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ARIVE Lecture Series
XR: Virtual and Augmented Reality

Introduction / The Eye in Extended Reality

Alexander Plopski
University of Otago, Dunedin, New Zealand

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Australasian Researchers in Interactive Virtual Environments

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ARIVE Partners

- ARIVE network links together existing world class AR/VR laboratories and groups
- One of the largest AR/VR networks internationally

- Initiated by Profs Mark Billinghurst and Bruce Thomas

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ARIVE Goals

Teaching

- Develop AR/VR training materials for use by ARIVE partners
- Create well trained AR/VR researchers and developers for industry

Research

- Share research resources and facilities
- Grow a thriving research community of faculty, research staff and students
- Generate novel research output and intellectual property

Commercialization

- Support the Australia/New Zealand AR/VR industry
- Conduct multi-institution research to meet the needs of our industry partners
- Transfer technology to national/international partners

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ARIVE 2020 Series

https://www.hci.otago.ac.nz/arive.html

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ARIVE 2021 Series

Lecture	Date	Topic	Who?
1a	August 17	Introduction / The Eye in Extended Reality	UO
1b	August 19	XR for Sports	UO
2a	August 24	Cinematic XR, teleport into the video	VUW
2b	August 26	Advanced Methods for User Evaluation in AR/VR Studies	UA
3a	September 7	Project Kiwrious: Activating Curious and Fearless Problem Solvers	UA
3b	September 9	TBD	
4a	September 14	Atea Project	UO
4b	September 16	Physiological Measurements of Presence in VR	UQ

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ARIVE 2021 Series

Lecture	Date	Topic	Who?
5a	September 21	AR/VR User Interactions	UniSA
5b	September 23	Using Space Around Us for Immersive Analytics	Monash
6a	September 28	Applied Immersive Games	UC
6b	September 30	Modelling & Simulation through XR and xAI Angles	UniNSW
7a	October 5	How to augment reality? - From neural cameras to subtle visual guidance	UO
7b	October 7	Gaze-based interaction in Virtual and Augmented Reality	UM
8a	October 12	TBD	
8b	October 14	Panel Discussion: Future Challenges of XR	All

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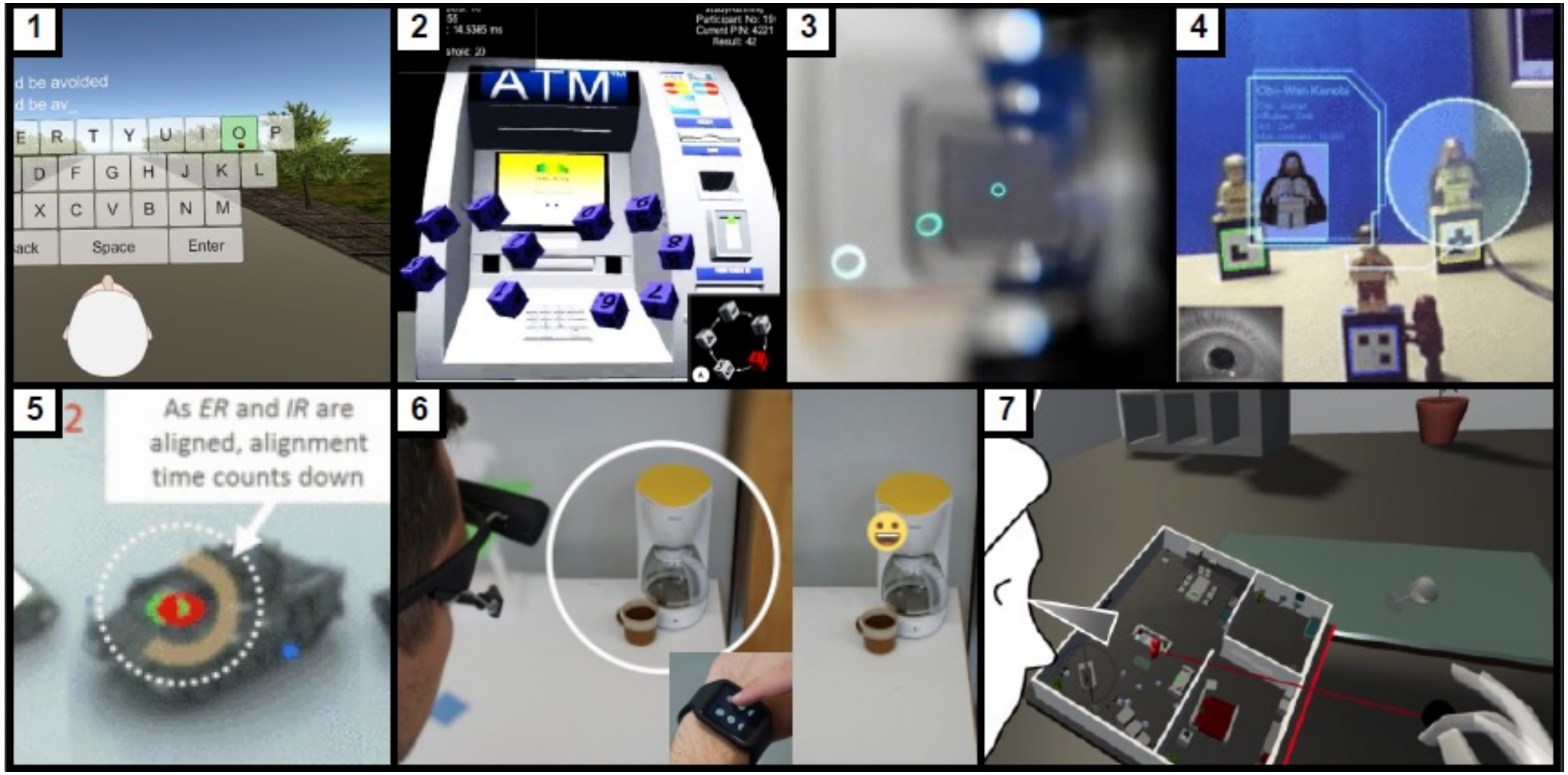

The Eye in Extended Reality: A Survey on Gaze Interaction and Eye Tracking in Head-Worn Extended Reality

Alexander Plopski, Teresa Hirzle, Nahal Norouzi, Long Qian, Gerd Bruder, Tobias Langlotz

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Shonan Seminar #135 (2018)

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Eye Tracking in Commercial HMDs

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Eye Gaze Interaction for XR

- What are the main categories of gaze interaction?
- What sub-categories have garnered attention?
- What are emerging and future directions?

