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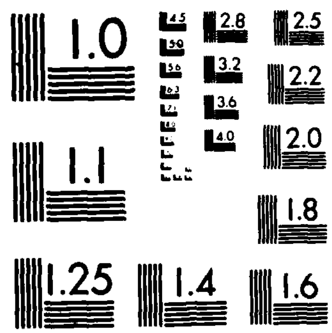

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VISIBILITY OR DISABILITY: NOTES ON ATTENTION

David Navon

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This paper evolved out of exciting and fruitful discussions at an informal attention seminar which took place during the summer of 1985 at the Institute for Cognitive Science, UCSD. Participants of the seminar were Michael Jordan, Ruthie Kimchi, Yoshiro Miyata, David Navon, and Donald Norman. Several ideas in this paper as well as the refinement of many others are due to the creativity of the group.

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This paper describes the framework of a theory of attention that posits parallel computations with little competition for common resources. The mind is likened to a set of processing entities called modules that may be active in parallel. Their activation is externally driven. Cooperation among modules is often required for achieving goals which in turn calls for communication. Attention is assumed to control only the communication among modules. It exerts attentional emphasis by bringing the output of a to-be-attended module to the information of a maximal number of other modules, while limiting the ability of deemphasized modules to disseminate their output. This is achieved by a mechanism called *decoupling* that controls the connections among modules. The control of decoupling that is required for attentional emphasis is associated with an aversive phenomenal aspect that is usually called effort. The decoupling mechanism is a vehicle for achieving selectivity. It is less fit for coping with multiple goals. The reason is that confusion and outcome conflict are likely when more than one goal is emphasized. The architecture of the control over decoupling and the strategies used to cope with various situations are elaborated on.

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Contents

Visibility or Disability: Notes on Attention

DAVID NAVON

A Pluralistic Concept of the Mind

Cognitive psychology has been taking quite a mechanistic approach towards the mind. Any machine has a specific function, broad as it may be, that it was designed to serve. It may be made of components, each designed to serve a specific subfunction, or it may call for other machines that are designed to serve a subfunction that cannot be served by any of its components. Still, the main premise of mechanistic views is the one-to-one mapping between mechanisms[1] and functions.

However, in nature, functions are not always accomplished by one function-dedicated or function-tailored mechanism, or by a hierarchy of such mechanisms. Rather, functions are often achieved by the cooperation of many entities, each having its own properties. The entities are not like a mechanism or a component that were *designed* to serve a specific function. They simply exist, and they typically *specialize* in doing things that no other entity is capable of doing. Any such entity may do whatever it does independently of any other entity. However, when a goal is recognized, it may often happen to be a novel one, and may require the cooperation of many entities, each doing something within the range of its specialization. Thus, those entities do not have a fixed function; rather, they have specializations, but are modular in their use. Let them be called *modules*. An obvious instance of a set of modules is the human society; another one is a beehive.

If the mind is a collection of independent processes (cf. Hinton & Anderson, 1981), perhaps mental processes function within the mind much like people do in their community: They specialize in some computation, and they may be called to apply their specialized ability for some goal that is recognized as important and that typically requires the cooperation of a number of processes.

For example, while writing this sentence, numerous processes—logical, associative, linguistic, and motor—have probably been activated. Since this sentence is probably unique, as many others are, these processes are neither subordinated to any molar process nor determined by any one driving process. Any one of these processes, e.g., the schema for the verbal expression of tense relationships in English, may be activated in other occasions for other goals. Thus, the processes must be independent processing entities that cooperate as called for by circumstances.

A critical requirement for attaining the desired cooperation is *communication*. Communication is required for two major objectives: to announce current goals and to transfer or exchange information pertinent for accomplishing the goals. Thus, goals are more likely to be attained when they, as well as the processing modules involved in accomplishing them, can adequately communicate among themselves. However, sufficient communication is not guaranteed for all goals that the environment might

[1] The concept of a mechanism is, of course, not restricted to tangible structures, but rather encompasses implemented algorithms as well.

suggest at any particular moment. This constraint dictates two basic facts of life in the community of processing modules comprising the mind:

- Goals compete for communication, and attention is called forth to resolve the conflict.
- Goals can survive better when they secure for themselves some communication through learning.

