Eye-Tracking as a Window to the Mind

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Microsoft

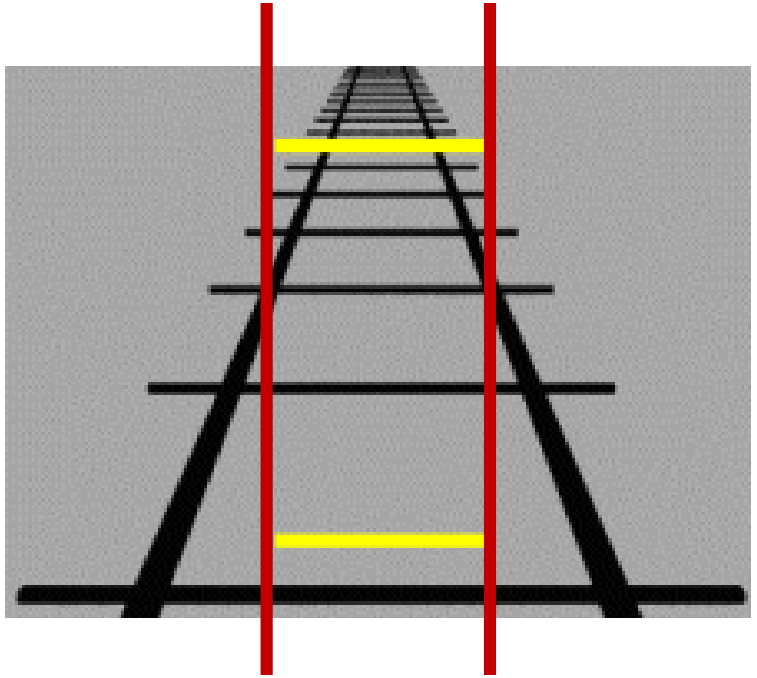
Overview

- Visual Perception and Illusions
- The Anatomy of the Eye
- Eye Movements in Everyday Tasks
  - Visual search
  - Navigation / Driving
  - Face Recognition / Social Interactions
  - Sports
  - Reading

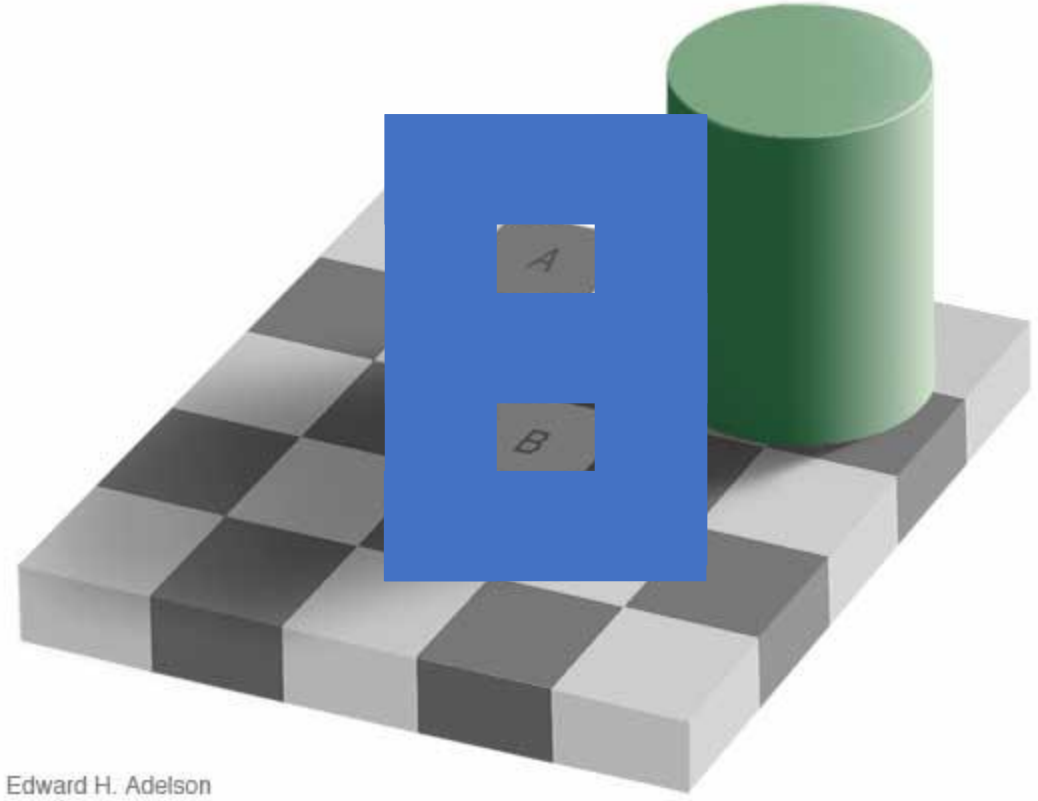
Visual Perception

- Visual perception involves a tremendous amount of work done by the brain
  - More than 50% of the brain is involved in visual processing
    - Top down processing: context\expectation driven
    - Bottom up processing: stimulus driven
- We can “see” evidence of the brain’s influence from visual illusions

