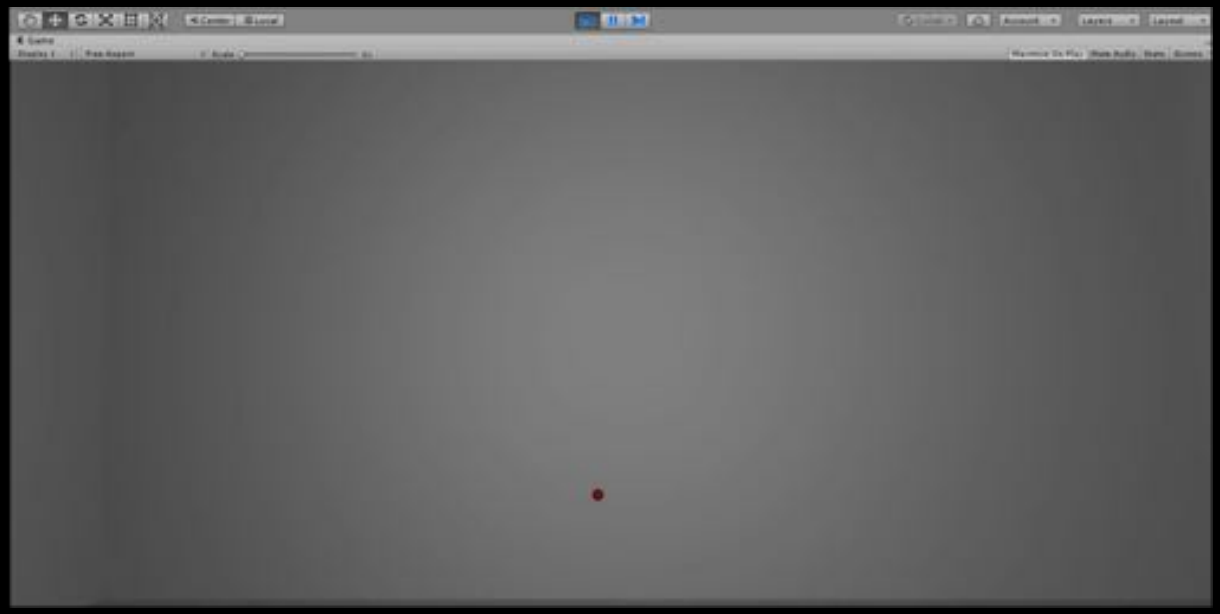
Component	Explanation
Informed Consent	Purpose of study, Risks/Benefits, Data, Opt out, Agree?
Instructions	What participant is asked to do, depends on research question
Calibration	Map eye image to gaze coordinates

Task Components: General

Component	Explanation
Informed Consent	Purpose of study, Risks/Benefits, Data, Opt out, Agree?
Instructions	What participant is asked to do, depends on research question
Calibration	Map eye image to gaze coordinates
Validation	Check how well calibration was done

Validation

- Qualitative validation: confirm data looks accurate
- Quantitative validation: average error was 1.2^{o} for all participants



Pop Quiz!

Topic	Learning Objectives
Part 2: Methods for collecting eye tracking data, including sample protocols and pitfalls to avoid	Design a data collection protocol

Why is it not sufficient to report the spec sheet value for calibration accuracy?

Answer: That is the validation accuracy they got when they did their in-house evaluation, not what you got during your experiments.

Task Components: General

Component	Explanation
Informed Consent	Purpose of study, Risks/Benefits, Data, Opt out, Agree?
Instructions	What participant is asked to do, depends on research question
Calibration	Map eye image to gaze coordinates
Validation	Check how well calibration was done

Task Components: General

Component	Explanation
Informed Consent	Purpose of study, Risks/Benefits, Data, Opt out, Agree?
Instructions	What participant is asked to do, depends on research question
Calibration	Map eye image to gaze coordinates
Validation	Check how well calibration was done
Stimulus	What the participant is looking at

Task Components: General

Component	Explanation
Informed Consent	Purpose of study, Risks/Benefits, Data, Opt out, Agree?
Instructions	What participant is asked to do, depends on research question
Calibration	Map eye image to gaze coordinates
Validation	Check how well calibration was done
Stimulus	What the participant is looking at
Inter-Stimuli Transition	Center gaze with fixation target, Break, Re-calibrate

Task Components: 360 specific

Component	Explanation

Task Components: 360 specific

Component	Explanation
Apparatus: Movement	Sitting or standing? Swivel chair?

Task Components: 360 specific

Component	Explanation
Apparatus: Movement	Sitting or standing? Swivel chair?
Apparatus: Height	Height of tripod different from viewing height

Task Components: 360 specific

Component	Explanation
Apparatus: Movement	Sitting or standing? Swivel chair?
Apparatus: Height	Height of tripod different from viewing height
Stimulus: Starting orientation	What shows up as “straight ahead” for viewer

Task Components: 360 specific

Component	Explanation
Apparatus: Movement	Sitting or standing? Swivel chair?
Apparatus: Height	Height of tripod different from viewing height
Stimulus: Starting orientation	What shows up as “straight ahead” for viewer
Breaks: Sickness/Discomfort	Re-calibrate if participant removes headset

Activity!

