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The Fitts Law Filter Bubble: A Response to Heiko Drewes

Julien Gori

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1 Foreword

This paper assumes that the reader is familiar with Fitts’ law and how it is used by HCI researchers [9, 18, 21], as well as rudimentary concepts in information theory. For a primer on information-theoretic concepts and their application to modeling aimed movement, the reader is referred to our work [15]. In a recent paper [5], Heiko Drewes argues that there is a filter bubble or echo chamber in HCI surrounding Fitts’ law. Put briefly, Heiko Drewes’ discourse is that:

1. researchers in HCI have upheld the narrative that Fitts “did it wrong” and that they “did it right”.
2. that Fitts’ analogy for ID is based on geometry and not Shannon’s Theorem 17,
3. that Shannon’s Theorem 17 does not apply because the channel analogy “does not work”,
4. that Mackenzie’s theory for the ID is incorrect,
5. that there exists an echo chamber, or filter bubble, in the HCI community when it comes to research on Fitts’ law,
6. that the HCI community should research Fitts’ law applications but not the law itself.

Heiko Drewes submitted his work to the *Alt.Chi* forum, the track for “alternative” papers at the flagship HCI conference “CHI”. It has an open review process, but these reviews are accessible only during the reviewing phase. I have been asked about my review, which I attach as an appendix to this document. Other reviews were made by other people, but they are not accessible anymore as far as I know.

2 Answers to Heiko Drewes’ discourse

Researchers in HCI have upheld the narrative that Fitts’ law “did it wrong” and that they “did it right” I personally don’t believe in a narrative that is common to HCI. There have been at least two reassessments (between Zhai, and Soukoreff and Mackenzie [24, 21], between Gori *et al.* and Soukoreff and Mackenzie [15, 21]), which seems to show at least some disagreements within the community itself. Further, discussing and evaluating models is much more complicated than a matter of being right or wrong. Bohr’s 1913 atomic model, while technically obsolete—a wrong model then?—remains taught to this day. Note that in that sense, it is also unfounded to consider the Shannon formulation as the “right one”, as sometimes claimed in the HCI community [21].

Fitts’ analogy is based on geometry and not Shannon’s Theorem 17. Fitts himself has used both geometrical arguments and Shannon’s Theorem 17. Fitts gradually moved from his 1953, not well-known paper [8] which uses the geometric explanation, to his better known 1964 paper [10] which uses Theorem 17, while his best-known 1954 [9] paper sits in between and uses both arguments. We have already made this explanation [15, Section 3], and in fact an almost identical argument was made before us by Soukoreff and Mackenzie [21, Section 3]. Fitts’ 1964 paper undoubtedly refers to information transmission, channel capacities, and Theorem 17. Below is the exact start of that paper that should dispel any doubts:

The relation of response variability and response magnitude has long been one of the major topics of interest in psychophysics. Recently the effects of these two variables plus that of response duration have received renewed emphasis in connection with studies of the information capacity of the human motor system. For physical communication systems having limited bandwidth (W) and

signal power (S), and perturbed by white Gaussian noise of average power (N), Shannon (1948, Theorem 17) showed that channel capacity (C) is equal to

$$C = W + \log_2 \frac{S + N}{N}$$

bits per second. Arguing by analogy, Fitts (1954) reasoned that the average amplitude (A) of a human movement is equivalent to average signal plus noise amplitude, and that half the range of movement variability is equivalent to peak noise amplitude (n), and proposed that an index of task difficulty (ID) be defined as

$$ID = \log_2 \frac{A}{n}$$

Shannon's 1948 seminal work on information theory which inspired Fitts dealt essentially with compression (source coding) and transmission (channel coding). The geometric arguments of Fitts in 1953 [8] and Drewes [4, 5] are about compression, but the theorem 17 arguments, used by Fitts in 1954 and in 1964 [9, 10] and by Mackenzie [17, 18, 21] are about transmission. Analogies with compression essentially explain that it requires N bits to locate a target in a discrete grid of size 2^N . As shown in [15], following the "aiming is choosing" rationale, one can create such a grid from the aiming task by laying out the target over the entire distance D . Depending on how exactly the targets are laid out at the edges (is D measured from center to center, from the outside edge to the outside edge, or from the inside edge to the inside edge), one recovers Fitts' [9], Welford's [23], and Mackenzie's [17] formulations for ID. However, without a transmission component, compression arguments are incapable of explaining errors.

