16 Visual Attention

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16.1 What Is Attention? What Is Attention For?

Issues of attention bear on every area of cognitive science. In addition
to the questions that arise within individual cognitive domains, students
of attention find themselves confronted, inevitably, by the problems of
integration and coordination among different cognitive domains in the
overall control of behavior. The latter constitute traditionally the central
problems for theories of attention and must be counted surely among
the most complex and difficult problems in cognitive science.

Understanding any complex mental function no doubt requires ex-
planation at many different levels. David Marr (1977, 1982), particularly,
emphasized the importance of clear, explicit formulation at the level of
what he called the computational theory, that is, the level at which the
overall purposes or goals of a given category of cognitive processes are
to be specified and at which the internal and environmental constraints
under which they must operate, and that make those processes possi-
ble, are formulated.

What would a computational theory that was adequate to the func-
tions of attention be like? What is the overall purpose (or what are the
overall purposes) of attention, and what are the determining and enabling
constraints on attentional processes?

Answers to these questions go to the foundations of our current
understanding of attention. Many theorists in recent years have been
inclined to conceptualize attention—and attentional selectivity—as es-
sentially the consequence of some kind of system limitation: the result of
limited or insufficient processing resources or processing capacity in the
brain. Much of the empirical research on attention, following from this
very general orientation, has been concerned with identifying the nature
of these system limitations and their functional locus within the archi-
teecture of human (and nonhuman) information processing.

One objective of this chapter is to present a somewhat different con-
cception of attention, one that emphasizes the constraints of behav-
ioral coherence and univocal perceptual-motor control in determining
the nature of attentional selectivity. It also emphasizes the diversity of attentional functions. Prompted in part by advances in our understanding of information processing in parallel distributed systems (chapter 4), and by related developments in psychology and cognitive neuropsychology, I have tried to set out a conceptual framework for the functions of visual attention that offers an alternative to the traditional preoccupation with issues of limited capacity and selectivity of "processing."

As this chapter is at pains to point out, there are many different computational functions of attention. To keep things within manageable bounds, the discussion is confined to certain functions of visual attention, in the context of immediate perceptual-motor activity. A large part of the behavioral research on visual attention in recent years has used selective-response measures (often speeded response) to visual stimulation. It seems appropriate therefore to set as our principal, if limited, objective the task of understanding the attentional processes involved in this (actually very large) class of visual motor performance.

The plan of this chapter is as follows: Section 16.2 provides a critical review of the concept of central limited capacity as the causal origin of selective attention. Assumptions underlying the related concepts of "early" versus "late" selection, controlled versus automatic processing, and multiple limited processing resources are also critically examined. Section 16.3 introduces a neurobehavioral perspective on visual-spatial attention, focusing on acquired disturbances of spatial attention and some underlying neurophysiological mechanisms. Section 16.4 returns to the questions with which we began, regarding the purposes of and computational constraints on basic functions of attention. A conceptual framework is provided in which attentional functions of many different kinds contribute to (and are responsible for) both the coherence and continuity of goal-directed behavior and its flexibility and responsiveness to changing events. Finally in section 16.5 a number of experimental paradigms of selective visual response is reviewed in the light of these two contrasted theoretical frameworks.

16.2 Attention and Limited Capacity

Limited Capacity

In the preceding paragraphs two basic questions were posed: What are the fundamental constraints on processes of attention, and What are their overall purposes? According to the view of attention that has provided the conceptual framework for the majority of research in that area since the 1950s, the answers to these two foundational questions are apparently clear: (1) The fundamental constraint that underlies all the operations of attention, imposing their essentially selective character, is the limited information-processing capacity of the brain. (Thus "If the brain had infinite capacity for information processing, there would be little need for attentional mechanisms" (Mesulam 1985, p. 125.) (2) Hence, according to the predominant view, the basic function or purpose of attentional mechanisms is to protect the brain's limited capacity system (or systems) from informational overload. ("Selection takes place in order to protect a mechanism of limited capacity" (Broadbent 1971.)

This conception was articulated in its original and most influential form by Broadbent (1958, 1971, 1982). According to Broadbent, the constraints of limited capacity directly affect the processing of sensory information. Registration of some simple physical characteristics of the sensory input is possible in parallel; on the other hand semantic categorization, or identification of feature combinations, through access to associative memory, is not. Thus in Broadbent's theory, the "limited capacity system" was identified explicitly with a system of perceptual-semantic categorization. Information not selected was therefore excluded from semantic categorization or identification, and selection, according to this interpretation, was synonymous with selective processing, that is, the shutting out of nonselected information from further analysis.

Broadbent's original conception of the selective process, his well-known "filter theory" (Broadbent 1958), underwent later modification in that nonselected sensory inputs were no longer supposed to be strictly excluded from the limited capacity systems, but only attenuated in signal strength. Hence "categorization" could sometimes occur even for nonselected stimuli, on the basis of incomplete feature analysis, given a category with sufficiently lowered criterion (Broadbent 1971, 1982).

However, the basic concept—of limited central processing capacity as the fundamental causal constraint that imposed the need for selectivity of processing—remained unchanged. Moreover despite other important differences the idea of limited capacity, in one form or another, as the basis of attentional limitations has remained a central—in some cases an unquestioned—assumption in otherwise very diverse theoretical approaches to attention (Duncan 1890, Kahneman 1973, Mesulam 1985, Neisser 1967, Norman and Bobrow 1975, Posner 1978, 1982, Schneider, Dumas, and Shiffrin 1984, Shiffrin and Schneider 1977, Treisman 1988, Ullman 1984, and Wickens 1984, among many others).

The idea of a central limited capacity (and of the consequent necessity of restricting processing, beyond some level, to a selected subset of available information) has been linked explicitly by some theorists to intuitive concepts of the limited nature of consciousness, or phenomenal awareness. Posner (1982), for example, has invoked "a limited capacity system that might be identified with conscious awareness." For many authors the relationship between these ideas appears to be self-evident. ("Since we are aware of only a small amount of this information [on our retina] at any one time, most of it must be filtered out centrally" (Moran and Desimone 1985.) Any careful reading of the literature can produce dozens of such examples.) The identification of a postulated central "limited capacity system" with certain ideas of consciousness may...
be responsible at least in part for the extraordinarily widespread, intuitive appeal of the concept of limited capacity. As I have argued elsewhere (Allport 1988), however, this identification does little to clarify the computational basis of the postulated limitation in capacity.

Possibly even more important for the longevity of this idea (of limited processing capacity) has been the belief that no other explanation for the selectivity of attention was in fact available. As Broadbent remarked, "The obvious utility of a selection system is to produce an economy in mechanism. If a complete analysis were performed even on neglected messages, there seems no raison for selection at all" (1971, p. 147, my italics).

Early versus Late Selection: Underlying Assumptions

Given this general background of ideas, or assumptions, about the causal origins of attention, one issue that has preoccupied students of attention over the past twenty-five years concerns the stage or level of analysis at which the supposed bottleneck of limited capacity was located, and hence—according to the same general assumptions—the level at or before which "selection" must take place. This is the long-running controversy over so-called early versus late selection.

As outlined, Broadbent originally argued that selective filtering of sensory information must occur at a relatively early stage of analysis, that is, before the stage of perceptual recognition or categorization. Variations on this hypothesis have been put forward by several other authors (for example, Francolini and Egeth 1980, Hoffman 1986, Johnston and Dark 1985, 1986, Kahneim and Treisman 1984, Treisman and Gelade 1980, Ullman 1984, among many others). From quite early on, however, a range of contrary views has also been proposed, again both on empirical and on theoretical grounds, to the effect that a processing bottleneck can be found only at a relatively late stage, if at all, and specifically after the level of semantic categorization (see, for example, Coltheart 1984, Deutsch and Deutsch 1963, Duncan 1980, Kantowitz 1974, Keene and Neill 1978, Marcel 1983, Mewhort et al. 1984, Neill 1989, Norman 1968, Posner 1982, Schneider and Shiffrin 1977, Shaffer and LaBerge 1979, Tipper 1985, Tipper and Driver 1988, Allport, Tipper, and Chmiel 1985).

The empirical evidence that has been put forward to support (or to disconfirm) these apparently mutually exclusive sets of hypotheses has been extensively reviewed (see, for example, Allport 1980b, Kahneim and Treisman 1984, Keene and Neill 1978, Johnston and Dark 1986). These empirical arguments are not recapitulated here. We are concerned for the moment with the underlying assumptions that, to some degree, have been common to both positions. The fact that, after a quarter-century of energetic experimental research, the controversy, in these terms, over early versus late selection appears still not to have been empirically resolved (or at least that theoretical consensus has not been achieved) suggests that the conceptual framework within which this issue has been formulated requires further critical attention (Allport 1987, Lambert, Beard, and Thompson 1988, Neumann 1987, Posner and Badgio 1988, van der Heijden 1987).

One important set of assumptions underlying this debate concerns what is supposedly early and what is supposedly late in cognitive processing, including assumptions, implicit or explicit, about a presumed, monotonic ordering of stages of processing. Early selection, according to its conventional characterization, depends solely on the coding of physical, sensory attributes and operates primarily or even exclusively in terms of spatial location—hence the popular metaphor of a spatial spotlight of attention. Late selection, according to the same theoretical dichotomy, operates in terms of category membership. An assumption evidently built in to these theoretical alternatives is that the encoding of spatial location and spatial relationships is computed (uniquely?) as an early stage in a some monotonic hierarchy of stages of visual processing, and that the encoding of categorical identity, or of other "semantic" attributes, occurs (uniquely?) at a later stage of processing—either in cascade, following the stage of spatial/sensory encoding, or only after the earlier stage has been completed. Hence, according to this theoretical dichotomy, any operation—in particular any selective operation—contingent on spatial/sensory properties or relations is attributed (by definition) to an early stage of processing; any (selective) operation contingent on categorical or other semantic criteria is attributed (by definition) to a late stage of processing.