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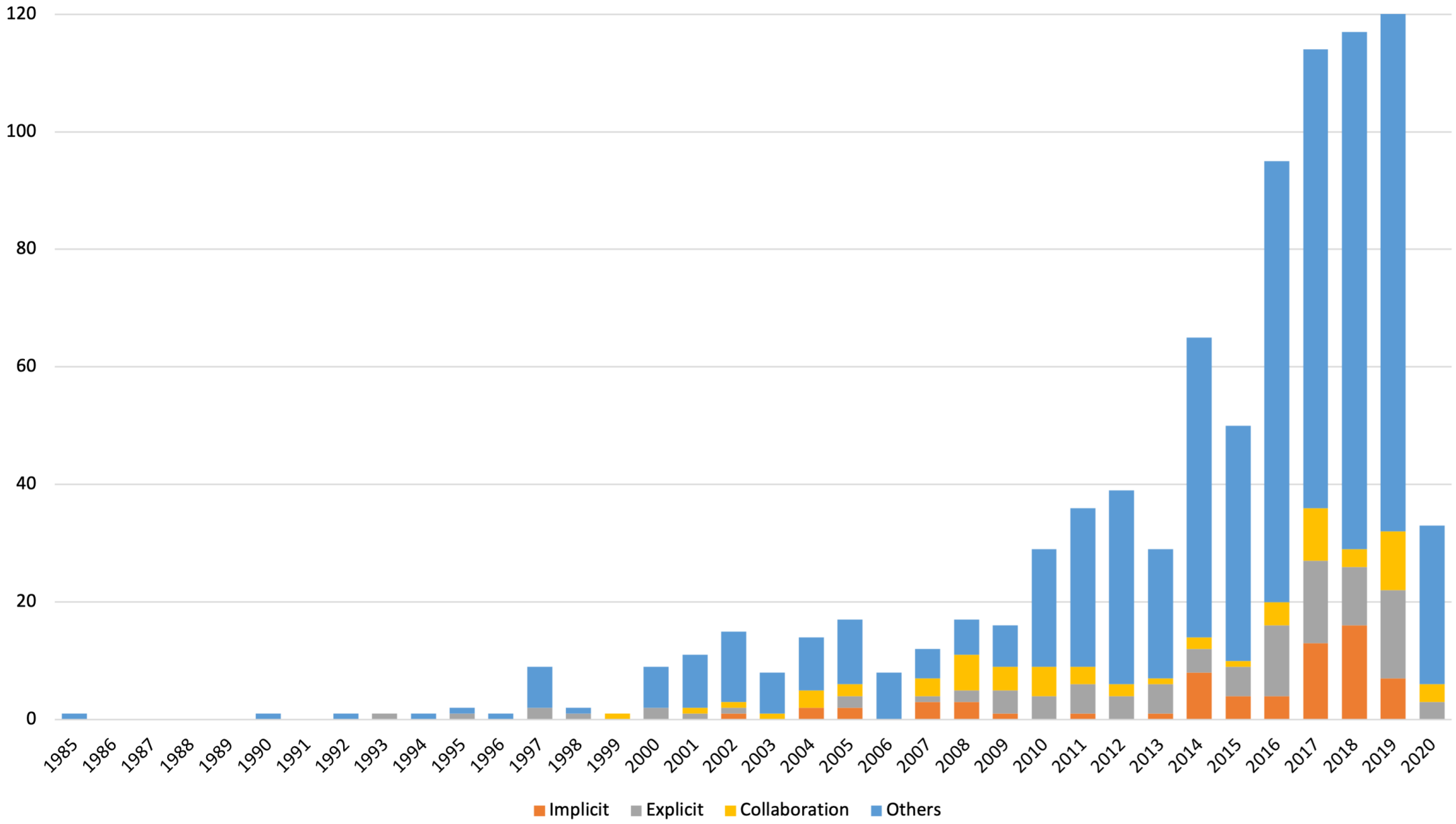

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Paper Collection

1278 publications retrieved from SCOPUS; Keywords:

MR related terms	"Augmented Reality" OR "virtual reality" OR "mixed reality" OR "Head mounted display" OR "heard worn display" OR "eye wear"
Eye tracking related terms	"Eye tracking" OR "gaze tracking" OR "eye gaze"

Initial Review and Classification

422 Unrelated Papers

90 No access
331 Mention but do not utilize the keywords
1 Plagiarism

856 Papers Addressed Eye Tracking

Multiple classifications possible

507 User Study
258 Gaze Patterns
239 System or Application Paper
158 Perception
149 Explicit
145 Diagnosis or Psychological Study
119 Eye Tracking Algorithms
109 Eye Properties
93 HMD Concept
87 Collaboration and Virtual Agents
87 Rendering
78 Implicit
65 Calibration
27 Review
23 User Classification

In-Depth Review and Summary

Exclusion Criteria

Suggesting a use case, but different paper focus
Eye tracking not used for interaction
Different versions of the same paper (conference, journal, demo, poster)

Final Selection

99 Explicit
63 Collaboration
53 Implicit

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Eye Gaze Interaction for XR

Explicit

- Eye gaze is used consciously

Implicit

- Eye gaze used in the background

Collaboration

- Eye gaze used in collaborative scenarios

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Eye Gaze Interaction for XR

- What are the main categories of gaze interaction?
- What sub-categories have garnered attention?
- What are emerging and future directions?

3.1 Explicit Gaze Interaction	3.2 Implicit Gaze Interaction	3.3 Collaborative Gaze Interaction
Eye-Only Interaction Comparative Studies, Dwell-Time, Alternatives, Continuous Input	Information Management, Spatial Presentation, and View Management	Eye Movements in Avatar-Mediated Collaboration
Multi-Modal Interaction Eye and Traditional Input, Eye and Speech, Eye and Gestures, Eye and Head Rotation, Eye and BCI	Information Management and Visual Presentation	Eye Movements in Human-Agent Collaboration
	Rendering	Shared Gaze in Task Space Remote Collaboration
		Augmented Gaze Cues in Shared Space Collaboration

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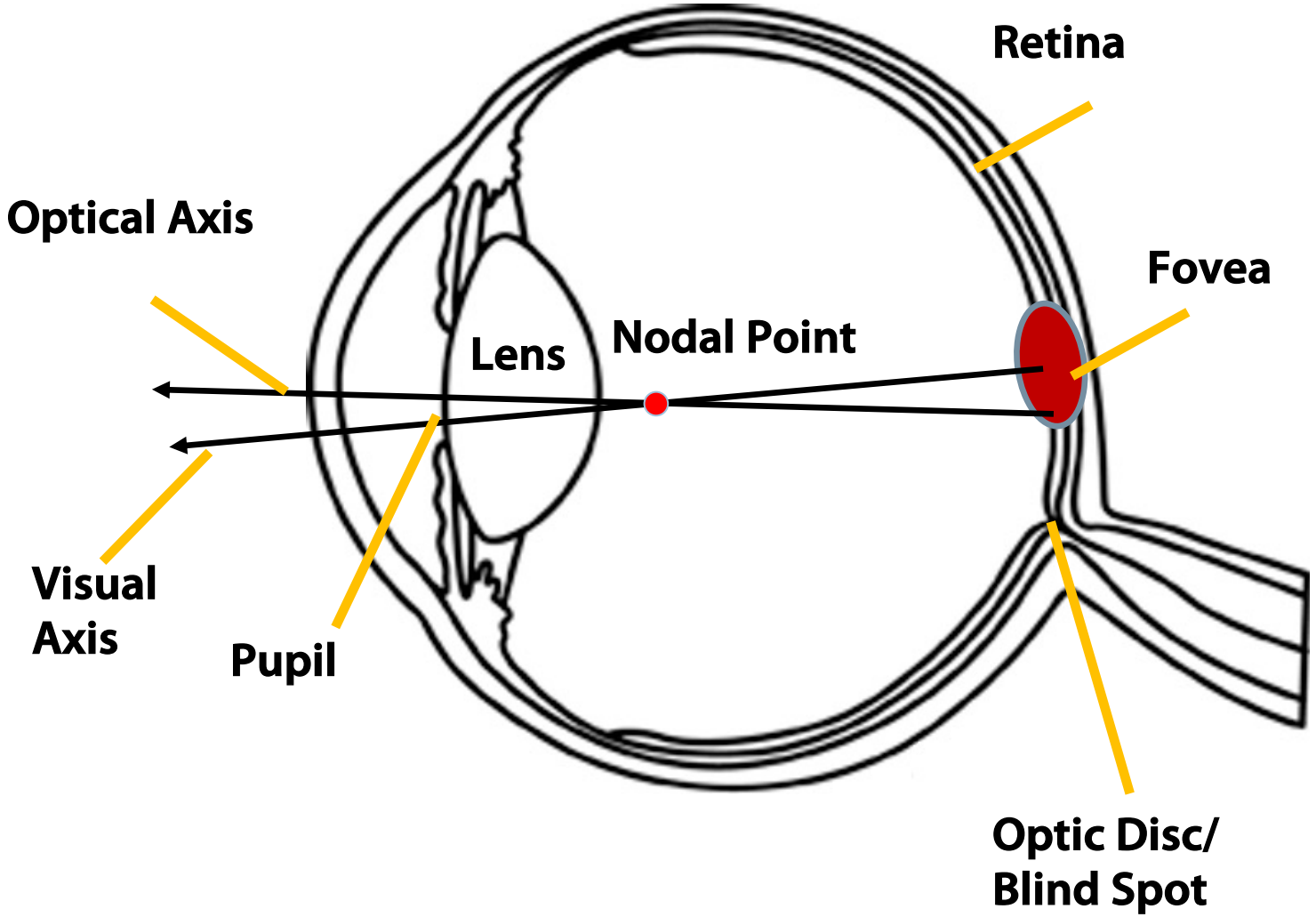
Eye Model



