Designing Interactive Systems I

Introduction, The CMN Model, Fitts' Law

Prof. Dr. Jan Borchers
Media Computing Group
RWTH Aachen University

Winter Semester ’24/’25

https://hci.rwth-aachen.de/dis

Who am I?

Studied CS at Karlsruhe (& Imperial)

- Human-Computer Interaction

PhD in CS at TU Darmstadt (& Linz, Ulm)

- Interaction with multimedia
- HCI design patterns

Assistant professor at Stanford & ETH Zurich

- Interactive rooms
- UbiComp user interfaces

Full professor at RWTH since Oct. 2003

- Augmented Reality, Wearable & Textile UIs
- Personal Fabrication, IDEs, Soft Robotics, Dark Patterns

Our Team

Paul Preuschoff, M. Sc.
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Sarah Sahabi, M. Sc.
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The Question Flow Chart :)

Does it contain matters of personal concern?

No (Default) → RWTHmoodle Forum

Yes → Email with the subject prefix **[DIS1]** to Sarah **&** Paul (not Jan 😉)

Alternatively: A quick chat after the lecture ☕

Human–Computer Interaction?

Source: https://ux.stackexchange.com/questions/15471/any-actual-reason-for-complicated-uis/15479

Source: https://www.pexels.com/de-de/foto/mann-hande-laptop-macbook-3777572/

Source: Yovko Lambrev - commons.wikimedia.org

Usability Sells!

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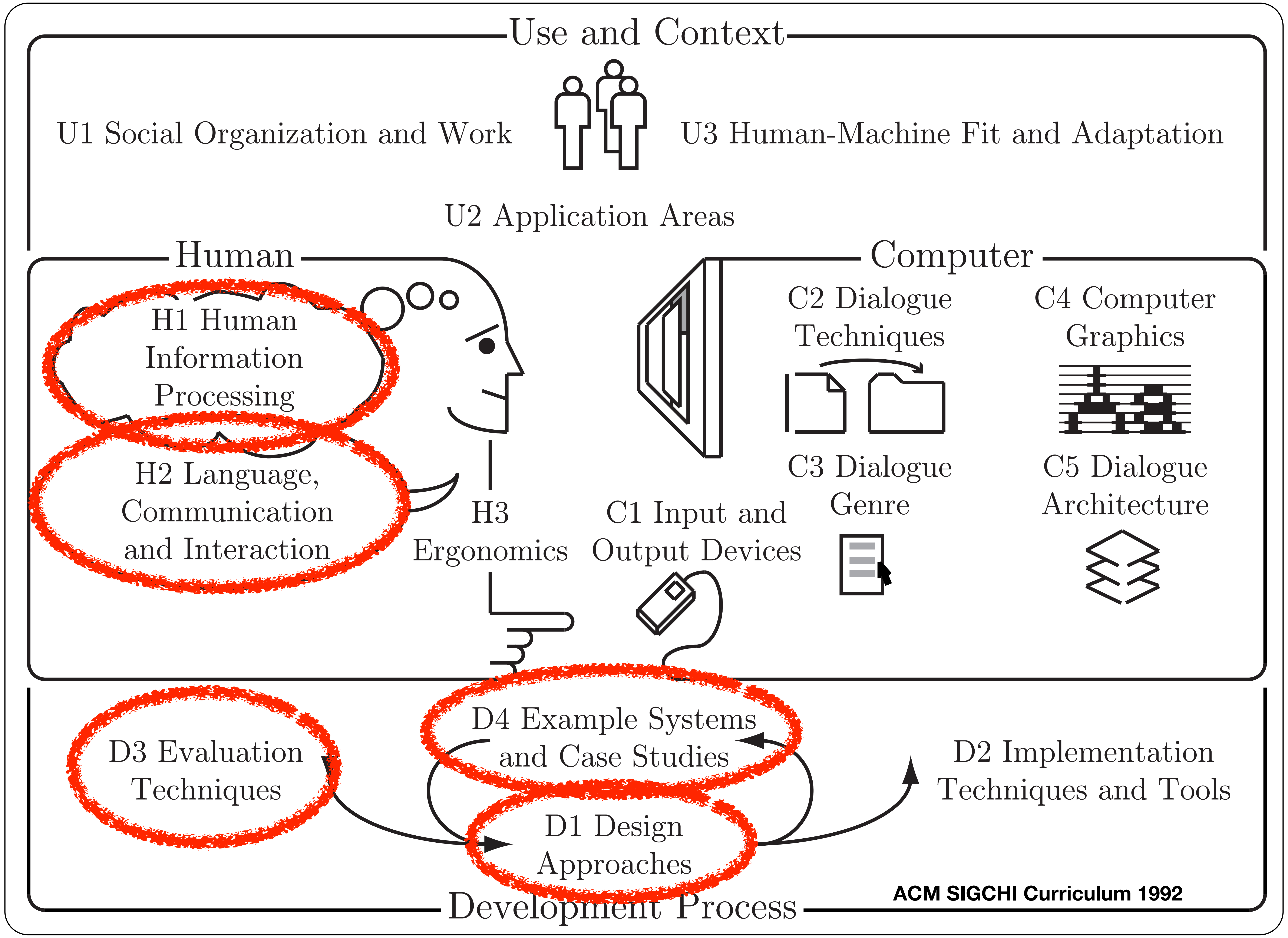
What is HCI?



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Class Topics

Human

- Performance
- Models of interaction
  - Affordances
  - Mappings
  - Constraints
  - Types of knowledge
  - Errors
- Design principles

Case Studies

- History of HCI
- Visions of HCI
- Phases of Technology

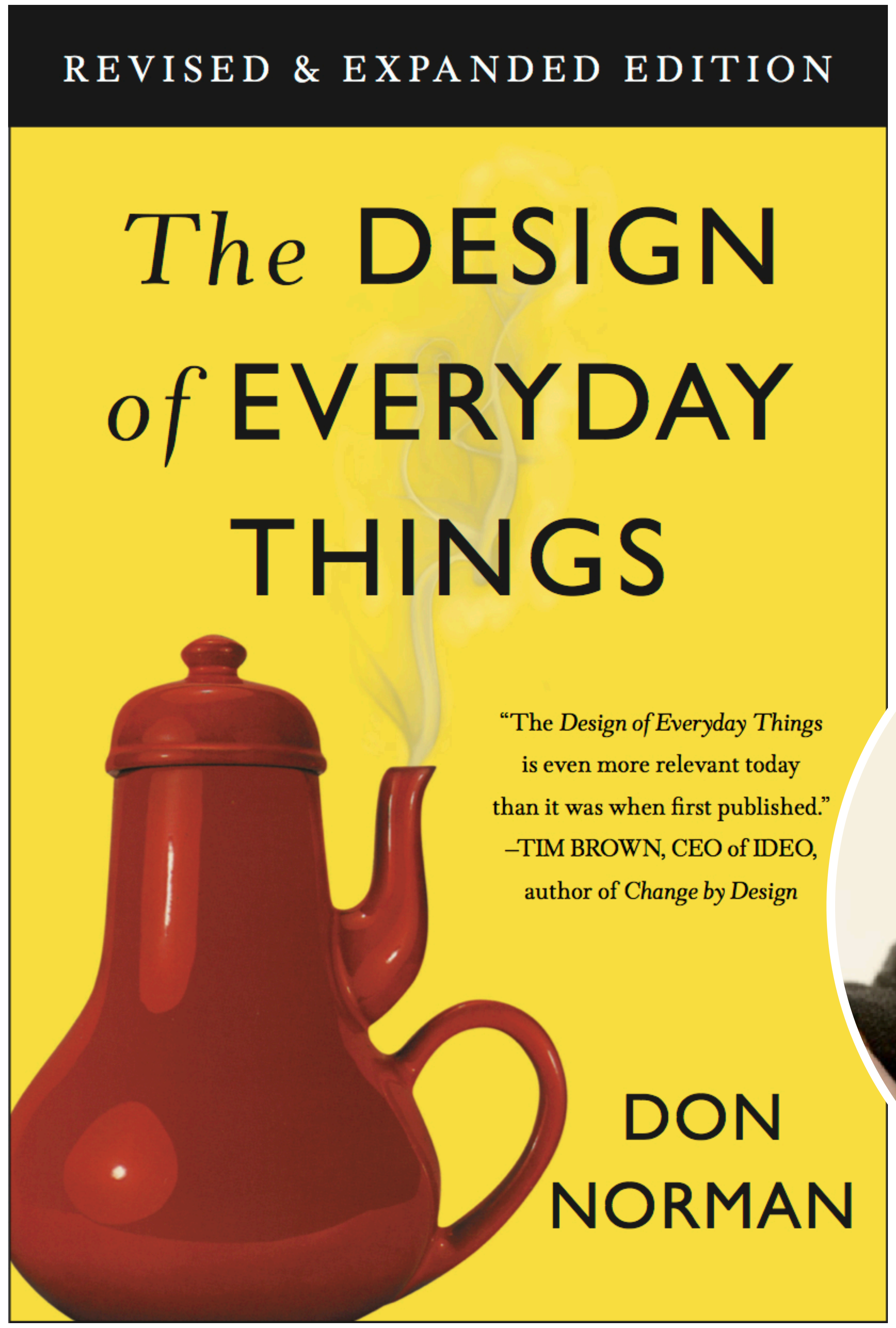
Development Process

- Iterative design
- User observation
- Ideation
- Prototyping
- User studies and evaluation
- Interaction design notation

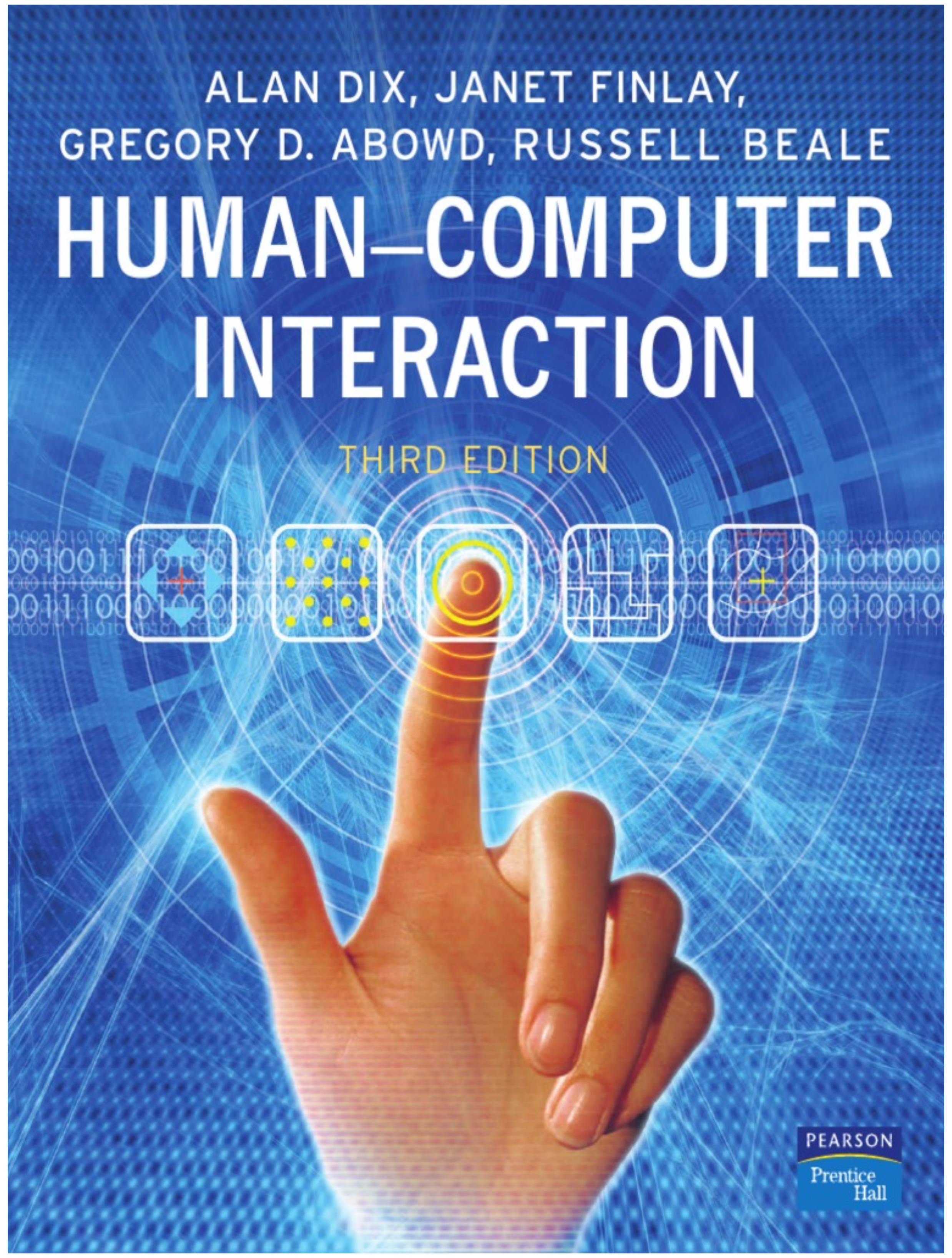
For more details, see hci.rwth-aachen.de/dis

Textbooks

Required Reading



Recommended Reading



Media Computing Group

Our Classes

When?	Type	Credits (ECTS)	Name
Winter	**Practical Lab**	**7**	**The Media Computing Project**
Winter+ Summer	**Seminar**	**4**	**Post-Desktop User Interfaces**
Summer	Lecture	6	Current Topics in HCI
Winter	**Everything :)**	**6**	**iOS Application Development**
Summer	Lecture	6	Designing Interactive Systems II
Winter	**Lecture**	**6**	**Designing Interactive Systems I**
		Only for B.Sc. students	
Summer	Proseminar	4	Human-Computer Interaction
Summer	Practical Lab	7	M3: Multimodal Media Madness

