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3

The Modularity of Sentence Processing Reconsidered

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The idea that the sentence processing system is modular has fallen out of fashion. The proposal got off to a promising start with the publication of results in the early to mid-1980s suggesting that word meanings are activated without regard to their global contexts, and that sentence structures are assigned to words at least initially without consideration of whether the structure would map on to a sentence interpretation that made sense given prior knowledge or given the contents of the immediate linguistic or visual context. Eventually, the modular view of sentence processing became strongly associated with what was termed the "two-stage" model of comprehension, a model which assumed that an initial syntactic analysis or parse was created by implementing a couple of simple parsing operations, and that this initial parse was then revised if it either did not lead to a globally connected syntactic structure, or if it led to a meaning that did not fit the comprehender's expectations and goals. By the late 1980s, connectionist approaches to cognition were becoming increasingly popular, and although one of their most salient properties is their flexibility, connectionism became strongly associated with interactive architectures, and those were assumed to be nonmodular. About a quarter century of research has since been directed at trying to show that sentence processing is not modular, and that instead the interpretation assigned to a sentence is influenced by all kinds of knowledge and sources of information ranging from visual context to beliefs about the intentions and even social background of the speaker. The nonmodular view is so widely accepted at this point that it is now almost mandatory to end scholarly papers and presentations with the observation that the findings support a highly interactive system in which knowledge sources freely communicate. It has been a

very long time since anyone in the field came forward with any sort of argument in support of the modularity hypothesis.

In this chapter, we will review the evidence that is meant to support this overall consensus in the field that sentence processing is nonmodular. We will begin by summarizing the original (1983) modularity proposal. We will briefly examine the important features of a module as described in the (1983) book (*The Modularity of Mind*—henceforth, *TMOM*), focusing specifically on how those properties were interpreted by researchers working on sentence processing. Then, we will summarize a large literature that emerged in response to the idea that sentence processing might be modular. The organization will be thematic: We will consider first the debate concerning the use of what might be described as intra-linguistic information, including prosody and lexical information. From there, we will consider the debates focused around the use of context, including both visual and discourse context. We will argue that although some of the simplest and most obvious versions of modularity might be implausible, it is a distortion to assert that the data undermine modularity in sentence processing entirely. Indeed, seen in a fresh light, the results of the bulk of studies conducted over the last 25 years can be taken as evidence for a more refined and detailed view of sentence comprehension, which retains many of the features of a modular system. The point is to use the findings from the studies to inform how we understand what the sources of information are and how they are organized, activated, and combined. We will also suggest that, in many cases, the claims for nonmodularity have simply been exaggerated—particularly those based on experiments using the so-called *visual world paradigm* (VWP).

An interesting new development in the field of sentence processing is the advent of new approaches emphasizing the shallowness of sentence comprehension. These approaches go under a few different names, including *good-enough language processing* (Ferreira et al., 2002), *shallow processing* (Sanford & Sturt, 2002), *late assignment of syntax theory* (Bever, Sanz, & Townsend, 1998), *analysis-by-synthesis* (Fodor, Bever, & Garrett, 1969; Garrett, 2000), and *noisy channel/rational communication* (Levy, 2008; Gibson, Bergen, & Piantadosi, 2013) models of processing. The common assumption is that comprehenders simplify, misinterpret, or alter the input to end up with an interpretation that is more compatible with semantic expectations. These models have been difficult to categorize with respect to the modularity hypothesis. On the one hand, the idea that comprehenders use simple tricks or heuristics to obtain at least an initial interpretation seems compatible with modularity, particularly the features relating to shallowness. In addition, the models are consistent with other approaches to cognition that emphasize the limited use of information for speed and sometimes, even, for more accurate performance (Gigerenzer, 2004; Kahneman, 2011). On the other hand, because these models suggest that the system is biased toward plausibility or, in more current terminology, because they emphasize the role of "priors" in the Bayesian sense, they seem to emphasize nonmodular aspects of

the system; they seem to highlight the idea that the sentence processing system is driven by semantic considerations and above all wants to create interpretations that are semantically or pragmatically compelling. One of our goals will be to try to sort through these possibilities and make the case that these approaches are consistent with a modular approach to sentence processing, if we emphasize shallowness rather than encapsulation.

