Aalto University

ELEC-D7011 Human Factors Engineering

Day 1: Human performance

June 3, 2024
Antti Oulasvirta
Aalto University
cbl.aalto.fi

Welcome to the intensive week!

Daily schedule:

9.15 - 11.00 Introduction and in-class exercises

11.00 - 14.00 Pairwork and lunch

14.00 - 15.30 Project presentations and wrap-up

Monday June 3

Performance

Tuesday June 4

Cognition

Wednesday June 5

Error

Thursday June 6

Experiments

Friday June 7

Systems engineering

Today

Morning 9.15-11

Introduction

Pairwork topics

Pairwork + lunch 11-14

Afternoon 14-15.30

Project presentations

1. **Motivation**
2. **HFE**
3. **Perception**
4. **Motor control**
5. **Pairwork topics**

3 inclass exercises

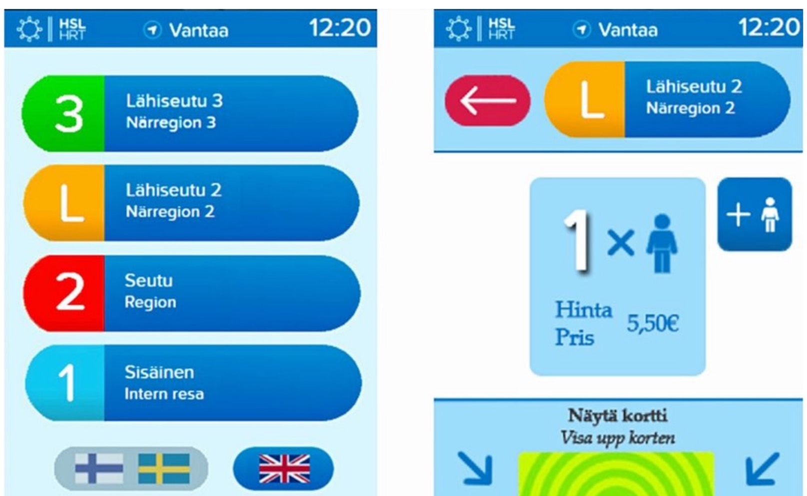
Example student project: HSL card reader redesign case

Opiskelijat: Näin HSL:n matkakortinlukijasta tulisi looginen ja nopea

18.1.2017 09:35:02 EET | Aalto-yliopisto

Jaa

Toimivamman käyttöliittymän suunnittelussa hyödynnettiin käyttäjien ideoita ja matemaattista mallinnusta.



Our focus today:
1. Minimize expected selection time
2. Optimize visual flow
3. Minimize task completion time

Preparations

1. Let's form pairs

2. Open the answer document

https://shorturl.at/QjXyG

1. Motivation
2. HFE
3. Perception
4. Motor control
5. Pairwork topics

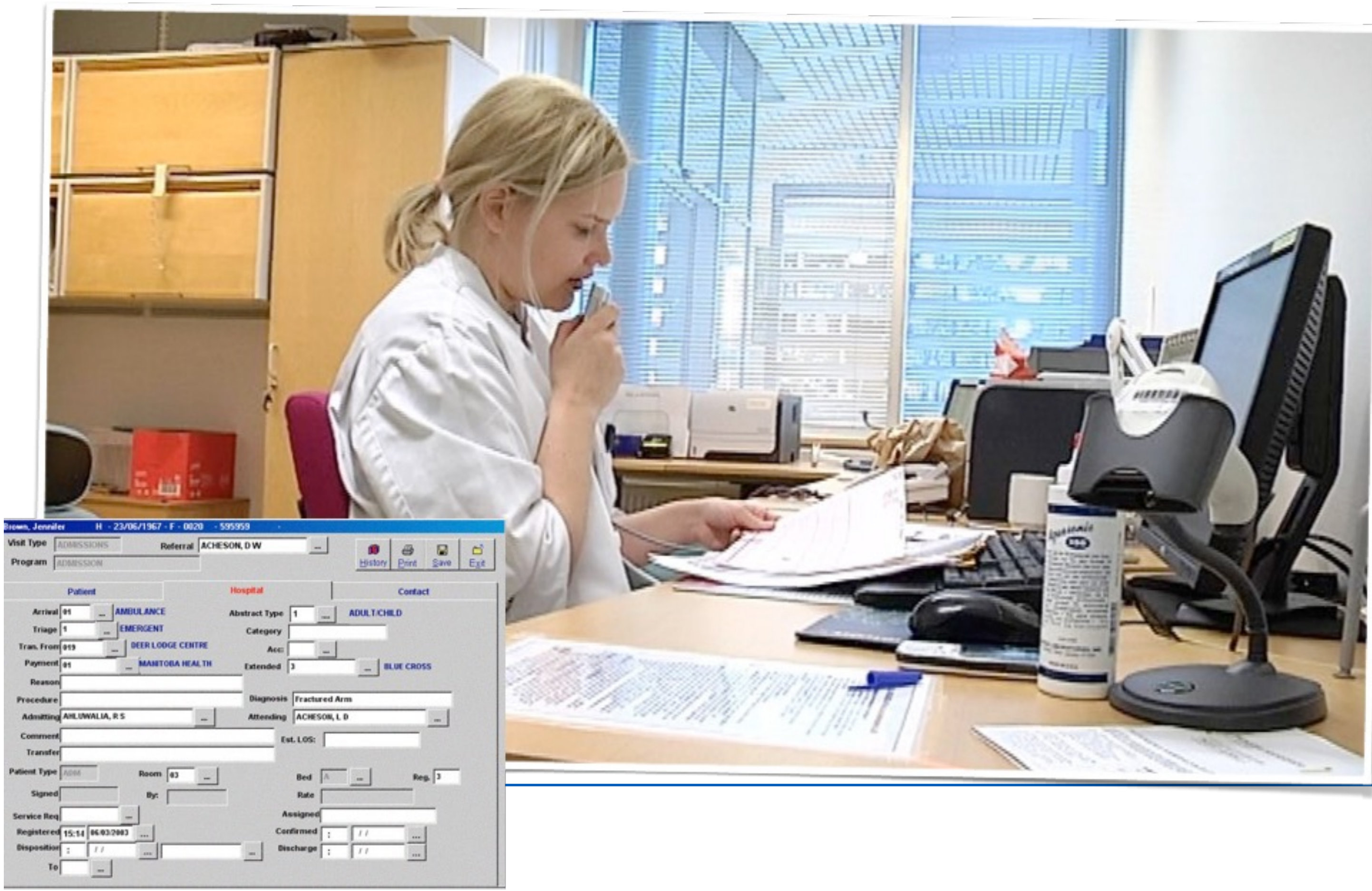
Motivation

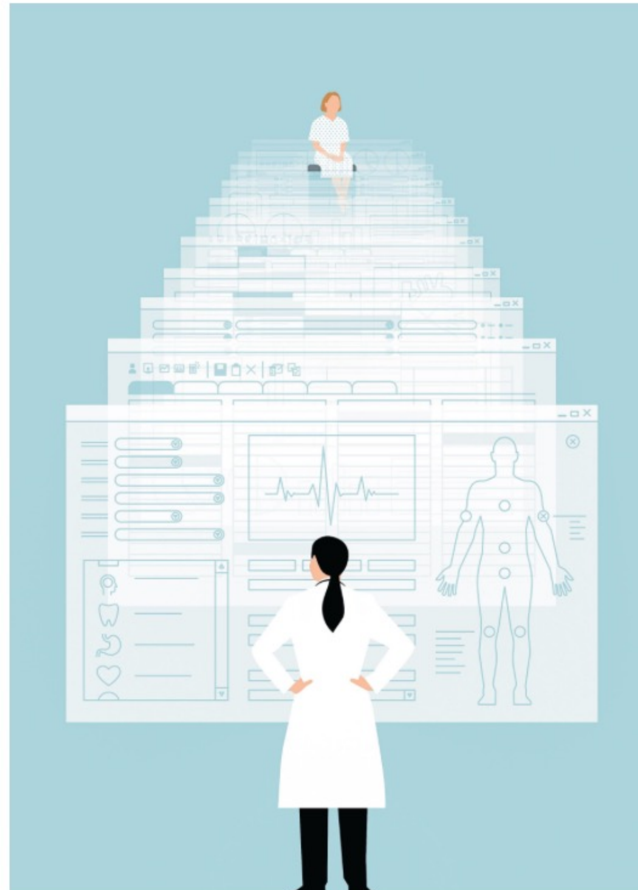
Why study human factors?

Understanding users is a top 3 reason for failure/success of IT projects

Also: 10-30% of R&D budgets goes to user interfaces

Design of technology affects well-being





ANNALS OF MEDICINE NOVEMBER 12, 2018 ISSUE

WHY DOCTORS HATE THEIR COMPUTERS

Digitization promises to make medical care easier and more efficient. But are screens coming between doctors and patients?

By Atul Gawande

November 5, 2018

Humans are beyond intuition

Can you read this?

Aoccdrnig to rscheearch at Cmabrigde Uinervtisy, it deosn't mttaer in waht oredr the ltteers in a wrod are, the olny iprmoetnt tihng is taht the frist and lsat ltteer be at the rghit pclae. The rset can be a total 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.

And you will read this last

You will read this first

And then you will read this

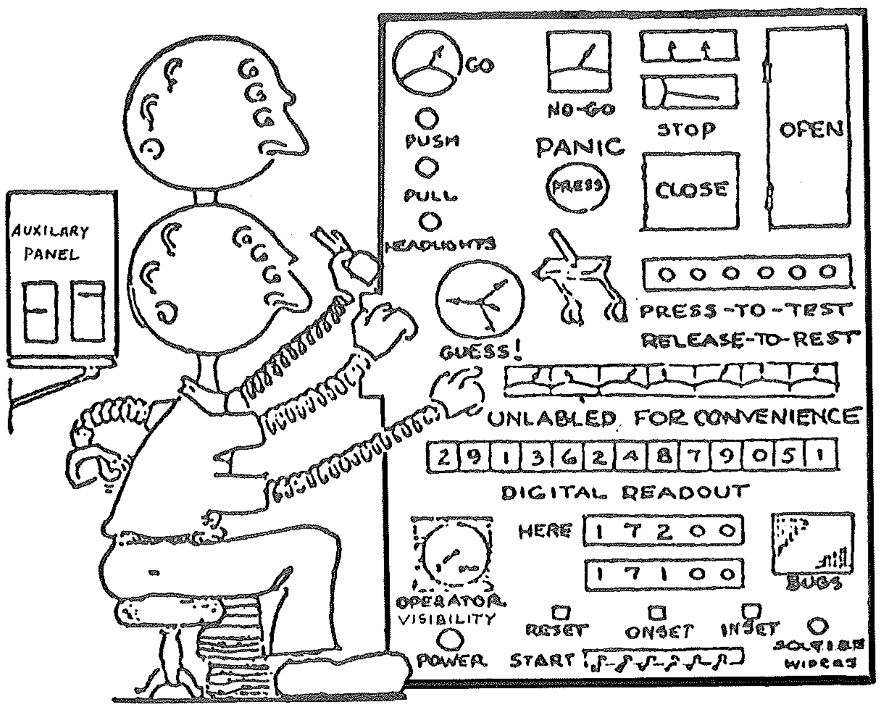
Then this one

Find the Calendar icon:

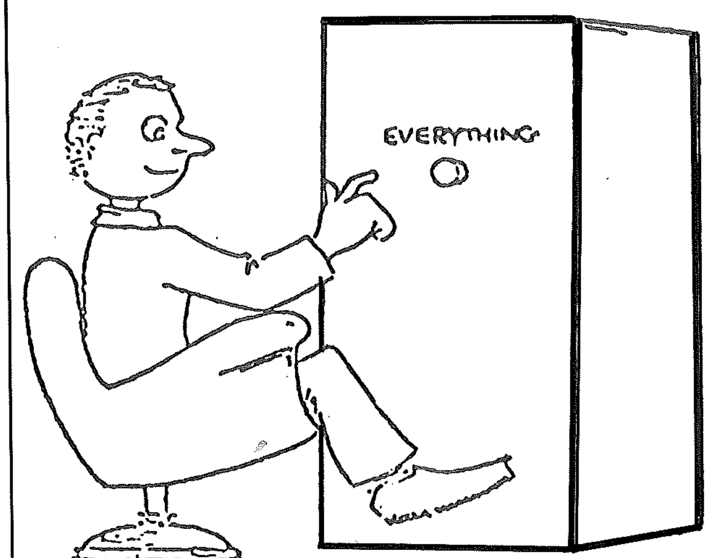
+

People are different

Good design reduces complexity



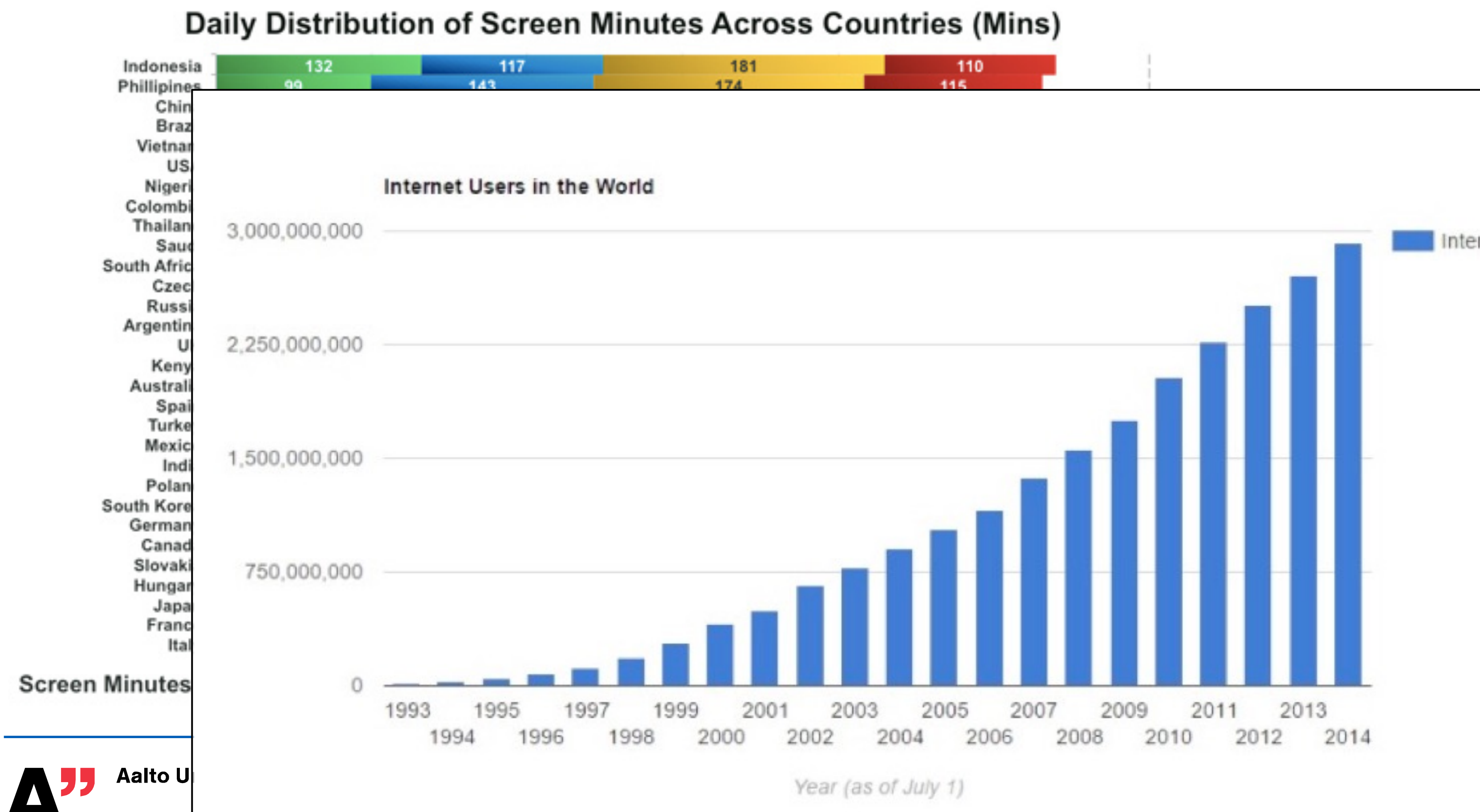
TYPICAL SOLUTIONS (1)



TYPICAL SOLUTION (2)

Poor design is a cause of death

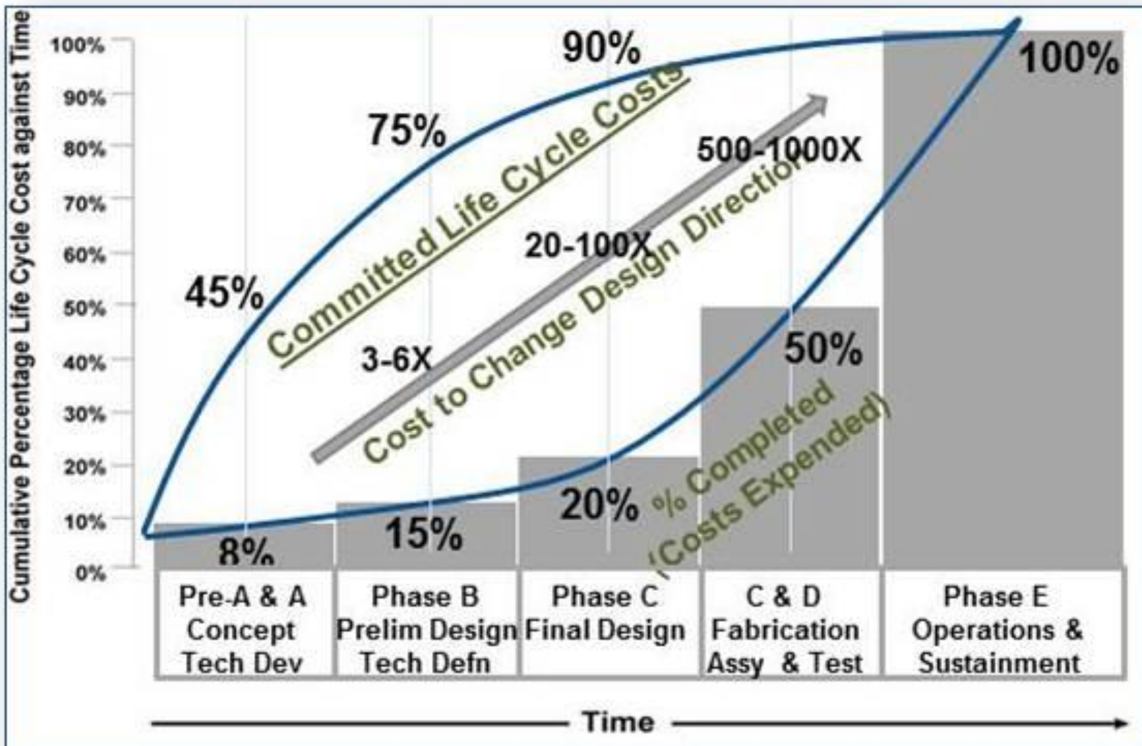
Design impacts a large number of people



Legal responsibility

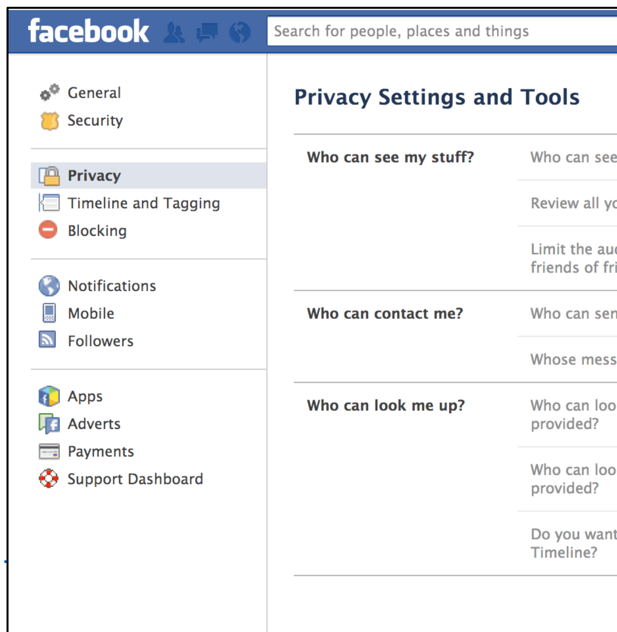
Reduce development costs

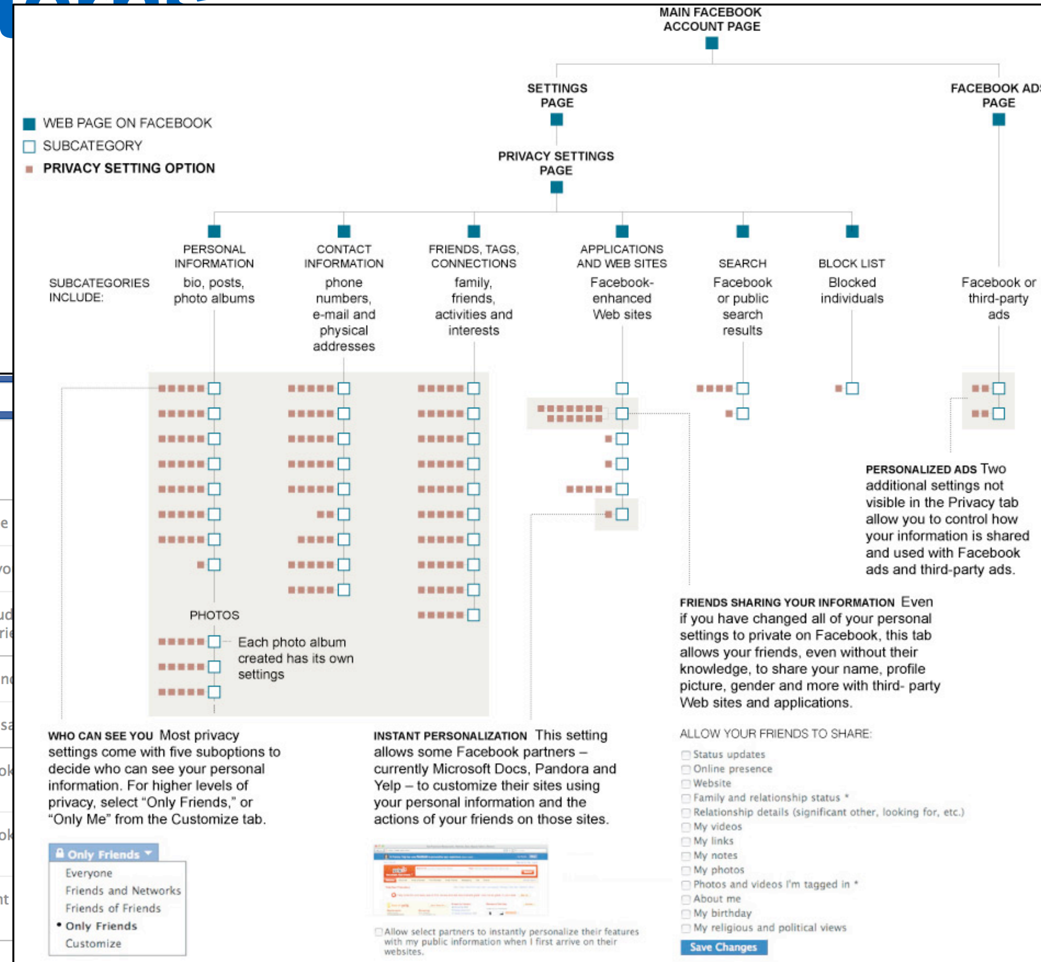
The later you account for human factors, the more it costs



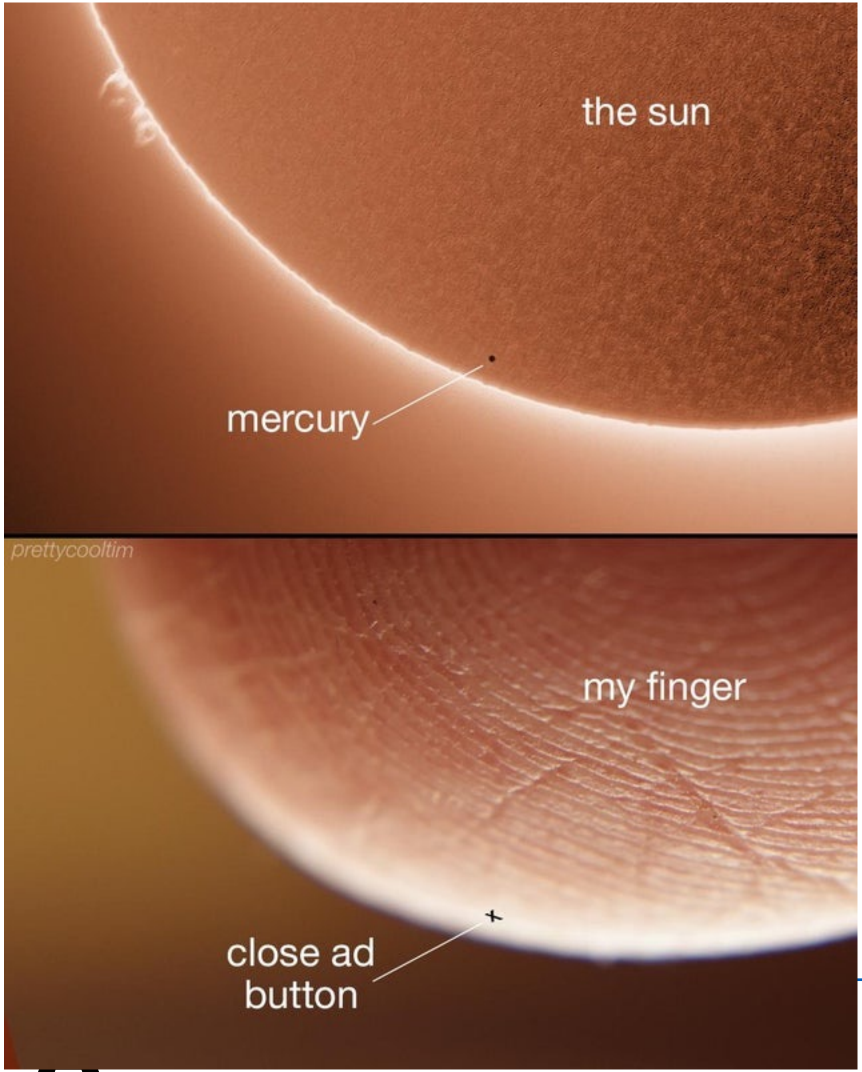
“Locked in costs”

Fight dark patterns



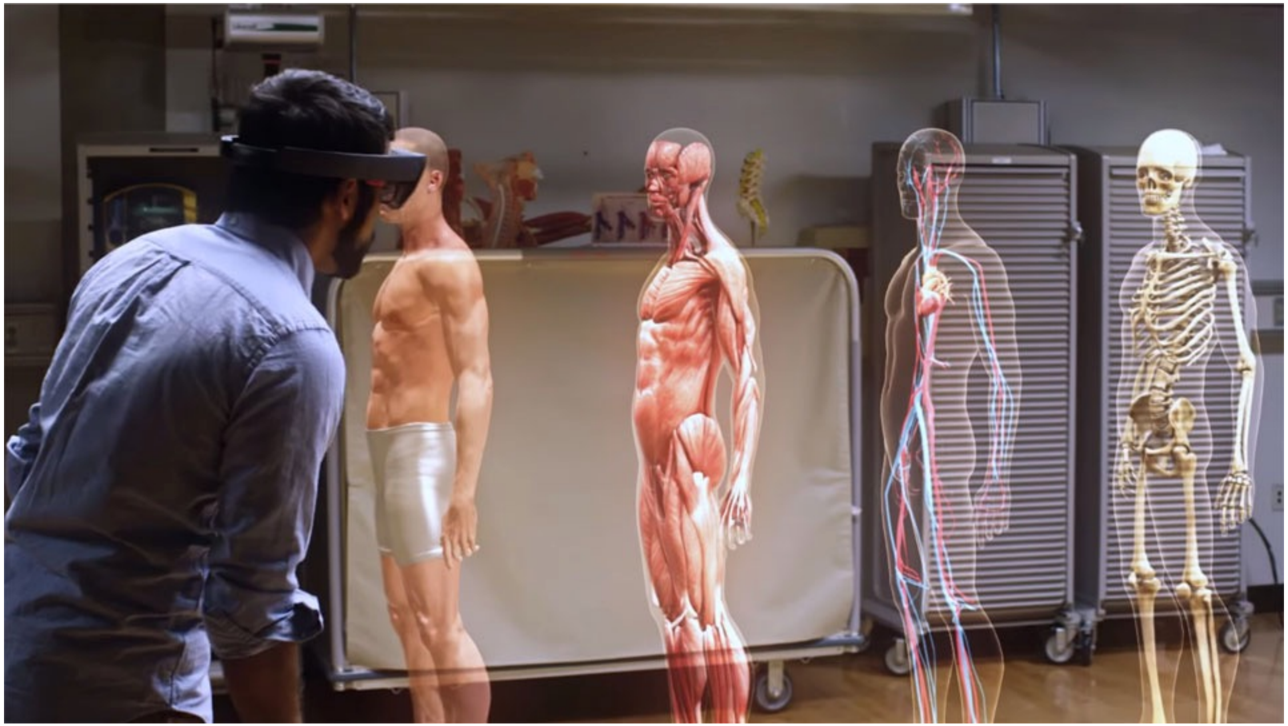


Dark patterns 2: advertisements



Innovate new experiences

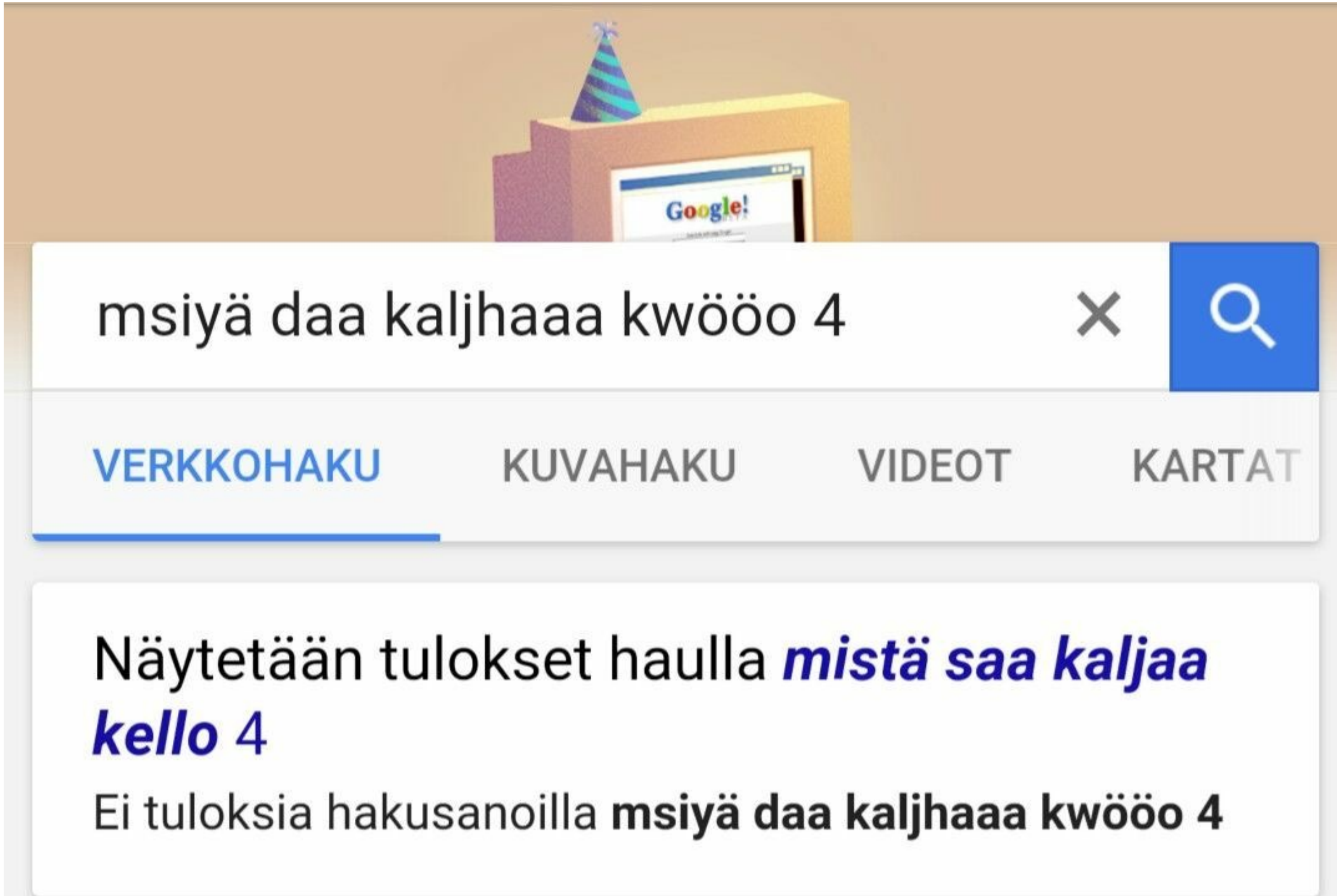
Envision new work practices



Compete with usability

Optimize user performance

Recover from human errors



Understand emergent phenomena

Case in point: Zoom fatigue

Summary: Why study human factors?

1. Increase efficiency, enjoyability, and robustness of technology
2. Avoid catastrophies and loss of life
3. Offer proofs and guarantees for design
4. Improve the hit rate of products with user-centered design
5. Reduce development time of ICT
6. Harness new technological innovations quicker

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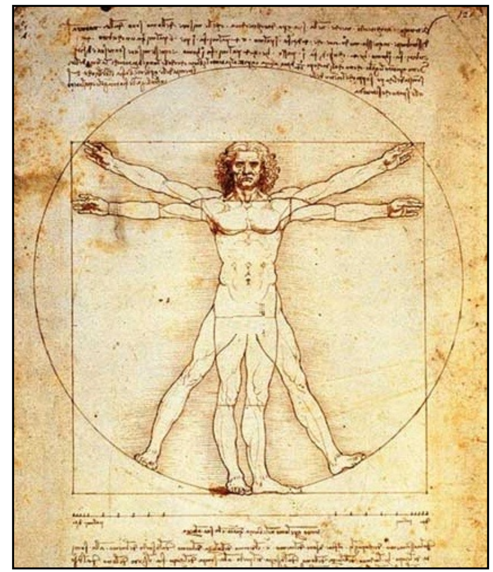
Human factors engineering

Human-centricity:
Human is the criterion for decisions

Human factors starts from human needs, limitations, and capabilities

- Perception
- Attention
- Motor control
- Reasoning
- Sensory capabilities
- Working memory
- Long-term memory and learning
- Biomechanics and anthropometrics
- Needs, motivations
- ...



Formulate measurable objectives related to people

Some human-related objectives for engineering

Improve effectiveness

Improve efficiency

Improve safety

Improve satisfaction

Improve experience

Decrease errors

Reduce fatigue

Reduce the learning curve

Ensure operability and usability

Meet user's needs and wants

Positive perception of product

Key design goals

Fit

- Does the product meet the users needs and expectations? Are the right features included, do they—and can they—use those features?

Errors

- Objective measure provided by the overall task error rate and the frequency and severity of the error. How many users make mistakes and are they able to recover?

Efficiency

- Objective measure yielded by time on task. How long does it take the user to complete the task? Often correlated with satisfaction.

Satisfaction

- Satisfaction measures are subjective measures provided by the user.

Learnability

- How easy the system is to learn. Can be expressed by a learning curve and typically is associated with error and efficiency rates over time to show trending

Engineering: Beyond luck and intuition

Understanding: Identify factors behind human performance, error, behavior and experience

Analysis: Quantify and compare properties of systems

Optimize: Use models and simulations to find best possible designs

Quality guarantees: Offer guarantees for solutions, implement them in standards and methods

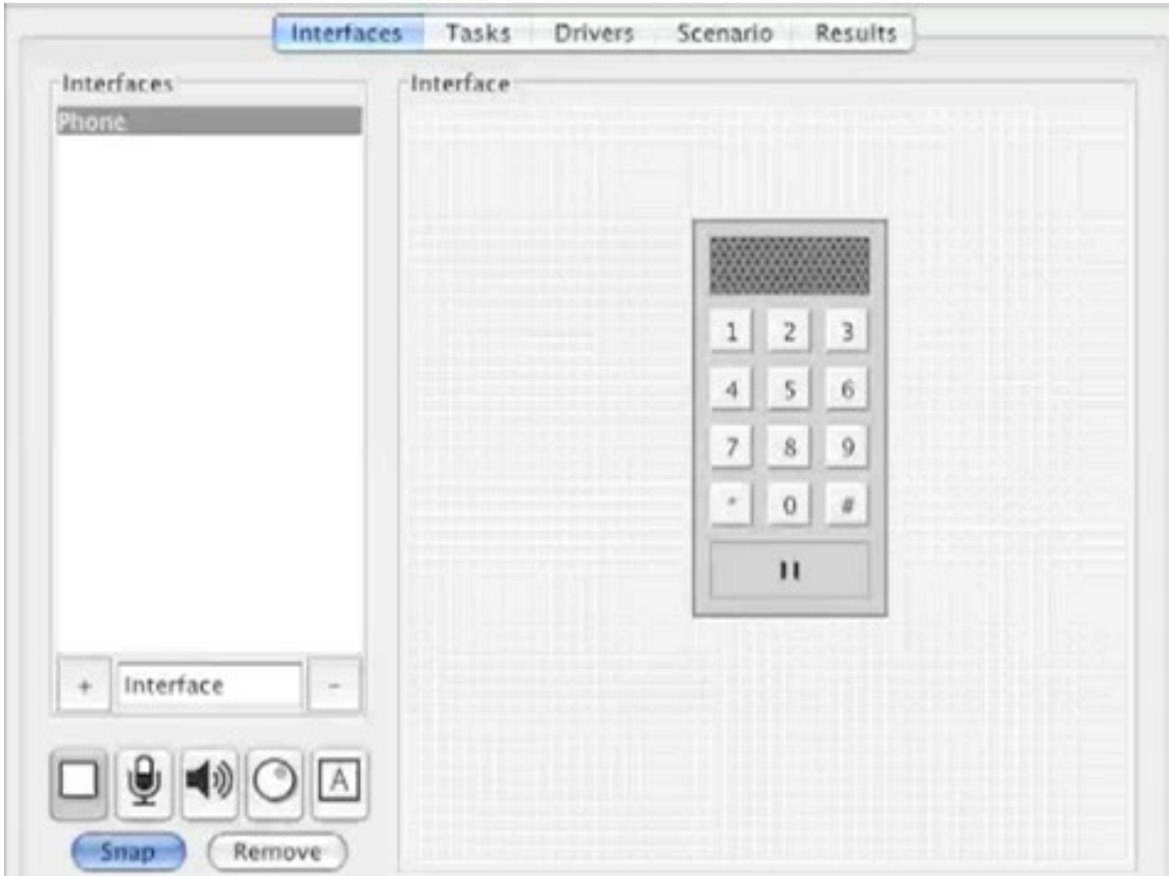
Insight: Facilitate idea-generation

A multi-disciplinary field

Human factors engineering (HFE)

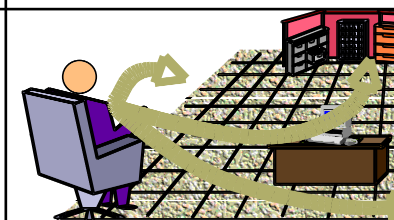
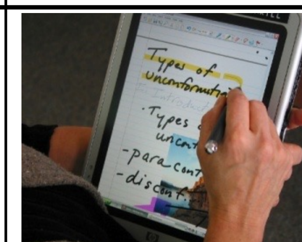
- **Integrates** human considerations within the system development process
- **A comprehensive**, multidisciplinary, technical and management process
- **Ensures** that the human contribution toward system performance is consistently addressed throughout the system life cycle

Models and simulations example: Distract-r



Dario Salvucci

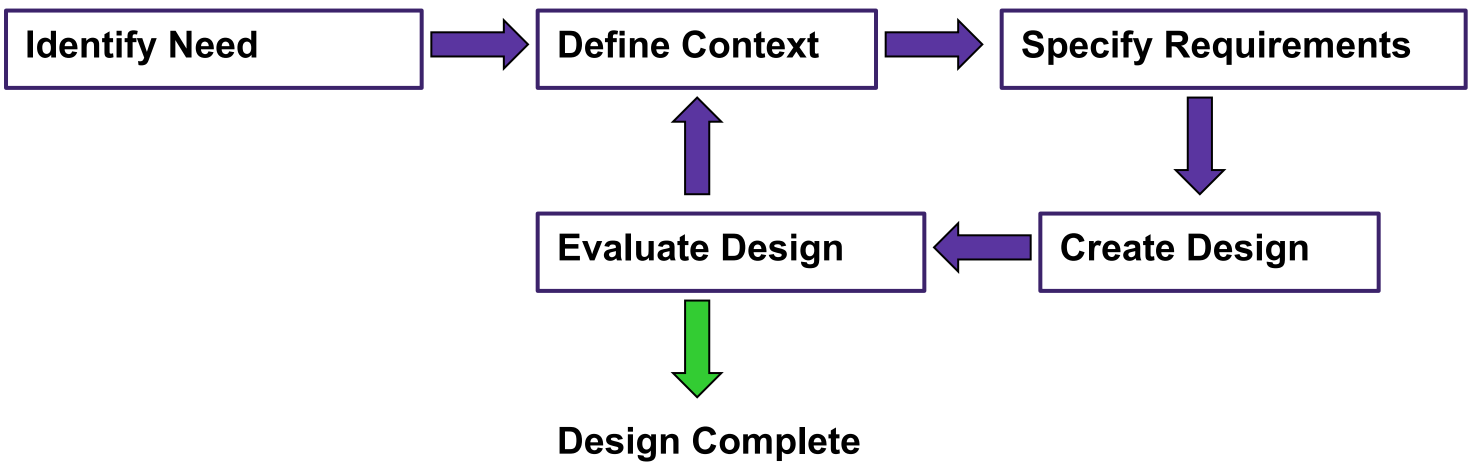
Multiple levels of analysis

10^7 (months) 10^6 (weeks) 10^5 (days)	SOCIAL	Social Behavior	
10^4 (hours) 10^3 10^2 (mins)	RATIONAL	Adaptive Behavior	
10^1 10^0 (sec) 10^{-1}	COGNITIVE	Overt Behavior	
10^{-2} 10^{-3} (msec) 10^{-4}	BIOLOGICAL	Physiological events	

A human-centred design process

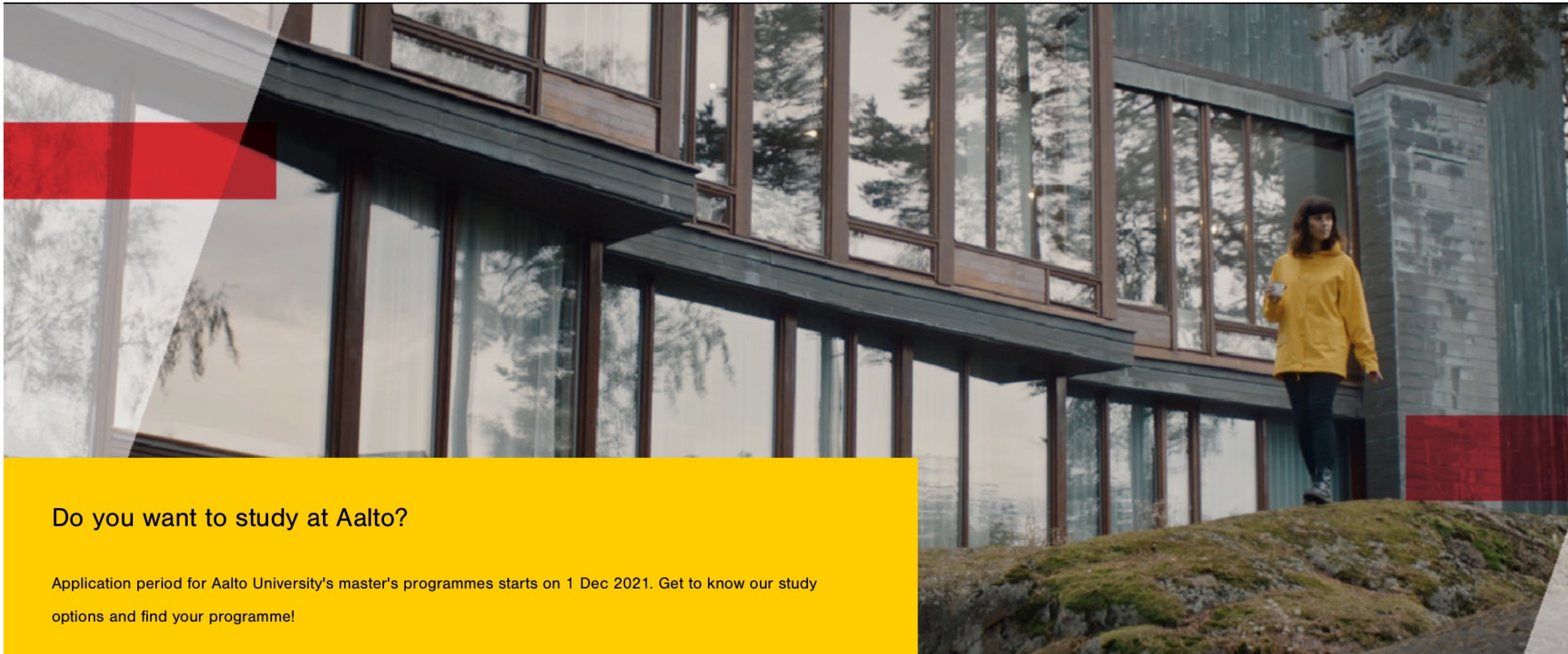
There are 5 fundamental steps to the process:

- **Identify need** for new technology based on user research
- **Define** the context of use: what are the tasks or objectives associated with the design.
- **Specify** requirements: what expectations or requirements must the design accommodate
- **Create** design solutions: prototyping, rendering, mockup building
- **Evaluate** designs: modeling, usability testing, and ergonomic assessment



NASA's Human Factors Process

Perception



Do you want to study at Aalto?