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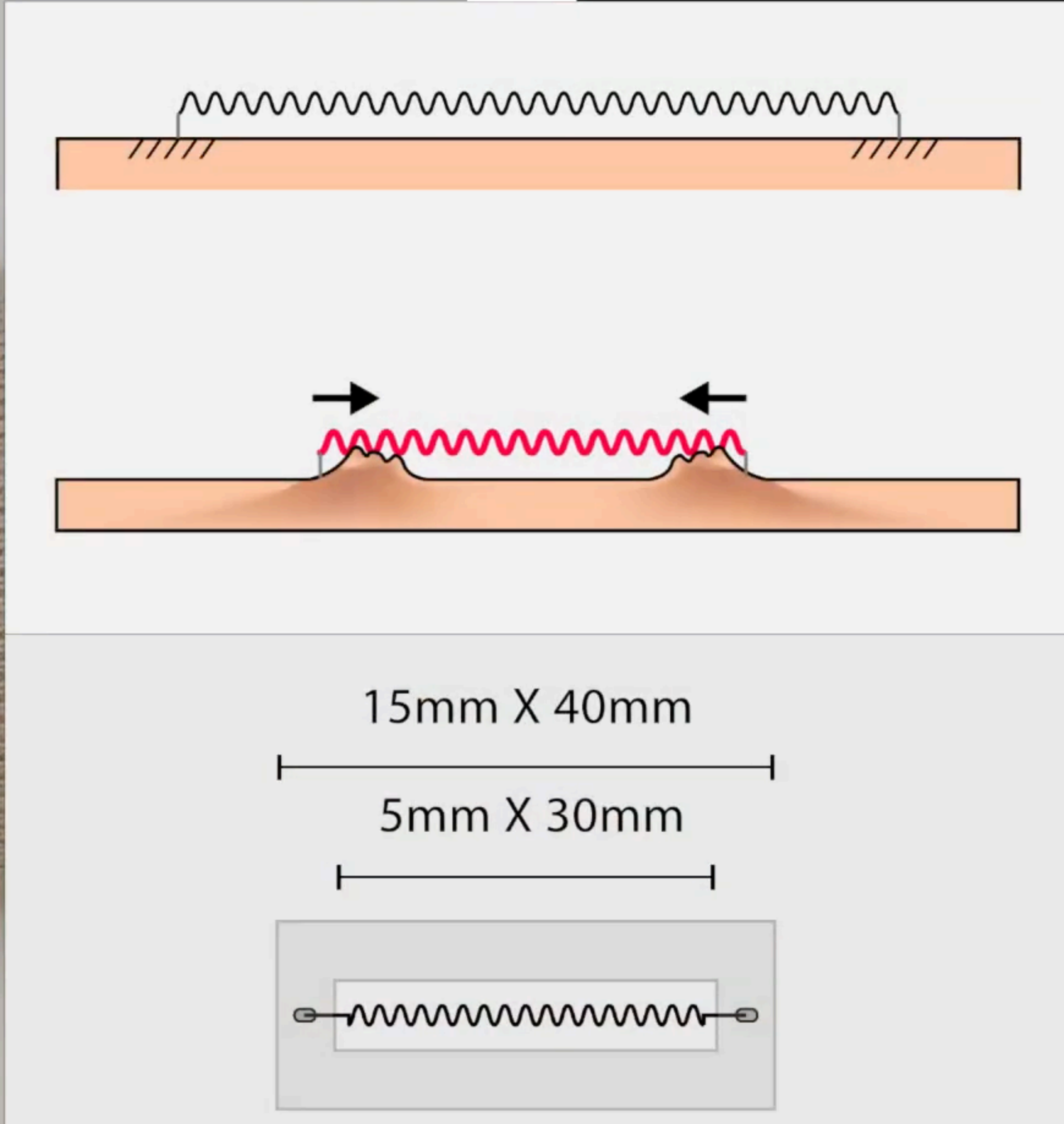
ARPen
hci.rwth-aachen.de/arpen

Springlets



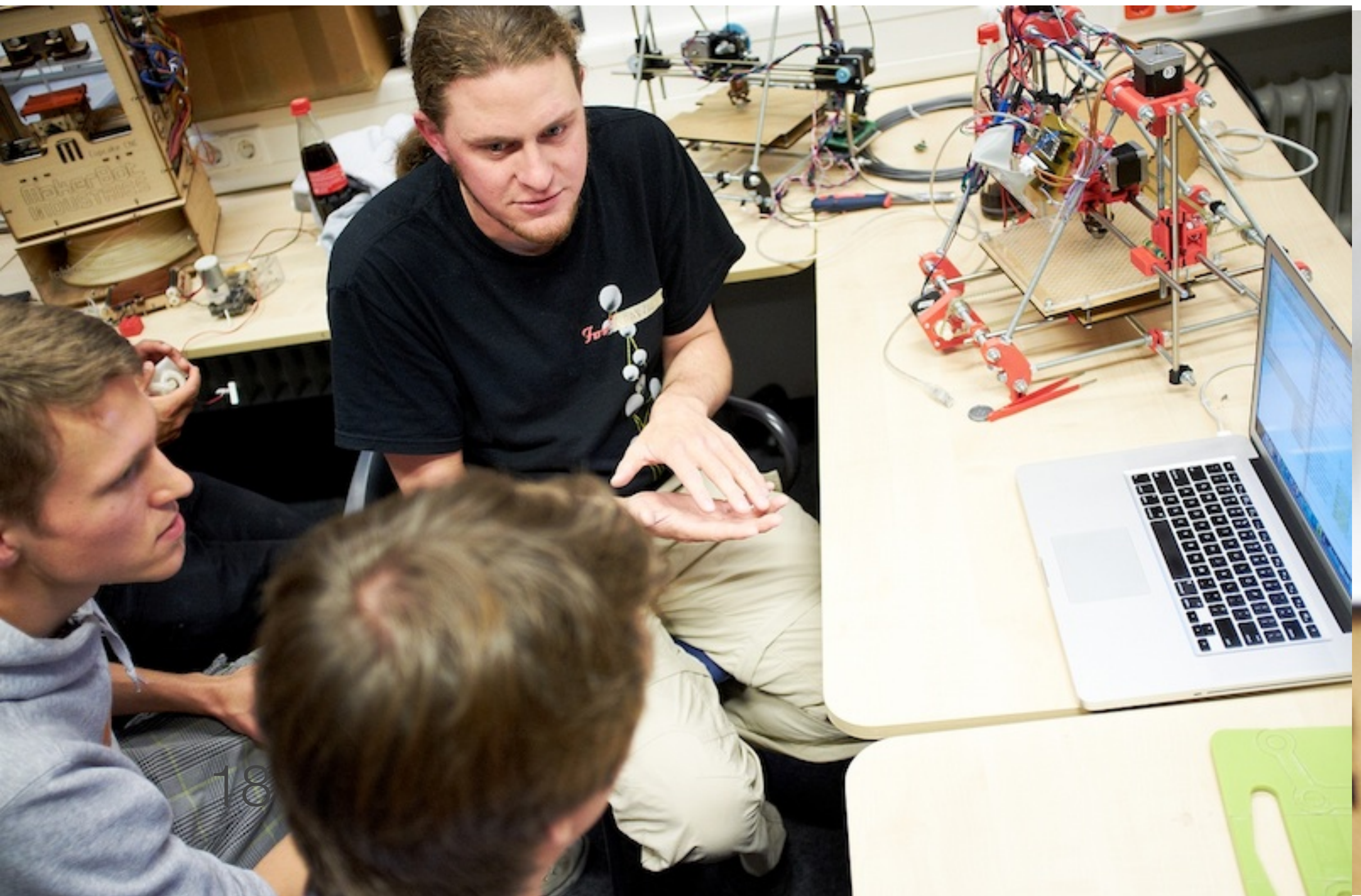
hci.rwth-aachen.de/springlets

Student Project in Multimodal Media Madness

hci.rwth-aachen.de/m3

Aachen Maker Meetup

- People doing strange things with electricity in Aachen
- 3rd Wednesday of every month
  Next event: **Oct. 16, 2024, at 18:30**
- Sign up here: **hci.rwth-aachen.de/amm**




CocoaHeads Aachen

- CocoaHeads: International meet-ups for macOS and iOS developers
- Last Thursday of every month
- Sign up here: **hci.rwth-aachen.de/cocoaheads**

DIS I: Course Structure

Course Structure

Lecture

Interactive classes with Prof. Borchers

Lab

- Discuss assignments

Oct 9th – Nov 26th

UX Project (graded)

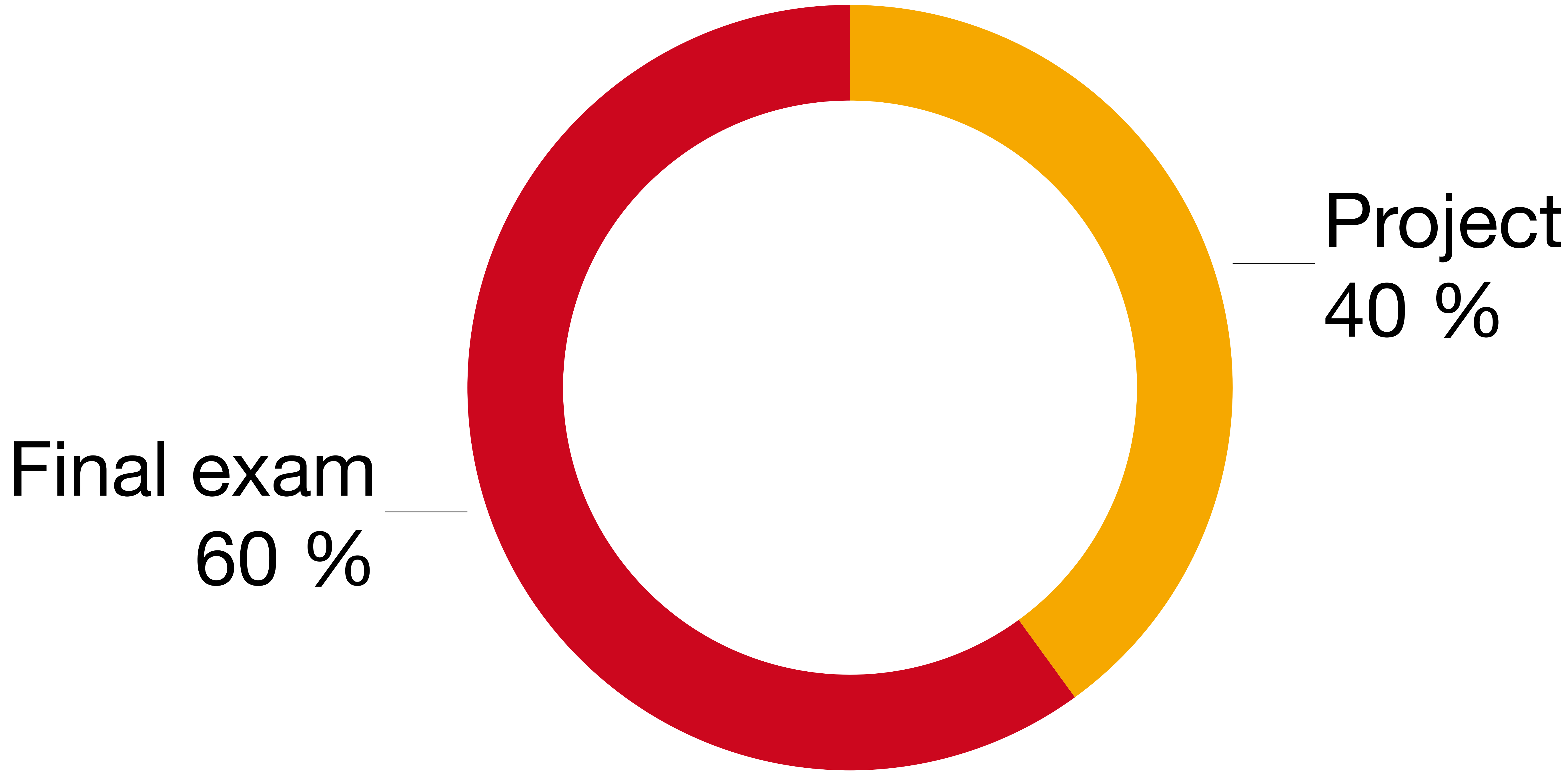
- Create your own UX project in a group of six
- Finally, showcase your project in a video

Dec 3rd – Jan 30th

Final Exam Feb 5th

Final Exam Mar 6th

Final Grade Distribution



! To pass the course, you must pass both project and final exam.

Registering for this Class

- Limited to **120 seats**
  - Register via RWTHonline and upload the Declaration of Compliance until **tomorrow** (Thu Oct 10, 2024, 23:59)
- Erasmus students, and others who cannot register via RWTHonline:
  Email Sarah & Paul your matriculation number and full name from your official *@rwth-aachen.de* email address with the following subject:

[DIS1] Registration <Firstname Lastname>

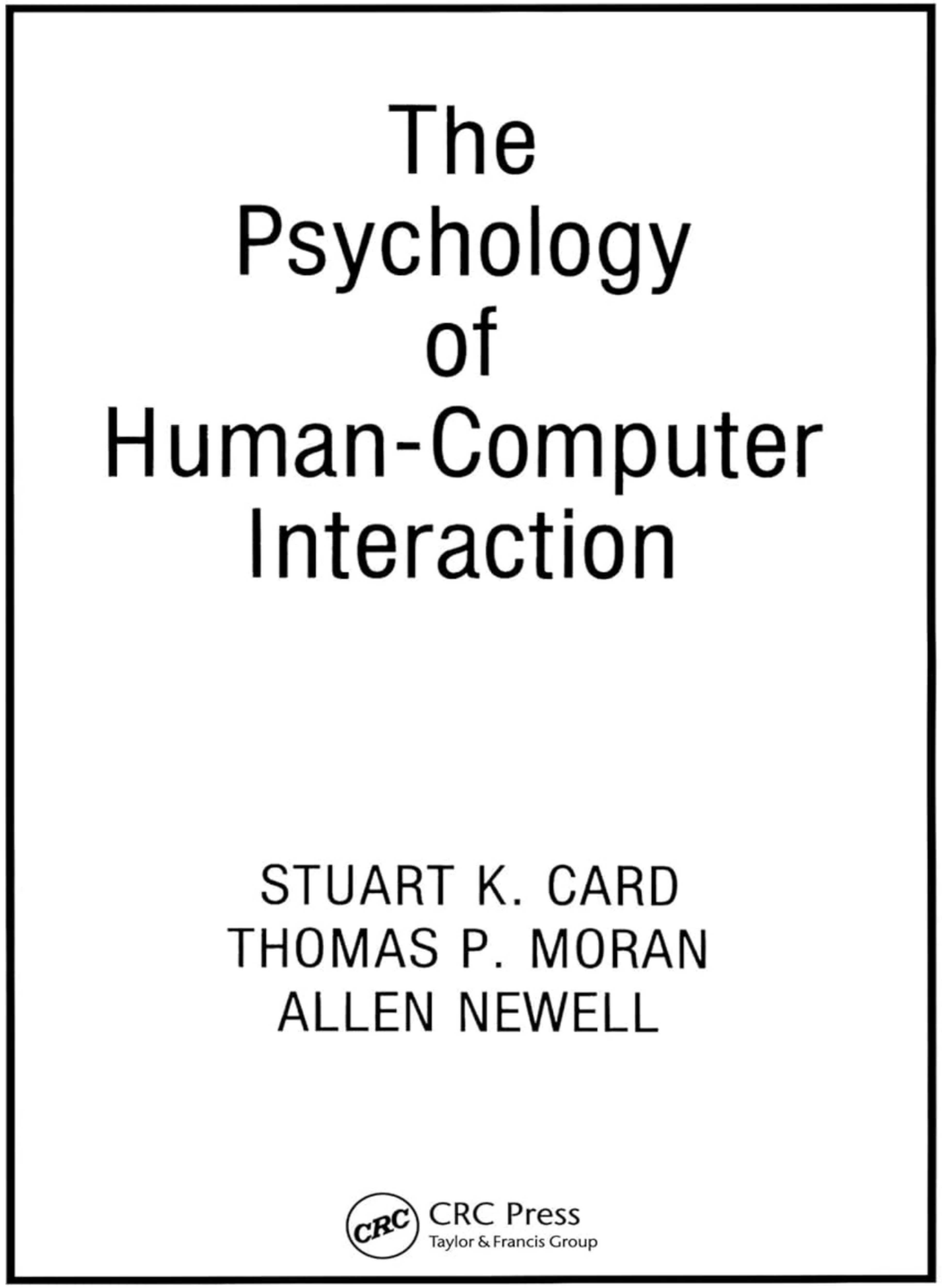
Exam Registration

Deadline to register: **December 7th, 2024**

- If you fail the first final exam, there will be a short period to register for the second chance
- You won't be registered for the second final exam automatically!