THE MODULARITY OF MIND

As is now well known, the modularity thesis assumes that some cognitive systems have the following features. First, there are what we might call the more biological properties: Modular systems are associated with *neural specialization*; for example, specific areas of the brain seem to respond selectively to linguistic input (Fedorenko, Duncan, & Kanwisher, 2012). In addition, modular systems *emerge during development* with little in the way of individual variation. Although recent research on child language has tended to emphasize major differences in vocabulary and some other aspects of language competence in children from different social and economic backgrounds (Hoff, 2006), it remains clear that core language capacities emerge in almost all children at about the same time and in roughly the same sequence (Gleitman & Wanner, 1982). Modules also tend to become *selectively impaired* when an individual suffers from a biologically based disorder such as dyslexia or when a person experiences brain damage (e.g., aphasia; Joanisse, Manis, Keating, & Seidenberg, 2000; Dick, Bates, Wulfeck, Utman, Dronkers, & Gernsbacher, 2001; Sitnikova, Salisbury, Kuperberg, & Holcomb, 2002; Caramazza & Zurif, 1976).

The second set of module properties have to do with what we'll describe as superficiality: Modules deliver *shallow outputs*, which in the case of language can be taken to mean that what the sentence processing system delivers to systems that operate further along the information processing stream is merely the conditions for an interpretation; for example, the system that must determine what action to be performed based on a spoken utterance does not have information about the presence of gaps or traces in the syntactic representation from which the interpretation was derived. Similarly, people have "*limited central access*" to the internal operations of the sentence processing system; they might obtain an interpretation for a sentence, but they can't reason about the sources of that interpretation or the intermediate representations that were constructed to obtain it. This set of properties concerning superficiality have received less attention than the others, but we will argue that they are at least as significant, and that they relate closely to the newer models of sentence processing that were mentioned earlier—models which assume that the sentence processing system often engages in shallow processing.

The final set of properties of a module are the ones that have been the target of the great empirical scrutiny, particularly in the area of sentence processing. These are the features that relate most closely to issues of information flow

in a cognitive system, and map on to the older distinction between so-called "top-down" and "bottom-up" streams of information flow (Zekveld, Heslenfeld, Festen, & Schoonhoven, 2006; Field, 2004). Most important of these is that a modular system must exhibit *information encapsulation*: a module can access its inputs and its own databases and processes, but it cannot access anything outside the module. Its operations are also therefore *domain-specific*: the module consults a narrow range of information and that database is stated in a proprietary vocabulary related to the domain of processing. And because of this domain specificity and information encapsulation, the system can operate *automatically* (mandatory operation) and *quickly*.

Fodor in (2000) reinforces the importance of information encapsulation by describing it as being at the "heart of modularity" (p. 63). For a system to be a module, it must consult only a limited computational database when it analyzes input. It is also perhaps for this reason that most empirical investigations of whether a system is modular, and in particular whether the sentence processing system is modular, have tended to focus on demonstrating that a piece of information assumed to be outside the module does or does not affect processing in that domain. But what the notion of information encapsulation should also highlight is the importance of determining the information sources that are assumed to be used by a particular module. In other words, delineating the representational domain of a putative module is critical to determining whether its operations conform to modularity. In the area of language comprehension, this point was never properly confronted before the claims for anti-modularity started to be made. For example, some of the earliest studies were focused on demonstrating that the sentence processing system takes into account information about prosody when it makes syntactic decisions. The idea was that because prosodic information was stated in a different vocabulary from syntax, it should not be able to affect the computation of a parse tree. The problem with this argument, however, is twofold: First, and more obviously, if a prosodic analysis is *input* to the module that performs syntactic analyses, then prosodic effects on parsing are to be expected and in no way violate the modularity thesis. Second, and perhaps a bit more controversially, if a representational format is proposed which blends syntactic and prosodic information, then again, prosodic influences on syntax are compatible with modularity, as are syntactic influences on prosody. This point will be discussed in more detail.