This set of assumptions appears extraordinarily difficult to reconcile with current neuropsychological evidence concerning the functional architecture of spatial and categorical coding in the brain. This evidence reveals a very high level of parallel modular specialization of perceptual and cognitive function (see section 16.3). In particular there is compelling evidence of the specialization of functionally and neuroanatomically separable, parallel systems concerned, respectively, with computing aspects of categorical identity ("What?") and with the computation of spatial relationships ("Where?") (see, for example, Ellis and Young 1988, Levine, Warach, and Farah 1985, Newcombe, Ratcliff, and Damasio 1987, Ungerleider and Mishkin 1982). Furthermore it is evident that the encoding of spatial location and spatial relations in terms of retinotopic and other head- and body-centered coordinates, as well as in terms of environmental relationships, is computationally highly complex (Feldman 1985, Hinton and Parsons 1988, Jeannerod 1987, Zipper 1986). Representation in terms of explicit visual-spatial location can be found from the earliest stages of visual coding through to very late levels of cognitive and even motor processing (see, for example, Goldberg and Segraves 1987, Rolls 1981, 1987). Indeed processes sometimes attributed to early selection may actually take place only after the independent processing of figural identity and relative location, namely in the inte-
Another critical assumption concerns what is meant by selection. In the terms in which much of the controversy over early versus late selection has been conducted, the level at which selection operates has been treated, equivalently, as the level beyond which the processing of "nonselected" (or "rejected") information is (must be?) foreclosed. Clearly if selection is supposed to take place in order to protect a mechanism of limited capacity, it is natural to assume—to take for granted—that selection necessarily means selective (that is, exclusive) processing. Thus, according to this presumed equivalence, when task instructions to attend to (that is, to respond to or remember) X and to ignore Y are executed with little or no interference (or facilitation) from the presence of Y, especially when Y is semantically related to X, this is liable to be interpreted as evidence ipso facto that Y was excluded from "further processing" of the kind provided by the limited capacity mechanism.

It is often claimed, for example, that in selective report tasks selection is based on sensory attributes, and/or by spatial location, is easier and more efficient than selection based on semantic criteria (Broadbent 1970). Kahneman and Treisman (1984), among others, have suggested that this empirical generalization provides possibly the strongest evidence available in favor of filter theory, or early selection, and hence, they argued, as contrary to late selection: that is, contrary to the "strong automaticity" of stimulus categorization.

In evaluating this conclusion, however, it is important to maintain a distinction between what may be called selective cueing—that is, the process (or processes) by which task-relevant information is marked out, or designated, on the basis of some selection cue, for control of a given response—and questions of selective processing. The efficiency of selective cueing is appropriately indexed, for example, by the presence or absence of response interference resulting from the presentation of task-irrelevant distractors (see, for example, Franzolin and Egold 1980, Kahneman and Treisman 1984). Efficient selective cueing, however, defined in terms of the effective designation (and segregation) of information for the control of a particular action, carries no necessary implications about the level of processing or nonprocessing of the information that has not been thus designated, and still less, any implications about the level or domain of processing in which capacity is limited. These questions are, in this respect, logically independent. Even if selective cueing based on spatial location (in the "Where?" system) can be shown to be specially effective, or to be distinctive in other ways, this finding would still leave wide open the question of whether perceptual-semantic categorization—computed by the functionally separable "What?" system—is or is not also selective: that is, dependent or not on the spatial direction of attention. And it would
cases be added to the first and be successfully performed concurrently; hence the limitation on transmission rate of the first task could not have been set by some global, task-independent capacity limit in simple informational terms (see, for example, Allport, Antonis, and Reynolds 1972, Spelke, Hirsh, and Neisser 1976). Even more problematic for the idea of an overall global limit on information processing in these terms as the basis for “attentional” limits to human performance is the fact that not all such task-combinations are equally successful or equally possible, despite the use of separate sensory modalities and separate effectors for each pair of tasks. A paradigmatic example was provided by Shaffer (1975), who showed that visually controlled copy-typing can be combined successfully with auditory-vocal shadowing of continuous speech; however, recombining the same types of input and output in reading aloud and audio-typing turns out, even for a highly skilled audio-typist, to be essentially impossible to perform concurrently. This is in spite of identical total amounts of preview and of sequential redundancy in these two different combinations (contra Broadbent 1958).

In this combination of tasks the auditory test provides an optimally compatible specification for the required, vocal output, whereas typing (or writing) is specified most compatibly by the visual test. In this example and in others like it (see, for example, Allport et al. 1972, Hatano, Miyake, and Binks 1977, Spelke, Hirsh, and Neisser 1976), it is clear that the brain is able to maintain independent representations of two or more complex and continuously changing messages, in parallel, with minimal crosstalk between them, in the control of separate categories of encoding and action. Representational capacity in the message system or systems, therefore, does not appear to be the primary limiting factor. In contrast when the identical input and output messages are recombined, in the task of simultaneously reading aloud from one (visual) text while typing another text to (auditory) dictation, there is massive crosstalk interference—that is, the channel separation between the two processing streams breaks down—and performance on one (or both) of the individual tasks collapses (Shaffer 1975, Tierny 1973).

Related (though less catastrophic) costs of controlling crosstalk interference can be seen in a wide variety of Stroop-like selective-response tasks, where (again) asymmetries in the direction of interference appear to reflect corresponding asymmetries in the relative compatibility of “wanted” and “unwanted” information sources (“targets” versus “distractors”) vis-à-vis the representational domain required for execution of the task (see, for example, Beller 1975, Flowers, Warren, and Polanskey 1979, Glaser and Glaser 1982, Greenwald 1975, 1977, McClain 1983, Virali and Egeth 1985). For example, explicit semantic categorization appears to be cued more directly or compatibly by pictures of objects than by their written names, whereas oral naming is specified more compatibly by a written word than by a corresponding picture (see, for example, Rosch 1975, Seymour 1979). Suppose that a written word is presented, superimposed on the line drawing of an object. The subject can be instructed to respond selectively either to the word or to the pictured object. Glaser and Dangelhofer (1984) found that in a word- or picture-naming task, incongruent but related words interfered with the naming of pictures, but not vice versa; in a semantic categorisation task, on the contrary, incongruent pictures interfered with the response to words, but not vice versa.

Accounts of these asymmetrical effects in terms of a simple time-of-arrival hypothesis can be rejected (see, for example, Neumann 1980, Glaser and Glaser 1982, Glaser and Dangelhofer 1984). The pattern of results in this and many other selective-response tasks can be summarised as follows: (1) When the designated target stimulus provides relatively the most compatible information source available for encoding into the representational domain (semantic category, color, name, relative location, and the like) needed for execution of the task, then minimal or zero interference from other, less compatible information sources is observed. (2) In contrast when the to-be-ignored distractor information provides an equally, or even more compatible, specification (information source) for encoding into the required domain of representation than does the task-designated target information, interference—that is, delay in response, overt crosstalk error, or both—is liable to occur. (3) The extent of interference will then depend further on the availability of other (for example, spatial) cues, enabling effective segregation of target and nontarget information.

The heterogeneous nature of attentional limitations, as illustrated in these examples, and the evident failure to identify, consensually, one unique functional locus for a “processing bottleneck,” as implied by Broadbent’s theory, motivated two important modifications in the concept of limited capacity.”

**Automatic and Controlled Processes**

One modification, advocated, for example, by Shiffrin and Schneider (1977; Shiffrin and Schneider 1977), involved drawing a distinction between what may be called the message system—all those mechanisms responsible directly for information transmission in perceptual-motor tasks—and a control system that operates on the message system. In Broadbent’s (1971) theory it was evidently the message system that was critically limited in capacity. For Shiffrin and Schneider, in contrast, capacity limitations were essentially a property of the control system, where control was conceptualized as some sort of unitary resource of fixed, limited capacity. Shiffrin and Schneider further assumed that all attentional selectivity and all forms of distractor interference resulted from competition for (and capture of) the same limited control (or the same controller). According to this
view, mental processing can be characterized either on the one hand as
automatic, that is, not requiring “active control or attention by the sub-
ject” and hence (so the theory asserts) capable of running concurrently
without interference—without capacity limitations—or on the other
hand as nonautomatic or controlled and hence ex hypothesiis tightly ca-
pacity limited and generally serial in operation, consequently subject to
severe concurrency costs (Shiffrin and Schneider 1977, pp. 155–170).

This dichotomy has been devastatingly criticized by Ryan (1983),
specifically as applied to the item-recognition task that Shiffrin and
Schneider employed. Virtually every defining attribute of these con-
trasted operations (automaticity/control), Ryan showed, was violated
by existing item-recognition data. In particular he presented evidence
that more than one supposedly controlled process, according to Shiffrin
and Schneider’s criteria, can run concurrently, without mutual interfer-
ence. In the end, Ryan argued, we are left with just one defining
attribute of this dichotomy: controlled processes are load dependent (in
the item-recognition task), automatic processes are not. “Because all the
other defining attributes fail to distinguish between the operation,”
Ryan concluded, “one is forced into the conclusion that the net theo-
retical gain . . . is simply a relabeling of old phenomena. There is no
new and independent theory at all; we are left with trivial redescription
of the fact that ensemble size is sometimes an important variable in
human performance” (Ryan 1983, p. 177). In an important series of
experiments Logan (1978a,b, 1979, 1980) showed also that ensemble
size effects, as indicators of automaticity/control, can be independent
of other measures (concurrent memory-load effects, probe reaction-
time) put forward also as indicators of capacity demands.