The Human

Model Human Processor: The CMN Model

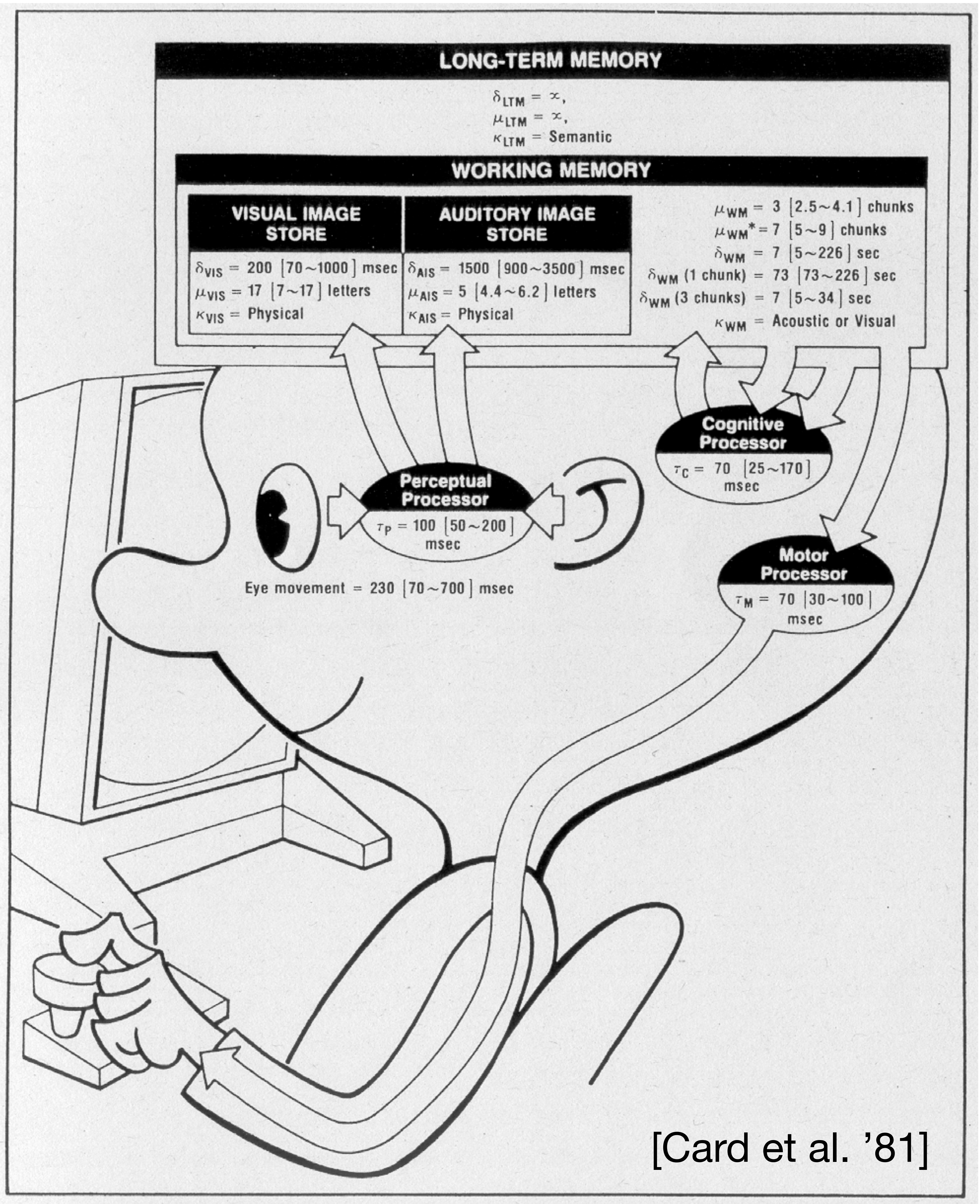

The Psychology of Human-Computer Interaction

STUART K. CARD
THOMAS P. MORAN
ALLEN NEWELL

CRC Press
Taylor & Francis Group

Model Human Processor

- 3 processors with associated memory
- Slow, middle, fast performers



[Card et al. ’81]

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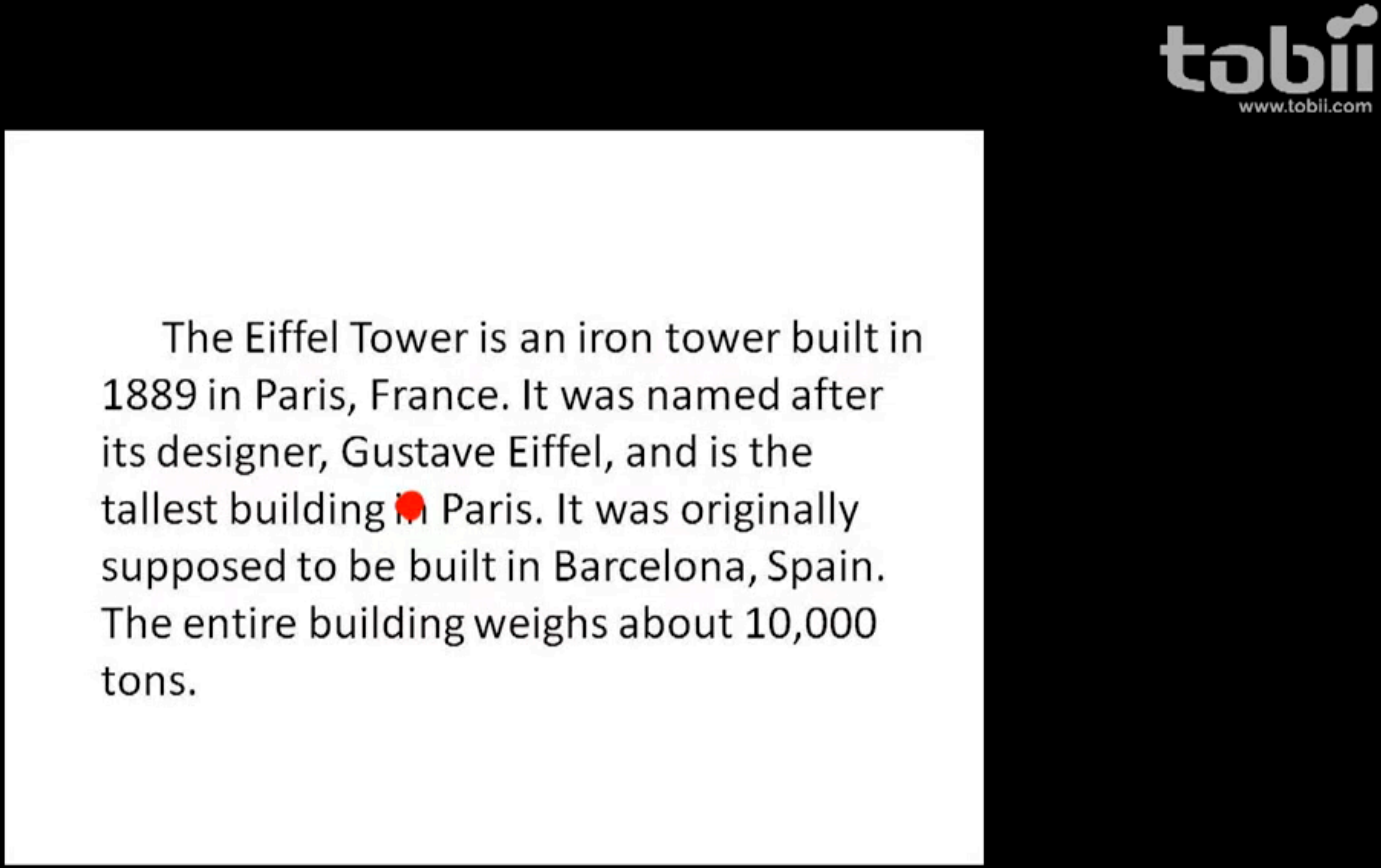
In-Class Experiment 1: Perceptual Processor

- Work in pairs of two
- Read out the text from *Experiment 1* to your group partner
- The other partner observes the eye movement of the reading person
- Then switch
- What did you observe?



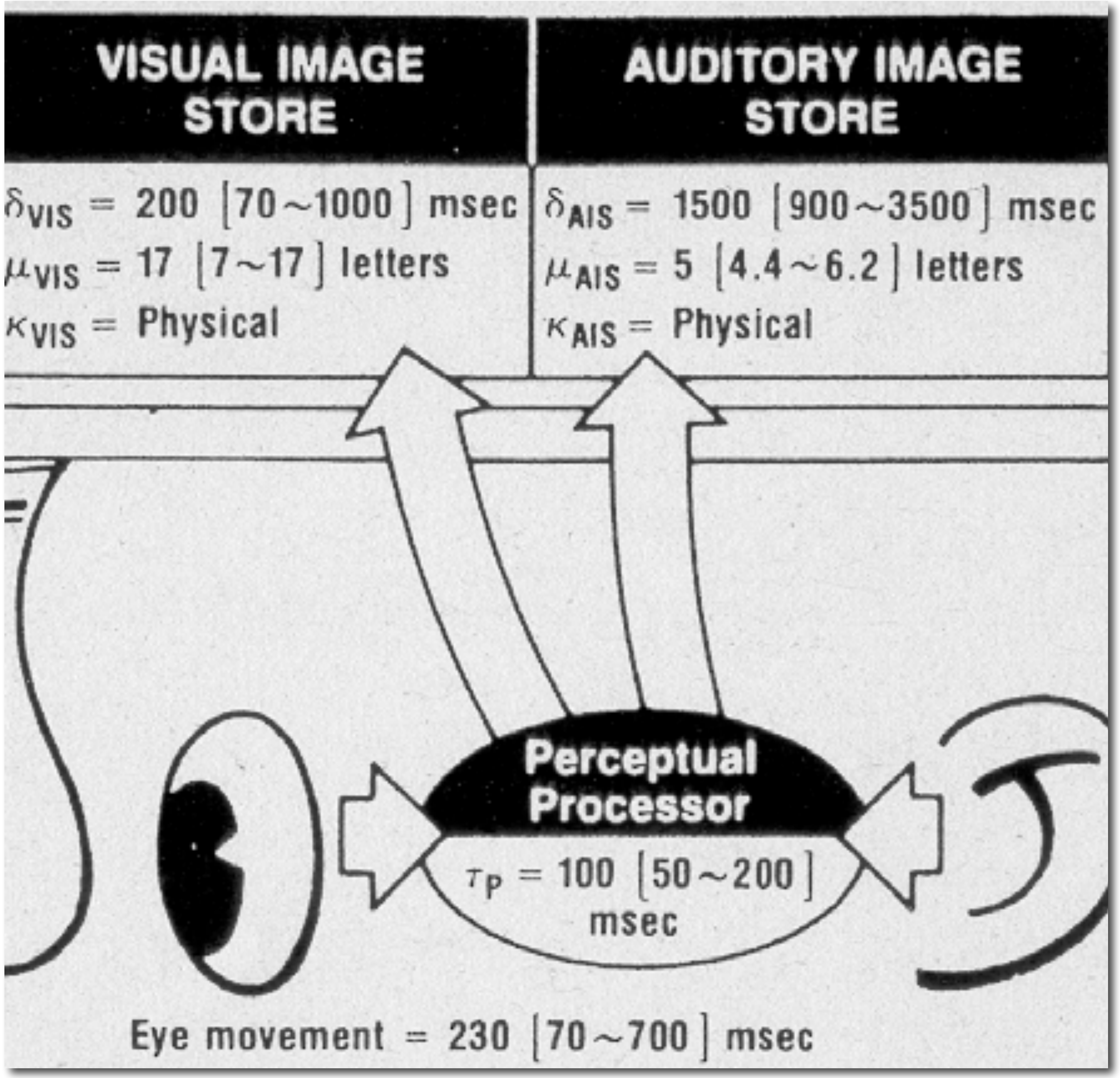
http://www.youtube.com/watch?v=VBTZNydUh0w

How your eyes move when you are reading

(Recorded using an eyetracker)

Perception

- Eye saccades: ~230 ms
- Explains reading rates:
- Maximum:
  ~13 characters per saccade
  ⇒ ~652 words per minute



In-Class Experiment 2: Bloch's Law

A

In-Class Experiment 2: Bloch’s Law

B

In-Class Experiment 2: Bloch's Law

C

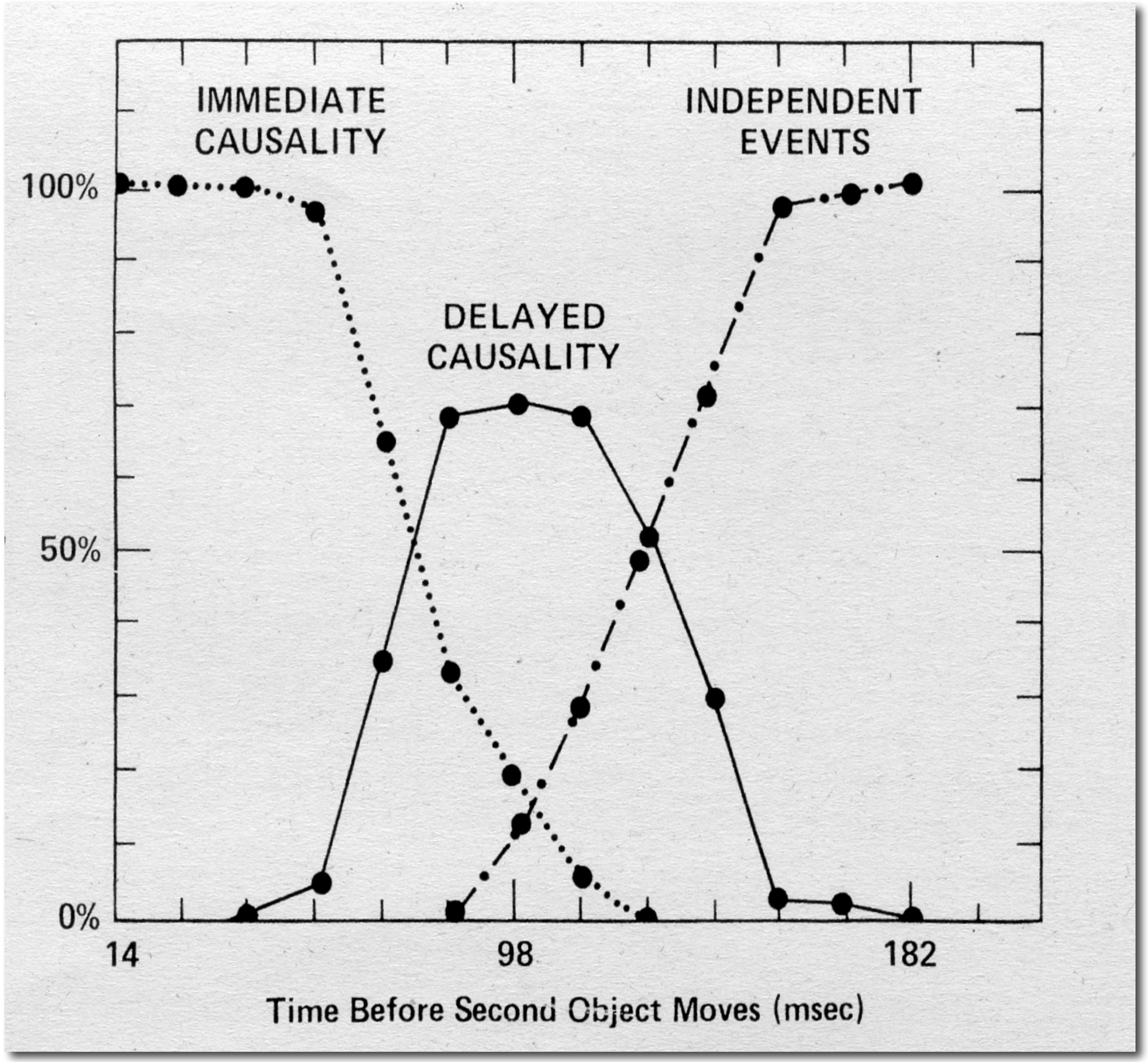
A: 0 ms delay

B: 50 ms delay

C: 100 ms delay

Perceptual Processor

- Stores sensor signals in visual & auditory stores
- Perception time: $\tau_P \approx$ **100 ms**
  - Explains animation rates (10 fps for "MiddleMan")
  - Explains max. delay before causality breaks down
  - Shortens with intensity



