The Fitts' Law Filter Bubble

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ABSTRACT

Fitts derived a formula that allows one to calculate the time it takes to hit a target of a given size. MacKenzie called this formula imperfect and suggested an alternative formula. This paper asks some simple questions about MacKenzie's theory. If the human-computer interaction (HCI) community does not have satisfying answers, it means that MacKenzie's formula is unfounded. In consequence, the HCI community should stop using and citing MacKenzie's formula and use Fitts' original formula instead and only when necessary. Additionally, the HCI community should review the Fitts' Law research of the last 35 years concerning criteria that indicate an echo chamber and a filter bubble and debate whether they want to publish papers based on information theory in the future.

CCS CONCEPTS

• **Mathematics of computing → Information theory**; • **Human-centered computing → Interaction design theory, concepts and paradigms**.

KEYWORDS

Fitts' Law, MacKenzie's formula, information theory, Shannon's Theorem 17

ACM Reference Format:
Heiko Drewes. 2023. The Fitts' Law Filter Bubble. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems (CHI EA '23), April 23–28, 2023, Hamburg, Germany*. ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3544549.3582739

1 INTRODUCTION

In 1948, Shannon published his famous work *'A mathematical theory of communication'* [9] which founded information theory. This theory introduced a new concept of measuring information. Shannon's theory is closely related to thermodynamics, sharing concepts like entropy, and is well-founded on a solid mathematical basis. This inspired many researchers to apply Shannon's framework and terminology to their field of research.

One of these researchers was Fitts, a psychologist, who applied information theory to aimed movements of the human body [3]. Fitts used Shannon's concept of an *information channel* with a limited information transmission capacity [9] for the nervous system controlling a pointing action of the arm and the hand to a target of a given size. Fitts argued that the bandwidth of the *information channel* is the limiting factor for the speed at which the pointing action can be performed.

The validity of this approach is debatable as the limiting factor for the pointing action is not a question of the transmission capacity of the nerves seen as an *information channel*, but a question of the processing power of the human brain. In particular, referring to noise and Shannon's Theorem 17 as the limiting factor [3] was not a lucky choice. However, with small changes in terminology, Fitts' approach is reasonable, makes sense, and his theory is of practical value for designing user interfaces. Additionally, it is possible to derive Fitts' formula from other assumptions without bits and noise[1].

In 1958, Elias wrote an editorial with the title *'Two Famous Papers'* [2] where he was critical of the application of information theory to other fields of research and suggested that researchers stop writing such papers. It seems that psychology heeded his advice.

In 1989, MacKenzie discovered Fitts' paper and noticed that Fitts' work applies to mouse movements and therefore has relevance for HCI. However, MacKenzie claimed that Fitts' formula is imperfect and unfounded and published his paper *'A Note on the Information-Theoretic Basis for Fitts' Law'* [7] where he suggested another formula, which should be *'more theoretically sound'* [8].

From this moment on Fitts' Law euphoria started in the HCI community with hundreds of publications referring to Fitts' Law but using MacKenzie's formula. Many researchers did Fitts' Law evaluations and reported very good correlation values (see [1]) in the same way they do for p- or f-values in their statistical evaluations. Some researchers, however, presented extensions to MacKenzie's theory with modified or new formulas. References to both types of research are not given here by intention.

In 2010, Drewes published a paper with the title *'Only One Fitts' Law Formula Please!'* [1] and argued that contradicting formulas are not legitimate in science and that the HCI community should agree on one correct formula. Drewes also questioned MacKenzie's analogy to Shannon's Theorem 17.

In 2018, instead of discussing whether MacKenzie's analogy is legitimate, Gori et al. published the paper *'Speed-Accuracy Tradeoff: A Formal Information-Theoretic Transmission Scheme (FITTS)'* [6] and alleged Fitts to have introduced the analogy to Shannon's Theorem 17 and accused Fitts of abuse of information theory [5].

It is the purpose of this paper to disprove MacKenzie's and Gori's narrative that Fitts did it wrong and to show that the opposite is true.