Ponzo Illusion



Color Constancy

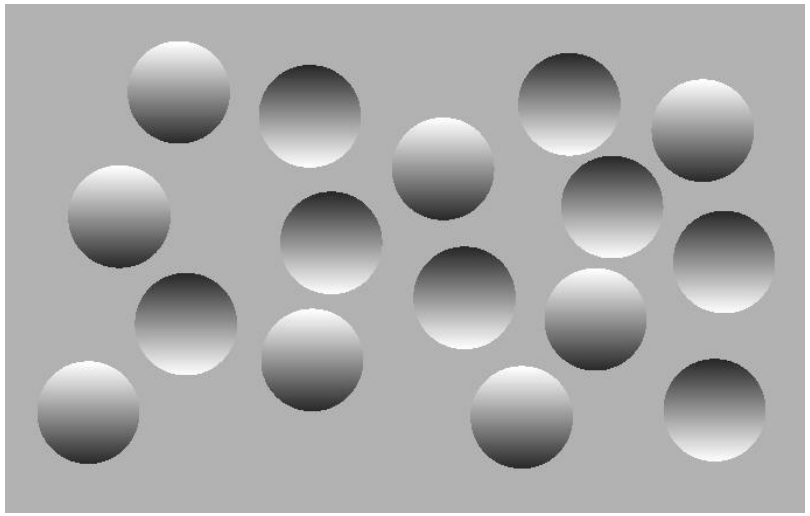


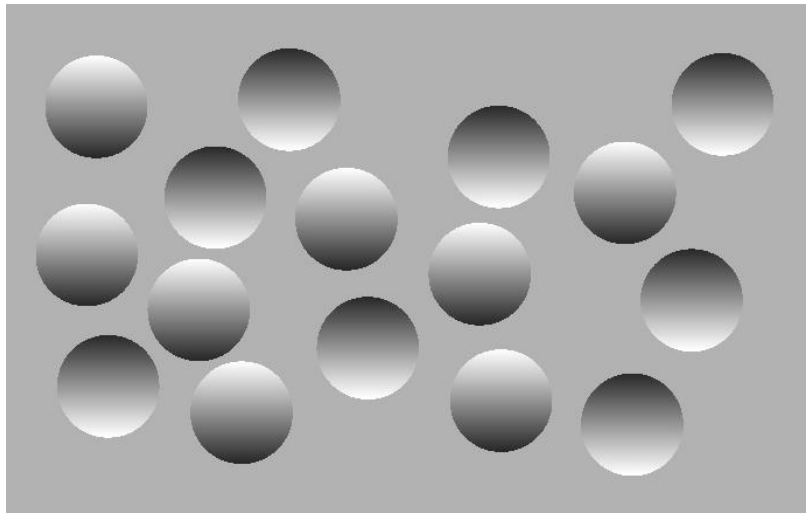
Edward H. Adelson

Square “B” appears to be lighter than Square “A” BUT…

“A” and “B” are actually the same color

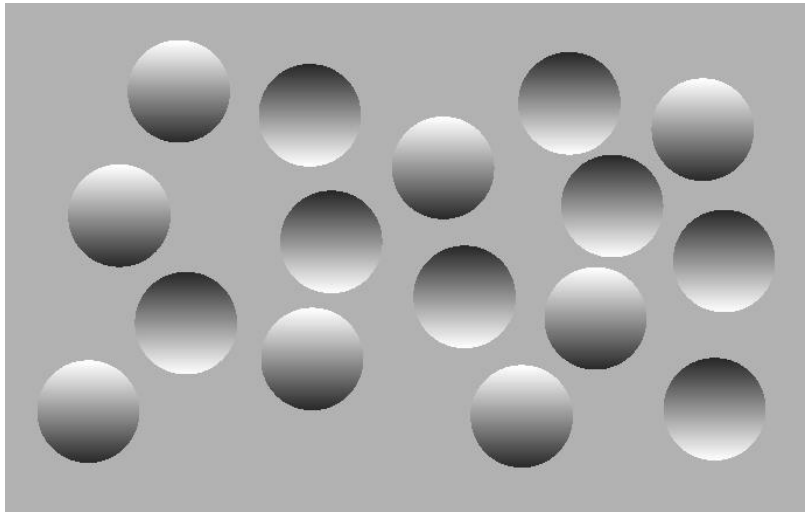
Light & Shadow

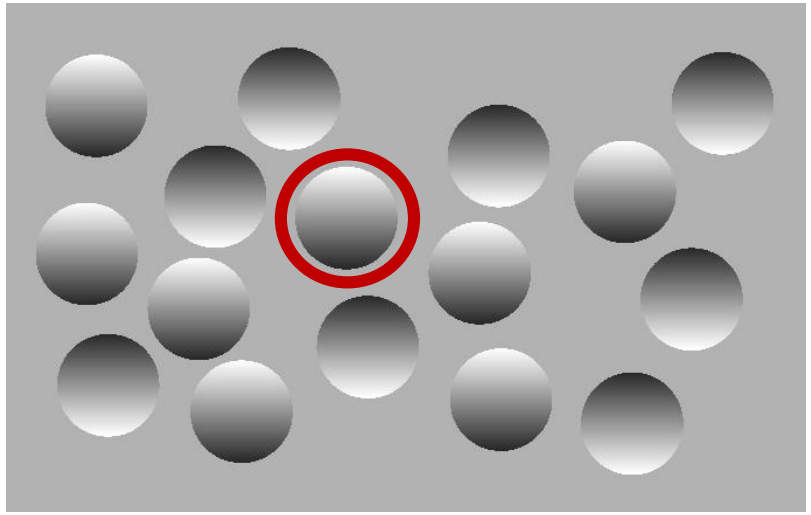




The brain interprets light coming from above, creating the illusion of concave and convex curves.