Shannon's Theorem 17 does not apply because the channel analogy does not work Heiko Drewes' argument is that Fitts wrote about "capacity of the human motor system and its associated visual and proprioceptive feedback mechanisms" while Shannon's channel is only "a medium to transmit a signal from transmitter to receiver *e.g.*, wires, cables, frequency bands, beams of light *etc.*". Heiko Drewes also explains that a computer and a brain, both part of the feedback loop, add computing power and memory, both of which are not present in Shannon's definition.

As suggested by the variety of mediums described by Shannon, a channel is best viewed as an abstract mathematical object; it is nothing more than a conditional probability $p(Y|X)$ of an output Y given an input X . It can thus be applied to a wide range of situations, in the same way that one could compute a correlation between two random variables X and Y whatever these represent.

Further, as explained in [15, Section 2, Fig. 1], the channel is only one part of the transmission scheme, which also includes an encoder just before the channel and a decoder just after it. Both the encoder and decoder have memory and computing power; the transmission scheme (*i.e.*, what Heiko Drewes calls the feedback loop) can thus contain elements with memory and computing power, even within the scope of Shannon's information theory.

What about feedback? Shannon initially did not investigate feedback in his 1948 work.¹ However, as soon as 1956, Shannon [1] showed that feedback does not increase the capacity of a discrete memoryless channel with additive white Gaussian noise. This result was later extended for continuous channels². Hence, the presence of feedback does not change Theorem 17 under Fitts' assumed channel. It is important in this context to understand what a memoryless channel is. In a memoryless channel, the output at any given time depends *only* on the previously received input (Markov property). On the contrary, a channel with the conditional probability $p(Y_k|X_k, X_{k-1})$, where the output at any time depends on the two last inputs, is an example of a channel with memory. For example, a channel with correlated noise is a channel with memory. A channel with independent Gaussian noise is a channel without memory. The property of a channel to have memory or not thus only characterizes the nature of the noise that is affecting the transmission; in both cases, the encoder and decoder do have memory and computing power.

The critical reader might know that feedback is very important to the production of human movement, and ask what good is a theory that says that feedback does not bring any advantages to describe human behavior? The answer is that feedback makes transmissions simpler and hence, more plausible: the capacity of the channel is a limit on transmission rates; Shannon's theory only proves the existence of a coding scheme that can reach this limit, but does not tell what that scheme actually is. It has taken researchers and engineers 45 years, and the invention of *TurboCodes* [2] to "crack" that scheme for a channel *without* feedback, relying on interleaving multiple convolutional codes and iterative decoding. On the other hand, it took Peter Elias [7] 40 years less to give an optimal scheme for the same channel *with* feedback information, with a code so simple Elias' paper is entitled *Channel capacity without coding!*

¹It does feature the analysis of a potential "correcting device", but it is used only to correct the output directly in a feedforward manner, not to feed that information back to the encoder for better encoding.

²and later for different noises. It is also known that feedback can increase capacity for some channels (*e.g.*, channels with memory).

We precisely used that same scheme by Elias in our recent model for the speed-accuracy tradeoff of aimed movement [13, 14, 12]. In these publications, we show that the use of feedback information leads to a biologically plausible encoding and decoding scheme, and that this scheme explains Fitts’ law.

So, there is no fundamental mismatch between Shannon’s transmission results on one side, and memory, processing power and feedback information on the other.

As a final illustration that results on transmission can be applied successfully “beyond the wire” here is a non-exhaustive list of surprising use cases of Shannon’s work on transmission: side-channel attacks in embedded hardware [3, 20], a “cancer channel” to describe somatic mutations [6], *Kelly gambling* [16] used by gamblers to maximize payout *e.g.*, in blackjack [22].