In this paper we concentrate on the role of attention in managing communication in a multiple-goal environment.

The scope of the discussion in this paper is quite broad. I felt that it would have been hard to make sense out of the theoretical ideas if they had been presented as a body of hypothetical assertions laid down one by one. Rather, I elected to relate the ideas, as they are presented, with observable phenomena and phenomenal experience.

Structures and Outcome Conflict

The concept of a module as defined here (unlike in some other places, e.g., Fodor, 1985) is of a quite specialized process limited in its capability and horizon. Being so limited, it often interacts with other modules. Modules operate within, or deliver their products to, media which may be called *structures*. A prominent example of a structure is a public communication device such as a blackboard (Lesser, Fennell, Erman, & Reddy, 1974; Newell, 1973; Rumelhart, 1977). When modules operate concurrently within the same structure, outcome conflict may emerge: that is, the operation of a module may generate some outcome—output or side effect—that interferes with the operation of another module (see Navon, 1985). For example, when several messages are presented on the blackboard at the same time, selection errors may occur and search latency increases for all users. Another example of a structure is a connectionist network of units of the type described, e.g., by Schneider (1985). Outcome conflict may arise in such networks from the covariance between the vector messages transmitted by concurrent modules. In contrast with blackboards in which publicity may serve some cause (see below), in connectionist networks the sharing of communication channels seems to have no advantage.

Structures may be common to some or all modules. This has two consequences: (a) outcome conflicts may range from general to specific and (b) modules may share one or more structures. The more the modules share, the more outcome conflict is generated.

However, sharing is not associated only with costs. The outcome of a module may be facilitative for the operation of another module. Furthermore, sometimes the interaction of modules sharing the same structure is necessary to accomplish a goal that cannot be accomplished by just one or by a given set of modules. The goal requires a novel solution that may be brought about by fruitful associations among the outputs of several modules.

Activation: Externally Driven and Uncontrollable

So far the mind has been described as a collection of independent entities called modules, interacting in processing environments called structures. Of course, the modules are not active all the time. They are active as long as their *trigger* is detected and as long as their *stopping state* is not. The trigger is a state that is produced by some other modules, and that is initiated by some input that is exogenous to the cognitive system: namely, stimuli or needs. The stopping state is the condition for the decaying of the activity of the module. Both the trigger and the stopping state are defined internally and are not mutable. Since the detection of the trigger is a sufficient condition for activating a module (and so is the detection of a stopping state for stopping its activity), cognitive activity is not arbitrary but rather deterministic. On the other hand, since effects on activation are stipulated by *detection* rather than by mere presence, there is room for variability in the behavior of processing modules. Later it will be explained how states might not be readily detected within the system described here. Activation is determined only by these conditions and cannot be induced, amplified, or attenuated by any agent within the processing system—that is, activation is externally driven and sovereign of any central intervention.

How can the system deal with goals that involve the cooperation of modules which sometimes have never cooperated before? A goal is announced by a module that, like any other module, is driven by some stimuli or needs. Some other modules may then independently suggest means of cooperating, either by retrieving means-ends associations from past experience or by computing the relevance of the means to the goal. Means may, in turn, be interpreted as ends to be achieved by other means. This kind of distributed, uncontrolled decomposition of the goal proceeds until the means of cooperating are detected by modules for which they serve as triggers and whose activity eventuates in some action. Such a system may easily be driven into chaos, however, as with any system in which processes that interact are activated by independent sources with no central control.

Attention: Determining the Agenda Without Tapping Activation

Attention is the instrument for making the agenda of the mind less anarchistic and more consistent in terms of goals accomplished during the same time range. The activity of an attention-free mind would probably be very erratic. The organization that does exist is presumably due to the intervention of attention.

But how can the agenda of the mind be controlled if there is no control over the activation of modules? To envisage the difficulty, imagine a chairman of a noisy meeting who has no power to grant floor privileges or to enforce silence on unwelcome speakers. The answer is that, as often is the case when there is no direct control, there are means of indirect control. Attention is making use of such means.