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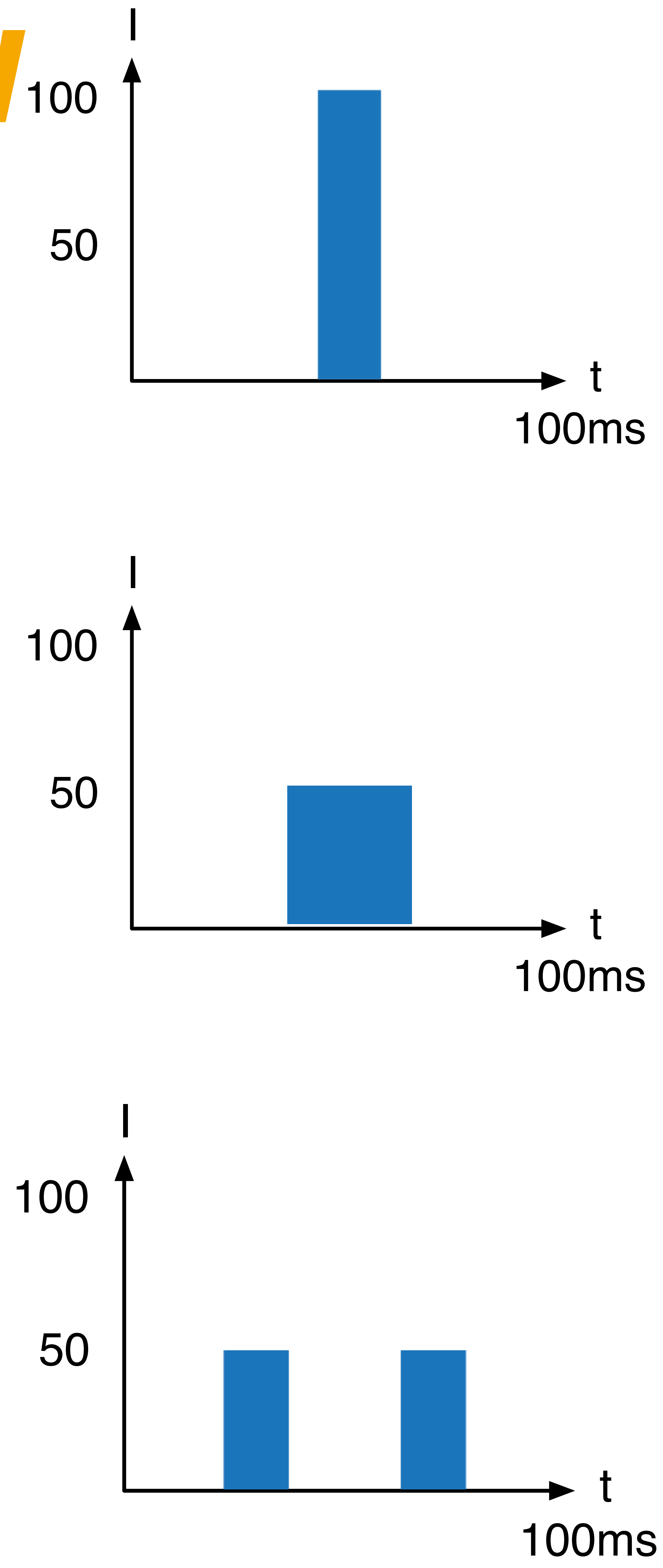
Perceptual Processor & Bloch's Law

- Bloch's Law: **R = I × t**
  - R response
  - I intensity
  - t exposure time
- The eye integrates stimuli over a time window τ_P
- Bloch's Law only holds for $t < \tau_P$ ("exposure time")



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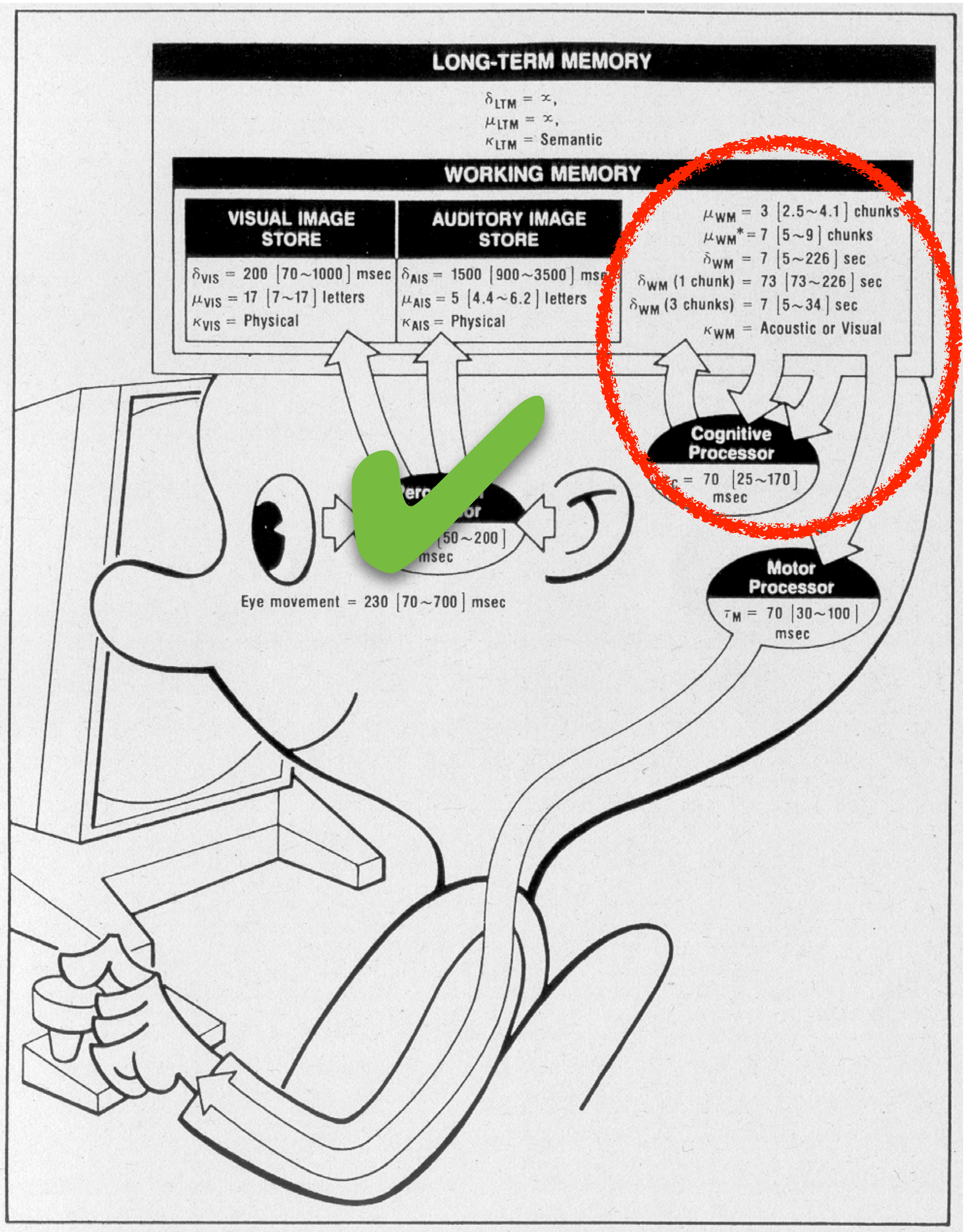
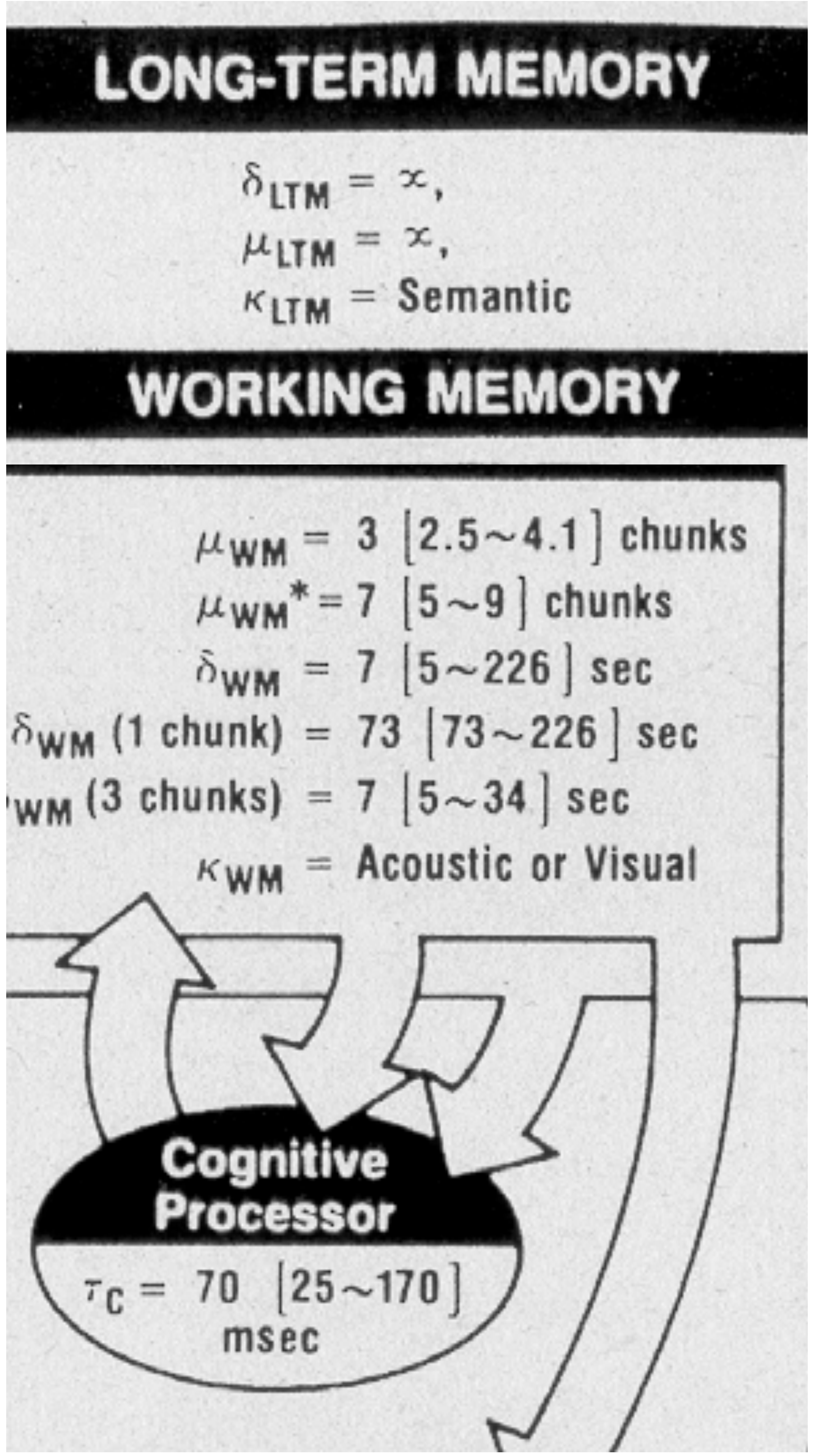

LONG-TERM MEMORY
$\delta_{LTM} = \infty$,
$\mu_{LTM} = \infty$,
κ_{LTM} = Semantic
WORKING MEMORY
VISUAL IMAGE STORE
δ_{VIS} = 200 [70~1000] msec
μ_{VIS} = 17 [7~17] letters
κ_{VIS} = Physical
AUDITORY IMAGE STORE
δ_{AIS} = 1500 [900~3500] msec
μ_{AIS} = 5 [4.4~6.2] letters
κ_{AIS} = Physical
μ_{WM} = 3 [2.5~4.1] chunks
μ_{WM}* = 7 [5~9] chunks
δ_{WM} = 7 [5~226] sec
δ_{WM} (1 chunk) = 73 [73~226] sec
δ_{WM} (3 chunks) = 7 [5~34] sec
κ_{WM} = Acoustic or Visual
Cognitive Processor
= 70 [25~170] msec
[50~200] msec
Eye movement = 230 [70~700] msec
Motor Processor
τ_M = 70 [30~100] msec

In-Class Experiment 3: Cognitive System

- As a group of two
  - One of you (P1) reads out a random sequence of 5 digits from your sheet to the other (P2)
  - Then P2 counts backwards aloud from 50
  - Then P1 asks P2 another question
    (like what they had for dinner three days ago?)
  - Then P2 writes down the numbers that they still remember.
- Switch roles, repeat with 9 digits.
- Finally, switching roles again, read the long sequence of numbers to your partner, stopping somewhere suddenly. See how many of the last numbers they can repeat immediately.

