2

AN EXPLANATORY FRAMEWORK FOR ATTENTION

2.1 Introduction

Theorists of the mind have constantly raised questions about whether we understand attention. Russell Poldrack notes:

> "I don't think we know what 'attention' is. It's a concept that's so broad and over-used as to be meaningless. There's lots of things people in psychology and neuroscience study that they call 'attention' that are clearly different things" (Russell Poldrack, 2018).

Such skepticism is long-standing. A century earlier, Karl Groos noted:

> To the question, "What is Attention?", there is not only no generally recognized answer but the different attempts at a solution even diverge in the most disturbing manner (Karl Groos, 1896).

Linked across a century, Poldrak and Groos voice similar worries: that there is no accepted answer to the question, "What is attention?", and relatedly, there are too many answers to it. It appears we do not have an adequate *metaphysics* of attention, an answer to the Metaphysical Question. Two recent articles announce in their titles: "There is no such thing as attention" (Anderson (2011); see also Anderson 2021) and "No one knows what attention is" (Hommel et al. 2019). Yet there is a thriving research program on attention with over forty thousand papers with "attention" in the title since 1950 (PubMed

search). How can we reconcile such doubt with such productivity? Is the entire field really confused? Are they producing gibberish?

Experimentalists are likely unconcerned with the commonly avowed skepticism because the research program on attention thrives without an adequate analysis of attention. This would explain why the Metaphysical Question has not been more rigorously addressed. I tender a different possibility: the research program thrives precisely because everyone is operating with the same, largely implicit, notion of what attention is. An effective response to skepticism and disagreement is to show that everyone is committed to the same answer to what attention is or at least to a central form of it. The joint commitment is secured by the conception being sewn into the fabric of experimental practice.

I provide a deductive argument for this claim. In valid arguments, if the premises are true, then the conclusion's truth is logically guaranteed. If the argument is sound, then the weight of logic is not to be ignored, and skepticism regarding attention is unwarranted. Given the argument's conclusion, we then anchor an explanatory framework for attention drawing on the theory of explanation in cognitive science provided by David Marr.

2.2 The Use-Mention Fallacy and other Confusions to Avoid

This chapter provides conditions for attention through conceptual analysis. Some object that such analysis is perseveration about nomenclature, word play, just "semantics". Unfortunately, these responses are fallacious, confused, or both. This section identifies and sets aside common mistakes.

Some responses commit the *use-mention* fallacy. The metaphysical question is one about a psychological capacity, a part of the non-linguistic world. To talk about attention, a psychological phenomenon, we *use* the word, "attention". Hence, "attention" (the word) refers to attention (the phenomenon). This is no different from using the word "seeing" to talk about seeing. The metaphysical question, "What is attention?", *uses* the word

"attention" to ask about the psychological phenomenon. If we were asking about the word, we'd pose a different question, say: What is "attention"? Note that *attention* is now quoted. The word "attention" is being *mentioned.* The answer to the nomenclature question would be this: "attention" is an English word that picks out a psychological kind, namely attention. Many complaints that the analysis of attention is merely verbal commits the use-mention fallacy.

"Well, it's all just *semantics!"* This is another common retort. What the objector might mean is that the analysis is merely verbal in which case, return to the admonition about the use-mention fallacy. Alternatively, the objector is confused about "semantics". Semantics concerns the semantic value of words like "attention". In doing semantics for psychology, we assign a semantic value to the word, here the relevant psychological phenomenon. The results of cognitive science are not irrelevant to semantics. After all, for psychological terms, it is precisely the job of cognitive science to investigate the referents of those terms, to tell us what memory, seeing or attention is and hence what the corresponding terms pick out in the world. In our case, cognitive science investigates what "attention" refers to investigating the various properties of attention. While cognitive science is not interested in the word per se, in investigating attention, it thereby clarifies the meaning of the term, "attention". Consider other scientific terms like "gene", "electron", or even "planet".