Finally, it is important to recognize that, in *TMOM*, Fodor also argued that modularity should be construed is a matter of degree: "One would thus expect—what anyhow seems to be desirable—that the notion of modularity ought to admit of degrees. The notion of modularity that I have in mind certainly does" (p. 37). A system is modular "to some interesting extent" if it exhibits some of the properties summarized earlier; not all of them need to be present. At the same time, as we have also seen, the one property that seems necessary for a system to be described as modular is information encapsulation, at least for Fodor.

THE "TWO-STAGE MODEL" OF SENTENCE PROCESSING

For a variety of historical reasons, almost from the beginning, the idea that the sentence processing system might be modular became almost entirely conflated with testing a particular model of parsing—the so-called "two-stage model" first developed by Lyn Frazier (Frazier & Fodor, 1978) and then elaborated by her colleagues, including the first author (Ferreira & Clifton, 1986; Rayner, Carlson, & Frazier, 1983; Frazier, Pacht, & Rayner, 1999). Thus, in the interests of full disclosure, we acknowledge that the first author is strongly associated with this model, and both authors believe it is a compelling and empirically valid approach to explaining sentence comprehension. Nonetheless, it is important to recognize the historical coincidence that at the same time that *TMOM* was published, the two-stage model was also dominant. That model made several critical architectural assumptions from the perspective of evaluating the modularity hypothesis in this cognitive domain: First, the model assumed that a single parse is constructed for any sentence based on the operation of two simple principles: *Minimal attachment*, which constrains the parser to construct no potentially unnecessary syntactic nodes, and *late closure*, which causes the parser to attach new linguistic input to the current constituent during a parse, rather than going back to a constituent created earlier or postulating the existence of a new constituent. In addition, the two-stage model in its 1980s form assumed that the only information that the parser had access to when building a syntactic structure was its database of phrase structure rules. It therefore could not consult the syntactic information associated with lexical items. For example, in the sequence *Mary knew Bill* the noun phrase (NP) *Bill* would be assigned the role of direct object because that analysis is simpler than the alternative subject-of-complement-clause analysis, and the information that *know* takes sentence complements more frequently than direct objects could not be used to inform the initial parse.

Similarly, decisions concerning the creation of the initial parse could not be influenced by prosodic information either. For example, given something like *Because Mary left Bill*, the NP *Bill* would be syntactically integrated as a direct object, even in the presence of a major intonational phrase boundary after *left*. Of course, during this period when the two-stage model and modularity were both relatively new, the question how prosody might affect parsing had to be put largely on hold because there were few good techniques available for studying the earliest stages of spoken sentence comprehension. And, as was argued in *TMOM*, the modularity of a system cannot be assessed with offline measures or techniques that provide information about the final stages of processing; to assess modularity, it is necessary to tap into early online processing. Yet another historical coincidence is that, in the 1980s, eye movement monitoring systems started to become affordable and easier to use, and so more and more psycholinguistic laboratories acquired some type of eyetracking device. But, at this point, eyetracking was applied almost exclusively to investigations of visual language processing (reading), and reading was assumed not to involve prosody in any

serious way. (This assumption would change, of course, with the "implicit prosody" hypothesis of reading, but that is a topic for a different volume.) Eventually, researchers did venture into the field of spoken language processing and studies examining prosody in parsing were conducted. We will discuss those studies shortly.

In summary, the modularity thesis was tested against a specific model of sentence processing—a model which assumed that the parser proposes analyses serially and consults only phrase structure rules to make syntactic decisions. Eventually, evidence against the two-stage model would be construed as evidence against modularity as well, even though obviously other architectures for sentence processing are conceivable and even plausible. Moreover, findings that challenged assumptions such as the lack of access to subcategory information were not used to inform and update the assumptions about how any hypothetical sentence processing module might be organized or might operate; instead, they were taken as evidence against modularity itself. Having set the stage for the tests of modularity in this way, we now turn to experimental work designed to evaluate the modularity of sentence processing, keeping in mind that they were also, simultaneously, tests of the so-called two-stage model of parsing.