How is the indirect control achieved? It is made feasible due to the fact that activation of a module in itself has a quite limited effect on the system. We have to remember that usually goals cannot be attained by any one module. Thus, to achieve a goal, several modules have to be activated in parallel, in sequence, or in any other, more complicated, schedule. A way to have control on goal achieving is to tap the likelihood that the modules involved are co-activated with the appropriate timing. In default of an agent that can affect activation, let alone supervise transfer of control in any other means, the only way to accomplish a multiple-module goal is (a) to ensure communication between all relevant modules and (b) to deny communication from other modules. This is achieved by a mechanism that is called *decoupling*. Decoupling is the way to regulate communication in the system in a reversible way. Let us digress now to describe possible means of communication among modules.

Communication: Contingencies, Couplings, and Blackboards

A critical tenet of the view presented here is the mutability of communication. Conventionally, communication between processes is assumed to be rigid: It is present to the extent that the relationship between the processes is well established by practice or by frequent co-activation. I propose, instead, that even in this case communication may not be guaranteed. At least some lines of communication may be mutable.

Let us suppose that modules may be interconnected by either of two types of connections: *contingencies* or *couplings*. Contingencies are strong connections between onset-onset or product-onset. They form patterns of activation among contingent modules (e.g., actions, object representations, object-action chains, images). Couplings are weak associations that relate modules whose activations may be relevant for each other, but do not entail each other. For example, the visual, conceptual, and articulatory schemas of the word *table* are connected by contingencies; the schemas for *table* and *food* are related by a coupling. Or, the modules for stepping on the clutch pedal and shifting the shift stick are presumably contingent, whereas the modules of steering and looking at the car mirror may be coupled but not contingent.

An important distinctive feature of couplings is their mutability: They are subject to partial or total attenuation by the decoupling mechanism that functions as an attention controller. Contingencies are not mutable, so they act as if they are fixed messages (excite or inhibit). A module cannot detect information that triggers it if it is decoupled from the source of that information. However, even if the module is not decoupled, it may fail to detect information if it is flooded by information from many other modules.

So far, I have described communication that is specific to a pair of modules. However, not all communication is private. There are public communication devices, a general blackboard or several blackboards, possibly of various levels of globality, each serving a specific set of modules. Some of the structures mentioned above as the processing environments within which modules interact may actually be blackboards. It is worthwhile to elaborate on the functional advantages of having public communication devices on top of private communication channels. First, it is desirable that private communication is established only between modules whose relevance has been determined. This is not only for reasons of economy, but for reasons of efficiency: Direct communication is better reserved for highly relevant information; otherwise, modules may be incapacitated by information explosion. However, the output of a module which usually is irrelevant for another specific module may nevertheless be occasionally relevant. It is important, then, that modules have some access, cumbersome as it may be, to information yielded by other modules with which they are not connected, in case it seems relevant. This function is served by the public communication devices. These can be used to transmit information intended for (a) all modules, (b) particular modules, or (c) modules with which the information source is not connected. Second, transmitting information via a public channel has some advantage over private communication: The receiver acquires not only the information itself, but some important meta-knowledge as well, especially on the presumed state of knowledge of other potential receivers with respect to the information. For that matter it is sufficient that the receiver is generally informed about the range of modules that use the channel. Such meta-knowledge may be crucial if the utility of the receiver's operation totally depends on a concerted effort on the part of several receivers, or at least on congruence with their operations. Third, as will be seen below, dissemination of information is a self-strengthening process. Accordingly, a module that is expected to need information at time t_2 would rather have at time t_1 a range of receivers that is much wider than the set of modules with which it is directly connected. Hence, there are some good reasons for having public communication devices. If the devices exist, then each module as a rule has fast access to highly relevant information and slow access to large amounts of less relevant, or potentially relevant, information. The slow access makes the detection of the potentially relevant information quite uncertain if the public channels are flooded.

Now that the distinction between private and public communication has been made, it is in order to specify more precisely the sense in which nonpublic communication is private. A private channel is one that connects two specific modules, so that when the channel is not attenuated, information emanating from one module is received by the other without having to resort to a common public device. However, it is assumed that a module cannot exercise a policy of selective confidentiality so as to make one or more of its coupled parties receive messages that other coupled parties do not receive. All the module's coupled parties receive the same information. It is as if each module has some frequency band through which it broadcasts its messages, and any module coupled with it is tuned in (or can tune in). In a sense, it is as if every module has its own message board that is accessible only to modules coupled with it.