In the meantime the attempt to apply the same dichotomy (automatic/
controlled) to the whole range of dual-task concurrency costs appears
to have been, for most practical purposes, abandoned. The enormous
empirical diversity of effects, varying apparently with the particular
combinations of tasks rather than with any supposedly intrinsic charac-
teristics (automatic? controlled?) of the tasks individually, has made it
profoundly implausible that any single-factor resource limitation might
be able to accommodate them (For reviews see, for example, Gopher
and Sanders 1984, Gopher, Brickman, and Neumann 1982, Heuer and Wing
concept of automaticity, see Neumann 1984.)

Nevertheless the shift of emphasis toward issues of task preparation
and attentional control, inspired by the work of Logan (1978a), Posner
(1978), Shiffrin and Schneider (1977) and others at around this time,
and away from the earlier focus on the idea of informational limitations
in the message system, was important. It still apparently awaited a clear
recognition, however, that the limited capacity (in a loose, descriptive
sense) of attentional control was what had to be explained, rather than
an explanation.

Multiple Resources  The principal alternative approach for advocates
of capacity or resource limitations as the explanatory basis of attentional
limitations has been to postulate a variety of different specific resources,
viewed as multiple, intervening variables, though sometimes retaining a non-
specific general resource as well (see, for example, Wickens 1980, 1984,
Gopher and Sanders 1984). In their present form at least these ap-
proaches appear subject to two complementary and discouraging weak-
nesses. On the one hand no existing formulation of multiple resource
theory is able to account for anything like the existing range of data
from dual-task experiments. (For critical reviews of this literature, see
Navon 1984, Neumann 1985, 1987.) On the other hand, to the extent
that more and more specific resources are postulated to account for
each new pattern of interference, the approach becomes increasingly
little more than a redescription of the data, lacking in explanatory
power.

Heuer (1985a) has pointed out the fundamental similarity between
capacity models and factor-analytic models of human performance
scores (Spearman 1927), with which they share a number of formal
weaknesses, whether as general-factor or as multifactor models (For-
mally both approaches offer explanations of global performance-mea-
sures in terms of hypothetial variables that have linear or monotonic
relations to performance.) In terms of their formal correspondence, it is
clear that the concept of multiple resources in general, like multiple
factors in factor-analytic models, cannot be falsified, since it can be
fitted in principle to any set of data. What is fundamentally needed,
however, if the metaphor of multiple, limited resources is to have any
genuine, explanatory force, is a computational theory of why and in
what way certain specifiable functions (or separable subsystems) in
the brain are capacity limited, in the sense that multiple-resource theory
requires, whereas other computational functions are apparently not lim-
ited in the same way.

Navon (1984, 1985) has provided an extended and forceful critique of
the whole concept of limited “resources,” or limited processing capacity,
arguing that this concept, albeit intuitively appealing, in practice fails
to offer predictions that are either diagnostic or indeed falsifiable. The
concept is therefore, Navon has argued, a theoretical “soup stone,”
excess theoretical baggage, liable if anything only to distract attention
from the real need for explanation.

Identifying Specific, Limited Resources  The identification of postu-
lated specific resource limitations with specific, functionally separable
subsystems, whose ontological status is inferred from quite different
experimental paradigms—for example, from the evidence of “doubly
dissociated” functional impairments in cognitive neuropsychology (see,
for example, Shullice, McLeod, and Lewis 1983)—may provide some
constraint on the ad hoc multiplication of resources. Such identification
is extraordinarily difficult to establish, however, and can remain a matter of belief, somewhat as in the labeling of factors in factor-analytic approaches.

A number of computationally rather more specific hypotheses has been put forward, regarding different possible forms of perceptual (specifically visual) capacity limitations dependent on different forms of combinatorial constraint (see, for example, Bergen and Julesz 1983, Treisman and Gelade 1980, Treisman 1986, 1988, Ullman 1984). For a contrasting, connectionist approach, see, for example, Mozer 1988).

Treisman's theory, for example, proposes that although individual visual features are encoded spatially in parallel over the visual field, conjunctions of visual features can only be securely and accurately encoded in a strictly serial manner, one conjunction at a time. The scope of this hypothesis, however, like that of Bergen and Julesz, is quite specifically confined to the processing of visual stimuli. Clearly such hypotheses are not able to offer any definite predictions about nor provide explanations for the limits of dual-task performance, nor any other supposedly "attentional" issues not directly concerned with visual feature encoding. This is certainly in itself no criticism of such theories; far from it. It is important to recognize, however, insofar as these theories may successfully identify one type of attention limitation—they are certainly explicitly presented as theories of "attention"—that other theories are still required to account for other kinds of attentional constraint.

This is clearly an important possibility: that different functions of attention owe their origin to quite different computational constraints. Certainly there is no a priori reason to suppose that all of the phenomena attributed, in ordinary language, to "attention" have a common explanation nor (still less) that they derive from a single structural bottleneck, as the either-or controversy over early versus late selection appears implicitly to have assumed.

16.3 Neuropsychology of Spatial Attention

Section 16.3 introduces a somewhat different, neurobehavioral perspective on attentional functions, with emphasis on the functions of spatial attention. This section includes a summary overview of neuropsychological data, illustrating the distributed, modular character of cognitive functions, including specifically attentional functions. There follows a brief review of neuropsychological disorders of spatial attention and spatial neglect. Traditionally in the cognitive psychology of attention, studies of the often very dramatic pathologies of spatial attention have played surprisingly little part in either the development or evaluation of attentional theories. Nevertheless, as I try to show, the characterization of these disturbances of spatial attention carries a number of radical implications for the characterization of normal attentional functions. Finally, and closely related to this characterization, the section concludes with a short summary of neurophysiological evidence on the modulation of neuronal activity in spatiotopic coding systems, as a function of spatially directed attention.

Neuropsychological Architecture: Distributed Modular Function

Neuropsychological and neuropsychological data reveal a multiplicity of parallel channels and of quasi-modular cognitive subsystems, specialized for different elementary cognitive operations (see, for example, Coltheart 1985, Creutzfeldt 1985, Ellis and Young 1988, Goldman-Rakic 1988, Posner, Petersen, Fox, and Raichle 1988). This distributed multi-channel organization is found not only in perceptual (Bailow 1986) and motor systems (Wise and Evarts 1981) and in perceptual-motor interaction (see, for example, Ashby 1987, Creutzfeldt 1985, Dean 1988) but also in language and other higher cognitive functions (see, for example, Allport, Mackay, Prinz, and Scheerer 1987, Caramazza 1988, Ellis and Young 1988, Petersen, Fox, Posner, Mistant, and Raichle 1988, Shullice 1987). Connectivity between individual subsystems, although very rich and generally reciprocal, is also highly selective. Moreover although some hierarchical relationships between subsystems can be pointed to, particularly within sensory and motor areas, the evidence points to a very large measure of parallelism and of hierarchical (or reciprocal) control. No one subsystem, it appears, could be characterized as uniquely "central."

Similar principles of organization are also evident in attentional functions. Thus different aspects of attentional set and executive control can be disturbed selectively by different patterns of frontal injury (Duncan 1986, Elingael and Damasio 1985, Luria 1966). Using imaging techniques that enable the measurement of local changes in metabolism and regional cerebral blood flow (rCBF) in active humans, Roland and his colleagues have been able to identify a number of different regions of human prefrontal cortex that are activated selectively during different aspects of attentional task preparation and execution (Puster 1985, Ingvar 1983, Roland 1982, 1985, Roland and Friberg 1985). One of these regions, for example, becomes selectively activated during preparation for Stroop-like selective-response tasks, whereas a different, adjacent region appears to be involved in contingent (if-then) sequencing of cognitive operations. Using similar techniques, Posner and colleagues (1988) obtained evidence that a region of anterior cingulate cortex, on the medial surface of frontal lobe, is activated specifically in the process of target detection in semantic monitoring tasks. However, semantic processing or categorization per se, does not appear to engage either of these anterior attentional systems.

Other subsystems, forming a complex distributed network of cortical and subcortical components, appear to be responsible for the spatial direction of attention. The relevant subsystems include posterior parietal cortex, frontal eye fields, posterior cingulate cortex, various thal-
Disturbances of Spatial Attention: Varieties of Spatial Neglect

Disturbances of spatial attention, following injury to different elements of this network and resulting in spatially selective (for example, unilateral) neglect, may affect either just one sensory modality or many (see, for example, Chedru 1976, DeRenzi, Gentili, and Pattacini 1984). In severe, multimodal cases of lateral neglect, the patient appears behaviorally unaware of (or unresponsive to) the presence of objects or events on the neglected side, behaving as though that part of his or her world has effectively ceased to exist. In some patients the symptoms of unilateral neglect may be confined only to distant objects in extrapersonal space; in other patients they may be restricted to their own limbs and body surface (Bisiach, Perani, Valler, and Berli 1986). There are also experimental demonstrations in monkeys of unilateral neglect confined to visual objects in near peripersonal, or bitting, space, with normal attention to distant visual objects, and vice versa (Rizzolatti, Gentili, and Matelli 1985).