CHI EA '23, April 23–28, 2023, Hamburg, Germany

ACM ISBN 978-1-4503-9422-2/23/04.
https://doi.org/10.1145/3544549.3582739

[1] https://www.hcibook.com/e3/plain/online/fitts-cybernetic/

2 FITTS' FORMULA

With Fitts' formula, it is possible to calculate the time needed to hit a target with diameter W (from width) at distance A (from amplitude). Figure 1 shows a Fitts' Law task and the definition of A and W.

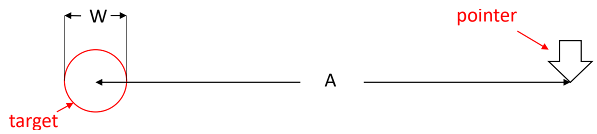

Figure 1: Definition of width W and amplitude A for a Fitts' Law task.

With the assumption that the needed time is proportional to the number of bits required to solve the task, Fitts had to assign a numerical value in bits for his pointing tasks, which he called the *Index of Difficulty* (*ID*). Fitts derived his formula from the assumption of noise on a transmission line. The number of distinguishable levels is the maximal amplitude range divided by the amplitude range of the noise (see Figure 2).

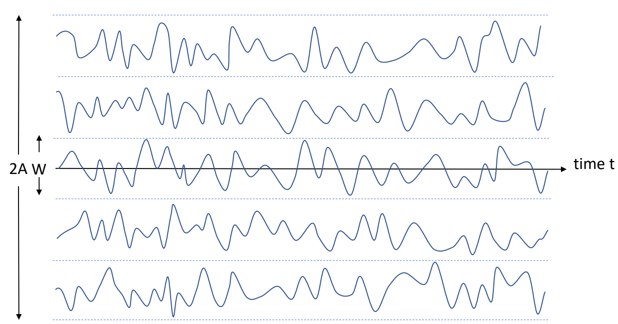

Figure 2: The noise amplitudes and the number of distinguishable levels (here it is five).

With n distinguishable levels it is possible to encode $log_2(n)$ bits. Fitts made an analogy to mechanical waves with the arm movement as the full range and the target size as noise [3]. Therefore, Fitts introduced the *Index of Difficulty ID* as:

$$ID = log_2(\frac{2A}{W}) \quad (1)$$

The time t to hit the target is proportional to the ID and the proportionality factor is typically named b. Together with a reaction time a, Fitts' Law has the following form:

$$t = a + b \cdot log_2(\frac{2A}{W}) \quad (2)$$

In Fitts' experimental setup the stylus used as a pointer closed an electric circuit in its start position. The clock started to run at the moment the stylus was lifted and stopped when reaching the target. There was no reaction time involved and the parameter a does not appear in Fitts' publication.

It is necessary to mention that Fitts' analogy for the ID is based on geometry and NOT on Shannon's Theorem 17, which is a formula to calculate bandwidth, which means the number of bits that are transferred in a time unit. Shannon's Theorem 17 has nothing to do with the *Index of Difficulty ID* as the ID has no time aspect. Shannon's Theorem 17 would relate to the b-parameter, or $1/b$ to be precise, and not to the ID. However, as shown in the next section, Shannon's Theorem 17 does not apply at all.

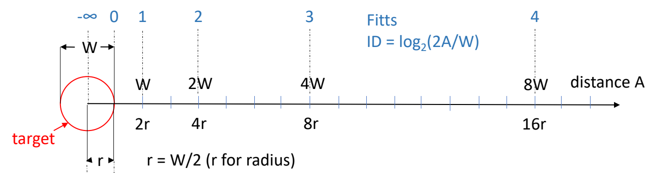

Figure 3: Index of Difficulty according to Fitts.

Fitts' definition of the ID makes sense. When the pointer is on the target edge the ID is zero as the goal is reached. Every doubling of the distance from the target center to the pointer increases the ID by 1 bit. Figure 3 shows the ID for different distances A for a target of fixed size according to Fitts.

3 SHANNON'S THEOREM DOES NOT APPLY[2]

Fitts' theory would have been less debatable if he would have derived his formula from the bits needed to position a plotter pen with a demanded accuracy. However, the plotter was invented at the time when Fitts did his research.