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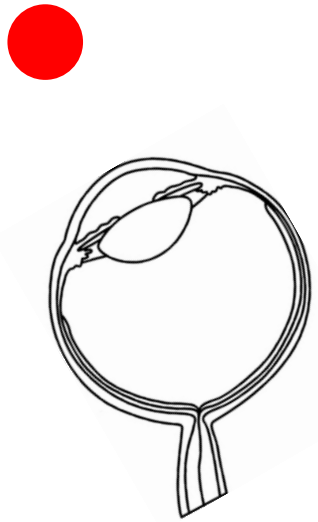
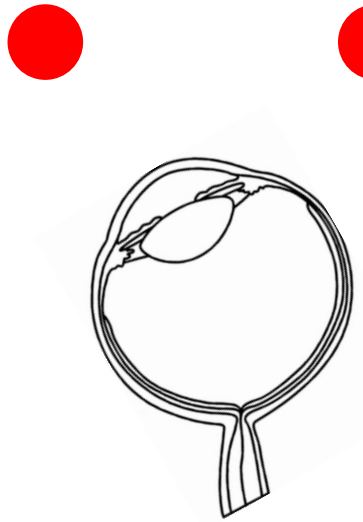
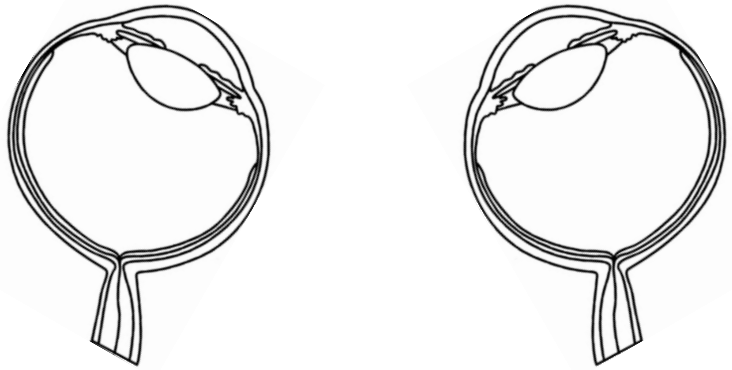
Eye Movements



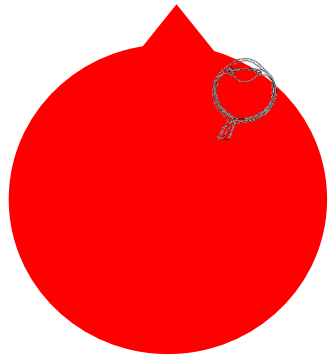
Smooth Pursuit



Saccades



Vergence



Vestibo-ocular

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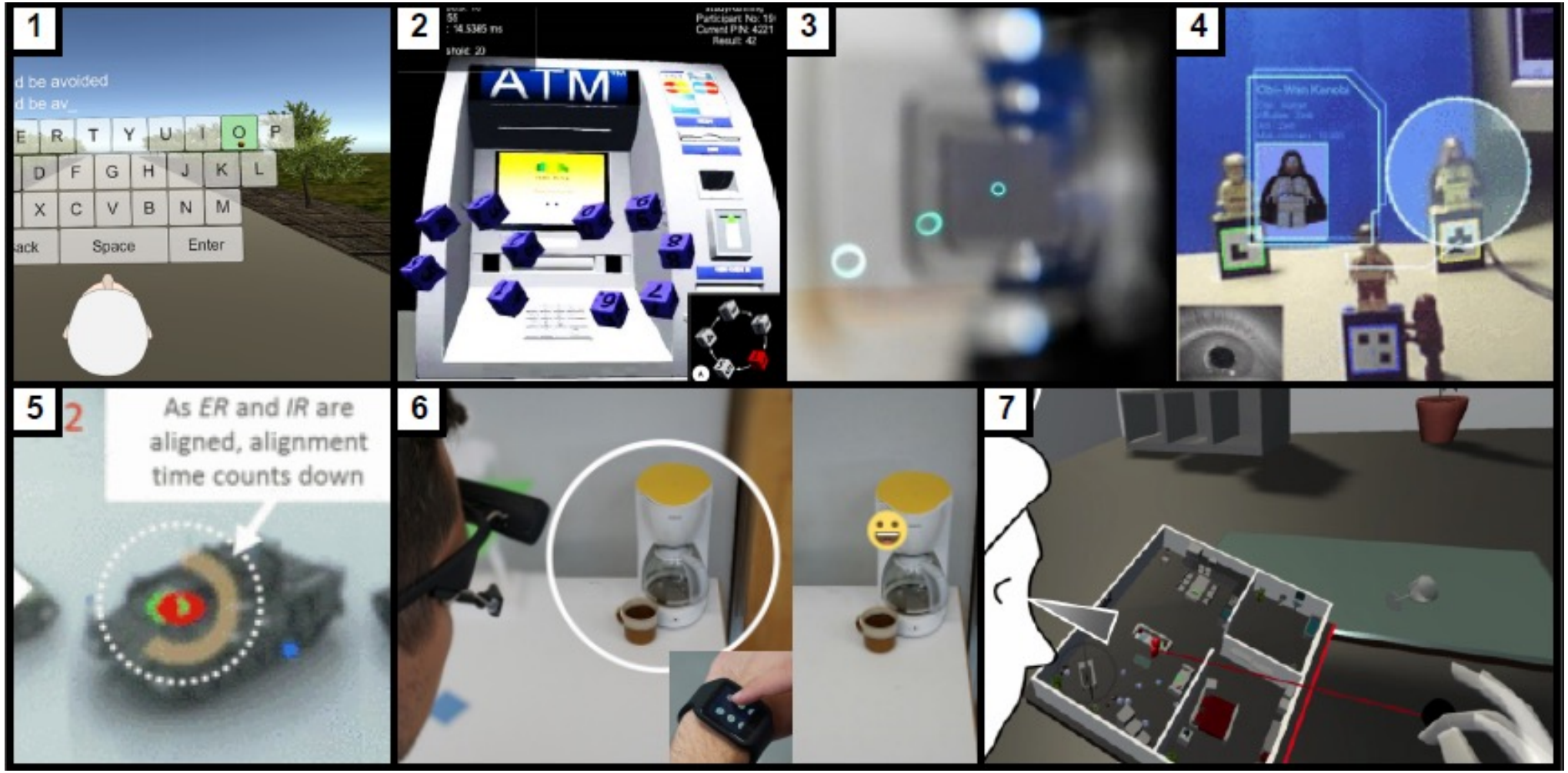

Explicit Eye-Gaze Interaction

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Dwell Time

Gaze “fixates” at a point of interest

- Eye gaze remains within a small area
- Lack of large saccades

- “Midas touch” problem
- Variable fixation duration and dispersion
  - Common dispersion: 1 degree
  - Common duration: 0.5-2s

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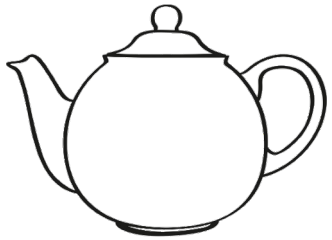
Smooth Pursuit

Gaze follows a given stimulus

- Target determined through correlation of gaze movement with different targets
- Variable duration to avoid “Midas Touch”
- Trajectory affects selection time and accuracy



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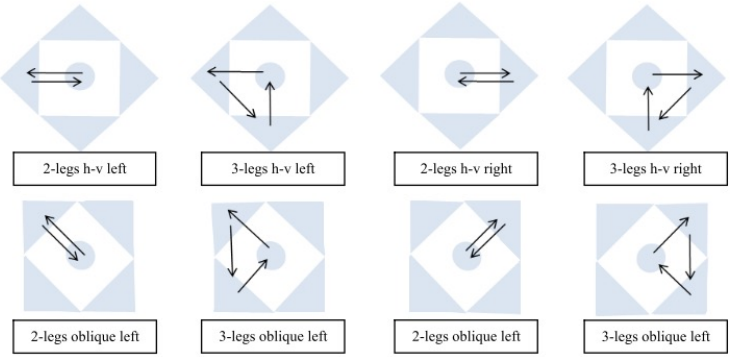
Eye Gestures