The Importance of Being Visible

Let us now return to the function of attention. I have postulated that goal achieving is a cooperative process among modules, and that activation is externally driven and uncontrollable. It follows that to achieve a goal, the component modules require communication. When communication is not exclusively private, the way to attain it is by publicity. Thus, attentional emphasis amounts to visibility: A module is emphasized when its throughput and output are brought to the information of a maximal number of other modules, at least of those modules that may be concerned. Since frequently it is not clear which modules may be concerned, or how to directly access them, the wider the circulation, the higher the likelihood of success.

However, no module is prominent if every module is prominent. If too many modules are emphasized, especially if they share common structures, much outcome conflict arises. For one, the public communication devices would display a large amount of information, which would make it less likely that any one module would detect the pieces that are pertinent, namely, that trigger the module. So, to be emphasized, the background of a module should be de-emphasized. This is done by limiting the ability of background modules to communicate with other modules.

Selective Decoupling

Attentional emphasis is attained by selectively attenuating couplings of most modules except for the emphasized ones. To be more definite, what the attentional system modulates is presumably the strength of messages sent from modules to either their coupled parties or to the blackboards. Messages from background modules are attenuated. Thus, their likelihood of affecting the other modules, including relevant ones, is small. The background modules have no way to know of their activation or their output. On the other hand, emphasized modules have both open communication channels among themselves and publicity among all other modules. Thus, their chances to propagate their output and affect other processes are good.

Consider the metaphor of an intelligence community, suggested by Kahneman and Treisman (1984). Suppose there is no hierarchy in that community. Every agent is active as long as there is some information that the agent can collect; However, the impact of the information is limited by its circulation. If the agent has few communication channels, or they are jammed, or the agent has limited access to any public channel, then the agent's activity will most likely be overlooked. Moreover, in this case it will not induce any further activity in the community. On the other hand, the products of activity of agents that have better communication will be noticed, will be used when relevant, and will evoke related activities. So, the system is biased in favor of current information coming from the source, and further activity in the community will be biased to collect information related to the one suggested by the source.[2] The way to bias the system in favor of some sources is to see to it that they have good communication to the exclusion of other sources. This is analogous to attentional emphasis.

Awareness and Publicity

It is straightforward to define the relationship between attention and awareness within the view presented here. Modules that are emphasized have more publicity, thus are more available to any other processes. *Awareness*, in the functional sense, may simply amount to the *availability of information to other processes.* Perhaps awareness for the output of a given module is directly related to the number of other modules that have access to the output of that module. Perhaps it is related just to the availability of the output to certain processes that control speech, rational thinking, or other high-level

[2] Which might be the cause of some misconceptions and biases in the functioning of intelligence agencies.

functions. In any event, the more emphasized a module is, the more likely its output is to be "available to awareness."

This can be illustrated quite clearly in the context of the intelligence community metaphor. Awareness of the community for information delivered by a certain agent might be defined as the visibility of that information within the community rather than as its availability for some external authority. Awareness for that information is enhanced by good communication, which is in turn afforded by the manipulations of communication meant to emphasize information coming from that source.

Attention and Effort

To recapitulate, the mind is likened to a set of modules that may be active in parallel. Their activation is externally driven. Attentional control is mediated by the strength of couplings, namely, of outgoing messages to other modules. Selective modulation of the strength of couplings leads to more awareness for emphasized modules and more impact of them on ongoing and further activities of other modules. The activity of de-emphasized modules may keep going on, but it is not propagable. The activity of emphasized modules does propagate.

If to attend is to selectively decouple, namely, to attenuate some couplings and preserve others, then attention is work. We may call it *attention work*. Its nature is more akin to the work of supervisors than to that of the workers they are in charge of, but attention is clearly work as well. Let us assume that the control of coupling that is required for attention work is associated with what is phenomenally felt as *effort*. Effort is not any scarce commodity. It is the aversive valence of the operation of decoupling. The more sustained decoupling is, the more aversive it is. Since effort is aversive, motivation is needed to override the aversion, so that decoupling can be done. The amount of decoupling actually exerted at any moment depends on the balance of motivation to accomplish the goal and the aversion. Any factor that manipulates either of these may affect performance via the amount of decoupling exerted or sustained.

