

# A PSYCHOLOGIST VIEWS HUMAN PROCESSING: HUMAN ERRORS AND OTHER PHENOMENA SUGGEST PROCESSING MECHANISMS

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## ABSTRACT

I argue from studies of human performance, including slips of action and skilled typing that human processing structures are of a special sort, with weak binding between functions and arguments, with strong excitatory and inhibitory interactions among simultaneous processes, and with the parts of action sequences neither strongly ordered nor tightly coupled. I argue that analyses of human performance imply a class of processing structures quite different than is commonly envisioned within Artificial Intelligence.

### 1. How do people do more than one thing at a time?

An important aspect of everyday behavior is that we do several different activities at the same time, oftentimes for simultaneous (and possibly conflicting) purposes. Even when we do not attempt simultaneous actions, we still might be planning or reviewing one set of things while performing or accomplishing another. We delay and defer goals or actions as needed, waiting for appropriate times for them to be accomplished. This occurs for several reasons. Some biological goals do not need to be satisfied at any particular instant, but within reason, can be executed at convenience (e.g., such things as eating, sleeping, or toilet activities). Some daily tasks have similar characteristics (e.g., going to the bank or post office, purchasing some needed item). Some tasks have to be deferred because there is not sufficient time or information to complete them during one session of work (e.g., writing a scientific paper, reading a book, learning a complex task). Finally, even for tasks that are continually active from start to completion, they may span such a long duration that other things are also done along the way, and the individual components of the major task may have to wait for minutes or even hours before being executed.

These problems appear to be analogous to the scheduling problems of modern real-time computers, and some of the analyses from that field are relevant. However, the human is a special kind of biological processor, and I suspect that surprisingly little of what we know of time-shared computers applies to the human. The difficulties in doing two or more tasks at the same time are well known. There are only two ways that a system can do two or more things together at the same time. One way is to have sufficient processing machinery that the two tasks use different resources and do not interact. The second way is to switch back and forth between the two, saving the complete status of the current state before switching tasks and then restoring the state completely when switching back.

Which method do people use? There is clear evidence for both. Different processing structures control walking and talking, eating and seeing. The same processors are switched among tasks

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when we listen first to this conversation, then to that, or when driving a car while conversing, looking first at the road, then at the passenger. The interesting cases arise when neither solution seems applicable because the several tasks interact with one another. Some kinds of mental activity can cause pupil size to increase (as expert poker players know). We hear better in the direction in which we are looking (even if we do not turn the head) and, conversely, it is hard to ignore the sounds from the direction in which we look, even when we are trying to listen to something else [12]. Novices cannot tap different rhythms with different hands, but expert musicians can. Thoughts can intrude upon actions. The initiation of action can interrupt thought. Emotions -- and even such things as hunger -- can disrupt thought. We tend to remember sad things when we are sad and happy things when we are happy. Different parts of our system intrude upon others, apparently in subtle, continuous ways, a point exploited by Freud.

### A. Studies of attention (psychology) and time-sharing (computer science) do not provide helpful information

These characteristics of real behavior pose some interesting and important puzzles for students of human information processing. We know little about how such multiple goals and tasks get scheduled and accomplished. There has not been much study of this aspect of behavior. This is especially true in view of the psychological literature on simultaneous attention that argues strongly for limits on our ability to do several tasks at any one time. I myself have argued such a point, telling audiences of undergraduates how people are limited to doing roughly one thing at a time. Of course, while I say this, I am pacing back and forth in front of the class, avoiding the table and chair in my path, juggling a piece of chalk from hand to hand, planning the remainder of the lecture, and worrying about how I am going to get through the demands of the rest of the day. My actions contradict my speech, but in actuality, it is even worse. Any one of the "single" things I am doing is a complex set of overlapping activities. The act of speaking, for example, involves many components, many of which should really be considered separate tasks. In speaking, there is the high level planning of the utterance, the formation of the structure of the sentences, the proper morphological selection and construction of the words, and the complex control of the speech organs and of the numerous muscles in the face, mouth, throat, and chest that must operate in parallel with overlapping control signals. Thus, even a so-called single task is really many simultaneous tasks.

