

Reflections on Card, English, and Burr, 1978

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About 20 years ago, I was a graduate student at the Ontario Institute for Studies in Education at the University of Toronto. The acronym, HCI, for human-computer interaction, meant little to me at the time, but there was a course with Human-Computer Interaction as the title. It seemed interesting, so I enrolled. Today, I consider HCI my field of research, and this is in large part due to that course. In fact, it is due to one paper I read during that course.

The course readings included a textbook (I will not name it here) and a dozen or so papers. Overall, I was not very excited. Many of the readings were a tad thin on substance, in my view at least. This feeling changed completely when I read the paper to which this essay is directed: "Evaluation of mouse, rate-controlled isometric joystick, step keys, and text keys for text selection on a CRT." by "Card, English, and Burr." Now, it might not seem a must-read paper from the title, but don't be fooled. I read the paper, because I had to for the course. And I'm glad I did, because it changed my life. That's an overstatement, I

suppose, but it is true that this paper was a tipping point for me. I read it. I liked it. I liked it a lot. I was inspired and motivated to dig deeper. Before I knew it, I was hooked. HCI was for me!

The paper is important because it was the first detailed comparative evaluation of the mouse. Card, English, and Burr established, beyond dispute, that the mouse was a superior input device for selecting objects on a display. They compared it to a joystick and to two key-based methods for selecting text. Their three conclusions say it all. Briefly,

1. The positioning time of the mouse is significantly faster than...
2. The error rate of the mouse is significantly lower than...
3. The rate of movement with the mouse is nearly maximal...

The number of follow-on papers on pointing devices in HCI is likely in the hundreds, and all are guided by this seminal work by Card, English, and Burr.

The 1970s was an exciting time for computing. Bit-mapped graphics displays were replacing character-mapped displays, and researchers were investigating new ways for humans to interact with computers. About 10 years earlier, Douglas Engelbart invented the mouse (English, Engelbart, and Berman 1967). Researchers at Xerox, including Card, English, and Burr, were looking to improve the design (eventually putting a rolling ball inside it) and to evaluate and compare the mouse in new paradigms of interaction.

The paper presents what we in HCI often call a "user study". Unbeknownst to me at the time, the study was, in fact, an empirical experiment

with human participants conforming to the standards for such as refined over many decades in experimental psychology. Card, English, and Burr's paper is a representative and guiding example. The study was thorough. They tested four devices while systematically varying the distance to move, the size of the targets, and the angle of movement. They practiced participants to a clearly described criterion of expertise. Throughout, the paper is an exemplar of sound research and concise reporting. Of course, I read it again in preparing this essay. Terrific, still. Take a moment to read the abstract:

Four devices were evaluated with respect to how rapidly they can be used to select text on a CRT display. The mouse is found to be fastest on all counts and also to have the lowest error rates. It is shown that variations in positioning time with the mouse and joystick are accounted for by Fitts's Law. In the case of the mouse, the measured Fitts's Law slope constant is close to that found in other eye-hand tasks leading to the conclusion that positioning time for this device is almost the minimal achievable. Positioning time for the key devices is shown to be proportional to the number of keystrokes which must typed.

Why copy the abstract here? First, to convey the content. But, let me add. I review a lot of submissions to conferences and journals. It is extraordinary how often I am compelled to criticize the abstract in my reviews. Not here. This abstract delivers in 112 words exactly what it should. It tells the reader "what was

done" and "what was found". No more, no less. Researchers too often treat an abstract as an introduction to the paper, and fail to convey the most salient findings. The rest of Card, English, and Burr is crafted just as well. Carefully executed and succinctly delivered.

But, there is more. Card, English, and Burr went beyond a typical user study. Here are the first two sentences in the Discussion:

While these empirical results are of direct use in selecting a pointing device, it would obviously be of greater benefit if a theoretical account of the results could be made. For one thing, the need for some experiments might be obviated; for another, ways of improving pointing performance might be suggested.

This is an inspired preamble to their discussion on building models – models of interaction that (a) embed a theoretical account of the underlying human processes and (b) can serve as prediction tools for a priori analyses of alternative design scenarios. The remainder of the paper is about modeling using Fitts' law. They build and compare Fitts' law models for the mouse and joystick. This snagged me. The idea and mechanics of building a predictive model were new to me. It was empirical. It was built on established theory. It combined this theory with direct measurements of human behaviour. The result is an equation predicting the time to select a target based the distance (D) to the target

and the target size (S). Although the form is usually different today, Card, English, and Burr give the equation as

$$T = a + b \log_2(D/S + 0.5)$$

The log term is the "index of difficulty", in bits. It has been the subject of considerable research and debate in the 50+ years since Fitts' original paper. But that's another story.

One of the most provocative aspects of Fitts' law – and it is elaborated in detail in Card, English, and Burr – is that the slope coefficient in its reciprocal form ($1/b$) carries the units "bits per second". This term, called "throughput" today, is a performance measure representing the rate of information processing exhibited by users while performing point-select tasks. Wow! Are we humans mere channels for information transmission? Of course not, but the analogy works extraordinarily well, as the correlations for Fitts' law models are often well above $r = .900$. Clearly, this was fertile ground for further research.

Before I knew it, I was reading the original papers by Fitts (1954) and others and chipping away at a few problems and issues that were apparent to me, such as the need to include accuracy in the model, ways to apply the model to two-dimensional tasks, and the benefits of a more theoretically correct formulation for index of difficulty (MacKenzie 1992). Needless to say, Card, English, and Burr was the first use of Fitts' law in human-computer interaction. Many dozens of Fitts' law papers have followed.

Card, English, and Burr's call for modeling in human-computer interaction was the seed for what today is a major component of research in our field. Not everyone in HCI accepts the benefits of models of interaction, however; so, let me finish by making a case for modelling.

A model is a simplification of reality. Consider an architect's scale model of a building or a physicist's equation for the trajectory of a tossed ball. Both are reductions or simplifications of more complex phenomena. They are useful because they allow us to explore the phenomena, think about them, make changes, and so on – without actually constructing the building or throwing the ball. A great many problems in HCI have been explored in this manner over the years. A recent example is the Fitts-digraph model for text entry. It combines Fitts' law with a language model. The language part is a set of letter pairs (digraphs) and their frequencies in a language corpus. The Fitts-digraph model yields a prediction of text entry speed, for example, using a finger on a small keyboard (e.g., RIM's *Blackberry*) or a stylus on a virtual keyboard on a PDA's display. Fitts' law gives the time to tap each key given the size of the key and the distance from the previous key, and the language model tells us the relative occurrence of each movement. Combine the two and you have a prediction of text entry speed for a given keyboard in a given language. That's not the main point, though. In an effort to design a better keyboard, we might consider some changes, such as resizing some of the keys, rearranging the letters, reducing the number of keys by placing two

or more letters on each key, or adding additional interactions for word completion, and so on. These changes can be explored, each accompanied by a predicted entry speed, without actually building anything. This is a powerful way to explore the text entry problem, and, indeed, there has been considerable work in this vein in recent years in HCI (MacKenzie and Soukoreff 2002). I hope, in some way, you are convinced that models are great tools for HCI research. It all began with Card, English, and Burr.

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