Topic	Learning Objectives
Part 2: Methods for collecting eye tracking data, including sample protocols and pitfalls to avoid	Design a data collection protocol

You want to record eye tracking data when participants with different levels of public speaking experience have to do a public speaking task in VR.

5 mins!
Share when you are done!

Logging Data

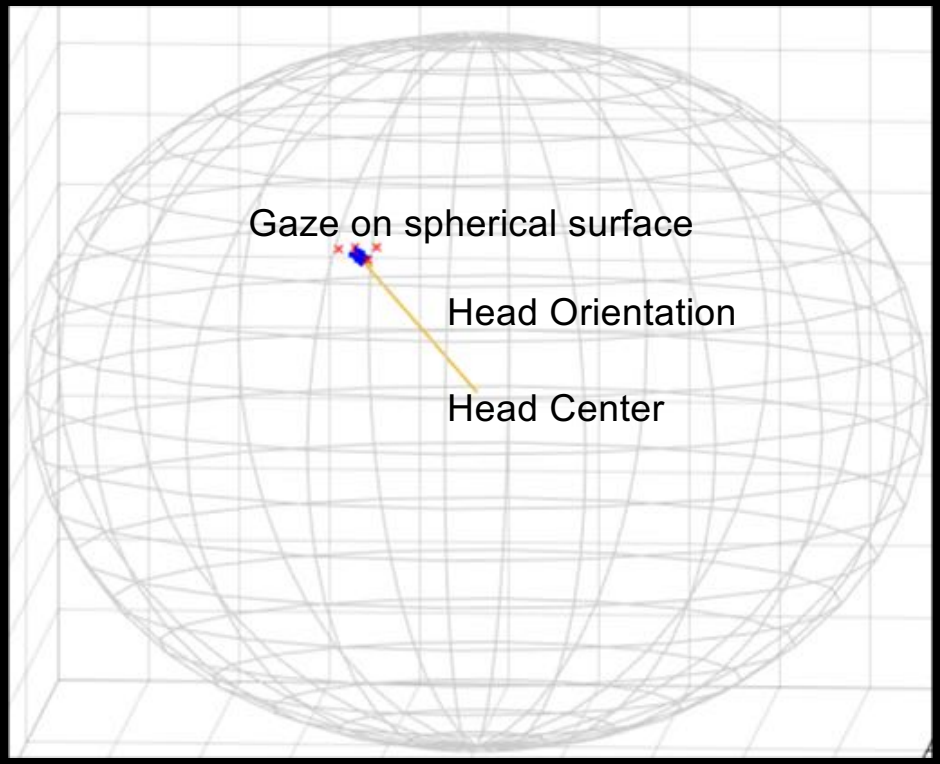
- Participant ID
- Order of stimuli presentation
- Calibration accuracy (Initial + any re-calibrations)
- Gaze data files
- Responses to questions

Gaze Data Representation

- Head orientation + Gaze relative to head

(Head = Viewport)

- Gaze relative to world + Head relative to world
- Latitude and Longitude
- Euler Angles
- Quaternions



Resources

- Books
  - Eye Tracking Methodology, Andrew Duchowski, 2003
  - Eye Tracking: A Comprehensive Guide to Methods, Paradigms, and Measures, Holmqvist and Andersson, 2011
- Papers at ACM Symposium on Eye Tracking Research and Applications (ETRA)

Opportunities

- Datasets:
  - Datasets for 360 computational saliency
  - Datasets to understand viewer attention in 360 cinema (audiovisual content, narrative content)
- Methods:
  - Effect of protocol on known biases (e.g. equator bias, initialization bias)
  - UX for annotating and visualizing data

Xu et al. Gaze Prediction in Dynamic 360 Video CVPR 2018

Datasets	Scene	Videos	Video clip duration	Frames/Images	Viewers	Ground-truth annotation	HMD	Outputs
Sitzmann *et al.* [36]	Static	-	-	20	86	Eye tracking and Head movement in VR	Oculus DK2	Fixation points and Head position
Rai *et al.* [34]	Static	-	-	98	40-42	Eye tracking and Head movement in VR	Oculus DK2	Fixation points and Head position
Yu *et al.* [42]	Dynamic	10	10sec	2,500	10	Head movement in VR	Oculus DK2	Head position
Lo *et al.* [30]	Dynamic	10	60sec	15,000	50	Head movement in VR	Oculus DK2	Head position
Corbillon *et al.* [5]	Dynamic	7	70sec	16,450	59	Head movement in VR	Razer OSVR HDK2 HMD	Head position
360° Sports [19]	Dynamic	342	NA	180,000	5	Annotate salient object in panorama	Without using HMD	Manually labeled bounding box
Ours	Dynamic	208	20sec - 70sec	210,000	25	Eye tracking in VR	HTC VIVE	Fixation points and Head position

Thank You

- Return for Part 3 by Olivier Le Meur after coffee