Application period for Aalto University's master's programmes starts on 1 Dec 2021. Get to know our study options and find your programme!

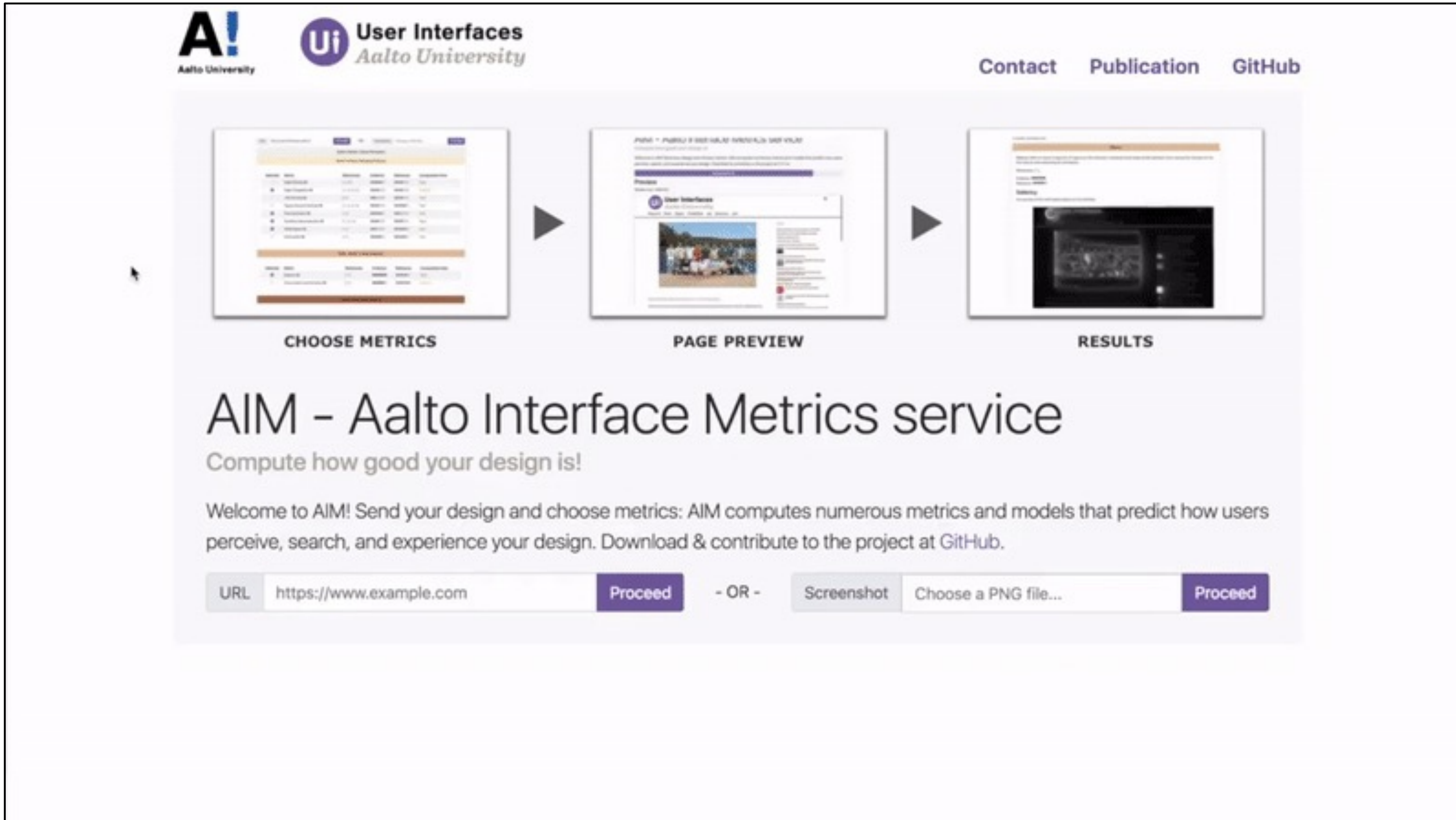
→ All study programmes

Spotlight

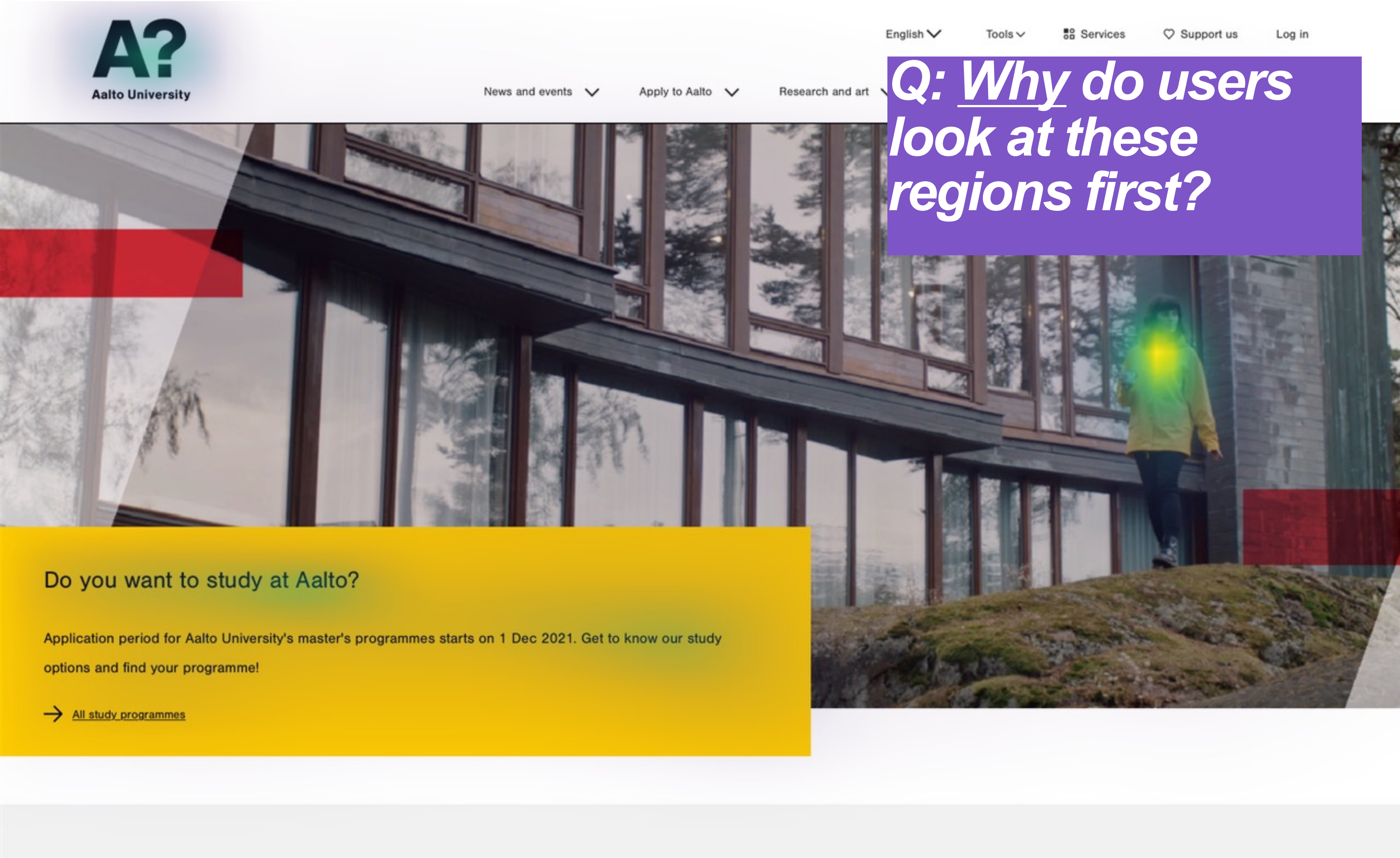
See all news

What did you look at?

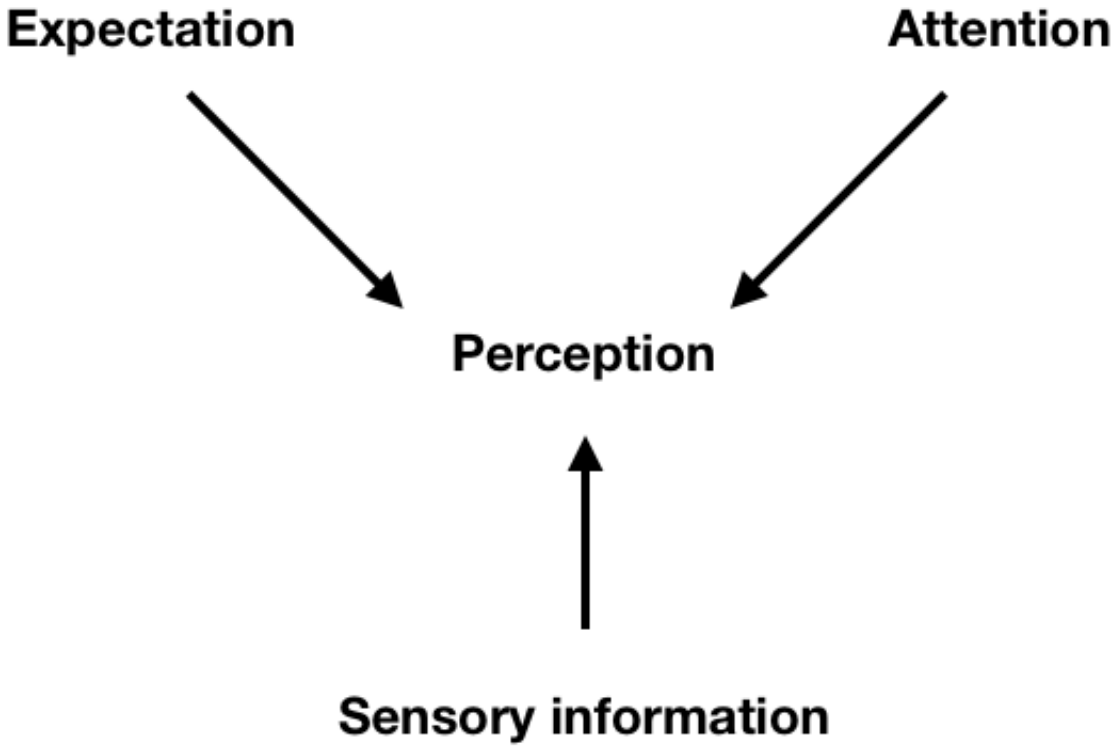
interfacemetrics.aalto.fi



Q: Why do users look at these regions first?



Visual perception



Learning objectives in this block

1. HVS: Basics

- “7 windows of visibility”
- Selective attention

2. Visual saliency

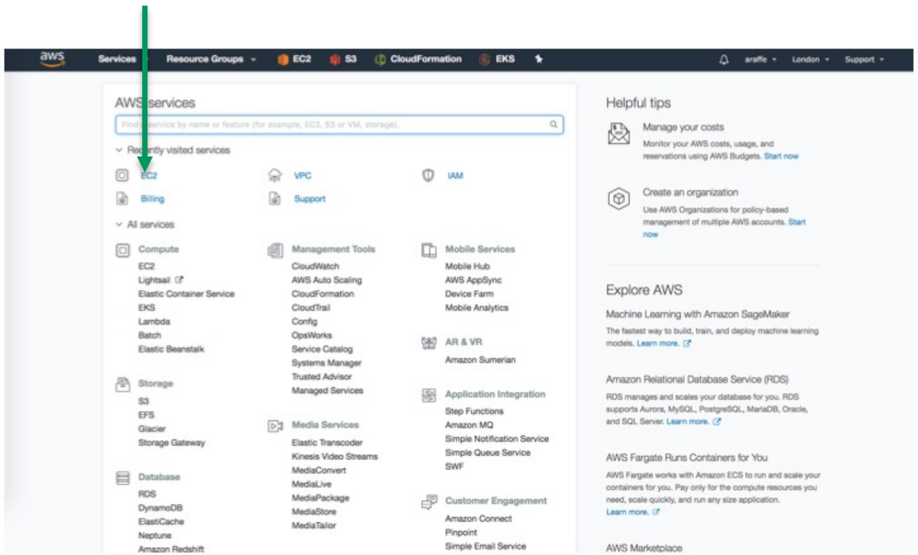
- Simulation models
- Deep learning models
- Perceptual clutter

Slides

External Web service

Assignment: Saliency optimization

Example from last year



Original

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Human visual system: Basics

Vision is one of human sensory modalities

A sensory modality transduces physical stimulation into electrochemical reactions in neurons for processing in the brain

Vision (seeing) ← This lecture

Audition (hearing)

Tactition (touching)

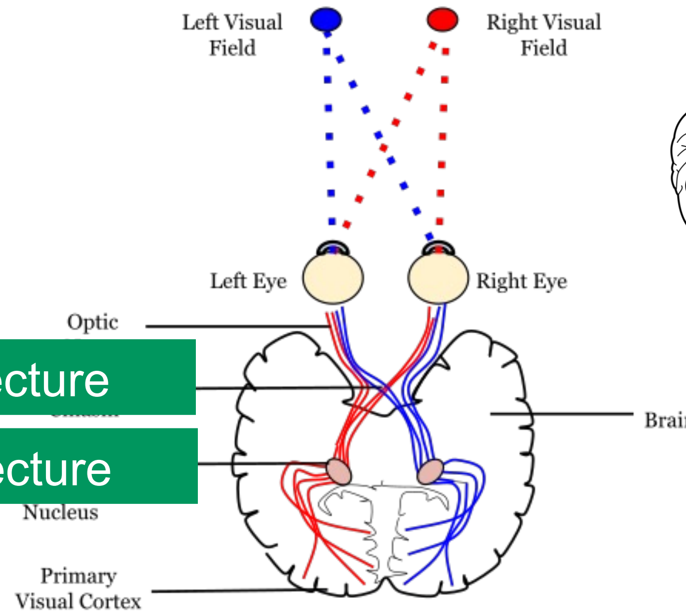
Olfaction (smelling)

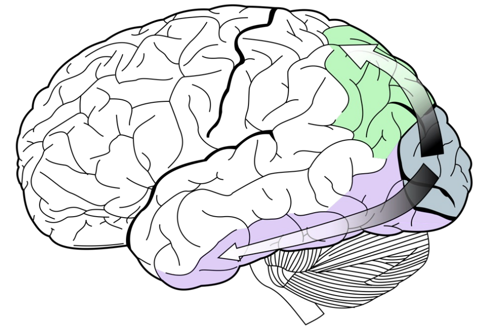
Gustation (tasting)

Proprioception (limb position)

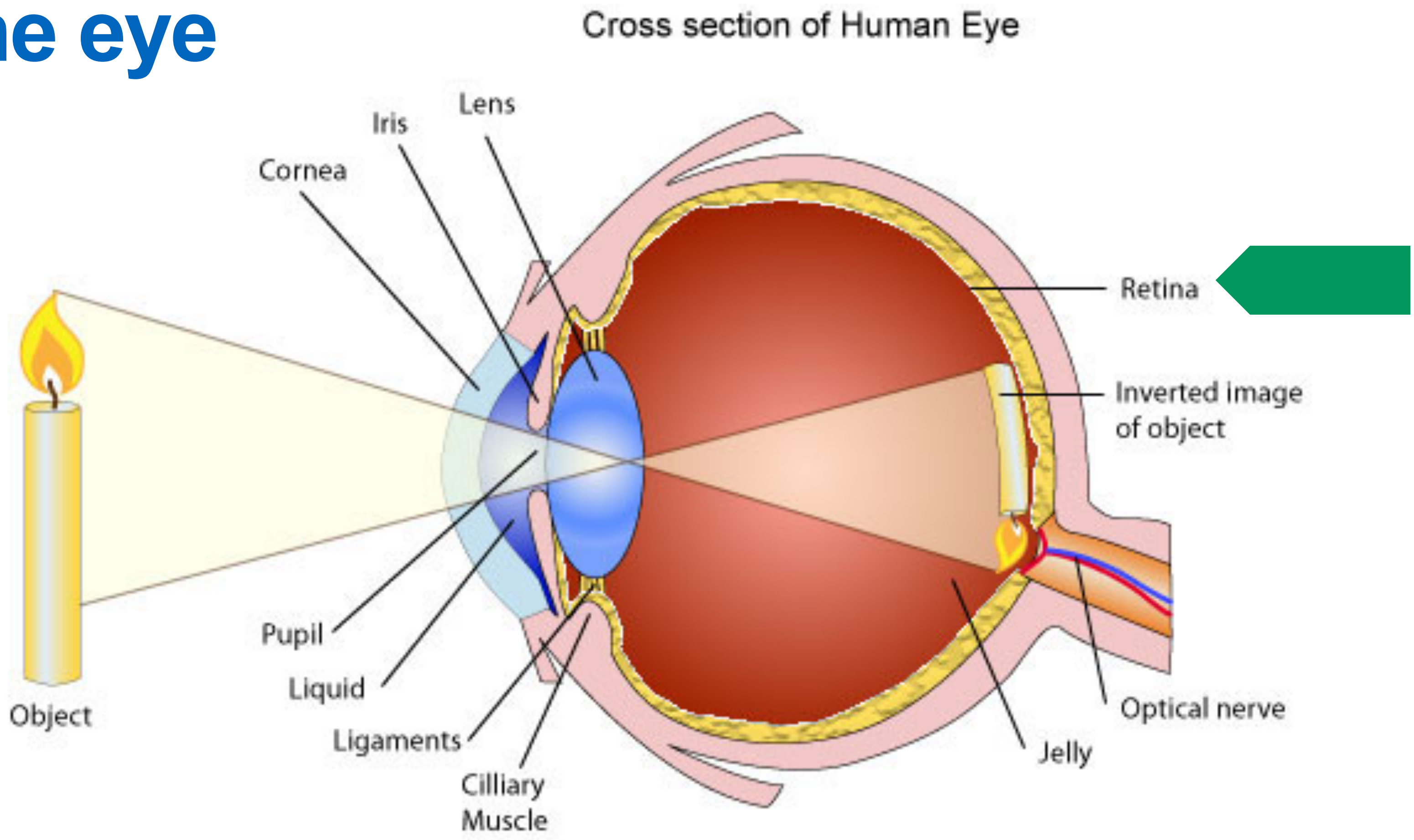
Scientific perspectives to HVS

- **Anatomical view**
- **Physiological view**
- **Developmental view**
- **Neuroscientific view**
- **Cognitive view** — This lecture
- **Behavioral view** — This lecture





The eye

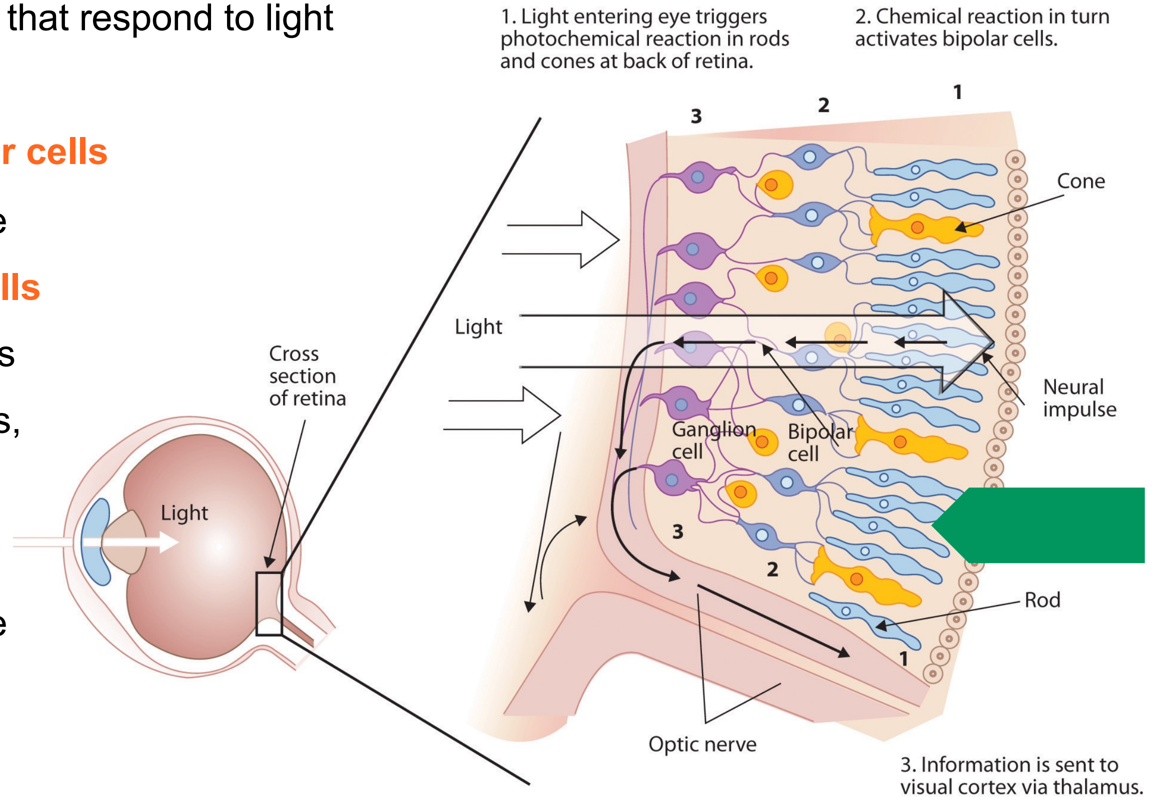


Cross section of Human Eye
Lens
Iris
Cornea
Retina
Inverted image
of object
Object
Pupil
Liquid
Ligaments
Cilliary
Muscle
Jelly
Optical nerve

The retina

The retina is made up of layers of neurons that respond to light

Light falling on retina activates **(1) receptor cells** (i.e., rods and cones) which in turn activate **(2) bipolar cells** and then **(3) ganglion cells** through cascading photochemical reactions that transform the light into neural impulses, which carry visual information via the optic nerve to the visual processing areas in the visual cortex at the back of the brain where meaningful images are composed



optic nerve = a collection of ganglion cells

ganglion = a cluster of nerve cells (also known as *neuron*) existing outside the central nervous system

ganglion cell = a cell (or neuron) in a ganglion

http://2012books.lardbucket.org/books/beginning-psychology/s08-02-seeing.html

Receptor cells

Rods and cones are visual neurons

RODS: detect black/white/grey colours but not much detail

function best in dim light

located around the edges of the retina

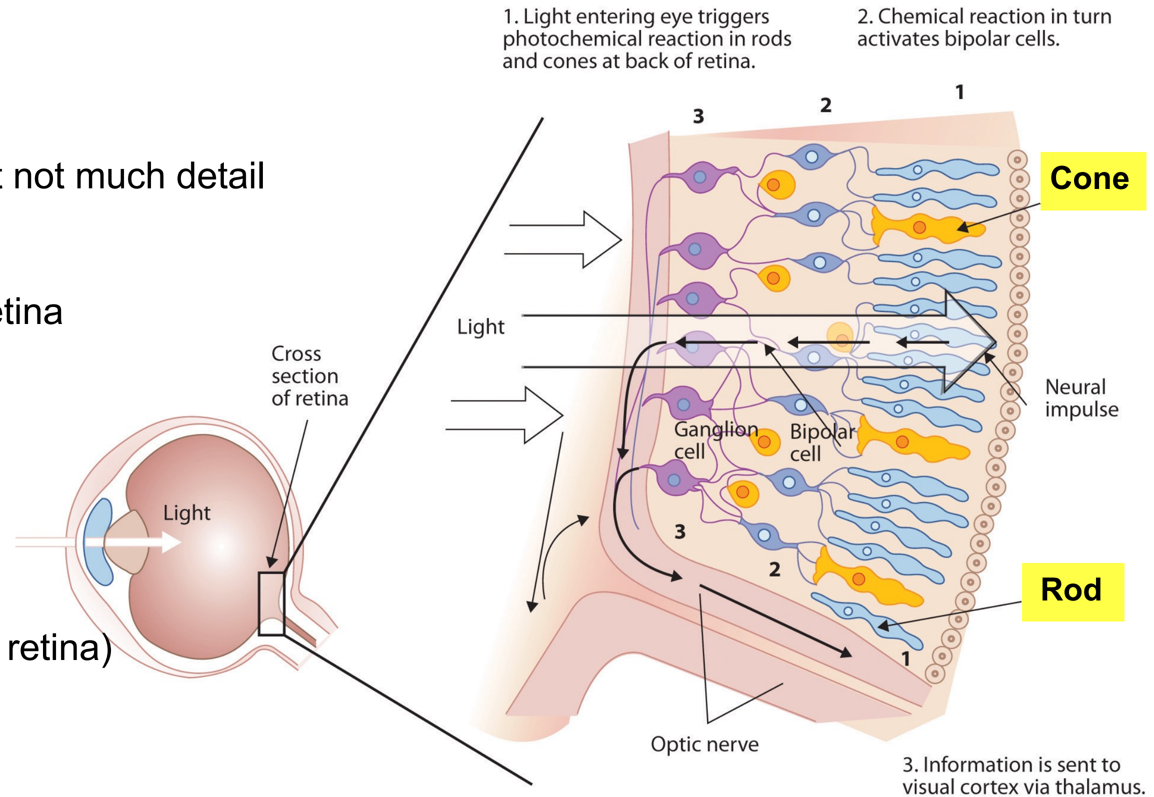
~120 million in each eye

CONES:detect fine detail and colours

function best in bright light

densely packed in fovea (centre of retina)

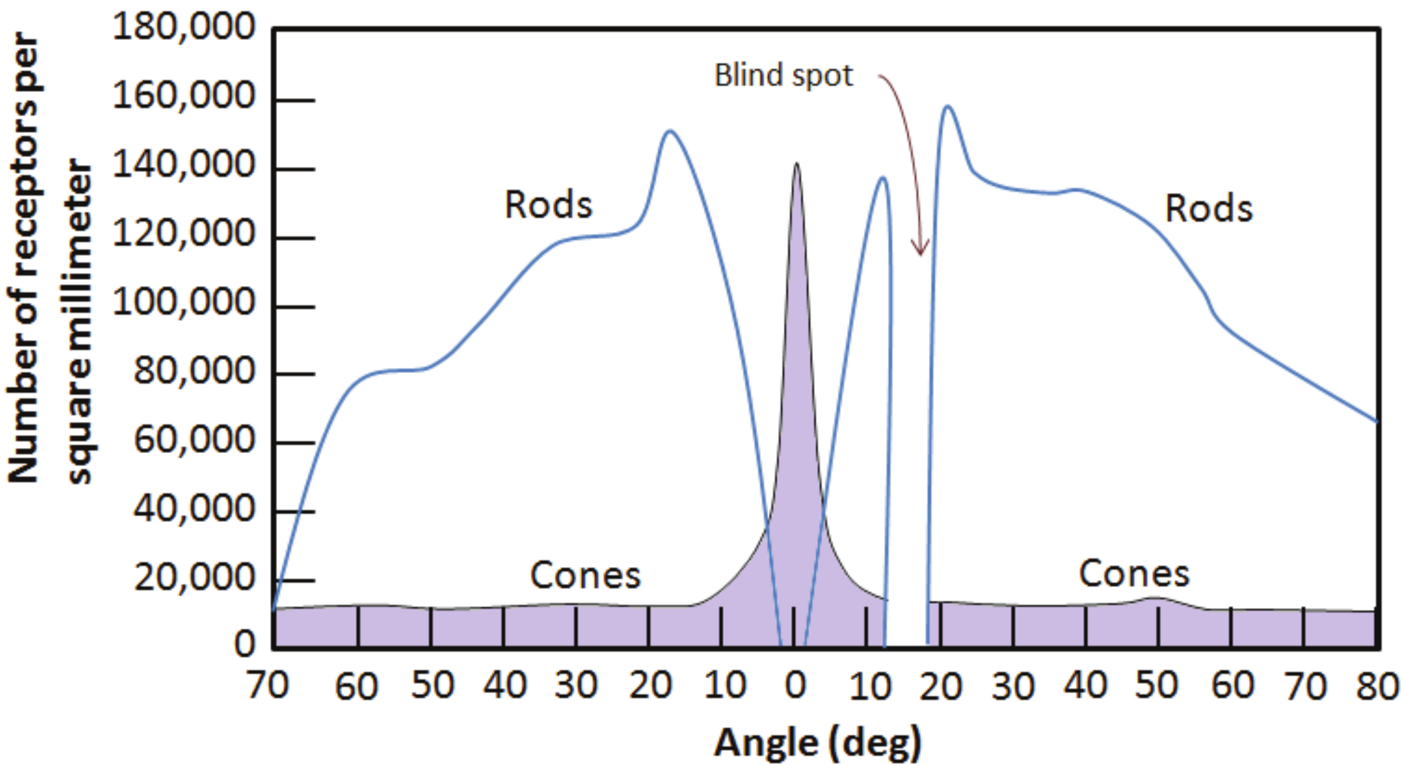
~5 million in each eye



Example: When focusing on 1 word in the text, neighbouring words seem blurred as the word in focus is mapped onto the cones, while others are mapped onto the rods which detect much less detail than the cones *(remember that acuity is maximum at fovea)*

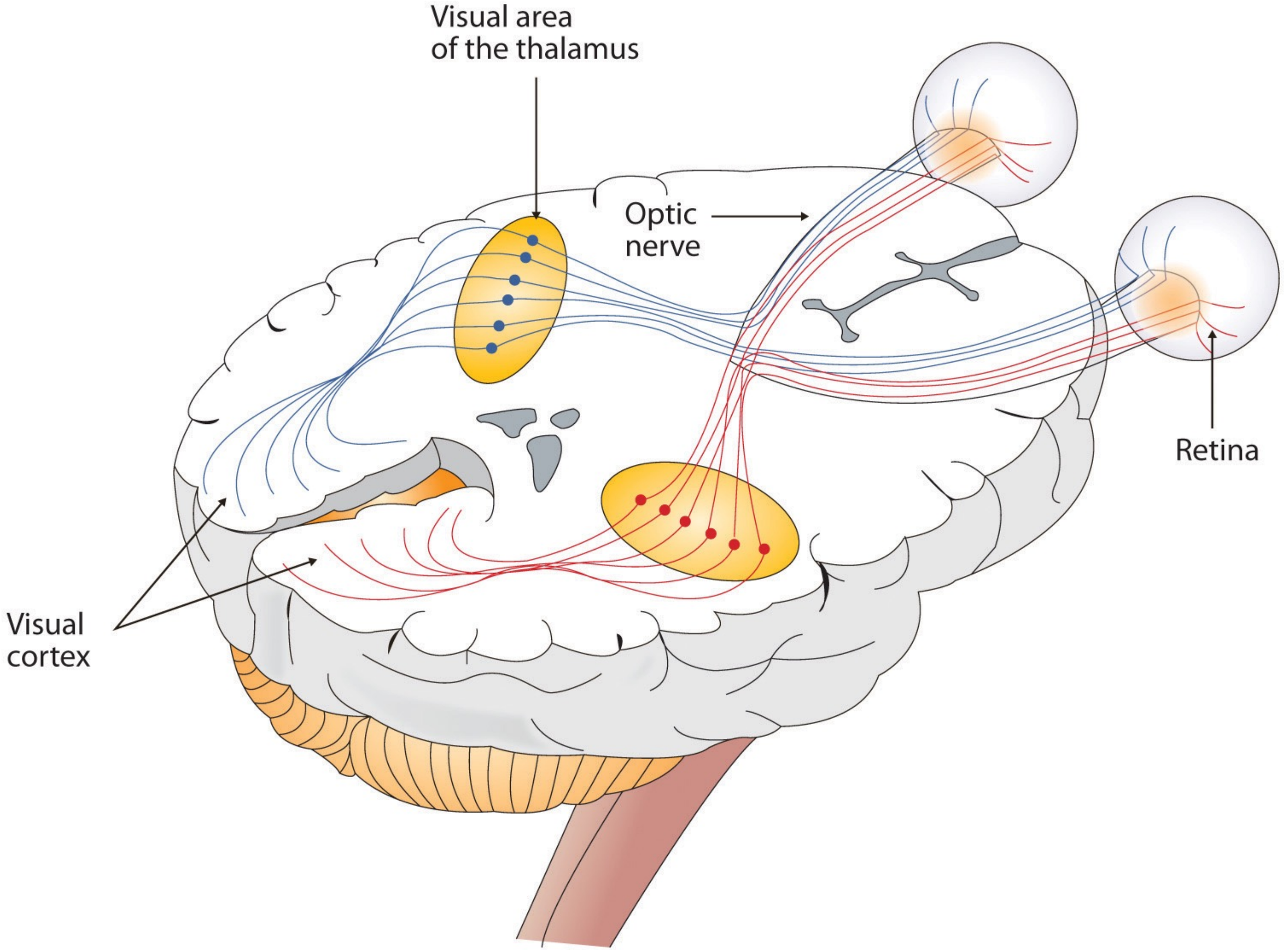
http://2012books.lardbucket.org/books/beginning-psychology/s08-02-seeing.html

Distribution of receptors on retina



Lin et al. (2012) *SNR analysis of high-frequency steady-state visual evoked potentials from the foveal and extrafoveal regions of Human Retina*

From the retina to the brain



Later...

http://2012books.lardbucket.org/books/beginning-psychology/s08-02-seeing.html

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“Windows of visibility”

