The Unbearable Slowness of Being

The limit of human behavior at 10 bits/s

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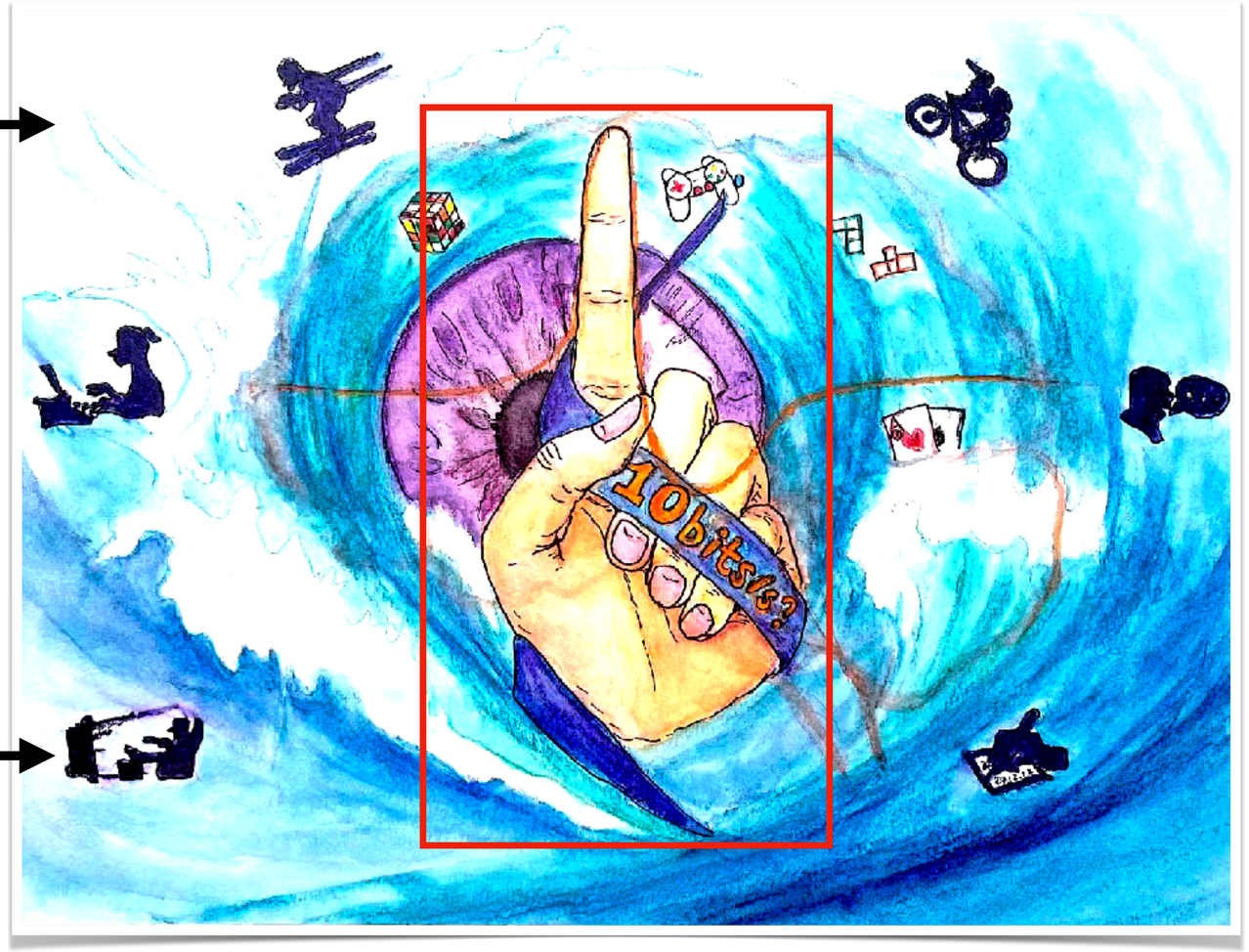
Chen Institute Workshop, April 11th, 2025
Cross-Species Modalities in Cognition and Behavior

Motor function →

Perception →



→ Cognition

“human behaviors, including motor function, perception, and cognition, operate at a speed limit of 10 bit/s.”

