An Activation-Trigger-Schema Model For the Simulation of Skilled Typing

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Abstract

We review the major phenomena of skilled typing and propose a model of the control of the hands and fingers during typing. The model is based upon an Activation-Trigger-Schema system in which a hierarchical structure of schemata directs the selection of the letters to be typed and, then, controls the hand and finger movements by a cooperative, relaxation algorithm. The interactions of the patterns of activation and inhibition among the schemata determine the temporal ordering for launching the keystrokes. To account for the phenomena of doubling errors, the model has only "type" schemata -- no "token" schemata -- with only a weak binding between the special schema that signals a doubling and its argument. The model exists as a working computer simulation and produces an output display of the hands and fingers moving over the keyboard and it reproduces some of the major phenomena of typing, including the interkeypress latency times, the pattern of transposition errors found in skilled typists, and doubling errors. Although the model is clearly inadequate or wrong in some of its features and assumptions, it serves as a useful first approximation for the understanding of skilled typing.

The Basic Phenomena of Typing

The fundamental phenomena fall into three categories: those involving timing of keystrokes, those involving errors, and those involving the general organization of the typing process. In this paper we simply list the phenomena. In a larger version of this paper, the individual phenomena are discussed and illustrated in detail (Rumelhart & Norman, 1981)

I: The timing of keystrokes

A. People can type very quickly.
B. Cross hand interstroke intervals are shorter than those within hands.
C. Within hand interstroke intervals appear to be a function of the reach from one hand to the next.
D. The time for a particular interstroke interval can depend on the context in which it occurs
E. There is a negative correlation between the intervals on successive strokes--especially when the alternate strokes occur on alternate hands.

II: Pattern of Errors

A. Transposition errors
B. Doubling errors
C. Alternation reversal errors
D. Homologous errors
E. Capture errors
F. Omission errors
G. Misstrokes

III: The general organization of typing

A. Skilled typists move their hands towards the keys in parallel
B. The units of typing seem to be largely at the word level or smaller
C. Sequences involving cross hand strokes seem to take longer to program than those involving only within hand strokes

A Model of Typing

We have constructed a model that has the following properties:

1. control of action sequences by means of schemata;
2. selection of appropriate motor schemata through a combination of activation value and triggering condition;
3. the representation of letter typing by means of a *pure type theory* (i.e., one with no type-token distinction).
4. the need for distributed (local) rather than concentrated (central) control of movement.

The basic framework that we follow is called an Activation Triggered Schema system (ATS). The model consists of a set of schemata, each with activation values. A schema has an activation value that reflects the total amount of excitation that it has received. When appropriate conditions have been satisfied, a schema may be "triggered," at which time its procedures become operative and control whatever operations they specify.

Figure 1 illustrates the basic structure of the model. The model incorporates the ATS system plus specific control mechanisms for the activations and selection of particular hand and finger movements. The input of the model is a string of characters that constitute the text to be typed. The output is a sequence of finger movements, either displayed on a visual computer-controlled display as the movement of the hands and fingers over a typewriter keyboard, or as a series of coordinate locations for the relevant body parts.

Figure 2 illustrates the basic assumptions of the activation process using the word **very** as an example. First, the schema for the word is activated by the perceptual system and parser. This, in turn, activates each of the child schemata for keypresses. Each keypress schema specifies the target position, with position encoded in terms of a keyboard centered coordinate system. These target positions are sent to the response system which then must configure the palm and finger positions properly. Each keypress schema inhibits the schemata that follow it. This means that proper temporal ordering of the keypress schemata is given by the ordering of the activation values. In addition, the activation values are noisy, which leads to occasional errors.

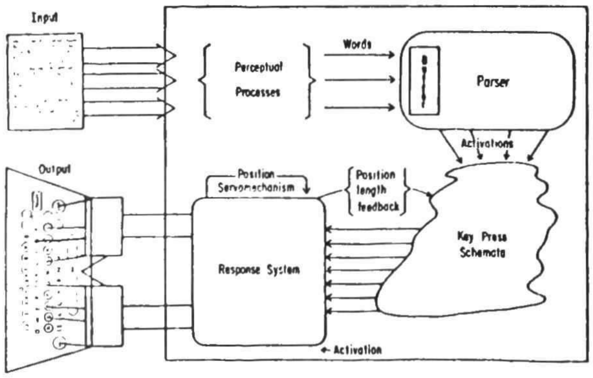

Figure 1. The information processing system involved in typing.

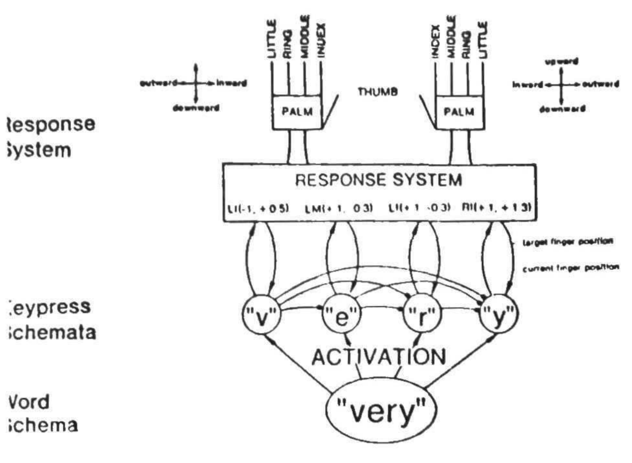

Figure 2. The interaction of activations when the word **very** is to be typed. Inhibition is shown by the lines with solid circles at their termination.