Fitts used Shannon's Theorem 17 to argue that there is a limitation for the b-parameter (the reciprocal of the bandwidth), which means that there is a lower bound for the b-parameter or a minimum time to process a bit. Fitts wrote about *'the performance capacity of the human motor system plus its associated visual and proprioceptive feedback mechanisms'* [3]. In contrast, Shannon defined the channel as:

> *"The channel is merely the medium used to transmit the signal from transmitter to receiver. It may be a pair of wires, a coaxial cable, a band of radio frequencies, a beam of light, etc."* [9, p. 2]

Based on this, a cable with a computer in-between is not a channel and the same is true for nerves with a brain in-between. A computer or a brain adds additional power to the system by power supply or food. A computer or a brain also adds memory to the system, a property a channel does not have. In consequence, the feedback loop from visual cognition to motor response is not explainable by an information channel and Shannon's Theorem 17 is not applicable. While Fitts' formula is correct, the argumentation with Shannon's Theorem 17 is wrong.

In fact, it is unnecessary to refer to Shannon's Theorem 17 to argue that there is a limitation in the bit transfer as there is nothing infinite in the physical world. Referring to a formula would make

[2] This section was added after review and discussion

sense if this formula is used to calculate a value for the limit, however, Fitts did not do that. Thus, it is not clear why Fitts referred to Shannon's Theorem 17.

At the first glance, the argumentation with a channel and Shannon's Theorem 17 sounds scientific, but a second look reveals that Fitts was not familiar with the basic concepts of information theory. Fitts' argumentation with Shannon's Theorem 17 is an example which shows that Elias' concerns about using the vocabulary of information theory expressed in his editorial [2] seem to be justified.

Unfortunately, Fitts continued his argumentation with Shannon's Theorem 17 in his publication from 1964 [4] and prepared the ground for MacKenzie's theory.

4 MACKENZIE'S THEORY

MacKenzie found Fitts' paper and recognized that Fitts' Law applies to aimed movements with a mouse device. However, MacKenzie was not satisfied with Fitts' formula and stated in his publication in 1989:

"Fitts recognized that his analogy was imperfect." [7]

This leads to the questions:

Q1: Where did Fitts mention that his analogy is imperfect?
Q2: What makes Fitts' analogy imperfect?

MacKenzie wrote about Fitts' formula:

"we demonstrate that Fitts' choice of an equation that deviates slightly from the underlying principle is perhaps unfounded." [7]

For a perfect formula, MacKenzie suggested a *'direct analogy with Shannon's Theorem 17'* [7] which results in MacKenzie's definition of the ID:

$$ID_{MacKenzie} = log_2(\frac{A}{W} + 1) \tag{3}$$

Figure 4 shows the ID for different distances A for a target of size W according to MacKenzie.

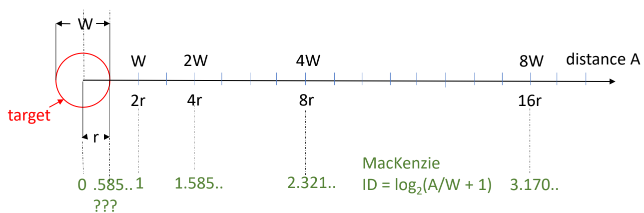

Figure 4: Index of Difficulty according to MacKenzie.

The value for the ID is positive even if the pointer is inside the target. This leads to the next question:

Q3: Why, according to MacKenzie, is there still some difficulty left when the pointer reached the target edge?

A positive ID when the pointer is already inside the target leads to negative values for the a-parameter. This happened in the evaluation presented in the paper *'A comparison of Input Devices in Elemental Pointing and Dragging Tasks'* of MacKenzie, Selen, and Buxton [8] and seems to be a source of confusion until today. In this paper, MacKenzie refers to his formula with the words:

"There is recent evidence that the following formulation is more theoretically sound." [8]

This raises the question:

Q4: Where is the evidence that MacKenzie's formulation is more theoretically sound?