There is an irony in the accusations of word play since one pervasive feature in the attention literature is how easy it is to use "attention" where this use adds little explanatory value. Britt Anderson (2011) proposed a useful exercise. Take any passage in which "attention" is used in an explanation of some neural or behavioral effect. Cross out the word and see if anything substantive is left out. Here is Anderson's example, taken from one of the pioneers of the psychology of attention, Anne Treisman:

> For example, when Treisman (1985) writes "Some discriminations appear to be made automatically ~~without attention~~ and spatially in parallel across the visual field. Other visual operations ~~require focused attention and~~ can be performed only serially." The references to attention can be struck out without losing any understanding of the empirical results, and their inclusion doesn't deepen our theoretical understanding (Anderson 2011, 4).

The irony is that “attention” or “attentional” has often become an obligatory flourish in writing in cognitive science. A joke one of my vision science colleagues noted to me is that if there is an anomaly in one’s data, it usually is because one didn’t adequately control for attention, as if attention were the experimentalists monster under the bed, almost a useful fiction.

In the vein, a common phrasing is to use “attention” as a placeholder for a cause. Thus, attention is said to cause selection, modulation, efficiency and accuracy of neural or behavioral response. As empirical posits, these are substantive claims that must be substantiated. Arguably, what Groos and Poldrack are aptly complaining about is the failure of the science of attention to identify such a mechanism while proliferating the possible meanings of attention (see Allport (1993)). Yet the assumption that there is such a mechanism persists in part because it is easy to speak of attention as a cause, again a rhetorical flourish. There are, certainly, substantive questions about whether “attention” picks out several things or, in a material mode, whether attention is many things, but the point here is to note the irony of those who worry about others’ use of language when the fields use of a single term has not exhibited conceptual discipline.

Finally, it is worth noting a common but inadequate analysis of the term “attention” that is offered in textbooks and scientific articles as fixing the meaning of the term:

> attention is the selection of information for further processing.

This answers the metaphysical questions, and thereby provides the meaning of the term, “attention”. Unfortunately, this claim is false, subject to easily constructed counterexamples. Selective information processing is found in many systems where attention is not. For example, at the human retina, there is selection of information from light of specific wavelengths for further processing. By the common analysis, there is information for further processing on the retina, hence attention on the retina. To my knowledge, no one has ever made the latter claim, and I wager that all theorists of

attention would deny it. The selectivity of the photoreceptors are not sufficient for attention. If so, then the retina provides a counterexample to the common analysis. The reader can construct further counterexamples as an exercise.

That said, the idea of selectivity is part of our understanding of attention in folk psychology and in cognitive science. One form of attention, *selective attention,* exemplifies a type of selectivity at which the faulty analysis gestures. Section 2.4 identifies the selective form that is assumed in the cognitive science of attention because it is at the methodological core of experimental paradigms modulating attention. In the next section, we introduce the explanatory structure to be fleshed out through our review of the empirical literature in psychology (Chapter 4) and neuroscience (Chapter 5).

2.3 The Marrian Framework

David Marr's begins his book, *Vision,* as follows:

> What does it mean, to see? The plain man's answer (and Aristotle's, too) would be, to know what is where by looking. In other words, vision is the *process* of discovering from images what is present in the world, and where it is (Marr 1982, 3).

Marr and James both emphasize that we all know the answers to the relevant questions, "What is seeing?" and "What is attention?" respectively. Marr's opening question suggest two of our questions. He begins with the metaphysical question regarding vision, "What is vision?", but then answers it by considering the functional question for vision, "What is the purpose of vision?" The answer from the plain man addresses both. To see, Marr notes, is to know what is where by looking. The point of seeing is to yield knowledge of the external world and to specify vision's function is to begin to explain what vision is, a *functionalist* account of seeing.