Cognitive System

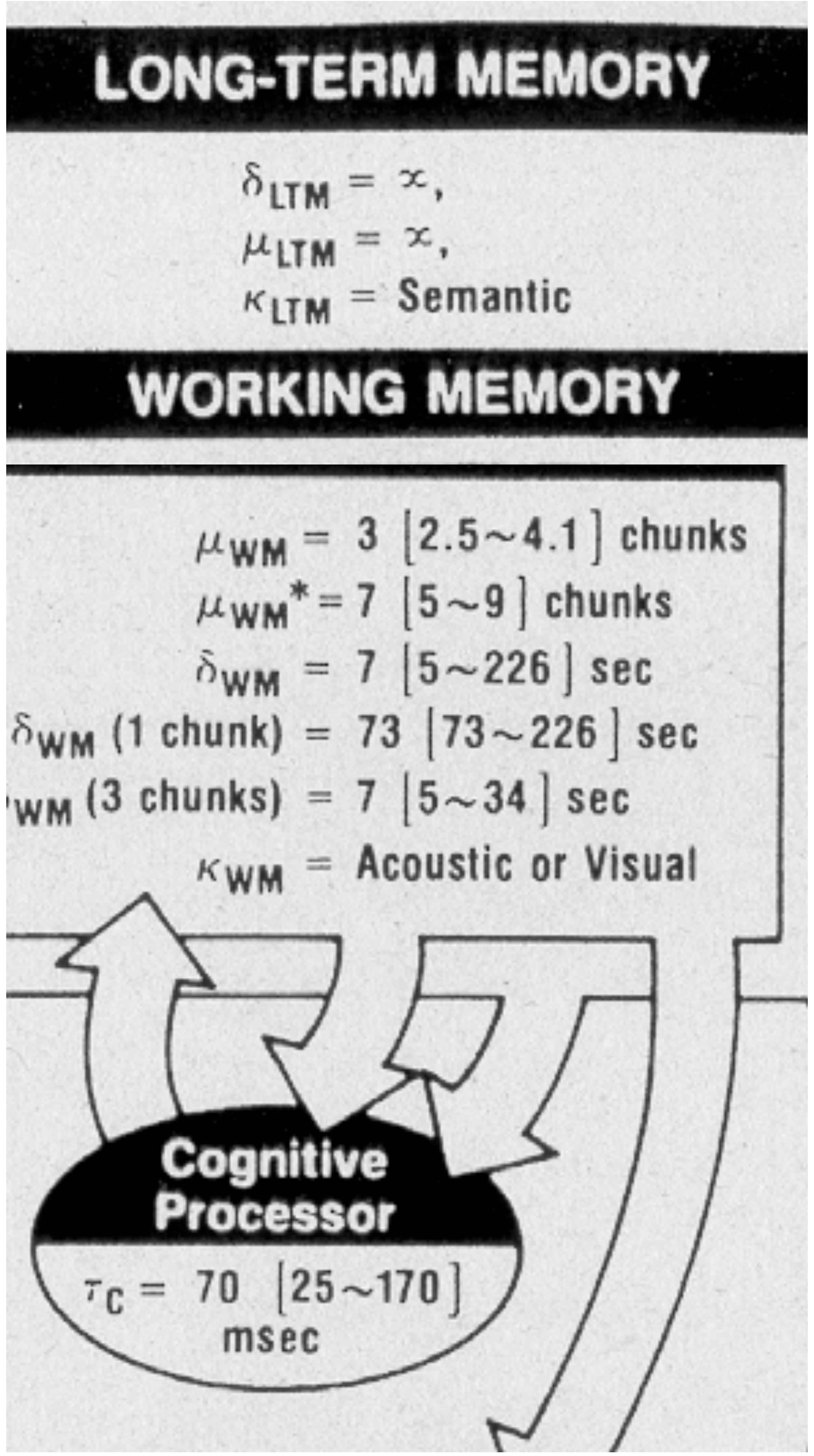
- Chunks depend on user & task
- Working memory:
  - Capacity: $\mu_{WM} = 7 \pm 2$ chunks (Miller '56)
  - Half life: $\delta_{1,WM} = 73$ s (1 chunk)
    $\delta_{3,WM} = 7$ s (3 chunk)
  - Visual/acoustic encoding
- In 2001, Nelson Cowen showed that μ_{WM} is actually 4±1 chunks.



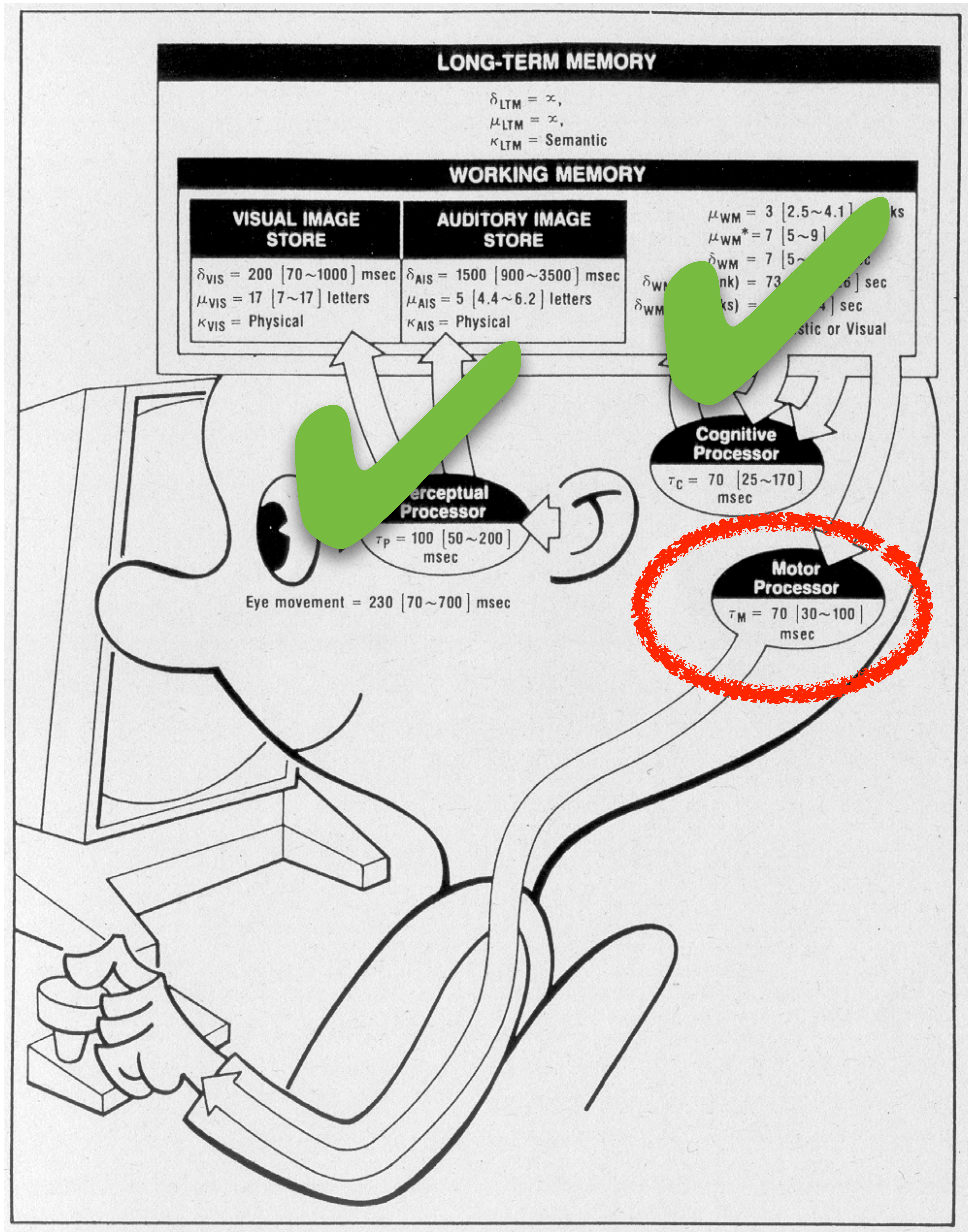
Cognitive System

- Cognitive processor:
  - Processing time $\tau_C = 70$ ms
- Long-term memory:
  - Infinite capacity and half life
  - Semantic encoding (associations)
  - Fast read, slow write

$\Rightarrow$ Remembering items maxes out at 7 s/chunk learning speed (1 pass)

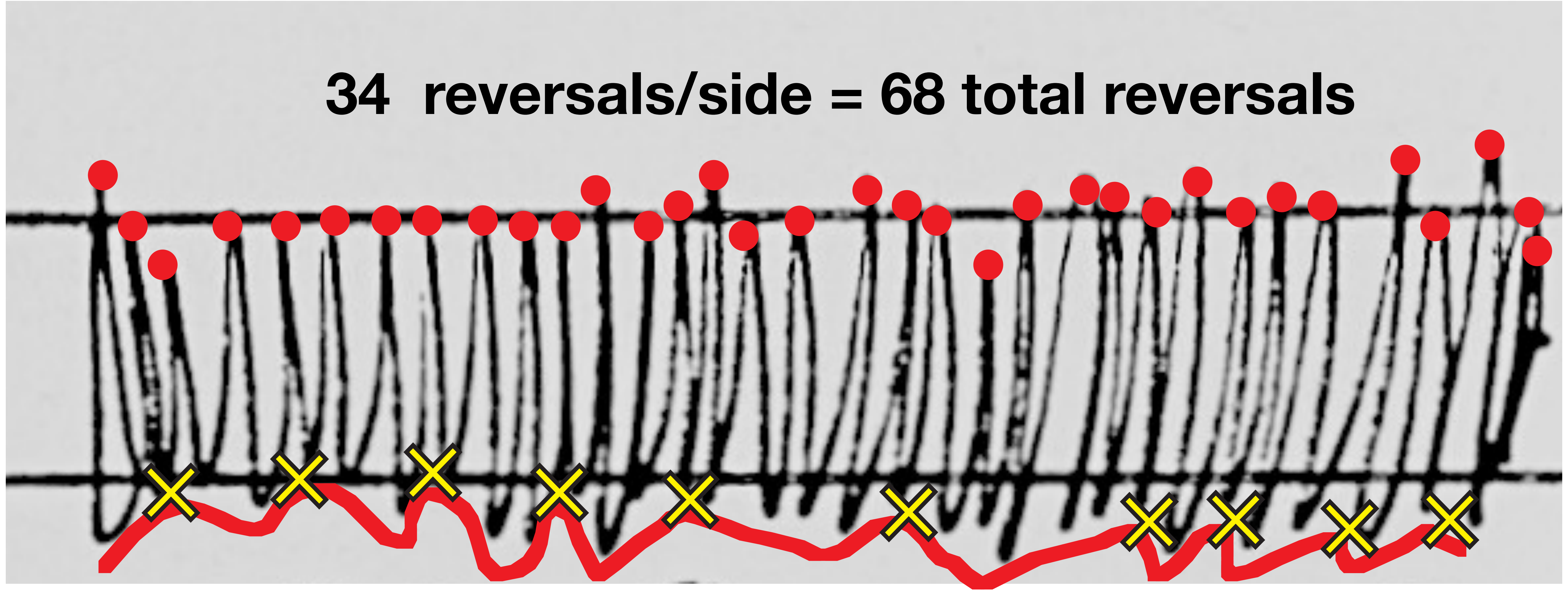


Model Human Processor



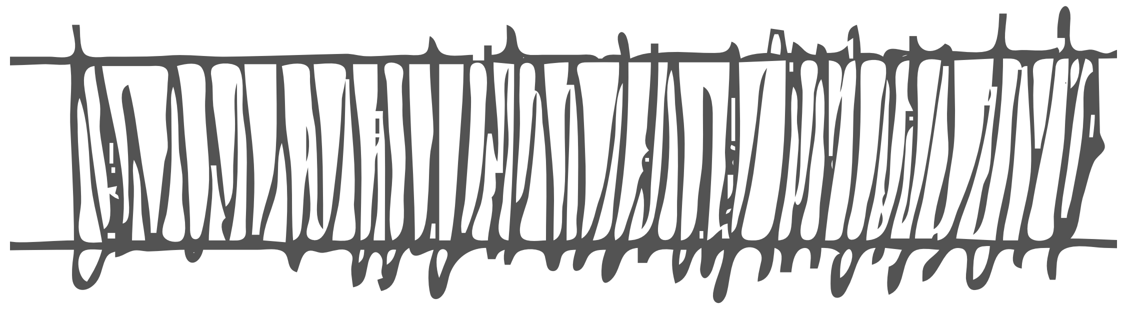
In-Class Experiment 4: Motor System

- Experiment: draw strokes between lines for 5s. Try to reach both lines.
- Count number of reversals
  - How many milliseconds per reversal?
- Create a contour of stroke bottoms, count number of corrections
  - How many milliseconds per correction?