Psychologists deal with this apparent contradiction between theoretical belief and reality by talking of the distinction between automatic and non-automatic actions, stating that automatic acts are not under conscious control and do not require attentional resources. As a result, there is no limit on how many of these can be done at any one time, as long as there is no conflict in the use of any particular physical or psychological structure. The trouble with this explanation is that it doesn't tell us anything about how it is actually accomplished. To be polite to my field, I will make the

excuse that this explanation is still at an infant stage of development. The statement allows us to reconcile our observations of real behavior with the theoretical belief in attentional limitations by saying that, well, not everything requires attention, not once it is well learned. Regardless of what you might think of the statement and of the lack of specificity in the arguments, there is another problem with the approach; the attentional limitations are only part of the problem. We still don't know how any organism can simultaneously perform many tasks. What kind of structures are necessary, and which are really present in the human? How can we account for the errors that people make?

Now turn to computers and, in particular, the work in Artificial Intelligence. Let me quickly assure half of my audience - and warn the other half -- that AI doesn't have any idea of how to handle the problem either. The relationship between the study of Artificial Intelligence and human intelligence should go two ways, and although psychologists have often taken more from AI than AI has taken from us, I think the direction of the information flow is changing. In this case we are equals, there is only a weak ebb between two stagnant pools.

Most of the intelligent programs that have so far been developed within AI are single minded, experts in their single domain of inquiry, but unable to deal with any other domain. Even when there are systems that can deal with several different domains or sub-domains of a topic, they do them in a sensible fashion, one at a time, rather than in the inelegant, cluttered human fashion of attempting to think of everything at once, mixing up the concepts of one with those of the other. The virtue for the computer is elegance and power. The virtue for the human is creativity and flexibility.

#### B. Human error is suggestive of a special form of mechanism

I want to argue for a different kind of processing mechanism than is usually considered by people within Artificial Intelligence. In the end, it may not be wise to model many aspects of human intelligence with conventional processing structures. But before I get to that, let us review the argument.

The multiple-purpose, multiple processing aspect of our behavior leads to difficulties. I have already listed some phenomena that imply interactions among processing structures. In this paper I concentrate upon the form of human errors. Thus, we make errors. We are easily distracted by events, stopping to do things we had not intended, or we are captured by habitual acts, performing them instead of the ones intended. At times, we can be data driven, responding to sensory signals, whether we intended to or not. This can be useful, for it allows us to react appropriately to unexpected events in the environment. It is not so useful when data driven processing interrupts our intended actions, at times so distracting us from our intentions that we neglect to complete them. These errors imply that we neither separate the tasks well nor switch completely among them. As a result, we intermix components, lose track of our status on any given task, and oftentimes do the right thing on the wrong occasion.

Errors give insight into the system, for they offer powerful clues as to the operation of the underlying mechanism. We need not agree with Freud's view that "the meaning in them is unmistakable, even to the dullest intelligence, and strong enough to impress even the most critical judgment", but we can still agree that they are strongly suggestive. Errors can be divided into several different categories. I divide errors into two major classes: mistakes and slips, with the division being whether the error occurred prior to or after the formation of the highest level intention. I define a mistake to be an error in forming the intention. Thus, a mistake can result from knowledge that is erroneous or incomplete, either in

the information that the person brings to the situation or that is available from the environment. The mistake can also arise in the psychological mechanisms of decision and planning that are involved in the formation of the intention. I define a slip to be a failure in carrying out the intention properly. That is, the appropriate action is started, but somewhere along the path of execution it is diverted or deflected.

There are several collections of slips [2,3,9,11]. The instances are both humorous and informative. A business executive roared "Come in" instead of "Hello" when answering the telephone. A friend politely said "Come in" instead of "Sit down" when inviting a new person to join the two of us at a table in a hotel restaurant.\* Pilots have raised the landing gear instead of the flaps. One person reported cleaning a fish and throwing the cleaned fish overboard, keeping the entrails. In preparing for a party, one person put the cake in the refrigerator and the salad in the oven. Computer users report numerous errors: typing commands into the text editor while in "insert" mode, or text while in "command" mode; deleting files instead of moving them. There are data-driven errors, in which the sight of something leads to an unintended action - one of my students calls this the "parking spot error" if you come across a parking spot while driving through a city, you may find yourself parked in it, even if you had no intention of stopping there. (The same student reports dashing into an elevator that happened to open its doors just as he was walking by, even though he hadn't meant to take an elevator.) A reasonably common typing error is the "doubling error" - doubling the wrong letter in a word, yielding bokk or claas instead of book or class.