Perform a fixed pattern with the gaze

- Very distinct patterns
- Need to be learned



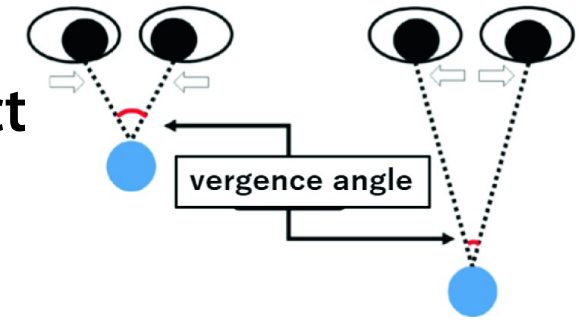
Istance et al. [36]

Half-blinks and blinks

- Selection is confirmed with a half-blink/blink
- Can be combined with patterns/dwell

Vergence

- Change eye vergence while fixating a target object
- Indicator of depth selection



Hirata et al. [79]

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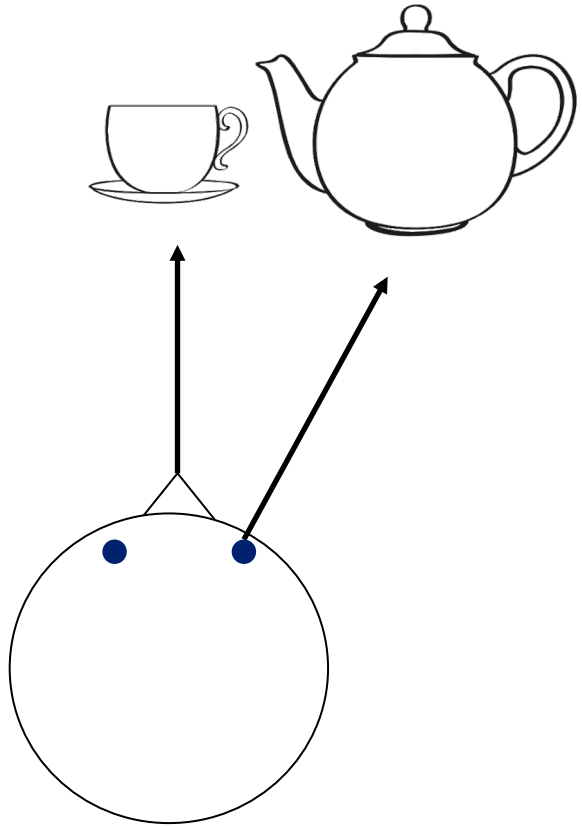
Eye Gaze vs Other Input

- Conflicting results in terms of accuracy and speed

- **Eye vs. Head**
  - Eye gaze is less fatiguing and more natural
  - Head gaze more accurate
  - Speed and accuracy depend on the hardware

- **Eye vs Controllers**
  - Eye gaze can affect situational awareness
  - Can perform similarly for targeting



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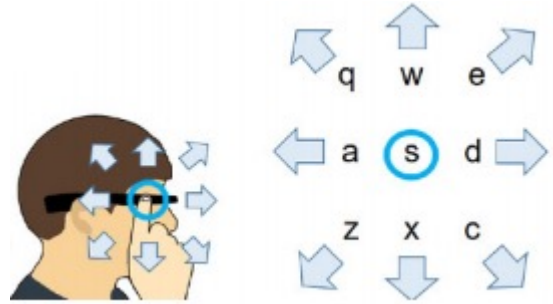
Multimodal eye gaze

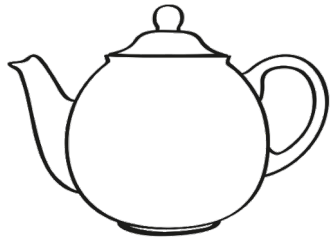
- Eye gaze is used as a pointer,
  other modality used for manipulation
  - Hand Gestures
  - Head Rotation
  - Traditional input methods
  - Speech



Ahn et al. [86]

- Vestibulo-Ocular Reflex

- Brain-Computer Interfaces
  - Event-related (de)synchronization
  - Steady-state Visual Evoked Potential



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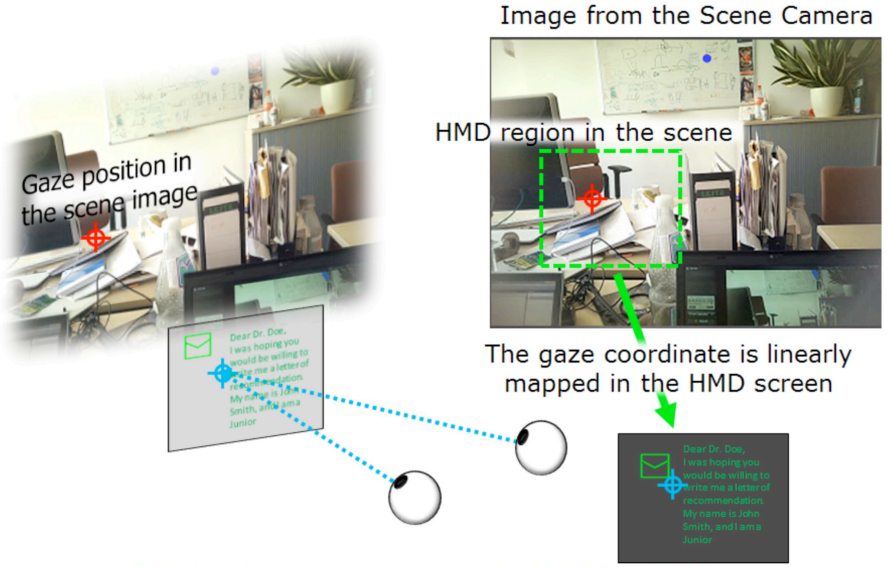
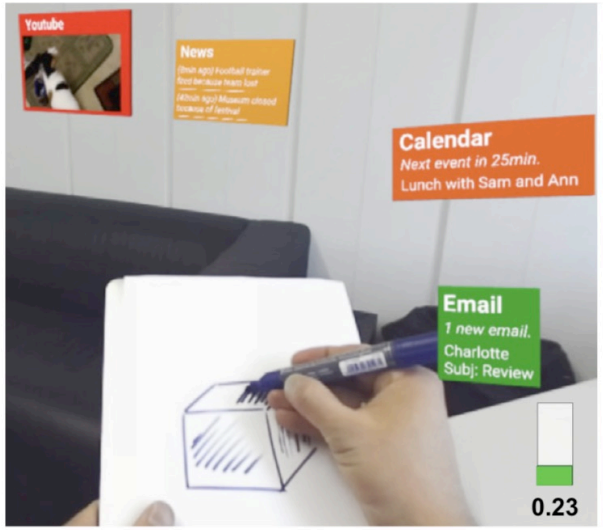
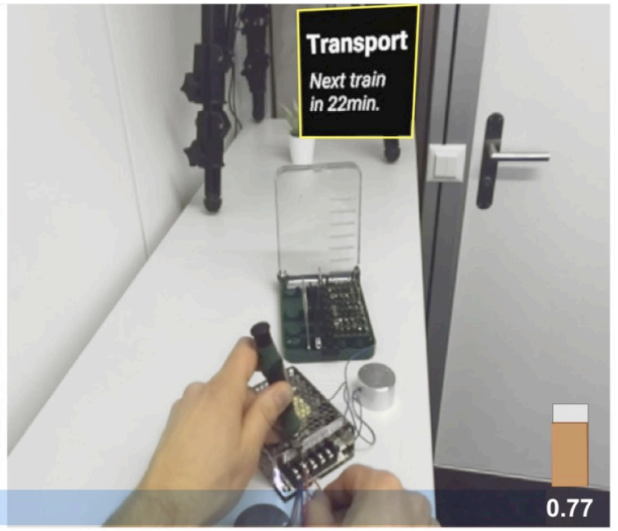