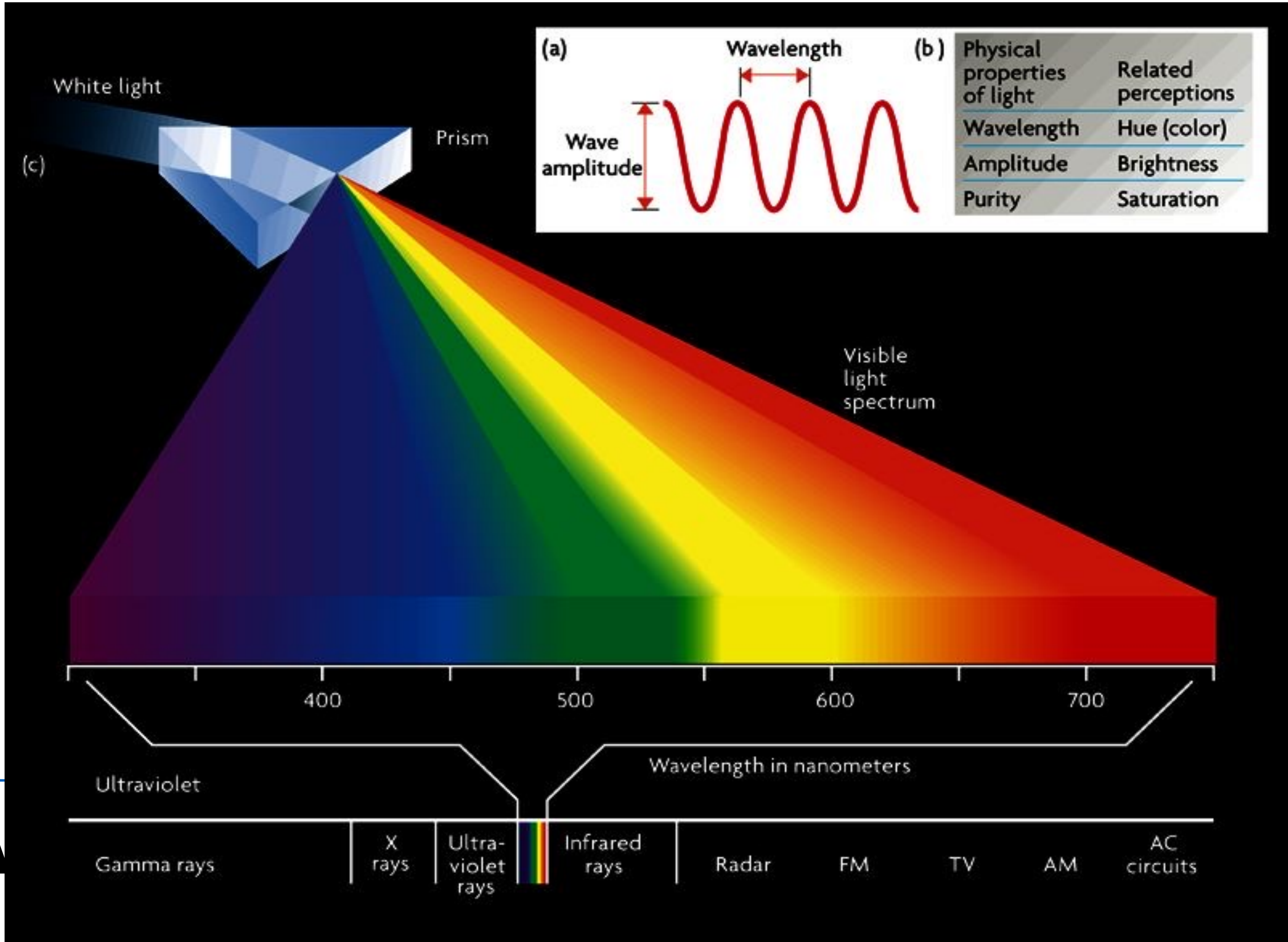
By Colin Ware 2012

Windows of visibility

Important limits to HVS

1. Wavelength
2. Field of view
3. Trichromaticity
4. Luminance
5. Spatial frequency
6. Local contrast
7. Fixation

1. Visible wavelengths



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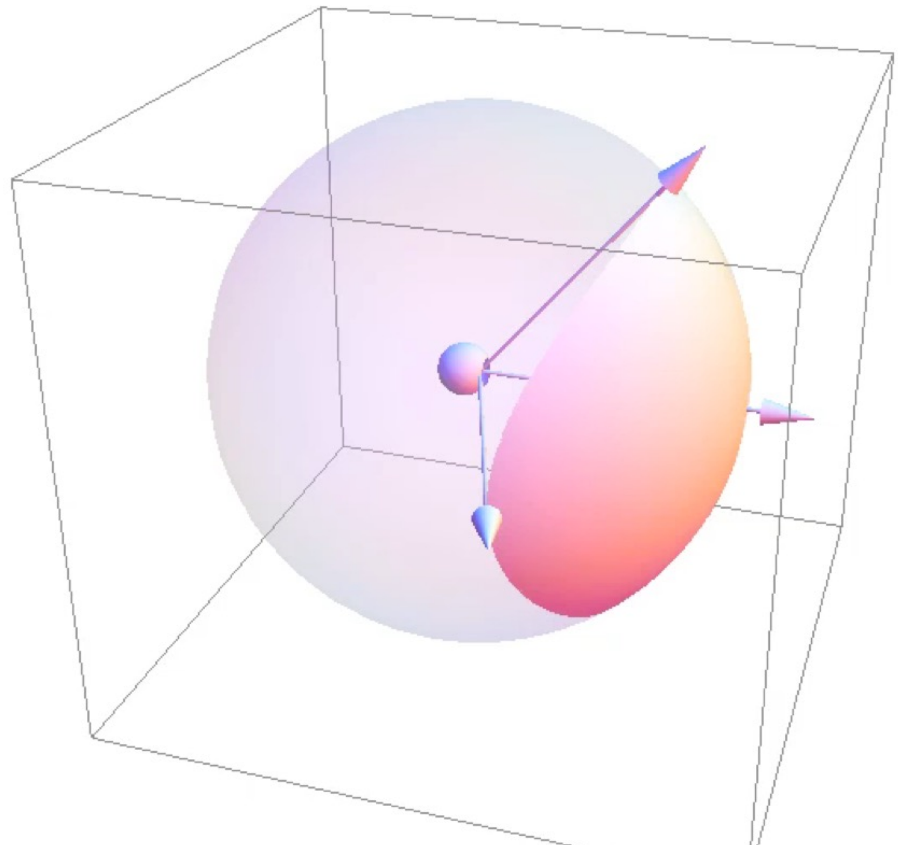
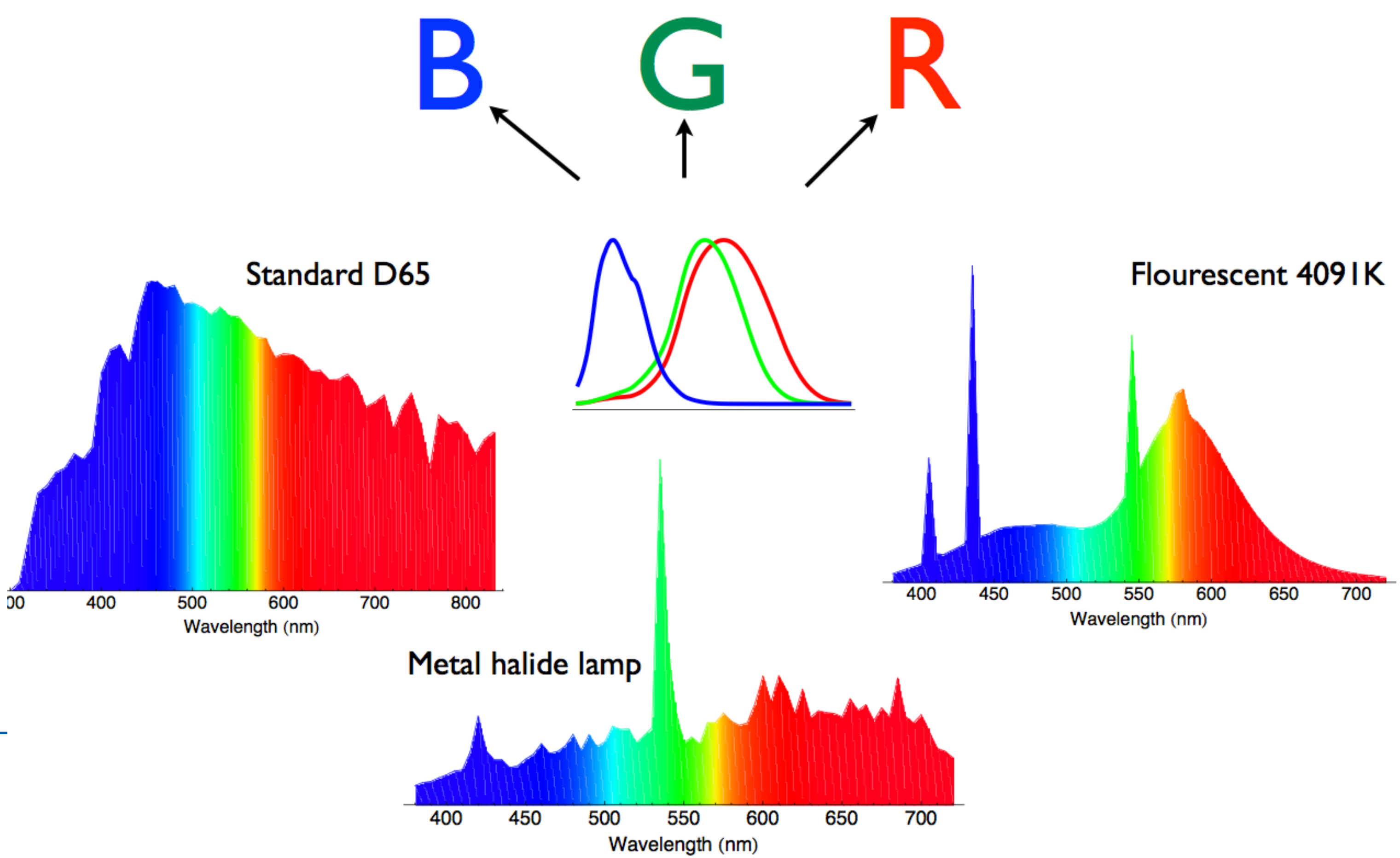
2. Field-of-view window



Almost 180 degree horizontal vision
Color vision narrower than vision for shape and motion

3. Trichromaticity window



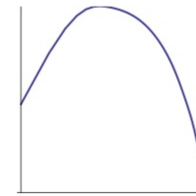
4. Intensity window

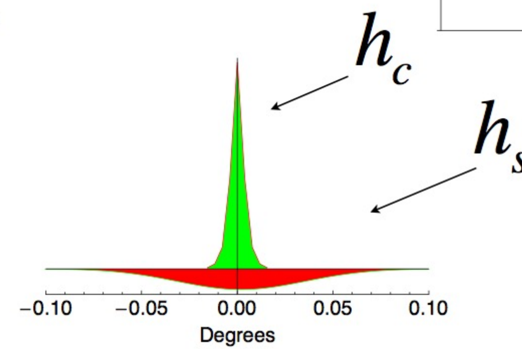
candela (cd) is a unit of luminous flux per unit solid angle

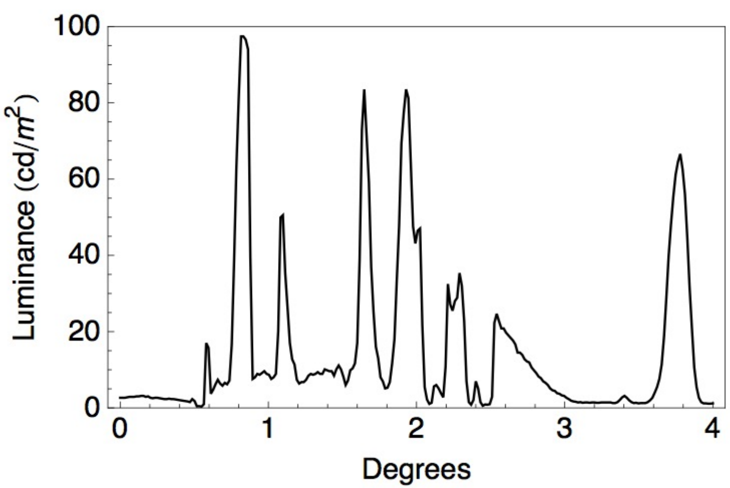
5. Local contrast window

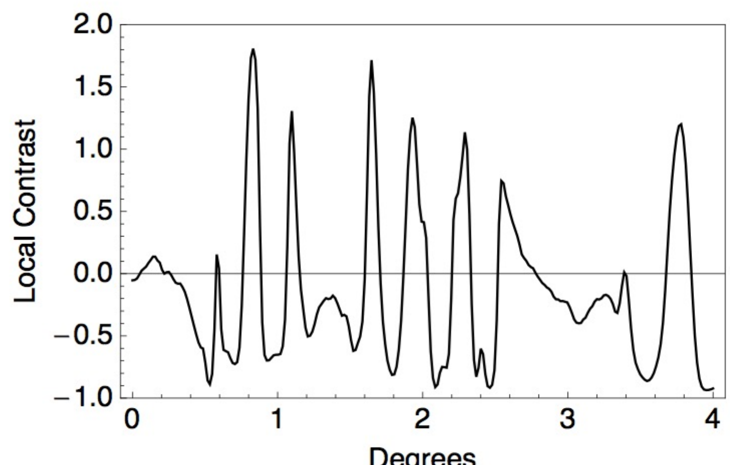
$$c = \frac{h_c * r - h_s * r}{h_s * r}$$

$$= \frac{h_c * r}{h_s * r} - 1$$



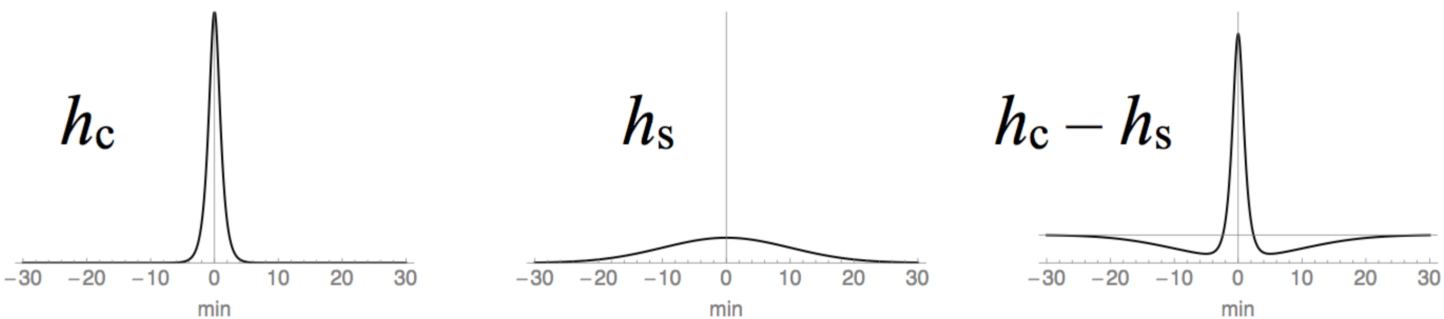






Local contrast computation

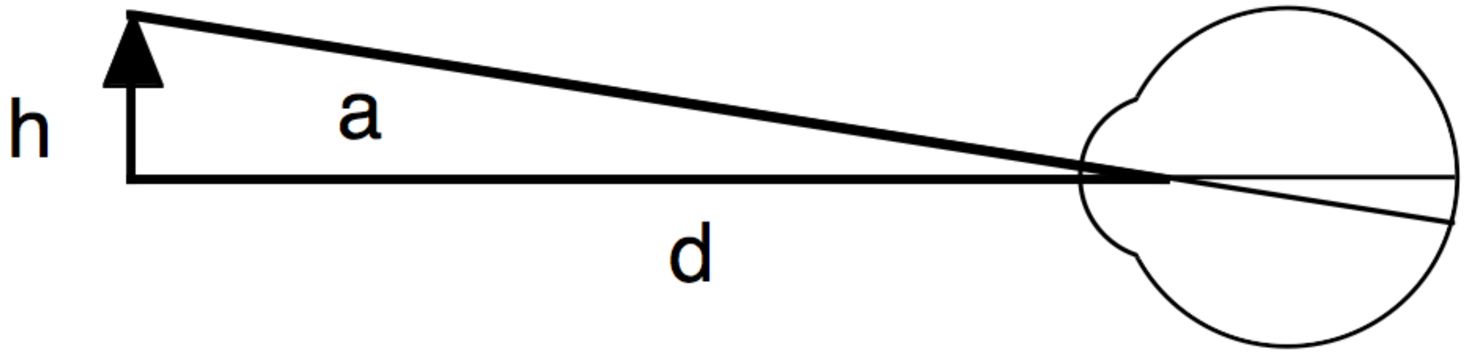
$$c = \frac{h_c * r - h_s * r}{h_s * r} = \frac{h_c * r}{h_s * r} - 1$$



- r is relative luminance
- h_c and h_s are center and surround convolution kernels
- Determine the contrast sensitivity function

Visual angle

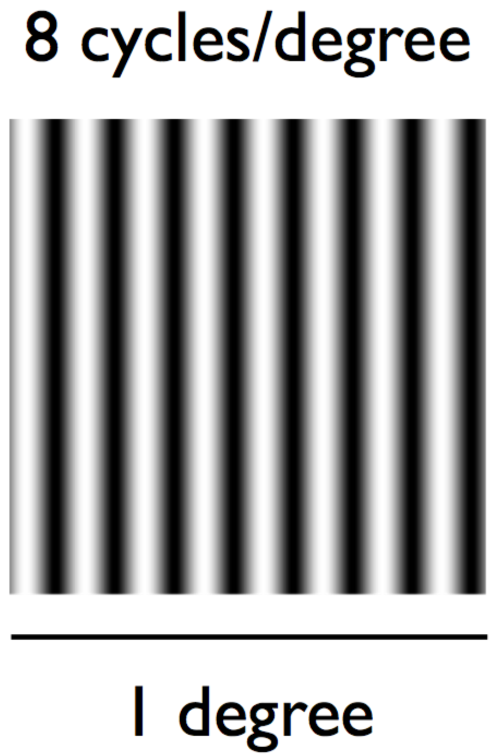
$$a = \tan^{-1}(h/d)$$

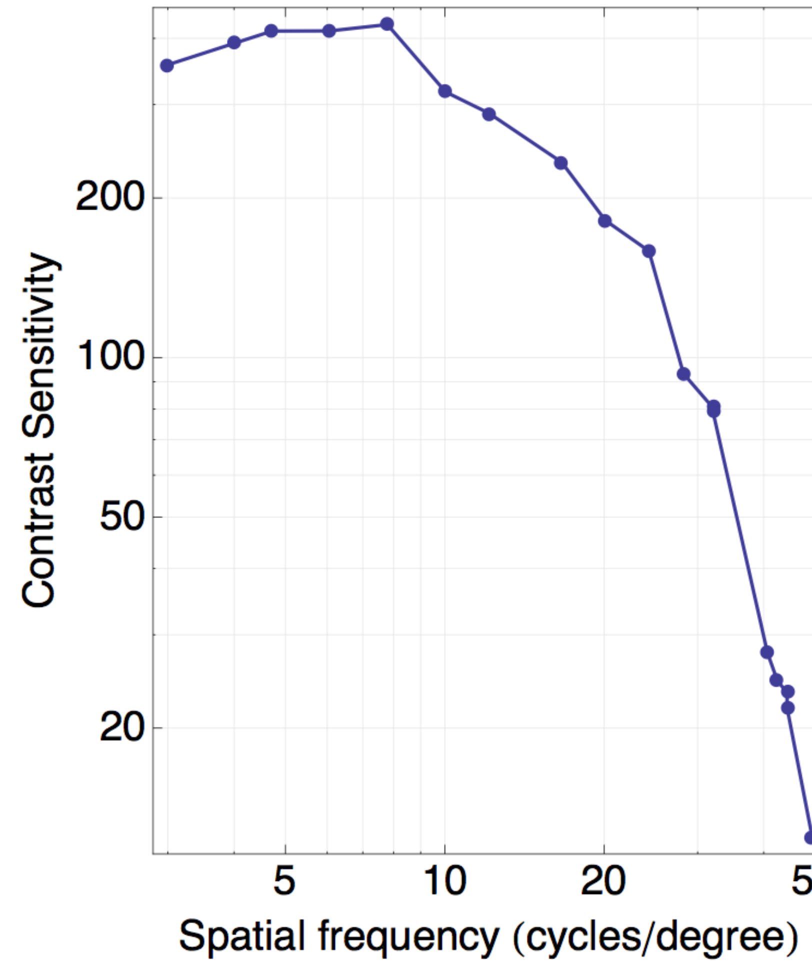


your thumb at arm's length = 2 degrees

1 cm at 57 cm (arms length) = 1 deg

6. Spatial frequency window





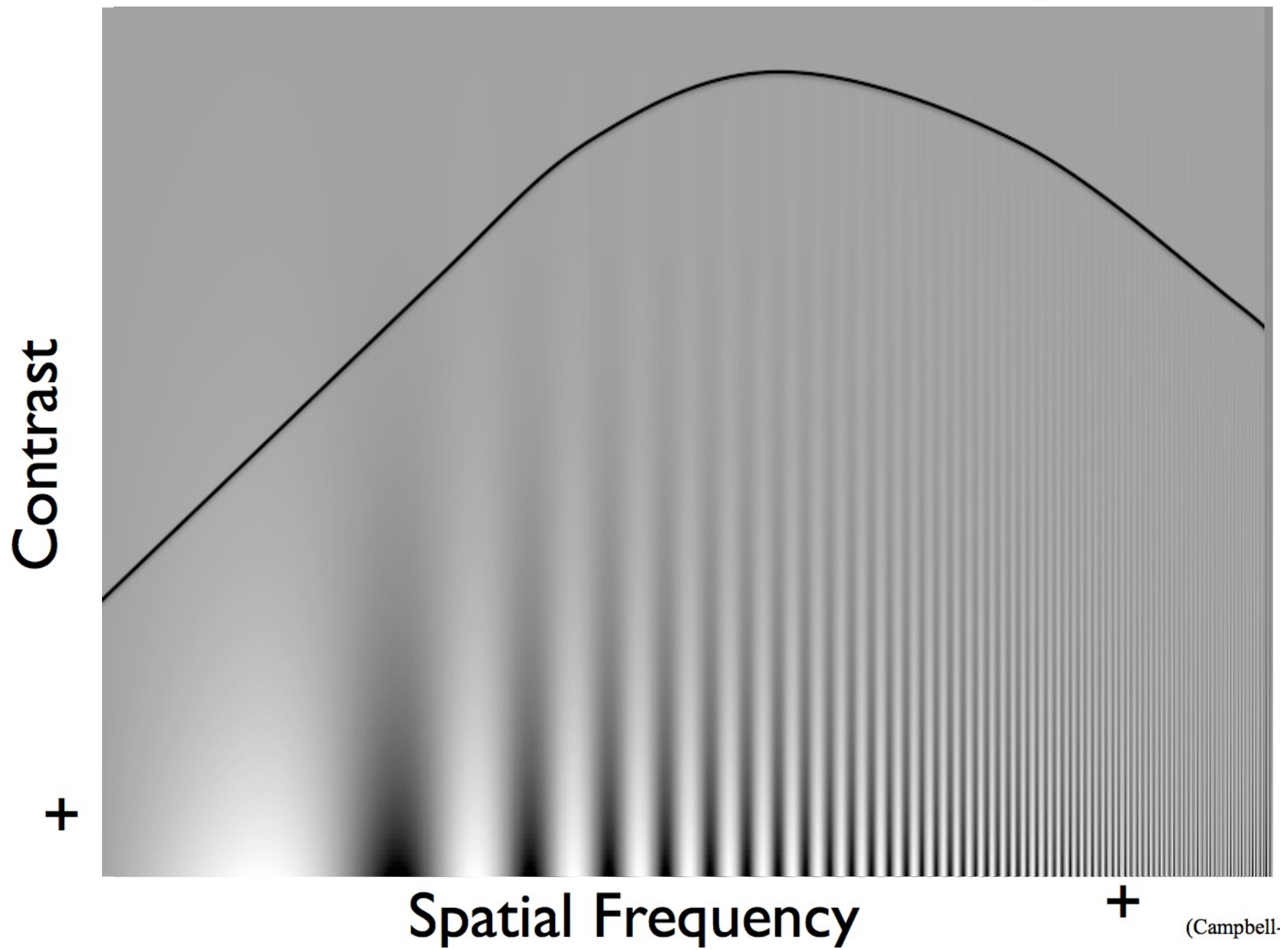
A

Spatial frequency

original

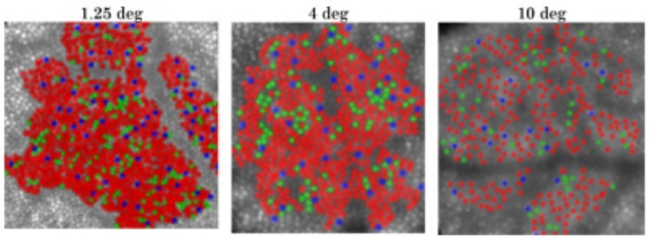
low frequencies
only

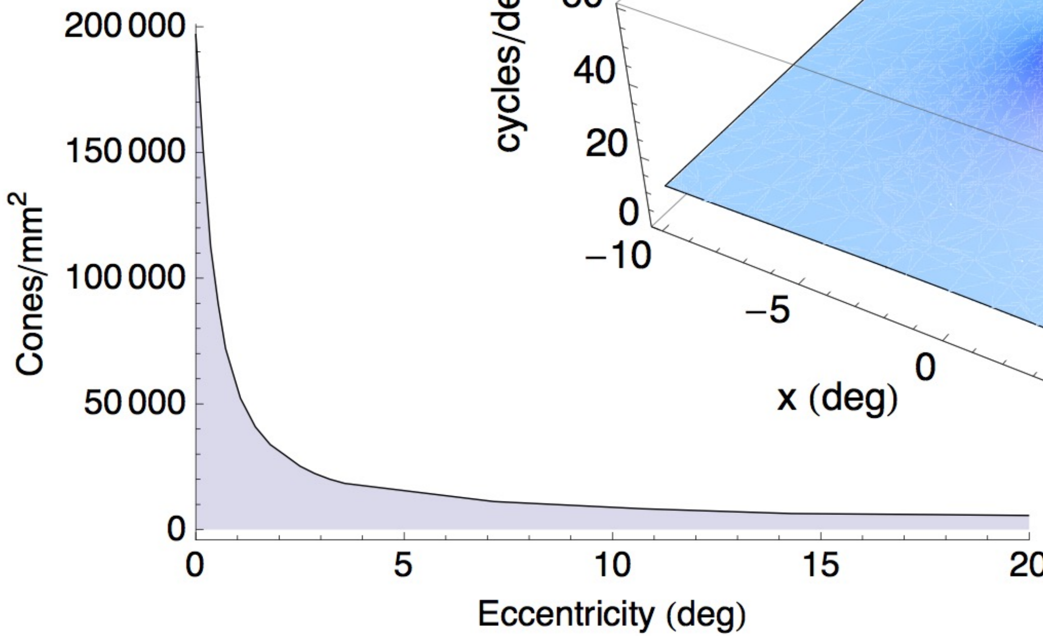
Contrast sensitivity function (CSF)

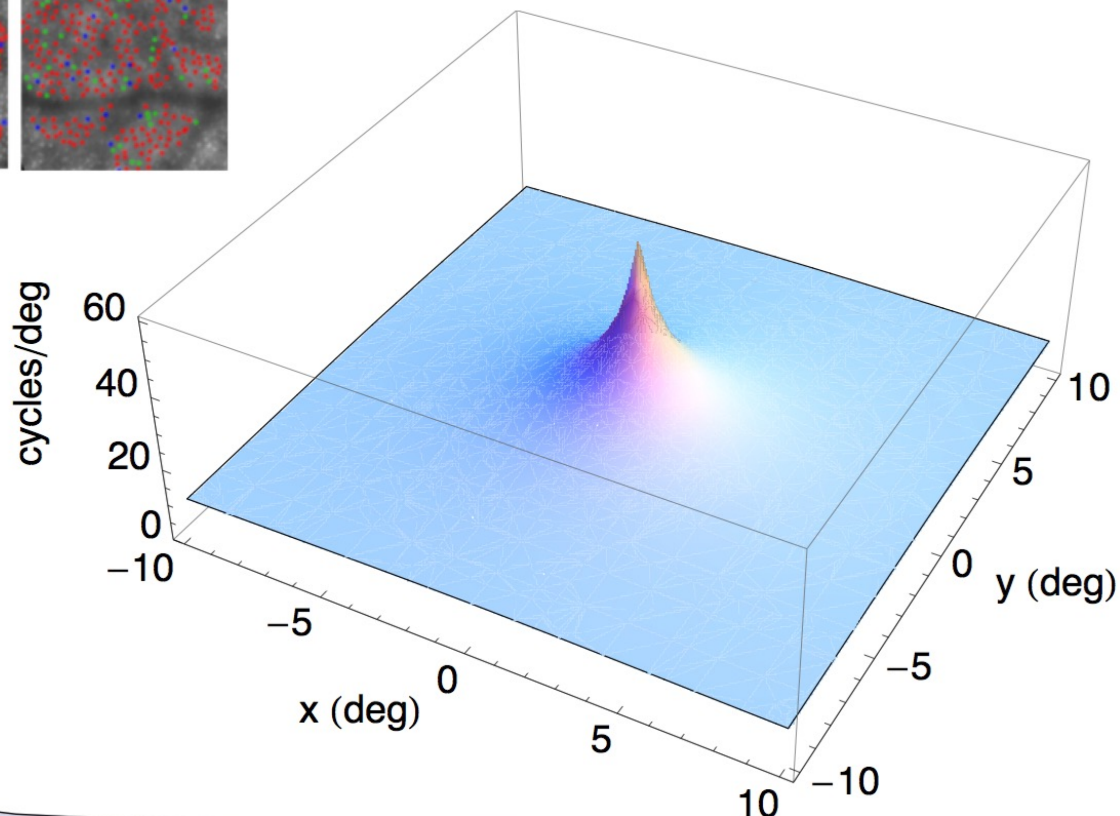


(Campbell-Robson Chart)

7. Window of fixation ("attentional spotlight")







Perceptual processing

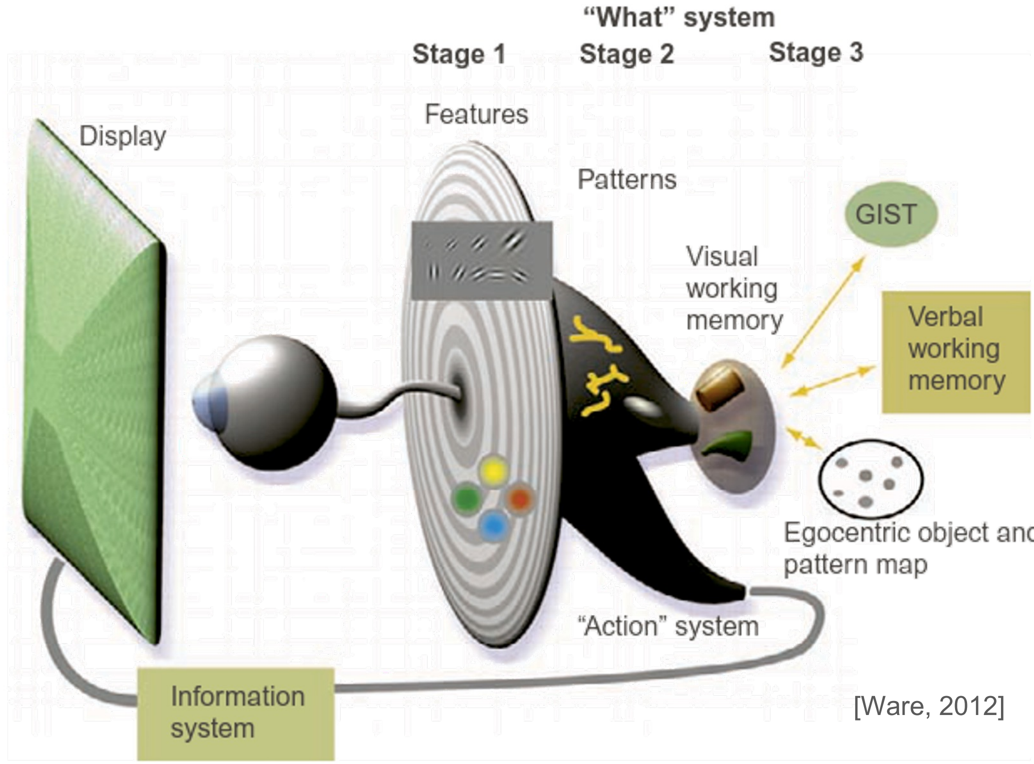
Stage 1. Parallel processing to extract low-level properties of the visual scene

- rapid parallel processing
- extraction of features: orientation, colour, texture, movement patterns
- iconic store
- bottom-up, data driven processing

Stage 2. Pattern perception

- slow serial processing
- involves memory
- arbitrary symbols relevant
- different pathways for object recognition and visually guided motion

Stage 3. Sequential goal-driven processing



[Ware, 2012]

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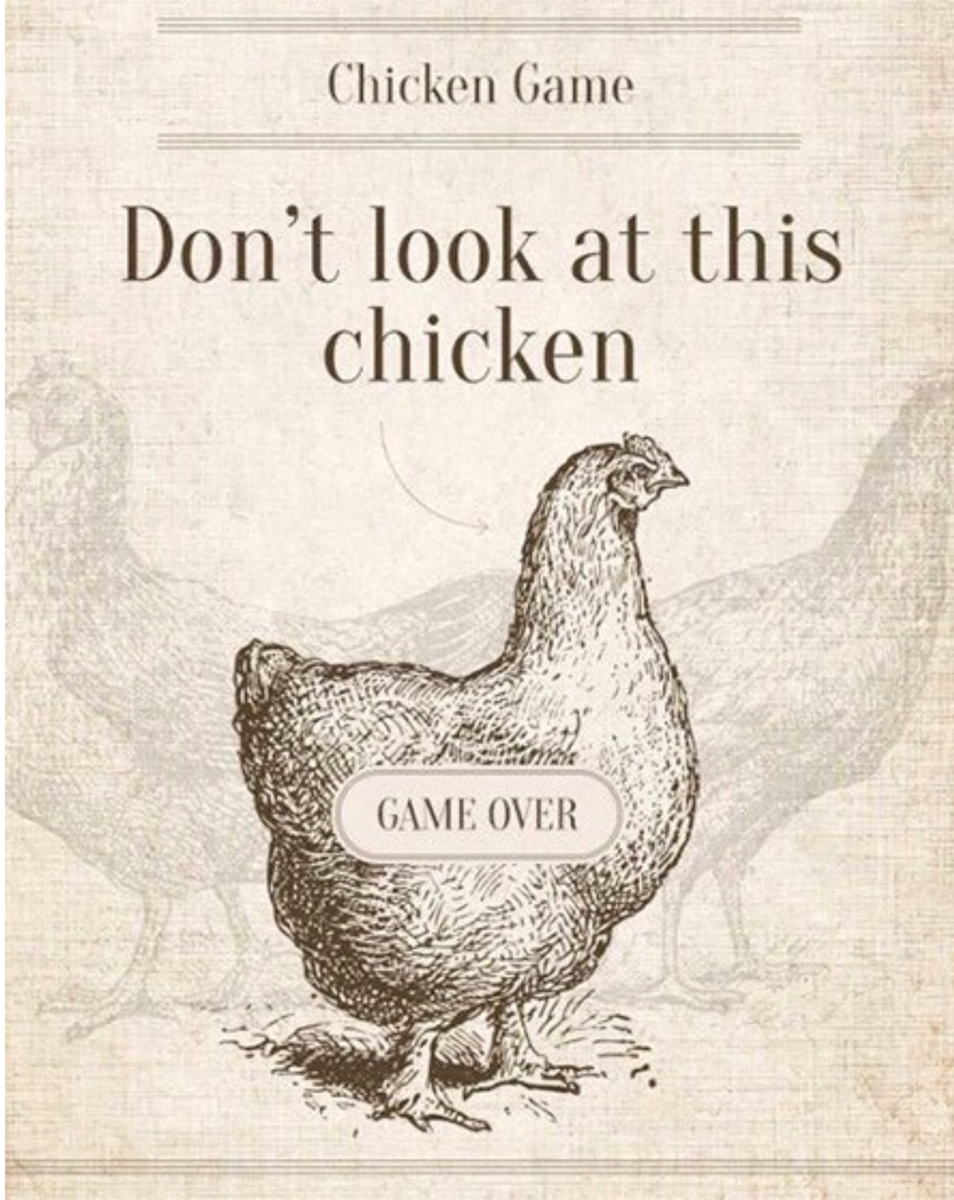
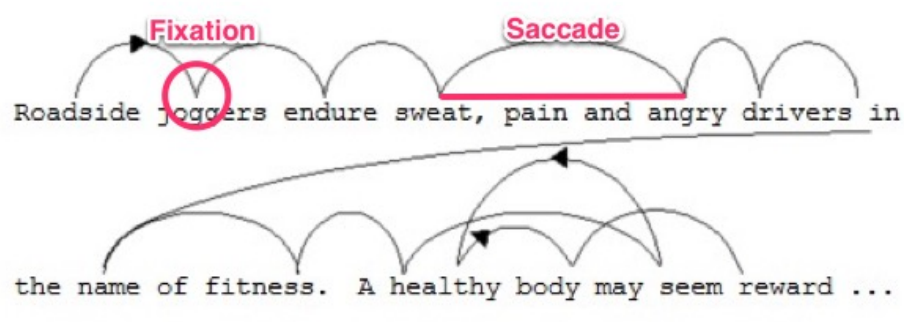
Visual attention

Next slide: A “game”


Chicken Game
Don’t look at this chicken
GAME OVER

Eye movements

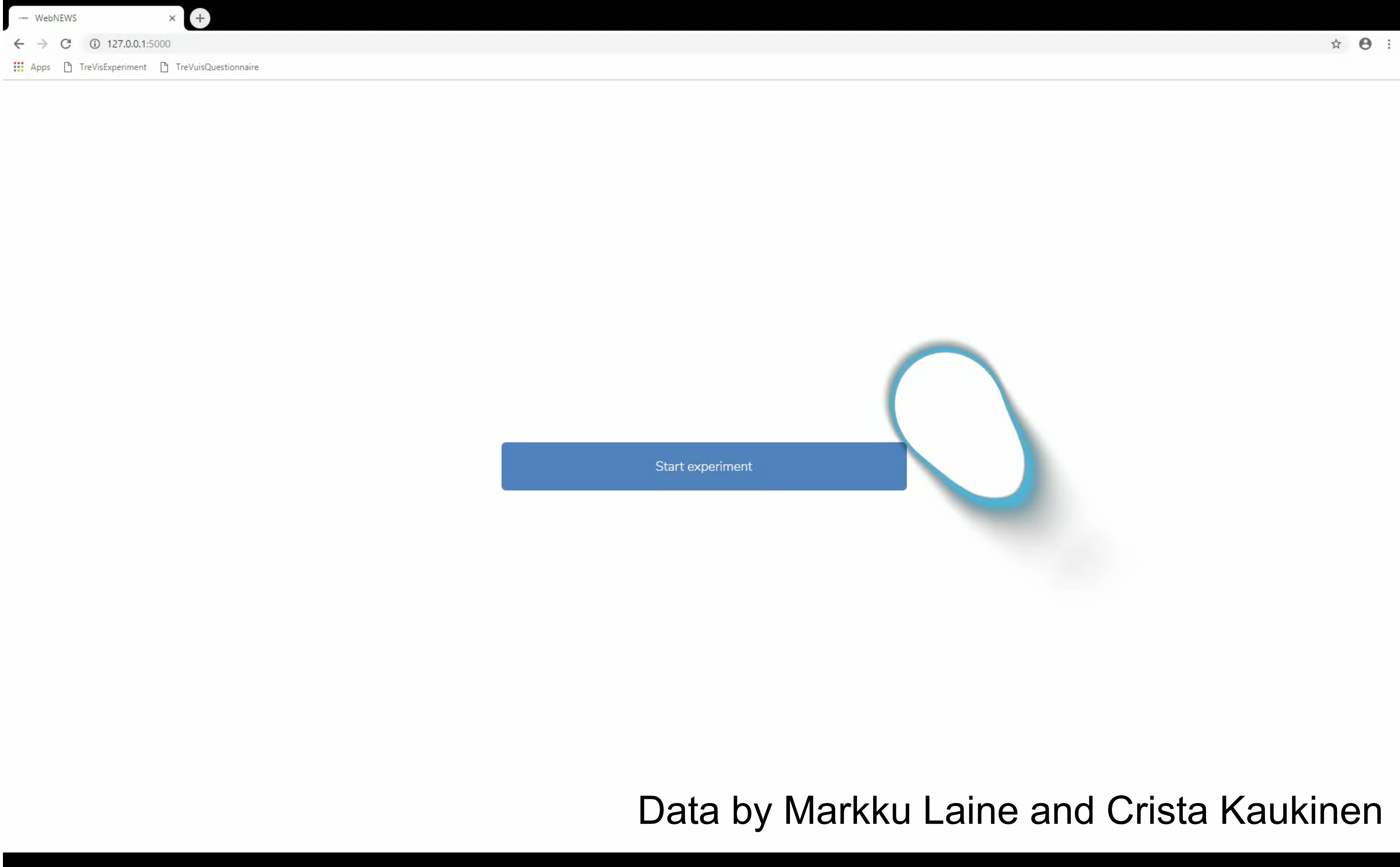


Saccade (30-50 ms)

- Moves the gaze point
- Nothing is 'seen' when saccading

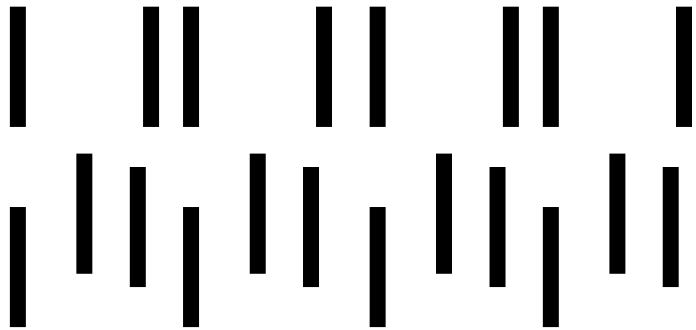
Fixation (200-400 ms)

- Extracts information
- Jittery

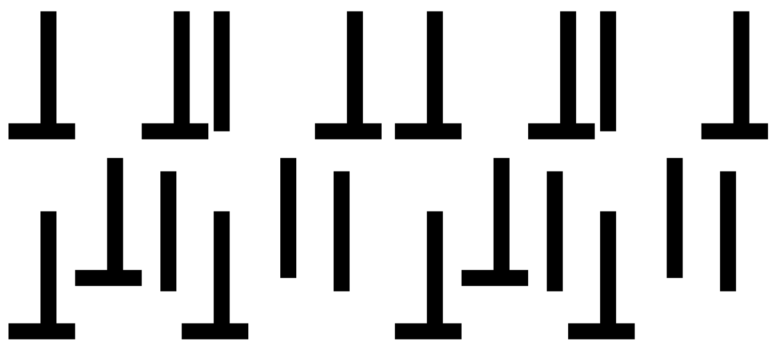

WebNEWS
127.0.0.1:5000
Apps
TreVisExperiment
TreVuisQuestionnaire
Start experiment
Data by Markku Laine and Crista Kaukinen

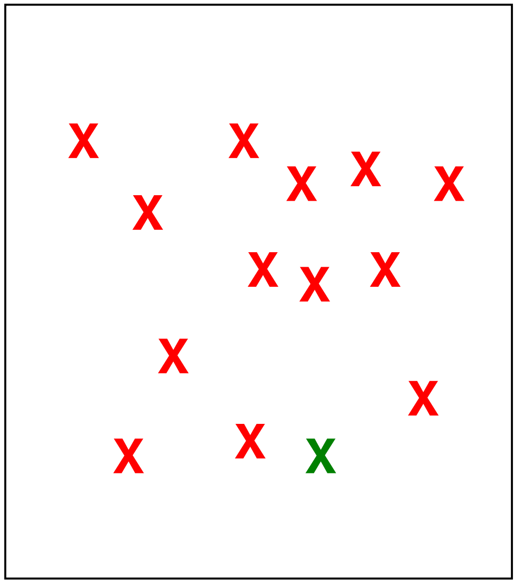
Selective attention

Feature search (pop-out): Visual search based on a discriminative feature: color, shape, size, orientation (FAST!)