Examples of slips can be found in both speech and motor actions. One example is to select the wrong word, as in "Wouldn't it be cheaper, I mean faster, to go that way?" I classify this as a "description" error, one that results from an error in memory retrieval. The word that was first retrieved shares features of the semantic description of the intended word. The error can per-severate, as in "They have Chineese -- Japa - Mexican food to go."

There are other forms of verbal slips. A blend occurs when two competing patterns are merged, as in "clut" which merges "close" and "shut". In a Spoonerism, components of the words are interchanged, as in "Ruman and Normalhart" instead of the intended "Norman and Rumelhart" (The examples come from Norman [91, and Fromkin (2,3].)

Freud made the point that most errors have multiple causes, and that seems to be true of these as well. For the several people who have reported going to their bedroom to change clothes for dinner and finding themselves undressed and in bed, they may have been "captured" by performing the initial stages of a familiar habit and unconsciously completing the familiar instead of the intended, but they may also have been unconsciously attempting to avoid the dinner. The invitation to "Come in" to the restaurant table could have been affected by the fact that one of us was sitting in a semi-enclosed booth (and the person who made the slip so argued). In my experience, these subtle, clinical interpretations seem initially far-fetched, but are confirmed with surprising frequency by the people who make the slips. Thus the puzzle for those who wish to figure out the mechanism, how do different sources of information interact to lead to slips (while also accounting for the fact that most of our actions are correct)?

The various phenomena I have described, plus others, imply that the parts of action sequences are neither strongly ordered nor tightly coupled. That is, I think that the biological system is str-

\* All the slips reported in this paper have been collected with some care as to accuracy and with the original intention verified by the perpetrator. See the original publication for details.

lured so as to use ambiguous information for memory search, to allow itself to be responsive to multiple sources of information, to combine and overlap data paths, and to deliberately intermix what one would have thought to be independent processing streams. Although these properties can lead to errors, I believe that they are also exactly the sort of thing that gives us much of the power of human creativity and judgement, to allow us to be tolerant of noise and of error, to behave flexibly, to respond in imaginative and creative ways to novel events, and to be able to shift our strategies and behavior when the situation shifts.

The basic concept is simple. We assume that the human information processing system is mediated by means of many separate processing structures, each of which can do only simple operations, but each of which is coupled to numerous other structures. We call these structures *schemas*, and we allow each to have an activation value that excites or inhibits its neighboring schemas and is triggered into controlling an action sequence whenever the combination of its activation value and the goodness-of-fit of its specific trigger conditions exceed a threshold value. (For a closely related argument and description of computational structures, see [1].) For present purposes, all that is needed is the understanding that there are independent processing structures, each capable of controlling action, and that synchronization and cooperation among them is handled by activation and inhibition links among schemas. More discussion can be found in [17,8,9,10,13].

**TABLE 1**  
**CLASSIFICATION OF ACTION SLIPS**  
(Adapted from Norman, [9])

- I. Slips in the formation of the intention
  - A. Mode errors - erroneous classification of the situation
  - B. Description errors - ambiguous or incomplete specification of the intention
- II. Slips that result from faulty activation of schemas
  - A. Unintentional activation
    1. Capture errors - when the intended sequence is similar to another better learned or more frequent sequence - the latter may gain control
    2. Data driven activation - external events activate schemas
    3. Associative activation - currently active schemas activate others with which they are associated
  - B. Loss of activation
    1. Forgetting an intention that commencing with the sequence
    2. Misordering the components of a sequence
    3. Leaving out steps in a sequence
    4. Repeating steps in a sequence
- III. Slips that result from faulty triggering of active schemas
  - A. False triggering - a properly activated schema is triggered at an inappropriate time
    1. Spontaneous - reversals of event components
    2. Blends - combinations of components from two competing schemas
    3. Thoughts leading to actions - triggering of schemas only meant to be thought, not executed
    4. Premature triggering
  - B. Failure to trigger
    1. The action was preempted by competing schemas
    2. There was insufficient activation
    3. The trigger conditions failed to match

Action slips come in many different varieties. I have attempted the analysis shown in Table 1, based upon a theoretical framework that assumes that actions are caused by the activation and triggering of schemas.