Light & Shadow

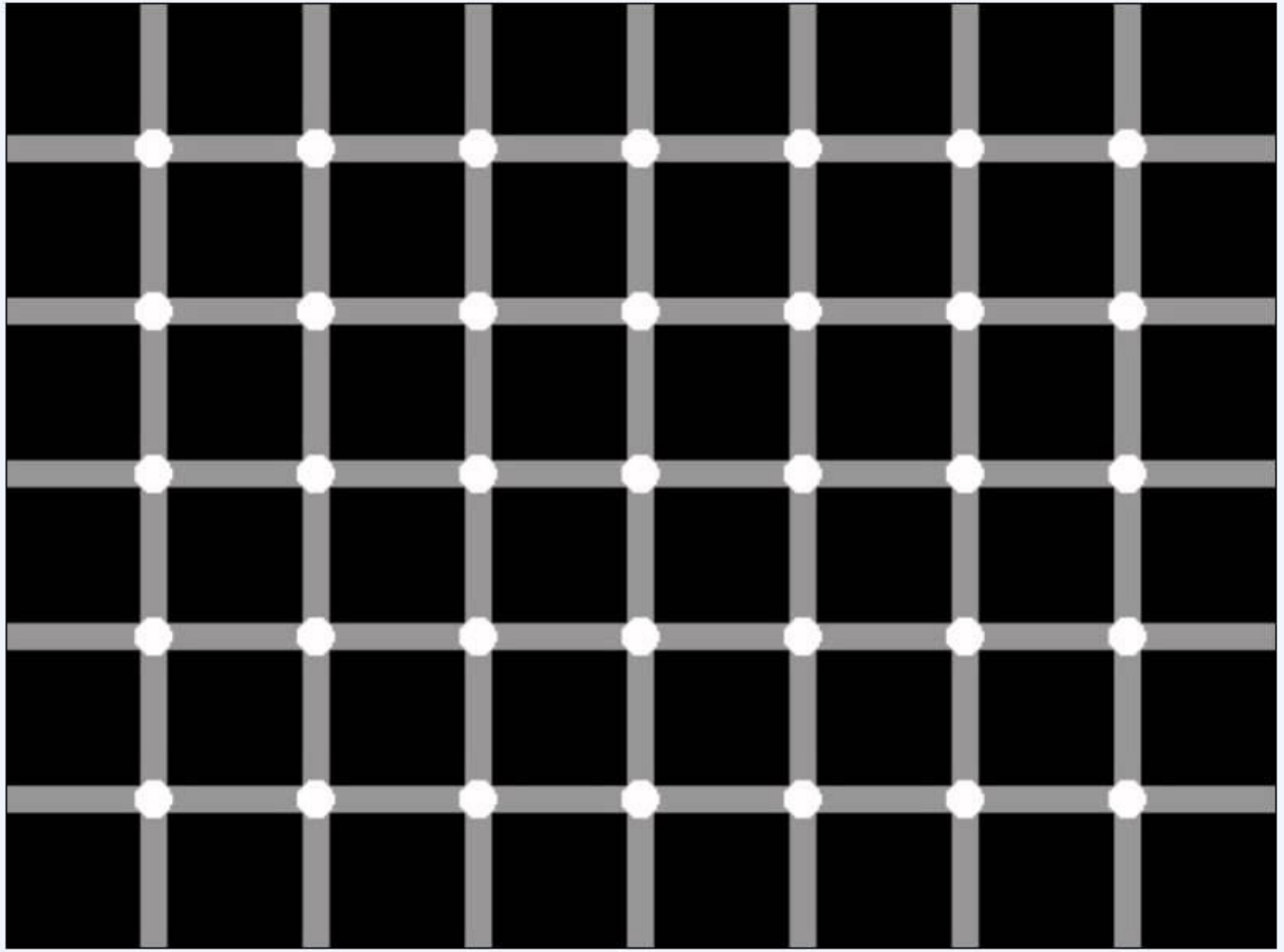


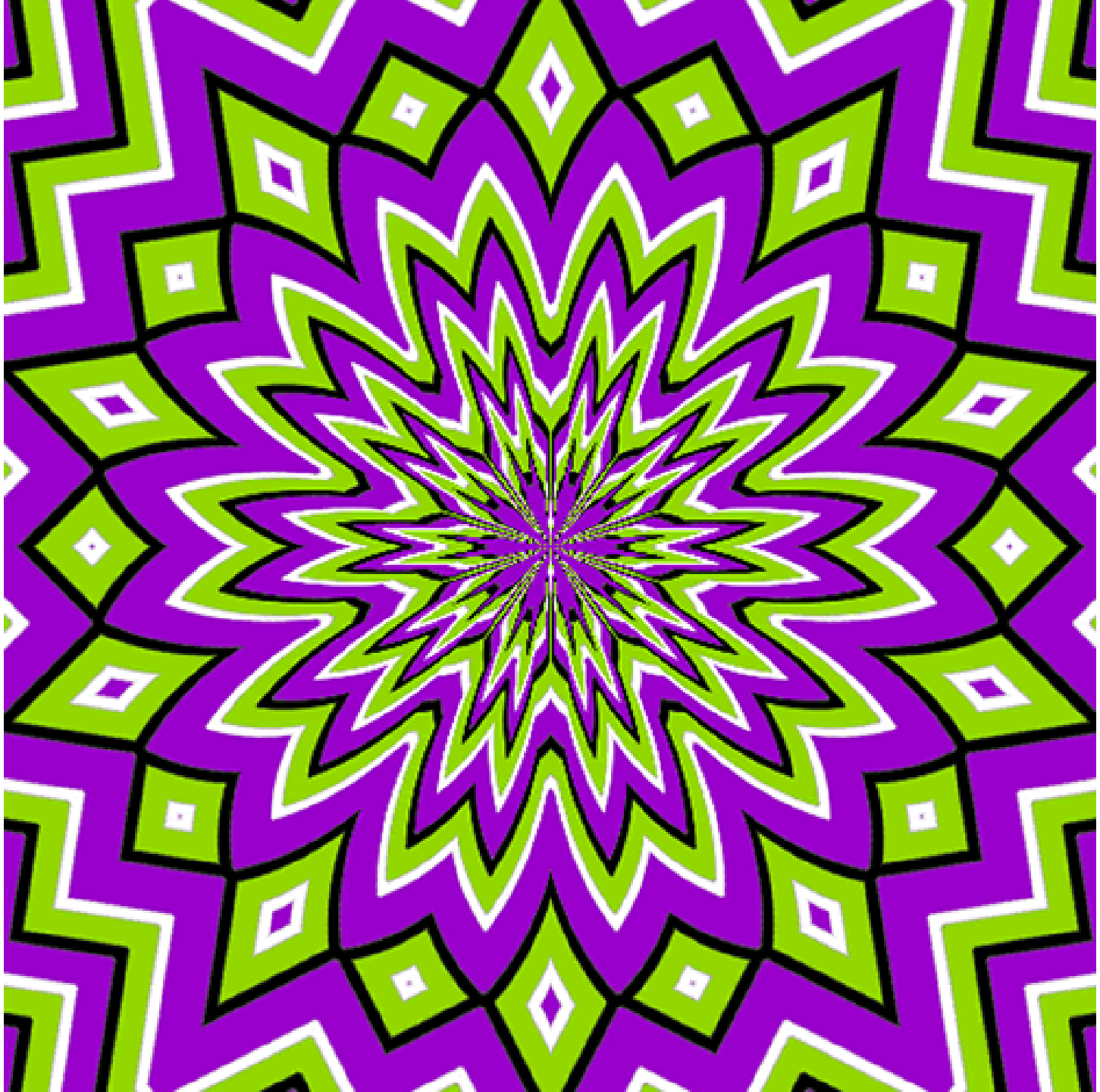


Eye-Movements and Active Vision

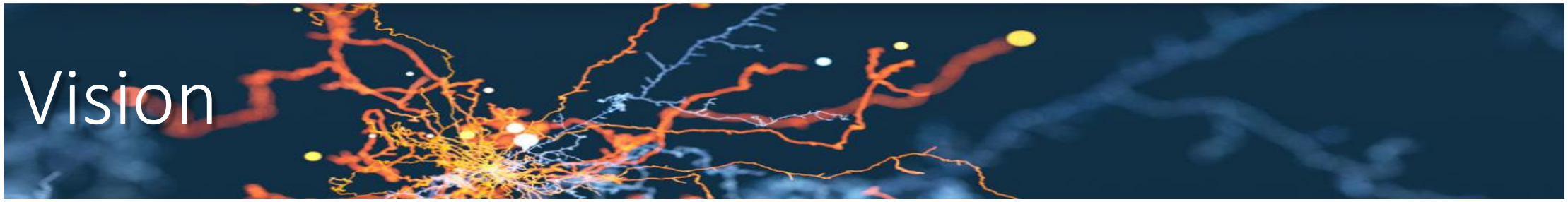
Why study eye movements and active vision?

- What we see depends on our gaze location
- Our gaze location depends on:
  - What we see: bottom up perception
  - What we know (what we have seen before): top down perception





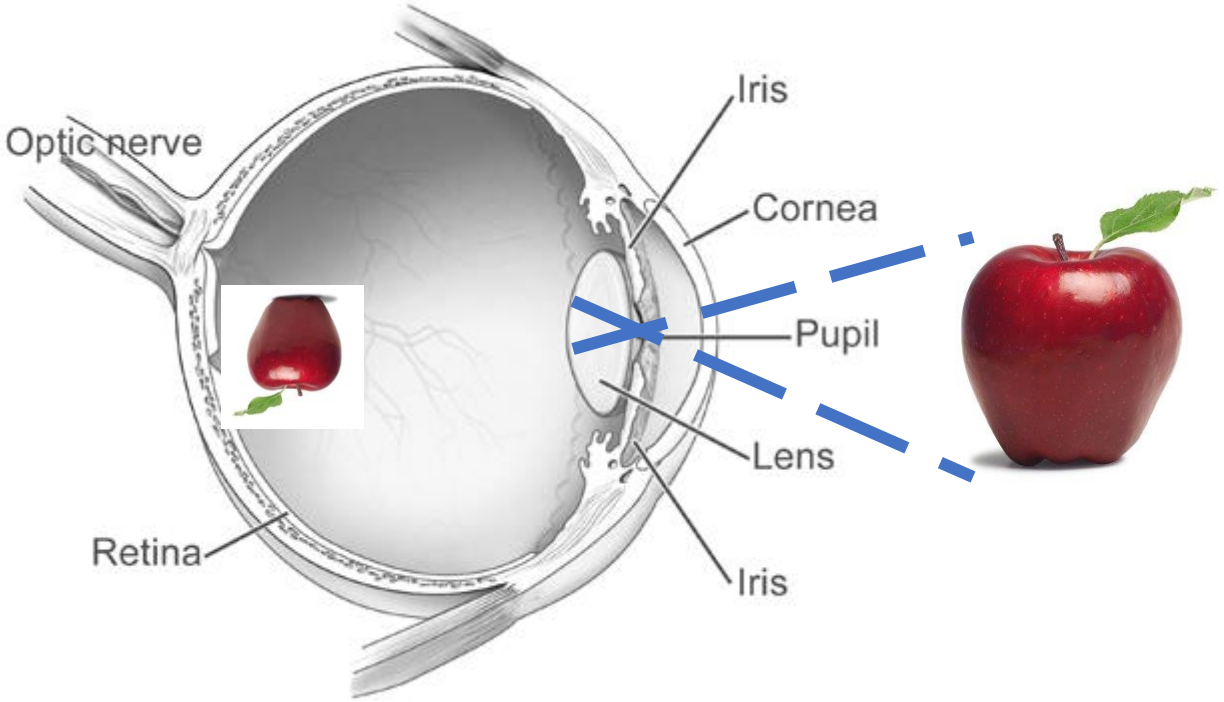
Vision



- These Illusions indicate that our vision isn't a 100% accurate rendition of the world around us.
  - Instead, our brain takes shortcuts to give us a reasonably accurate view of the world—one good enough to direct our actions.