Marr assumes that the plain man's answer is to be explicated by his own translation of it: vision is an information process. In the sentence that follows the quoted passage, Marr continues: "Vision is *therefore*, first and foremost, an information-processing task…" (3, my italics). By "task", Marr has in mind a process ultimately to be investigated by neuroscience although the functional question has an explanatory priority. Marr thus moves from functional *role,* what purpose or goal the capacity serves, to the *realizer* of that role, namely the implementation of the function. For example, consider the role of being a can opener and the different physical devices that realize the function of can openers.[1] Similarly, we can focus on the neural processes that implement vision as *knowing by looking*. This links the neuroscience of vision to the psychology of vision.

FIGURE 3.1 INSERT HERE (MARRIAN LEVELS)

Let us focus on Marr's three-tiered explanatory schema as a way to unify empirical work on attention that addresses relevant metaphysical questions. Marr's basic idea is that an adequate explanation requires approaching the phenomena from multiple levels, something most cognitive scientists would also endorse. These are "the different levels at which an information-processing device *must* be understood before one can be said to have understood it completely" (24; my italics). Indeed, Marr's own work led him to prioritize the highest level in his explanatory hierarchy, what he called the *computational theory.* Here, we specify what the phenomenon is for, what role it plays. The computational theory thus identifies the functional role of the phenomenon we are interested in. For vision, the plain man's answer gives the computational theory, and Marr reconceptualized this idea as the visual system's taking in information from a two-dimensional image corresponding to the stimulation of the retina (the input from looking) and generating a visual representation of the three-dimensional world (the output as knowledge).

The next two levels are the *algorithmic/representation* level and the *implementation* level.[2] In the former, the theorist specifies algorithms understood as procedures which, when carried out, implement the functions described in the computational theory and the representations on which the algorithms operate. For example, Anne Treisman and Garry Gelade proposed a Feature Integration Theory (FIT) of attention where they postulated that elements of visual feature maps are "bound" together to yield object representations. FIT proposes a specific part of the algorithmic realization of vision. After all, visual

representations of the three-dimensional environment require visual representations of objects, and FIT specifies a process that generates visual representations of an object by transforming representations of features. Feature binding is effected by an attentional mechanism, metaphorically conceived of as a spotlight. With an algorithmic specification, we can then look for its physical (neural) implementation. Certainly, the construction of a Marrian explanation is a give and take, with advances at one level leading to refinements at another. For our purposes, Marr's insight is that if we can find the right computational theory, this provides an organizing principle for other levels of analysis fleshed out as part of the give and take of theoretical and experimental approaches. The goal in the next section is to establish a computational theory for attention, extracted from the very methodology of experimental work on attention.

2.4 The Deductive Argument

A Marrian computational theory of attention tells us what the function of attention is. The science of attention is methodologically committed to a specific conception of attention that is entailed by James' well-known characterization:

> Everyone knows what attention is. *It is the taking possession by the mind*, in clear and vivid form, *of one out of what seem several simultaneously possible objects or trains of thought*. Focalization, concentration, of consciousness are of its essence. *It implies withdrawal from some things in order to deal effectively with others* (my italics).

The folk conception James' articulates (what we all know) speaks of attention deployed as part of acting intentionally, so the mind actively takes possession of the target, what cognitive scientists refer to as *voluntary*, *endogenous* and *top-down* attention. In contrast, attention outside of the agent's control would involve the taking possession *of* the mind *by* an object, what is often called *automatic, exogenous* or *bottom-up* attention. Here, we focus on the first form, drawing on the italicized functional core of attention in James' description: attention is the subject's mentally selecting a target, among others, in order to deal effectively with it. *Dealing with* something is acting in response to it, so it involves a selective response to a specific target rather than other potential targets. It is to do something to the target, to *act*. From this, we derive the *Jamesian condition*.

If a subject selects target Y to inform acting, on it (dealing with Y), then S attends to Y.

We can then argue as follows across experimental paradigms X to investigate attention:

1. For any X taken as standard paradigms for attention: if X is an appropriate probe of attention, then the Jamesian condition holds.