The side or direction of space showing neglect, and so-called extinction under double simultaneous stimulation (DSS), may be defined in terms of a variety of different spatial coordinates: body-centered, gravitational, possibly retinal, and also in terms of external-object-centered coordinates. Thus, for example, left neglect typically affects the left side of individual objects and of perceptual groups of objects, though side of object and side of body-space can interact (Bisiach, Capitani, and Porta 1985, Calvano, Petrone, and Levine 1987, Gazzaniga and Ladavas 1987, Heilman and Valenstein 1979, Jeannerod and Biguenet 1986, Kinsbourne 1977, 1987, Rapcsak, Watson, and Heilman 1987). In some patients symptoms of lateral neglect appear to depend on the side of space (relative to the body midline) to which visual attention is directed; in other patients, on the contrary, what matters appears to be the side of the body on which a manual action is to be performed, independent of the direction of gaze (Coslett, Bowers, Fitzpatrick, Hans, and Heilman 1986. See also Jeannette, Brouchon, Gauthier, and Samson 1986 for an example of an interaction between unilateral visual neglect, in a target-detection task, and the hand used to indicate target detection.)

There is also evidence suggesting that unilateral neglect can be specific to the orthographic domain, doubly dissociated from neglect affecting nonlinguistic visual space (Bisiach, Merigan, and Berti 1985, Costello and Warrington 1987, Ellis, Plude, and Young 1987).

The neuropsychological evidence thus indicates extensive specialization of different subsystems and different aspects of spatial attention. Across these different spatial domains, however, the character of the attentional disturbance appears uniformly as a directional bias, orienting spatial attention away from the neglected side and toward the ipsilateral side (Kinsbourne 1979, 1977, Jeannerod and Biguenet 1987). Several features of this characterization deserve emphasis:

Relation to Premotor Organization Rizzolatti and his colleagues have provided a range of evidence, in monkeys as well as in humans, that indicates a close relationship between spatially or directionally specific impairments in prefrontal control of particular (for example, oculomotor, buccal) effector systems and corresponding disturbances of visual-spatial attention, favoring a "premotor" theory of spatial attention (Matelli, Olivieri, Saccani, and Rizzolatti 1983, Rizzolatti, Matelli, and Pavesi 1983, Rizzolatti, Riggio, Dascola, and Umita 1987). It is also known that covert orienting of visual attention, facilitating behavioral response to stimuli in the attended location (Posner 1980, Posner et al. 1987), is greatly enhanced in normal subjects by premotor eye-movement preparation toward the cued location (Remington 1980, Shepherd, Findlay, and Hockey 1986) and can be antagonized by the voluntary preparation for or peripheral cueing of a sacade in another direction (Maylor 1985, Müller and Rabbitt 1986, Shepherd et al. 1986).

Object-Based Perceptual Representation The observation that lateral neglect and extinction characteristically affects whole objects or coherent subparts of complex objects and groups of objects implies that hierarchial, object-based, structural representations of the presented array have been formed independently of the impaired operations of spatial attention, and that the disordered attention then operates on such a representation. Volpe, LeDoux, and Gazzaniga (1979) reported a pioneering study related to this issue; more recent explorations have been reported by Sano and Michel (1987) and Sano, Polsinskie, and Posner (1987). Clearly these and related phenomena invite extensive and systematic further research.

Directional Bias Posner and his associates (Posner 1980, Posner et al. 1987, Rafal et al. 1988) have identified the underlying deficits in spatial
neglect associated with different neuroanatomical lesion sites, with directional impairments in at least three functionally separable components of spatial orienting: disengagement, shifting, and reengagement. The directional bias favoring stimuli in the (relative) ipsilesional direction and producing dramatic distortions of perceptual space, can be enhanced or diminished by appropriate spatial cuing (Riddoch and Humphreys 1983) and by unilateral vestibular stimulation (Rubens 1985; see also Jeannerod and Biguen 1987). Similar though less extreme lateral biases can be induced in normal subjects, with tachistoscopic presentation in either left or right visual fields (Reuter-Lorenz, Moscovitch, and Kinsbourne 1986). Notice that an interpretation of spatial neglect as a form of pathological orienting-bias differs radically from one that postulates merely the absence of perceptual processing resources in respect to some part of perceptual space.

Spatial Attention Beyond Sensory Feature Integration Henriksen and Gelade 1980 has proposed that spatial attention is closely involved in visual feature integration, operating over separate (retinotopic) feature maps. Given that unilateral neglect effects nonvisual sensory aspects of spatial attention that are disturbed in pathological neglect are independent of low-level, sensory feature integration. This conclusion leaves open whether some other function of spatial attention is involved in or necessary for sensory feature integration. The important point is that there are major functions of spatial attention, subject to the disturbances in variety of spatial neglect, which appear to be entirely separable from processes of visual feature integration.

Attentional Modulation of Neuronal Activity

Over the last decade or more, single-unit recording in monkeys engaged in spatially selective attentional tasks has revealed a consistent pattern of spatially selective enhancement of response, in neurons sensitive to visual stimulation in the attended region. The effect has been observed in each of the principal brain areas known to be involved directly or indirectly in visual attention (for example, auditory or motor and postural spatial orienting or covert spatial attention), and in which lesions typically evoke symptoms of spatial inattention or neglect. This phenomenon is referred to as the spatially selective enhancement effect (SSEE). Several excellent reviews of the SSEE are available, including Bushnell, Goldberg, and Robinson 1981, Goldberg and Bruce 1985, Robinson and Peterson 1986, and Wurtz, Goldberg, and Robinson 1980.

No evidence of the SSEE has been found in visual area V1. In some systems, including superior colliculus and frontal eye fields, the SSEE appears linked to the preparation of eye movements; in others, particu-

ularly in posterior parietal cortex, the SSEE is observed whenever the animal maintains conditional readiness to respond to a given visual location, independent of the modality, or spatial direction, of the intended response. It is suggested that this spatially selective enhancement (increased gain) of visual response provides a mechanism of (spatially selective) priority assignment for the potential control of action, which is fundamental to the operation of spatial attention. Within these same spatiotopic coding systems there is no evidence of a complementary process of selective suppression or inhibition affecting nonselected locations. That is, spatial selectivity (in the "Where?" systems) appears to be implemented through a process of priority assignment rather than through suppression or attenuation of nonselected locations.

There is, however, a very different sort of suppression effect that has been found to follow the engagement of visuospatial attention, namely, the sharply reduced responsiveness of lower-level oculomotor systems to visual or other sources of potential command (Fischer 1986, Goldberg, Bushnell, and Bruce 1986, Goldberg and Segawa 1987). Spatial attentional selectivity in this respect evidently acts to suppress extraneous actions, not to attenuate the quality of sensory input.

16.4 Toward a Computational Theory of Attention

The data summarized in the preceding section offer a rather different perspective on attentional functions than that provided by the traditional orientation (section 16.2) dominated by issues of central limited capacity and of early versus late selection. The neuropsychological and neuropsychological data point to a multiplicity of attentional functions, dependent on a multiplicity of specialized subsystems. No one of these subsystems appears uniquely "central." I have noted also evidence for a significant interdependence between the orienting of spatial attention and the preparation of action. Within systems responsible for the spatial direction of attention, moreover, there appears singularly little indication of selectivity of encoding or representation (limited processing capacity) but clear indication of a process of prioritization (selective enhancement). What is this priority for? These and other unresolved issues, outlined in section 16.2, suggest that our conceptualization of attentional functions—their purposes and constraints—deserves more thorough reappraisal.

Traditional proponents of late selection (as characterized in section 16.2) were faced with an obvious difficulty. If the selectivity of attention was not imposed by capacity limitations (combinatorial constraints and the like) in perceptual-semantic encoding, then why should attention be limited—or selective—at all? This was the basis of the a priori objection to late selection put forward by Broadbent (1971), which was quoted earlier. In some cases this question has simply not been addressed. Thus "late selection" appeared sometimes simply as a variant of the
original limited-capacity hypothesis, but with the postulated capacity limitation attributed to a later, postsemantic stage of processing. This is to represent attention and attentional selectivity, however, as no more than the consequence of some ultimately arbitrary system limitation ("if the brain had infinite capacity for information processing, there would be little need for attentional mechanisms.")

An alternative approach, advocated here, is to assume that attentional functions have evolved to satisfy a range of positive, biological (or "computational") purposes. Section 16.4 is therefore an attempt to outline what some of these purposes might be and to identify some of the fundamental constraints, both external and internal, that determine them. I focus initially on certain essential attentional functions involved in the perceptual (specifically here, visual) control of action. Later the discussion is widened to outline a more general theoretical framework for the functions of attention.

**Attentional Selectivity as Selection-for-Action**

Many authors have suggested that the selectivity of attention is in some way related to or dependent on the need for coherent control of action (for example, Allport 1980a, b, Keefe and Neill 1978, Marcel 1980, 1983; Neill 1989, Neumann 1987, Posner 1978, Shahide 1972, 1978). How precisely, should this relationship be defined?

Any goal-directed action requires the specification of a unique set of (time-varying) parameters for its execution—parameters that determine the outcome as this particular action rather than any other: as this particular vocalic or manual gesture, this particular directional saccade, and so forth. Consider now what is required if these parameters are to be controlled by sensory (say, visual) information.

Suppose that visual information has to guide manual reaching, for example, to grasp a stationary object or to catch a moving one. Clearly, many different objects may be present in the visual field, yet information specific to just one of these objects must uniquely determine the spatial/ temporal coordinates of the end-point of the reach, the orientation and opening of the hand, and so on. Information about the positions, sizes, and the like of the other objects within view and also available, must not be allowed to interfere with (that is, to produce crosstalk affecting) these parameters—though they may need to influence the trajectory of the reach in other ways. Consequently some selective process is necessary to map just those aspects of the visual array, specific to the target object, selectively onto appropriate control parameters of the action. I have termed this the functional requirement of selection-for-action (Allport 1987, Allport, Tipper, and Chmiel 1985; see also Neumann 1987). A similar problem is apparent, for example, in the classic task of selectively shadowing (continuously repeating) one of two concurrent speech messages. Only one vocal output sequence is possible at a time.