One Last Example

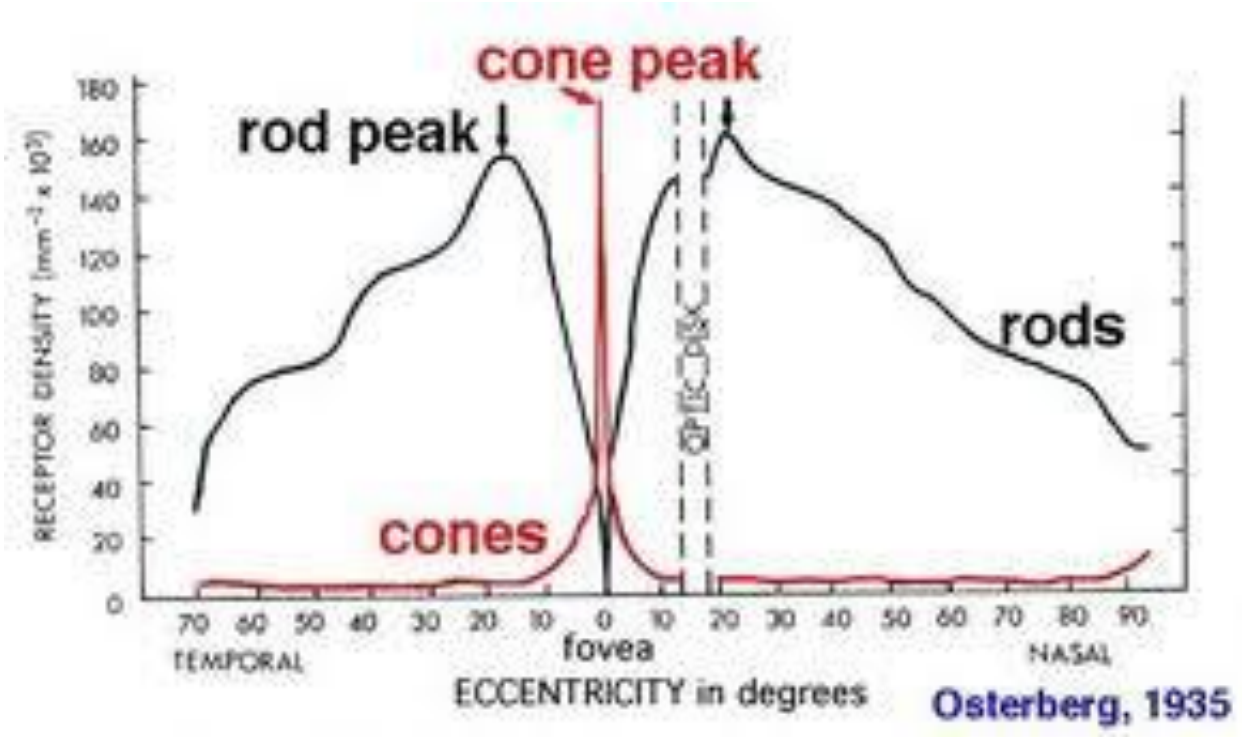
Anatomy of the Eye



- Retinal image is 2D
- Image is inverted due to curvature of lens
- Image is carried through optic nerve to occipital lobe

Visual Acuity and the Retina

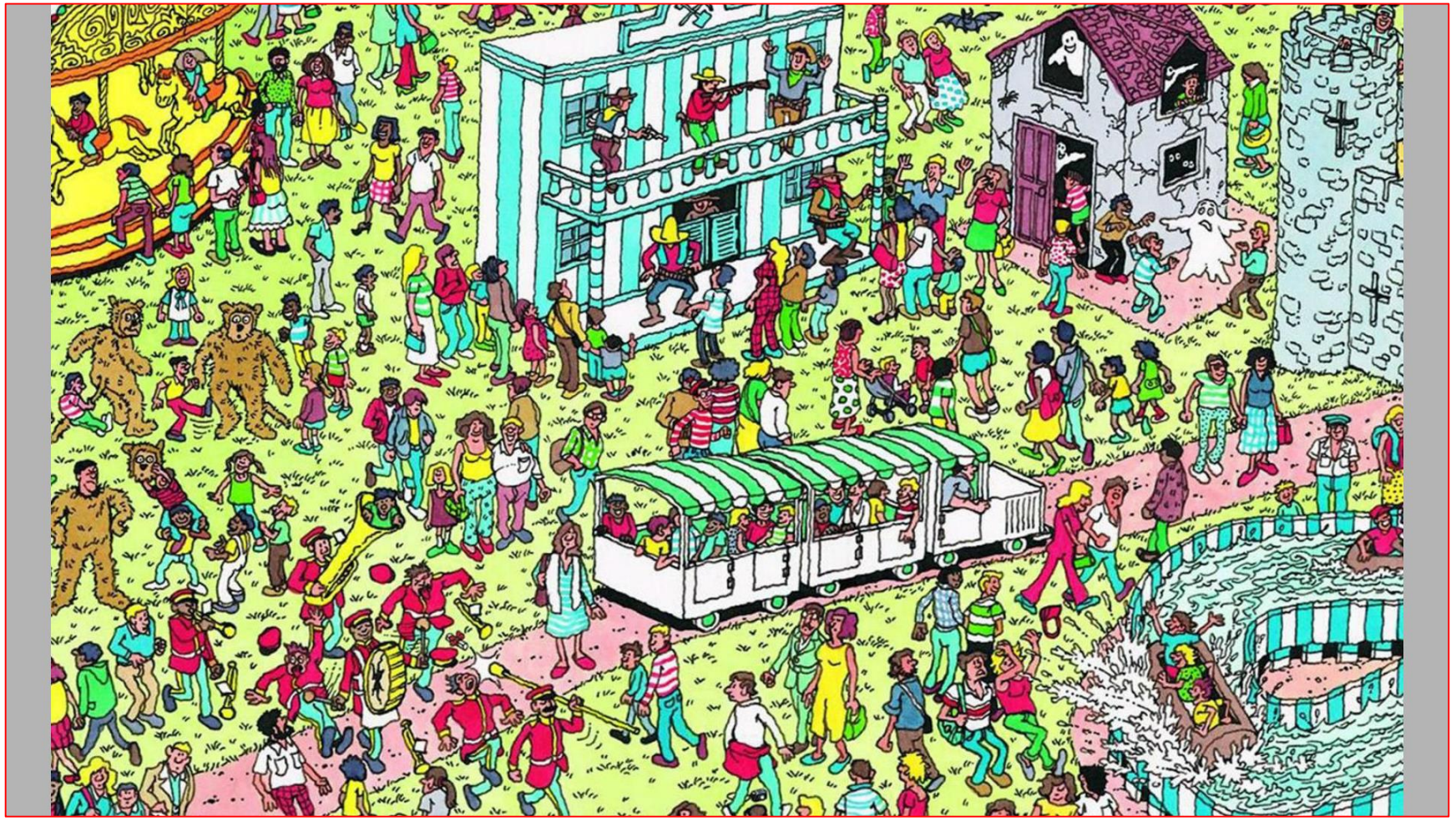
- Types of receptors:
  - Rods: movement, brightness, night vision
  - Cones: fine detail, hue (color)
- Distribution of receptors:
  - Fovea: 2% of central vision, almost entirely cones
  - Parafovea: 4% either side of the fovea, mix of rods and cones
  - Periphery: everything outside the parafovea, almost entirely rods