10 bits/s

Information theory (Shannon & Weaver, 1964)

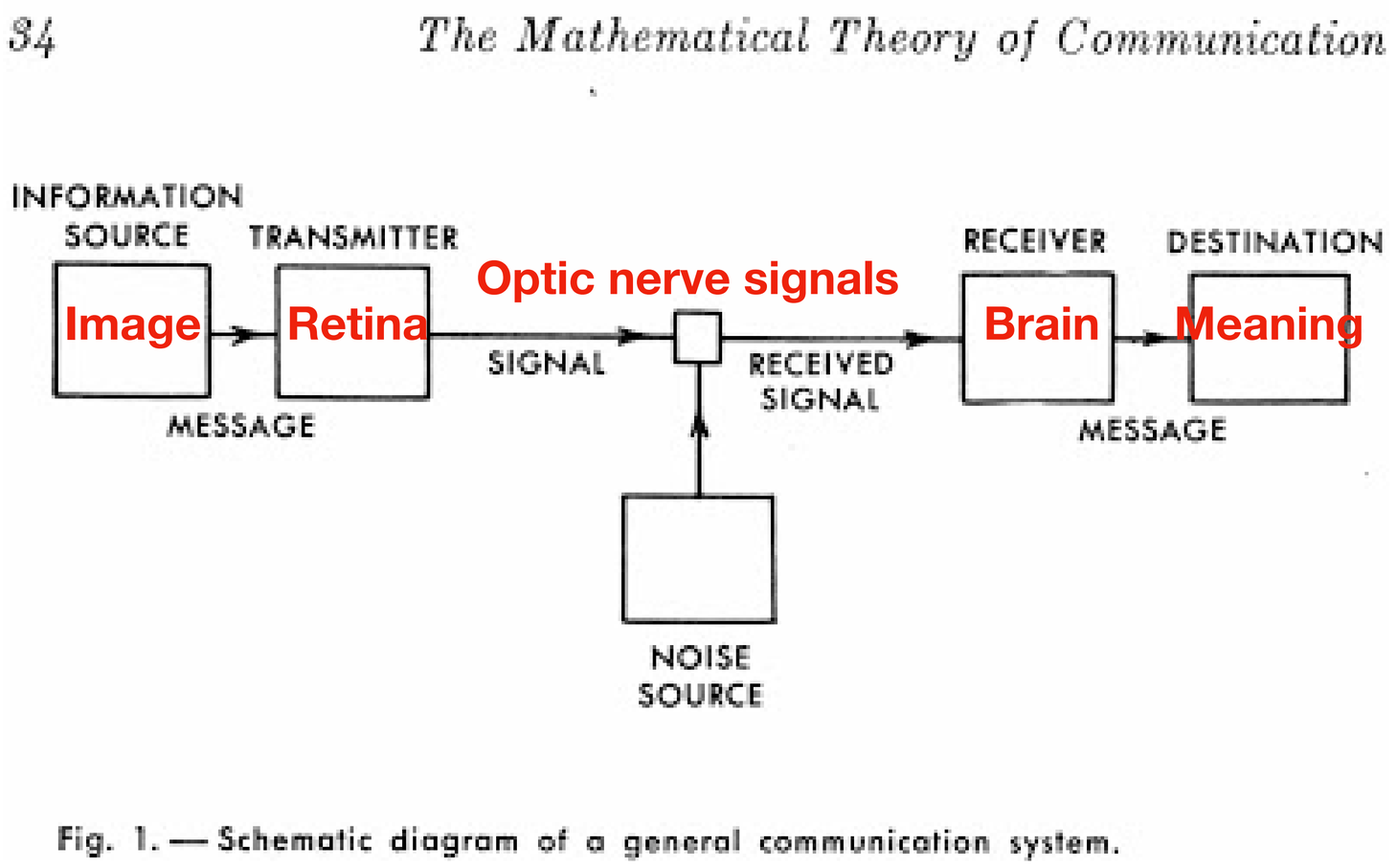


Fig. 1. — Schematic diagram of a general communication system.