EVALUATING THE USE OF LANGUAGE-INTERNAL SOURCES OF INFORMATION

We begin with the question whether lexical information, and in particular, information linking elements such as verbs with the kinds of constituents with which they may occur, affects initial parsing. On the surface, it would appear to be rather odd to think this information would not be used, because in many theories of grammar, verb subcategorization information is stated in a syntactic vocabulary (Chomsky, 1965; Gahl & Garnsey, 2006; Hare, McRae, & Elman, 2003). For example, the information that the verb *put* must occur with both a noun phrase and a prepositional phrase can be represented as something like *put[__NP PP]*. As *TMOM* emphasizes, to establish whether a system is modular, it is critical to understand what its proprietary databases are. If we assume that a parser builds syntactic structures using syntactic information, then it would not seem unreasonable to assume that verb subcategorization information would be integral to the parser's operations. And, indeed, the earliest studies examining this question suggested that it is. Following from linguistic arguments based mainly on intuition data (Ford, Bresnan, & Kaplan, 1982), Mitchell and Holmes (1985) investigated this question by looking at the processing of sentences such as *The historian suspected the manuscript of his book had been lost*. They found that participants took less time to read the phrase *had been lost* when it co-occurred with *suspected* rather than with a verb such as *read*, which was presumed to occur because *suspected* takes sentential complements more frequently (see also Ford, Bresnan, & Kaplan, 1982). This result could be interpreted as evidence that the parser consults two sources of syntactic information

during construction of its initial parse: phrase structure rules and verb subcategorization frames. It is not obvious that it stands as evidence against the modularity hypothesis.

Soon afterward, however, Ferreira and Henderson (1990) conducted a follow-on study designed to address a limitation of the Mitchell and Holmes (1985) experiments: Because Mitchell and Holmes employed a phrase-by-phrase reading task, it was possible that the reading times conflated initial and reanalysis processes. Self-paced reading requires participants to make a decision on each displayed chunk concerning whether to push a button to receive the next chunk or stay put in order to get more processing time. Ferreira and Henderson therefore designed a similar experiment but used the eye movement monitoring technique, which has exceptional temporal resolution (a sample of the eye position is taken approximately every millisecond) and spatial resolution. They found that verb bias had no effect on early eyetracking measures (e.g., first fixation and gaze durations) but did influence global measures such as total reading time. They concluded that the parser does not consult verb-specific syntactic information, but that such information is used in later stages to revise a misanalysis. They also viewed the results as confirmation of the two-stage model of parsing, which assumed this basic architecture.

Following publication of Ferreira and Henderson (1990), a large number of studies were conducted designed to challenge these conclusions (Wilson & Garnsey, 2009; Trueswell & Kim, 1998). Although some findings consistent with theirs were also reported (Pickering & Traxler, 1998), the field eventually coalesced around the idea that verb information indeed informs initial parsing. Moreover, this idea was also taken as evidence against the original two-stage model, which is appropriate. However, in addition, the finding that verb information influences early parsing processes was also taken as evidence against modularity. But as our arguments thus far should make clear, we believe this conclusion is far too broad. One can easily imagine a modular theory of sentence processing in which the sources of information consulted to derive an initial parse include all the syntactic rules or principles relevant to projecting phrase structure, including verb subcategory information. In short, evidence for lexical guidance of early parsing decisions is not evidence against modularity, because the lexical information is plausibly internal to the syntactic module.