2. X is an appropriate probe of attention

3. Therefore: the Jamesian condition holds.

The form of the argument is logically valid*:* If the premises of the argument are true, then the truth of the conclusion is guaranteed. The argument's variable, X, ranges over all experimental paradigms taken by the reader as appropriate probes of top-down, voluntary attention. This secures the truth of (2) for the paradigms in question. A reader who rejects (2) for *every* X gives up on an experimental science of attention.

This leaves (1), argued for as follows. Consider how a scientist must go about studying attention to some target *O*, say to space, feature or object. For example, one might be interested in studying visual attention to a material object when one reaches for and grasps it. The scientist's experiment is adequate to probing attention to *O* only if the task, T, adequately sets the subjects' visual attention to *O*. After all, experimenters typically do

not leave the direction of attention up to their subjects. They remove such responsibility with a well-designed task where task instructions set attention by directing attention to an appropriate target. The task guarantees appropriate attention because *correct* performance requires that the agent's response be guided by selection of *O* rather than any other possible target. Thus, the experimenter is guided by a specific instantiation of the Jamesian condition:

> *Experimental Sufficient Condition:* If a subject selects target *O* to inform task performance of T, i.e. deals with *O* in doing T, then S attends to O.

Earlier, we noted the inadequacy of the common description of attention as selection for further processing. What is missing is a specification of the *point* or *goal* of further processing. James answer is that it serves the guidance of behavior or action in the broad sense, one's dealing with things. The experimentalist follows James by treating selection of a target to perform a task as the relevant further processing in attention.

Yet why think that a specific task T is linked to attention in the empirical condition? Why isn't this arbitrary, something merely stipulated by the experimenter? For consider a ball as an arbitrary O and the massive number of tasks that we can design that involves a response to it. We can point to the ball with any part of the body: hand, foot, elbow, a nod of the chin or moving our eyes. We can grasp it with either hand, push it with our foot or knee, we can commit it to memory or describe its features verbally or in inner speech, we can draw pictures of it, imagine it changing, and so on. We can design any of these tasks, some admittedly silly, to study various aspects of motor and mental movements. Each of the desired responses is informed by visual selection of the target O. In each case, the response is based on the subject's visually attending to O, say by looking at it. Yet why should selection in any of these cases amount to attention, even in the silly examples? Still, if attention is paid to O when pointing at it with the finger, then it is also visual attention when pointing at it with a flick of the chin or with one's toe. Similarly for the other responses.

I suggest that there isn't any real controversy that each of these tasks involves visual attention, and yet each involves a very different response. Attention is secured in a non-

arbitrary way because the experimentalist has a simple justification available: James' condition. In all of the cases noted, from silly to serious, attention is secured because the agent selects O to respond to it. She does something selectively. That general idea, of selection for dealing with things, James's condition, can be invoked to justify every specific version of the experimental sufficient condition used in science, even for tasks not yet established. It is hard to see what other condition could have this broad reach. Thus, for any paradigm taken to be an *appropriate* way to probe attention as instantiating the empirical sufficient condition, the paradigm implies the correctness of the Jamesian condition for the latter justifies why instances of the former are appropriate. This establishes premise (1) for the relevant paradigms set by premise (2). The conclusion then deductively follows.

The Jamesian condition fixes one type of attention as at the core of empirical investigation, a subject's selecting a target to deal with. This provides a clear and decisive way to respond to worries about attention in cognitive science, for it brings to light a claim that all scientists of attention are committed to. The proper answer to someone who takes the science of attention seriously but complains that we don't know what attention is can be formulated in this way: in science we study attention in the sense of a subject's selection of a target to inform performance. To deny this is to object to the very methodology of empirical work on attention.