10 bits/s

Information theory (Shannon & Weaver, 1964)

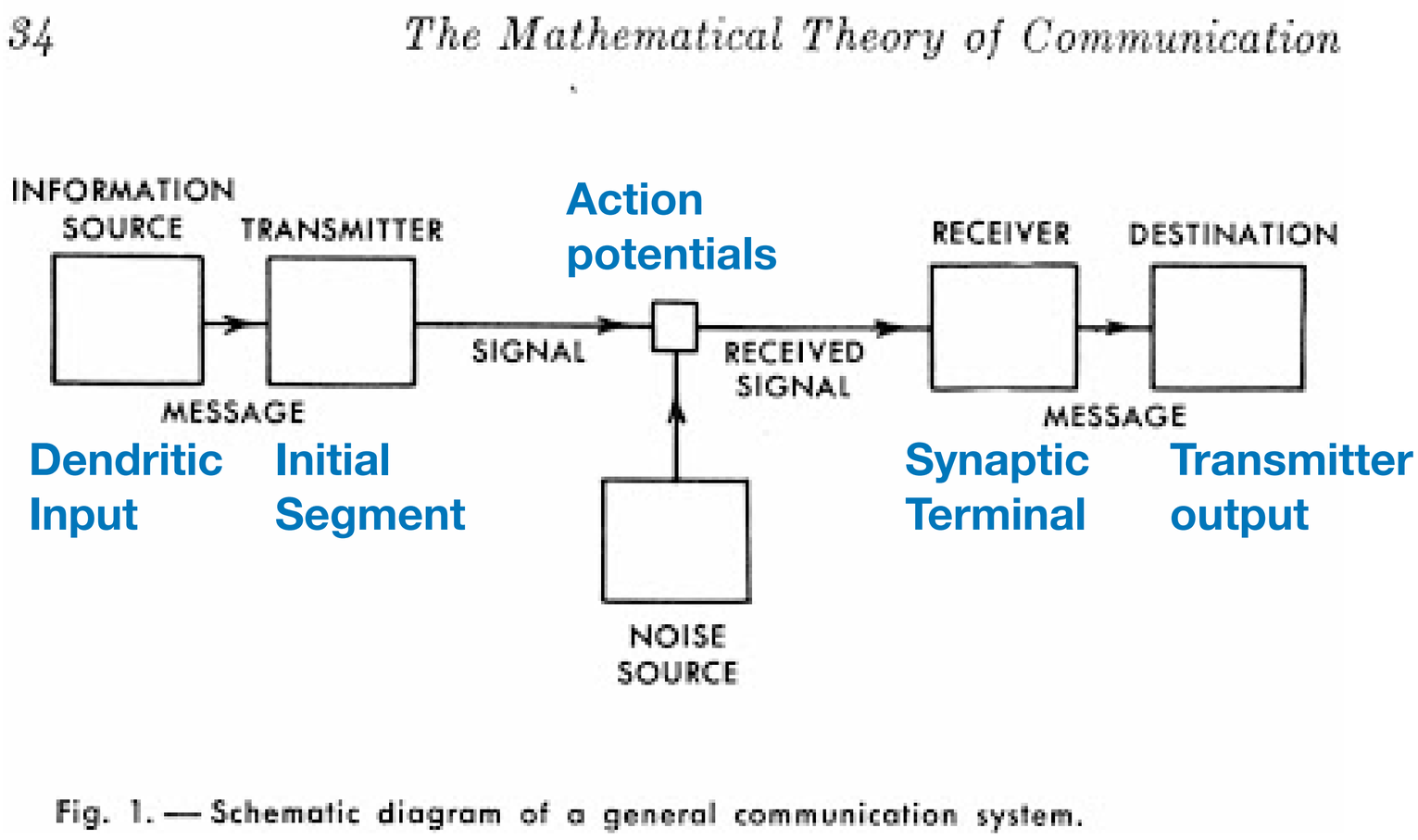


Fig. 1. — Schematic diagram of a general communication system.