The computational problem is therefore how to avoid crosstalk interference (or even fusion) in designating one auditory input stream to have unique control of the parameters of vocal response. The problem arises independently of any a priori limitation of central processing capacity, from the concrete requirements of coherent and univocal control of action.

The necessary control of action of course includes decisions not to perform a given action. The sensory input is clearly able to govern decision processes affecting action at many different levels, including decisions about what category of action and whether (as well as when) it is appropriate to release it. Selection among competing sources of control parameters in the sensory input is equally essential for the coherence of action preparation, or action planning, even though no overt action is in fact released or is released only at a later time— including, for example, in later so-called "perceptual reports." The attentional selectivity with which we are concerned is therefore selection for potential control of action.

**Coordination, Segregation**

It is important to recognize that perceptual selection, in the sense of selection-for-action, does not necessarily imply a binary partitioning—a dichotomizing—of information into "selected" and "unselected." Not infrequently, separate concurrently available information sources, sometimes in different spatial locations (or in different modalities), have to be selected for control of different parameters of action at the same time. This can be demonstrated, for example, when subjects are engaged in concurrent, quasi-independent perceptual-motor tasks, such as those described in section 16.2. It is also, and much more commonly, seen when two or more different categories of action are actively coordinated, each under visual control. Every goal-directed action has a range of conditions needed for its successful execution. When the conditions for two or more intended actions conflict, then one or both must be modified sufficiently to enable their continued execution. Failing that, one activity must be given priority while the other is postponed or abandoned.

Take the example of catching a ball while running, perhaps over uneven ground. In this example visual parameters of the approaching ball—time-to-contact (von Holsten 1987)—must selectively control spatiotemporal parameters of the catching action. At the same time visible features of the terrain have to be characterized as providing suitable footholds. Generally more than one potential footing or "stepping stone" is visible at a time; each one affords a different, time-varying value of the control variables needed to modulate aspects of the running action (for example, vertical thrust) so that each individual stride is targeted selectively to land on a specific stepping stone (Warren, Young, and Lee 1986). Clearly, complex coordination between these two constituent
activities is needed. Equally clearly, when such coordination is successful, spatially distinct, nonoverlapping sources of information must each be the focus of separate and concurrent processes of visual selection-for-action.

Another important requirement in quasi-independent, concurrent tasks is to keep the streams of information appropriately segregated so as to avoid unwanted crosstalk between them. Limitations in the performance of many concurrent task-combinations can be understood as limitations in the ability to segment and to keep separate different processing streams (Allport 1980a,b, 1987, Kirsbourne and Hicks 1978, Navon 1985, Neumann 1987). Some of the evidence favoring this interpretation was referred to briefly in section 16.2

Visual-Spatial Segmentation and Selection-for-Action

The visual information source that is selected to control a particular set of action parameters may be, spatially and temporally, sharply localized, such as a ball to be caught, possibly one approaching ball among several, or it may be comparatively global, such as an optic flow field, the separation between two physical objects defining a passable or impassable gap, and so on (Lee and Young 1985, Warren and Whang 1987). For effective visual-motor control therefore visual selection-for-action must be capable of being focused selectively on any one coherent source of visual information (potential control parameters), however that information might be spatially distributed in the visual array. Very often the appropriate source of control parameters can be characterized as a separable visual "object"—that is, an entity that can be individually named, categorized, avoided, or otherwise independently acted on. (In this sense of the word, for example, a visible "gap," passable or otherwise, can undoubtedly count as a potentially separable, visual object.) This constraint implies that (possibly very complex) processes of perceptual grouping and segmentation may have logically to precede the effective focusing of visual selection-for-action.

The segmentation problem is well illustrated in the case of visual selection among one of two (or more) spatially superimposed, outline or moving forms (Rock and Gutman 1981, Neisser and Becklen 1975, Allport, Tipper, and Chmiel 1985). The selective process appears to operate extremely effectively in these conditions, both in phenomenal as well as behavioral terms. It seems clear, however, that shifting or zooming of a notional "attentional spotlight," operating simply in two- or three-dimensional spatial coordinates (Posner 1980, Downing and Pinker 1985, Johnston and Dark 1986), would not be theoretically adequate to account for this kind of visual object-selection.

Many factors are known to influence perceptual segmentation. It is therefore to be expected that these factors will interact very powerfully with the efficiency of attentional selection (Driver and Baylis 1989, Duncan 1984, Kahneman and Henik 1981, Kahneman and Treisman 1984, Pinnemetal 1981, Treisman 1988). Evidence from the pathology of spatial attention (section 16.3) suggests that perceptual segmentation, guided top down by object-specific (for example, lexical) knowledge, occurs independently of—that is, logically prior to—the impaired attentional process (see, for example, Steeoff, Pollatsek, and Pooner 1987)

A Conceptual Framework for Functions of Attention

So far in this discussion I have concentrated on the logic of attentional selectivity in the visual control of action, independently of any possible a priori limitations of processing capacity. Processes of selection-for-action are needed furthermore whether the intended source of control parameters is visual or auditory, internal or external, perceptual or imaginative—that is, wherever alternative, potentially competing information sources are available for the same control variables.

It may be useful at this stage, however, to widen the context of discussion to consider briefly the outlines of a more general computational theory of attention, within which these functions of selection-for-action are largely instrumental. We therefore return once more to the foundational questions with which we began: What is the overall purpose (or what are the overall purposes) of attentional systems, and what are their determining and enabling constraints?

Multiple Constraints

The following basic ecological constraints impose a number of strong requirements on any attentional motivational system.

- Unpredictability and time constraint: First, we are concerned with systems that have to operate in an environment that is, at best, only partly or incompletely predictable. Furthermore it is an environment that can change at any moment extremely rapidly, in ways that may be of critical importance for the organism. If appropriate action is not taken at once, there may be no second chance.

- Multiple goals: Second, we are concerned with systems with a very wide range of potential goals of action. Priority (importance, urgency) regarding the implementation of different goals must be continuously adjusted, moment by moment, as potential threats or opportunities arise in the environment and as internal conditions (blood-sugar, bladder-pressure, and so on) as well as cognitive variables (plans and subplans, "insights," and so on) change or develop. Priority assignment is necessary in that implementation (or protection) of one goal is frequently incompatible with the simultaneous implementation or protection of other concurrently valid goals and may also prejudice the subsequent satisfaction of these other competing goals.

- Multi-functional systems: Third, we are concerned with multi-functional organisms (humans and other species, natural or artificial). By this is meant organisms (or robots) whose subcomponents (sense organs, ef-
factors, cognitive subsystems) are not in general uniquely dedicated to particular goals or to particular categories of action. Subcomponents must therefore be selectively engaged and coordinated to implement particular activities and particular goals.

Behavioral Coherence The primary purpose of an attentional system must be to ensure the coherence of behavior under these often conflicting constraints. Coherent, goal-directed behavior requires processes of selective priority assignment and coordination at many different levels (motivational, cognitive, motor, sensory). Together this set of selective and coordinative processes can be said to make up the effective attentional engagement (or attentional set) of an organism at any moment. Processes responsible for establishing and maintaining coherent, attentional engagement must involve a number of (logically) separable elements, of which the following represent a minimal, abstractly specified, and certainly incomplete listing:

- selective priority assignment among competing (and cooperating) goals, in a complex, time-varying goal hierarchy, for control of immediate action;
- the engagement and coordination of specific cognitive subsystems to implement current goals;
- selective recruitment (preparation, tuning) of appropriate effectors;
- selective priority assignment among competing available information sources (including sensory information sources), for control of specific parameters of action (selection-for-action);
- selective recruitment (preparation, tuning) of appropriate mappings or transformations between different coding domains (see, for example, Hinton 1981).

Maintenance and Shifting of Attentional Engagement Many—indeed all—perceptually guided activities need time for their completion, that is, for their end-goal to be achieved. The appropriate attentional engagement (or set) has therefore to be maintained, or protected in some way during the course of that activity. On the other hand given the unpredictable (that is, incompletely predictable) and potentially dangerous environment that we have taken as one of our fundamental constraints, it is of course vital that such attentional engagement can be diverted or overridden by changing external— or internal—events.

The critical problem for any attentional system (in multifunctional organisms) is therefore how to satisfy two conflicting requirements: the need for continuity of attentional engagement, against the need for its interruptibility. Failure to shift attentional engagement when faced by environmental threats (or opportunities) can of course be fatal to an organism’s survival or physical integrity. At the other extreme constant shifting or fragmentation of attentional engagement, triggered by every sensory event of environmental affordance, would make sustained, purposeful activity impossible and result only in behavioral chaos. Between these two equally disastrous extremes lies a range of more or less viable solutions. All of them depend on some means of evaluating, or at least estimating, the relative motivational importance and temporal urgency of the potential threats and affordances outside the current attentional engagement, relative to the estimated importance and urgency of the current activity or activities. (Both variables—urgency and long-term importance—are needed and should presumably be able to trade off against one another.)

Humans (and other species) appear to have adopted a combination of several different partial solutions to this problem, which can be broadly grouped into three categories: (1) internally generated, predictive control of attention shifting, depending on a range of heuristic processes of widely varying levels of sophistication; (2) externally elicited shifts of attentional engagement, cued by the detection of more or less complex triggering conditions; and (3) active combinations of (1) and (2), as, for example, in many forms of exploration and search. I should therefore add, as a further indispensable attentional function, continuous (parallel) monitoring of the environment (internal as well as external) for changes relevant to current and long-term goals.