The more effort is involved with decoupling, the stronger is the activation of de-emphasized modules, the more coupled they are with to-be-emphasized modules, and the weaker is the initial activation of the to-be-emphasized modules. In the fortunate case that the emphasized goal is compatable with most urging needs and impinging stimuli, it feels that little effort is expended. The effort should be more sustained, the more lengthy the process of accomplishing the emphasized goal. Thus, the amount of effort depends on four variables: strength of activation, strength of background activation, susceptibility to background activation, and complexity. Those effects may be due to the amount of required decoupling, or to the degree of aversiveness associated with the particular decoupling called for, or to both.

The operation of the modules need not be stipulated by the supply of any mental energy. It is tempting to posit that energy of this sort is nevertheless required for the operation of the decoupling controller itself, namely, for the attention work (cf. James, 1890, ch. 11). The notion advanced here is that even that may be gratuitous: The decoupling controller may be a mechanism that is designed to yield to the requests of modules, without relying on any source of energy. As argued, effort may be understood as the phenomenal effect of the operation of selective decoupling in the presence of competing activations. In any event, whichever of these conjectures (namely, decoupling requires energy vs. nothing requires energy) is correct, both seem quite disparate from the common view of attention as a mental commodity used by the process being selected (e.g., Kahneman, 1973; Navon & Gopher, 1979; Norman & Bobrow, 1975).

Is effort the inevitable shadow of attention, or does it characterize only attention to modules having no "immediate interest," as James (1890) suggests? The view taken here is that although *awareness* per se may result from activation of unselected modules, the act of *attention* is defined by decoupling. Decoupling may be aversive, and to the extent that it is, attention must be associated with effort. The observation that the effort associated with attention seems to vary with the objects of attention may be attributed to difference in frequency, strength, or stability of competing activations. For example, when one tries to concentrate on the proof of a mathematical theorem, activity driven by basic needs and external stimuli is not precluded. The stronger the activity is, the more effortful decoupling appears. On the other hand, when one directs attention to a conspicuous stimulus or is in the process of gratifying an urgent need, distraction exerted by thoughts or goal-oriented activity is less likely, due to the sporadic, ephemeral, or rapidly decaying nature of their driving source (see also the section "Sustained Attention"). In the rare cases that alternative thoughts are tenacious, concentrating on the "natural" object, urgent or pleasant as it may be envisaged, does feel to be effortful.

The Effects of Selective Decoupling

In a totally coupled system, activation spreads rapidly since couplings are intact. This leads to the following consequences: First, any activation that is either data-driven or need-driven tends to propagate, strengthen itself, and flood the communication channels with its output. Second, large amounts of information are available to all modules, which makes the access to relevant information difficult; this leads to delays which may be considered as outcome conflicts. Third, the likelihood of cooperation is high since all modules have much information about the activity in other parts of the system.

The major effect of decoupling is emphasis. The output of emphasized modules is disseminated among all processes, including ones that are relevant, yet are not privately communicable. Since the output of other modules does not benefit from the same publicity, the output of emphasized modules will enjoy relative exclusivity or salience, so that the chances of inducing relevant activity in other modules is greater for the emphasized modules. Also, the emphasized modules will not be flooded by information emanating from irrelevant modules. The protection gained by information selectivity ensures fast access to relevant information and reduces susceptibility to bias generated by invalid sources, but on the other hand reduces the chance of utilizing information provided by a module that is de-emphasized because it seems irrelevant.

As for the de-emphasized modules, they suffer *isolation costs*: namely, they cannot get other modules to continue what they have started because the output of the de-emphasized modules is not propagated. That may either lead to incomplete processing and loss of information, or, if processing is nonetheless completed, to lack of awareness of its output. An extreme example is the case of tunnel vision, in which objects outside the focus of attention may be completely overlooked. A somewhat different case is that of a mathematician who is so absorbed in generating a proof for some theorem, that any signal that lunch has not been eaten is disregarded. De-emphasized modules may be able to recover from the state of isolation once the emphasized activity is finished so that the system is recoupled. At that time, if the de-emphasized modules are still active (e.g., if they are driven by a persisting sour. ɔf stimulation like stomach contractions), they may regain some propagation.