## II. Studies of skilled behavior provide more clues

### A. Skilled typing has interesting properties

Another source of information about how people do simultaneous actions comes from the study of skilled tasks. One such

task is expert typing, and detailed study of the typist reveals some interesting insight into the nature of skilled human performance. Typing is a single task that requires multiple control of the 10 fingers and 2 hands - there are 60 tendons and 30 joints involved simply in the movement of the fingers. Study of typing is today one of the major themes in our laboratory, and the analyses of typing errors and typing performance tell us quite a bit about the nature of cooperative interaction among simultaneous activities. At this point I will only mention two aspects of skilled typing. One is the doubling error in which the wrong letter in a word is doubled, so that a word like book or manner is typed as bokk or maaner. The other is the overlapping nature of the execution of the finger movements [41]. The finger movements start several letters ahead of their scheduled arrival time, oftentimes out of sequence of the final temporal order in which they are made. It is as if each finger starts as soon as it can towards its intended target, and the hand appears to cooperate, configuring itself so as to make maximum movement towards as many targets at a time as possible.

This latter example is important, for it illustrates a situation in which simultaneous tasks cooperate rather than compete. This cooperation among possible competitive tasks happens frequently. Suppose you wish to pick up several pencils and a piece of paper at the same time, using only one hand. The normal finger movements that would be performed were only one object to be picked up are modified to allow for cooperation among the fingers and hand to accomplish the multiple goal. I predict that one of the changes that occur in performance as a person becomes expert is a change from mutual competition of simultaneous actions to mutual cooperation. The behavior therefore changes from doing but a single action at a time to overlapping, cooperative performance of several simultaneous acts.

**TABLE 2**  
**THE BASIC PHENOMENA OF TYPING**  
(Adapted from Rumelhart & Norman, [14])

- 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 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 Error
  - C. Alternation reversal errors
  - D. Homologous errors
  - E. Capture errors
  - F. Omission errors
  - G. Mistrokes
- 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

Studies of typing reveal a number of phenomena that provide considerable constraints on the possible mechanisms that could be responsible for the actions. A list of the phenomena we have examined is presented in Table 2.

### B. The doubling error implies that there is no type-token distinction

Consider the doubling error. How could it come about? In our attempt to devise a formal model of the typing process [14], we took special note of errors of doubling and alternation. (An alternation occurs in a word like *these* in which the *e* alternates, but when typed, the wrong letter is alternated, as in *thses*.) The ex-

istence of doubling and alternation errors pose special problems. Consider the word book. According to our arguments, the word would be represented by schemas for each of the letters; b o o k . It is easy to see how such a representation could lead to transposition errors (such as boko) but not to doubling errors. It would be easy to make up a schema for a doubled letter (so that the word would be represented by the schemas bdouble-ok), but this would not lead to the doubling errors either.

The doubling error turns out to have two major implications. First, it implies that there are special schemas that signal the existence of doubled letters, and that occasionally these schemas get applied to the wrong letters. In a computational terms, this means that the binding between the arguments of the special schemas (or doubling occasionally get made improperly). Second, the need for a special schema to mark doubled letters implies a difficulty in having the regular letter schema signal the double. Why isn't the word book represented by the schemas b o o k ? The reason would seem to be that this would require two instances (types) of the schema for o, the existence of the doubling error implies that such repeated tokens of a schema might not be possible.

Thus, the existence of doubling errors forced us to a pure "type" model, in which each letter could only have a single keypress schema, the keypress schemas exist only as "types," with no "token" schemas. There must be a special schema that signals the presence of a doubled letter. Moreover, there must be a weak binding between the special schema and the arguments upon which it operates. In our model, we let the binding be established via activation values, with noise sometimes leading to errors in the binding. The existence of alternation errors led to the same conclusion, special schemas that signal the presence of alternating letters, with a weak binding between the schema and its arguments.