In the same paper, MacKenzie et al. [8] assigned values for the b-parameter to different devices (mouse, tablet, trackball). This concept finally went into ISO 9241-9[3] as throughput TP. This seems to be in contrast to Fitts' concept [3] which introduced the b-parameter as a property of an *information channel* in the human nervous system. Fitts did three different pointing tasks (Reciprocal Tapping, Disc Transfer, and Pin Transfer) and got b-parameters in the same range. Fitts wrote:

"The consistency of these results supports the basic thesis that the performance capacity of the human motor system plus its associated visual and proprioceptive feedback mechanisms, when measured in information units, is relatively constant over a considerable range of task conditions." [3]

This leads to the next question:

Q5: Is the b-parameter a property of the device or of the human?

Despite ISO 9241-9 manufacturers of mouse devices do not print the TP on the packaging of their products. Instead, mouse devices are advertised with a dpi value which is a value for the control-gain ratio.

5 THE FILTER BUBBLE

MacKenzie's theory caused euphoria in the HCI community. The HCI community was excited to have its own formula based on information theory. Publishing something on Fitts' Law was beneficial for a career in the HCI community. In consequence, there are more than 20 000 citations of MacKenzie's work up to now[4].

Fitts' Law research in the HCI community can be seen as an echo chamber and filter bubble. The large number of publications is the echo chamber and the review process for publications is the filter for the bubble. Reviewers rejected papers with missing Fitts' Law evaluation even for topics where Fitts' Law does not apply,

[3]https://www.iso.org/obp/ui/#iso:std:iso:9241:-9:ed-1:v1:en
[4]https://scholar.google.ca/citations?user=G9MSEncAAAAJ&hl=en (22.7.2022)

for example, eye movements. If reviewers demand questionable evaluations, there will be authors who deliver them.

In consequence, some researchers applied Fitts' Law to eye movements although psychology textbooks state that eye movements are ballistic. Task execution times of ballistic movements do not depend on target size and therefore do not obey Fitts' Law. It is not clear whether these researchers applied Fitts' Law to eye movements in contradiction to the result from psychology or out of ignorance to it. Research on Fitts' Law for eye movements is a bubble inside the bubble. As the problem with Fitts' Law for eye movements is not based on information theory, it may deserve its own paper.

The narrative for the Fitts' Law filter bubble is that psychology, or at least Fitts, did it wrong and HCI does it better. MacKenzie says that Fitts' formula is imperfect [7] and Gori [5, p. 36] accuses Fitts of abusing information theory.

"Fitts' work, based on a loose analogy with Shannon's Theorem 17, is a good example of abuse of information theory." [5, p. 36]

However, there is no proof for this assumption and it seems that the opposite is the case. It is typical for filter bubbles that critique is ignored. The publication of Drewes [1] in 2010 did not trigger a discussion within the community. Instead, Gori, Rioul, and Guiard [6, p. 5] used Drewes' arguments against MacKenzie's theory without reference and turned these arguments into an allegation against Fitts. Gori's statement [5, p. 36] that Fitts' work is based on a loose analogy with Shannon's Theorem 17 perverts the facts, which is typical for filter bubbles. Fitts did not use an analogy to Shannon's Theorem 17. It was MacKenzie who introduced this analogy and he complained that Fitts did not use it:

"The reason Fitts did not use Shannon's original equation was not stated." [7]

Another example of how the advocates of the Fitts' Law filter bubble deal with critique is given in the paper *'Speed-Accuracy Tradeoff: A Formal Information-Theoretic Transmission Scheme (FITTS)'* [6] by Gori et al.:

"Elias [..], an important figure of the information theory society, urged authors to stop writing papers using information theory outside of its intended scope. In retrospect, Attneave's survey of 1959 looks like a funeral tribute. Since the end of the sixties, very few new articles in psychology have referred to information-theoretic principles." [6]

Gori et al. [6] did not discuss that Elias might have had good reasons for recommending to stop writing such papers. With the metaphor of a funeral Gori's statement suggests, that the corps buried by psychology in 1958 stood up as zombies in the HCI community.

A characteristic trait of agents operating within filter bubbles is avoiding external validation of statements and the invalidation of external critiques, for example by the information theory society [2]. An easy way to get an external opinion is to ask the physics department of the local university for a review.