Thus, selective decoupling is clearly harmful for de-emphasized processes. It is usually beneficial for emphasized ones, except when they could have benefited from information output by some de-emphasized modules. This occurs when a single goal is pursued, and decoupling is done to concentrate on that goal. The case of divided attention (or, shared attention; see Navon, 1985) is discussed later.

The Decoupling Controller

The system described here is characterized by the distributed nature of both control and knowledge: It is externally driven, and each of its entities, namely, the modules, has a very specific function and limited information about other modules. One might wonder whether the cost of lack of both knowledge and initiative at the level of components is not necessarily reflected in a need for high sophistication of some executive function, which in this case is the decoupling controller. It may be suspected that the function assigned here to the decoupling controller requires that it be as complex as a homunculus. Specifically, it might appear that the decoupling controller should have a vast amount of knowledge about the specialization of modules, couplings among them, and addresses[3] of both modules and couplings. I suggest, however, that this is not necessarily the case.

The decoupling controller may be regarded as an arbitrator negotiating demands made by parties it does not recognize. Suppose every activated module computes its need for communication—private as well as public—on the basis of its activation and goal pertinence. The module then issues a request and tries to communicate it to the decoupling controller. The likelihood that the request is transmitted depends on the accessibility of lines of communication from that specific module to the *decoupling controller*. Thus, attaining visibility is a self-strengthening process, and, as is usually the case with such processes, it is hard to get it started without happening to have some amount of visibility from the outset.

The decoupling controller is designed to deal with many requests, and make decisions that depend only on the configuration of need-for-communication requests it receives at any given time. The decision rules may be formulated solely in terms of amount of requests and communality in channels being applied for or goals being served. They may not bear on the specialization of modules, their likelihood of accomplishing their own objectives, or the relations among activities of different modules. Thus, the decoupling controller need not know anything about the requesting modules. Furthermore, to execute the decisions, the decoupling controller would have to selectively operate on different couplings—decoupling a number of couplings while preserving some others tightly coupled. Does that entail access to an exhaustive directory of coupling addresses? Not necessarily: The requests may specify the addresses of couplings that are to remain coupled. For example, suppose each of the modules A, B, and C requests communication to each other as well as to some public communication device, P, and states its pertinence to a common goal, G. In default of any more dominant set of requests, the decoupling controller will presumably design the forthcoming combination of coupling states in accord with those requests. It will impose general decoupling with the exclusion of the requested couplings (namely, AB, AC, BC, AP, BP, and CP) whose addresses are specified in the requests being granted. Thus, sophisticated as it may be, the decoupling controller definitely need not have either much permanent knowledge about the modules and their interrelationships or much information about current goals.

Sustained Attention

Attentional emphasis is more critical for attaining a goal the more processing the goal involves: The less complex a task is, the more likely it is to withstand outcome conflict. Thus, when selective decoupling is badly needed, it is often needed for a relatively long period of time. However, maintaining the same state of decoupling for a long period seems to be a problem in itself. Since the decoupling controller is responding to requests from modules, how can it be guaranteed that emphasis is not switched before the goal is accomplished?

If the requesting modules are driven by a need or sufficiently changing stimulation, the requests are refreshed as long as the source persists and stopping states have not been satisfied. Thus, if there is no novel alternative source of activation, attention may be sustained quite easily. The problem arises when the requesting modules are triggered by a goal state that is announced publicly. To be sure, the visibility of the goal results from some prior mental activity, but frequently the driving agent of that activity has already vanished. At some moment before the goal is accomplished, pressures of alternate activations might threaten to deprive the emphasized goal of its exclusive status, while there is no exogenous source that drives the activity of the modules that have requested the current state of decoupling. The person might feel then a shade of vagueness about the motives for current emphasis as well as some hesitation about persevering in it. What will presumably be needed for sustaining attention in that case is some review of the topicality of the goal. Conceivably, the decoupling controller might probe the

[3] In the sense of sites rather than in the sense used in von Neumann machines.

requesting modules to perform a quick recomputation. Occasionally, such recomputation will require attentional emphasis in itself, in which case the cognitive progress towards the goal will be interspersed with reflections about the sense in engaging in it—not an uncommon experience.