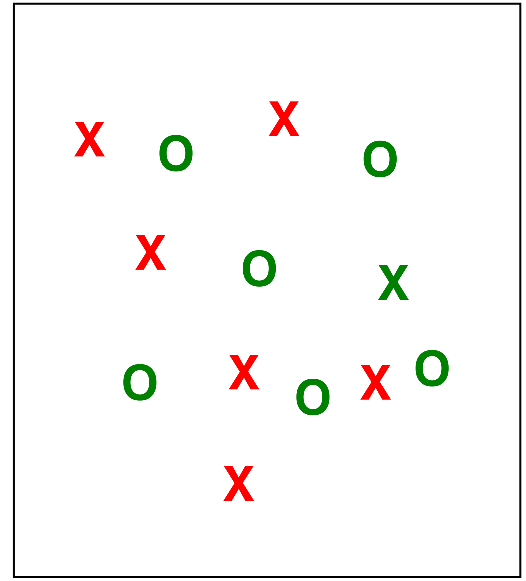


Conjunctive search (SLOW!)



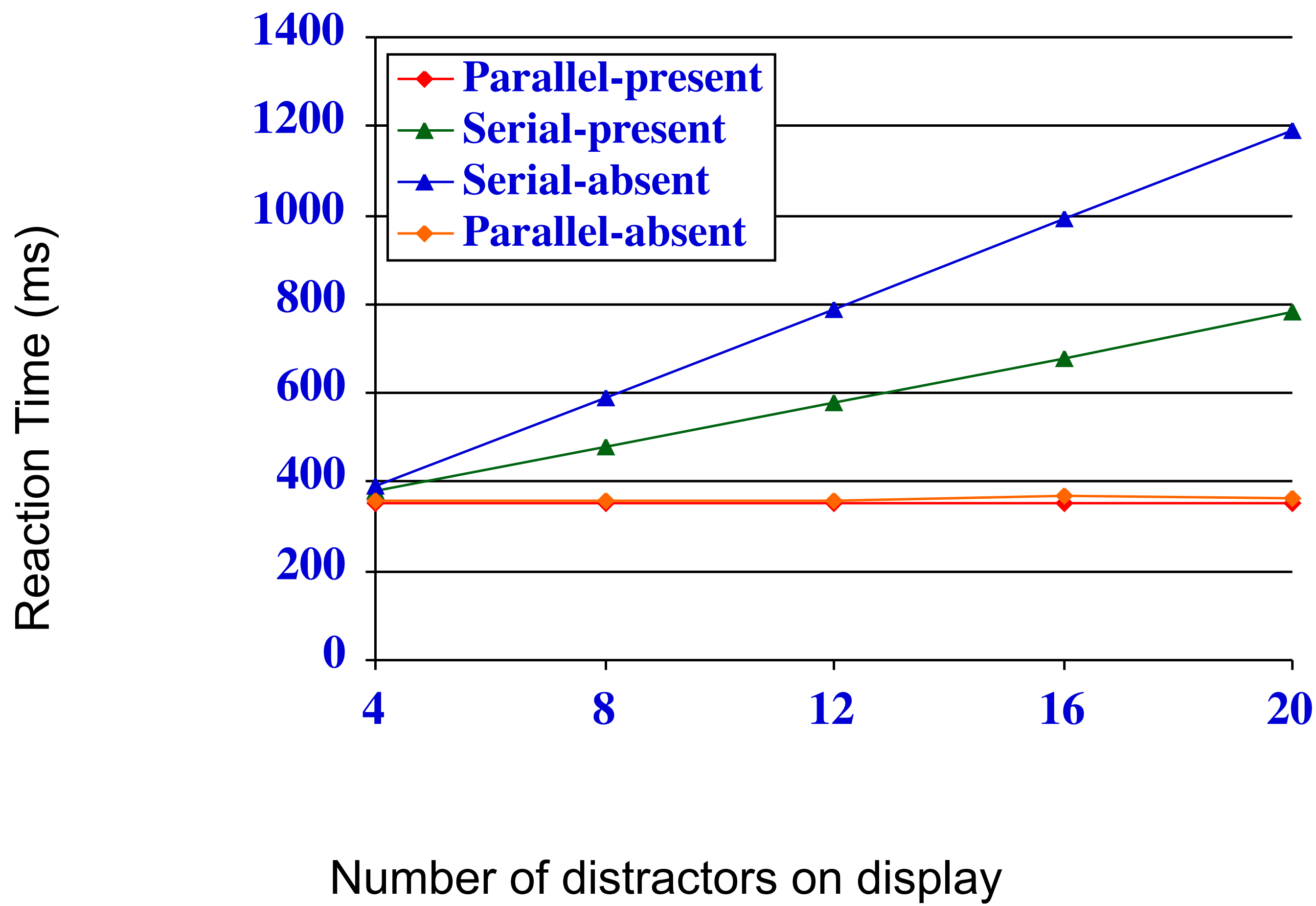


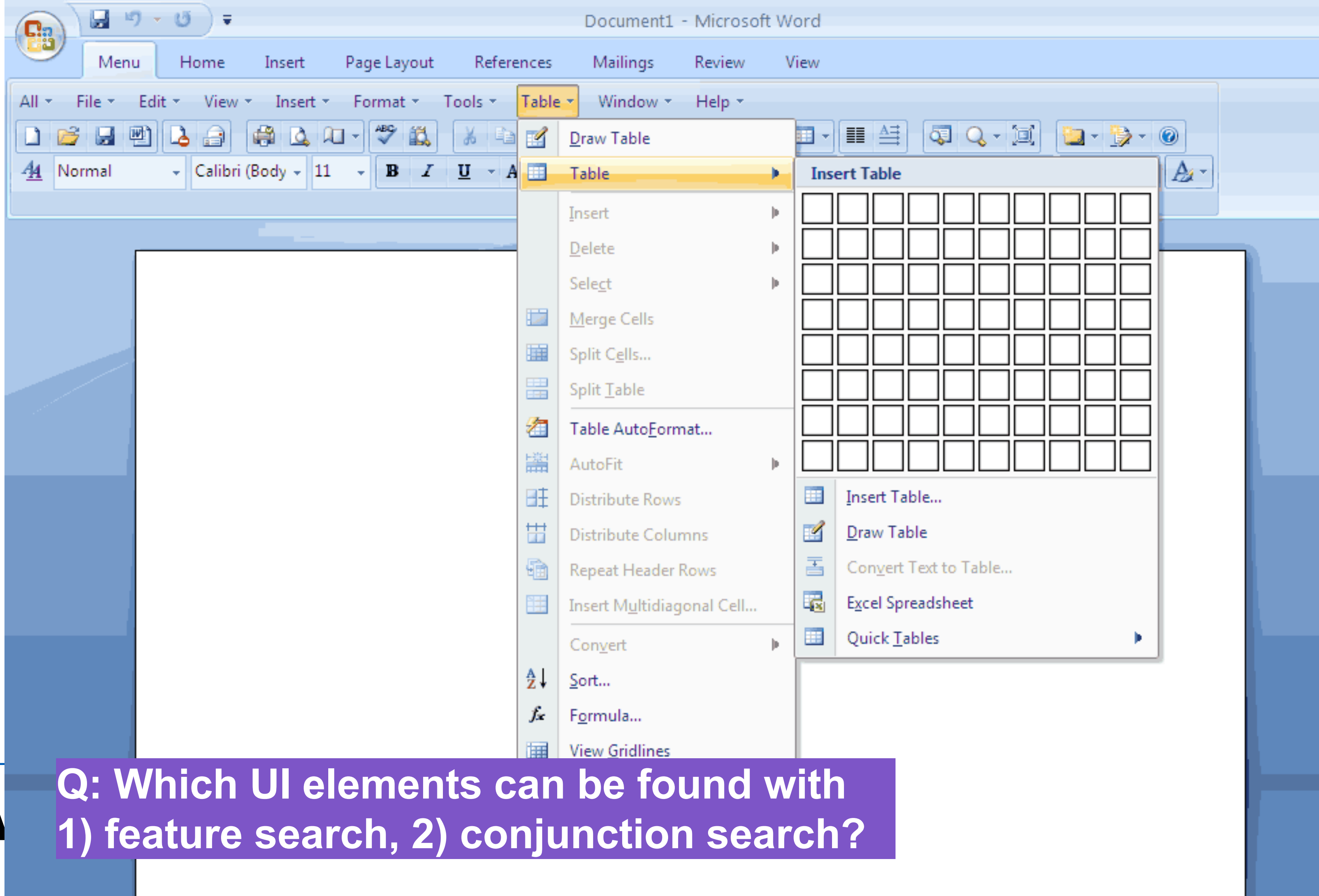
Feature search



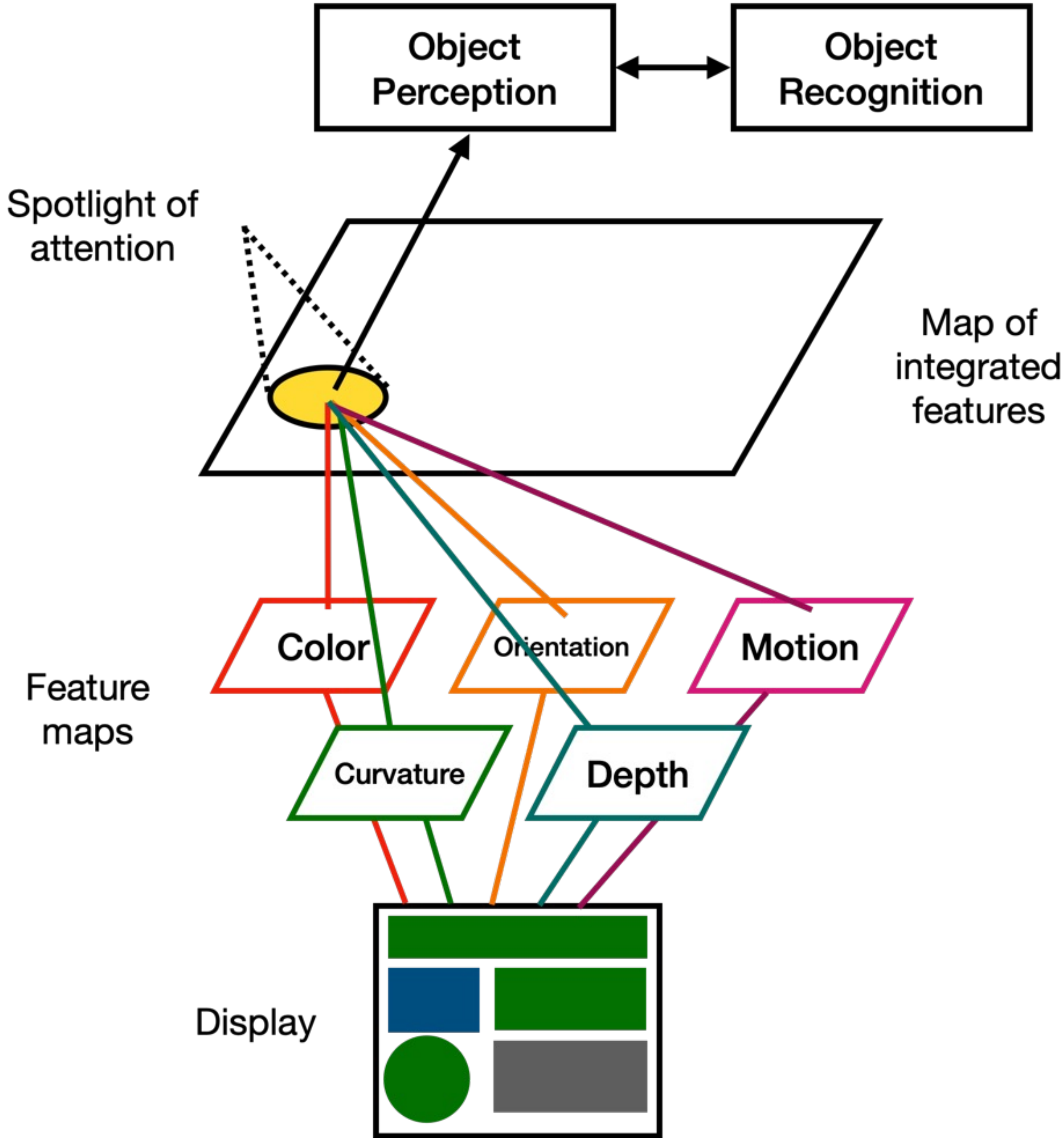
Conjunctive search

“Serial” vs “Parallel” Search





Q: Which UI elements can be found with 1) feature search, 2) conjunction search?

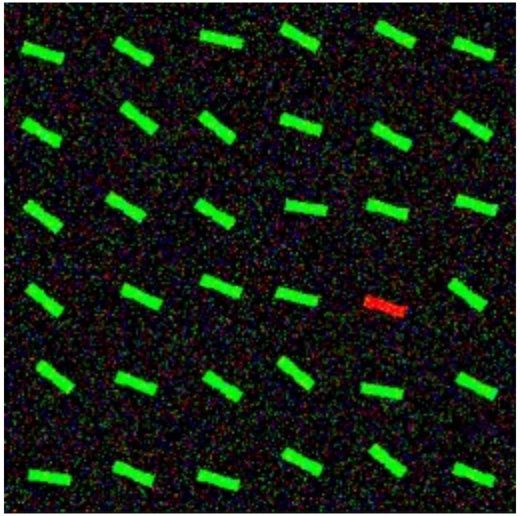

Object Perception
Object Recognition
Spotlight of attention
Map of integrated features
Feature maps
Color
Orientation
Motion
Curvature
Depth
Display

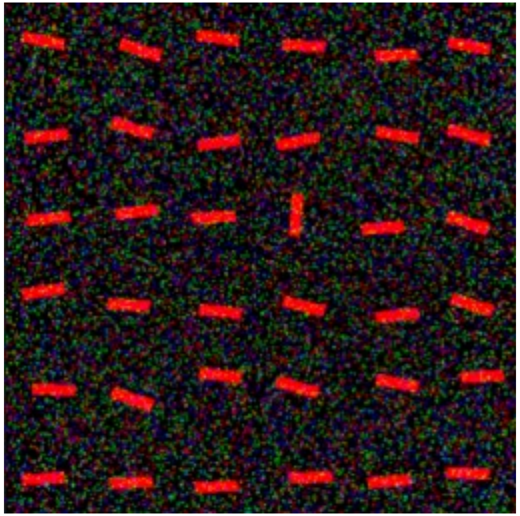
Aalto University

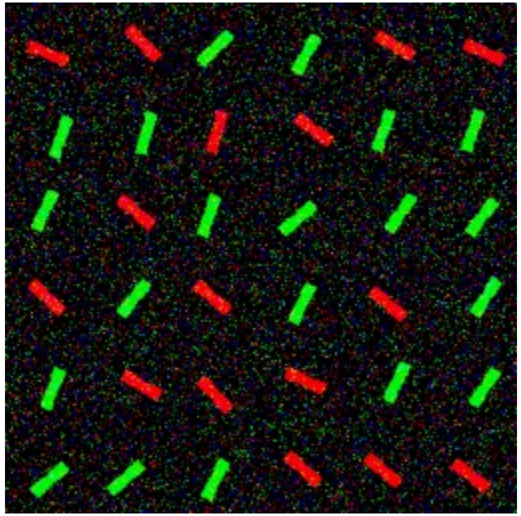
Visual saliency

Saliency

Saliency refers to the probability with which a feature can grab our attention within 1-3 seconds from stimulus onset



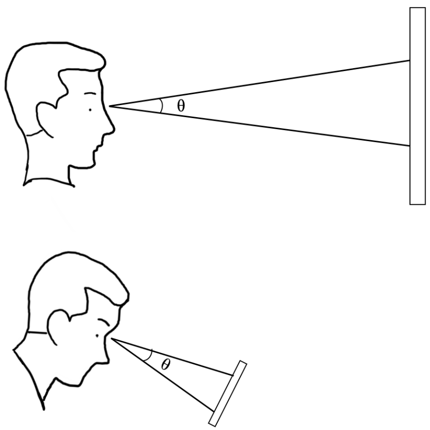





CYCLE

Experimental research on visual saliency

Show a novel stimulus, track first 1-3 seconds of where participants look at



Top-down (learned) biases

Center bias

Horizontal bias

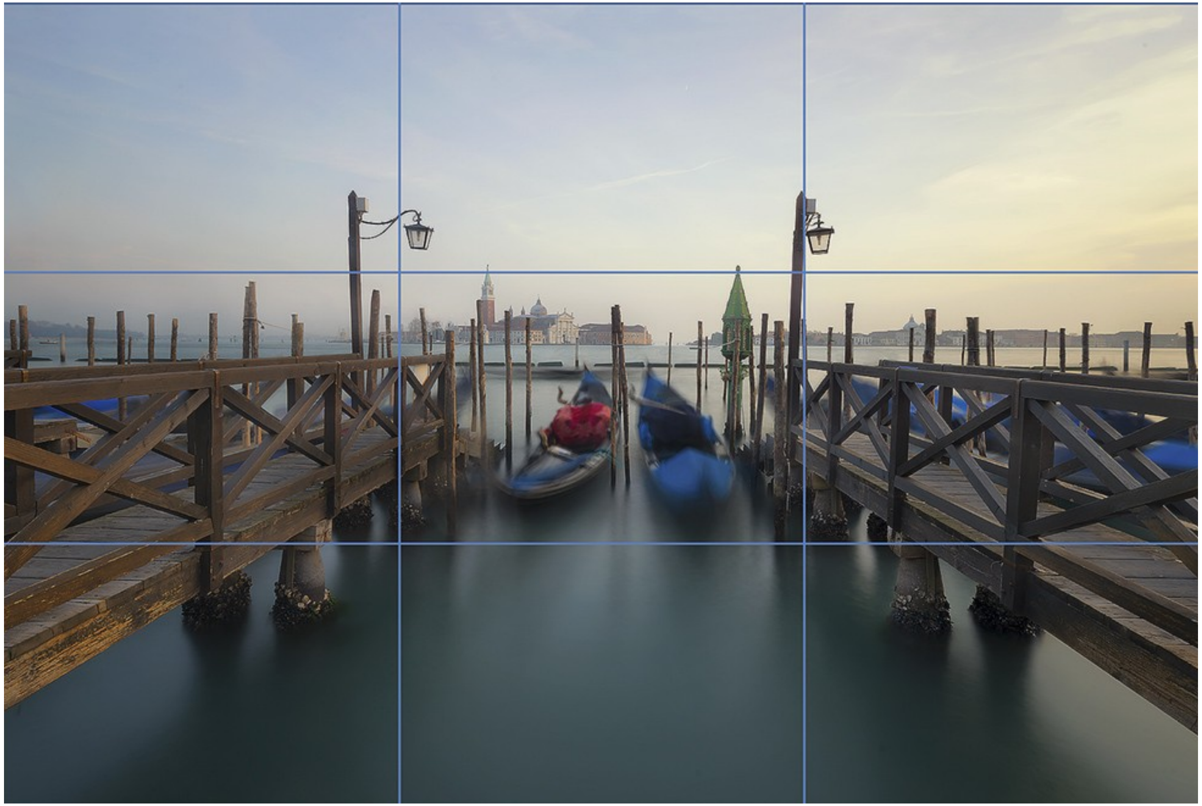
Color bias

Text bias

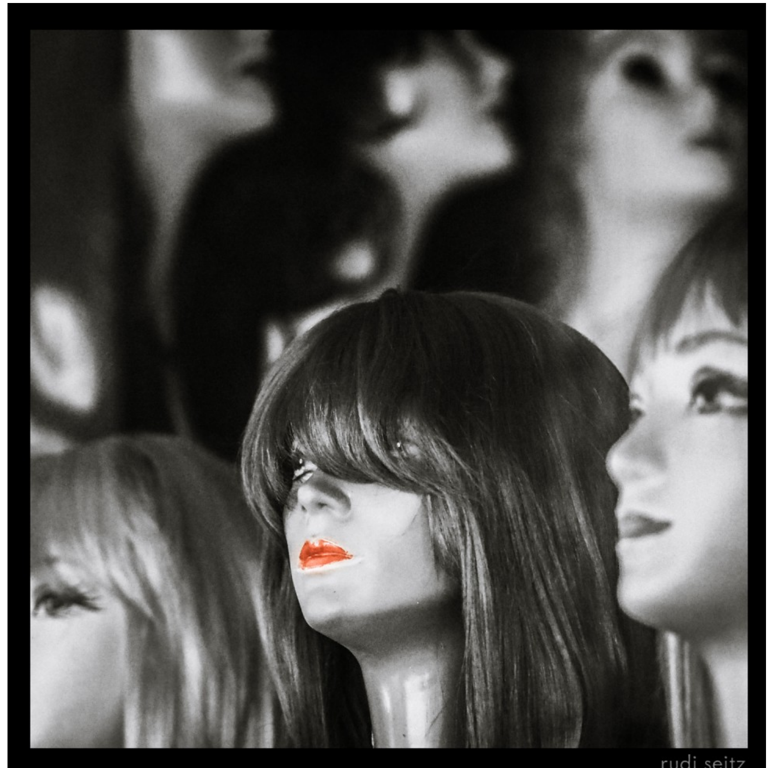
Face bias

Center bias

Horizontal bias



Color bias



Text bias

केएसबीपी पथकर नाका
KSBP TOLL PLAZA
LANE 2
Cars / Jeeps
कार / जीप
केएसबीपी व शहर वाहतूक नियंत्रण शाखा, कोल्हापूर
आपले
सहर्ष स्वागत
करीत आहे
KSBP
KSBP TRAFFIC PARK
KOLHAPOOR

Face bias

Top-down and bottom-up aspects of saliency

Bottom-up saliency: memory-free, based on activation of feature detectors (”image-dominated”)

Top-down saliency: learned, memory-dependent, task-oriented, adaptive. ”Biased”.

Saliency also depends on the person: Experience, emotions, context, etc.

Saliency models

Input

Output

Overlay

Overview of models

Bottom-up

- Itti et al., 1998
- Harel et al., 2007

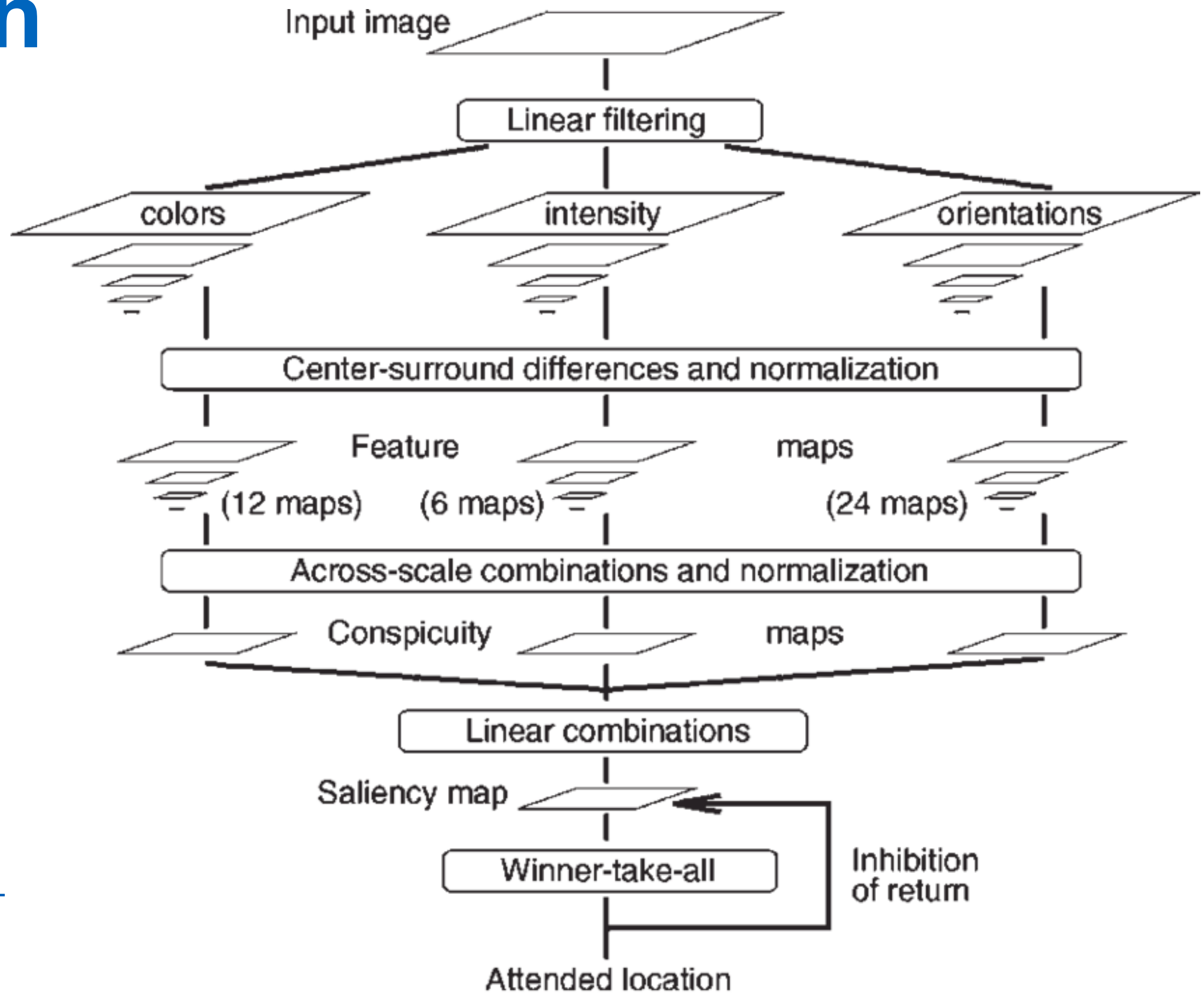
Top-down

- Yang & Yang, 2017
- Tanner & Itti, 2019

Hybrid

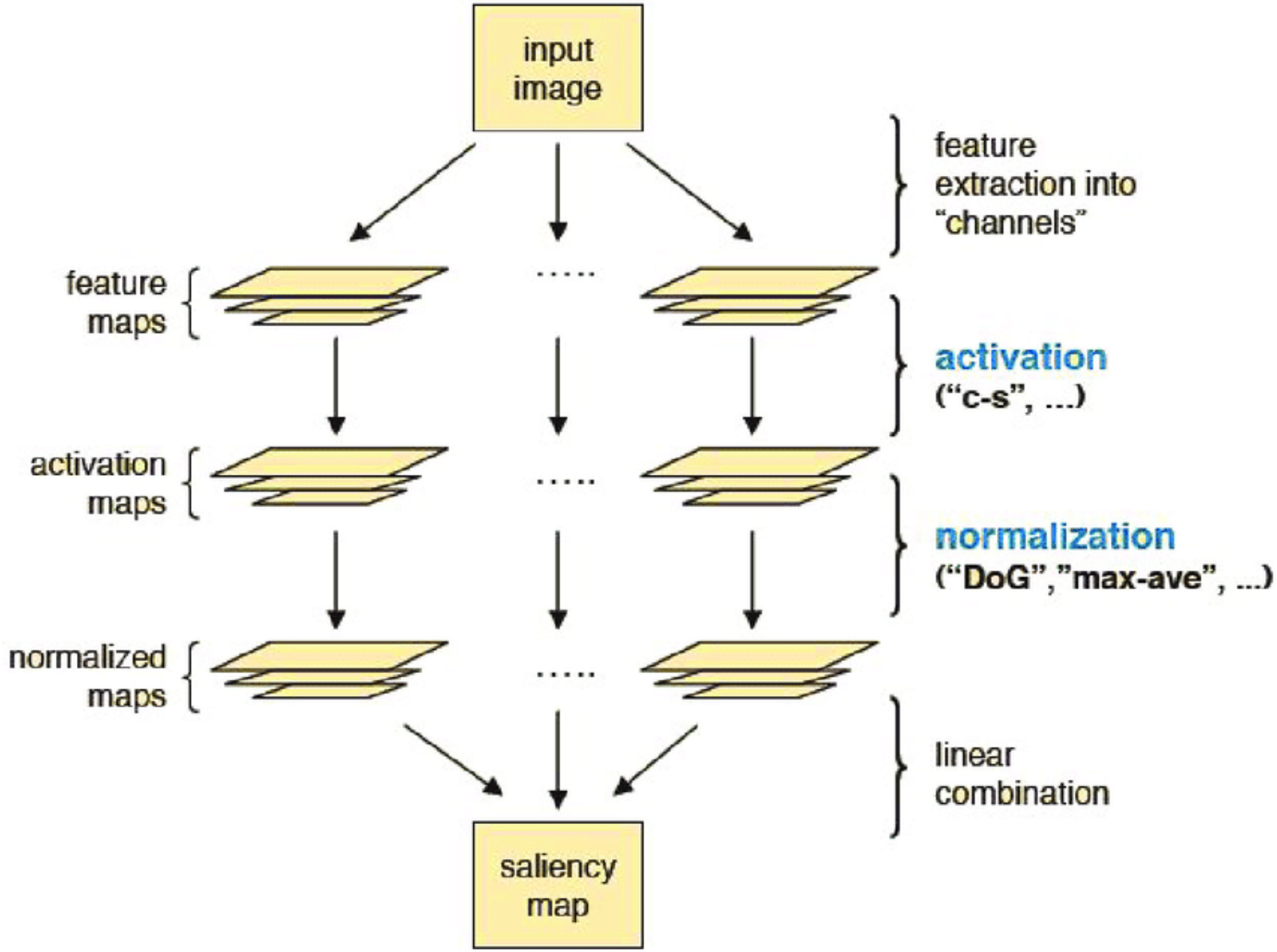
- Torralba, 2003
- Borji, 2012

The Itti-Koch bottom-up model



Itti et al. 1998

GBVS



Harel et al. 2007

Examples

Source (a), Itti-Koch prediction (b), GBVS prediction (c)

(a)

(b)

(c)

Deep visual saliency models

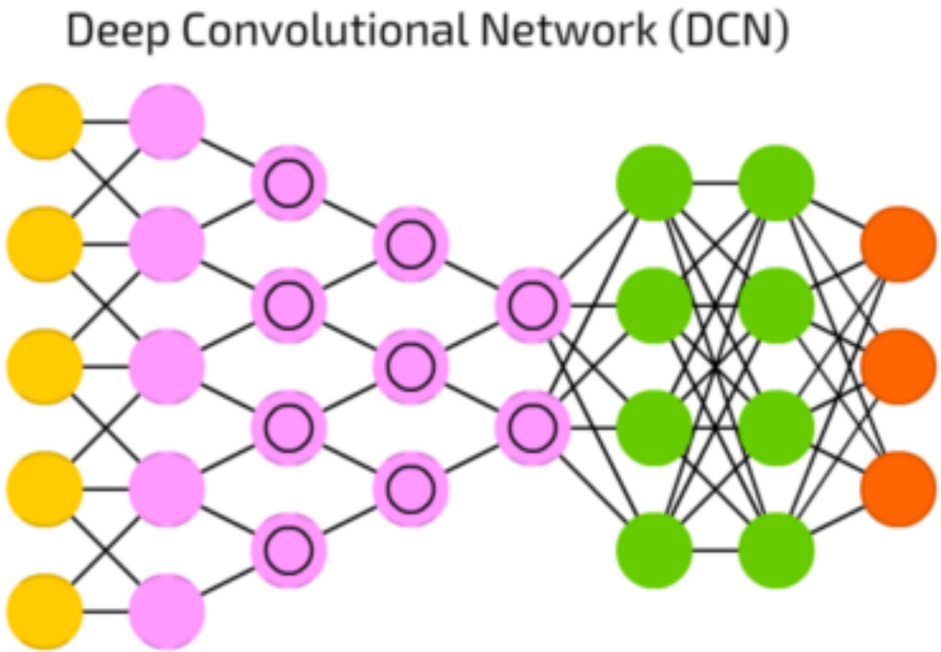
Many models

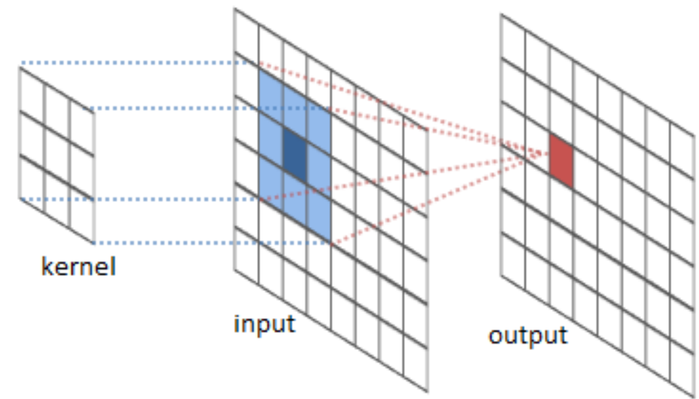
- Huang et al. (2015) *SALICON: Reducing the Semantic Gap in Saliency Prediction by Adapting Deep Neural Networks*
- Cornia et al. (2016) *A Deep Multi-Level Network for Saliency Prediction*
- Pan et al. (2016) *Shallow and Deep Convolutional Networks for Saliency Prediction*
- Pan et al. (2017) *SalGAN: Visual Saliency Prediction with Generative Adversarial Networks*
- Kruthiventi et al. (2017) *Deepfix: A fully convolutional neural network for predicting human eye fixations*

See https://arxiv.org/pdf/1810.03716.pdf

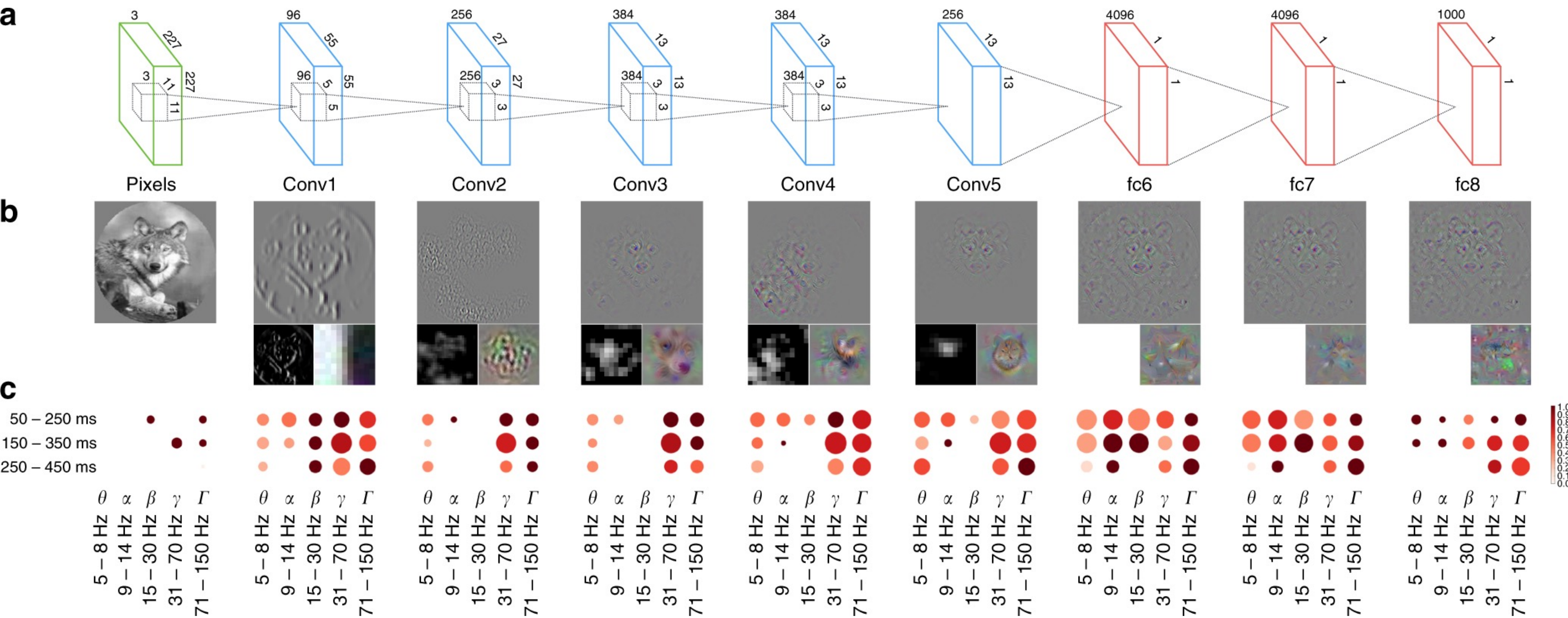
And many more!