I find skeptics hesitant to embrace the conclusion or simply ignore it. The cost is to end up complaining, again, that we don't know what attention is. Yet the argument is deductively valid *and* sound*,* that is all the premises appear to be true or at least accepted by a theorist who accepts the cogency of experimental work on attention as set by the second premise, so all the standard attention tasks. If the premises are true, one is *logically compelled to accept the conclusion*. This is not a conclusion one can shrug off except if one rejects the force of logic. It is not to be deflected by fallacious charges of word smithing or confused invocations of playing with semantics. The skeptic must show that one of the premises is not true, but then they would simply reject the science of attention. That is, to put it mildly, not a good option.

Still, even for the hard-hearted, consider a weaker way to understand the argument that suffices for our purposes. The conclusion points to a reasonable unifying principle that applies to all notable experimental paradigms. Indeed, we shall see the Jamesian condition implicitly invoked over and over again across experiments in cognitive science.

The logical explication then amounts to a way of motivating a plausible proposal by making explicit a widely shared implicit assumption. Thus, the conclusion offers a concise way to unify a large number of experimental paradigms of attention. For in each of these paradigm, the experimental subject is selecting a task-relevant target to inform performance. The discovery is recognizing that each case instantiates a plausible idea that James articulated a century ago: attention is the subject's selecting something to deal with.

We can use the Jamesian condition as a functional description of the form of attention widely studied in science. It thus *establishes a computational theory of attention that the science of attention is committed to given its experimental methodology*. The condition provides an organizing principle for investigating the algorithmic level of description as well as its neurobiological implementation. This unification arises for a simple reason: the experiments that inform construction of algorithms, identification of neural correlates and proposals for neural mechanisms are organized by experimentally implementing the Jamesian condition in specific tasks. That is, the relevant data is collected under that condition. In that way, James's condition connects all levels of analysis in the study of what is called top-down attention, attention set by performing specific tasks (we shall critical exam "top-down" talk later, Chp. 3.XX).

We can return to the dual complaint in the Poldrack and Groos quotes by answering the first worry, that nobody knows what attention is. This is set aside by showing that everybody does know what attention is, at least in cognitive science. It is what everyone studies using standard paradigms for top-down attention. Still, there is a second part of their worry which hits its mark: "attention" (note, the word) is used in many different ways. It is *polysemic* but in a way that is, perhaps, theoretically unproductive.

2.5 Polysemy in "Attention"

We have focused on a notion of selective attention that I have argued is built into the methodology of the science of attention. But "attention" covers other phenomena. Daniel Kahneman, in *Attention and Effort,* introduced selective attention with this passage:

> The existence of mechanisms that control the significance of stimuli can hardly be denied. For example, a pigeon may learn to favor a red triangle over a green circle. On a subsequent transfer test, will the pigeon favor a red circle over a green triangle, or will he prefer the triangle? The behavior of different pigeons leads to different answers; the psychologist is tempted to state-not very helpfully-that some pigeons attend to shape while others attend to color (2).

The psychologist's use of "attention" is perfectly helpful in that it identifies the phenomenon to be explained, a subject's behavior, here the pigeon's ability to be visually tuned to task-relevant stimuli. The term is not helpful in identifying the "mechanisms that control the significance of stimuli." One might call these to be discovered mechanisms "attention", but is this polysemy advisable? This would license the following confusing claim: attention (the phenomenon of the subject's selecting a target to respond to) is explained by attention (the mechanism) (cf. the second criticism of Hommel et al. (2019)). Why embrace a polysemy that would allow such grammatical "circular" formulations? One would be better served by noting that the animal's attention must be implemented in some type of neural tuning or selective mechanism (recall the retina, the first instance of selection, but not attention). If "attention" means many more things, then the variety of confusing formulations will multiply.