The information rate of motor function

Example 1: Typing

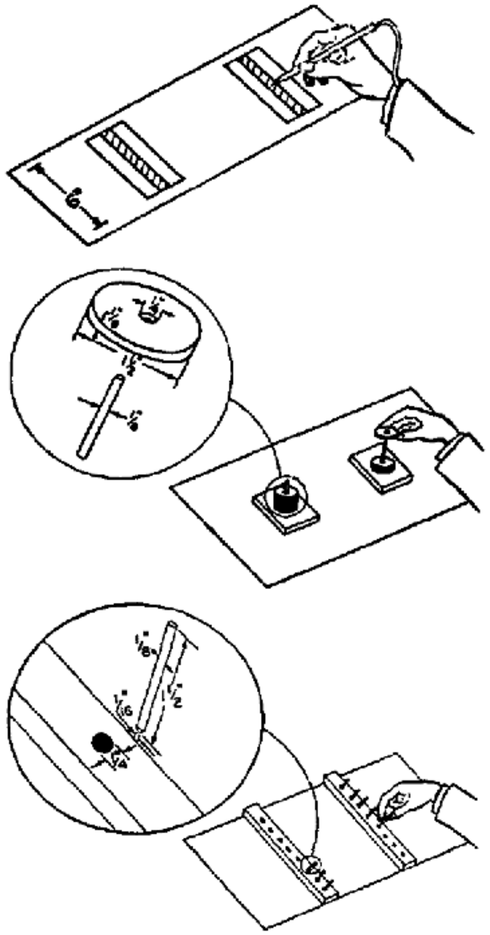
- 120 words per min (Dhakal 2018)
- 5 average characters per word (Shannon 1951)
  - Random: $\log_2 26 = 4.7$ bits/character
  - With structure: 1 bit per English character (Shannon 1951)

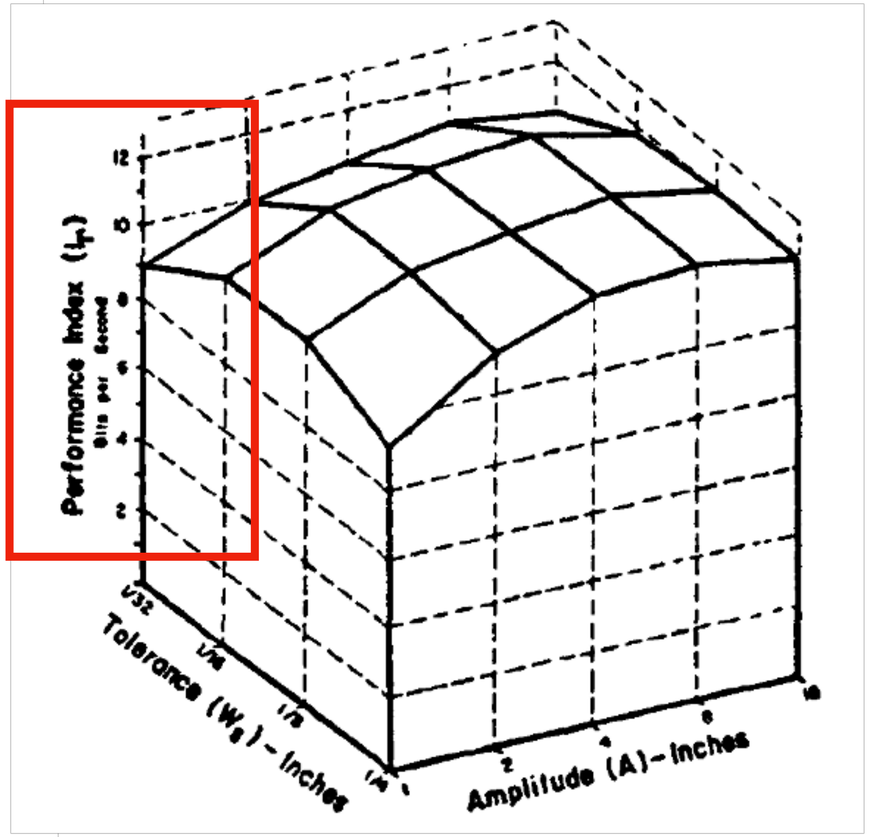
$$I = 2\frac{\text{words}}{\text{s}} \cdot 5\frac{\text{characters}}{\text{word}} \cdot 1\frac{\text{bit}}{\text{character}} = 10\frac{\text{bits}}{\text{s}}$$

The information rate of motor function

Example 2: Fitts 1954 the capacity of the motor system

- Performance of motor tasks depends on
  - Distance (A)
  - Target size (W)
- Timescale: 15-20s
- Information rate: 10-12 bits/s





The information rate of perception

Example 3: Blind-folded 3x3x3 Rubik Cube

- The number of permutations of the cube:
  - $4.3 \times 10^{16} \approx 2^{65} = 65$bits
- Perception time: 5.5s
- Information rate: 11.8 bits/s

The information rate of thinking

Example 4: “Twenty Questions”