The function of exclusive visibility in the first place is to minimize the likelihood that such threats to the continuity of the process will be occasioned by interfering requests. The reduced visibility of irrelevant modules is meant to weaken their propagation, thereby preventing the conglomeration of clumps of those modules with sufficient number of requests to tip the scale of decoupling in their favor. Accordingly, the fate of sustaining attention to a goal that has little immediate interest depends not so much on the continual conviction that the goal is of prime importance, but rather on the success of selectivity during previous phases of processing: When attention is sharply tuned from the outset, the likelihood of further distractions that are not due to novel stimuli is small.

Thus, one reason the dynamics of attentional emphasis is self-strengthening is because it diminishes the influence of alternate potential objects of attention. Yet there are more positive reasons: The highly visible interim products of attended-to processing may evoke the activity of previously inactive modules that now find themselves pertinent. If those modules are fortuitously associated with need sources, their subsequent requests may be refreshable due to the more enduring nature of the need source. Hence, indirect, unstable motivation may be augmented by intrinsic motivation that provides stationary support for attentional emphasis (cf. James, 1890). A strategical manner for controlling attention that is to be sustained is discussed in the following section.

Focused Attention

As seen above, concentration is typically at the mercy of the constellation of forces acting on the decoupling controller for or against the to-be-attended object. Sometimes, however, the distracting power of alternate activations is anticipated to be too high to let it have a fair chance. Ample examples can be found in the experimental literature on selective attention (e.g. Cherry, 1953; Duncan, 1980; Moray, 1959; Navon & Miller, 1985; Treisman, 1960; 1964): For example, if in a dichotic listening paradigm, a subject who is supposed to shadow the text played to the right ear allowed his attention to be determined by the natural contest of activations, he would be violating the experimenter's instructions. As a safeguard against unwelcome distractions, the decoupling controller can temporarily attenuate communication from to-be-ignored modules to *itself*; those modules are not only denied the visibility at a particular moment, as is usually the case with de-emphasized modules, but are also deprived for a certain period of the means of *struggling for* visibility. Hence, stimuli that would normally have provoked attention may go unnoticed (e.g., Corteen & Dunn, 1974; Moray, 1959; von Wright, Anderson, & Stenman, 1975). Thus, whereas in many everyday situations, attentional selection reflects just momentary, or more enduring, preference (see Neisser, 1976, ch. 5), in other situations, including many experimental ones, which require the restriction of attention to some class of events, attentional selection involves active rejection of the complementary class. Strong evidence that this is the case is provided by negative priming findings reported by Allport, Tipper, and Chmiel (1985). However, to be insured against the risk of overlooking vital information delivered by disabled modules, their communication to the decoupling controller is attenuated rather than blocked (cf. Broadbent & Gregory, 1964; Treisman, 1960; 1964; 1969), or at least that is the case with a subset of them that is likely to be always pertinent, such as one's own name (see Moray, 1959).

Sharing Attention

So far, decoupling has been described as a vehicle for achieving selectivity. Selectivity is mainly needed for favoring goal-relevant over data- or need-driven activations. Decoupling is used to attenuate supposedly irrelevant output, and it takes more effort the more irrelevant activations exist at the moment. This mechanism was not designed, and is not fit, for coping with multiple goals at the same time. The reason is that the very same factors that make decoupling functional for emphasizing modules relevant for a single goal fail the system when it tries to share emphasis between two goals. If attention secures great publicity to just one set of modules, then any information available to the modules, through private channels or within public communication devices, is relevant to them. However, when communication is enabled for two sets of users, confusion is very likely, and it can be avoided only at the cost of large delays. To illustrate, consider the analogy of a message board posted at the staff room of a newspaper. Suppose two teams of ten persons each are each working on one story. The message board would be quite useful if only one team used it. However, when two teams use it, errors and delays result. The more complex the tasks, namely, the more modules are involved in attaining one goal and the more output they generate, the more detrimental the effect of sharing attention. The optimal way for two goals to be achieved at the same time is when for every goal there is a dedicated module or a set of modules connected by contingencies. This is a structural change in the system that takes a long period to establish. When no such structures are available, the only alternative is to use decoupling, which as said is ill-devised for that purpose. That is, decoupling is *required* for shared attention between unpracticed tasks, but is very *inefficient*. The more complex a task, the more harmful the consequences of shared attention.