Mackenzie’s theory is incorrect As explained in our previous work [15, Section 3.2 and Section 5.1], Mackenzie’s analogy with transmission is indeed incorrect both for the nominal and effective versions of Fitts’ law.³ Whether Mackenzie’s analogy is appropriate or not, it implied two concrete amendments to Fitts’ law: the first is a modification of the index of difficulty (from Fitts’ original formula $ID = \log_2(2D/W)$ to $ID = \log_2(1 + D/W)$). As shown in [15, Section 3.1] and above, both Fitts’ original and Mackenzie’s indexes can be retrieved from a geometric argument, and as shown by many authors, the differences in both indexes are practically meaningless⁴. The second amendment is the idea that there is an effective version of the law, where W in ID is replaced by 4.133σ in which σ is the spread of endpoints. According to Mackenzie, the effective version corrects for target misses, and as a result it allows normalizing participant strategies *i.e.*, it makes pointing performance from one participant which emphasizes speed comparable with that of another which emphasizes accuracy. While we have demonstrated that Mackenzie’s “derivation” of the effective law was flawed [15, Section 5.1], it does not mean that the effective version of the law is senseless. In fact, we have recently demonstrated theoretical support for the fact that movement time in a pointing task can be well predicted by a linear function of $\log(D/\sigma)$ [12].

There exists a Fitts’ law echo-chamber in the HCI community An echo chamber is an “environment or ecosystem in which participants encounter beliefs that amplify or reinforce their preexisting beliefs by communication and repetition inside a closed system and insulated from rebuttal”. As explained in the first paragraph of this section, it is not true that there has been no rebuttal for Mackenzie’s ideas, or for that matter, other works surrounding Fitts’ law — Heiko Drewes is another example member of the CHI community that has published works criticizing Mackenzie’s [4, 5]. That being said, research communities are exactly that — communities, and some closedness to the outside world and amplification of the inside world is unfortunately expected. HCI is clearly not an exception to that. However, from my experience, it is hard to say if the state of affairs is any worse than in other research communities. Hence, rather than talking about a filter bubble, it would at best (or at worst, depending on the viewpoint) be more suited to talk about an “epistemic bubble” [19].

It is also true that the HCI literature has seen many works around Fitts’ law, and the question that comes to mind is whether Fitts’ law is overrepresented in the CHI community, in particular in regard to what it actually provides — a simple model that describes reasonably well endpoints in a very constrained task. While I may not have a definite answer for this question, I may give one factor that contributes to this status for Fitts’ law. Fitts’ law is seen as one of the few foundational concepts of HCI, and is thus often referenced in textbooks and introductory lectures. As such, most HCI researchers have been exposed to Fitts’ law at some point.

As a future investigation, it would be interesting to determine whether the HCI community is more closed to results from other communities than the average applied science community, perhaps based on graph analysis as suggested in [11].

The HCI community should research Fitts’ law applications but not the law itself This begs the question whether HCI researchers should only be end-users of models. One scientifically sensible strategy is to reserve the development of theoretical models to other fields such as (computational) neuroscience, (mathematical) psychology *etc.* and the applications of these models in an HCI context to venues of the CHI community. This is indeed what we have done with [14, 12]. That strategy however does not solve all problems: Mackenzie’s formulation for the ID that is criticized by Heiko Drewes, was, in fact, not published in an HCI venue, but in *JMB*, the *Journal of Motor Behavior*, a journal that published research in movement neuroscience. That being said, most of the published HCI work that deals with Fitts’ law tackles problems specific to HCI, for example, the extension to 2D and 3D pointing, aiming towards rectangular targets at an angle *etc.*, which mostly target the HCI community.

³This was recognized by Fitts himself, because amplitudes and not powers are used, in a footnote in [10]. The analogy further suffers from three other problems as shown in [15, Section 3.2].

⁴except for very small levels of ID , but in that case the target is usually underutilized [?], which poses other problems

3 Appendix

The original review, cosigned by myself, Olivier Rioul and Yves Guiard:

This commentary is written by Julien Gori, Olivier Rioul, and Yves Guiard, authors of
→ the 2018 paper "Speed-Accuracy Tradeoff: A Formal Information-Theoretic Transmission
→ Scheme (FITTS)".