activity: **doodling**, cognitive load: **low**

activity: **brainstroming**, cognitive load: **medium**



activity: **maintenance**, cognitive load: **high**

Implicit Eye-Gaze Interaction

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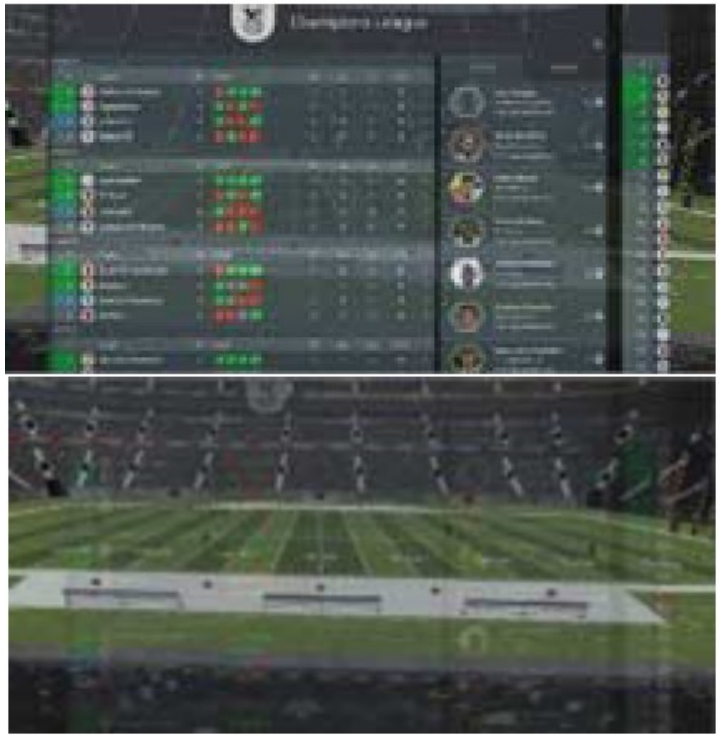
Spatial Presentation

- Many interfaces adapted from 2D systems
- Adjust the visibility according to user gaze
  - Transparency
  - Location

- Few context-aware systems



Pai et al. [114]

Tönnis et al. [122]

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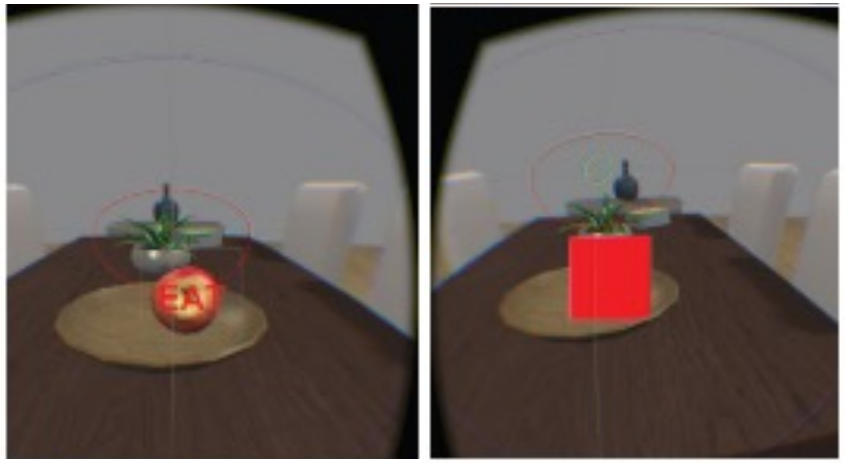
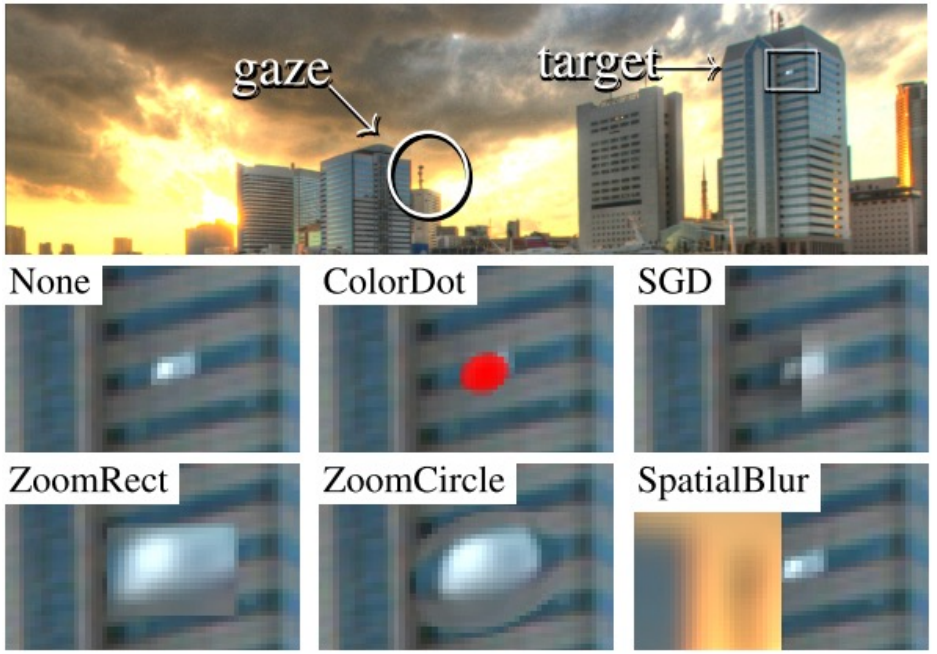
Visual Presentation

- Adjust amount of information based on focus
- Extensive explorations of subtle guidance techniques
  - Similar performance
  - No technique truly imperceptible



Ivaschenko et al. [125]



Grogorick et al. [134]

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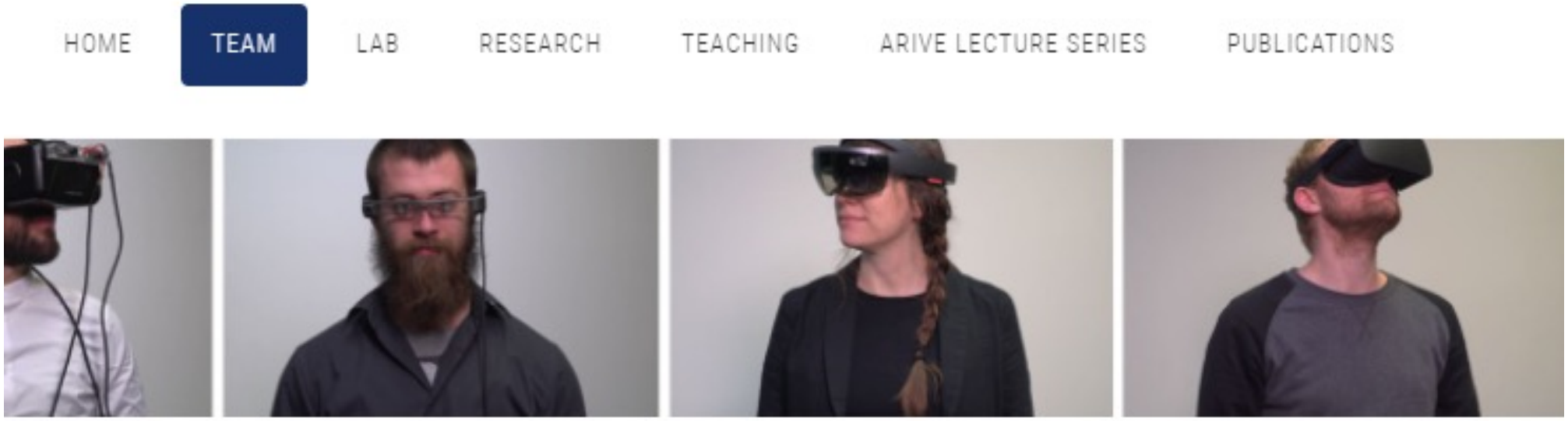
Rendering

- Replicate human perception
  - Extensive focus on Foveated Rendering
    - Adapt rendering quality
    - Physically shift a high-quality inset
    - Latency of 50-70ms may be tolerable