10 corrections/side = 20 total corrections

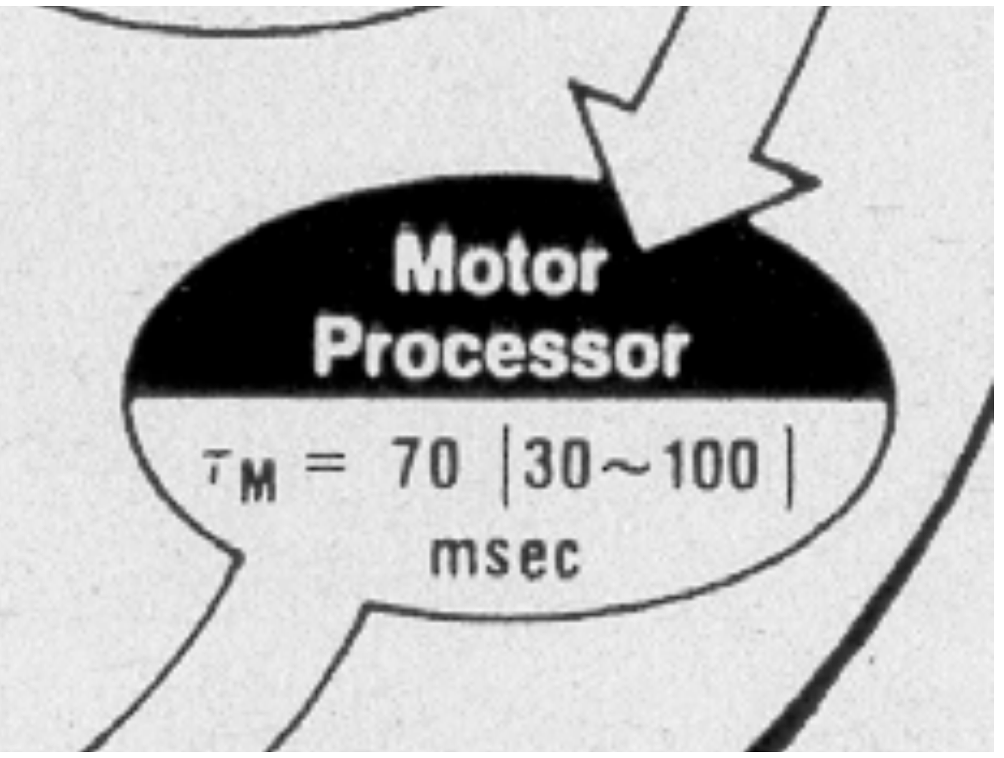
Motor System

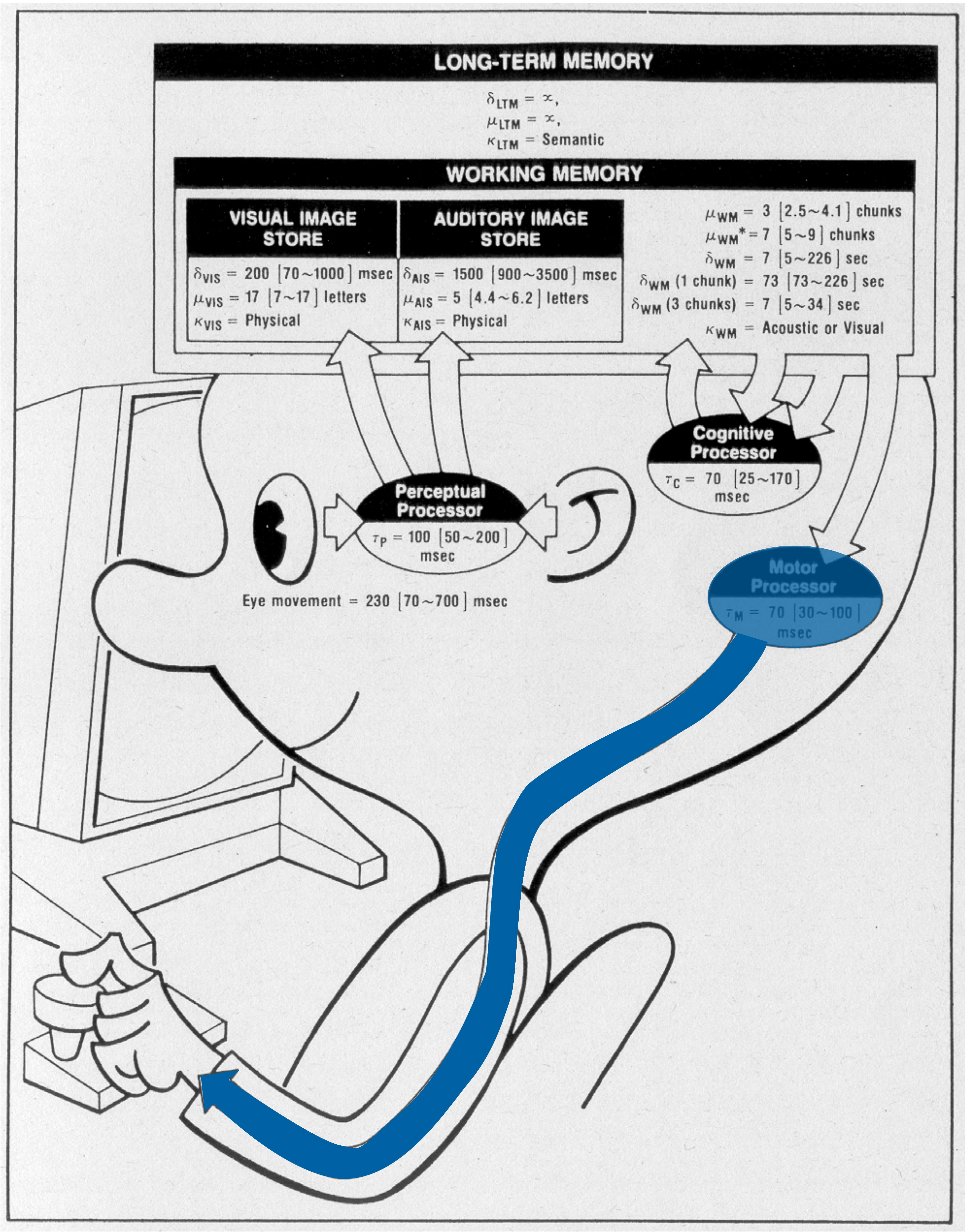


74 ms/reversal
250 ms/correction

- Motor processor (open loop)
  - τ_M = 70 ms

⇒ Average time between each reversal





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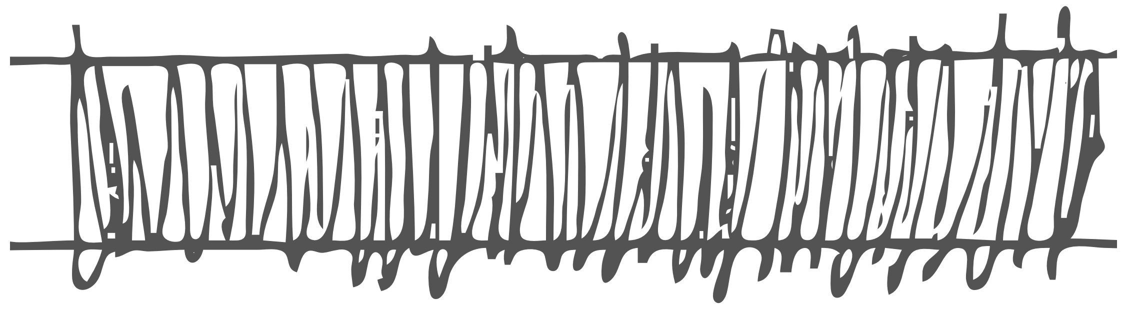
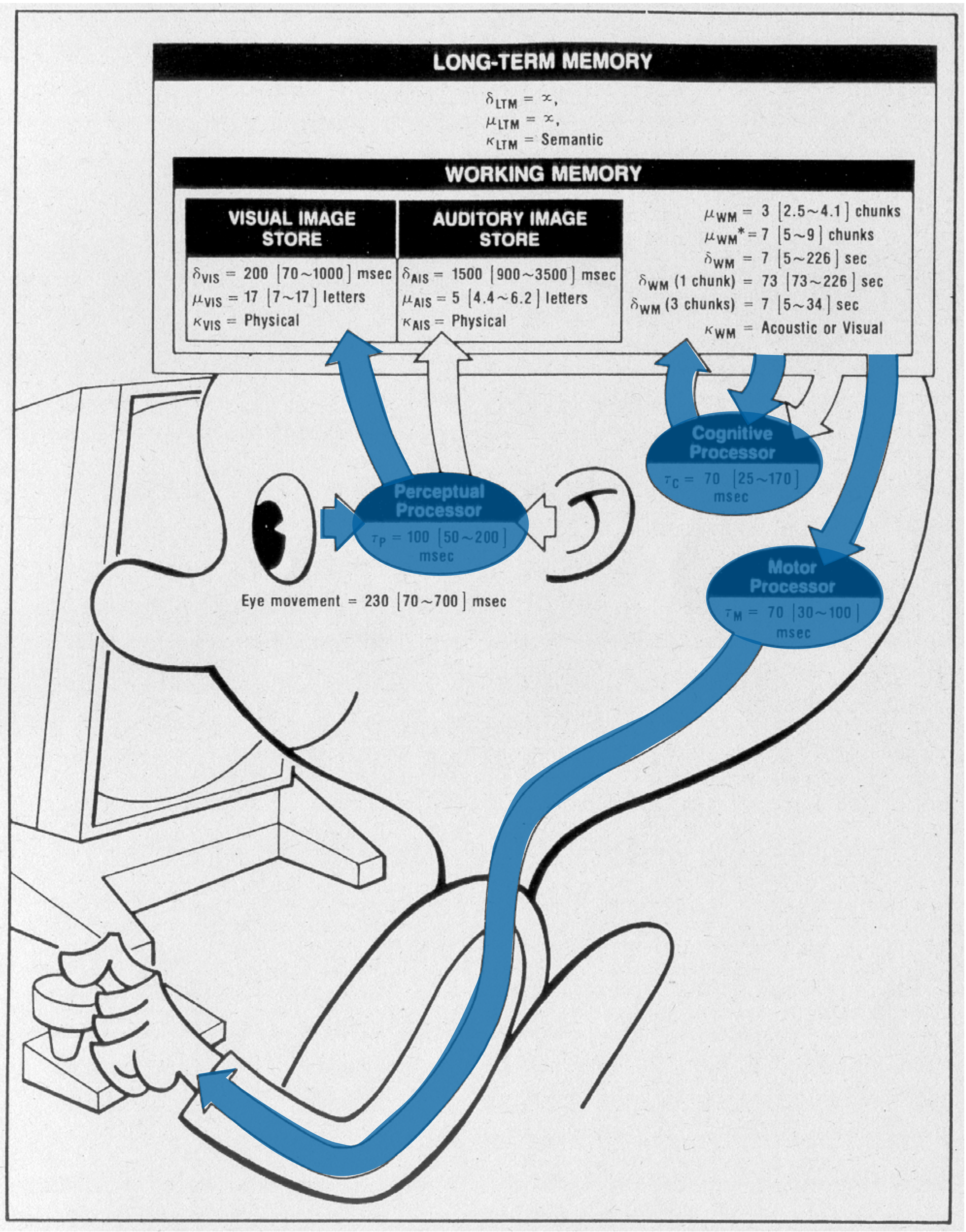
Motor System



74 ms/reversal
250 ms/correction

- Closed loop:
  - $\tau_P + \tau_C + \tau_M = 240$ ms

$\Rightarrow$ Average time between each correction



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Fitts' Law

In-Class Experiment 5: Tapping Task

1cm

4cm

8cm

16cm

Same for 0.5 cm and 2 cm wide strips

Tap for 10 s, count taps afterwards

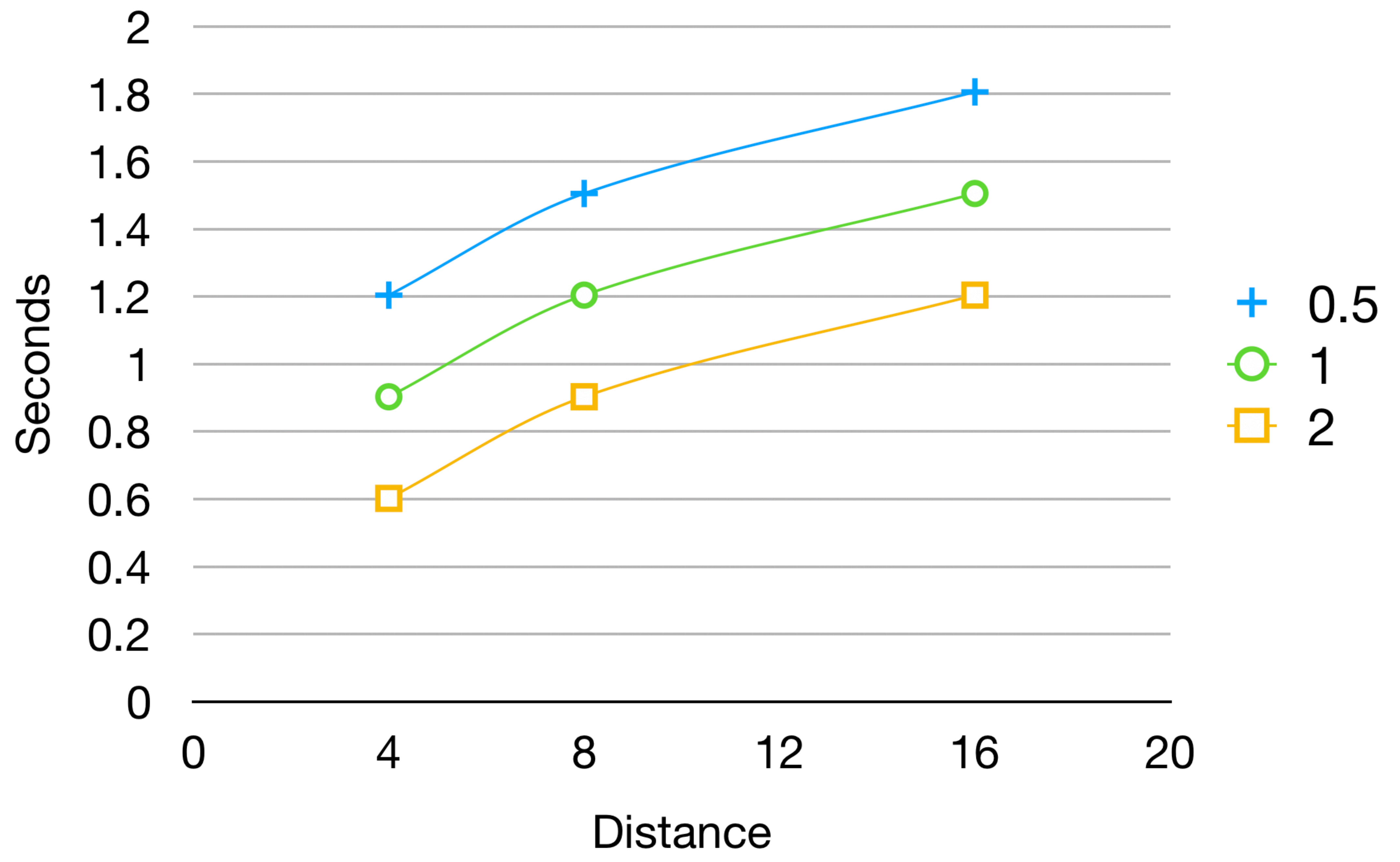
Tapping Task Results

- Doubling the distance adds roughly a constant to execution time

  ⇒ indicates logarithmic nature

- Doubling the target width (W) gives about same results as halving the distance (D)

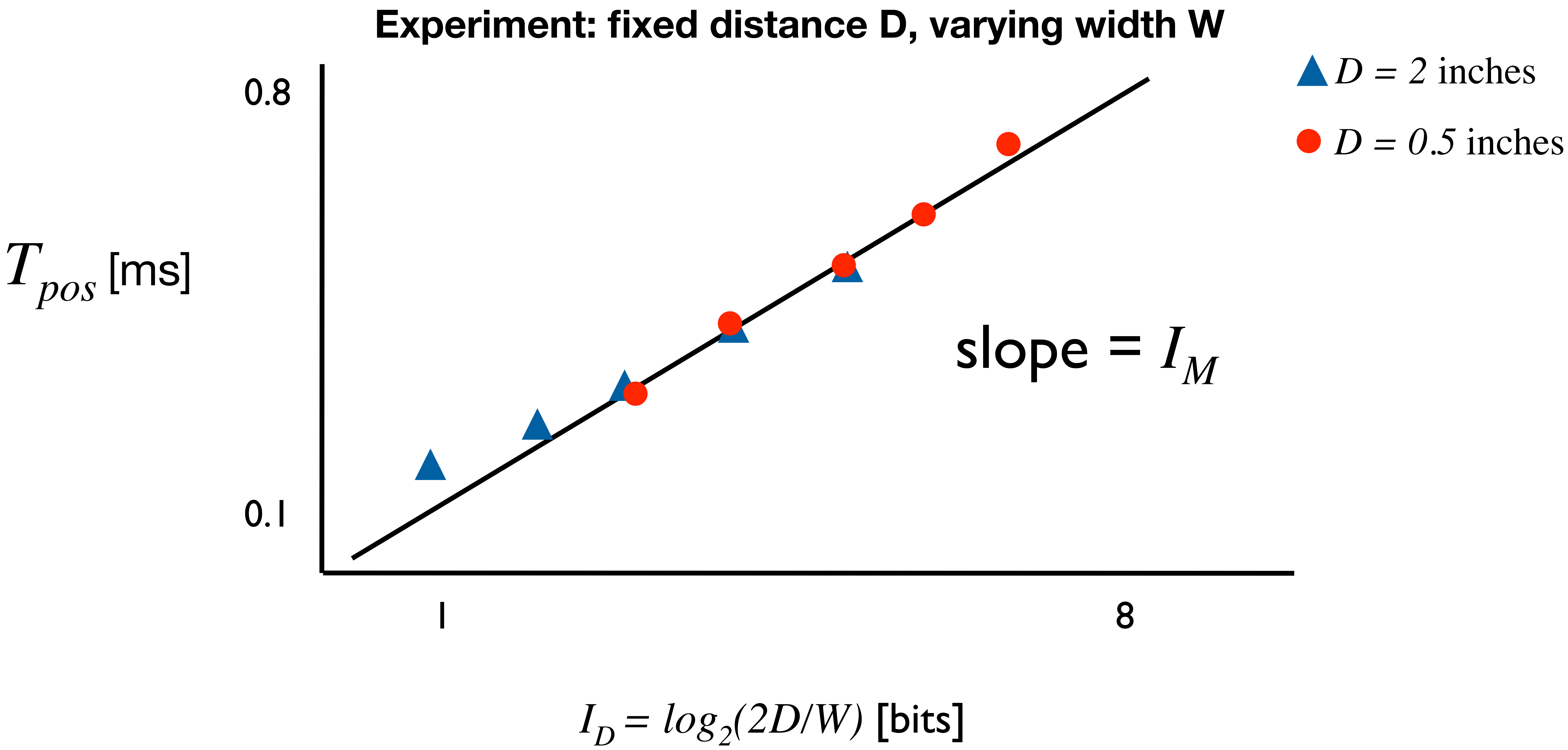
  ⇒ indicates connection of D/W in formula