Next, let us consider the question how prosodic information might influence sentence processing. The starting point for most studies published in the topic is that syntactic and prosodic structures are related, and in particular, major syntactic boundaries such as those separating clauses are usually marked by phrase-final lengthening and changes in pitch (Ferreira, 1993). Some clause-internal phrasal boundaries are also marked, although much less reliably (Allbritton, McKoon, & Ratcliff, 1996)—for example, in the sentence *John hit the thief with the baseball bat*, the higher attachment of *with the baseball bat*, which supports the instrument interpretation, is sometimes (but not always) associated with lengthening of *thief*. The logic of the research enterprise was as follows: If certain

prosodic "cues" signal syntactic structure, then the parser might be able to use this information to avoid "going down the garden-path"—that is, it might be able to avoid misanalyzing the sentence structure. Of course, it is not obvious that the use of this information would constitute a violation of modularity, but that was the motivation for some of this research.

One of the earliest studies to consider this question was conducted by Beach (1991), and it claimed to show that prosodic information affects parsing. What the experiments actually demonstrated is that metalinguistic judgments about sentence structure were influenced by the availability of durational and pitch information linked to the final structures of the sentences. The obstacle to drawing any strong inferences concerning modularity at this stage in the history of the field was the unavailability of tasks for measuring online spoken language processing. The phoneme monitoring task had been abandoned in the 1980s (prematurely, as argued by Ferreira & Anes, 1994). The field still awaited the widespread use of electrophysiology to measure online processing of visual and auditory stimuli, and eyetracking had not yet been adapted to the investigation of spoken language. A couple of decades later, these techniques have yielded a wealth of information about the comprehension of utterances, and one of the ideas on which there is now a general consensus in the field is that prosody indeed influences the earliest stages of parsing. To take just one recent example, Nakamura, Arai, and Mazuka (2012) conducted an auditory study using temporarily ambiguous Japanese sentences and the visual world paradigm to investigate how contrastive intonation affected parsing decisions. Their results suggest that prosody can affect early stages of spoken sentence processing, leading comprehenders even to anticipate upcoming structure. Numerous other studies led researchers to similar conclusions (Price, Ostendorf, Shattuck-Hufnagel, & Fong, 1991; Kjelgaard & Speer, 1999; Millotte, Wales, & Christophe, 2007).

Now, how shall we evaluate these results and interpretations in light of the modularity hypothesis? If we conflate the two-stage model of parsing and the modularity hypothesis, then we must conclude that sentence processing is nonmodular. But we could instead update a model offered more than 25 years ago in light of this sort of evidence relating to prosody, as indeed the proponents of the two-stage model have (Carlson, Frazier, & Clifton, 2009; Frazier, Carlson, & Clifton, 2006). However, even if evidence is presented to refute specific models of modularity, this should not be taken as evidence against modularity as a whole, but only one potential form of modularity. Our argument is that, when considering modularity, it is important to establish not only what information sources are *internal* to the module, but also what information is *input* to that module. In the case of sentence processing, it seems reasonable to assume that prosodic cues or prosodic representations might be input to the sentence analyzer—that is, in terms of the more traditional bottom-up/top-down processing distinction, it seems plausible that prosodic analysis would take place *before* syntactic parsing. This idea makes some sense, as the flow of information during comprehension seems to be from sensory to conceptual, and prosodic features such as loudness, duration, and pitch are more sensory/perceptual than information about syntactic categories. Thus, prosody may indeed influence the earliest stages of parsing, but this does not undermine modularity.

THE USE OF CONTEXT AND PLAUSIBILITY INFORMATION DURING SENTENCE PROCESSING

Although investigations of verb subcategorization information and prosody are important for understanding the nature of sentence processing, it is not clear that they're useful for evaluating the modularity hypothesis, as we have argued. What is clearly relevant and indeed critical is information that certainly appears to be nonsyntactic. One of the earliest analyses came from Crain and Steedman (1985). They observed that many of the sentence forms treated as syntactically dispreferred by the two-stage model are also presuppositionally more complex. For example, consider the sentence *The evidence examined by the lawyers turned out to be unreliable.* According to the two-stage model, minimal attachment leads the parser to initially treat *examined* as a main verb, which causes the parser to be garden-pathed when the *by*-phrase is encountered. The parser must then reanalyze the structure as a reduced relative (see Fodor & Ferreira, 1998, for proposals concerning syntactic reanalysis). Similarly, the prepositional phrase attachment ambiguity in a sentence such as *John hit the thief with the stick* allows for two interpretations: initially, the *with*-phrase is interpreted as an instrument, but the *with*-phrase may instead serve as a modifier. As in the case of the reduced relative ambiguity, in this case too, the more complex syntactic analysis involves modification while the simpler analysis does not.