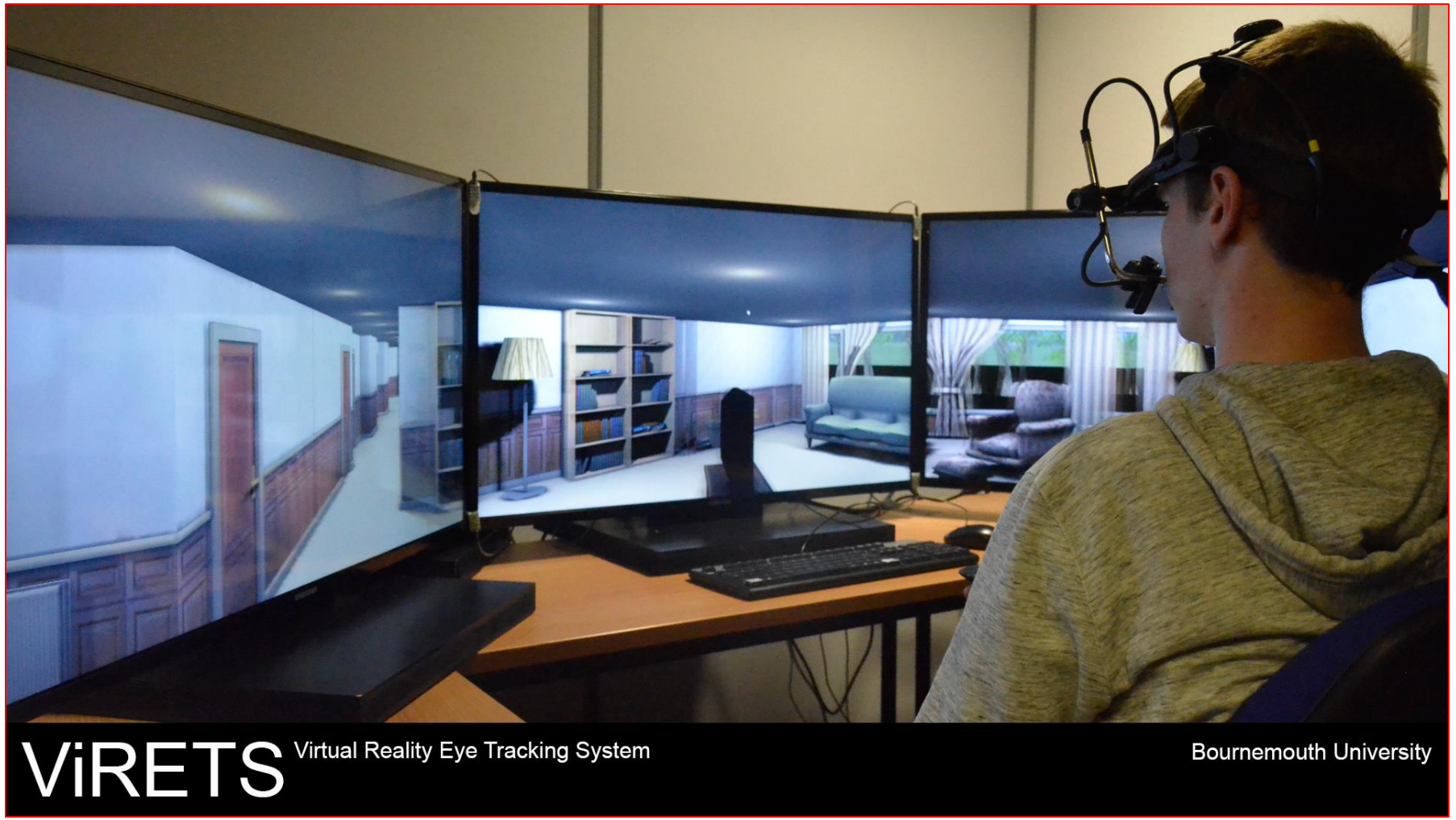
Two Main Types of Eye Movements

- Smooth Pursuit
- Saccades

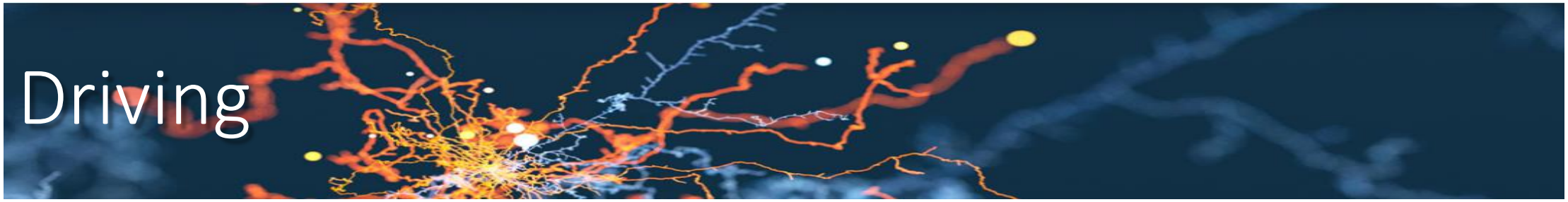
Visual Search



Navigation


ViRETS
Virtual Reality Eye Tracking System
Bournemouth University

Driving



https://youtu.be/6Rtg_pcRVig

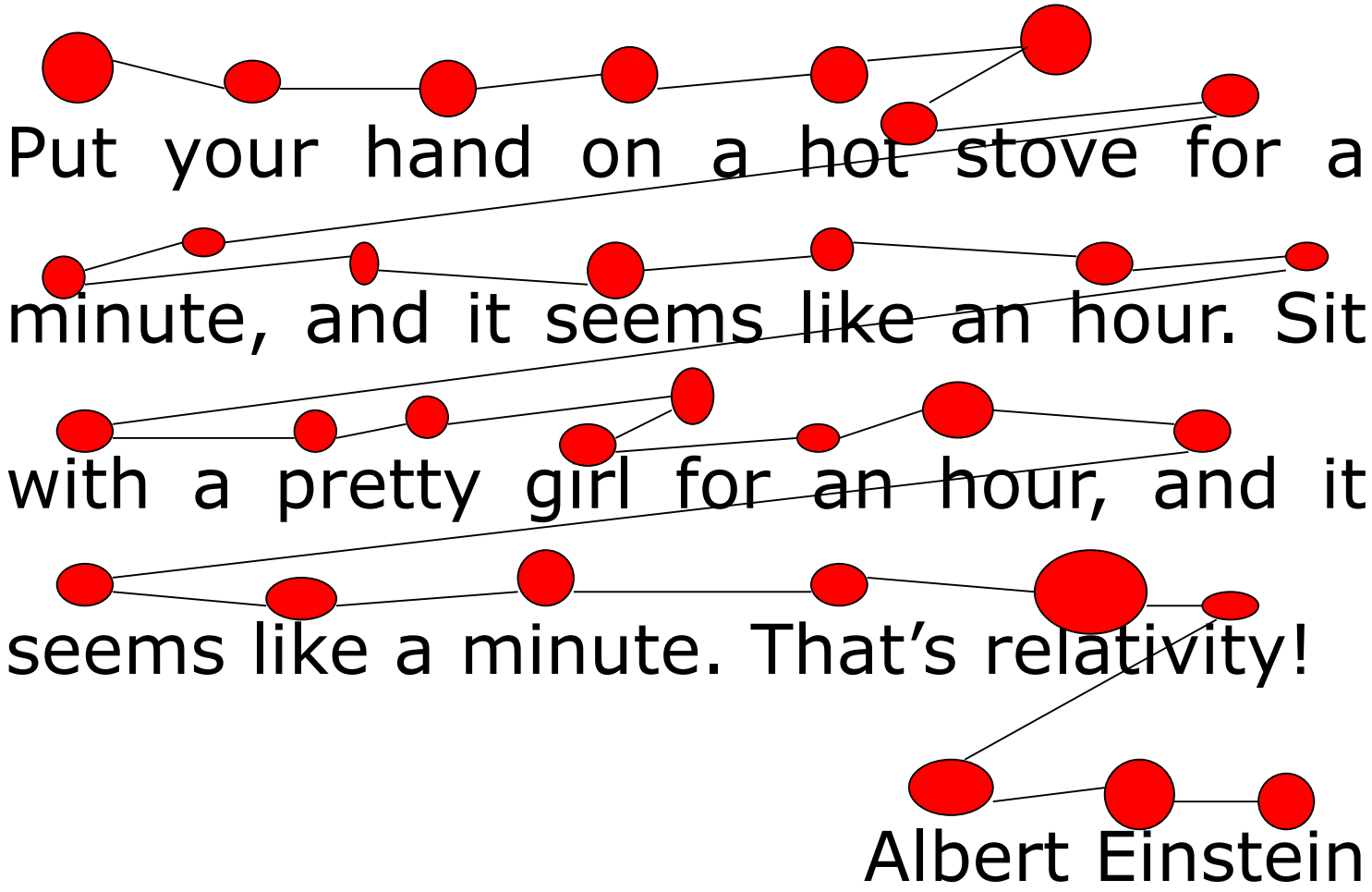
Face Recognition

Sports

Shopping

https://youtu.be/8ZntXrKZboM

Reading


Put your hand on a hot stove for a minute, and it seems like an hour. Sit with a pretty girl for an hour, and it seems like a minute. That's relativity!
Albert Einstein

Why Study Reading?

- Words are everywhere
  - Modern society practically demands literacy of it's members

Why Study Reading?

- Literacy level is highly predictive of yearly earnings (Green and Riddell, 2001)

Toothpaste or Hemorrhoid Cream

Why Study Reading?

- Written language is one of the greatest inventions of all time!
  - “Take it from us, and the Bible, all history, all science, all government, all commerce, and nearly all social intercourse go with it.”
    - Abraham Lincoln (Feb 11, 1859)
  - Written language is a highly effective means of communication
    - High content value
    - Author’s message can travel through space and time

Transposed Letter Effects and Letter Position Coding

"Aoccdrnig to rseerach at Cmabrigde Uinervtisy, it deosn't mttaer in waht oredr the ltteers in a wrod are, the olny iprmoatnt tihng is taht the frist and lsat ltteers be at the rghit pclae. The rset can be a toatl mses and you can sitll raed it wouthit porbelm. Tihs is bcuseae the huamn mnid deos not raed ervey lteter by istlef, but the wrod as a wlohe."