Motor System: Fitts' Law

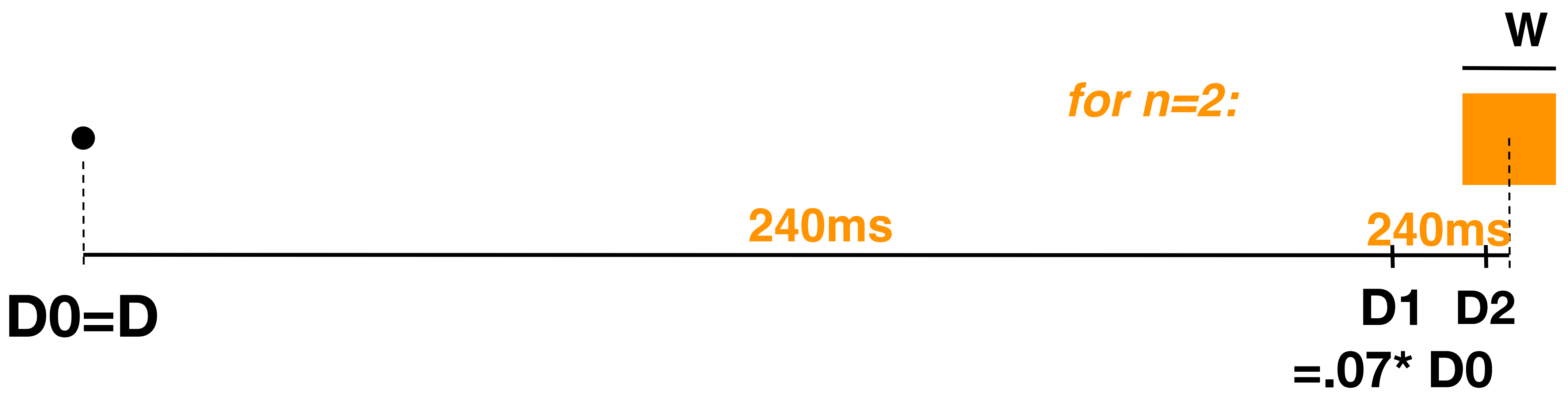
- Goal: Predict time to press buttons (physical or on-screen) as function of distance and size
- Result (Fitts, 1954): $T_{pos} = I_M \cdot I_D$
  - T_{pos} time to reach button
  - I_M =100 ms/bit index of movement, constant
  - $I_D = \log_2(2D / W)$ index of difficulty, in bits
- Fitts' law can be derived from CMN model

Visualizing Fitts' Law



Deriving Fitts' Law from CMN (1)

$$\begin{aligned}
D_i &:= \text{remaining distance to target after } i \text{ movements} \\
\epsilon &:= D_i/D_{i-1} < 1 \qquad \text{(relative movement precision, experiment shows)} \\
\epsilon &= 0.07 \qquad \text{(constant according to CMN model)}
\end{aligned}$$



$$\begin{aligned}
D_1 &= \epsilon \cdot D_0 = \epsilon \cdot D \\
D_2 &= \epsilon \cdot D_1 = \epsilon^2 \cdot D \\
&\dots \\
D_n &= \epsilon \cdot D_{n-1} = \epsilon^n \cdot D \quad \leq W/2 \qquad \text{(hand reaches target after } n \text{ movements)}
\end{aligned}$$

$$\begin{aligned}
\epsilon^n &\leq \frac{W}{2D} \\
\Leftrightarrow \quad n &\geq \log_\epsilon \left(\frac{W}{2D} \right) \qquad \text{(log for base } < 1 \text{ turns inequality sign)} \\
\Leftrightarrow \quad n &\geq \frac{\log_2 \left(\frac{W}{2D} \right)}{\log_2 \epsilon} \\
\Leftrightarrow \quad n &\geq -\frac{\log_2 \left(\frac{2D}{W} \right)}{\log_2 \epsilon}
\end{aligned}$$

Deriving Fitts' Law from CMN (2)

Total positioning time is $T_{pos} = n \cdot (t_{WP} + t_{KP} + t_{MP})$

Insert n to arrive at Fitts's Law:

$$
\begin{aligned}
T_{pos} &= -\frac{\log_2\left(\frac{2D}{W}\right)}{\log_2 \epsilon} \cdot (t_{WP} + t_{KP} + t_{MP}) && \text{(rearrange)} \\
&= -\frac{(t_{WP} + t_{KP} + t_{MP})}{\log_2 \epsilon} \cdot \log_2\left(\frac{2D}{W}\right) \\
&= -\frac{240\,\text{ms}}{\log_2(0.07)} \cdot \log_2\left(\frac{2D}{W}\right) && \text{(240 ms is CMN estimate)} \\
&\approx 100\,\text{ms} \cdot \log_2\left(\frac{2D}{W}\right) \\
&= I_M \cdot I_D && \text{q.e.d.}
\end{aligned}
$$

Improvements

- Welford's Formulation, 1968:

$$T_{pos} = I_M \cdot \log_2 \left(\frac{D}{W} + \frac{1}{2} \right)$$

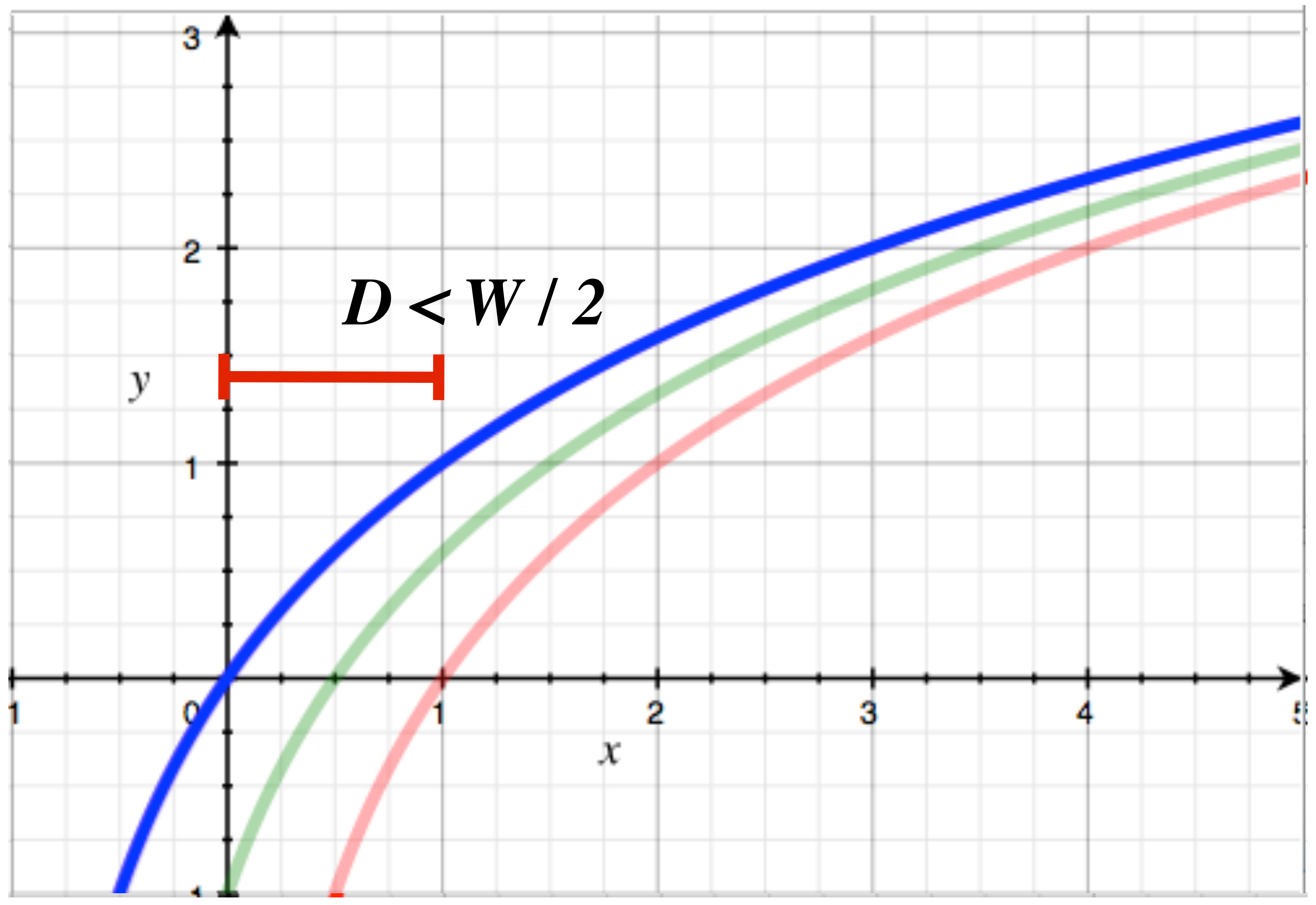
- Shannon's Formulation, ISO, 80's:

$$T_{pos} = a + b \cdot \log_2 \left(\frac{D}{W} + 1 \right)$$

  - *a, b* depend on device, determine experimentally

Use *a = 0 ms, b =* I_M *= 100 ms* for quick and dirty estimates

Improved curve fit, no negative times

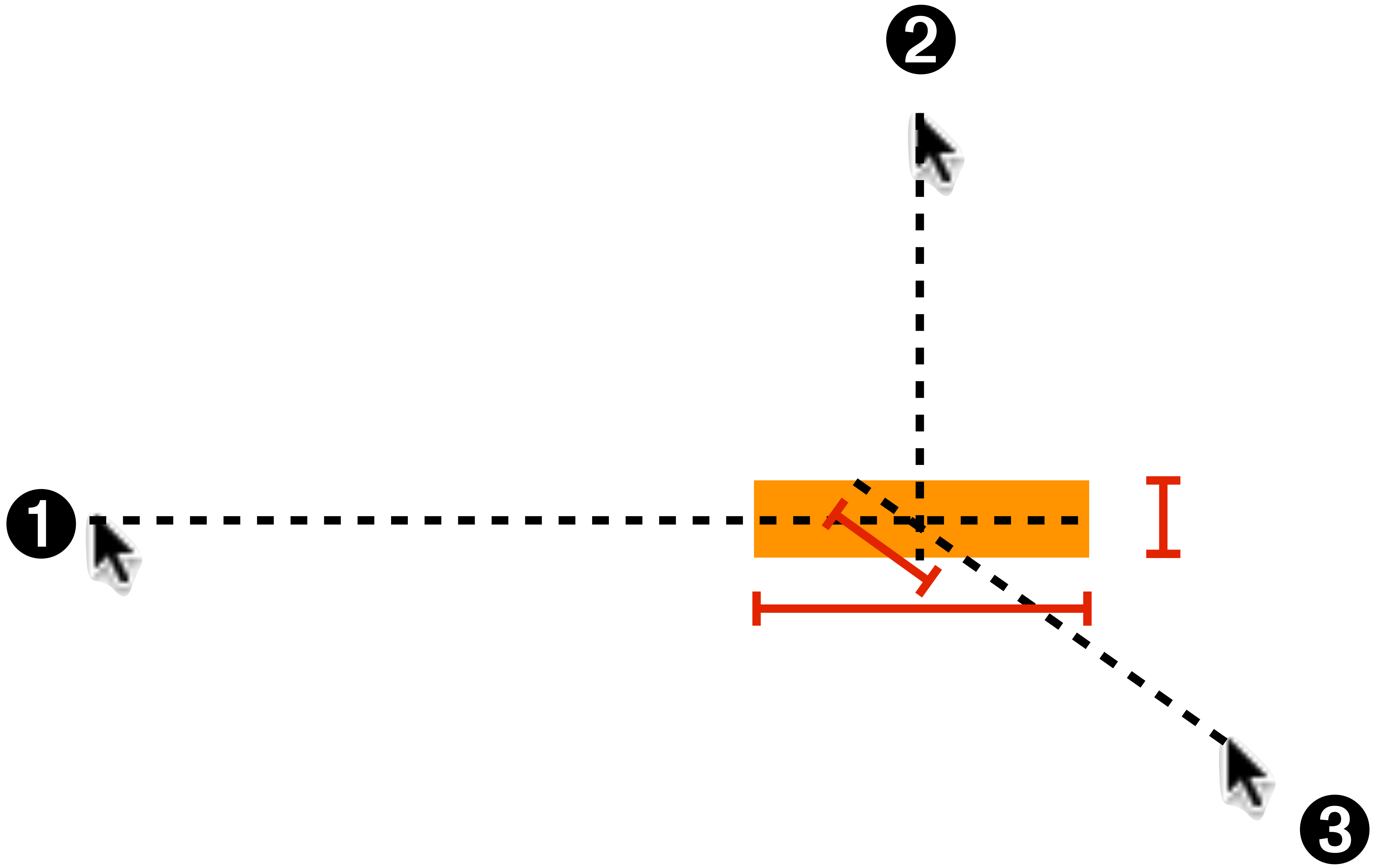


$$T_{pos} = I_M \cdot \log_2 \left(\frac{2D}{W} \right)$$

$$T_{pos} = I_M \cdot \log_2 \left(\frac{D}{W} + \frac{1}{2} \right)$$

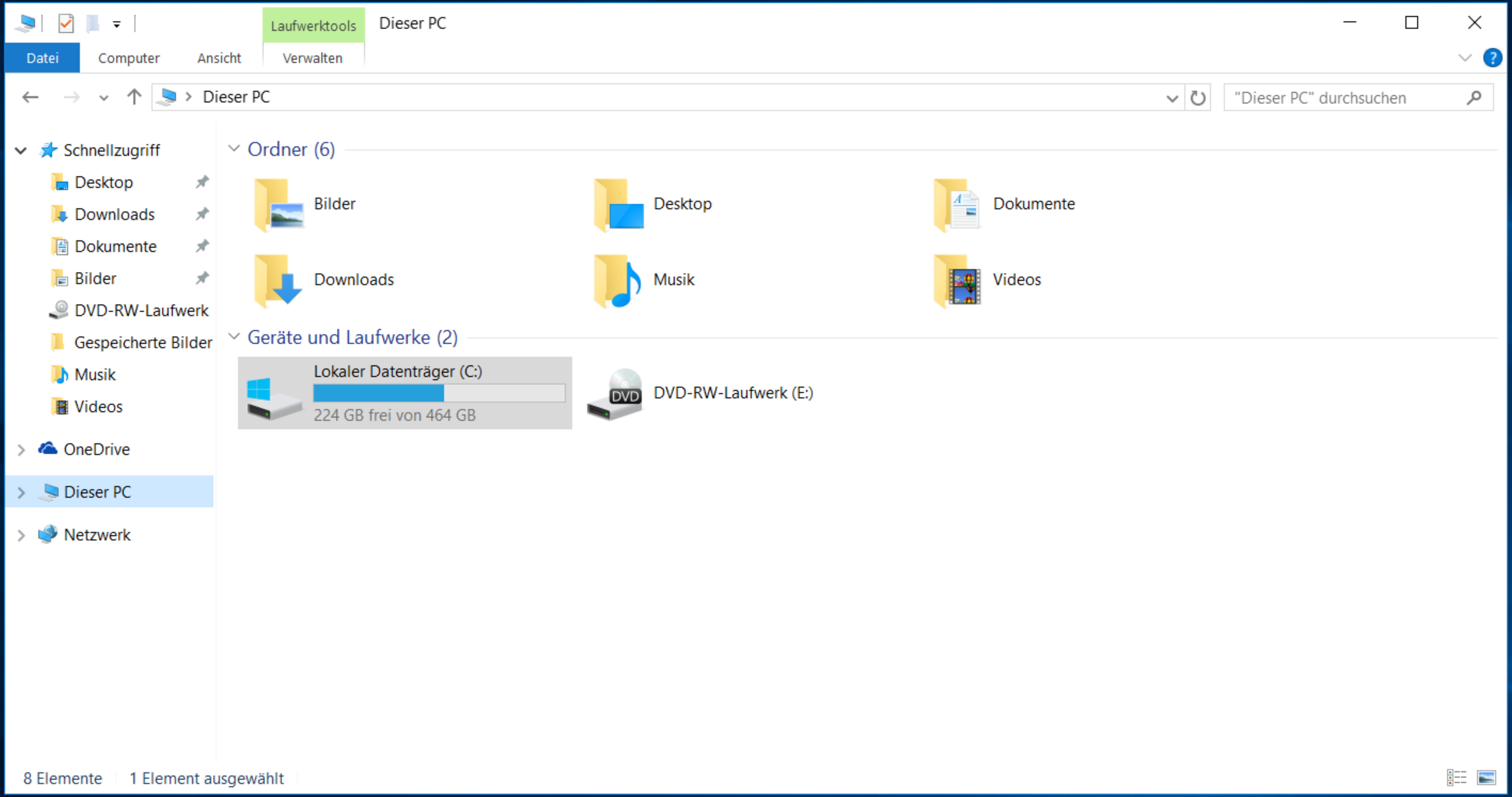
$$T_{pos} = a + b \cdot \log_2 \left(\frac{D}{W} + 1 \right)$$