Crain and Steedman (1985) pointed out that these modification interpretations are not just syntactically more complex; they're presuppositionally more complex as well. Felicitous use of a complex phrase such as *the evidence examined by the lawyer* requires that there be more than one type of evidence in the discourse so that the modifier can be used to pick out the correct referent. This analysis appeals to the Gricean Maxim of Quantity (Grice, 1975), which states that speakers should not include unnecessary information in their utterances (but see Engelhardt, Bailey, & Ferreira, 2006). They argued further that null contexts favor the minimal attachment interpretation because, without a context specifying a set of objects denoted by the head noun, the listener will assume the presuppositionally simpler interpretation. Crain and Steedman presented intuitive evidence that sentences with reduced relative clauses were easy to process in proper contexts, contrary to what the two-stage model would predict.

The problem with the Crain and Steedman (1985) argument, of course, is that offline judgments are not adequate for assessing modularity, because they measure only the output of any putative module. Certainly a sentence such as *The evidence examined turned out to be unreliable* sounds better in context than by itself (as does almost any sentence), but that observation gives us no insight into the processes that support the intuition. For that reason, Ferreira and Clifton (1986) conducted an eyetracking study to assess whether the effect of context

was mainly to influence offline interpretations, or if it indeed intervened in the initial syntactic decisions of the parser. Their data were consistent with the idea that context did not affect initial parsing decisions. Supportive contexts led to shorter global reading times and more accurate question-answering behavior, but early measures of processing revealed that processing times for reduced relative and prepositional modification structures were longer than for their structurally simpler counterparts.

To the best of our knowledge, the findings from this 1986 study still hold. The only serious challenge came from Altmann and Steedman (1988), who elaborated on the Crain and Steedman (1985) proposal and also reported a set of self-paced reading experiments that purported to provide contrary results. This in turn led to a debate between Altmann and Steedman, on the one hand, and Clifton and Ferreira, on the other (1988). However, as Clifton and Ferreira argued, it is unclear that self-paced reading data can trump eyetracking results because the self-paced reading measure has far poorer temporal and spatial resolution, and therefore is biased against detecting early effects of syntactic manipulations.

More interesting than this debate about techniques, however, are the actual details of the Altmann and Steedman (1988) theoretical proposal. We believe the importance of the position they took in that paper has not been adequately appreciated in the 25 years since the paper's publication. Altmann and Steedman argued for a sentence comprehension system with two important properties. The first is that their parser consulted a syntactic database very different from the one assumed in the two-stage model. The important difference is that the representational format for structural information was Steedman's Combinatory Categorial Grammar, which combines syntactic and semantic information (and even some aspects of prosody and intonation; see Steedman, 2000; Steedman & Baldridge, 2011). Thus, if the parser consults a database of structural information contained in that sort of vocabulary, then effects of certain semantic manipulations on initial parsing are not inconsistent with modularity. This argument is the same as the one we made earlier regarding the use of verb subcategorization information: If the information is part of the module's proprietary database, then use of that information cannot constitute a violation of modularity.

But the second property is even more important: Altmann and Steedman (1988) argued for what they termed a weakly interactive architecture. What this architecture amounts to is a system in which "syntax proposes" and "semantics disposes." Crucially, on this model, alternative structural analyses are activated in parallel, and context retains the interpretation that is most contextually appropriate. This sort of mechanism is the same as the one that had been suggested in earlier work to explain the processing of lexical ambiguity (e.g., *bank*), and was specifically discussed in *TMOM* as an example of how a modular system might work. The idea is that, bottom-up, all alternatives are retrieved and made available to subsequent modules that then choose the one that is most suitable. In the case of lexical ambiguity, both meanings of *bank* are activated (and not necessarily equally strongly; modulation of activation according to frequency

fits the context is retained while the other meaning either decays or is inhibited by executive cognitive systems. Similarly, all syntactic structures might be computed or retrieved, and the one that post-sentence processing systems like are retained while the others either decay or are inhibited. The important point, then, is that this type of interaction with context does not violate modularity, as Altmann and Steedman themselves emphasized with their description of their model as merely "weakly interactive."