Environmental monitoring may be expected to operate at many different levels. These should include fast, relatively crude or approximate systems, operating on rule-of-thumb (that is, associative) criteria, both learned and unlearned, as well as possibly slower and more sophisticated systems, supported also by processes of (discontinuous) predictive search under goal-directed control. Detection of a critical external or internal event must be capable of causing temporary interruption or inhibition of the current attentional engagement and a (rapid) shift of sensory priority assignment (selection-for-action) toward the information source responsible for the interruption—in other words it must be capable of triggering attentional orienting. Equally important, sensory-motor orienting must be capable of being inhibited by the competing, higher priority of the current attentional engagement.

Computation of this critical balance of priorities appears to be one of the central problems for any system of intelligent attentional control.

Implications: Multiple Interacting Functions of Attention One thing that becomes clear—if it were not so already—is that there are many different functions of attention. A theory adequate to some spectacles attentional function or functions may well be quite unsuited to explaining others. Certainly to pursue a general “theory of attention”, without first specifying the computational functions that the theory is to account for, would appear to be a likely recipe for disaster. Equally clearly to try to survey the entire range of cognitive operations that can reasonably
be described as "attentional"—even if the writer were competent to do so—would be altogether beyond the scope of a single review chapter.

I now return to the mechanisms of visual-spatial selection-for-action. What the preceding discussion also makes clear is that the processes of visual-spatial selection-for-action are instrumental to a number of different, and in principle competing, attentional functions or purposes: (1) to implement (and to protect the coherence of) the current attentional engagement; (2) to enable endogenously controlled shifts of perceptual-motor engagement, directed by a variety of different cognitive ("intentional," heuristic) processes; and (3) to enable exogenously elicited, visual-spatial orienting, in particular orienting cues by (spatially compatible) visual events. These different types of control appear to be mediated by a number of functionally (and anatomically) separable—but also in part functionally overlapping—subsystems (Posner et al. 1987, Posner 1988).

**Implementation Principles: Parallel Distributed Processing**

There is one further source of constraint that may radically affect attentional processes in living organisms. This is that all cognitive processes have to be realized by means of massively parallel computations, in distributed neuronal networks (chapters 4 and 8, Feldman and Ballard 1982). We know very little at present about the possible restrictions, if any, that this imposes on attentional or other cognitive functions (Sejnowski 1986). One possible restriction, however, arises from the so-called binding problem: the problem of representing what goes with what—that is, of integrating or linking together appropriate subsets of microfeatures, belonging to one information source or one processing stream, without also creating inappropriate or "illusory" conjunctions among the same and other sets of microfeatures (see, for example, Hinton and Lang 1985, Hinton, McClelland, and Rumelhart 1986, Sejnowski 1986, von der Malsburg 1981, 1985). Put another way, it is the problem of structuring information processing in parallel networks, so as to segregate different subprocesses running concurrently and to avoid unwanted crosstalk between them. Some examples of possible attentional constraints, arising from the problem of restricting crosstalk between concurrent processes, were discussed in section 16.2.2.

A general theoretical framework for attentional control (attentional engagement) within a parallel interactive system was first outlined by Norman and Shallice (1980). Models of attentional engagement in massively parallel systems have been further developed, for example, by Phil (1990), and Schneider and Shiffrin (1977). In these models as in models of parallel interactive systems for more specialized domains (for example, Mozer 1988), executive control is exercised only indirectly, typically through a mechanism of competitive priority assignment. This idea—of indirect priority assignment, implemented through the selective modulation (potentiation, tuning, output inhibition, and so on) of units

**in specific coding pathways—is a recurrent feature of many different theoretical approaches to attention.** Neurophysiological evidence of such a process, in the spatial domain, was reviewed in section 16.3. Several students of attention, notably Posner and his associates (Neely 1977, Posner and Snyder 1975; see also Johnston and Dark 1986 and Neill 1989 for recent reviews) have proposed that attentional modulation and the many different phenomena of **priming** in general share common underlying mechanisms.

**16.5 Review**

**Experimental Paradigms of Selective Visual Response**

In this chapter I have contrasted two different conceptions of attention and attentional selectivity. The first of these depends on the idea of **limited capacity**, in various forms, as the causal origin of attentional phenomena. The second, contrasting set of assumptions focuses on the necessity of attentional engagement—in particular, in many perceptual-motor activities, the need for what I have called **selection-for-action**—as a condition of behavioral coherence in multifunctional organisms. According to this viewpoint, many phenomena of selective attention in perceptual-motor tasks can be seen to reflect competing processes concerned respectively with the maintenance and shifting of visual-spatial selection-for-action.

In this concluding section it may be worthwhile therefore to look briefly at some familiar experimental paradigms, the results of which have been taken to support assumptions of limited capacity (and of precathegorical, selective processing) and to outline some alternative interpretations. I reviewed in section 16.2 a variety of phenomena of concurrent (dual-task) performance, and Stroop-like interference effects in selective response tasks, accounts of which appeared not to require (and were not well suited to) a causal variable of limited capacity.

**Probe Reaction Times**

Reaction time to a secondary probe stimulus (probe RT) has often been presented as a method of assessing the momentary processing capacity demanded by a concurrent primary task. (See, for example, Posner 1970 and Poulton 1981 for reviews.) A well-known difficulty for this general interpretation is that the resulting estimates of capacity demand for the same primary task can vary dramatically, depending on the characteristics of the particular probe task that is used (for example, McLeod 1977, 1978, McLeod and Posner 1984). Equally troublesome, probe RT can also fail to reflect other independent measures of information load in the primary task (Logan 1978b). A different interpretation, following the theoretical orientation suggested here (that is, without appeal to ideas of limited processing capacity), is to think of variations in the latency of response to a probe stimulus in terms of the time costs of attentional disengagement from the primary
task and of restructuring of selection-for-action toward the probe (compare LaBerge 1973, Posner 1980, 1988). Where both the primary and the probe tasks share the same response modality or involve a crossover of coding domains (see "Variations on the Idea of Limited Capacity" in section 16.2; see also McLeod and Posner 1984, Virzi and Egget 1985), they are likely to potential crosstalk in the triggering of speeded responses. In this case the integrity of the primary task will need to be protected by a high level of selective attentional engagement in favor of the primary task, and orienting to the probe stimuli will be correspondingly inhibited. Selection-for-action should presumably be most strongly protected around or preceding the moment of speeded response decision in the primary task: disengagement from the primary task will therefore be particularly delayed during this phase (Posner and Boies 1971, Logan 1978b, McLeod and Posner 1984). In contrast when the combination of primary and probe tasks is such that the risk of crosstalk between them is small, there should not be the same need to protect engagement on the primary task; the S-R mappings for both tasks can be maintained in a state of preparedness, concurrently, and the time costs of orienting to the probe stimulus will therefore be minimal, even during the response phase of the primary task (McLeod 1977, McLeod and Posner 1984).

A broadly similar account can be offered in relation to the time costs of self-paced task alternation. Jersild (1927) and Spector and Biederman (1976) found that the time needed to shift between different tasks could vary from zero time costs to well over a second in some cases, depending on the extent to which the executive stimuli uniquely indicated the cognitive operations to be performed.

Overlapping Tasks. The systematic delay of response to the second of two executive stimuli (S1 and S2), in the closely related "overlapping tasks" or PRP paradigm (Bertelson 1966, Smith 1967, Kantowitz 1974, Paishley and Johnston 1989), may be interpretable similarly in terms of the time cost of attentional disengagement, orienting, and subsequent reengagement on S2. Evidence that the systematic increase in latency of response to S2 (in the absence of delay in response to S1) represents a genuine postponement of R2 "response selection," rather than a process of continuous "capacity sharing" (Paishley 1984, Paishley and Johnston 1989) would appear to be consistent with this interpretation.29 The elimination of this characteristic pattern of R2 delay, when both tasks are individually highly compatible (Greenwald and Shulman 1973), but otherwise dissimilar from one another (Beebees 1977) is of course strongly congenial to this account.

Delay in responding to S1, which is sometimes observed, may be related to specific patterns of interference between the programming and execution of different movements, including with different hands (for example, Heuer 1980b, 1986, 1987, Heuer and Wing 1984). Heuer's data and his model of "programming-interactions" have a bearing also on the results reported by Beebees (1977).

Priming. Categorical Encoding and Selective Response. In studies of selective response and selective monitoring tasks, certain stimuli (or stimulus attributes) in a visual array are designated by the experimenter as relevant to control a speeded response (targets) and others as irrelevant and to-be-ignored (distractors). In these paradigms there is exten- sive evidence that many other dimensions of relevance to the subject's current goals and interests (that is, relevant to "currently active schemata"), in addition to the experimenter's instructions, affect the efficiency of selection-for-action. Interference (omission or slowing of response) caused by the distractors can be greatly increased or decreased, depending on whether distractors or targets are "primed." Johnston and Dark (1986) summarized a range of such results in two empirical generalizations: (1) "All levels of stimulus analysis can be primed for particular stimuli," and (2) "Stimuli conforming to active schemata are easy to attend to, but difficult to ignore." (Or more generally, "Selective attention can be guided by active schemata.")

The results of many different categorization or visual-search experiments with categorically defined targets have been interpreted as showing parallel encoding in terms of semantic category membership (see, for example, Duncan 1980, 1988, Egget, Jonides, and Wall 1972, Egget, Folk and Mullin 1989, Fisk and Schneider 1983, Hoffmann 1987, Lambert et al. 1988, Schneider and Shiffrin 1977). With appropriate pretraining (consistent mapping), selective report performance can also be based effectively on alphanumeric category (Merrill 1980, Duncan 1983, Bundeiser et al. 1984) and on semantic word category (for example, "any animal": Allport 1977) The plausible claim that both sets of results in detection or categorization and in selective report tasks depend on selective priming of the specified target category (Johnston and Dark 1986, Kahneman and Treisman 1984) does not appear to conflict in any way with the assumption that multiple symbolic stimuli can be categorized semantically, in parallel, in respect of the primed category.