Convolution



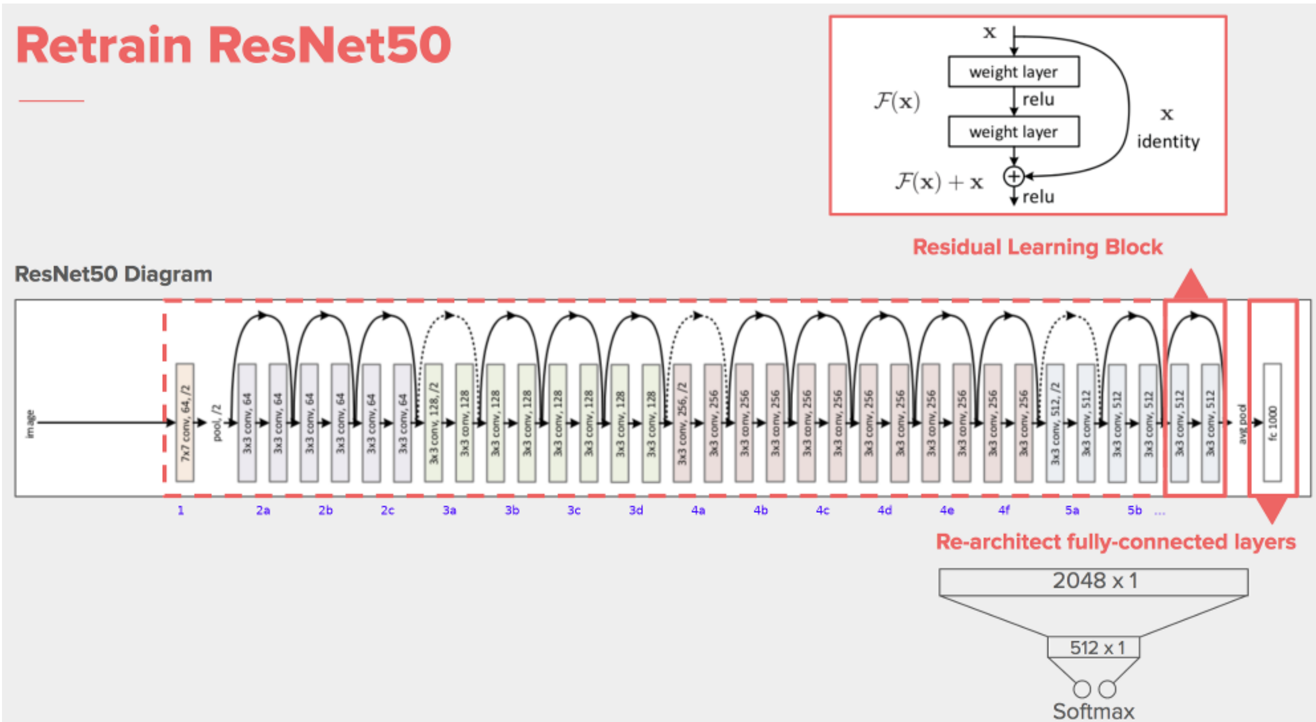


CNNs vs human brain

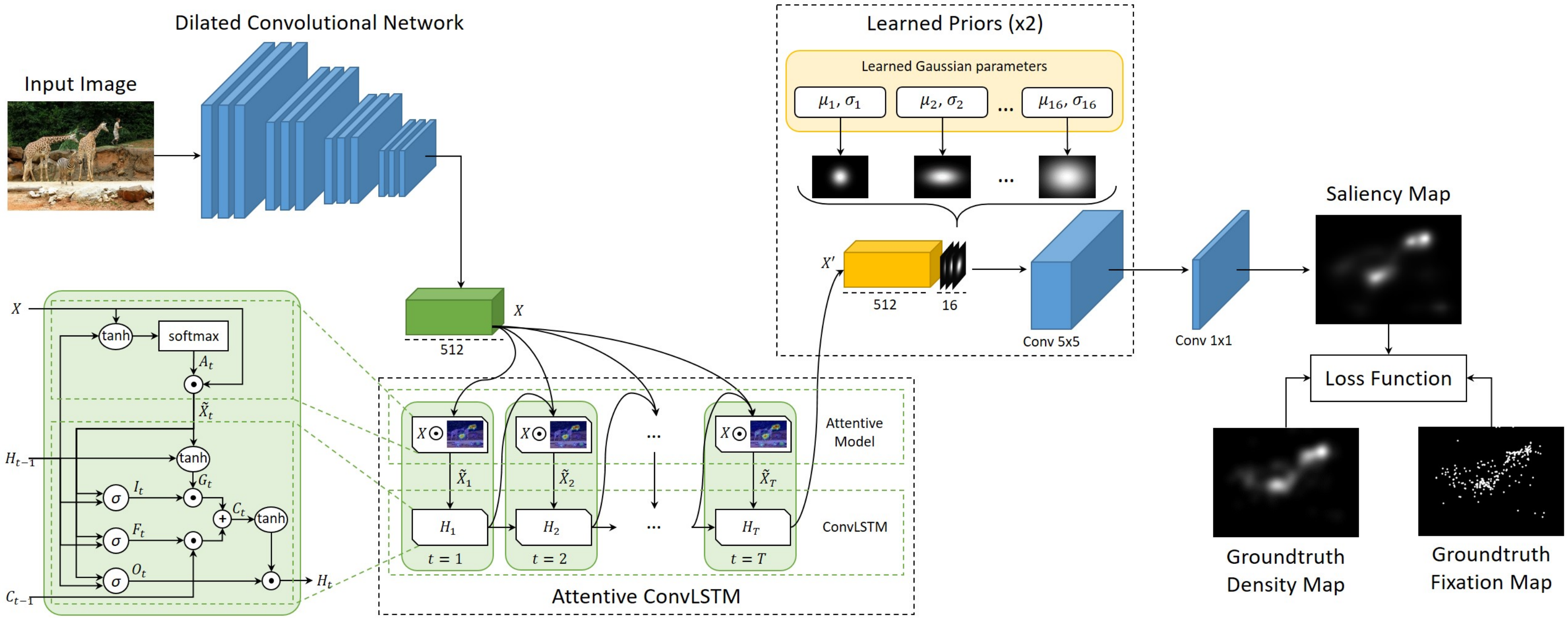


https://www.nature.com/articles/s42003-018-0110-y

A popular CNN: ResNet

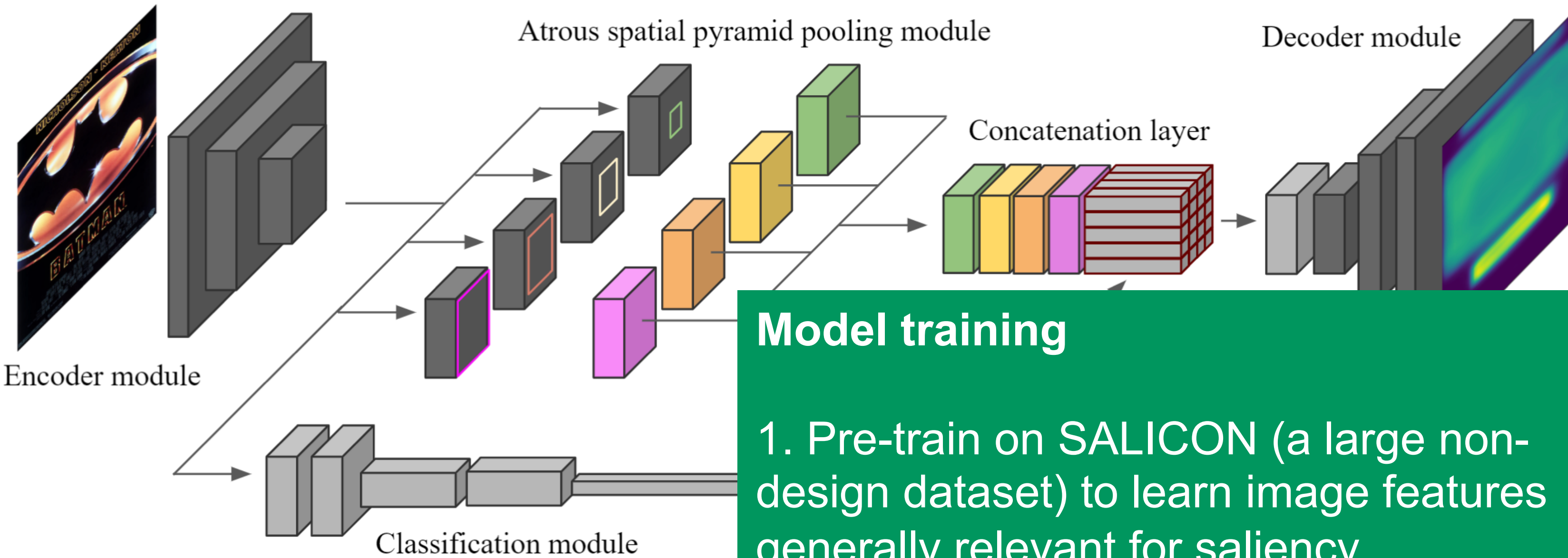


Saliency Attentive Models (SAM)



Cornia et al. (2018) *Predicting Human Eye Fixations via an LSTM-based Saliency Attentive Model*

UMSI: Unified model of saliency and importance



Model training

1. Pre-train on SALICON (a large non-design dataset) to learn image features generally relevant for saliency.

2. Fine-tune on a design-specific dataset (IMP1K). Mix SALICON images to the fine-tuning data to prevent "forgetting" them.

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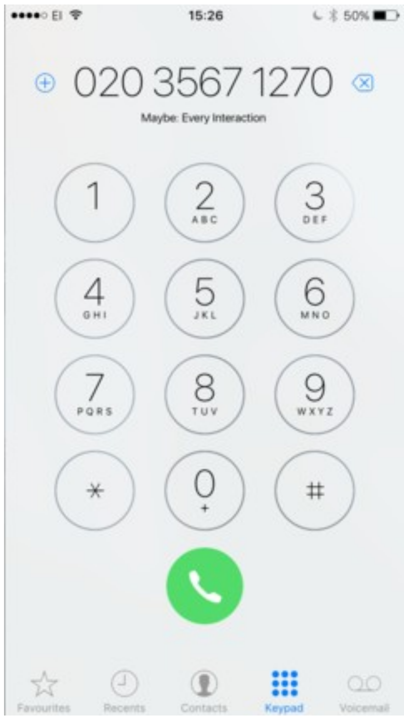
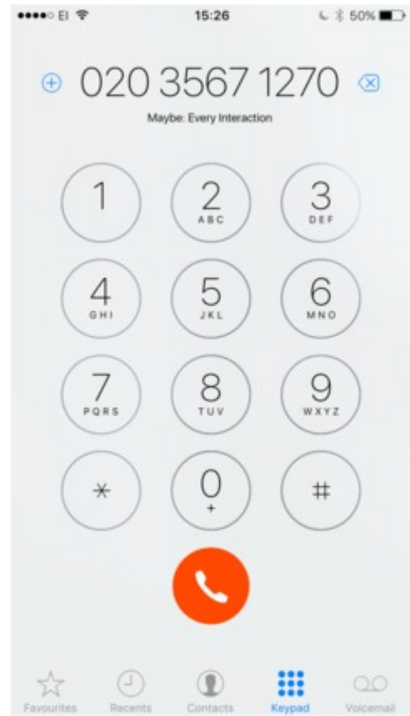
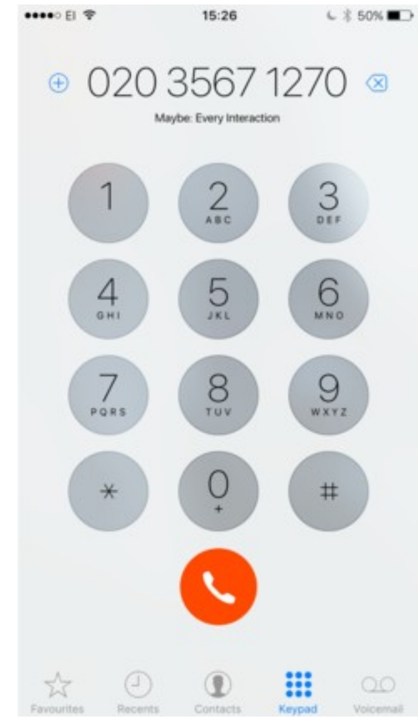
Applications

Driver attention prediction

Evaluation of UI designs







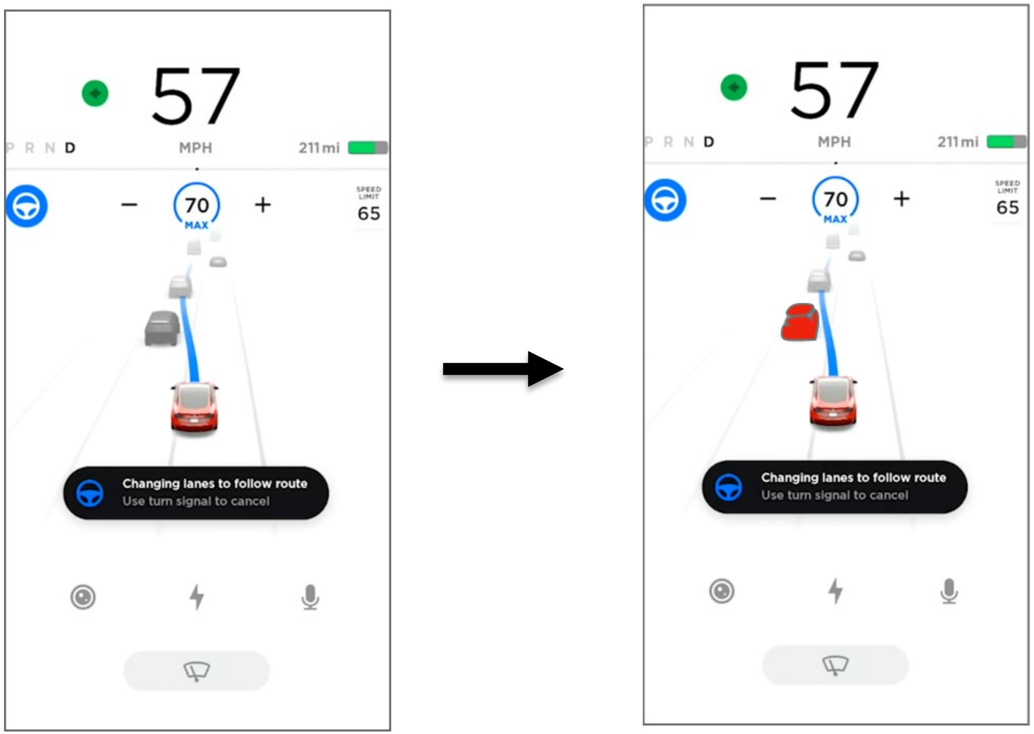
Example


15:26
50%
020 3567 1270
Maybe: Every Interaction
1
2 ABC
3 DEF
4 GHI
5 JKL
6 MNO
7 PQRS
8 TUV
9 WXYZ
*
0 +
#
Favourites
Recents
Contacts
Keypad
Voicemail

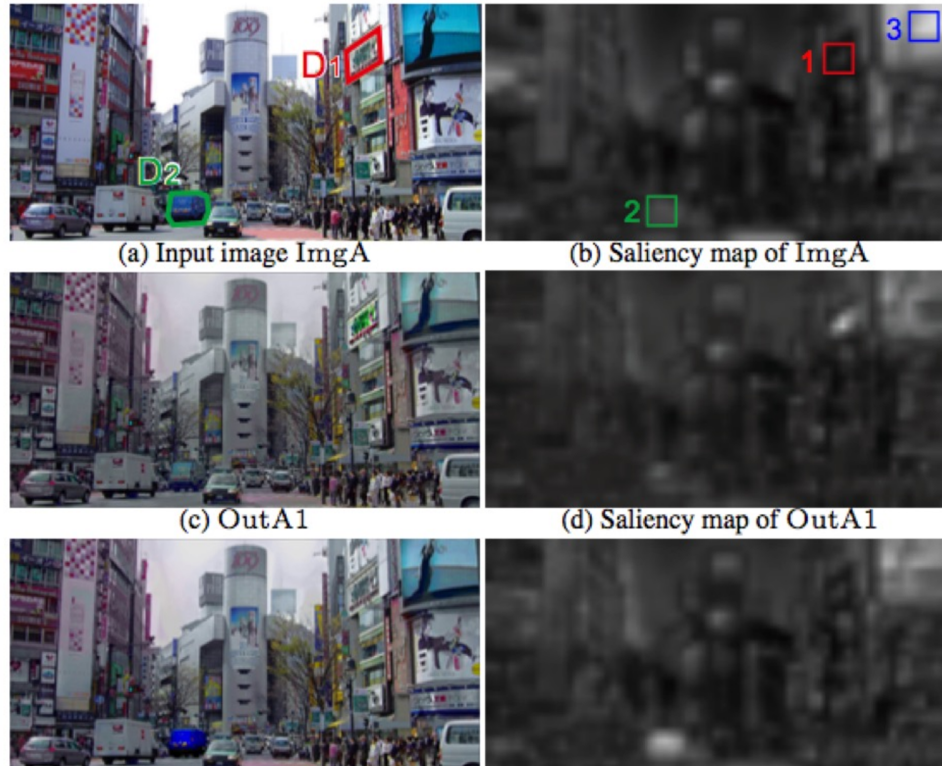

15:26
50%
020 3567 1270
Maybe: Every Interaction
1
2 ABC
3 DEF
4 GHI
5 JKL
6 MNO
7 PQRS
8 TUV
9 WXYZ
*
0 +
#
Favourites
Recents
Contacts
Keypad
Voicemail


15:26
50%
020 3567 1270
Maybe: Every Interaction
1
2 ABC
3 DEF
4 GHI
5 JKL
6 MNO
7 PQRS
8 TUV
9 WXYZ
*
0 +
#
Favourites
Recents
Contacts
Keypad
Voicemail

Grabbing attention to a situationally important element



Saliency editing

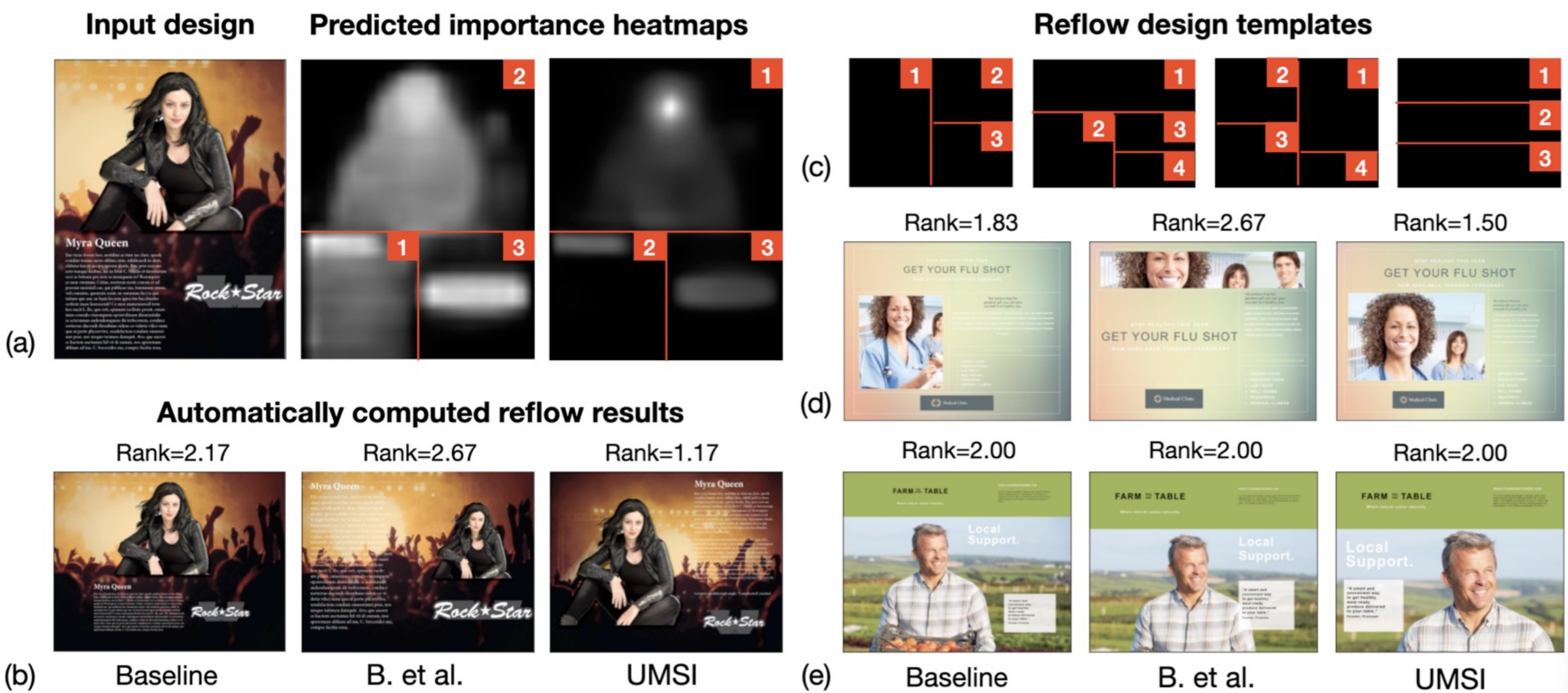


(a) Input image ImgA (b) Saliency map of ImgA
(c) OutA1 (d) Saliency map of OutA1
(e) OutA2 (f) Saliency map of OutA2

Increased the probability of attention to a desired region from 20% chance to 60%!

Hakiwara et al. PETMEI 2011

Visual flow optimization (UMSI)

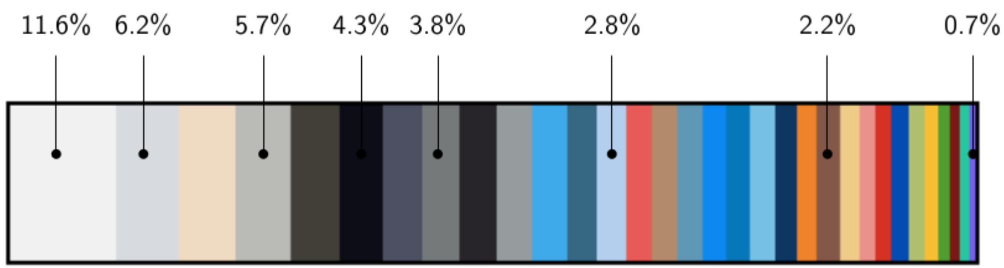


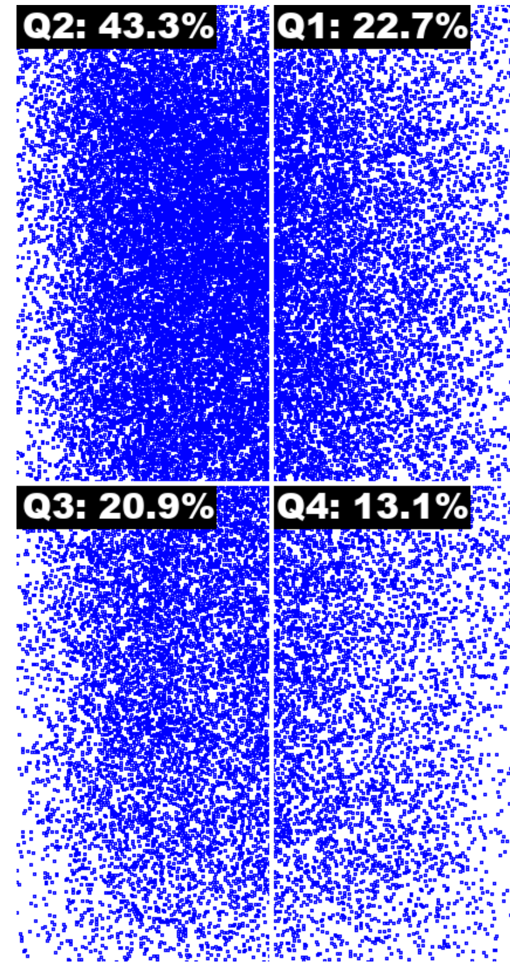
A deeper look into user interfaces

User interfaces...

...are they special?

Empirical results





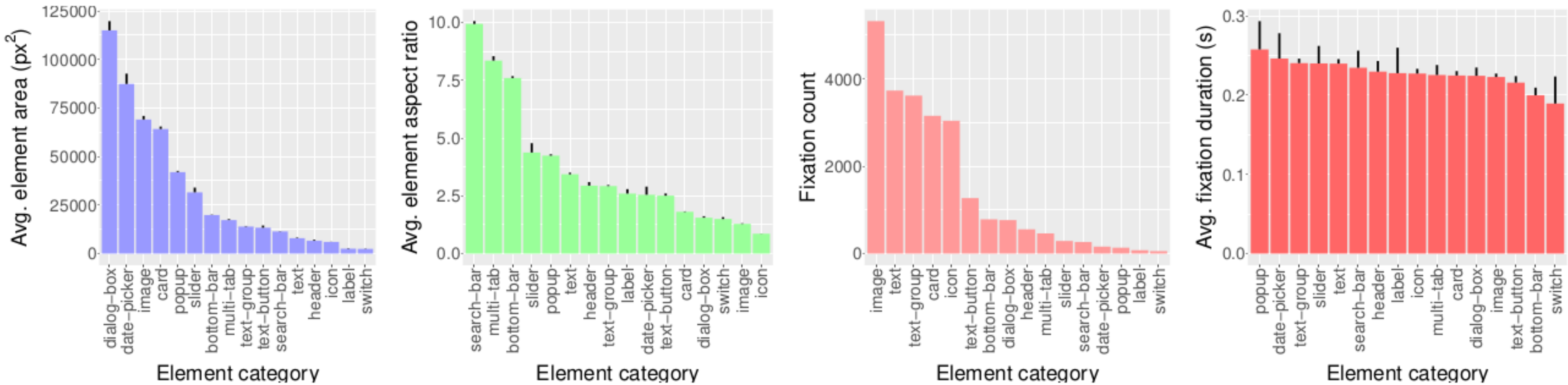
Top-left location bias

No center bias, no horizontal bias

No color bias

Leiva et al. MobileHCI2020

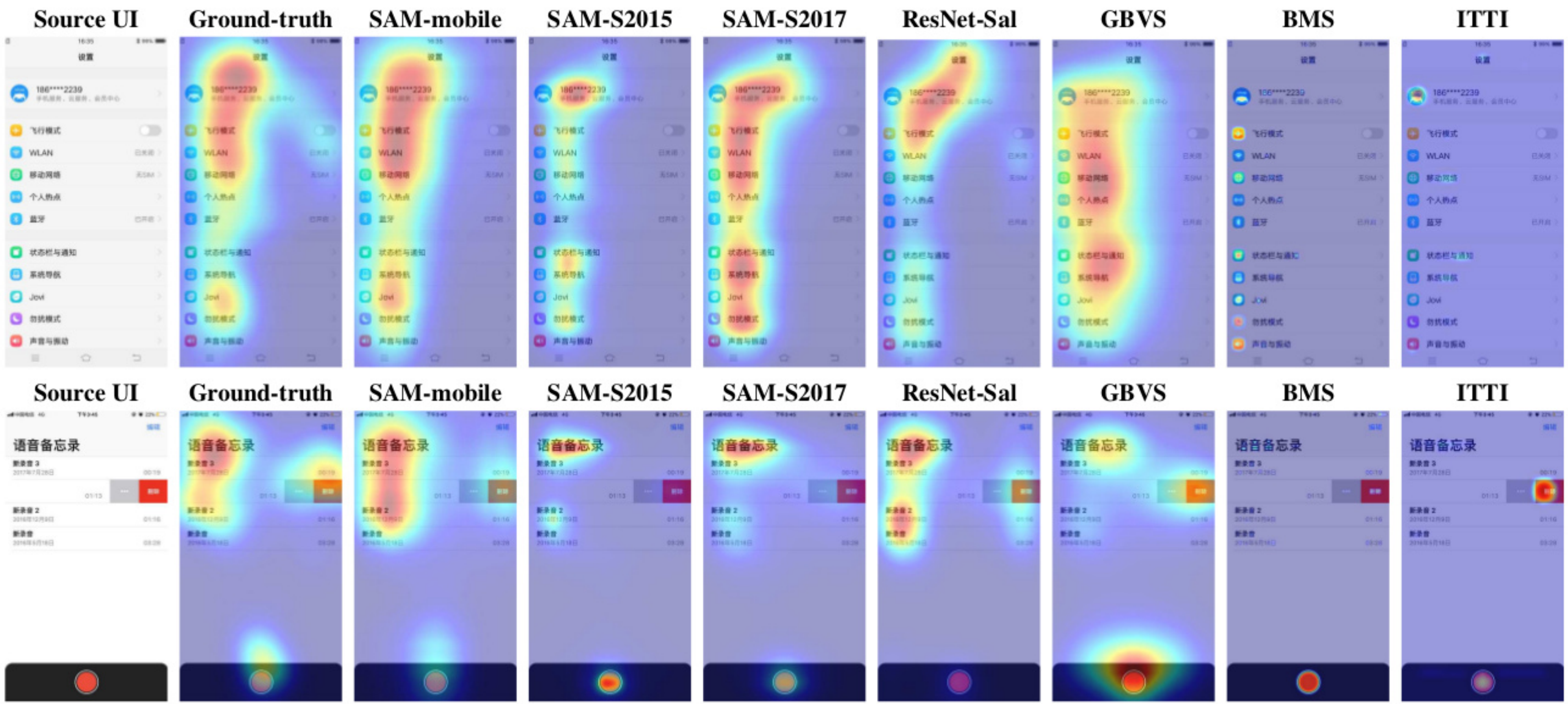
Empirical results



Text and image bias

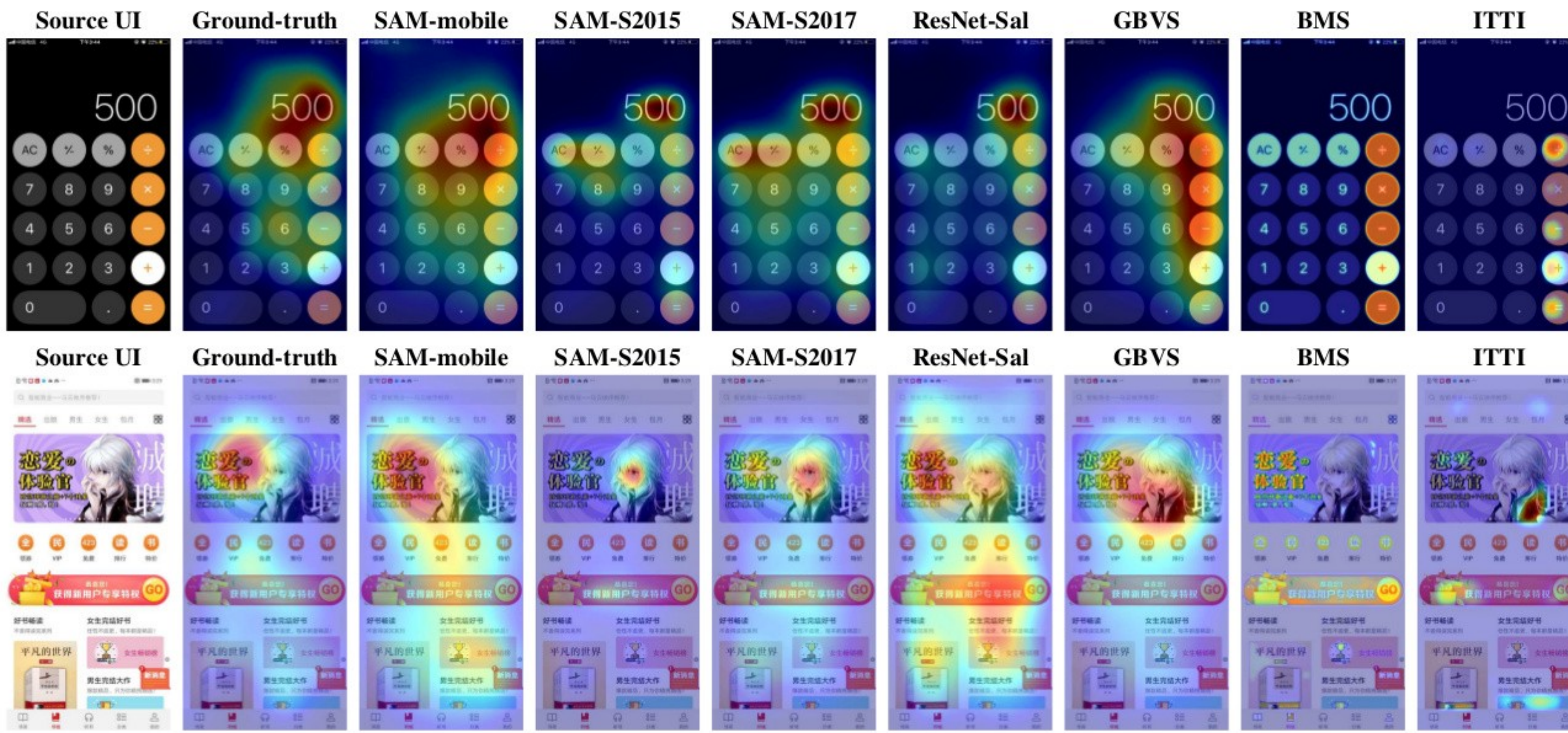
No size bias

Model predictions



Leiva et al. MobileHCI2020

Model predictions



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Leiva et al. MobileHCI2020

Terminals differ in low-level features

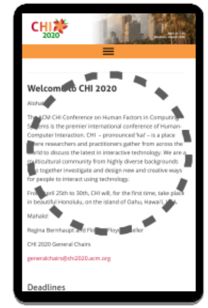
15" display

1600x900 px, 16:9 aspect ratio

Dominant color

Palette

6" display



375x812 px, 9:20 aspect ratio

Dominant color

Palette

Leiva et al. MobileHCI2020

Clutter

“The evil twin of saliency”

Q: What makes this cluttered?

"Like clutters like"

Objects with similar features (color, size, orientation, shape) congest each other

Quantity or density of objects

Previous measures of clutter

Number of visible objects
(Woodruff et al. 1998)

Number of data points per unit area
(Tufte 1983)

Quantity of countours, edge density, color variability
(Mack & Oliva 2004)

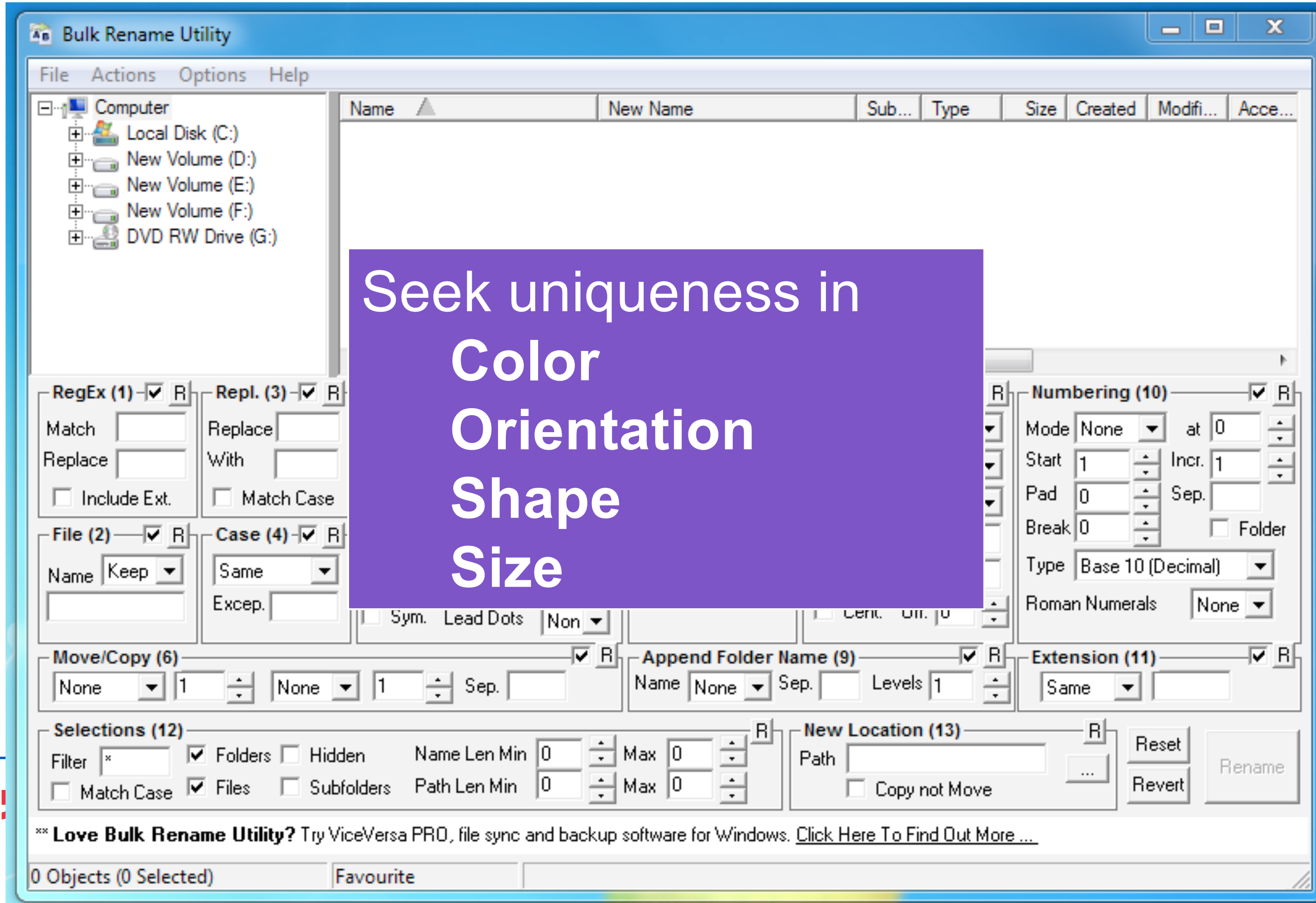
Ink per unit area
(Frank and Timpf 1994)

Density measures (Nickerson 1994)

- # of graphic tokens per unit area
- # of vectors needed to draw the visualization
- Length of the program needed to generate the visualization

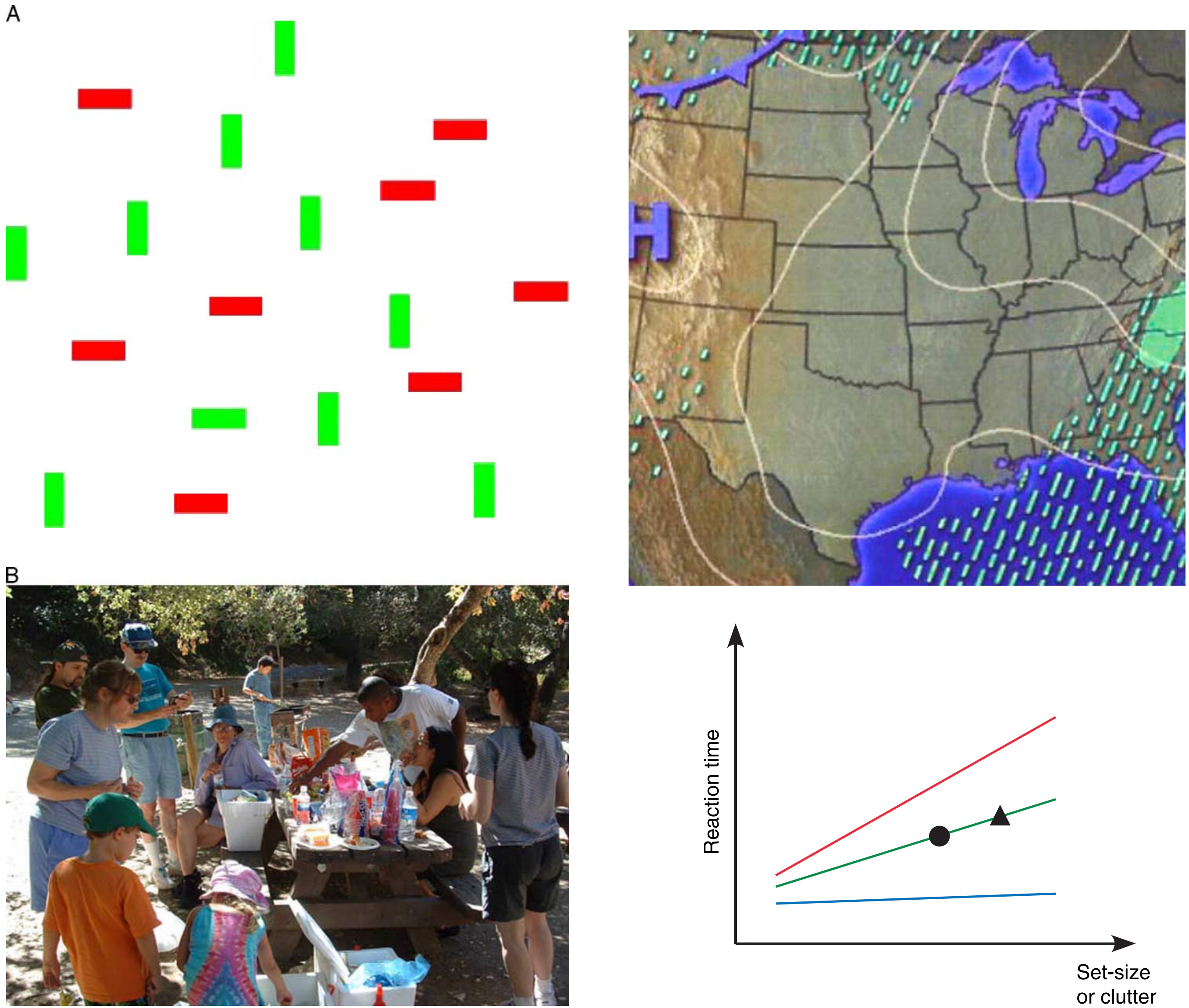

Q: Where would you place a note?

Q: How would you place an element?



Seek uniqueness in

- **Color**
- **Orientation**
- **Shape**
- **Size**


A
B
Reaction time
Set-size
or clutter

Q: How would you place an element?

Clutter as feature congestion

HVS has evolved to spot *unusual* items in scenes

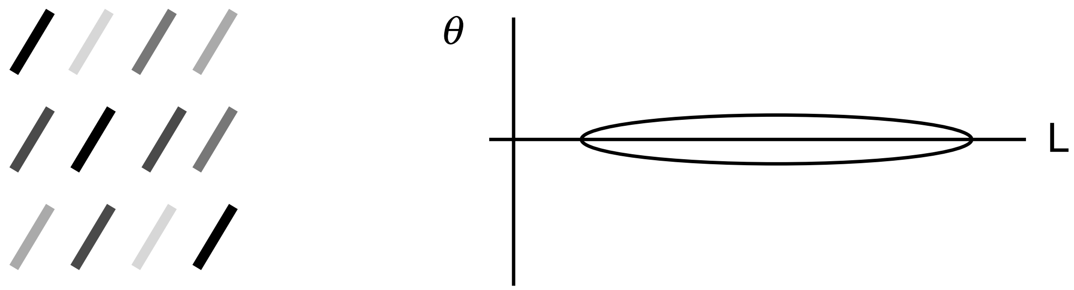
Clutter is the state in which excess items, or their representation or organization, lead to a degradation of performance at some task.

Excess and/or disorganized display items can cause

- crowding (Stuart & Burian, 1962),
- masking (Legge & Foley, 1980),
- decreased object recognition performance due to occlusion
- impaired visual search performance (Wolfe, 1998)
- forgetting due to exceeding the limits of short-term memory (Miller, 1994).

The idea (Rosenholtz)

If a feature vector is an outlier to the local distribution of feature vectors, then that feature is salient.



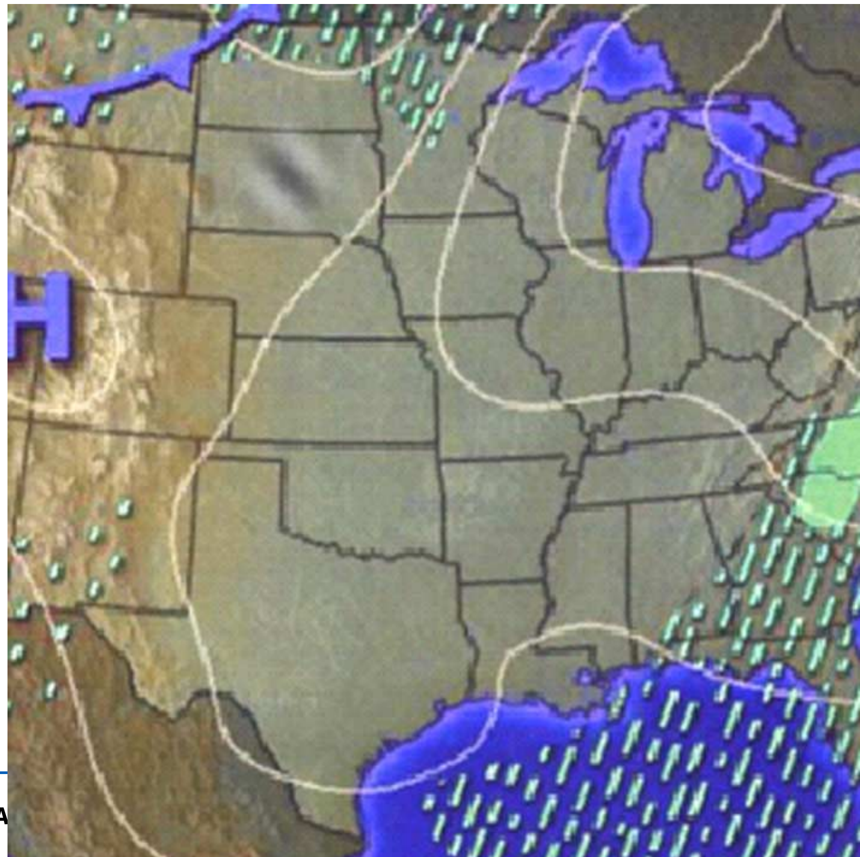
Feature Congestion model: Computation

1. **Compute local feature covariance per feature**
   - Luminance
   - Color
   - Orientation
2. **Combine across scale**
   - If congestion occurs at any scale → clutter
3. **Combine across feature types**
4. **Pool over space to get a single measure of clutter for each input image**

Empirical studies

Quickly, find scissors!