We first review some of the statements of Heiko Drewes that we show are factually
→ incorrect, and then list other statements in his paper which we feel are highly
→ speculative, and provide some comments.

About factually incorrect statements

1/ H. Drewes states 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." This is inaccurate for at least
→ four reasons:

a/ As is unfortunately common among HCI researchers, the meaning of bandwidth is
→ misinterpreted.

The bandwidth is the frequency range allowed in the transmission channel, not the bit
→ rate. This is explained in our paper [5, Section 2]. Also, Shannon's theorem 17 does
→ not "calculate bandwidth," but gives the capacity (the highest possible rate in
→ bits/s for reliable transmission of information) for a channel with additive
→ Gaussian noise. That capacity depends on the given signal-to-noise ratio and on the
→ given bandwidth. For more details see our paper [5, Section 2.4] which carefully
→ explains the differences between throughput, capacity and bandwidth.

b/ In the celebrated 1954 paper by Fitts, Fitts' law is explicitly based on Shannon's
→ Theorem 17. The theorem itself is cited in footnote 1 (bottom right of p.262), and
→ the word "capacity" appears 12 times in the first page alone. The opening sentence
→ of the paper is clear:

"Information theory has recently been employed to specify more precisely than has
→ hitherto been possible man's capacity in certain sensory, perceptual, and
→ perceptual-motor functions (5, 10, 13, 15, 17, 18). The experiments reported in the
→ present paper extend the theory to the human motor system."

c/ As explained in our paper [5, Subsection 3.1], Fitts did initially base his idea on
→ geometry in a not-too-well-known 1953 paper. But in the 1954 paper Fitts fully
→ embraced the channel capacity view.

d/ The problem with Fitts' approach is that the geometrical work is only used to define
→ the source of information, but once this is done, nothing is described further. In
→ [4, Subsection 3.1], we also start from Fitts' geometrical work to describe the
→ source of information, but we then detail the channel, noise and output, and
→ actually compute the capacity of the channel. What we show is that, while several
→ geometrical layouts are plausible (and it is rather arbitrary to try and decide
→ which one is the most appropriate) only one of them has the nice property that the
→ ID coincides with the Shannon capacity (in bpcu, and not in bit/s, see again [5,
→ Section 2]).

2/ H. Drewes states that "There was no reaction time involved and the parameter a does
→ not appear in Fitts' publication"

In fact, the intercept a was introduced by Fitts himself in his 1964 paper [R1]. The
→ title of his 1964 paper ("Information capacity of discrete motor responses") should
→ also dissipate any doubts related to the nature of Fitts' analogy with Shannon's
→ capacity formula (Theorem 17)

3/ About H. Drewes' Q1 to Q5 questions, we can give the following answers which contrast
→ with his argumentation:

Q1/ "Where did Fitts mention that his analogy is imperfect?"

| A1: In his 1964 paper, Fitts writes in a footnote: "The analogy with Shannon's Theorem
→ 17 is not exact, since the ID ratio involves an amplitude rather than a power ratio,
→ and since the range of variability is used in estimating noise amplitude".
→ Admittedly, Mackenzie's "correction" does not change this problem.

Q2/ "What makes Fitts' analogy imperfect?"

| A2: The answer is given by Fitts himself in the preceding quote, and has also been
→ identified by Drewes himself [1], and ourselves [5], and likely others, as it is
→ based only on a basic examination of the analogy.

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

| A3: It characterizes the entire perceptual-motor loop---both the human and the device.
→ In fact, keeping the human part constant (i.e., controlling the population), one can
→ use b differences to describe devices. Also, keeping the device part constant (ie
→ controlling the device), one can use b differences to describes populations.

4/ H. Drewes states that "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.' [6]"

In fact, Mackenzie here refers to the fact that Fitts did not use the $+1$ in the formula
→ of Shannon's Theorem 17, not that he did not use the formula at all.