- “Quick, **think of a thing**. Now I’ll guess that thing by asking you **yes/no** questions.”
- **The information:** 20×1bits
- **Thinking time:** 2-3 seconds
- **The information rate (information divided by time):** 10 bits/s or less

No.	Question	User’s Answer
1	Is the person female?	No
2	Is the person still alive?	No
3	Does the person have children?	Yes
4	Does the person have brothers or sisters in the family?	Yes
4	Is the person very smart?	Yes
5	Was the person born in America?	No
6	Is the person the white man?	Yes
7	Is the person’s family very rich?	No
8	Is the person a controversial figure in history?	Yes
9	Is the person related to politics?	Yes
10	Does the person have good looks?	Unknown
11	Does the person have short hair?	Yes
12	Is the person very famous?	Yes
13	Has the person once been very powerful?	Yes
14	Is the character of the person very aggressive?	No
15	Has the person been the president of a country?	Yes
16	Is the person a military?	Yes
17	Has the person once killed men?	No
18	Was the person born in Britain?	No
19	Was the person one of famous leaders in the World War II?	No
20	Has the person once been the emperor?	Yes

Semantic Scholar

Table 1. The information rate of human behaviors

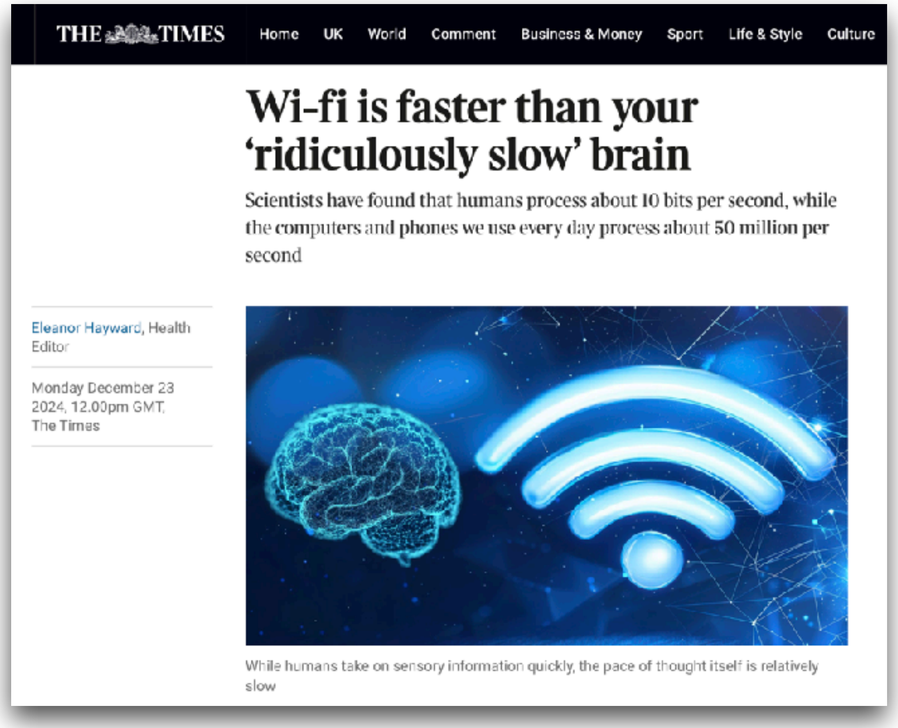
Behavior/activity	Time scale	Information rate (bits/s)	References
Binary digit memorization	5 min	4.9	International Association of Memory[9]
Blindfolded speedcubing	12.78 s	11.8	Guinness World Records Limited[6]
Choice-reaction experiment	min	~5	Hick,[11] Hyman,[12] Klemmer and Muller[13]
Listening comprehension (English)	min–h	~13	Williams[5]
Object recognition	0.5 s	30–50	Sziklai[14]
Optimal performance in laboratory motor tasks	~15 s	10–12	Fitts[15] and Fitts and Peterson[16]
Reading (English)	min	28–45	Rayner[17]
Speech in 17 languages	< 1 min	39	Coupé et al.[18]
Speed card	12.74 s	17.7	International Association of Memory[10]
StarCraft (e-athlete)	min	10	Guinness World Records Limited[19]
Tetris	min	~7	Tetra Channel[20]
Typing (English)	min–h	10	Dhakal et al.[3] and Shannon[4]

Zheng and Meister, Neuron (2024)

“human behaviors, including motor function, perception, and cognition, operate at a speed limit of 10 bit/s.”