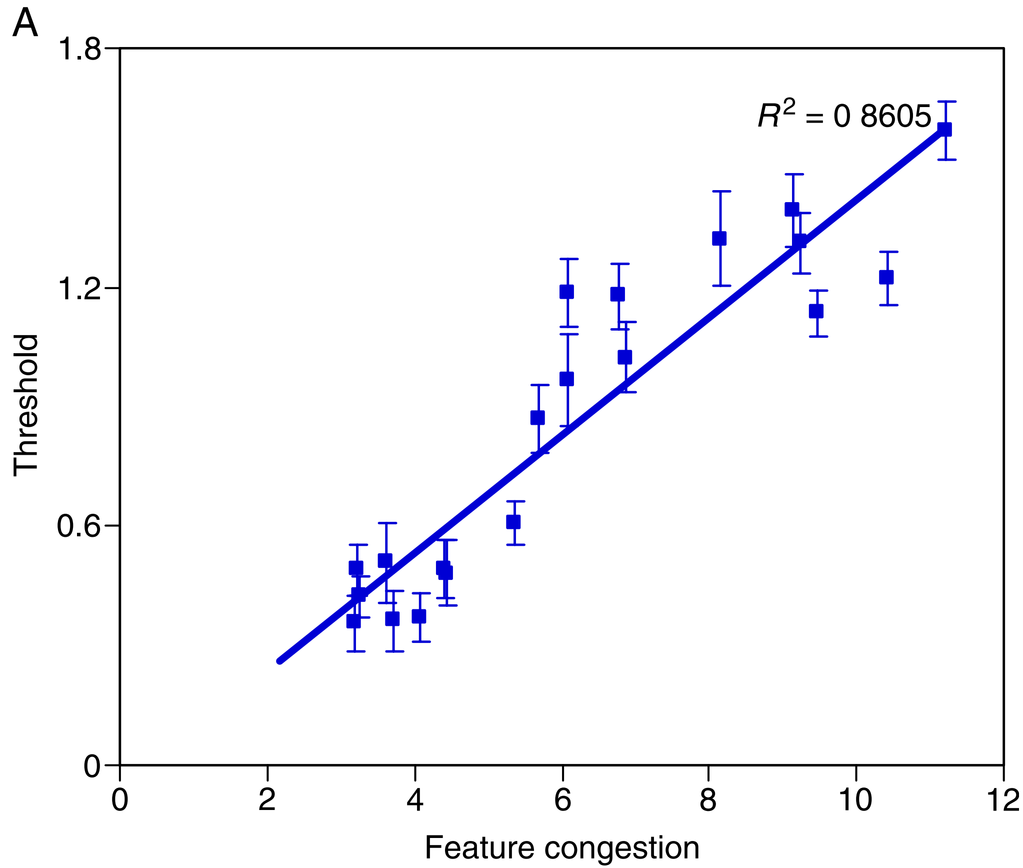
Typical tasks



Find the Gabor patch (gray “\”)

Find the arrow (pointing left)

Results


A
1.8
1.2
0.6
0
Threshold
R^2 = 0 8605
0
2
4
6
8
10
12
Feature congestion

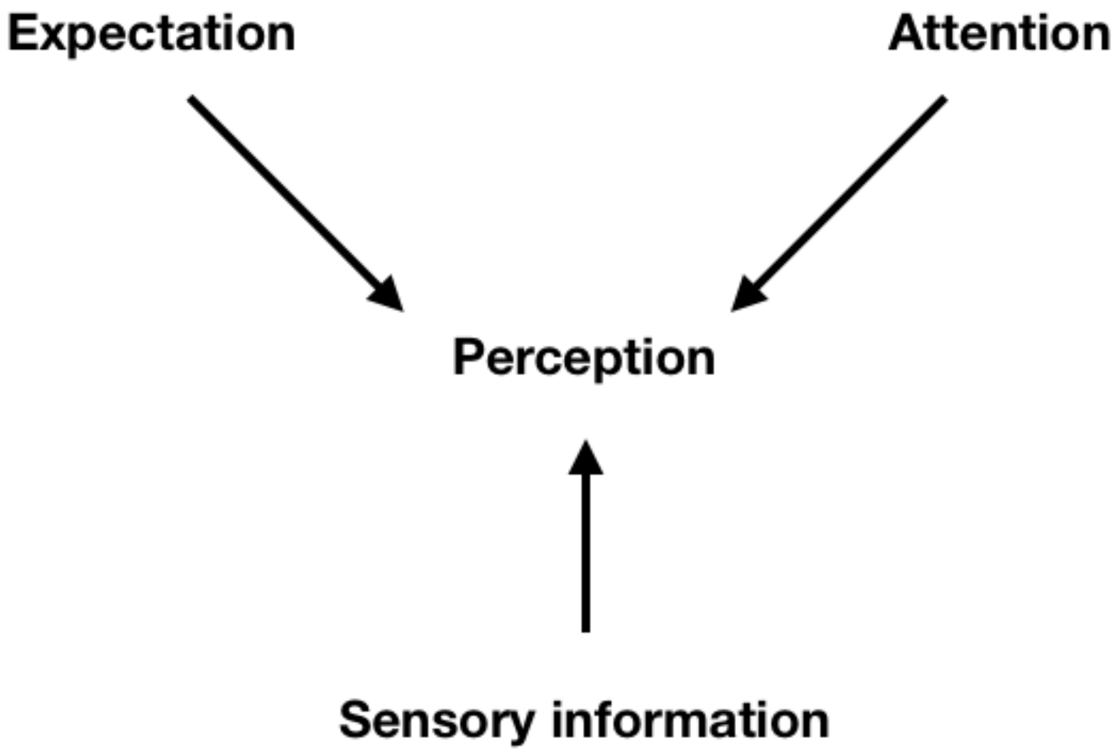
Summary

Clutter as feature congestion

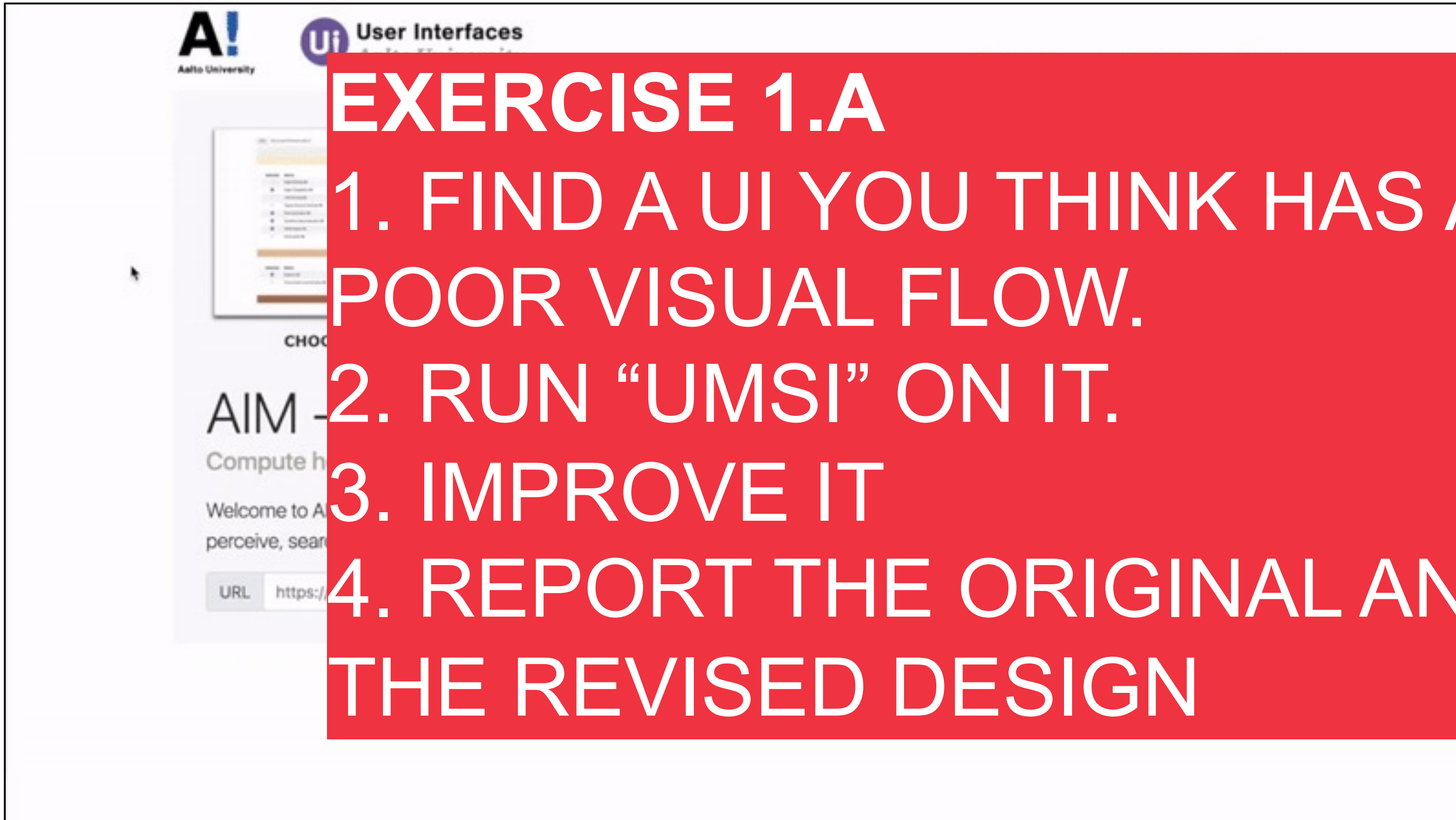
- **"Clutter is a state where nothing can be added that could be salient"**

Competition occurs *within* a cue type (color, luminance, orientation)

Summary



interfacemetrics.aalto.fi



EXERCISE 1.A

1. FIND A UI YOU THINK HAS A POOR VISUAL FLOW.
2. RUN “UMSI” ON IT.
3. IMPROVE IT
4. REPORT THE ORIGINAL AND THE REVISED DESIGN

https://shorturl.at/QjXyG

Aalto University

Motor control

Motor responses: The atoms of interaction

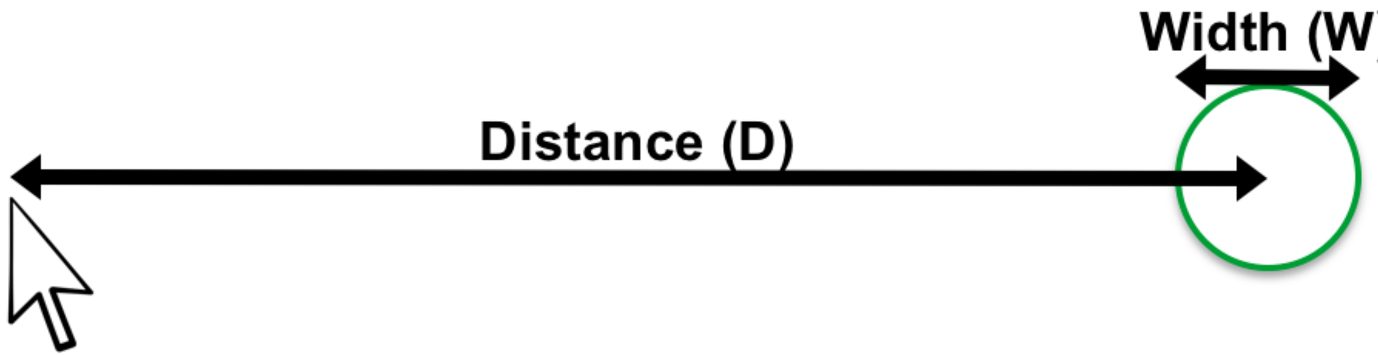
A few orienting questions

1. **Why are smaller targets harder to select?**
2. **Why do I fail in Level 20 or Flappy bird?**
3. **What is the probability of hitting into a car ahead of you if that car brakes?**
4. **Is the Qwerty layout optimal for German language?**
5. **What is the fastest possible time for an eSports player to shoot an enemy?**
6. **What is the fastest possible typing speed on an iPhone?**
7. **Why are gamers using joysticks *worse* than those using mouse+keyboard?**
8. **Why is it harder to draw a circle with a mouse than with a finger tip?**

Research on human motor control

Models of motor performance capture essential aspects of human performance in a statistically rigorous way

Example: Fitts' law



Fitts' law

$$MT = a + b\ \mathrm{ID} = a + b \log_2(D/W + 1)$$

Models of motor performance

What: Link performance-related variables to design-related and task-related variables

Why: Accurate and practical models to inform design and engineering

Statistical methods used for

- Model construction
- Model fitting
- Model validation
- Model selection

Learning objectives in this lecture

1. Motor response models
Motor performance in discrete input tasks, including aiming and choice

- Fitts' law
- Hick-Hyman law

2. Task performance models
Decomposition of task performance into elementary motor-cognitive actions

- KLM

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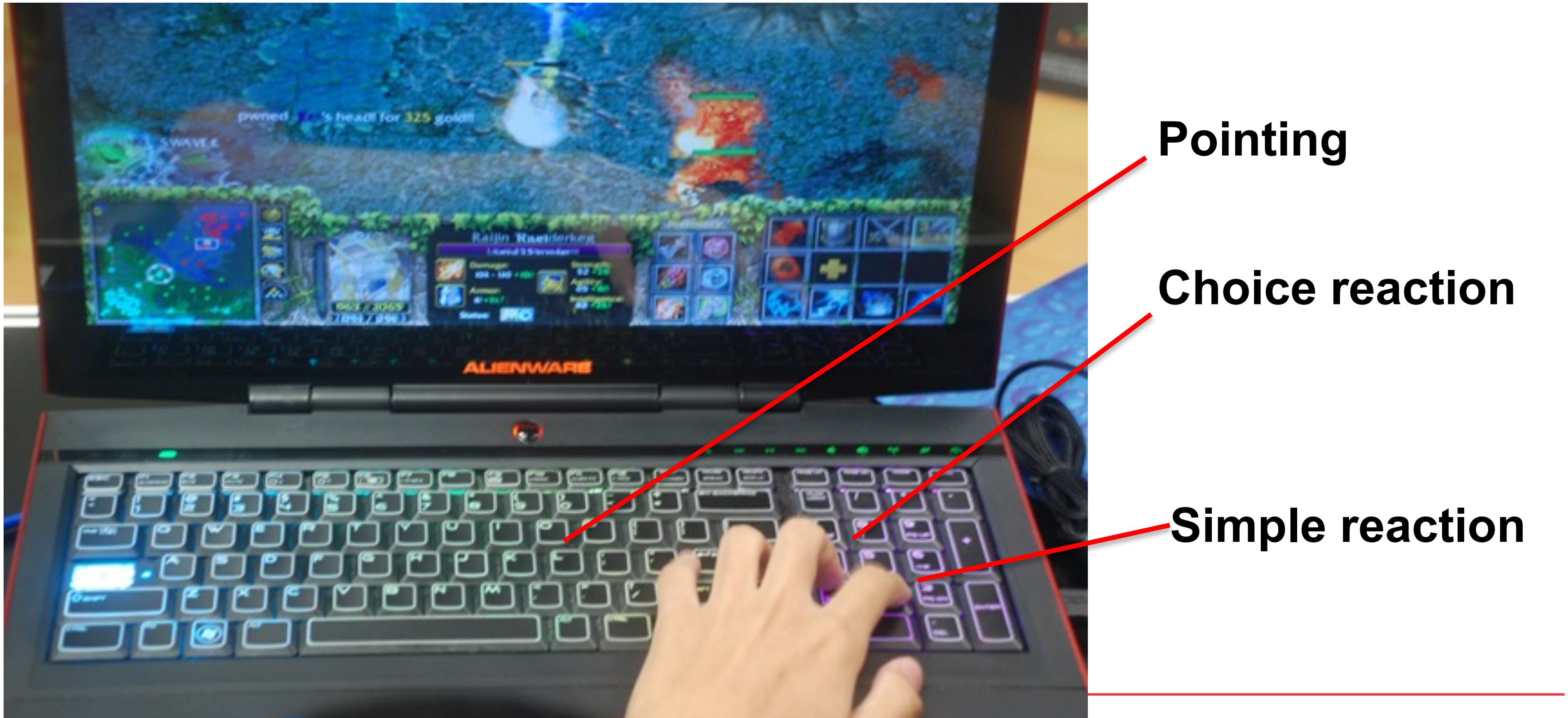
Introduction

Motor performance

Overview of motor responses



What is it?

A motor response is motor action taken by a user

- The user intends to select a particular (intended) option within a set of options offered at the moment
- This intention is communicated by moving an end-effector (e.g., finger tip, mouse cursor)
- To select a particular option (target), the end-effector must be brought within the spatio-temporal constraints that demarcate that target

In the beginning of a motor response

- The end-effector is in some state (initial position and velocity)
- The intended target is in some ego-centric relationship to the end-effector

A motor response consists of the trajectory of motion, and total response time, and the accuracy of the end point

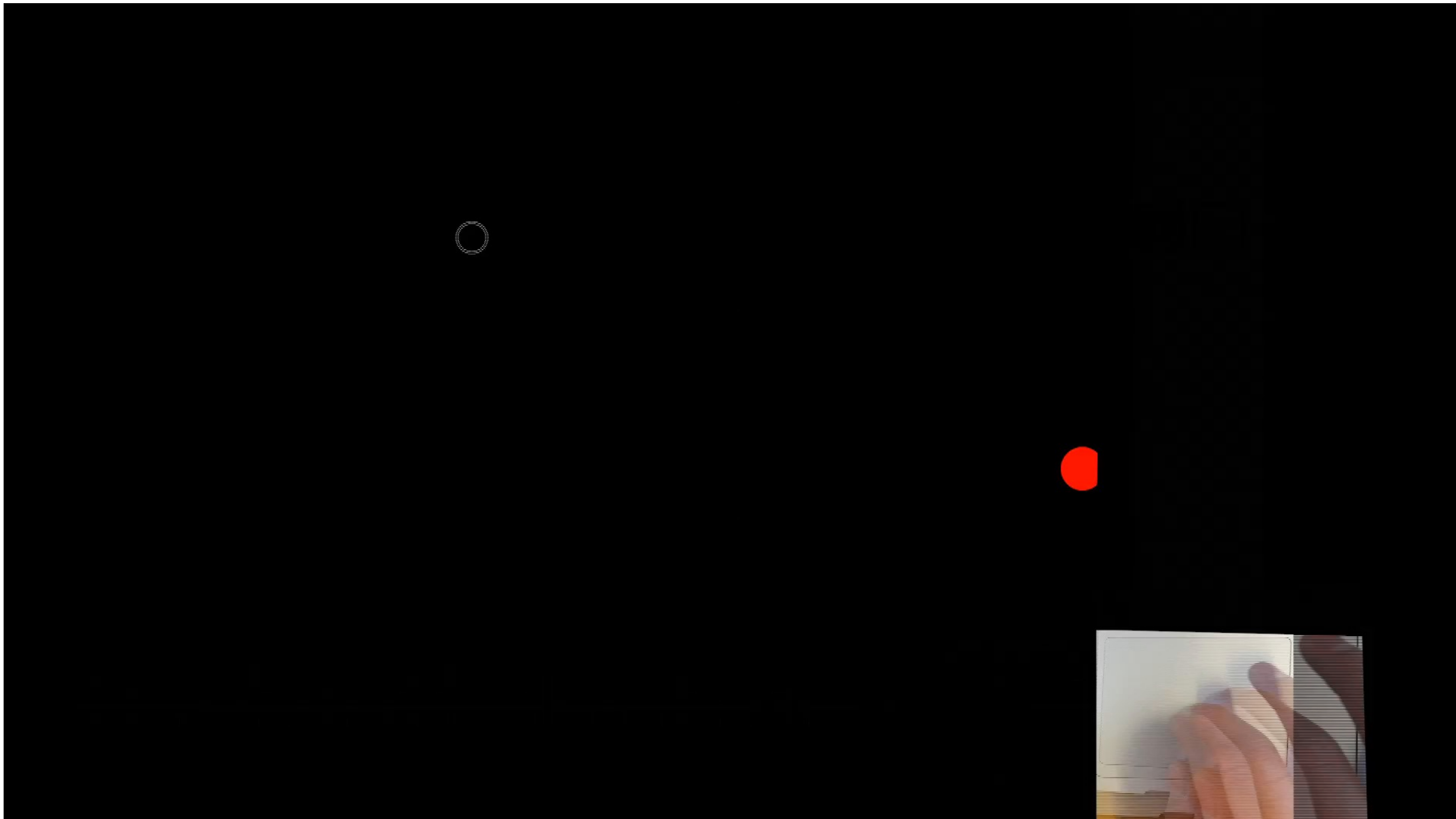
Q: Why is this NOT a response?

Types of motor responses 1/2

1. **Pointing**
   - Moving an end-effector across distance to a spatially defined target
   - Spatial demands posed to this response
     - *width of target*
     - *distance to target*
   - Performance objective
     - *Do this 'as quickly and accurately as possible'*
2. **Choice reaction**
   - Select a target by pressing the button that is the intended target
   - Choice demand
     - *selecting the right option among many*
   - No spatial demand
     - *No need to move end-effectors, as fingers are already on the buttons*
   - Performance objective
     - *'as quickly and accurately as possible'*

Illustrating spatial demands

(changing target distance and size)



Buttons on a patient monitor

Playing subway Surf

Types of motor responses 2/2

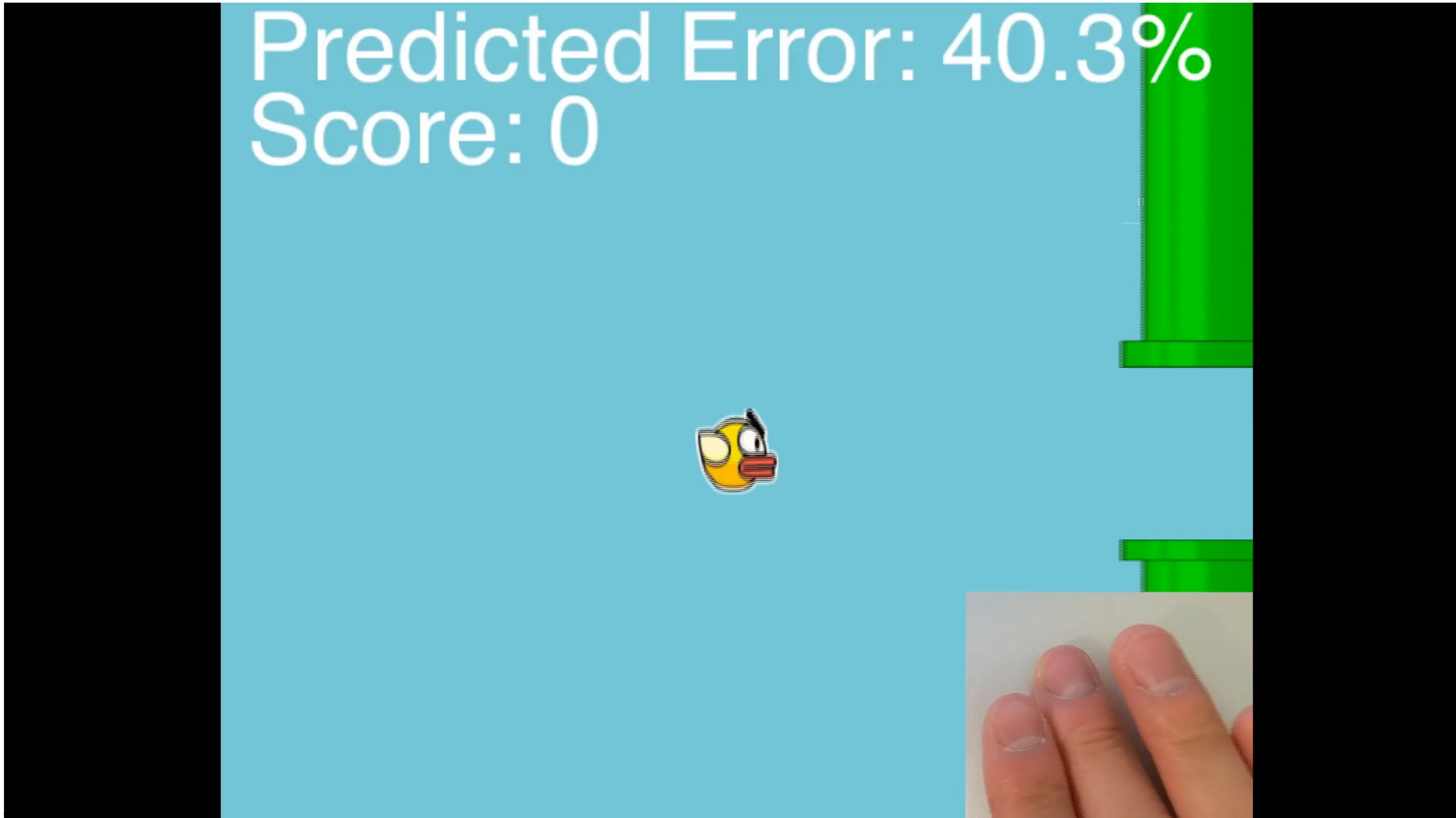
3. Temporal pointing

- Selecting a temporally moving target
- Temporal demands posed to this response
  - *width of target (in time)*
  - *distance to target (in time)*
- Performance objective
  - *Do this 'as accurately as possible'*

4. Interception

- Select a moving target by moving an end-effector on top of it
- The size and movement of the target object defines the spatial and temporal demands
- Performance objective: 'quickly and accurately'

Temporal demands



Interception

A spatially and temporally bound target

Empirical factors affecting performance in interception tasks

No. of response options

No. and type of distractors

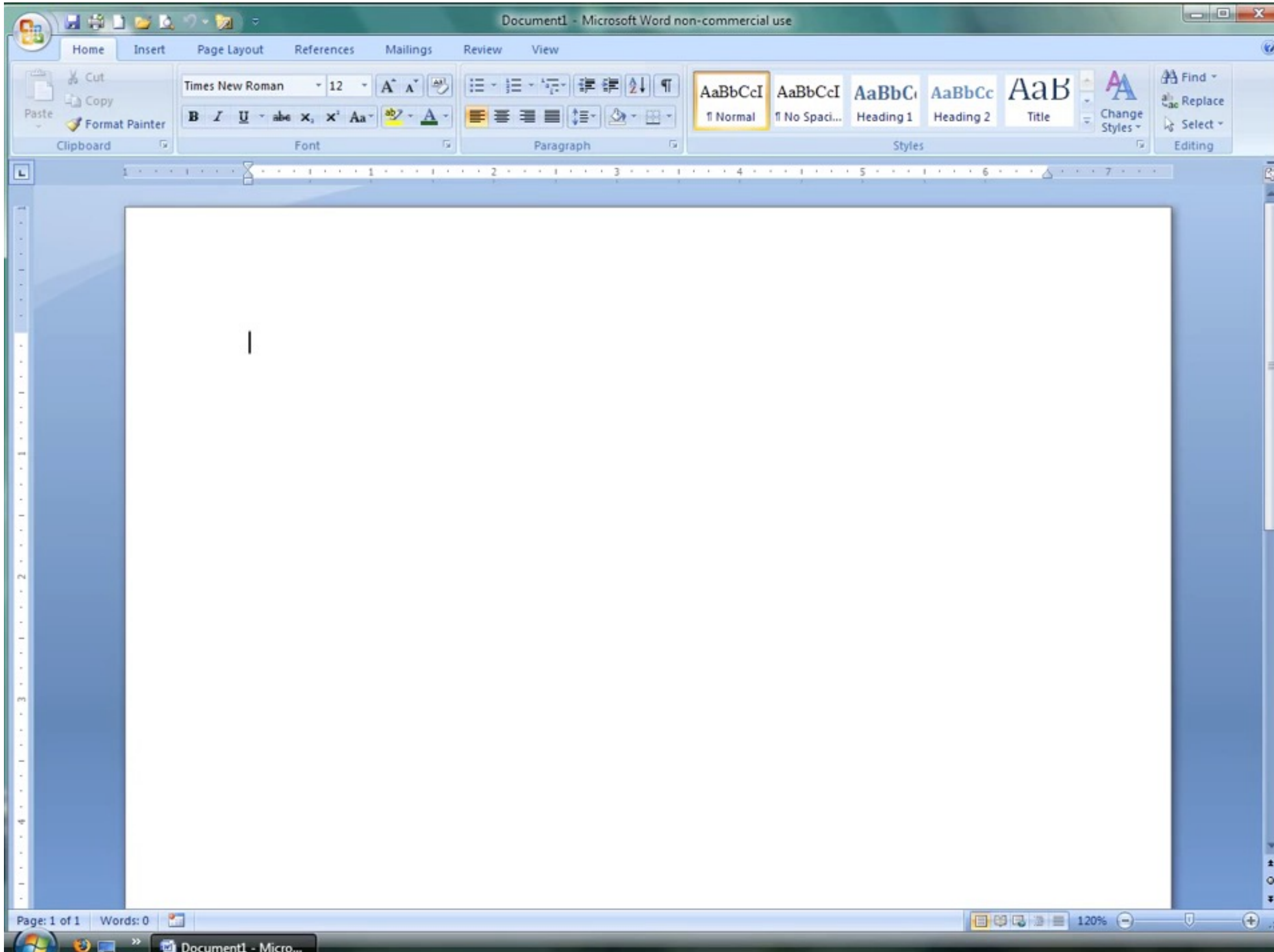
Visibility of target

Preview time

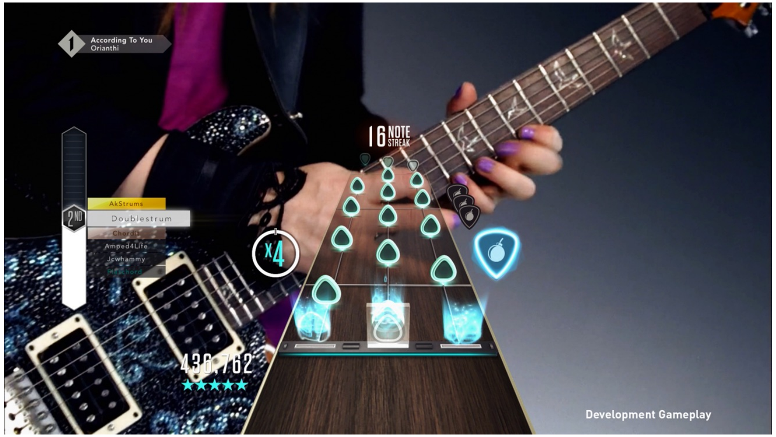
Input device

Feedback

Example: Microsoft Word



Q: Which response type?



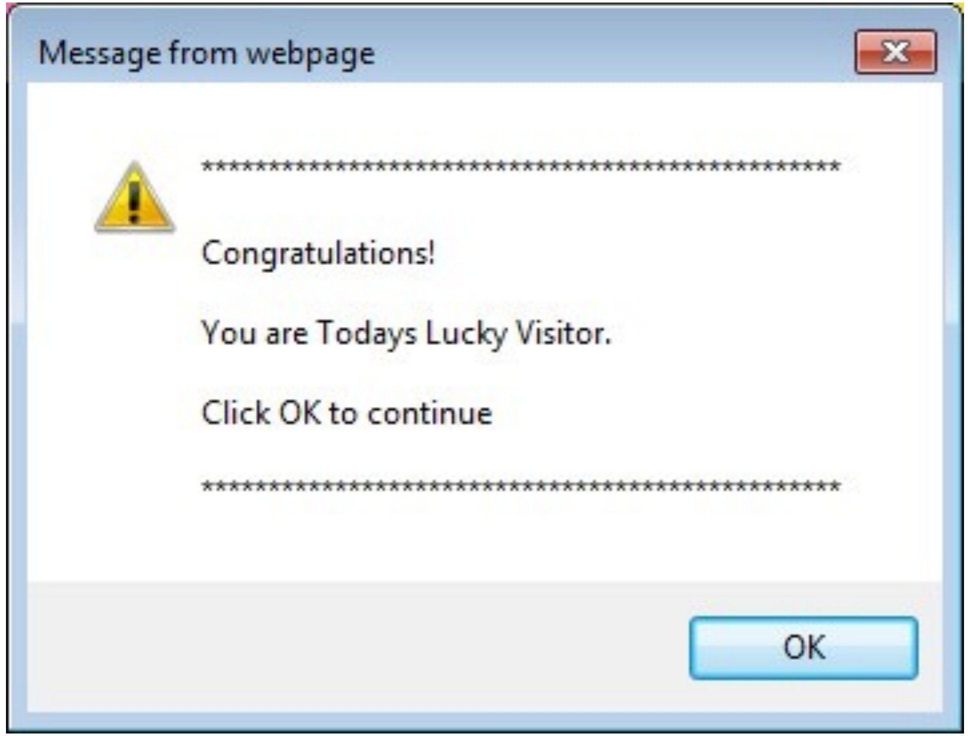
Why is this topic important?

Basic capabilities and limitations of humans in interaction

The "atoms of interaction": Motor responses underpin almost all human-technology interaction

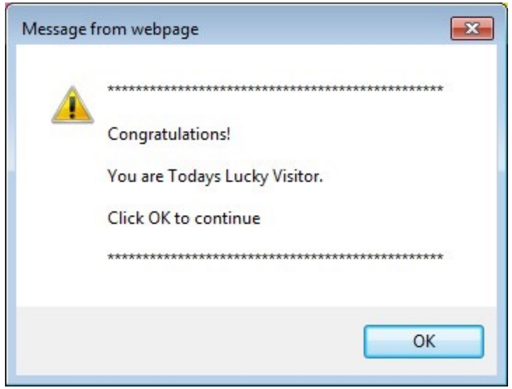
Models allow you to find optimal tradeoffs among design decisions

You can exploit them computationally in the generation, refinement, and adaptation of user interfaces


Message from webpage
****
Congratulations!
You are Todays Lucky Visitor.
Click OK to continue
****
OK

Analyzing a motor response

1. **Response set**
   - What are the available actions?
     - *List all the options that user has in this state*
2. **Response type**
   - Identify the type of motor response in question
     - *Pointing, choice, or both?*
3. **Performance objective**
   - Is the user trying to be fast or accurate or both?
4. **Initial state**
   - What is the initial state of the end-effector?
5. **Response demands**
   - Characterize the spatial and temporal demands of the intended target in relationship to the initial state



We need such analysis to translate everyday motor responses for modeling...