Transposed Letter Effects and Letter Position Coding

- What is true about the email
  - First and last letters are especially important
- What isn't true about the email
  - That there was research done at Cambridge investigating reading words with jumbled letters
  - That you can read words with jumbled letters without a problem (Rayner, White, Johnson, & Liversedge, 2006)
    - Large cost to having jumbled letters
    - Cost not as big as if letters are replaced
      - Judge → Jugde = easier
      - Judge → Judpe = harder

What is reading?

- Reading is the extraction of meaning from abstract visual symbols
  - Word identification
  - Planning and coordination of eye movements
  - Grammatical (syntactic) analysis
  - Meaning (semantic) construction
  - Discourse processing

Word Representations

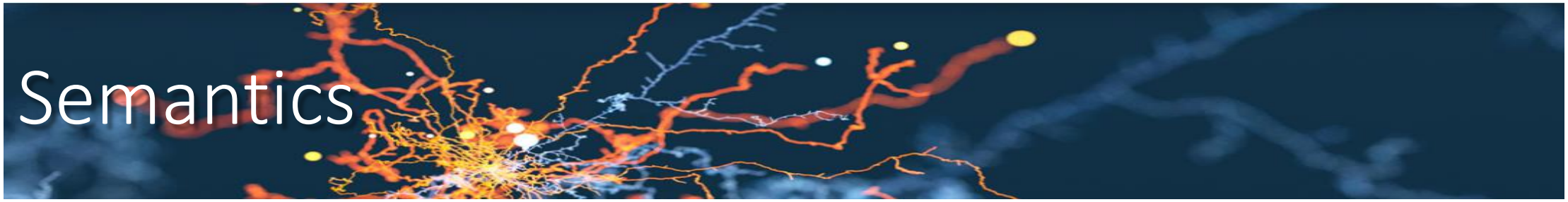
- Orthography: visual codes
  - Graphemes or letters
- Phonology: sound codes
  - Phonemes are the individual sound units in a language
- Semantics: conceptual meaning
  - Morphemes are the smallest meaningful units in a language

Typography vs. Orthography

- banana
- BANANA
- banana
- *banana*
- Banana
- BaNaNa

Orthography and Phonology

- Not a perfect relationship in English (Deep Orthography)
  - Heterographic homophones: beech, beach
  - Homographic heterophones: tear, tear
  - Regularity:
    - hint
    - mint
    - lint
    - tint
    - pint



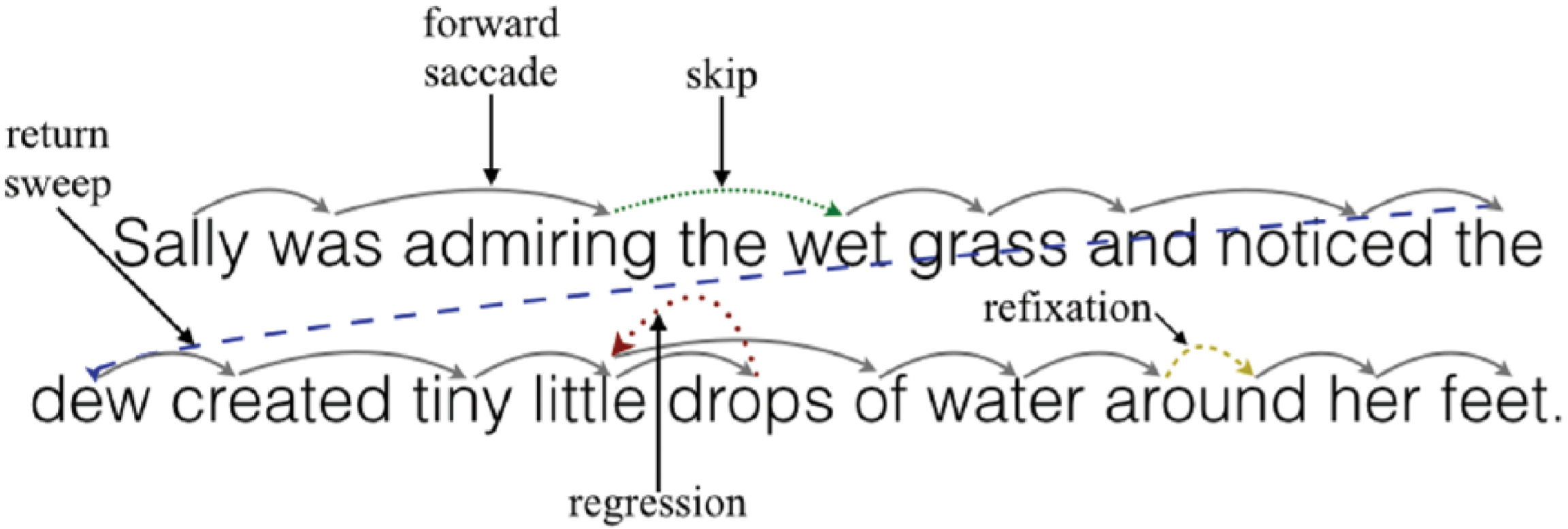
Semantics

- Conveying meaning
- Jabberwocky (Lewis Carroll)

  ’Twas brillig, and the slithy toves
  Did gyre and gimble in the wabe;
  All mimsy were the borogoves,
  And the mome raths outgrabe.