The scale of 10 bits/s

- Human behavior: **10 bits/s**
- Average Internet speed in California: **93 Mbps (~10^9bits/s)**



THE TIMES Home UK World Comment Business & Money Sport Life & Style Culture

Wi-fi is faster than your 'ridiculously slow' brain

Scientists have found that humans process about 10 bits per second, while the computers and phones we use every day process about 50 million per second

Eleanor Hayward, Health Editor

Monday December 23 2024, 12.00pm GMT
The Times

While humans take on sensory information quickly, the pace of thought itself is relatively slow

The New York Times

The Speed of Human Thought Lags Far Behind Your Internet Connection, Study Finds

A new study is "a bit of a counterweight to the endless hyperbole about how incredibly complex and powerful the human brain is," one researcher said.

The information rate of the nervous system

- Human behavior: **10 bits/s**
- Retina: 6×10^6 cones x 20 Hz bandwidth x 8 bits SNR **(~10^9bits/s)**

$$Si = \text{Sifting Number} = \frac{\text{Sensory information rate}}{\text{Behavioral throughput}} \approx \frac{1\ \text{Gbit/s}}{10\ \text{bit/s}} = 10^8$$

The slowness of being

We can only think of one thing at a time

- A “psychological refractory period” occurs before the second task can be processed
- Serial processing at the “central bottleneck”
- The neural resources do not set the limit!

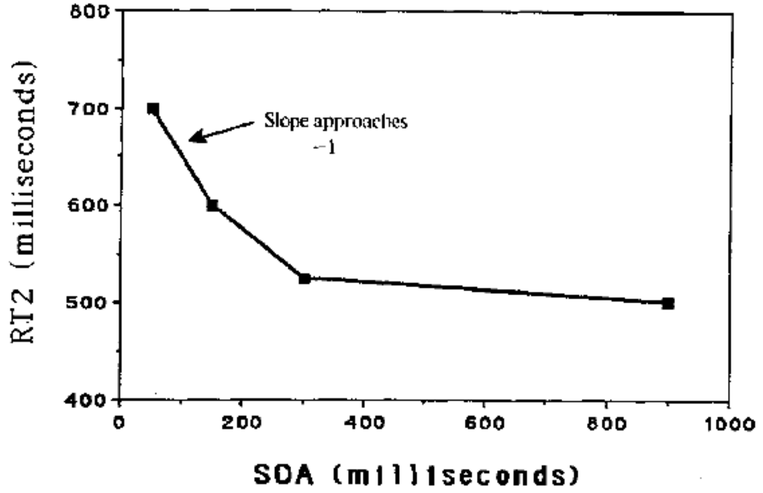


Figure 1. The psychological refractory period effect. Top panel: The first stimulus (S1) precedes the second stimulus (S2), and reaction times (RTs) are recorded to each. Bottom panel: typical pattern whereby the second reaction (R2) is slowed as the interval between the tasks is reduced. The slope approaches −1, indicating that (on average) the second response cannot be produced until a certain time after S1. R1 = first response; SOA = stimulus onset asynchrony.