Hoffmann (1987) has recently reviewed a number of experimental demonstrations, using arrays of multiple pictured objects, indicating semantic modulation of priority assignment for the selective control of action, but based on nonelective semantic encoding. Evidence indicating not only parallel categorization but full symbolic identification, in parallel, has been presented by Paishley and Badgo (1985, 1988). Their evidence is based on a task designed to force exhaustive identification, namely, that of naming the highest digit in an array of digits. A variety of experimental manipulations yielded results that argue strongly for the parallel identification of multiple alphanumeric symbols. It is not easy to see how these results are to be reconciled with the hypothesis that conjunctions of alphanumeric features (as in Ps, Rs, and Qs) can
be correctly perceived only through serial focusing of attention on each item in turn (Treisman 1988).

When selective report is cued by an extrinsic spatial cue on the other hand, selective priority assignment—selective cueing—may operate directly on the spatiotopic visual domain (early selection). As van der Heijden (1987) has pointed out in a review of spatially cued, partial report tasks, evidence to this effect is perfectly consistent with evidence favoring “unlimited capacity” regarding stimulus identification, at least so far as alphanumerical symbols are concerned and within the limitations of visual acuity.

Spatial Selection and Interference. It is often claimed that the amount of interference caused by task-relevant (or semantically related) distractors varies inversely with the spatial separation of target and distractors in the visual array, and this observation has been taken to support the metaphor of a spatial “spotlight” of visual attention (for example, Broadbent 1982, Johnston and Dark 1980). The experiments most often cited in support of this empirical generalization, however, have confounded spatial separation with retinal eccentricity (see, for example, Eriksen and Eriksen 1974, Eriksen and Schultz 1979, Gatti and Egeth 1978). When Hageman and van der Heijden (1986) endeavoured to unconfound these two variables, in a spatially separated version of the Stroop color-word task, they found no reliable effect of spatial separation. A related experiment by Eriksen and St. James (1986), however, appears to show such an effect. The issue deserves further investigation.

Other (Gestalt) factors of organization and perceptual grouping, in addition to spatial separation, are known to influence visual selection (Duncan 1984, Kahneman and Henik 1981, Reznikoff 1981). Driver and Baylis (1989) contrasted a factor of perceptual grouping (“common fate”) and spatial proximity directly in a paradigm modeled in other respects on Eriksen and Eriksen (1974). In three experiments they confirmed that, when these variables were directly opposed, perceptual grouping of target and distractors had considerably more influence than their spatial separation. “Far” distractors which were nevertheless perceptually grouped with the target produced more interference than did spatially “near” distractors—a result that runs counter to the spotlight hypothesis, in the form in which it is generally proposed, which predicts that visual attention can only be assigned to contiguous regions of the visual array as a whole. More sophisticated versions of the hypothesis are needed to accommodate these results. Data reported recently by Lambert (1987) and by Lamberts and Hickey (1989) suggest the need for, if anything, more extensive modifications of the original spotlight metaphor.

Spatial Attention and Selective Semantic Processing: The Evidence of Negative Priming. Proponents of early selection maintain that the semantic or categorical processing of symbolic distractors can be strongly modulated, or prevented altogether, through the spatial focusing of attention (Johnston and Dark 1986). This belief evidently rests on experimental demonstrations that the interference caused by semantically related distractors can be reduced or even eliminated when attention is directed away from the distractors. As discussed in relation to the controversy over early versus late selection (section 16.2), however, the absence of semantically based interference does not guarantee in itself the absence of semantic processing; it may indicate only that task-relevant and irrelevant information has been effectively segregated regarding the control of overt action.

The phenomenon of negative priming, which has received considerable experimental attention in recent years (Allport, Tipper, and Chapman 1985, Lowe 1979, 1985, Neill 1977, Neill and Westberry 1987, Tipper 1985, Tipper and Driver 1988, Tipper, MacQueen, and Beech 1988), has important bearing on this issue. In the basic experimental paradigm a stimulus appearing as the target for a current selective response is related to—or is categorically identical to—the distractor stimulus of the preceding trial. The effect, observed in many different variations of this basic paradigm, appears as an increase in the latency of response to the current selective target, compared with a neutral condition in which previous distractors and current targets are unrelated. That is to say, it is more difficult to select a stimulus, belonging to a given category, for the control of action, if that same category of object was actively ignored on the preceding trial. This categorical, negative priming effect transfers, for example, from a pictured object as distractor on trial n to a written word as target on trial n + 1 (Tipper and Driver, 1988), and from a color name as distractor to selective response to a subsequent ink-color (Neill, 1977, Neill and Westberry 1987, Lowe 1979). It also shows transfer between semantically related stimulus categories (Tipper 1985, Allport et al. 1985, Tipper and Driver 1988) and from one response modality to another (for example, from vocal to manual; Tipper et al. 1988).

There is some evidence also, from studies of individual differences, that the negative priming effect is strongest in subjects who are “efficient selectors,” that is, in those subjects who show typically the smallest interference from simultaneous distractors (Tipper and Baylis 1987, Beech and Claridge 1987, Tipper et al. 1989). As already noted, however, the fact that distractor interference can be reduced or even eliminated in efficient selection-for-action provides at best an insecure basis for inferring that the distractors did not reach semantic levels of encoding. To the contrary, the occurrence of the negative priming effect, specific to the conceptual or “categorical” identity of the successfully ignored distractor, provides direct evidence that they did reach semantic levels of encoding.

This argument can be sharpened as follows. Francolino and Egeth (1988) reported an elegant experimental demonstration, often cited in
the controversy between so-called early and late selection. Subjects were presented with a circular array of up to six red and black letters or numerals. The subjects' task was to count the number of red items and to ignore the black ones. Vocal RT was measured. When the red and black items consisted of (Stroop-like) numerals whose numerical value conflicted with the actual number of red items to be reported, mean RT was delayed. In contrast when the to-be-ignored, black items formed conflicting numerals, there was no interference: RT was unaffected. Francolin and Egget argued, on the basis of these results, that the symbolic value of the black distractor numerals had simply not been encoded. How secure is this inference? To pursue this question, Driver (1989) repeated Francolin and Egget's experiments. In doing so, however, he also manipulated the relationship between the to-be-ignored (but conflicting) numeral values on trial n and the number of red target items to be counted on trial n + 1, to look for effects of possible negative priming. The results showed significant negative priming not only from the irrelevant number value of the red target items but also, and of equivalent magnitude, from the successfully ignored black distractors, although these had caused no detectable interference on the preceding trial.

Since the negative priming effect is specific to the symbolic identity of the distractors on the preceding trial, the results provide direct evidence of categorical identity coding of these distractors. The inference from no interference to no semantic processing thus appears to be empirically incorrect.

The mechanism of negative priming is still unknown. The simplest suggestion would appear to be that interpretative codes activated by the to-be-ignored stimuli are themselves subject to a direct inhibitory process—that is, their activation is suppressed (Neill, 1979). Other evidence, however, argues against this hypothesis. In particular, when the coding of to-be-ignored distractors is probed not by a subsequent compound stimulus, requiring another selective process for control of the response, but by a "simplex" probe stimulus, not requiring selection between task-relevant and irrelevant attributes, the priming effect of a previous distractor reverses to become facilitatory (Lowe 1979, Allport et al. 1983). This result appears difficult to reconcile with any simple account of direct suppression or inhibition of activated memory codes. Tipper (1985, Tipper et al. 1988) has proposed instead an inhibitory process that selectively isolates active codes, representing the ignored distractors, from the control of action. He has suggested that when selection is not required for the simplex probe, this inhibitory process may be released. Priming by ignored distractors thus represents a combination of facilitatory and inhibitory effects. Further clarification of the mechanism (or mechanisms) of negative priming may be expected to add considerably to our understanding of the implementation of visual selection-for-action.

It will be clear that many questions remain to be answered regarding the categorical encoding of successfully "ignored" distractors. The evidence reviewed here certainly cannot be taken as showing that the spatial direction of visual attention (selection-for-action) has no effect on the representation of categorical or symbolic aspects of the to-be-ignored stimuli. What it does, however, is to throw, perhaps radically, the terms in which questions of this kind may be approached. In particular we need to distinguish very carefully between questions of encoding and categorization, and questions of access to the control of action.

Other Issues

The experimental paradigms discussed here are relevant to issues of attentional selectivity in the visual control of immediate action or immediate response. There are of course many other important issues regarding attention, including, for example, the understanding of a great range of executive functions. (In section 16.3.1 I noted briefly neuropsychological evidence of functional specialization among several different components of executive attentional control.) Different issues, however, involve different experimental paradigms. Different theoretical issues furthermore should be kept carefully distinct and not confused together in favor of a pretheoretical assumption that there is some unitary process, or function, or capacity called attention. Many experimental paradigms in cognitive science, for example, appear relevant to questions of selective memory encoding of visual information (chapter 17). It may be that visual selection-for-action is a necessary—though certainly not a sufficient—condition for the encoding of visual information into a reusable engram. Questions of the necessary and sufficient conditions for effective visual memory encoding (visual "selection-for-memory"?), however, go far beyond the scope of this chapter. For the present we can simply note that these are indeed separable questions which must now be set aside.