Another characteristic of filter bubbles is a constant stream of contributions. These contributions do not aim for clarification and a final understanding but increase the confusion and create demand for the next contribution. With this mechanism, Fitts' Law research has continued steadily for more than 60 years and will go on forever.

6 THE MEANING OF FITTS' LAW FOR HCI

Fitts' Law gives valuable design rules for creating graphical user interfaces. Fitts' Law tells that increasing a button's size means that clicking the button needs less time. However, if the button gets bigger the effect becomes smaller and finally marginal. Decreasing the button size means that it takes more time to click the button and the time increases drastically if the button gets very small.

Fitts' formula allows one to calculate values for the mean time required to click a button. For all practical purposes, Fitts' formula is good enough, as measured data from a Fitts' Law study show high variances. Alternative formulas which claim to calculate more accurate mean values are not necessary as the change in the mean is much smaller than the standard deviation in the data.

When scaling the geometry of a graphical user interface the times needed to press a button do not change. The distance to the target and the target size scale with the same factor and *ID*s do not change. This consequence of Fitts' Law applies to *responsive design* means the design for displays of different sizes.

Fitts' Law suggests making frequently pressed buttons bigger than less frequently pressed buttons. This approach can be used for the benefit of the users, but it can also be used for *dark patterns*. Looking at commercial websites reveals that the HCI community understands Fitts' Law and applies it.

Further research on Fitts' Law in the HCI community should focus on its application, but not on the law itself. People who want to research the underlying mechanisms can do this in the context of neurosciences. People who want to understand human motion capabilities can do this in the context of psychology and people who want to develop formalisms and schemes based on information theory should do this in the context of mathematics, theoretical physics, or the information theory society.

7 CONCLUSIONS

While the HCI community identified filter bubbles and echo chambers on the internet and started to research this phenomenon, the community is blind to its own filter bubble, which is older than any filter bubble on the internet. Unfortunately, it seems that the filter bubble is growing. While in the early stages MacKenzie had to confirm himself [8], there are now several groups of Fitts' Law researchers which now can confirm each other.

Using Fitts' Law as the scientific claim of the HCI community worsens the situation as this topic has the potential to prove the opposite. There is a difference between appearing to be scientific and being scientific. Impressive formulas, terms like *entropy* or *Gaussian noise*, and exaggerated statistical evaluations are not evidence of being scientific. It is not true that science has to be difficult and complicated. A scientific spirit looks for the simplest explanation and uses common sense.

It seems that information theory has an enormous fascination for scientists, especially from 'soft' disciplines. In consequence, a flood of papers using an information-theoretic framework was published in the years after 1948, the publication year of Shannon's theory.

Ten years later Elias wrote an editorial with the title *'Two famous papers'* [2] to which Gori refers. As this editorial stemmed the flood of information-theoretic papers in psychology, a paper with the same effect in HCI is highly desirable.

The HCI community is still a young discipline and does not have well-established scientific standards yet. With humans as the topic of research, the HCI community has similar problems in scientific standards as psychology. If psychology stopped information-theoretic approaches in their research, it may be a good idea to do the same in HCI.

Science should be free of contradictions and this is also valid across different scientific disciplines. Therefore it is not a good idea to conduct information theory-based research in contradiction with the information theory society as Gori [6] suggests. Instead, the HCI community should seek external confirmation for its information-theoretic research. The comment on MacKenzie's *'Note on the Information-Theoretic Basis for Fitts' Law'* [7] requested by the author from a physicist of Max-Planck Institute was extremely short and scathing. The HCI community should think about whether they want to host such type of research as this damages the reputation of the whole community. In times of *alternative facts*, the HCI community should take care not to lose its scientific truth. To achieve this goal, scientific rules and self-purifying mechanisms should be established.

Elias' suggestion from 1958 about papers using the vocabulary and conceptual framework of information theory is wise advice and still valid nowadays, especially for Fitts' Law research:

> *"I suggest that we stop writing them, and release a large supply of manpower to work on the exciting and important problems which need investigation."* [2]

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