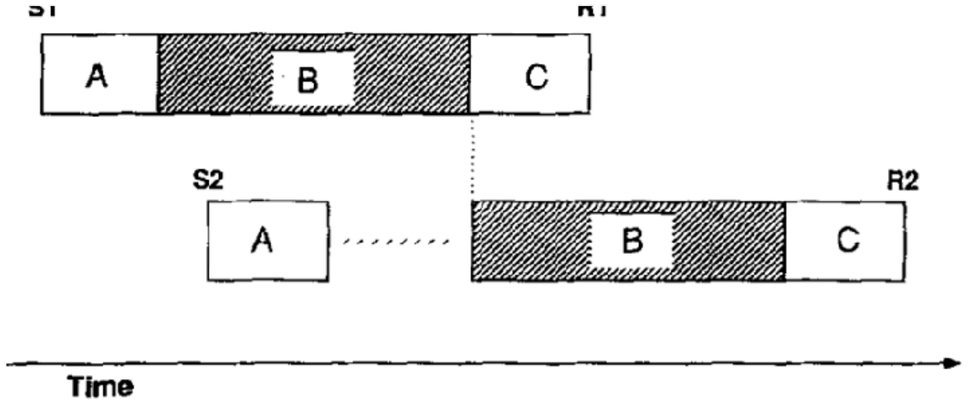


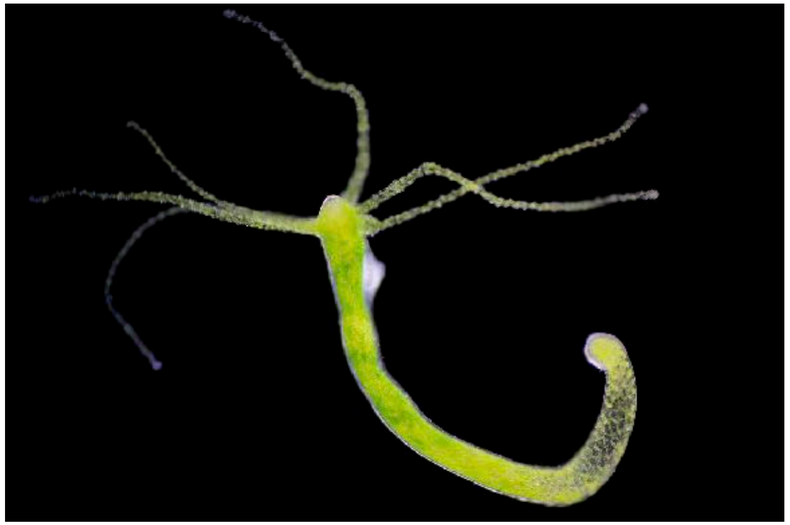
Figure 2. A central bottleneck model: The shaded portion of Task 2 cannot begin until the corresponding portion of Task 1 is complete. Other stages can operate in parallel, however. S = stimulus; R = response.

Pashler 1994

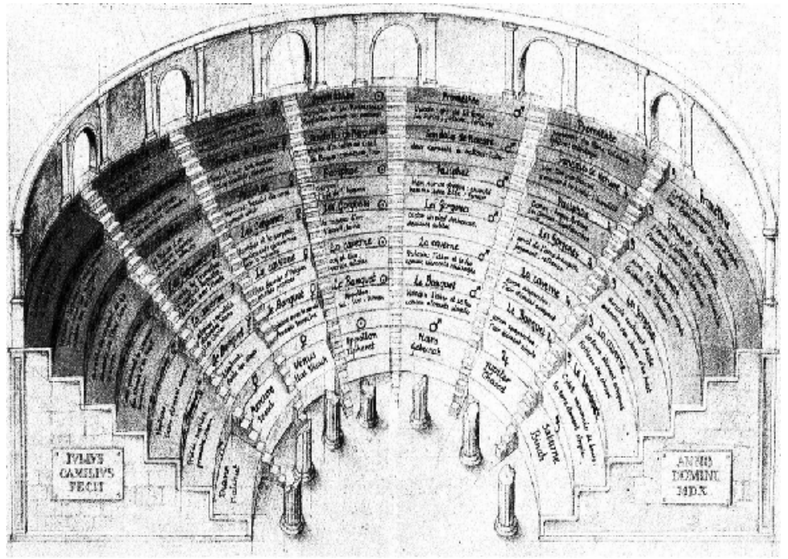
Why do we live at 10 bits/s?

A speculative answer

- One thing at a time — constrained by movement and gradient-based navigation
- Spatial navigation technique for memory: routing in a memory palace