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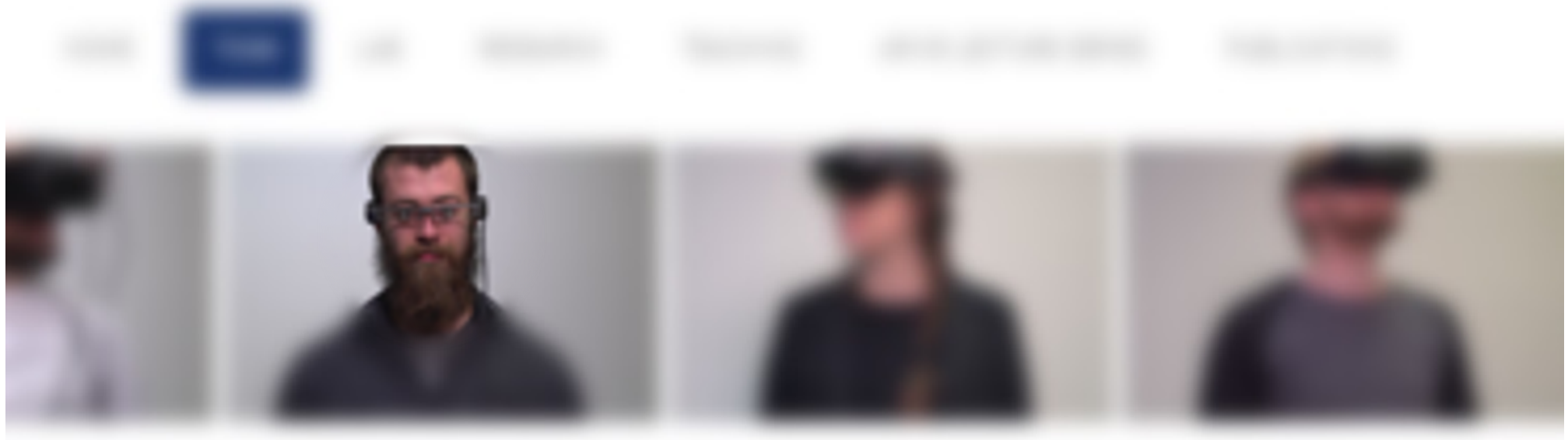
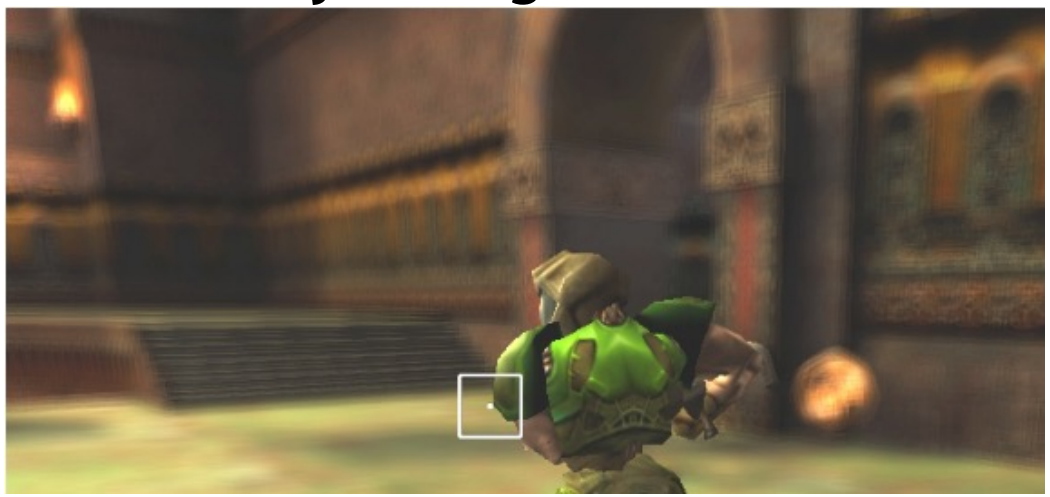
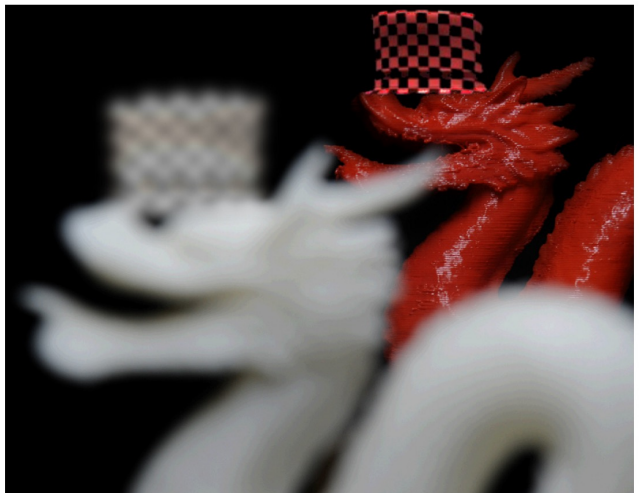


Rendering

- Replicate human perception
  - Extensive focus on Foveated Rendering
    - Adapt rendering quality
    - Physically shift a high-quality inset
    - Latency of 50-70ms may be tolerable
  - Replicate Depth of Field Effects
  - Adjust brightness of the rendered content



Hillaire et al. [146]



Rompapas et al. [146]

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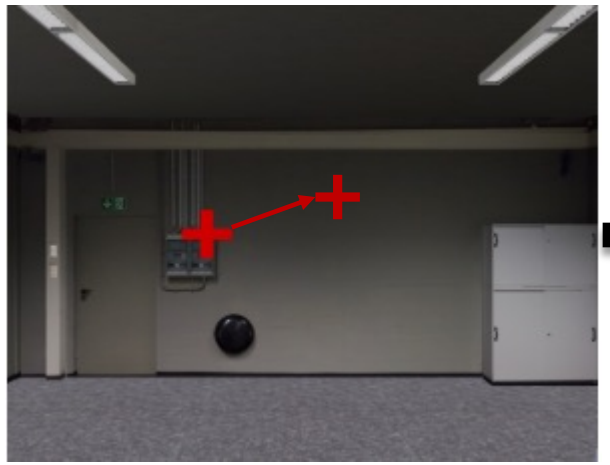
Rendering

- Recent resurgence of interest in saccade suppression
  - Rotations of up to 5 degrees and 0.5m not noticeable



Triesch et al. [151]

Marwecki et al. [154]

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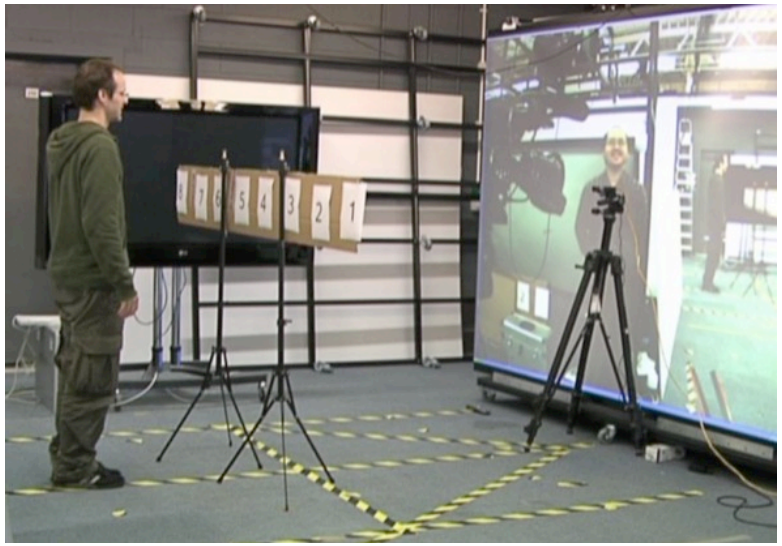