Emergency braking: Push the right pedal immediately

Calling an elevator: Hit the right button and get it activated; no hurry

Choosing an item to buy in Amazon: Select the correct one item, but there's no hurry

Example: Braking

1. The response set?
2. The response type?
3. Performance objective?
4. Initial state?
5. Response demands?

Learning objectives for motor response models

Recognize the right response type in a given setting

Know the two basic models (Fitts' law and Hick's law) and understand their scope: when they can/cannot be applied

Use models to compare and enhance designs

Analyze trade-offs in design by applying a model

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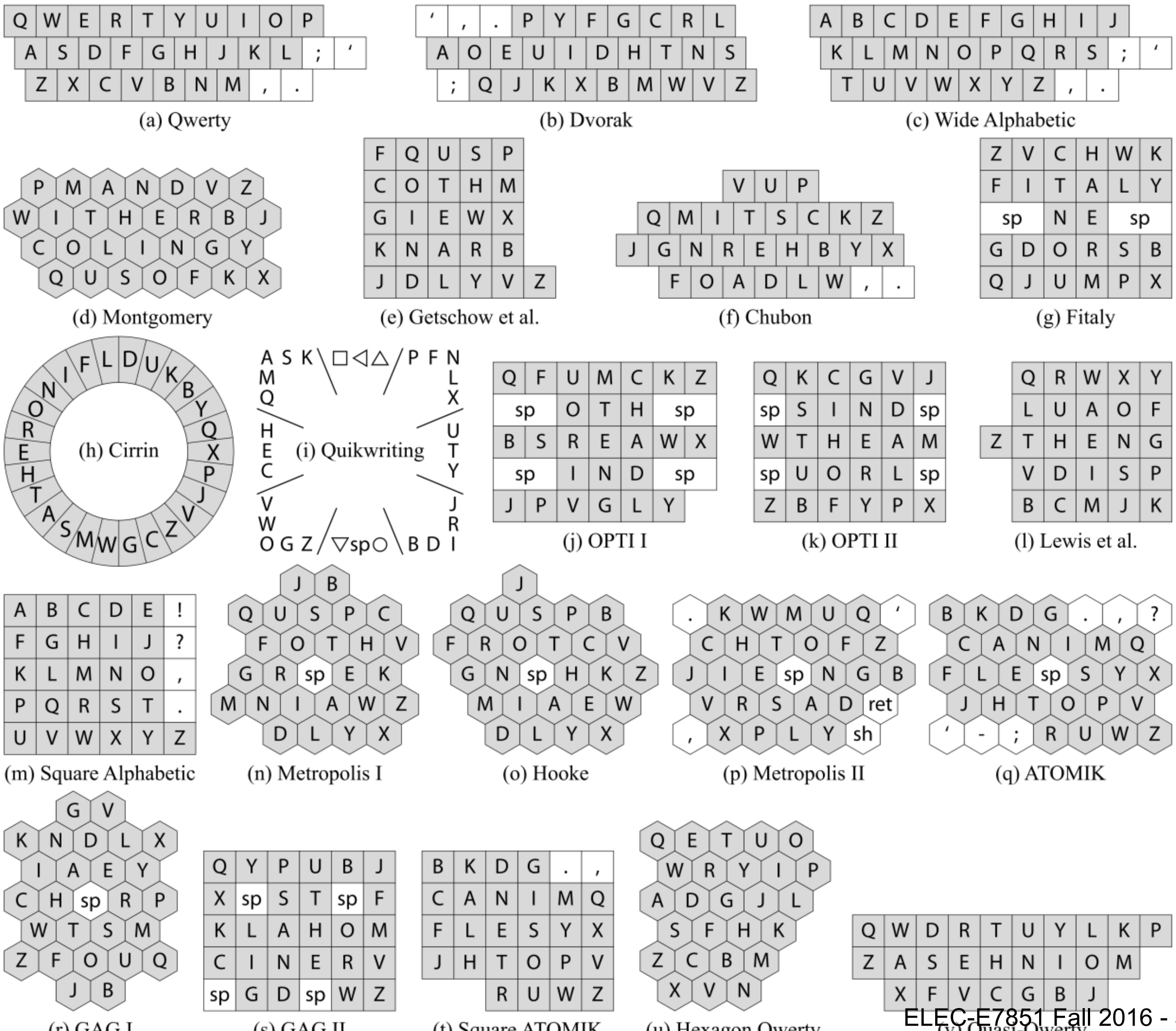
Application examples

Applications: Improve layouts

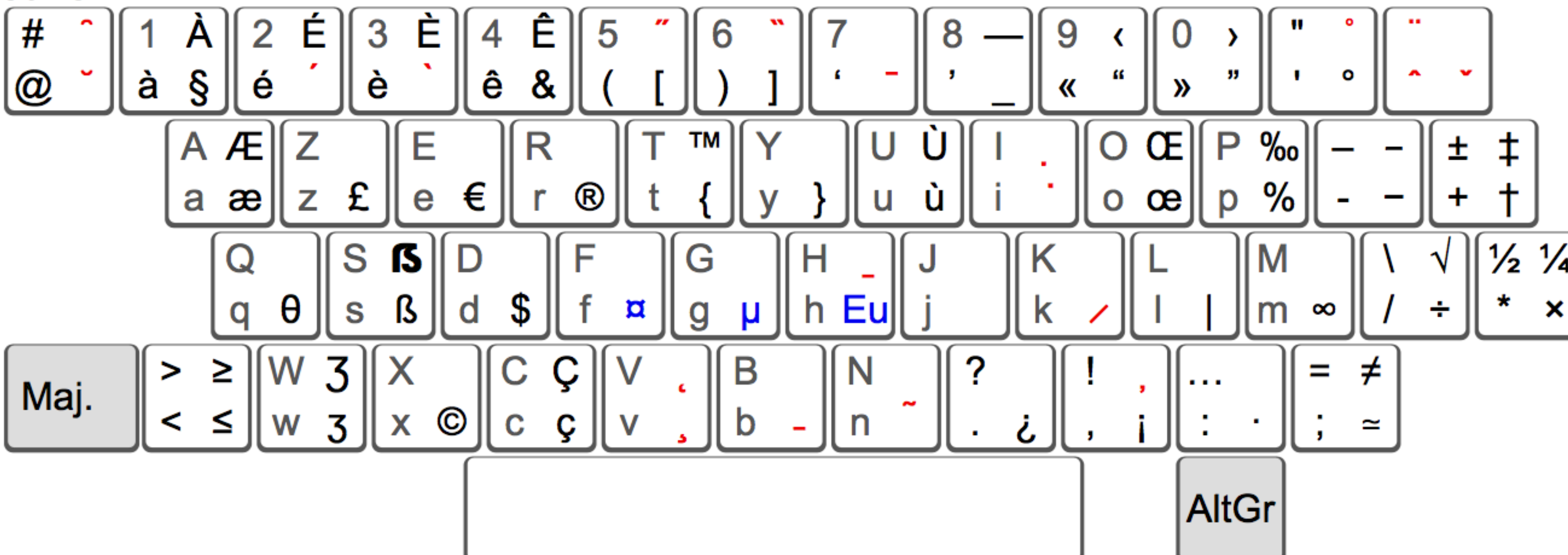
Figure 1. Pareto optimized Arabic keyboard layout

El Batran & Dunlop CHI’13


(a) Qwerty
(b) Dvorak
(c) Wide Alphabetic
(d) Montgomery
(e) Getschow et al.
(f) Chubon
(g) Fitaly
(h) Cirrin
(i) Quikwriting
(j) OPTI I
(k) OPTI II
(l) Lewis et al.
(m) Square Alphabetic
(n) Metropolis I
(o) Hooke
(p) Metropolis II
(q) ATOMIK
(r) GAG I
(s) GAG II
(t) Square ATOMIK
(u) Hexagon Qwerty
(v) Quasi-Qwerty

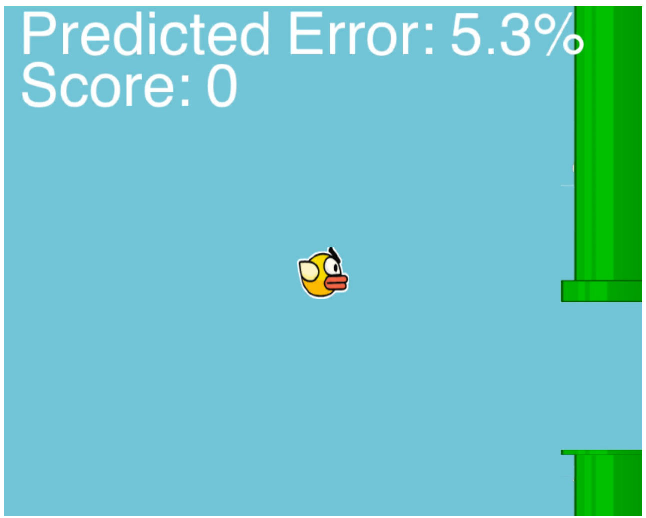
The new Azerty standard in France was optimized using motor response models

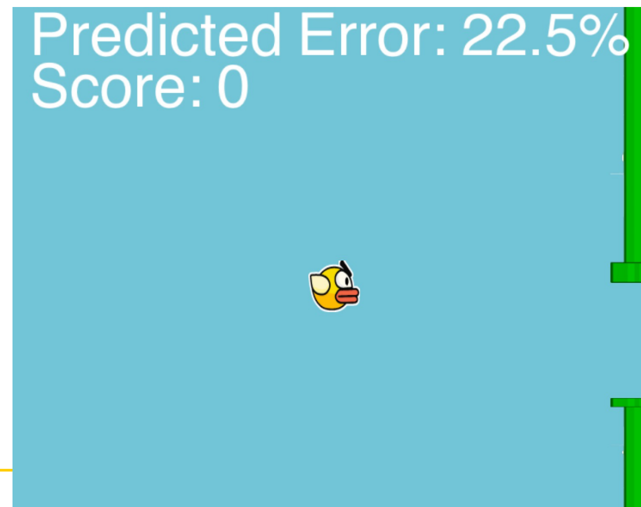
Nouvel AZERTY

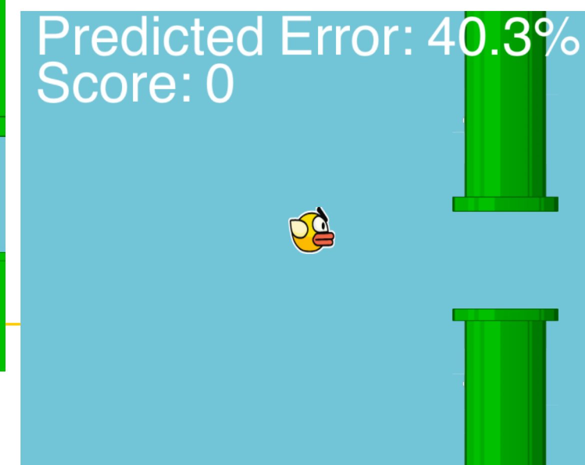


Design game levels: Control the level of difficulty

Example: Increasing temporal pointing demand to control the probability of game character dying





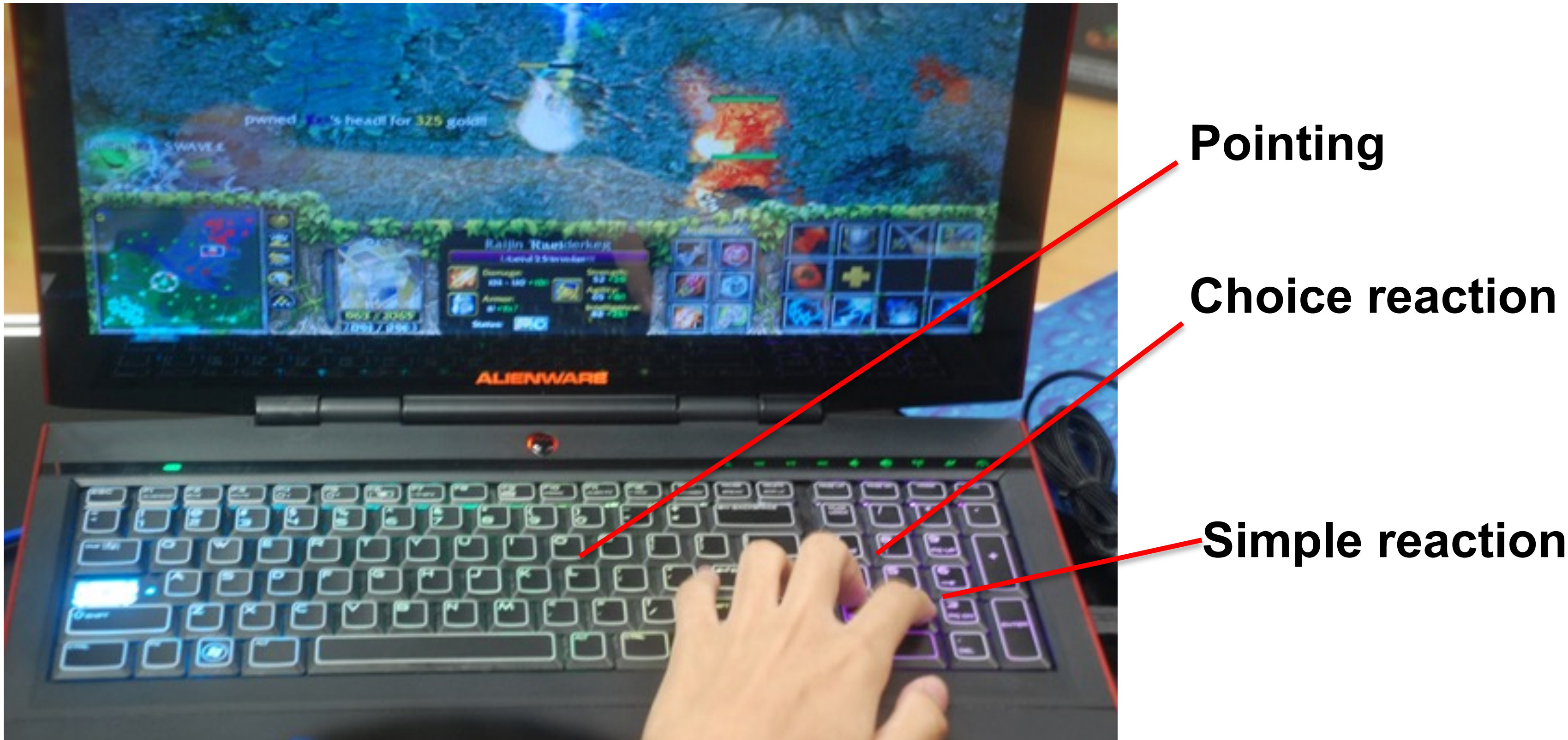


Goals today:
1. Fitts' law
2. Hick-Hyman law

Motor Response Models

From simple reaction to aimed movement

Overview



Overview

The mathematical formula will be given in Assignments, we here focus on the main concepts

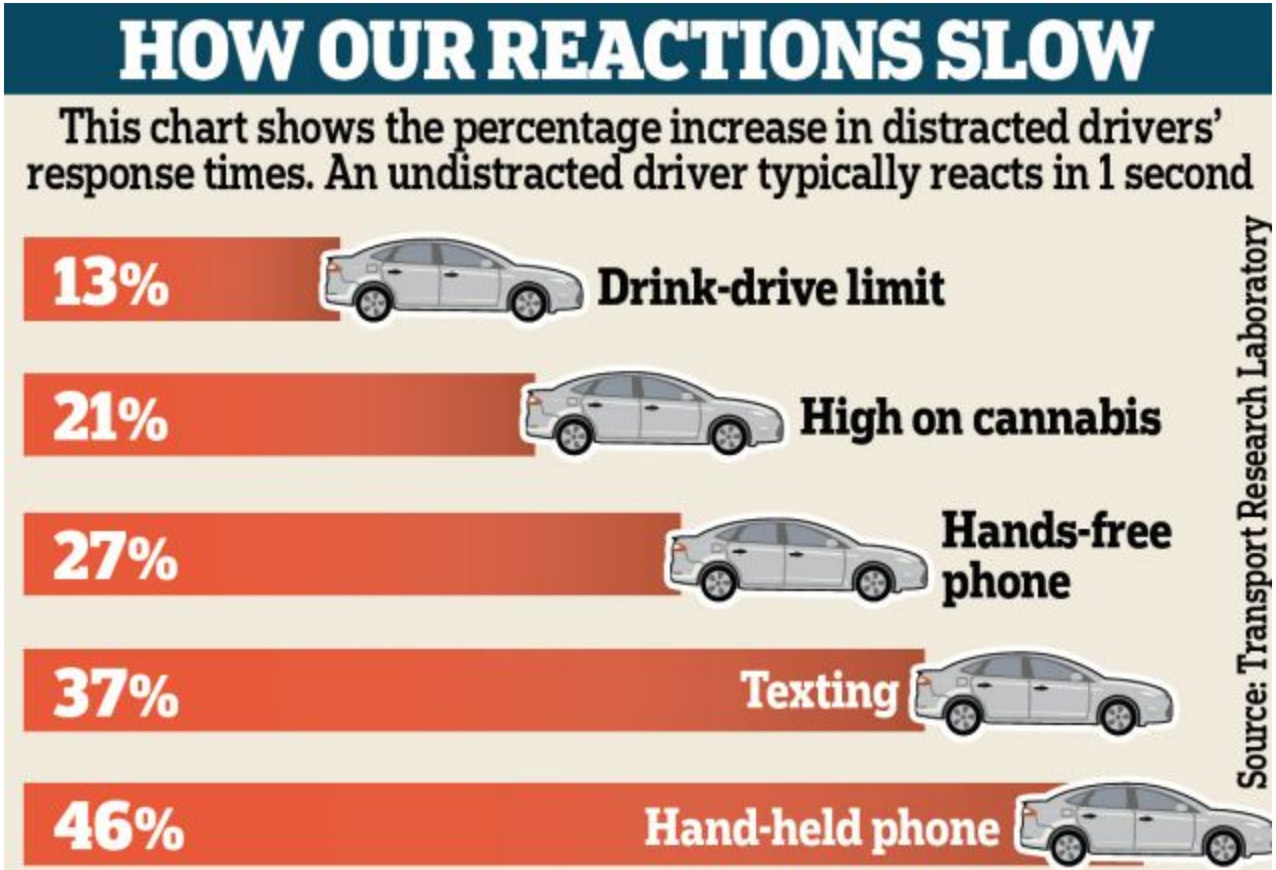
Heads up:

These models contain empirical parameters (coefficients) that are task- and user-specific

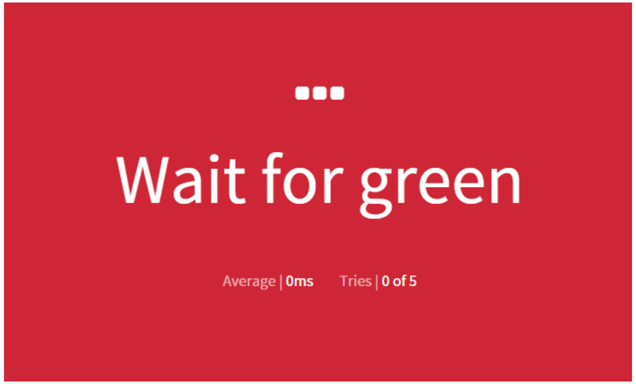
- Empirically obtained or inferred from data
  - Example: Using OLS (Ordinary Least Squares) to fit the two parameters of Fitts' law

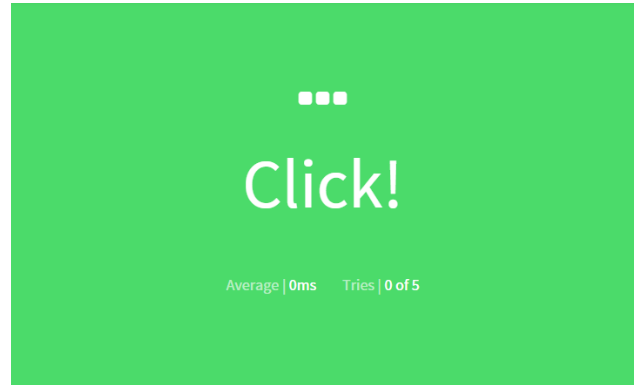
Simple reaction

Reaction times

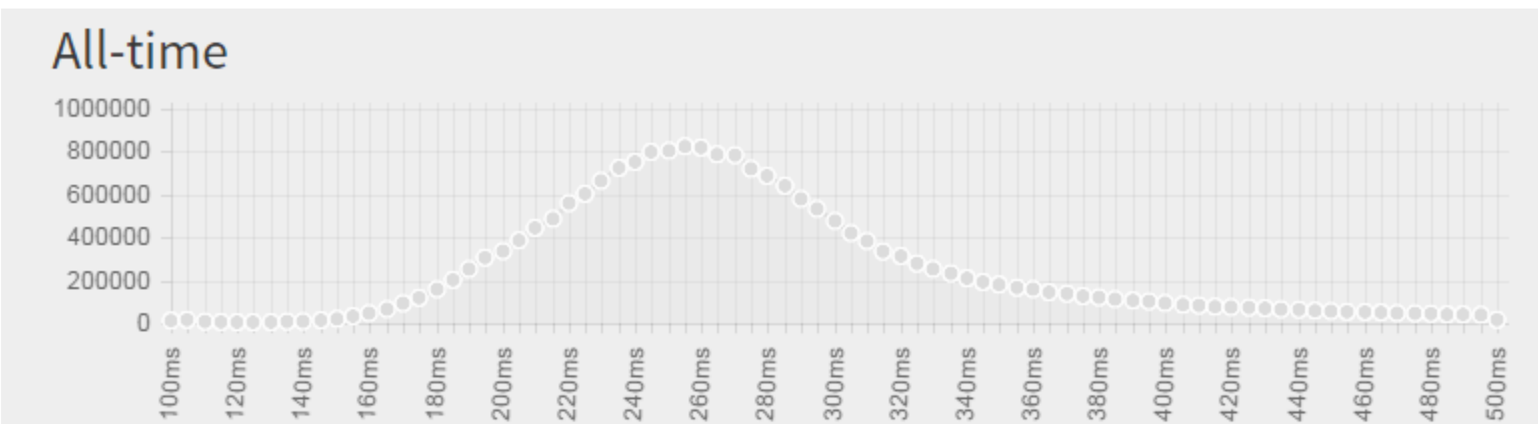


Reaction times “in the wild”





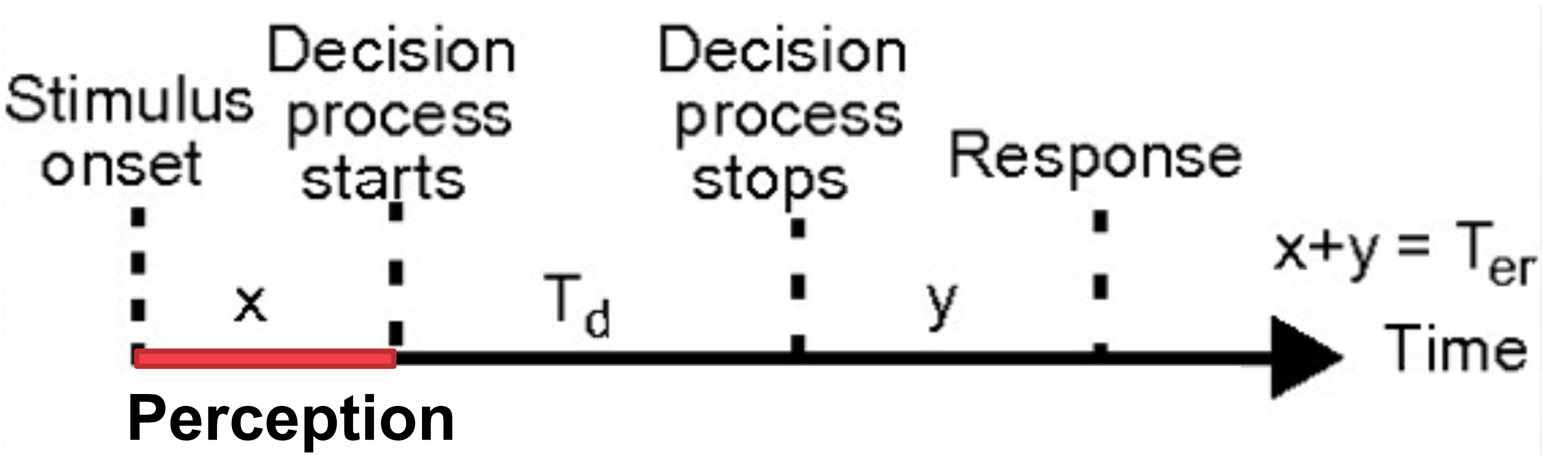
Over 22 million responses
Mean: 268 ms



humanbenchmark.com

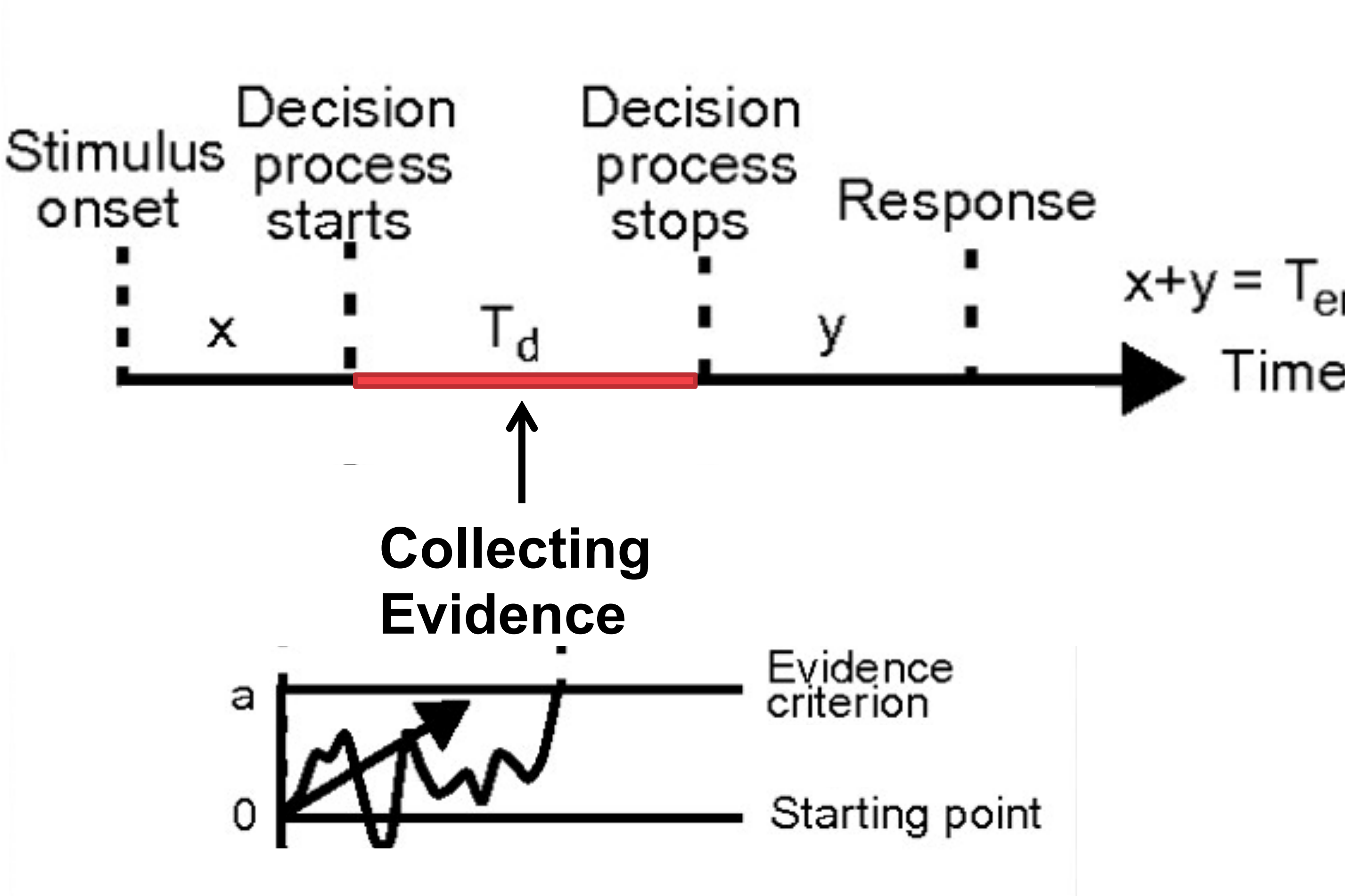
Case: Braking

Ratcliff model

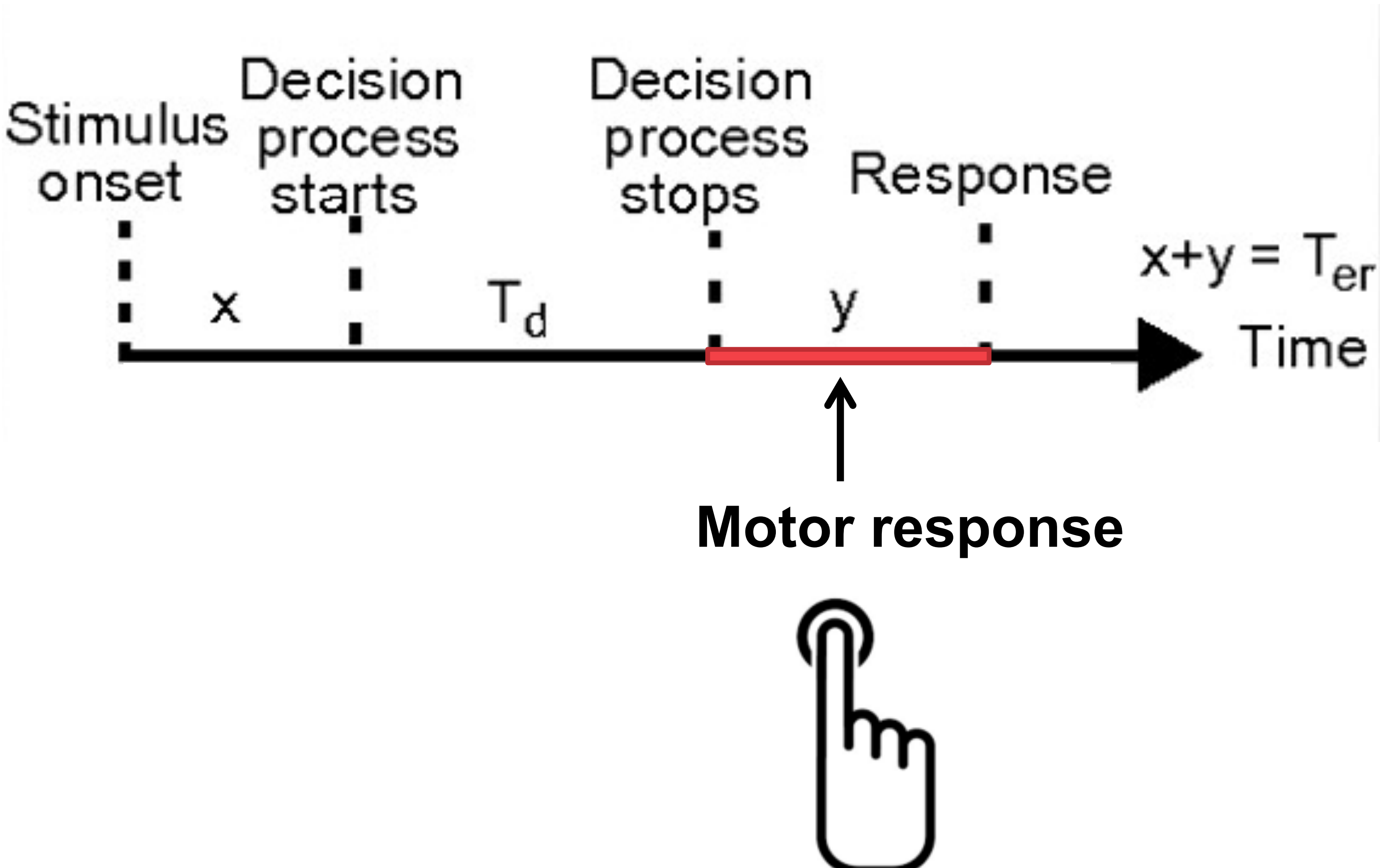


Perception and Encoding

Ratcliff model



Ratcliff model



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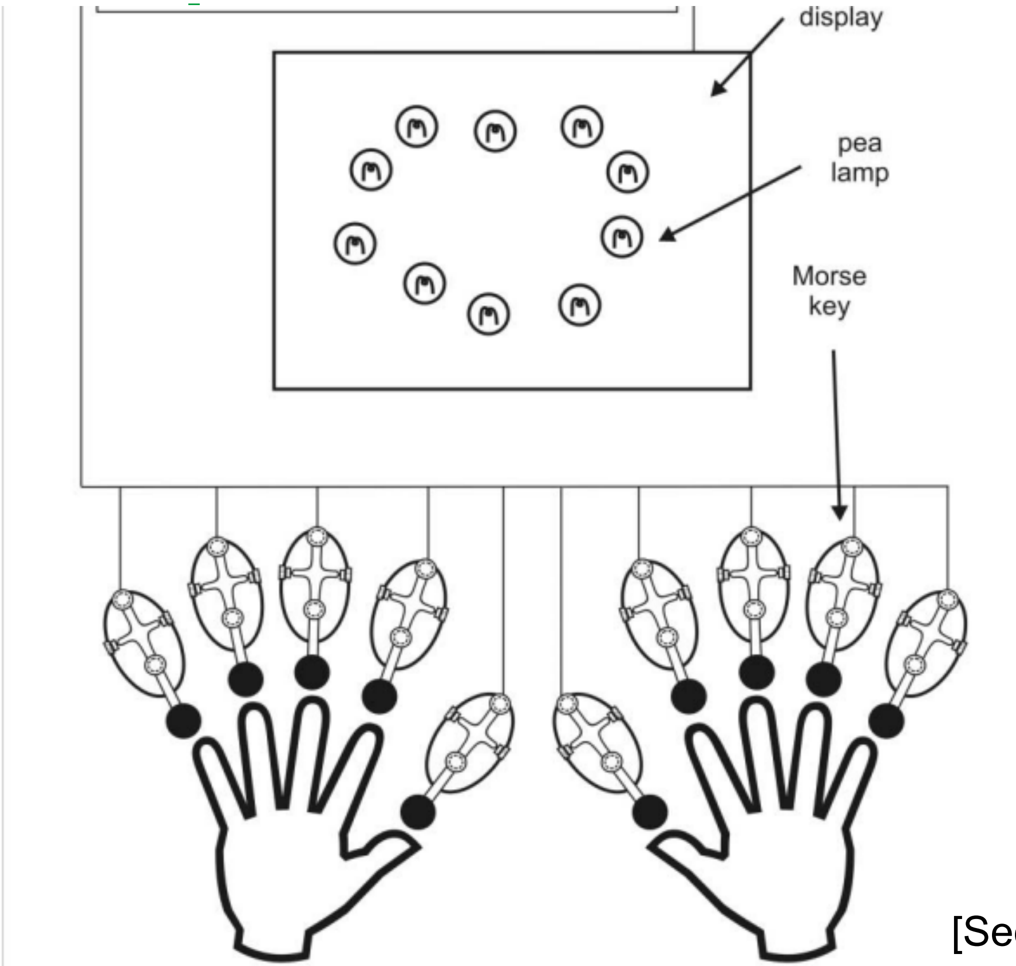
Choice reaction

A generalization of simple reaction (number of options N=1) to the case of N>1

Examples of choice reaction

Time taken to respond to a stimulus **appropriately**

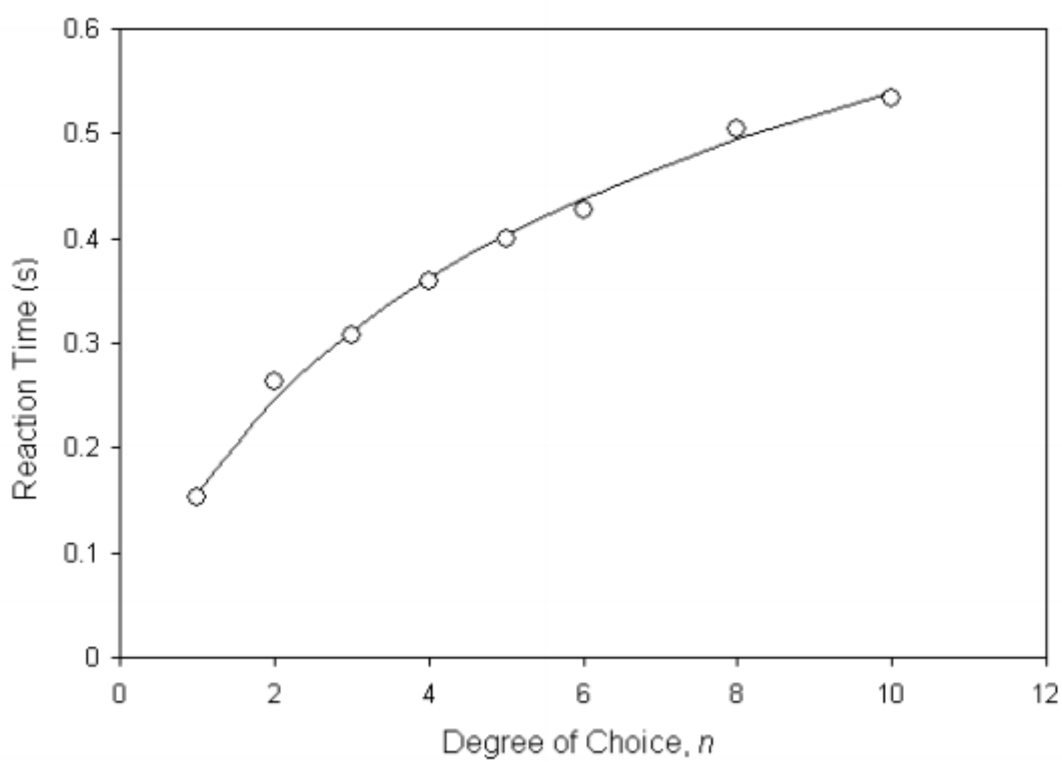
Hick's experiment



[Seow 2005]

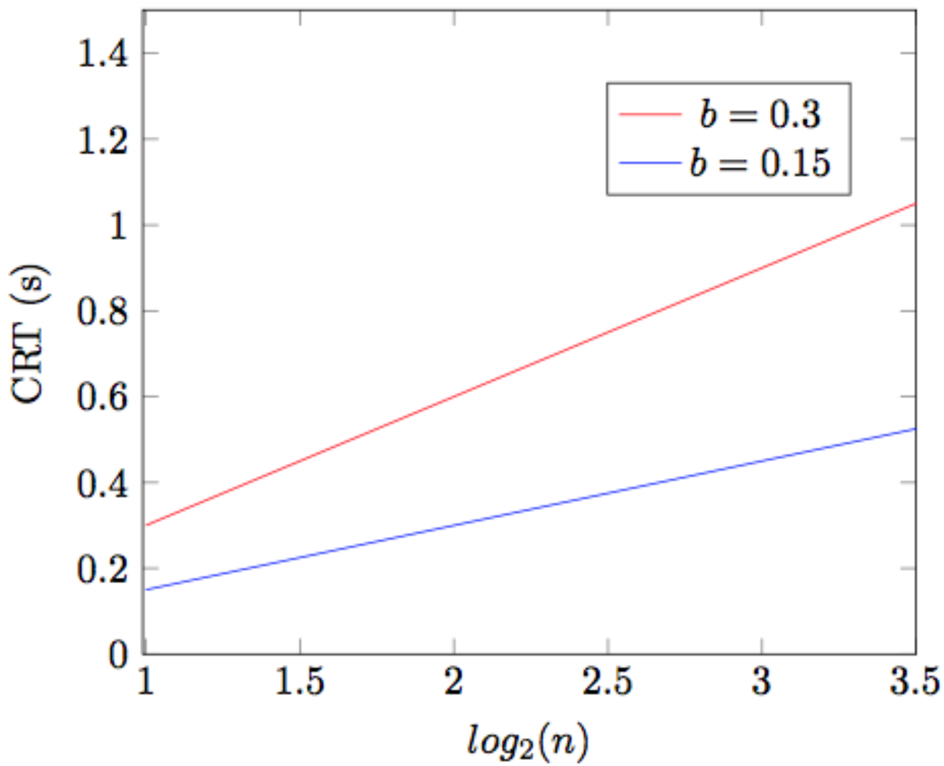
CRT as a function of number of options

$$RT = a + b\log_2(n)$$



CRT = choice reaction time

Comparing two users / devices



Information-theoretical interpretation

Reaction time increases with the amount of ***information***

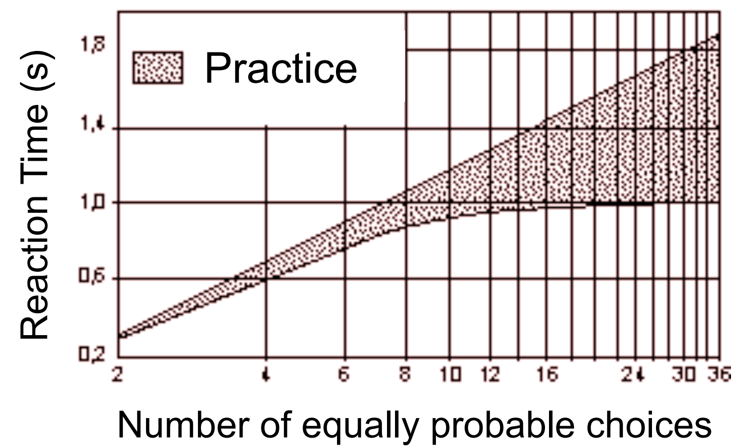
All choices have equal probability:

$$RT = a + b\log_2(n)$$

Choices have different probabilites:

$$RT = a + b \cdot H$$

$$H = -\sum_{i=1}^{n} p_i \log_2 p_i$$



Example: Game

Press arrow key to start

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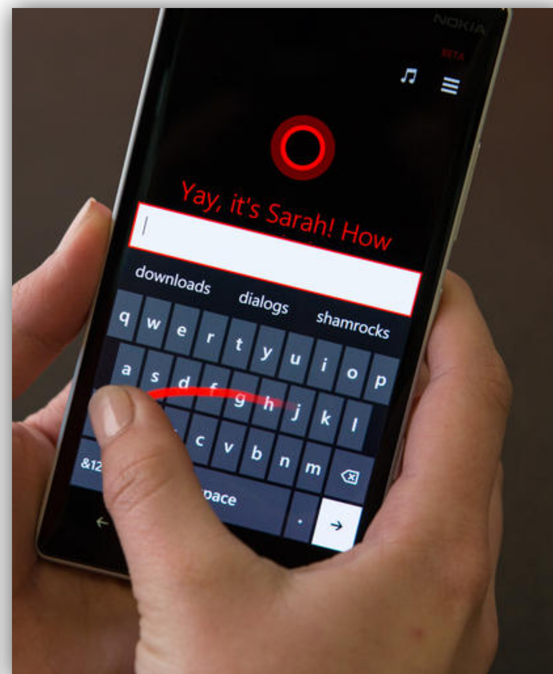
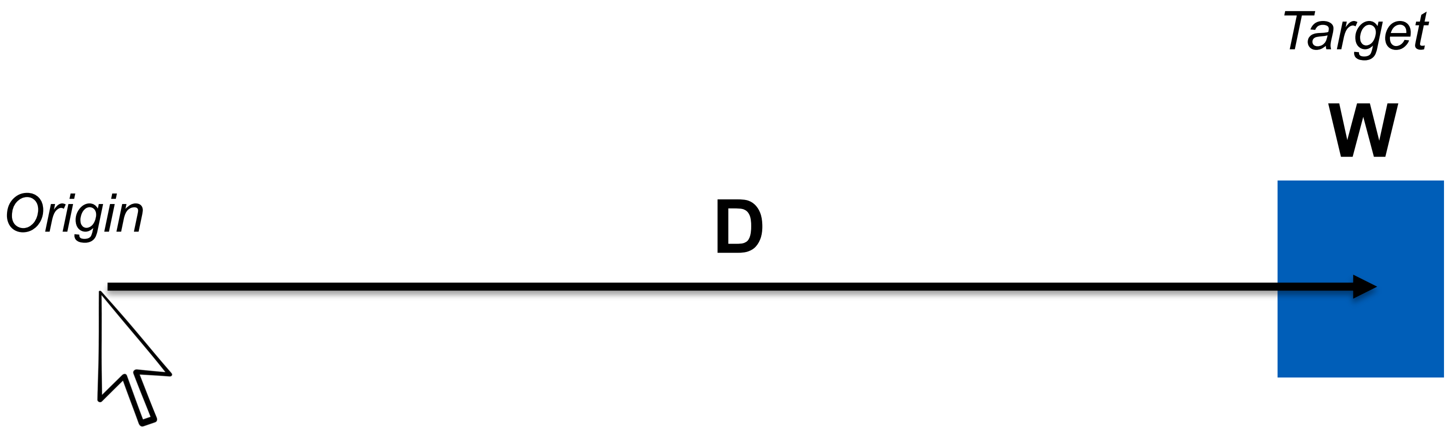
Aimed movements: Fitts’ law