About some other speculative statements:

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A/ H. Drewes states that "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".

We do not think that this has necessarily been the case | the citations of Mackenzie are
→ hardly proof of that.

B/ H. Drewes states that "Reviewers rejected papers with missing Fitts' Law evaluation
→ even for topics where Fitts' Law does not apply, for example, eye movements".

We do not have the same highly informed knowledge of H. Drewes about this level of
→ detail in the review processes of all HCI papers. Perhaps his statement is based
→ only on some personal experience, and does not apply generally.

C/ H. Drewes states that "The narrative for the Fitts' Law filter bubble is that
→ psychology did it wrong and HCI does it better."

We feel quite astonished by this statement, given our published criticism of Mackenzie's
→ derivation.

D/ H. Drewes states that "Gori et al. did not discuss that Elias might have had good reasons for recommending to stop writing such papers.", and the zombie metaphor.

We also did not discuss that Elias might have had bad reasons for doing so; we simply reported objectively what Elias had written. Also note that the bandwagon editorial of Shannon himself, about the same time as Elias', is much less aggressive.

E/ H. Drewes states that "Unfortunately, it seems that the filter bubble is growing"

Is there any evidence of that?

F/ H. Drewes states that "Therefore, it is not a good idea to conduct information theory-based research in contradiction with the information theory society as Gori [5] suggests".

We advocate conducting information-theory based research, *not* in contradiction, but *with full compliance* with the information theory society. Elias' argument does not apply here, since our work in [5], and even more in the follow-up work in [R4], is precisely an attempt at properly completing Fitts' analogy using the tools of information theory.

Other statements that we partially agree with
|||||

I/ H. Drewes states that "In consequence, some researchers applied Fitts' Law to eye movements although psychology textbooks state that eye movements are ballistic."

This has been said previously in [1, R2] and, partially based on the arguments made in [1, R2], further explained in [R3]. [R3] shows that the claim that "Fitts' law applied to eye gaze is a bubble within the bubble" is, if not false, at least exaggerated.

II/ H. Drewes states that "Gori accuses Fitts of abusing information theory [4, p. 36]. However, there is no proof for this assumption"

Similarly, Drewes accuses Mackenzie of abusing information theory; yet Mackenzie has almost exactly the same rationale as Fitts (see [5, Section 3.2]) Both Fitts' and Mackenzie's analogy are vague, for reasons mentioned above (see our answer to Q1).

III/ H. Drewes states that "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."

An even better way would be to get an opinion from someone from the electrical engineering department of the local university. Fortunately, one of the signatories of this commentary and of [5] is precisely a professor of information theory, well established in the IEEE information theory society, author of several papers in the IEEE Transactions on Information Theory, the flagship outlet of the information theory society.

Conclusion

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Heiko Drewes' inflammatory pamphlet should be taken with a handful of salt: not only is
→ it definitely contains false statements, it is also largely speculative.

Let us emphasize again that our work in [5] aims at properly completing Fitts' analogy
→ using the tools of information theory. While we believe the derivations to be
→ mathematically sound (we invite Heiko Drewes to have these reviewed by his
→ colleagues in the physics department), we gladly recognize that some of the
→ assumptions we made to achieve this may be questionable. For example, a truncated
→ Gaussian distribution is leveraged to provide a bound on the capacity of a channel
→ [5, Theorem 4.3], which may not be practically plausible. Still, our work has merit
→ in that it allows one to disprove some of Mackenzie's arguments, which have shaped
→ the use of Fitts' law in HCI.

Let us also point out that more recently, we have published a more realistic model of
→ movement in a neuroscience/cybernetics forum [R4]. We invite Heiko Drewes to read
→ that paper.

In this work, we present an alternative to Fitts' law evaluations, based on the tracking
→ of the variance of a set of pointing trajectories. This new model's implications for
→ HCI are discussed in a paper which we have submitted to CHI 23.

Therefore, as a final conclusion, we do agree with Heiko Drewes on one point: Fitts' law
→ may be over-represented in HCI, and it may be worthwhile thinking about other models
→ or evaluations.

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