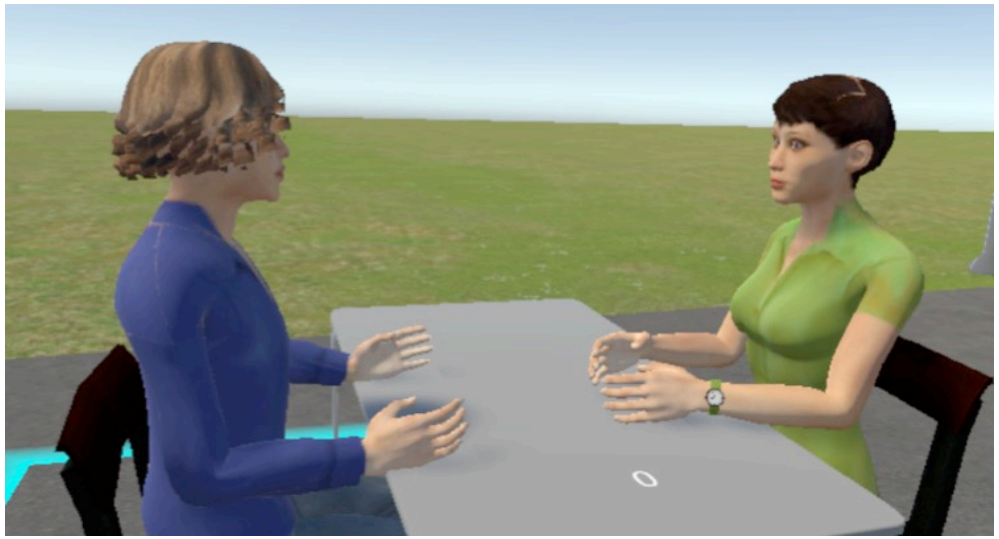

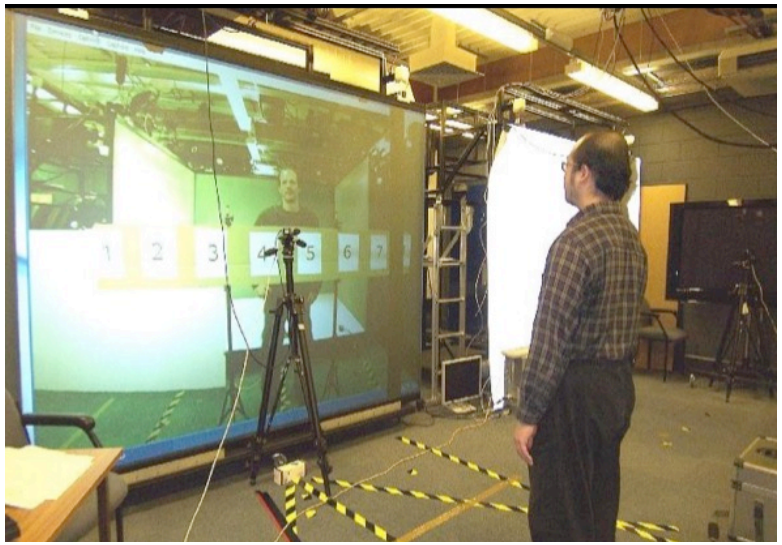

Collaboration

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Eye Movements

- Eye gaze is an important cue in conversations
  - Strong predictor of listening to and speaking to a person
  - Gaze cues support multiparty conversations
  - Eye movements are important for self-identification

Steptoe and Steed [180]

Borland et al. [189]

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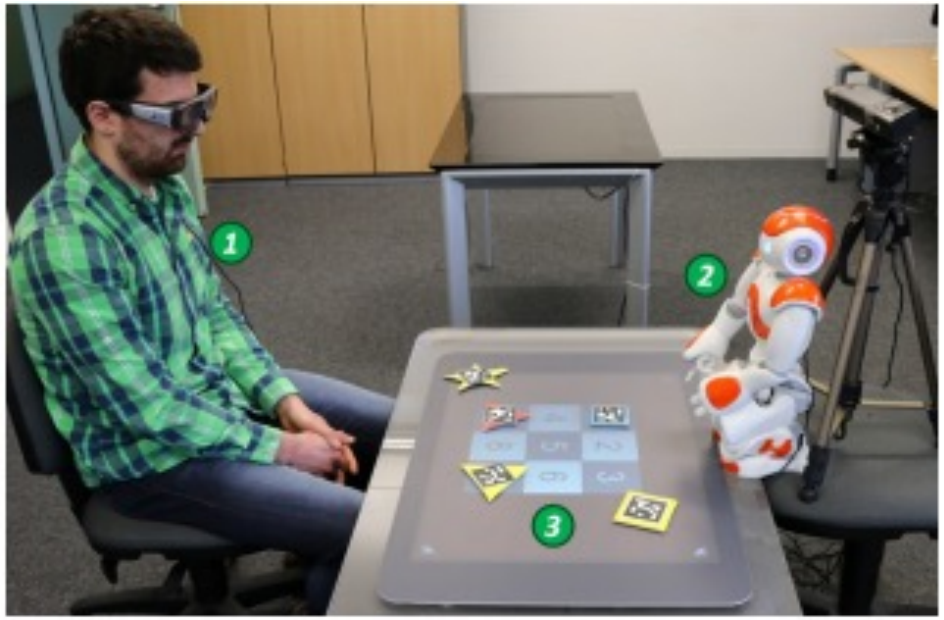
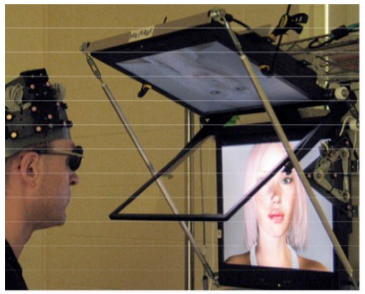
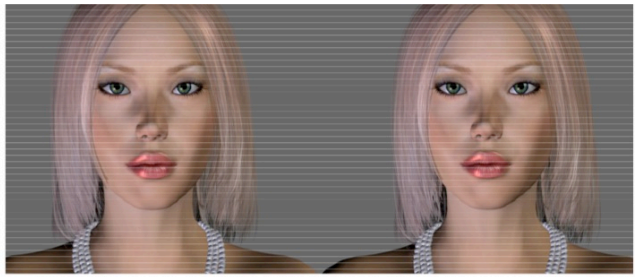
Eye Behavior

- Extensive focus on realistic gaze models
  - Traditional models do not consider the user's gaze
  - Reacting to user gaze can create more realistic conversational behavior
  - Joint attention can improve the perceived realism of virtual avatars

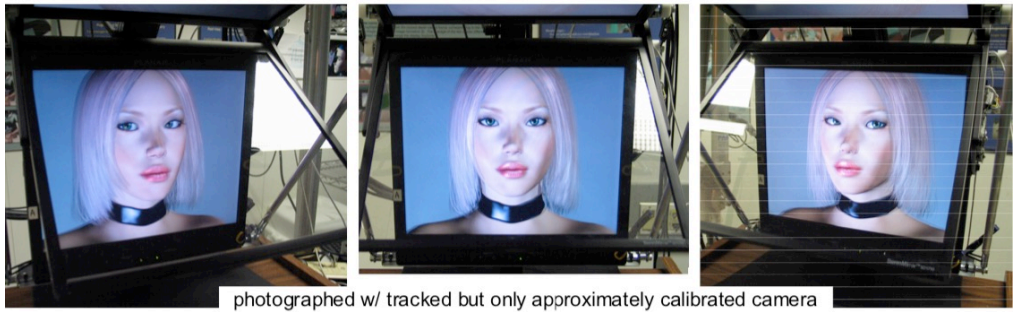


Mehlmann et al. [219]





Fuseable stereo image pair (wall-eyed, right eye image on the right)



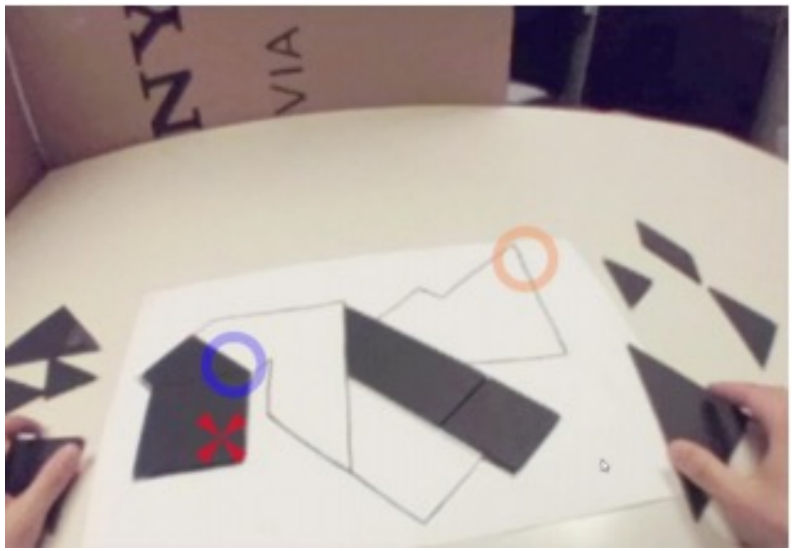
photographed w/ tracked but only approximately calibrated camera