The response system feeds back information to the keypress system about the current location of the fingers. Whenever the current finger position is within some criterion distance of its target position, and the relevant schema is the one most highly activated, then the triggering conditions are satisfied and the actual keystroke is launched.

Repeated letters imply that there are no token schemata.

A doubling error occurs when a word that contains a doubled-letter is typed, but with the wrong letter doubled: **bokk** instead of **book**. An alternation error is similar: **thses** instead of **these**. The doubling error has two major implications. First, it implies that there are special schemata that signal the existence of doubled letters, and that occasionally these schemata get applied to the wrong letters; the binding between the doubling schema and its argument is weak. Second, the doubling error implies that each letter can only have a single keypress schema; only "types," no "tokens". In the model, the arguments are not bound to the schemata, but are established via activation values. After a keystroke schema has been triggered (and after the resulting launch of the keystroke), this keypress schema can become "bound" to a doubling schema if one exists with a higher activation value than its own. Because activation values are noisy, occasionally this leads to errors in the linking of keypress schemata to a doubling schema. (The existence of alternation errors leads to essentially the same conclusion.)

Movement

In the model, each active schema pushes its relevant hand and finger toward its desired key at the same time, and the final overall configuration is determined by the competition among these forces. Each schema pushes with a force proportional to its activation level. As a result, the forces are weighted so as to cause the letter schema that is next in line to be typed to approach its key most quickly. The actual location of each finger is determined by the sum of the extensions of the finger and the hand. To type a particular typewriter key, it is only necessary that the end position be correct. The endpoint configuration is reached through an iterative relaxation process that only involves local computation. Because of the unequal weighting of activations, the process will eventually cause the most highly activated schema to move its finger-palm configuration to within a criterion distance from its target key, satisfying the trigger conditions and launching the keystroke.

Appraisal

In order to evaluate the model, we gave it a text of slightly over 2,000 words to type. The pattern of keystrokes and times were collected from the simulation and analyzed in exactly the same fashion as we had analyzed the data from our human subject. Overall, the fit of the model to the many phenomena of typing is good. Detailed analyses of the model performance indicate that the simulation results do show about the right pattern of interstroke intervals. Moreover, the correlation of model times with actual typing times for the 66 most common bigrams from our data with the data of 6 subjects yields an overall correlation between the model and the averaged data of about 0.86. The fit is not bad, however, the model clearly does not account for all that is happening. (Data for five of these subjects were collected by Donald Gentner.)

The model does produce errors in typing, the most important ones being transposition errors, doubling errors, and misstrokes. The proportion of errors in the model is determined by the amount of noise in the activation levels. In our subject's data we observed transpositions at about a rate of 1 for every 1800 keystrokes. We adjusted the noise level to yield errors at a rate of about 1 for every 30 keystrokes. Despite the large difference in rate, the basic pattern of errors is similar. For example, a large majority (76 percent) of the transpositions in the simulation occur across hands. This is about the same as our subject and comparable to values reported for others. At the level of noise employed in the simulation, 17 doubling errors were generated.

Conclusion

We have constructed a working computer simulation of a model that captures the appropriate spirit of the phenomena observed with human typists, although it does not yet offer a complete account of the typing process. Despite the lack of an internal clock or "metronome" for timing, the model provides a reasonably good account of the timing patterns observed among skilled typists, including the prediction of negative correlations among successive keystrokes, a characteristic of metronome models. In similar fashion, there are no specific context dependencies built into the model and yet the time that it takes to strike keys depends upon the context in which they occur. We have no specific stored timing patterns for specific words, yet the model predicts that words have characteristic time profiles. We have no specific mechanism for transposition errors, yet our model generates the correct types of transposition errors. Moreover, the co-ordinative structure assumed within the model yields a qualitative emulation of the pattern of overlapping movements shown in a high speed film of a typist.

A number of conclusions can be drawn from our studies. First, the existence of doubling errors strongly implies the existence of a pure "type" representation of the keyboard schemata, with their arguments only loosely bound. Second, the nature of the skill requires simultaneous, parallel control of the fingers and hands, and this requires some form of negotiation process to turn the potentially competitive movements into cooperative ones. The degrees of freedom problem can be turned into a degrees of freedom virtue. Third, the model must incorporate the entire environment within which the typist operates, from the reading of the text, to the cognitive and motor control systems, to the shapes and mechanical characteristics of the hands, finger, and keyboard. Indeed, some of the limitations of the current model may really result from limitations of how well we dealt with the environment surrounding the control processes. Perhaps the central conclusion to be drawn from our analysis of typing deals with the nature of skilled motor co-ordination. We propose that the motor control system carries out its computations relatively locally and in parallel. We presume that such a conclusion will be proven for all skills involving high speed performance.

References

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