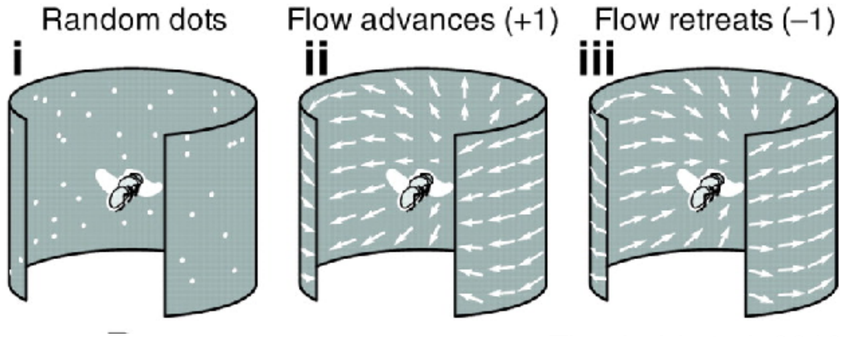


A hydra



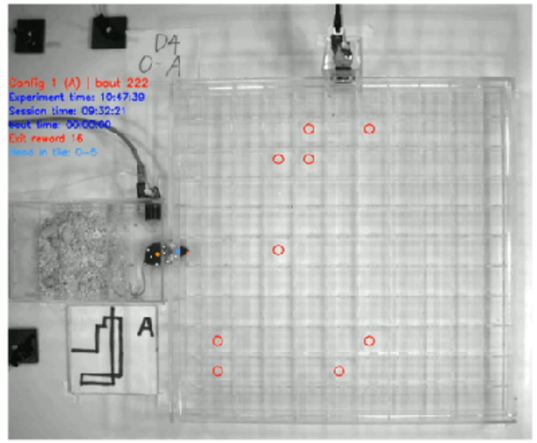
Giulio Camillo’s depiction of a memory palace (1511 AD)

The speed of life across species



Theobald et al. 2010

- A tethered fruit fly produces torque in response to virtual optic flow: **~0.63 bits/s**



Zheng et al. (In prep.)

- An experienced mouse solves the 9-hole Manhattan Maze in ~20 seconds: **~0.9 bits/s**

- Different ecological niches might have different information rates.

The information output of Brain-Computer Interface Caps at 10s bits/s?

BCI type	Reference	Task	Reported avg ITR (bps)
Intracortical	[437]	Handwriting decoding	6.56
Electrophysiology	[438]	Speech decoding	13.33
	[122]	Speech decoding	8.69
	[439]	Cursor control (grid task)	8.00
fMRI	[440]	Visual retrieval	3.24
	[441]	Text decoding	6.95
EEG	[442]	Free spelling	1.31
SSVEP-based EEG	[443]	Free spelling	16.86
SSVEP-based MEG+EEG	[444]	Visual decoding	5.20
SSVEP-based MEG	[444]	Visual decoding	4.53
OPM-MEG	[445]	Spelling	1.31
HD-DOT	[446]	Visual information decoding	0.55
fNIRS	[447]	Ternary classification	0.078
fUS	[448]	Movement intention decoding	0.087

Table 3: State-of-the-art in reported information transmission rates across brain-computer interface modalities and paradigms.

Mineault et al. 2025

Conclusions

- Human behaviors, including motor function, perception, and cognition, operate at a speed limit of **10 bit/s.**
- We can only think of one thing at a time, and that might be determined by our **ecological niche.**
  - We do not yet understand the neural/**mechanical constraints** on the serial processing.
- **Different species** may have different information rates of behavior outputs.

An American crow outside BBB, Caltech
Available in the next issue of *the California Tech*

Acknowledgement

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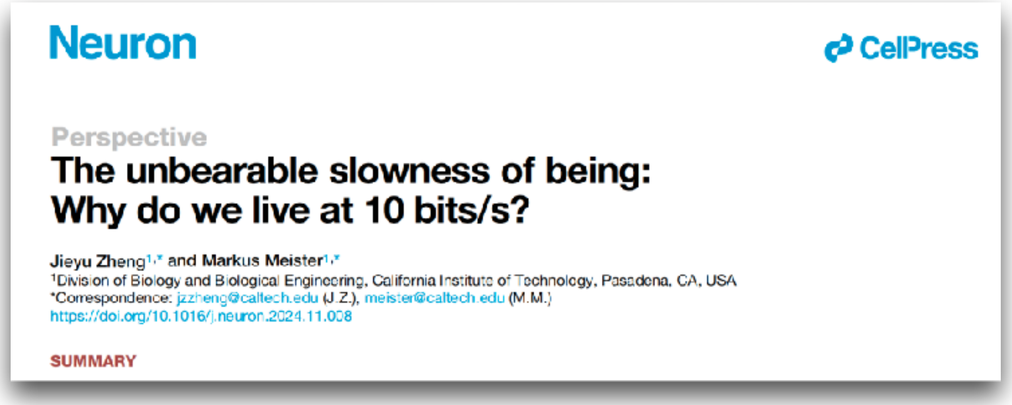

Meister Lab approaching 10 bits/s (skiing)

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