Global Decoupling

What are the alternatives for selective decoupling in a situation in which two goals are to be attained? One is obvious. One can *switch attention* between the two goals. Switching implies changing the selective decoupling. It seems like a complex process, more complex than say, throwing on a switch, or changing the range of a band-pass filter. That may explain why rapid switching back and forth is used less often than sequential processing (see, e.g., Broadbent, 1954).

The second alternative is what can be called *global decoupling*. Global decoupling brings the system to a state that is diametrically opposed to the state of a tightly coupled system in which activation spreads rapidly and all modules are flooded with information. In a globally decoupled system, communication channels, private as well as public, are practically blocked. No module enjoys the distinguished status of publicity. Each active module has to operate on its own, where only the contingent modules are affected by its operation. Thus, such a situation can be likened to a regime of compartmentalization imposed on an intelligence system, or to what happens under conditions of "communication silence" commanded on military units during combat. Every unit operates on its own. The more autonomous, self-supporting units survive and are likely to succeed. The less autonomous ones cannot carry out their mission. It follows that this state is ideal for concurrently performing two, well-practiced activities that do not need communication because each involves modules connected by contingencies. This state may be self-defeating if at least one of the activities calls for communication that is not established in contingencies.

Task Interference

How does global decoupling differ from selective decoupling in its effect on task interference? It is obvious why two unpracticed activities interact. However, if an unpracticed activity is conjoined with a practiced one, the pattern of interference depends on the mode of decoupling that is exercised. If the unpracticed one is emphasized, the practiced one will probably not suffer very much from isolation because it is basically self-sufficient, and the unpracticed one will enjoy the benefits of attention. If, however, the system is globally decoupled, rather than selectively decoupled, or if it is selectively decoupled in any way that does not favor the unpracticed task, then the unpracticed task will suffer since it cannot withstand isolation at all. It follows that an unpracticed task is sensitive to attentional priority, whereas a practiced task is less so (Brickner & Gopher, 1981). The number of concurrent practiced processes is practically uneffected by attentional priority, whereas the number of novel ones is effected (Schneider & Shiffrin, 1977).

By our view, attentional priority is not a continuous variable. Although decoupling is presumably a matter of degree, its effects may not vary very much: One state occurs when the emphasized task enjoys the status of exclusive publicity, in which case it will be performed well, while the performance of the concurrent task will depend on its tolerance for isolation. Another state is one in which both tasks are selected, so that both tasks will share the public channels, with both risking outcome conflict. Any more fine-grained effects of priority that are found (e.g., Gopher, Brickner, & Navon, 1982; Navon, in press) might be the result of strategic manipulation of queueing order across trials.

Is performance never limited by scarcity of some mental commodity? Modules are basically pieces of software. Each may or may not have its dedicated hardware. Even if it does not, units of hardware that can serve the module may be abundant. Conceivably, the module may sometimes have to queue for using some type of hardware. Within the framework proposed here this seems a possibility rather than a necessity. Thus, some surmised limits on the system may be regarded as scarce resources. However, the inevitable conclusion emerging from discussion is that resource scarcity is definitely not the exclusive constraint on performance and probably not a decisive determinant of it. Thus, the dubious empirical success of resource theory (see Navon, 1984) is not surprising.

Prospectus

The paper describes the mind as a system in which processing modules may operate in parallel, cooperation among them is often required, multiple-module goals compete for communication, and attention is called forth to resolve the conflict. At this point it seems senseless to elaborate the theory any further. The difficulties of producing meaningful activity with such a system are enormous, and only years of attempts to implement it will show whether it is likely to stand the sufficiency test. Nonetheless, even in its present state the theory seems to be as definite as many other hypotheses about the mind prevalent in cognitive psychology. It is quite complex, but so, presumably, must be any view of a mind without a homunculus.

We see three impending issues that the theory presented here will have to relate to: One, learning presumably secures communication to frequently occuring goals so that they would not depend on attentional interventio... How is this done? Two, the cognitive system is not always operating in the same fashion: There are various states of consciousness, and even in the ordinary wakeful state, arousal fluctuates. How can those phenomena be interpreted within the conceptual framework presented here? Three, decoupling entails selectivity, but it is not clear that this is universally compatible with optimal consequences of processing. Possibly, tasks or strategies employed under certain circumstances may require different states of decoupling. The theory has to be expanded to address the interaction of tasks with attentional strategy.

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