The same applies to many other issues that are sometimes described in terms of limited capacity, such as, for example, the time costs, or other constraints of visual-imagery generation (Kosslyn, Cave, Proctor, and Cave 1985, Brooks 1968) or maintenance (Phillips 1982) or the generation of random numbers (Baddeley 1966, Wagenar 1970). We should also perhaps ask ourselves in each case whether the limited capacity that is at issue is simply a redescription of the behavioral phenomenon to be explained, or whether it is intended in some way as an explanation.

Concluding Remarks

In the study of attention, as in other areas of cognitive science, research is shaped by a range of pretheoretical assumptions, implicit or explicit, as to what the subject at issue is about, hence how that area in general
is conceptualized and what are the principal empirical questions to be addressed. Thus according to many theorists, and perhaps widely also in ordinary usage, attention has been conceptualized as some unspecified but essentially limited mental energy or resource or capacity. What this resource supposedly enables is processing. Or rather, it enables certain sorts of processing ("further processing"). Other sorts of processing do not need attention.

Unfortunately there is little if any agreement about how these crucially different sorts of processing should be distinguished, nor about how the mysterious, limited resource or capacity (or capacities) is (or are) to be defined; nor yet how exactly—or even approximately—it (or they) is (or are) effectively limited. Yet despite this unhappy state of conceptual disarray, there is a temptation to cling to the underlying intuitions, to the effect that attention denotes essentially a limitation (a shortage, a deficiency) or something. After all isn’t it obvious that attention is intrinsically limited (that is, selective)? How else could attention be conceptualized?

From these very general initial intuitions it appears to follow that the central empirical questions about attention are questions about the selectivity of processing. If we could only establish experimentally where and when processing becomes selective, we might then come to understand the nature of the mysterious capacity limitations that made such selectivity of processing necessary in the first place.

Or have we got the whole issue upside down? These empirical questions about selective processing have proven in practice extraordinarily difficult to resolve. So much so that after thirty years of vigorous but inconclusive experimentation, we may reasonably question the heuristic value of the pretheoretical intuitions that motivated them to begin with.

Much of the experimental research directed at questions of selective visual processing (and essentially all of the research reviewed in this chapter) has been concerned in effect with the selective, visual control of action. For multifunctional organisms, even for organisms enjoying in principle unlimited perceptual processing capacity, a form of selectivity that is unavailable is selectivity of perceptual-motor control (selection-for-action). This form of selectivity (which can be studied directly by behavioral methods) should be carefully distinguished from selectivity of "processing", a concept that appears, in general, ill-defined and extraordinarily difficult to operationalize unequivocally in behavioral terms.

Within the domain of perceptual-motor performance (with which this chapter is concerned), it may be a more fruitful hermeneutic to focus research on a different set of questions regarding the functions of visual attention. These questions are not about processing limitations, or "bottlenecks", but about the mechanisms of attentional control: questions about the—multiform—computational mechanisms by which attentional engagement is established, coordinated, maintained, interrupted, and redirected, both in spatial and nonspatial terms, in the preparation and control of action. These, I suggest, are the primary questions for research on visual attention. Already in a number of areas such research is well under way. Its development represents a sufficiently challenging agenda for a future interdisciplinary cognitive science of visual attention.

Notes
1. Theories of selective attention have often considered selectivity in the visual and auditory modalities, and indeed in other senses, as fundamentally equivalent. Neumann, van den Heijden, and Allport (1980) have presented the case for carefully separating theoretical issues (and data) on selective processes within each of these different senses, at the present stage of theoretical development.

2. "In our general orientation, that selection takes place in order to protect a mechanism of limited capacity, the P system (serial processing system, or categorizing mechanism)" (Broadbent 1971, p. 178). "The limited capacity system is now thought of as producing one of a set of category states" (Broadbent 1971, p. 17). "The occurrence of a category state corresponds to the firing of one of Treisman's 'categorical units'" (Broadbent 1971, p. 150).

3. Thus "the selection of one car shuts out most of the information on the other" (Broadbent 1971, p. 140).

4. This identification has been a long-standing feature of Posner's thinking: "The key to understanding the nature of conscious attention is its limited capacity" (Posner 1978, p. 153).

5. "The principal theoretical issue confronting attention research today concerns whether selection is 'early' or 'late'." (Hoffman 1986, p. 221).

6. This distinction was first clearly pointed out, in my knowledge, by van den Heijden (1980). See also Duncan 1987. Toward the end of their review of early versus late selection, Kahneman and Treisman (1984, p. 66) put forward an initial proposal of a logically similar alternative. If adopted, however, it would probably substantially undermine their previous arguments for the "homomorphism" of categorial encoding, based on the presence or absence (or at least the reduction) of RI interference from semantically related distractors, depending on the spatial direction of attention. See section 6.5 for further experimental evidence related to this issue.

7. Paton (1972, 1977) has developed the distinction between symbolic, discrete information and (dynamic, continuous) specification, in the control of complex systems. (See Kelso and Kay 1987 for further discussion.) Systems specialized for the analysis of acoustic speech enable uniquely direct or "compatible" access to and specification for the control of vocal articulation (Mowbray 1987; Porter 1987). Latency of vocal repetition in an auditory syllable can be as low as 100 ms (Porter and Liberman 1980). In a similar way orthographic input provides an optimally compatible specification for written (typed) output (Greenwald 1972, Ellis 1982).

8. Stroop (1935) first showed that naming a color is delayed by the presence of an irrelevant written color-word.
9 Erikson and Erikson (1974) and Shapiro and Lakhair (1979) offer well-known examples of selective interference when both wanted and unwanted stimuli occur in the same representational domain, providing in principle equally plausible but conflicting information to control the diagnostic response. See also Hofmann 1987 and van den Heuvel 1981. Vittu and Egger's (1985) account of Stroop-like interference effects, though germane in several respects, would appear to have difficulty with these results. For previous related discussions see Allport 1980a, pp. 135-141, and McLeod and Pasner 1984, p. 85.

10 The immediate antecedents of this idea can be traced from Moray 1967 through Kahneman's (1973) notion of nonrational "processing effort" to Norman and Rehnov's (1975) heroic attempt to provide that idea with a systemic, operational basis. Unfortunately the latter was bought at the expense of confounding, once again, possible limitations of control ("processing effort") and of message capacity ("communication channels"), and the like. See Allport 1980b for further commentary.

11 Data presenting various difficulties for Tseirian's model have been reported recently, for example, by Allport et al. (1985), Duncan (1985), Duncan and Humphreys (1989), Egret, Jol, and Maffon (1989), Houch and Hoflin (1986), McLeod, Driver, and Clap (1986), Pastler (1986), Stolier and Budg (1988).

12 Other patterns of attentional modulation have been observed in predominantly categorical or identity-coding ("What") systems, for example in object-based systems (DeSimo and Munson 1985, Moran and Desimone 1986, Richard, Wurtz, and Sawa 1983, Spitzer and Richard 1986). The interactions between attentional effects in spatiotopic and identity-coding systems have yet to be studied.

13 The occurrence of fusion or "blend" errors, at many different levels of action control, in these (and other) categories of action (Becquer and Jengens 1979, Steenbergen 1985), is evidence that the central processes may emerge as the result of an abrupt transition between them, conflicting specifications, but this is no way removes the logical requirement of time-varying uniqueness, if the action is to occur at all.

14 Including coordination with respect to the competing demands for high-resolution vision. As is easily demonstrated, however, loss of individual stepping stones is not necessary for accurate control of locomotion.

15 Generation of the selected object in vision is neither necessary nor sufficient for the purpose of selective visual-motor control, though it may considerably enhance its accuracy (see, for example, Rigney, Janssen, and Probo 1985).

16 Processes responsible for establishing a time-varying goal hierarchy—especially regarding primary "biological" goals—constitute the traditional subject-sets of Motivation rather than Action. The moment-by-moment behavioral implementation of goals on the other hand, in particular the multiplicity of instrumental or secondary goals involved in everyday human activity and the selective and coordinate processes needed for their implementation, appears recognizably as a problem of attention. What is important to recognize, however, is not the location of some imaginary boundary between the provinces of attention and motivation but, to the contrary, their essential interdependence. The phenomenon and the functions of attention cannot be properly understood unless they are seen in terms of the more general purposes and constraints of behavioral priority assignment in multifunctional organisms.

17 Everyday "signs of action," illustrate, in their remarkable diversity and complexity, some of the many ways in which attentional engagement can be (temporarily) disturbed (Norman 1981, Reiss 1978).

18 S-R preparation for a simple probe EL task can be sufficient to reduce the efficiency of attentional engagement on a primary task (see, for example, Gotsdiner 1980). Appeal to a limited capacity for S-R preparations, however, would appear to be little more than a relabelling of the phenomenon to be explained, rather than an adequate explanation.

19 This interpretation is clearly not to be confused with one of the traditional variants of late selection in which an unexplained processing bottleneck is attributed to a discrete response-selection stage.

20 Thus "Activation of the meaning of an item may be restricted to just those items that are deemed relevant" (Franceson and Egert 1980). "The involuntarily reading of a distant color-word can be prevented by focusing attention on the relevant visual object" (Kahneman and Chajczyk 1983). "Interference from a familiar word seems to occur only if you are looking at it or doing something that is likely to prime that particular word. The process is clearly very much under strategic control and can be stopped..." (Broadbent 1982). "Stimuli outside the spatial focus of attention undergo little or no semantic processing." (Johnson and Dak 1986).

21 Different proponents of this idea refer equally vaguely to "central processing," sometimes (pleasingly taxonomically) to "limited-capacity processing," more concretely to "conscious processing." Compare also Johnson-Laird's (1983) 1988 conception of a central "operating system" and other related suggestions of separable subsystems responsible for consciousness (See Allport 1988 for further critical commentary.)

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