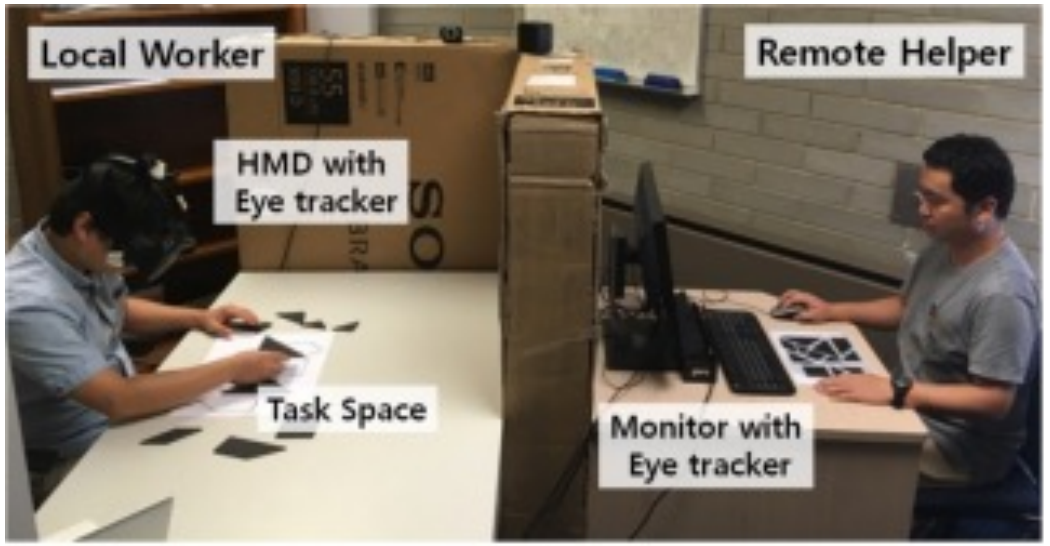
State [195]

ARIVE

Shared Gaze in Remote Collaboration

- Sharing gaze one-way is already beneficial
  - Improves co-presence
  - Improves performance
- Mutual gaze sharing significantly improves collaboration
- Head-pointing may result in better performance





Lee et al. [232]

ARIVE

Shared Gaze in Local Collaboration

- Highlighting of gaze cues improves collaboration
  - Gaze is better than head for disambiguating information
- Providing gaze history can further improve performance
- Most studies have been conducted in VR

Erickson et al. [242]

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Future Directions

Explicit

- Baseline for comparison of different techniques, metrics, questionnaires
- Determining benefits over existing techniques
- Longitudinal investigations
- Less constrained environments

Implicit

- Current applications are very simple and often just prototypes
- Application of activity recognition and mental state to adaptive interfaces
- Exploration of the 3D nature of XR

Collaboration

- Miscommunication due to latency in animated avatars
- Increasing focus on subtle information conveyed by the eyes (micro expressions)
- Increased focus on gaze sharing in collaboration
- Improved 3D gaze estimation

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Some Limitations

Search Terms

- Papers often use other terms, e.g., “saccades”, “pupil”

Did not consider other important areas

- e.g., privacy, gaze pattern study

Not a detailed analysis of each area

Subjective classification

Limited Scope

856 Papers Addressed Eye Tracking

Multiple classifications possible

507 User Study	**93** HMD Concept
258 Gaze Patterns	**87** Collaboration and Virtual Agents
239 System or Application Paper	**87** Rendering
158 Perception	**78** Implicit
149 Explicit	**65** Calibration
145 Diagnosis or Psychological Study	**27** Review
119 Eye Tracking Algorithms	**23** User Classification
109 Eye Properties	

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Summary

- Very exciting area of work
- Only explicit input extensively explored
  - Too many dwell papers
- Too many prototype and conceptual systems

- Promising directions:
  - Perceptual rendering and 5G
  - Adaptive and context aware interfaces
  - Gaze guidance and adaptation in 3D
  - Enhanced gaze cue sharing

ARIVE

THE UNIVERSITY OF AUCKLAND
NEW ZEALAND

UNSW
THE UNIVERSITY OF NEW SOUTH WALES

UC
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

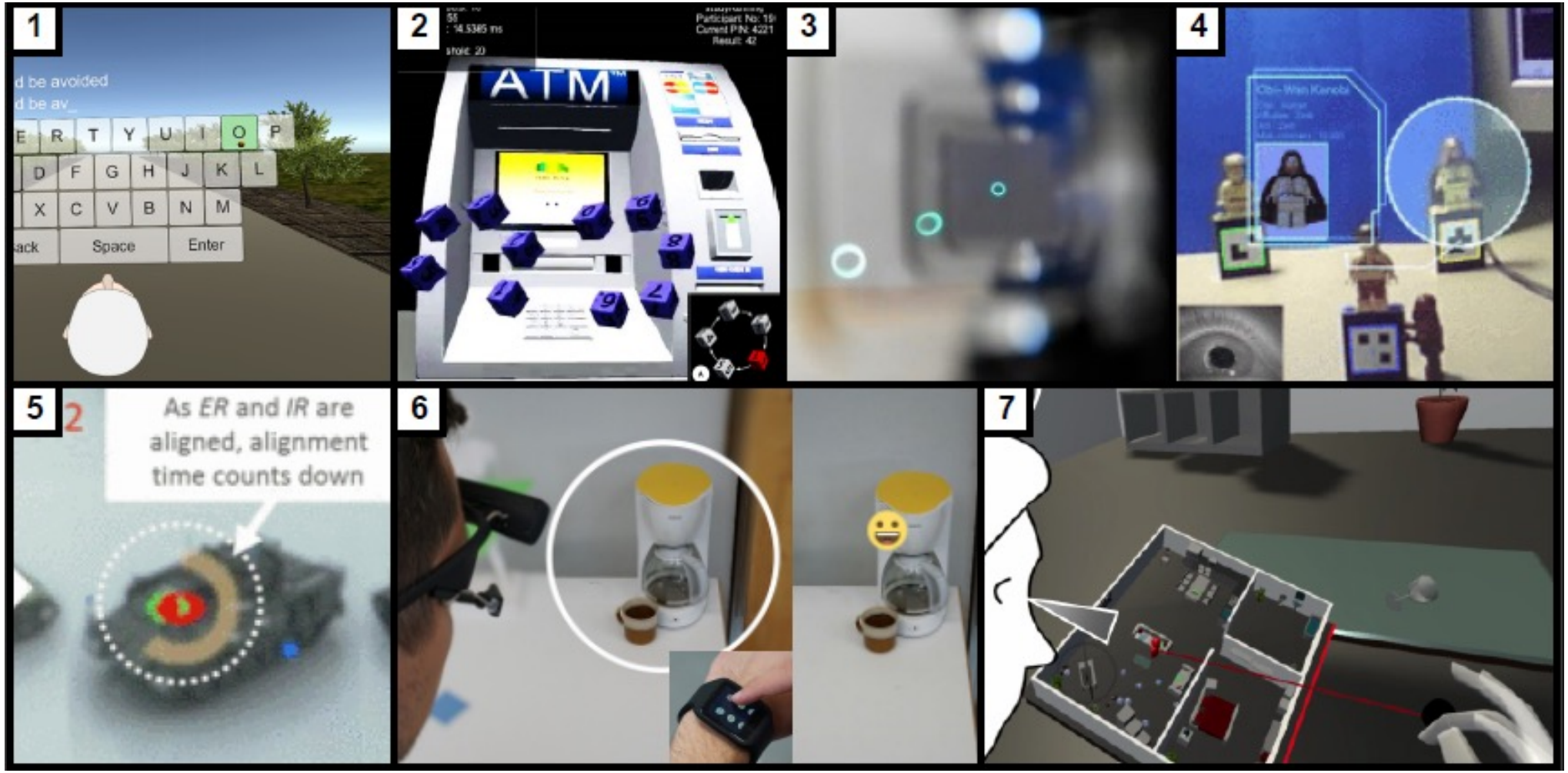
MONASH University

UNIVERSITY of OTAGO
Te Whare Wānanga o Otāgo
NEW ZEALAND

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

VICTORIA UNIVERSITY WELLINGTON

University of South Australia



The Eye in Extended Reality: A Survey on Gaze Interaction and Eye Tracking in Head-Worn Extended Reality

Alexander Plopski, Teresa Hirzle, Nahal Norouzi, Long Qian, Gerd Bruder, Tobias Langlotz