Target Width



[MacKenzie & Buxton, CHI'92]

Windows 10



Laufwerktools
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Computer
Ansicht
Verwalten
Dieser PC
"Dieser PC" durchsuchen
Schnellzugriff
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OneDrive
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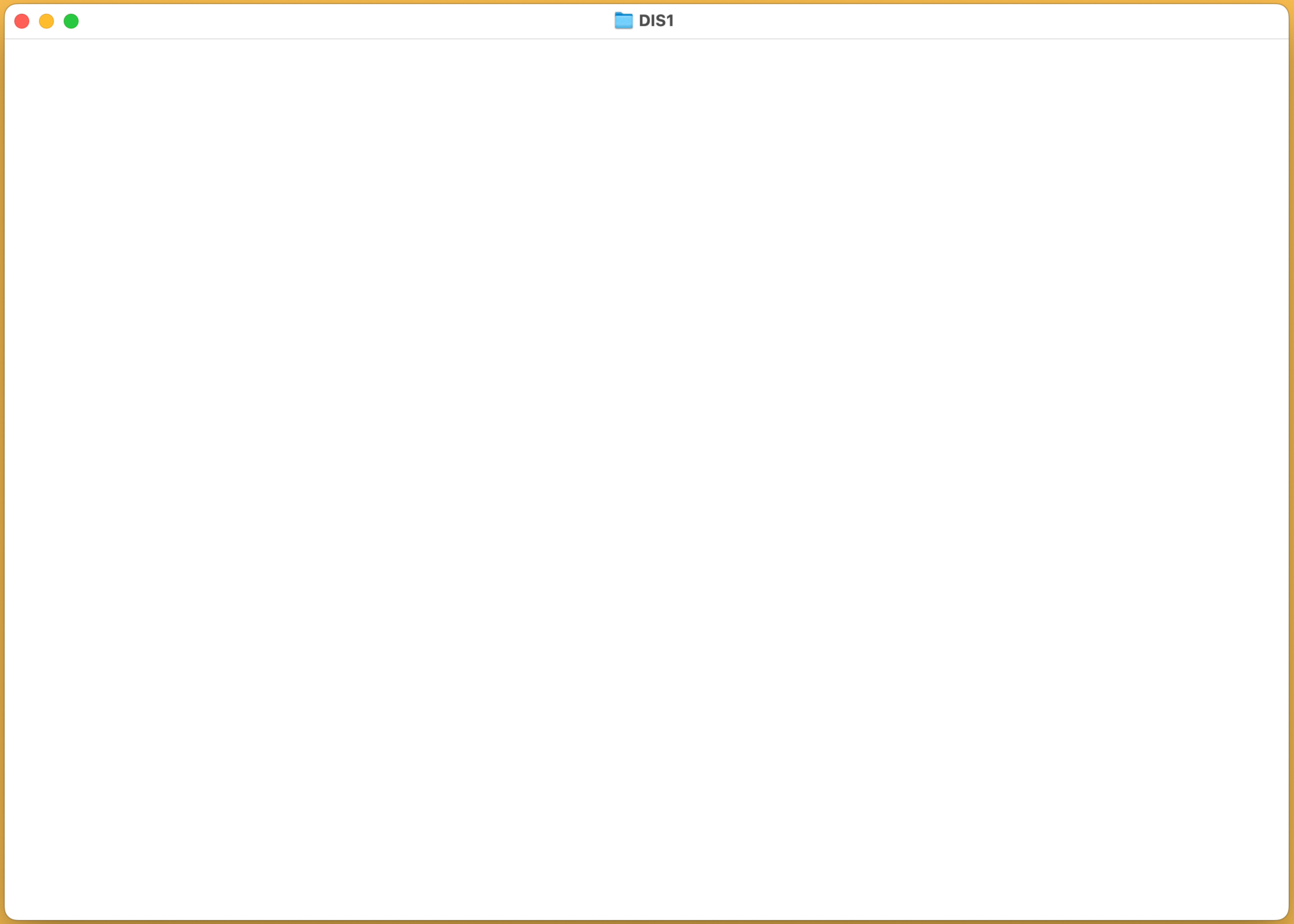
Netzwerk
Ordner (6)
Bilder
Desktop
Dokumente
Downloads
Musik
Videos
Geräte und Laufwerke (2)
Lokaler Datenträger (C:)
224 GB frei von 464 GB
DVD
DVD-RW-Laufwerk (E:)
8 Elemente
1 Element ausgewählt

Finder File Edit View Go Window Help Tue 11. Oct 09:51

macOS Monterey

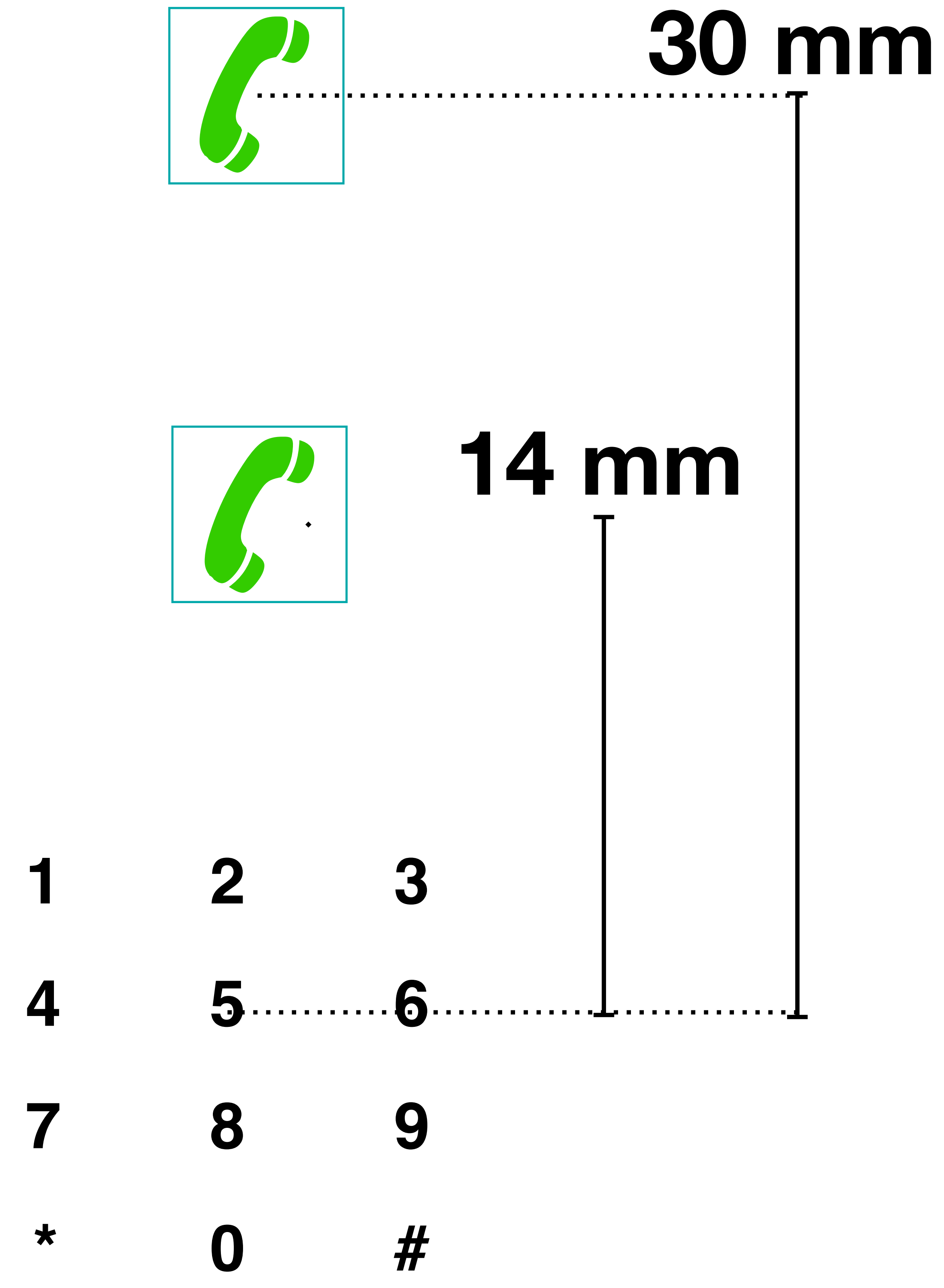


In-Class Exercise 6: Mobile Phone

- How much faster does calling become by moving the “call” button from 30 mm distance to 14 mm distance, measured from the middle of the keypad? The size of the call button is 2 x 2 mm

- Shannon’s Formulation: $T_{pos} = a + b \cdot \log_2(\frac{D}{W} + 1)$

- Use a = 0 ms, b =100 ms/bit



Solution

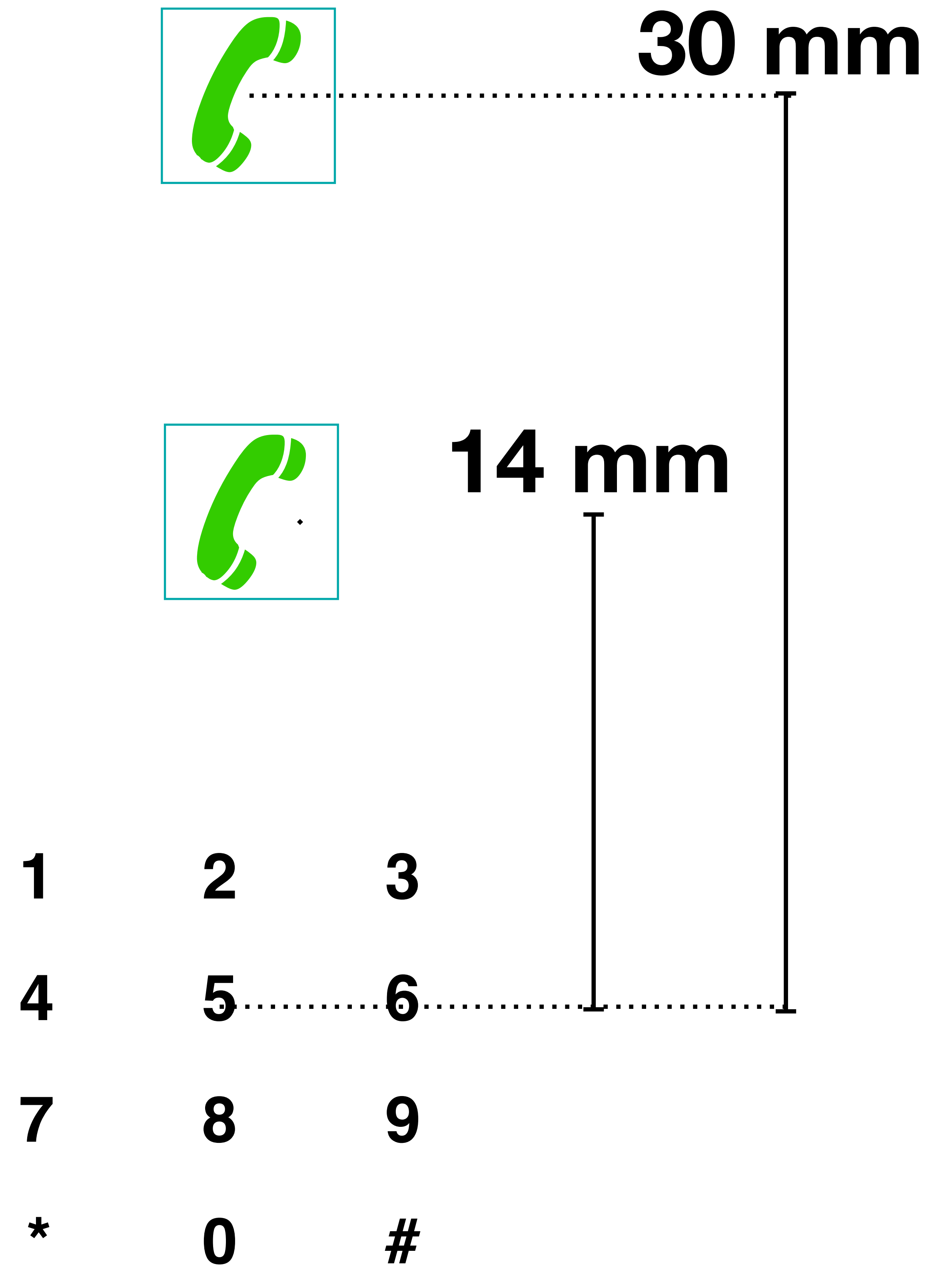
$$T_{pos1} = a + b \cdot \log_2(\frac{D_1}{W} + 1) \qquad T_{pos2} = a + b \cdot \log_2(\frac{D_2}{W} + 1)$$

$$T_{Diff} = T_{pos1} - T_{pos2} = a + b \cdot \log_2(\frac{D_1}{W} + 1) - (a + b \cdot \log_2(\frac{D_2}{W} + 1))$$

$$= b \cdot (\log_2(\frac{D_1}{W} + 1) - \log_2(\frac{D_2}{W} + 1))$$

$$= b \cdot (\log_2(\frac{30}{2} + 1) - \log_2(\frac{14}{2} + 1)) = b \cdot (log_2(16) - log_2(8))$$

$$= b \cdot (4bit - 3bit) = b \cdot 1bit = 100\frac{ms}{bit} \cdot 1bit = 100ms$$



⇒ Moving the call button speeds up each call by an average of about 100ms.

Summary

- The Media Computing Group does cool stuff
- HCI is about humans, computers, the design process, and the social context
- The CMN model allows estimating reaction times and memory performance
- You can calculate the average movement time of pointing devices using Fitts' Law
- You've experienced that mathematical laws seem to govern your perception, memory, and movement

What to Do Now

Today

1. Register for the course on RWTHonline
2. Upload your signed Declaration of Compliance on our website
   (If you have done this already, you don’t need to upload it again)

   File Name: `DIS1_DoC_<your last name>_<matriculation number>.pdf`

3. Feel free to check out our other class, iOS Application Development

Before next Lab on Tuesday

- Buy Don Norman’s The Design of Everyday Things (2nd edition, 2013)
- Start working on the assignment

Before next Lecture

- Read Dix’ Human-Computer Interaction, chapter “The Human” (pp. 11–59)
  (PDF available on RWTHmoodle)