### III. On possible psychological mechanisms

We see that there are several different aspects of skilled behavior:

1. Competition among actions, so that the doing of one thing inhibits the doing of another. For some combinations of actions, the mechanisms required are incompatible, so that the competition is necessary and in these cases some sort of priority or inhibitory processes are required.
2. Cooperation among actions, so that the operations of one action are modified to accommodate another. In this situation, most noticeable with skilled performers or with highly distinct, compatible actions, the simultaneous actions must engage in some process of "negotiation" to permit mutual performance. Thus, if one wishes to carry several objects at the same time -- for example, several pencils, a piece of paper, and a cup -- the normal movements and positions of the fingers, hands, and arms will be altered to make the cooperation possible.
3. Slips of performance, so that the components of one action sequence may get mixed up with the components of another, or the memory or the resource requirements for one will interfere with the requirements for the other, and so on.
4. Non-independence of action, so that the performance of one activity either affects or causes the performance of others, even when these other activities would appear to be quite unrelated. It is as if there were an overflow from the activation of one set of processing structures to neighboring structures, in which the major source of interaction results from physical proximity of the processing structures rather than from logical relationships among the activities being performed. (For an interest-

ing review of this concept, see [6].)

These different aspects of simultaneous performance provide hints as to the nature of the underlying mechanisms. I have already suggested that the doubling error in typing says something of the underlying representational structure, and of the possible mechanisms for binding a function to its arguments. Slips provide constraints on the nature of the underlying representational and processing mechanism. Examination of skilled typing provides another source of evidence, requiring some mechanism that can yield cooperative behavior among the fingers and hands. Studies of attention and of neurological deficits provide yet another source of information.

In our attempt to construct a processing model of these aspects of human behavior we have been forced to deviate from the more traditional processing structures. Instead, we find that a viable structure seems to require multiple, parallel units, all interacting with one another, activating (and inhibiting) one another, with a tradeoff between activation value and the goodness to fit to trigger conditions. The scheme that we propose is a relative of production systems, but the control structure that we propose is somewhat different.

#### A. The role of will in the control of action

We postulate that skilled action sequences are automatic, no conscious control of them is necessary. However, because people sometimes perform *AH* action when the conditions are not completely satisfactory, or hold back an action even when it would otherwise be appropriate, some other form of control is required. In [10], we suggest that the normal configuration of schemas that perform an operation can be thought of as a *horizontal thread* of control (the name taken from the fact that the processing structure (or some even sequence is often depicted as a series of horizontal processing stages). In normal circumstances, the horizontal thread suffices to carry out the action, with component schemas being triggered when their activation values and trigger conditions are satisfactory. However, attentional (conscious) control is necessary when there is concern about the adequacy of the horizontal thread structures (as in ill learned tasks, novel situations, or situations perceived to be dangerous). This is done through control of the activation values of schemas by means of *vertical thread* structures. The application of attentional activation to bias the control of the horizontal thread schemas we called "will." Thus, by the exertion of will, one can cause a schema to be triggered even if it would otherwise not have been or to prevent a schema from being triggered that would otherwise have been.

The application of vertical thread activation, will, is best illustrated by the situation where one wishes to perform an undesirable act (such as getting out of bed on a cold morning) or to prevent a desirable act (such as eating any more of a rich and tasty dessert). In both cases will is required, in the former to increase the activation values sufficiently to cause triggering of the schema even in the absence of a sufficiently good fit of the triggering conditions, and in the latter case, to prevent an activity, even though the normal activation values and triggering conditions have been met. In the latter case, continual attentional effort is required, for if attention lapses, the schema will revert to its normal activation values and triggering conditions, and the action will be performed.

The models of human processing suggested here need not be the only candidates. I mention them because they are suggestive of the sort of processing structures required to account for human performance. The important point is that conventional processing structures can not describe human behavior, a new breed of computational mechanism must be developed.

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