- 'It seems very pretty,' she said when she had finished it, 'but it's rather hard to understand!' (You see she didn't like to confess, even to herself, that she couldn't make it out at all.) 'Somehow it seems to fill my head with ideas— only I don't exactly know what they are!

Types of Reading Saccades



Eye Movements During Reading

- Average Fixation Duration: 200-250 ms
  - Strongly influenced by cognitive variables
    - Word frequency
    - Contextual constraint
- Average Saccade Length: 8-9 letters
- Regression Rate: 10-20%
- Skipping Rate: 8-20%
  - Strongly influenced by word length!

Display Change Methodology

- Moving window (McConkie & Rayner, 1975)
- Boundary change (Rayner, 1975)

Moving Window

```
XXe normal procXXXXXXXXXXXXXXXXXXXXXXXX
        *
```

Moving Window

```
XXXXXXXXXXXprocessing ofXXXXXXXXXXXXXX
                  *
```

Moving Window

```
XXXXXXXXXXXXXXXXXXXXXXX of words durXXX
                        *
```

Moving Window

```
The normal prXXXXXXXXXXXXXXXXXXXXXXXXX
      *
```

Moving Window

```
XXXXXXXXXXXXXXXXXXXXXXXXXXf words durinX
                            *
```

Reading Span

- Extends ~14 characters to right and ~3 to left of fixation
- No information below the line
- Word identification span is small
- Span is not fixed
  - Predictable words = more information
  - Difficult words = less information
  - Reading skill influences span
    - Younger beginning readers have smaller spans

Boundary Technique

- Kathy wrote four **reuafo** before turning twelve.

  *

Boundary Technique

- Kathy wrote four **reuafo** before turning twelve.

*

Boundary Technique

- Kathy wrote four **reuafo** before turning twelve.

*

Boundary Technique

- Kathy wrote four **novels** before turning twelve.

*

Preview Benefit

- If readers have a valid preview of a word before fixating it (when it is the word to the right of fixation), they spend about 30-50 ms less time on it than when they have no preview.
  - Orthographic benefit (*train*, trail, truck, house)
  - Phonological benefit (*cent*, sent, rent)
  - Little to no semantic benefit (*dog*, cat, pie)
    - Reading Chinese*

Why are return sweeps important?

- In normal text, about 20% of all fixations are preceded or followed by a return sweep.

- The first page of *Harry Potter and the Philosopher's Stone* requires a reader to make 30 return sweeps excluding any re-reading.
  - This translates as approximately 6,500 return sweeps for the 223 pages in the 1997 Bloomsbury paperback edition.

The officer had recently received special training which explained how best to implement the Superficial Rehab Directional Program (SRDP) that was required for the case at hand. With a manual in hand for support, he approached the criminal to begin the SRDP evaluation. First, the SRDP required the officer to draw up a comprehensive strategy that would tailor the procedure to the criminal's needs. The officer would then need to offer the criminal a chance to apply for a mentor to support them through the SRDP evaluation. The final stage that the officer would have to complete during the first SRDP session is that of building an alliance between both parties to ensure that subsequent sessions flowed smoothly.

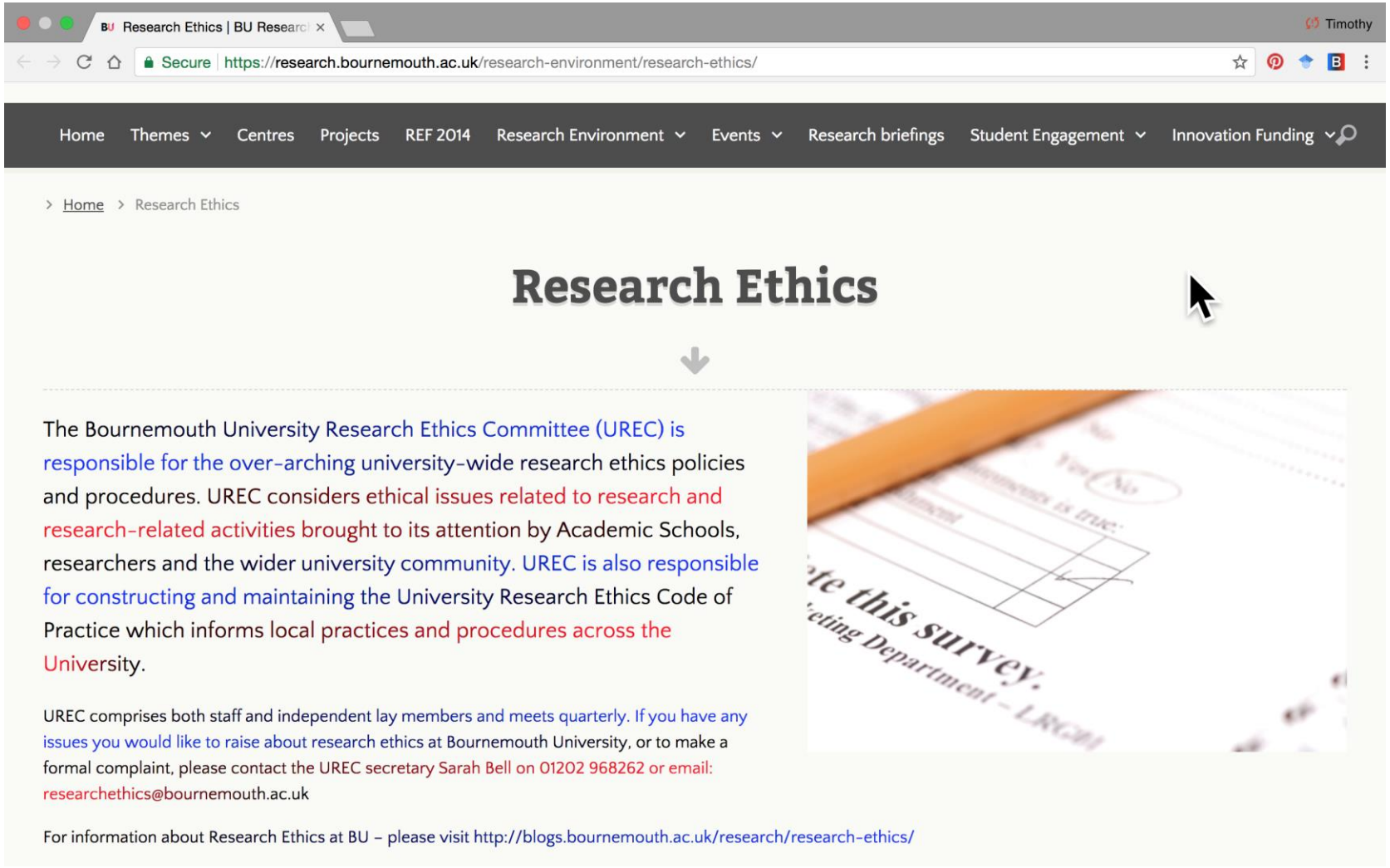
Return Sweeps Saccades

- Return sweeps are particularly vulnerable to oculomotor error
  - Saccadic range error (SRE)
    - Long saccades tend to undershoot their target
    - Short saccades tend to overshoot their target
  - Random error
    - Non-systematic error but increases with saccade distance
- Return sweeps undershoot their target by ~10%

Line length	Return sweep launch position	Return sweep landing position	Frequency of corrections in %	Amplitude of corrections in letters
10 deg. (37 letters)	3.9 (2.5)	6.0 (2.1)	33	3.4 (1.4)
16 deg. (59 letters)	4.2 (3.2)	7.8 (2.9)	50	4.6 (2.0)
22 deg. (81 letters)	4.7 (3.4)	10.1 (3.9)	68	6.1 (2.4)

Hofmeister, Heller, & Radach (1997)