Aimed Movements

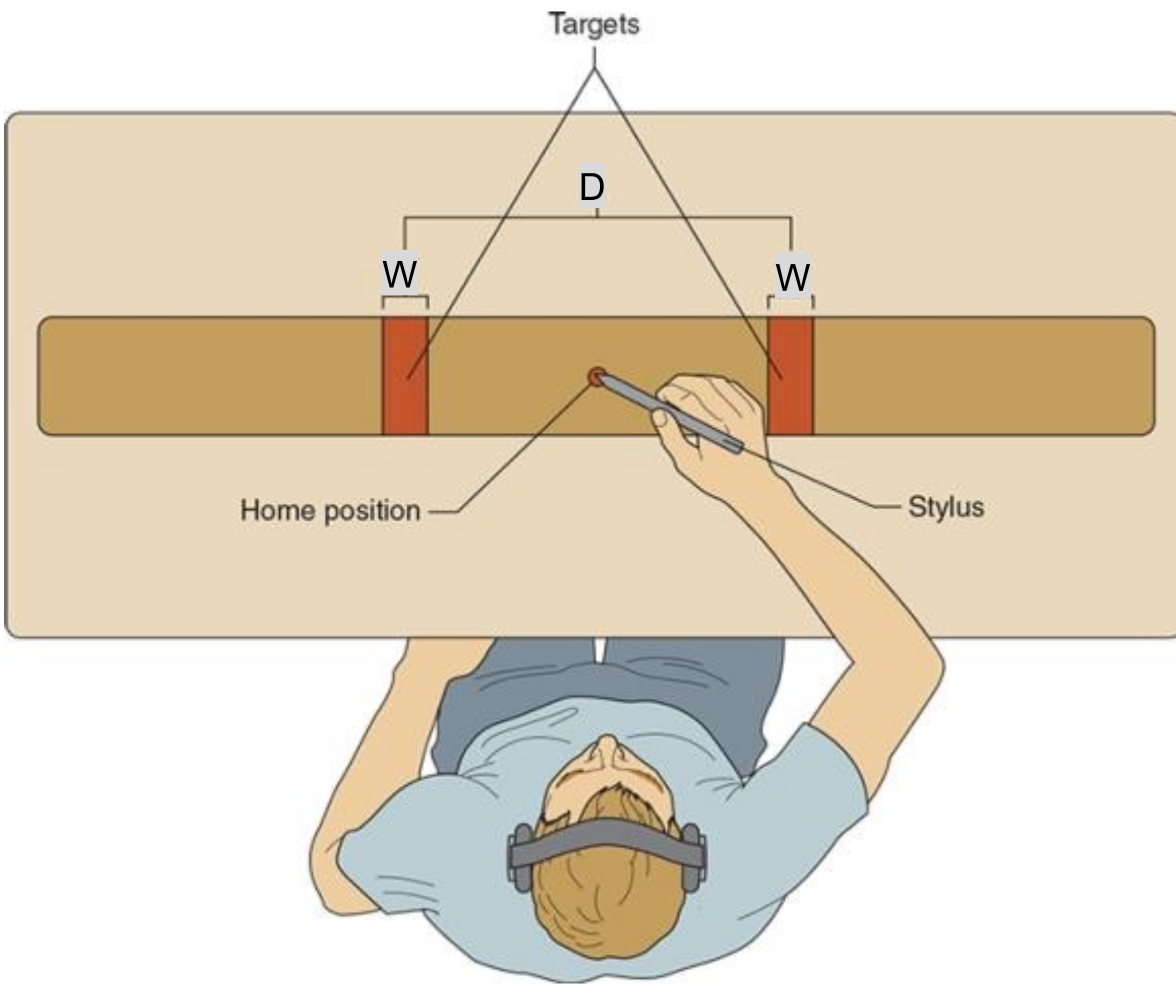


Response demands in pointing

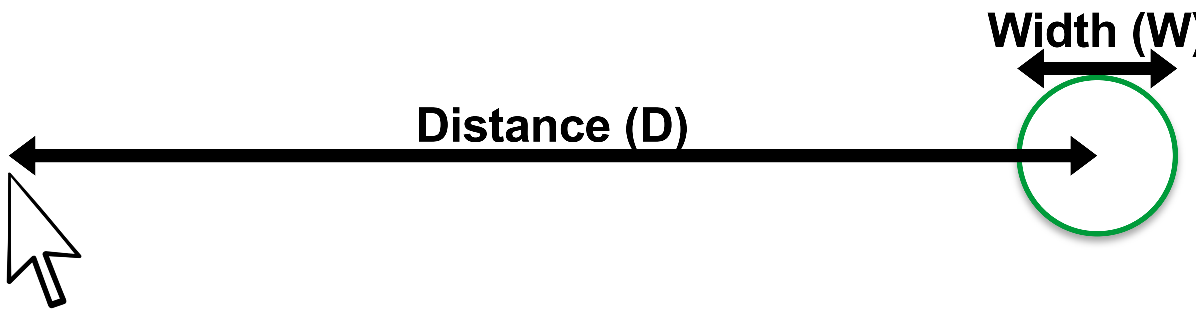
“Select the target as quickly as you can”



Reciprocal pointing experiment



Fitts' law: Idea



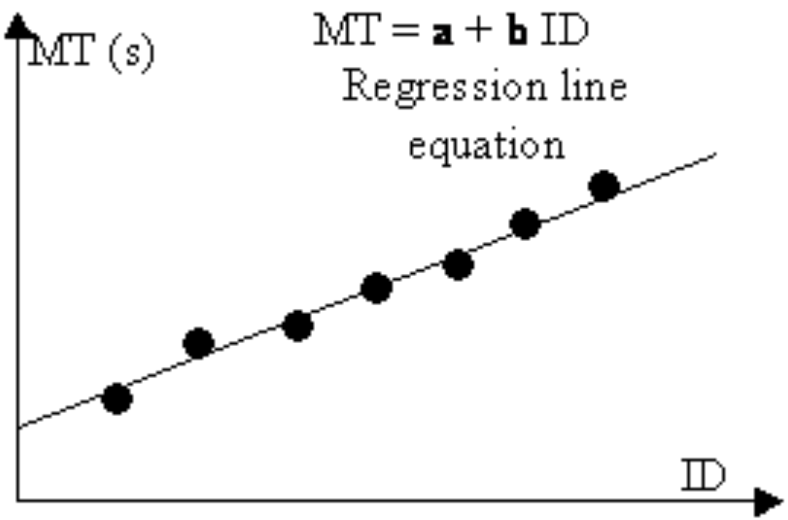
Fitts' law

$$MT = a + b\ \mathrm{ID} = a + b \log_2(D/W + 1)$$

Index of Difficulty

Q: Draw “the Fitts’ diagram”

X-axis: ”Index of difficulty”
Y-axis: Movevement time



Fitts' la
motor

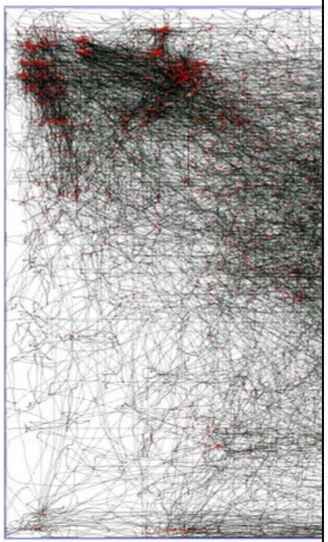
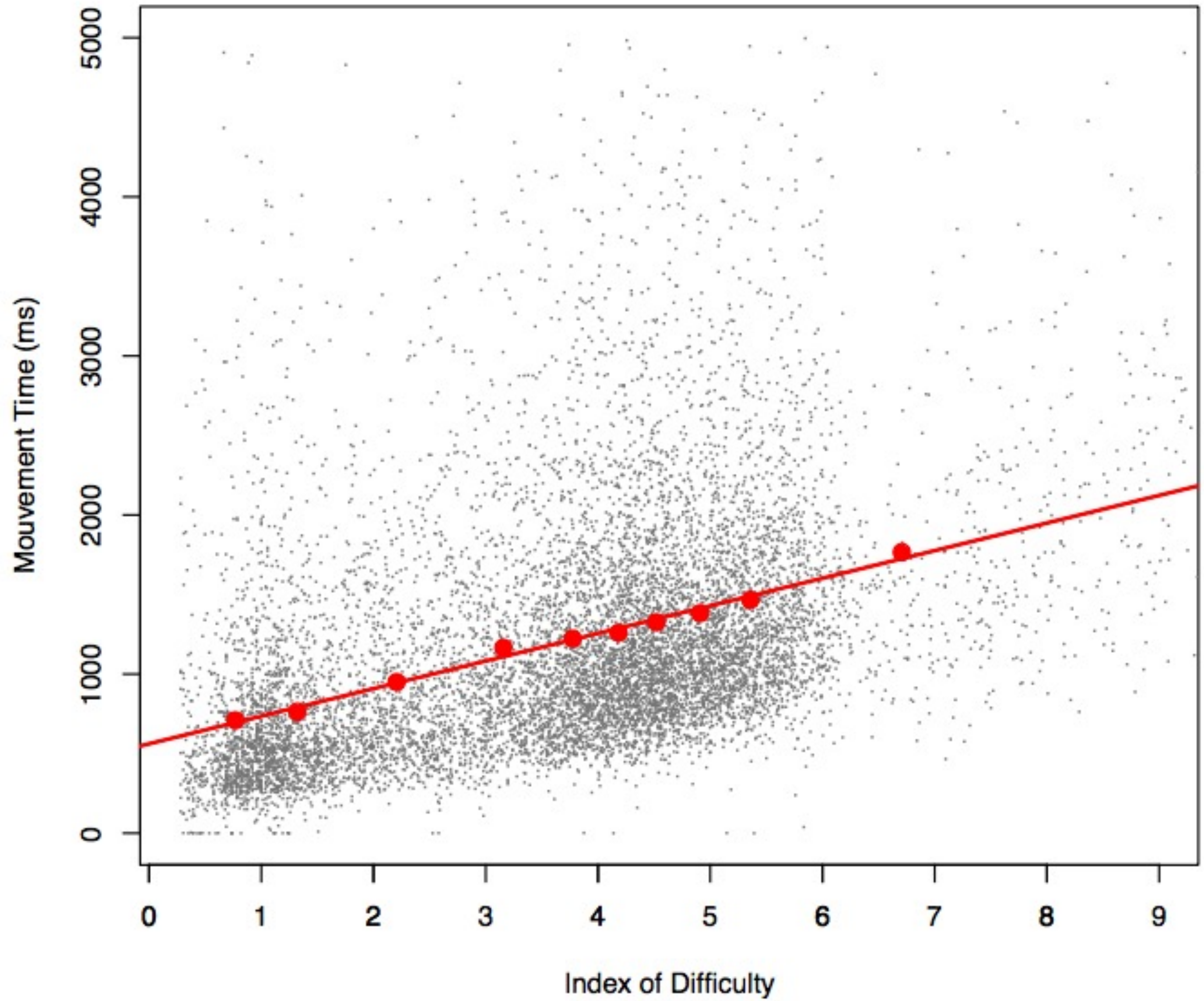
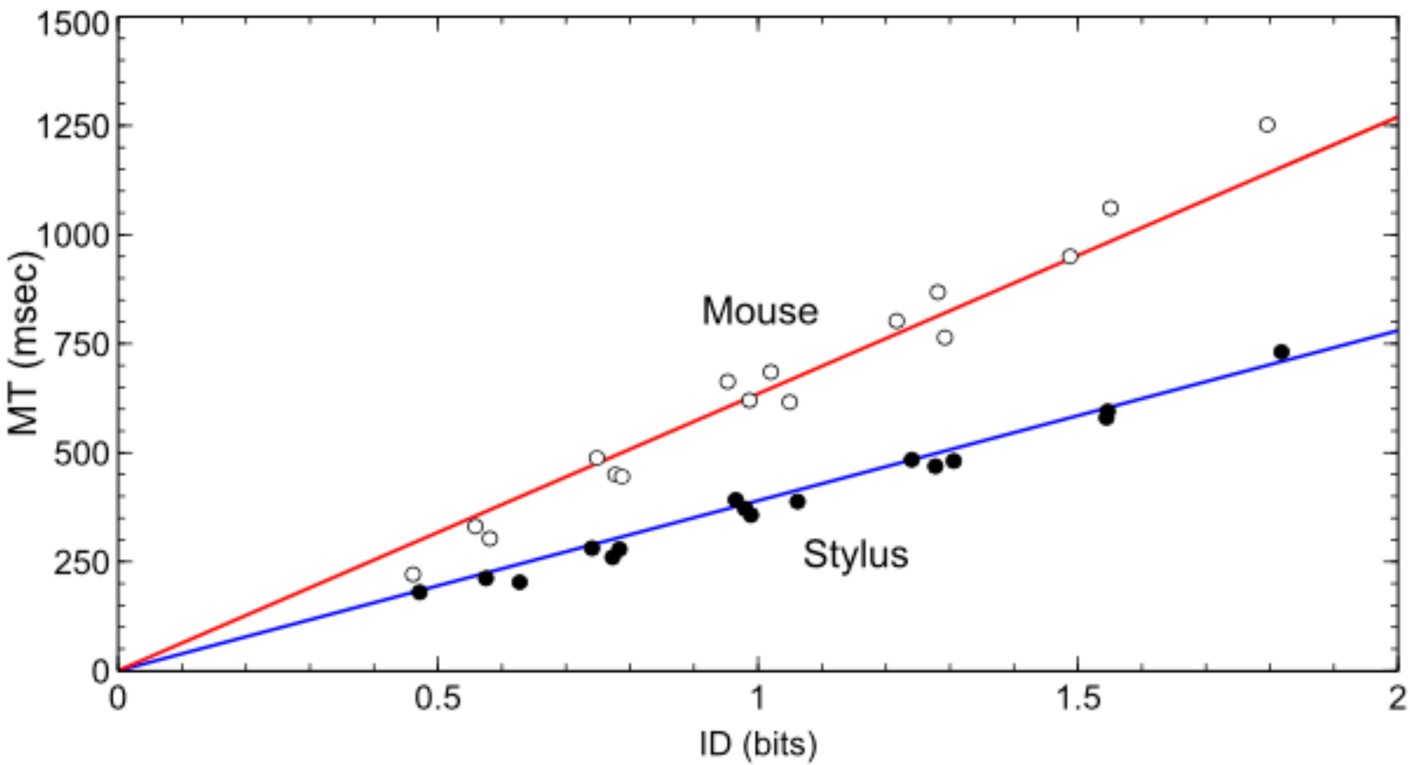


Figure 1. Mouse tra



Demonstration

Comparing input devices with Fitts' law



Example: Game

EXERCISE 1.B

1. PICK A UI THAT IS USED A LOT
2. RUN FITTS' LAW ON IT FOR 2-3 MAIN TASKS
3. IMPROVE THE DESIGN
4. REPORT THE ORIGINAL AND THE REVISED DESIGN

https://shorturl.at/QjXyG

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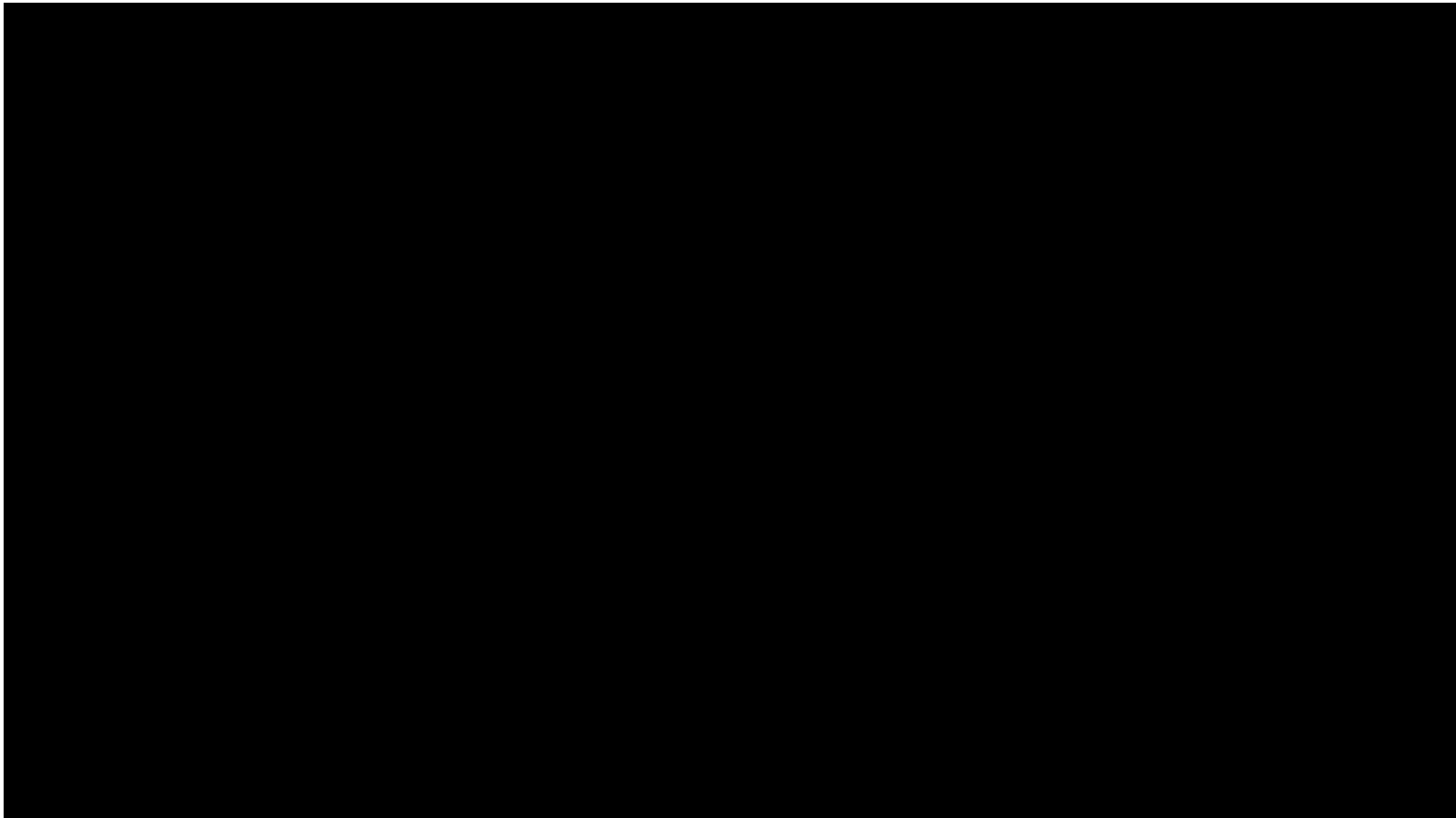
Temporal Pointing Model

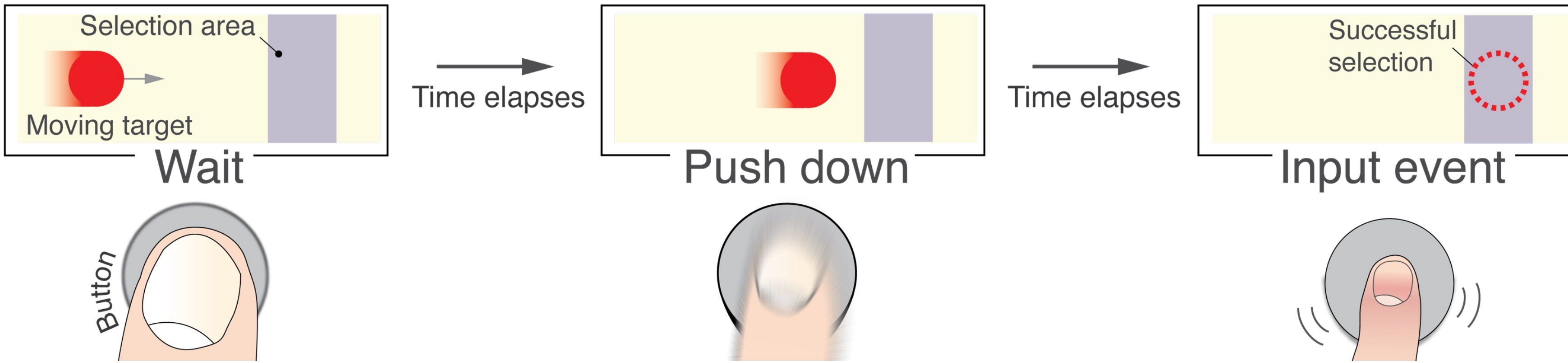
Empirical task: Blinking target



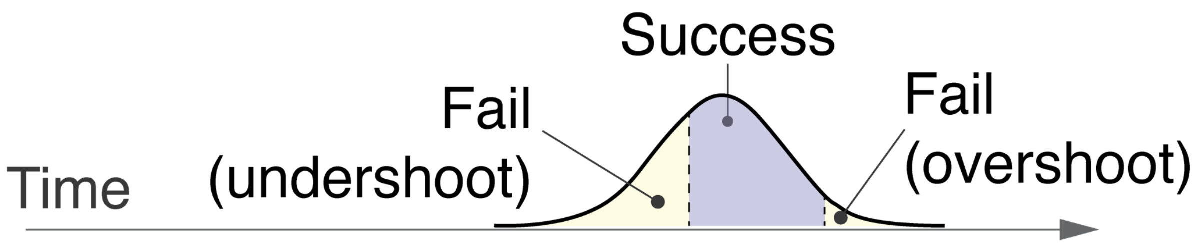
Temporal pointing task

"Press the button when the target appears under selection area"

Model applies when time to target is larger than 600 ms (some anticipation needed)



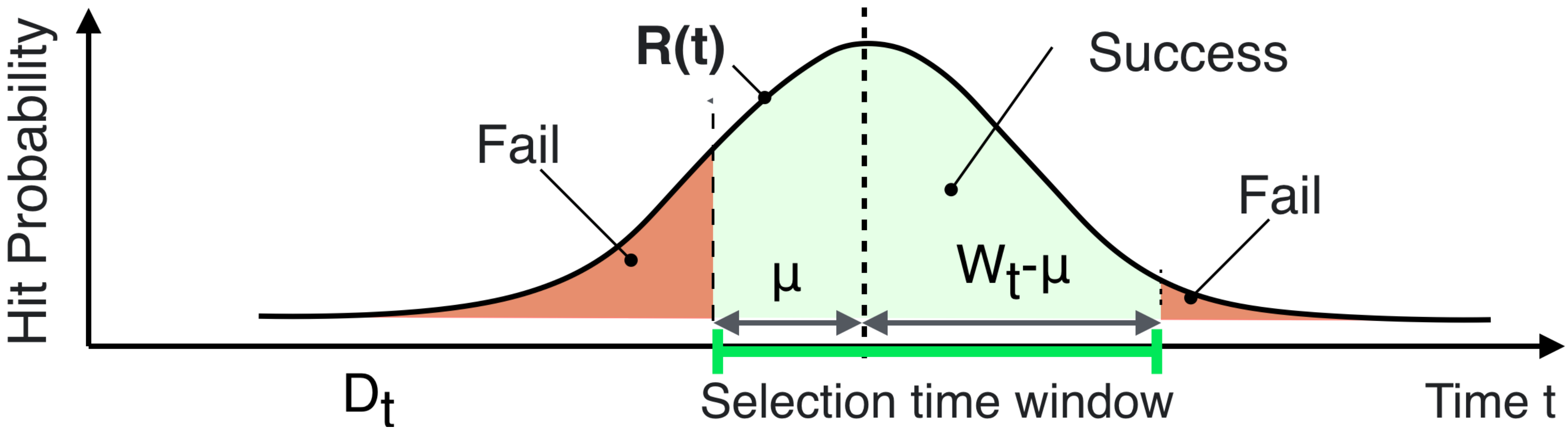
Temporal pointing model



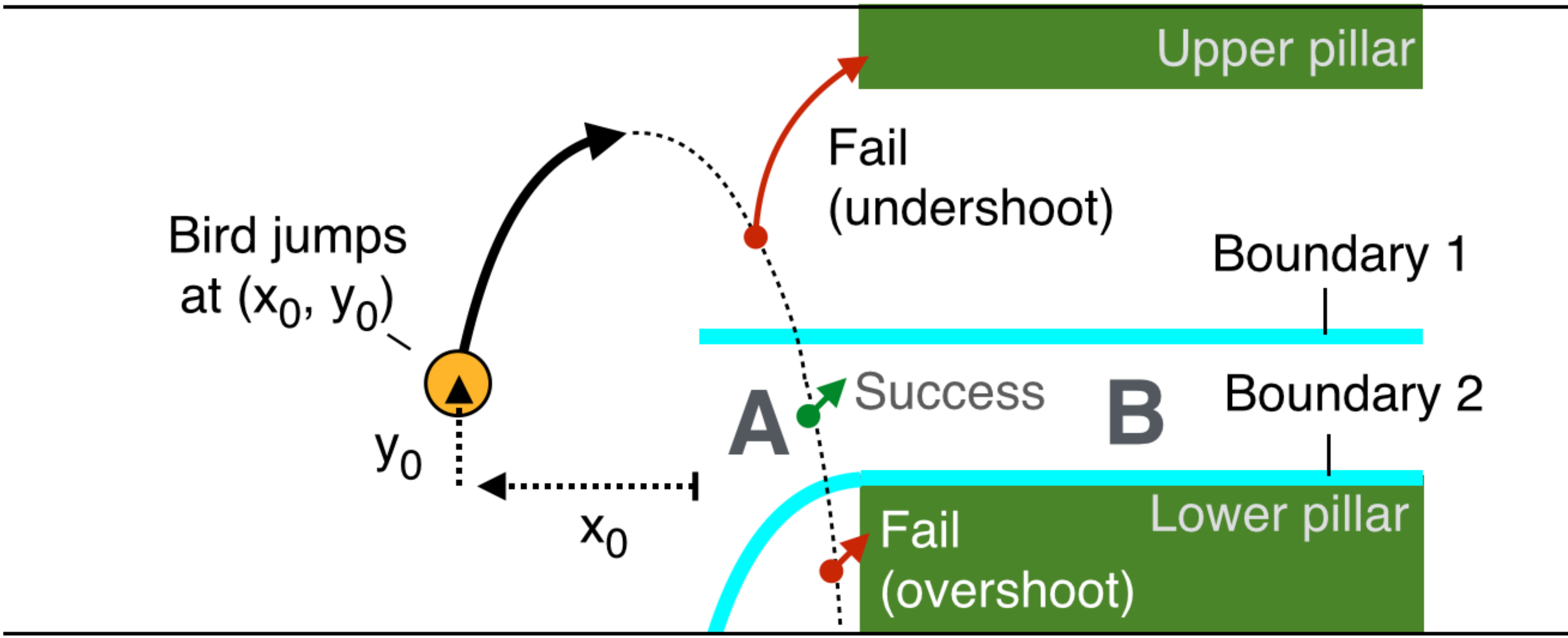
Formula for predicting error rate

$$E(ID_t) = 1 - \frac{1}{2}\left[erf(\frac{(1-c_\mu)}{c_\sigma 2^{(ID_t+0.5)}}) + erf(\frac{c_\mu}{c_\sigma 2^{(ID_t+0.5)}})\right] \quad (7)$$

Illustrated



Example application: Flappy bird



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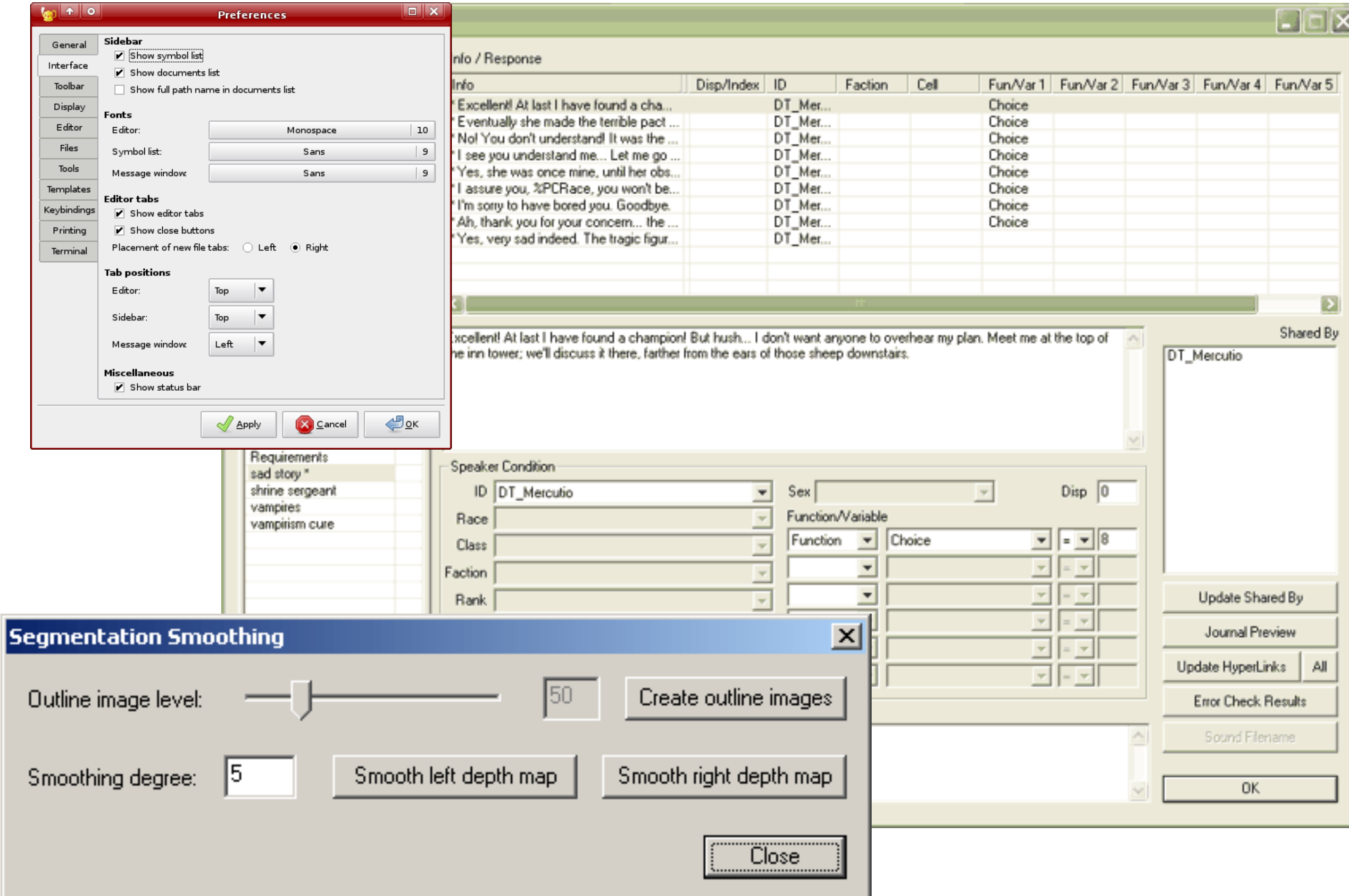
Keystroke Level Modeling

Point-and-click interfaces



Keystroke-level model

A model of task completion time in sequentially performed tasks consisting of simple actions. A memoryless model

Input: Operation sequence, UI elements and layout

Output:

Task completion time **=**

t_K [key stroking]

+ t_P [pointing]

+ t_H [homing]

+ t_D [drawing]

+ t_M [mental operation]

+ t_R [system response]

KLM, a task-level predictive model

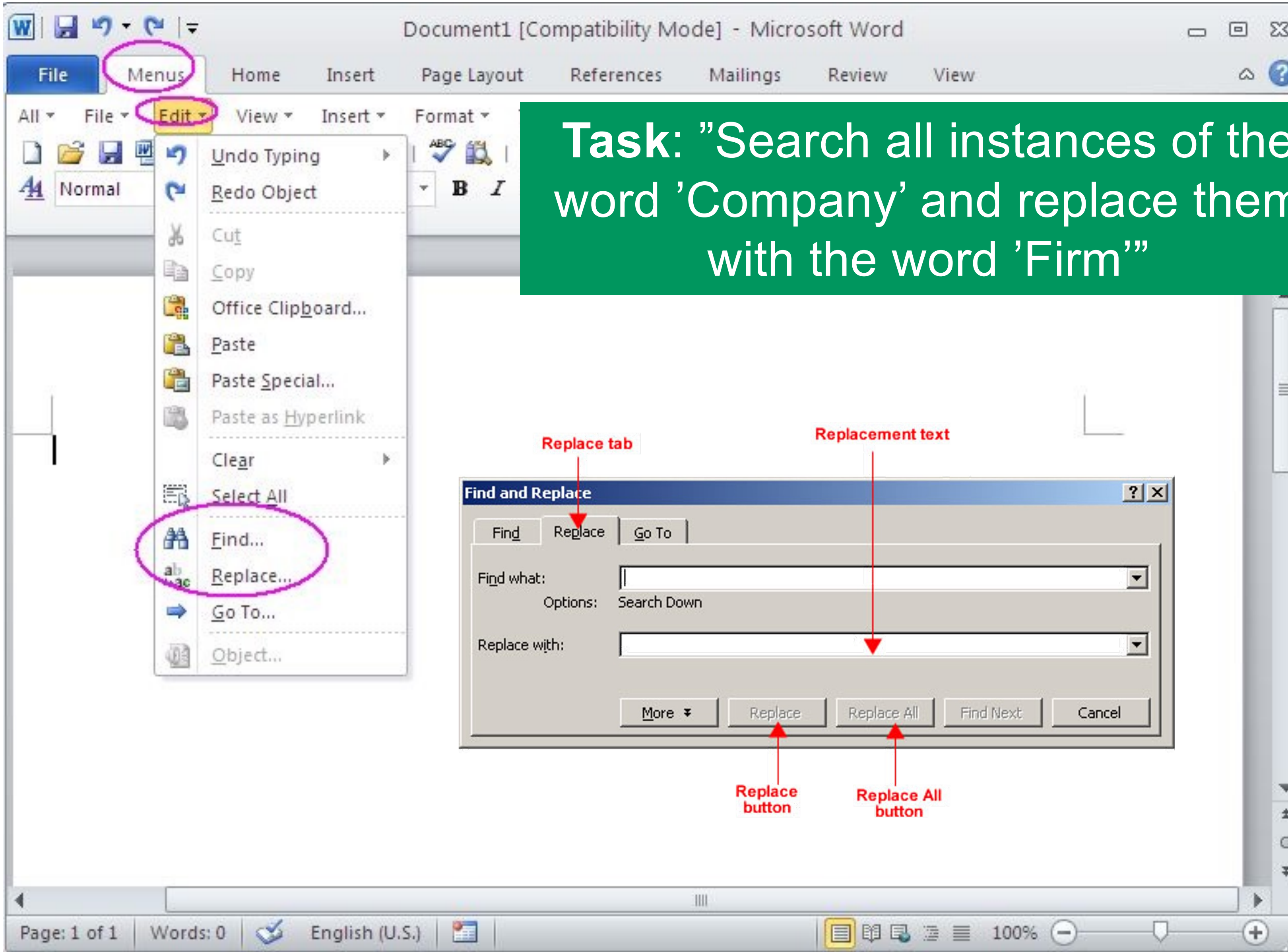
Pros

- Predicts total task completion time (TCT) for UIs operated by discrete commands
    - Some GUIs, web pages, forms, widgets, dialogues, panels, toolbars etc
- Informs design and evaluation

Cons

- A strictly sequential model; no multitasking
- Memory-less
- Focus is on task performance, other aspects of behavior and experience are ignored
    - *Lacks a notion of "semantics" and "contexts"*
    - *Overlooks individual and cultural differences*
    - *Only rough notion of learning (i.e., parameters can be updated)*
- Validity depends on task specifications and model assumptions

Task: ”Search all instances of the word ’Company’ and replace them with the word ’Firm’”



Keystroke-level model (KLM)

Task completion time =

t_K [key stroking]

$+\ t_P$ [pointing]

$+\ t_H$ [homing]

$+\ t_D$ [drawing]

$+\ t_M$ [mental operation]

$+\ t_R$ [system response]

t_K:
Expert typist (90 wpm): .12 sec
Average skilled typist (55 wpm): .20 sec
Average nonsecretarial typist (40 wpm): .28 sec
Worst typist (unfamiliar with keyboard): 1.2 sec

t_P: Fitts' law

t_H: Time it takes to move hand from one input device to another. Typically constant, e.g. 0.4s

t_M: Estimated by the researcher or looked up from a lookup table

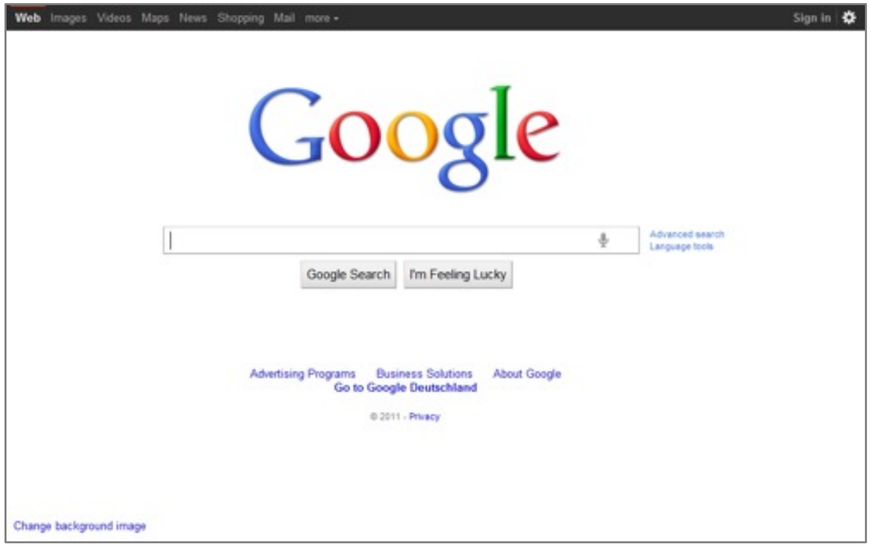
t_R: Observed response time

Example: replacing a word

Reach for mouse	H[mouse]	0.40
Move pointer to "Replace" button	P[menu item]	1.10
Click on "Replace" command	K[mouse]	0.20
Home on keyboard	H[keyboard]	0.40
Specify word to be replaced	M[word]	2.15
Reach for mouse	H[mouse]	0.40
Point to correct field	P[field]	1.10
Click on field	K[mouse]	0.20
Home on keyboard	H[keyboard]	0.40
Type new word	M[word]	2.15
Reach for mouse	H[mouse]	0.40
Move pointer on Replace-all	P[replace-all]	1.10
Click on field	K[mouse]	0.20
Total		**10.2**

EXERCISE 1.C

https://shorturl.at/QjXyG



Task: Do a KLM model for one user task on your page (e.g., ”Type ‘Aalto’ and press ‘Google Search’)

Paste your model to the doc

http://mattbors.tumblr.com/post/100671142990/the-ultimatum-game-more-comics-at-the-nib

Limitations of KLM 1/2

KLM is highly case-sensitive

- **KLM operator values are obtained empirically by carrying out tasks representative users and devices**
  - When these conditions change, estimates change, too

KLM ignores variability in human performance

- **Within-individual and between-individual differences are large**

KLM is memory-less

- **Prior states do not affect operator values**

Limitations of KLM 2/2

KLM applies to "script-like" task performance

- "Do this, then that, then that, …"

KLM has no model of perception nor cognition

– *No perception, choice, decision-making…*

KLM is limited to point and click style interfaces

- Selection & data entry mostly; Forms, settings, panels, menus etc

Simple error analysis with KLM

We assume that an error occurs with probability of *p*

With error, $TCT_{average}$ becomes

$$TCT_{average} = (1 - p) * TCT_{no\ error} + p * TCT_{error\ occurred}$$

Instructions:

- Identify the most costly and probable error
- Estimate *p*
- Do a separate model for that (what happens when the error occurs?)
- You can now compute $TCT_{average}$

Many common causes of errors are ignored in KLM

Motor execution variability

Misperception of display and change blindness

Level of skill (e.g., novices vs. experts)

Wrong or partial beliefs about the system

Spatial memory and inference (getting lost)

Cognitive load

Multitasking

Decision-making fallacies

Idiosyncratic differences (e.g., age groups)

Summary: KLM

Predicts skilled user's performance in *sequentially operated* tasks

Sum up time spent in six elementary operations

Parameter values are terminal and user specific

A handy "back of the envelope" tool for first estimates!

Aalto University

Pairwork topics

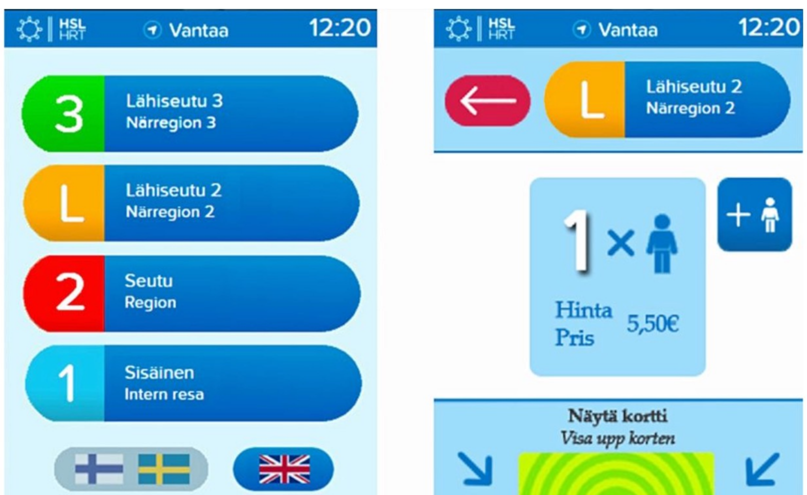
Example student project: HSL card reader redesign case 2017

Opiskelijat: Näin HSL:n matkakortinlukijasta tulisi looginen ja nopea

18.1.2017 09:35:02 EET | Aalto-yliopisto

Jaa

Toimivamman käyttöliittymän suunnittelussa hyödynnettiin käyttäjien ideoita ja matemaattista mallinnusta.



Topics and task

Topics

Public services in the web

Online banking

Ticketing apps

Aalto MyCourses

Aalto SISU

A news page

Task

- Select a concrete case
- Define your baseline
  - Select 1-2 UIs
  - Select 2-3 user tasks
- Analyze the baseline
- Iteratively improve it
- Analyze at least 1 (winner)
- Report (next slide)

Fitts' law
Saliency
KLM

Methods and deliverable

Methods

Analysis methods

- Fitts' law
- Saliency models
- KLM

Iterative prototyping (paper, Figma, Powerpoint, …)

Deliverable: Presentation

- 5 slides
  - Current design (baseline)
  - Design goals
  - Alternative designs
  - Winning design + analysis
  - Comparison to baseline
- 7 mins +Q/A

Scoring

Objectives

- Improvement % in MT
- Improvement in flow
- Improvement % in TCT

Constraints

- Improvements should not massively negatively affect the rest of the UI