Polysemy (some would call this "ambiguity") is available because the Jamesian condition does not fully settle the *metaphysical* question, for it provides only a *sufficient* condition. One can accept that condition while denying that it identifies a *necessary* condition. Accordingly, there could be other types of attention. For example, on some views, attention is necessary for perception or conscious awareness. Attention is selection for perception/awareness/consciousness. We shall return to this conception, perhaps the other most common account of what selective attention is. It is distinct from the attention as selection for action for intuitively, there can be perception and consciousness independent of one's doing anything. If so, these will be cases of attention without action. In contrast, a version of the Jamesian view, *selection for action*, holds that attention is selection for dealing with things in the broadest sense, so mental actions like thinking and imagining as well as bodily actions (XX). That view holds that attention implies action (see Chapter XX), a claim that many find implausible. Clarifying this will require explaining what actions are (Chapter 3).

Is attention many different things? Given that there is a common conception of attention in selection to deal with things that is as perspicuous as experimental methodology and is, at least implicitly, at the center of the science of attention, we should ask for a justification for extending the use of the term given the plain cost of unnecessary confusion. Why move away from a clearly articulated conception of attention to cloud our ideas of it by using the same term to name other things? Why call a boat a "car" when we all have a clear enough conception of what a car is? We shall return to what might justify conceptual extension when we consider the idea that attention is a quantifiable resource (Chp. 4.XX).

The Jamesian condition situates attention as a phenomenon fixed at the computational level. At the same time, "attention" is often used to identify phenomena at the algorithmic or neural levels. To take a historically important example mentioned earlier, Treisman and Gelade invoked an attentional spotlight as a mechanism in their explanation of the construction of visual object representations. Attention binds features for object representation, so the spotlight of attention is on a specific feature map, an algorithmic construct that is not the target of subject level visual attention. In another example, neuroscientists often speak of attention as modulating neural activity, say increasing the response of a neuron to a stimulus. The metaphor of a spotlight is a common way to capture both ideas. One challenge for these proposals is to demonstrate the existence of the posited mechanism, specified in different ways: binding and gain modulation (Chp. 4). Further, and this is crucial, even if a mechanism is found, why call that mechanism "attention"?[3] Better, why think that attention is many things? At this point, we raise the question to note that it is a substantive one. We shall push the worries more sharply in later chapters.

2.6 Fleshing out the Marrian Schema for Attention

In any event, we have one clear account of what (one form of) attention is that cannot be gainsaid by experimenters since they rely on it. Marr's proposal then suggests a natural way to organize attempts to explain what attention is. After all, if the computational theory expresses a condition that informs the construction of experimental paradigms, then neural data is collected during the implementation of the condition in measuring behavior, namely during tasks where the subject selects a target to guide instructed response. For example, one neural response commonly observed during a subject's selecting a target to respond to is gain modulation of the response of neurons that are

tuned to the target. A hypothesis to be tested is that this modulation is part of the machinery that *explains* the subject's selection of the target to perform the required behavior. We shall return to this in Chapter 5 when considering results in the neuroscience of attention. Similarly, algorithms are postulated to explain both the behavior and neural data, so are also tied to the Jamesian condition. Again, in Chapter 5, we shall consider algorithms which, in explaining neural effects such as gain modulation, potentially contribute to explaining the subject's selecting a target to inform task performance. On this picture, the fruitfulness of work over the last half-century is precisely that the same idea of what attention is informs the design of experiments and hence, provides a principle unifying that work and the resulting theory.

That said, the focus on task suggests a cautionary approach, for it is not guaranteed that for a set of tasks, we shall discover that they involve the same algorithms or neural implementation. If this is so, it will be a discovery that in different tasks, similar algorithms are deployed and similar neural implementations realized. Alternatively, we might find that similar tasks across different modalities are implemented in different algorithms and/or involve different neural bases. Accordingly, a conservative approach in the science of attention is to answer the metaphysical question for specific tasks: What is attention in task T? In effect, this is how the science has proceeded. If we can build a detailed Marrian account for any given T, then an important step will be to see if there is unification at other levels below Marr's computational theory or if the Jamesian form of attention is disjunctively realized. Indeed, while I have focused on top-down attention, there is also bottom-up attention and we have reason to think that the neural substrates for the two differ. If the bottom-up attention can be captured by a modification of the Jamesian condition, but remain essentially Jamesian in form, then attention will be disjunctive at the neural level (see Chp. On automatic attention, XX).