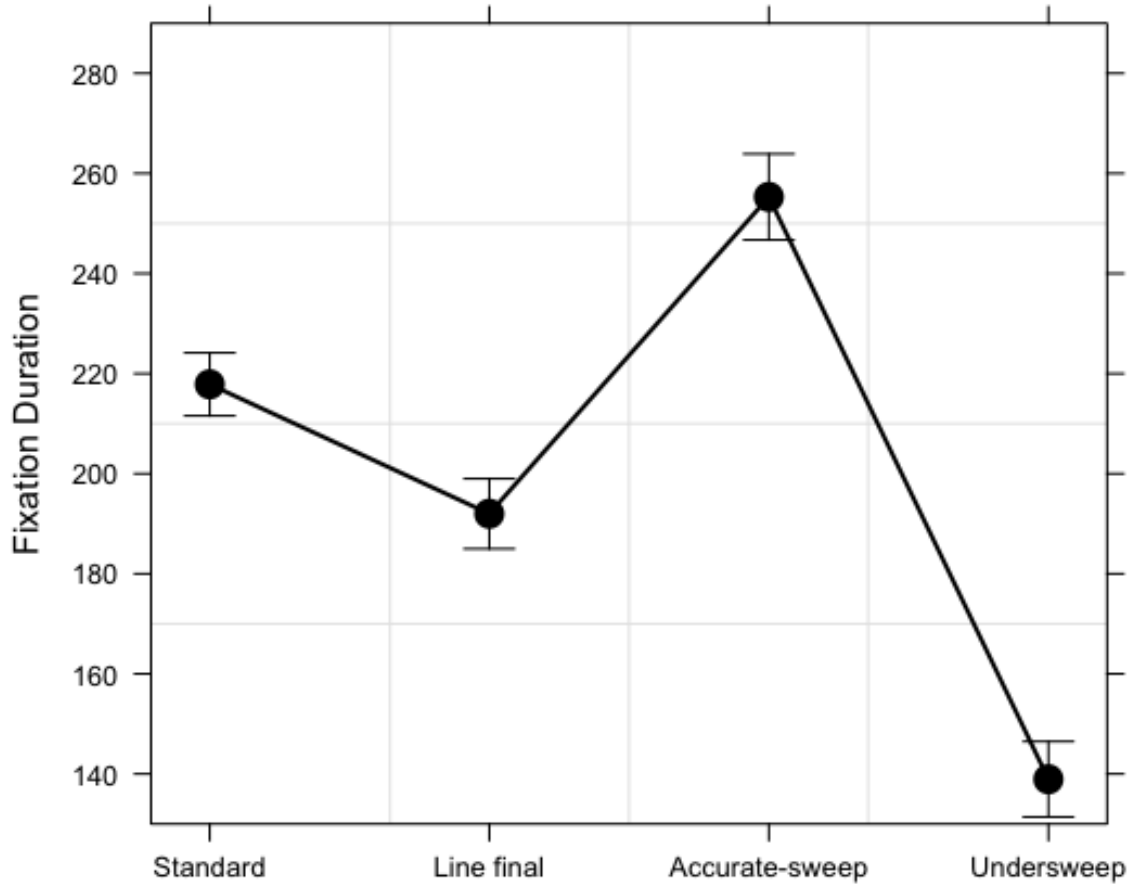
Beeline Reader



Return Sweeps and Fixations

- Four basic categories of fixations:
  - Non-return sweep fixations
  - Line final fixations
    - Shorter, assumed to be involved in return sweep planning
      - Uninfluenced by degradation (Hofmeister, 1997)
  - Line initial fixations
    - Accurate
      - Longer than standard fixations in reading (Dearborn, 1906; Heller, 1979)
    - Undersweep
      - Considerably shorter than standard fixations in reading (Heller, 1982)

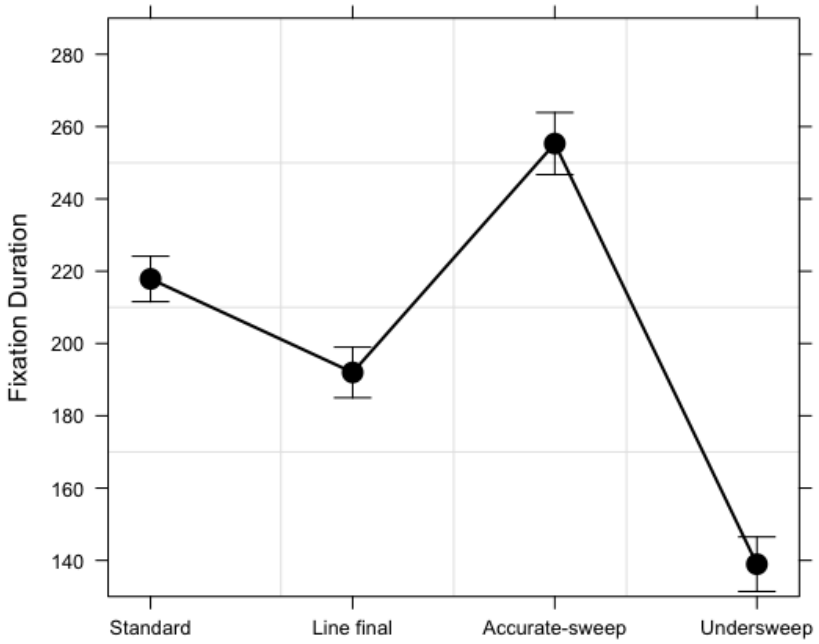
Return Sweep Fixation Durations



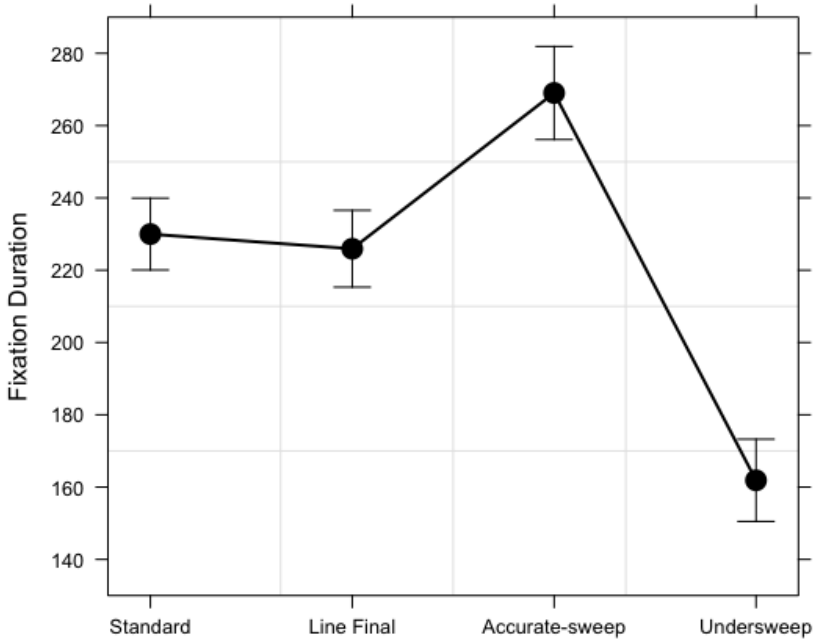
How does reading ability influence return sweep behaviour?

Adults vs. Children

A re-examination of Joseph, Bremmer, Liversedge, & Nation (2015)



Adults



Children

Future Directions

- Machine learning of scan paths
- Big Data on its way
  - Personal devices capable of tracking eye movements.
    - Hawkeye

https://youtu.be/fLktElD6QfU

Thank You For Listening

With special thanks to

Julie Kirkby

Adam Parker

Bernhard Angele

Martin Vasilev