We have then a framework for organizing empirical work to be discussed in the next chapters. A guiding principle is the Jamesian condition which provides a functional unification of theoretical and experimental work. As such it identifies attention as a phenomenon *to be explained.* Unproductive polysemy is driven in part by treating attention as the *explainer,* leading to theoretical malapropisms. This is not to deny that attention makes a difference, but for many areas of cognitive science, it is often a confusion to talk of explanation as a type of cause. Where attention is clearly a cause is what happens in response to a *subject's* paying attention, or not. Such effects of attention are of central concern since what people do is of central to concern. That is a clear notion of attention as a cause but it is the phenomenon that cognitive science aims to explain.

2.7 Summary

The current computational theory is incomplete since it provides only a sufficient but not necessary condition for attention. Still, it provides an empirically motivated starting point for relating empirical work in psychology and neuroscience. The idea is that we begin with some defined task T that requires visual attention. This gives us the computational theory for visual attention vis-à-vis T: visual attention is visual selection of some X that serves performance of T. We then canvass proposals for the algorithms that implement selection of X for task T and the representations that are needed. Moving to the level of neural implementation, we can then ask how the brain implements such algorithms and representations. Of course, work at each level will mutually inform and constrain each other. Ideally, at the end, we will have a complete explanation of one form of attention, namely selection of X for T. This can be iterated for other experimental tasks, leading to a complete story across Marr's three levels for each task. One hope is that we will identify commonalities and differences in mechanisms, both computational and biological, across tasks. We should not, of course, kid ourselves that this task will be easy, but we need an organizing framework. Interestingly, this framework was always there, and accordingly, we do know what attention is (at least a common form of it).

Suggested Readings

Marr's seminal discussion of his explanatory scheme us given in (1982, chap. 1). The skeptical literature is useful to narrow our focus, in particular Britt Anderson's initial shot across the bows and more recently, Hommel et al XX. In fact, the points made in this chapter are broadly consistent with those papers, albeit without the skeptical conclusion.

[1] In principle, each realizer can also be further functionally characterized say in terms of its subparts that work together to implement the whole. This allows for a common nested structure of roles and realizers (Lycan 1987).

[2] Specifically, Marr characterizes the computational theory in light of the following questions: "What is the goal of the computation, why is it appropriate, and what is the logic of the strategy by which it can be carried out?"; on the representation and algorithm level: "How can this computational theory be implemented? In particular, what is the representation for the input and output, and what is the algorithm for the transformation?; On the Hardware Implementation: "How can the representation and algorithm be realized physically?" These characterize "the three levels at which any machine carrying out an information processing task must be understood" (1980, p. 35) .

[3] What if vision science followed the conceptual moves in attention science. If we accept Marr's computational theory of vision, we have a target of explanation: knowing what is where by looking, this understood as the construction of a representation of the three-dimensional visible world in light of transforming a two-dimensional retinal (pixel) array. Seeing in this sense is what we are trying to explain. It is not itself an explainer, say a neural or algorithmic mechanism. Yet imagine that vision scientists expand "seeing" as attention theorists do for "attention". For example, imagine that vision scientists speak of visual areas as seeing: neurons in the visual ventral stream that are sensitive to objects "seeing" those objects since they take in visual input to generate information about visible objects. This yields two senses of "seeing": a subject sees and some specific neurons see. Thankfully, visual scientists do not do this, namely take a term at the computational level of explanation where it applies to psychological subjects and apply it

at lower levels, say to parts of the subjects' brains. They do not confuse what is to be explained with an explainer. Yet this conflation seems to be what we often do in the science of attention. The best response is to avoid conflation unless one can provide a compelling argument for it. But what argument would be sufficiently compelling to invite ambiguity?