A related debate has centered around another potential influence on initial parsing decisions—semantic plausibility. Ferreira and Clifton (1986) not only looked at the effects of discourse context on parsing; they also focused on plausibility information linked to animacy. The critical contrasting cases are *the evidence examined* versus *the defendant examined*. With the animate noun *defendant*, the verb *examined* is naturally interpreted as the thing doing the examining; but with the inanimate noun *evidence*, the same syntactic analysis leads to an anomalous interpretation. Ferreira and Clifton reported that the animacy information did not block the garden-path, which led them to argue for a strongly modular architecture. This conclusion has been the target of numerous challenges (Altmann & Steedman, 1988; McClelland, 1987; MacDonald, Pearlmutter, & Seidenberg, 1994; MacDonald, 1993), and at this point, the consensus seems to be that animacy does indeed influence initial parsing (but see Clifton, Traxler, Mohamed, Williams, Morris, & Rayner, 2003). And, in turn, this view is taken to be evidence against modularity. Again, however, animacy is a very basic type of semantic information which some languages treat as a grammatical feature (Dahl & Fraurud, 1996). If the lexical entries for nouns include a simple +/– animacy feature, then it is not implausible to think that a modular parser might be able to access that information in a lexical entry and match it to a lexico-syntactic rule stating that the subject of an agentive verb such as *examine* must be animate. In addition, our arguments concerning the propose/dispose architecture also hold: If syntactic alternatives are constructed in parallel and then selected on the basis of plausibility, then what we have is what Altmann and Steedman (1988) called weak interaction, which is compatible with the modularity thesis. Once again we see that a result incompatible with the two-stage model of parsing (which assumes serial analysis plus reanalysis rather than a propose/dispose architecture) was taken as evidence against modularity itself.

MODULARITY AND THE VISUAL WORLD PARADIGM

The early 1990s saw the creation of a new paradigm for studying sentence processing—the VWP. The idea behind the paradigm is simple: From reading studies, it was known that what the eyes fixate on and how much time is spent during a fixation are closely tied to attention and processing (Rayner, 1977). The VWP extends this logic to spoken language processing by pairing spoken utterances with simple visual displays containing mentioned and unmentioned objects. The "linking hypothesis" (Tanenhaus, Magnuson, Dahan, & Chambers, 2000) is that as a word is heard, its representation in memory becomes activated,

and this in turn automatically triggers eye movements toward the named object as well as objects semantically and even phonologically associated with it (Huettig & McQueen, 2007). The acceptance and widespread adoption of the task occurred because it lined up with several trends in cognitive science: First, there was an emerging emphasis on cognition and action—that is, on trying to capture how cognitive processes might be used to guide intelligent action and behavior. Second, the idea of multimodal processing was also catching on, with many cognitive scientists wanting to understand the way different cognitive systems might work together—in this case, the auditory language processing system and the visuo-attention system associated with object recognition (Henderson & Ferreira, 2004; Jackendoff, 1996). Third, there was growing interest in auditory language processing generally, and in the investigation of how prosodic information might be used during comprehension (Bear & Price, 1990). And, most relevant to one of the themes of this volume, there was dissatisfaction with the lack of experimental paradigms for empirically evaluating the modularity hypothesis. Reading techniques were of course useful and often quite powerful, but not all questions regarding language processing can be studied with reading (e.g., the use of overt prosody), and some researchers were bothered by the idea that reading is not as fundamental or primary a mode of language as is spoken language. Thus, the VWP was enthusiastically adopted. By now, hundreds of studies have been reported making use of it in one way or another (for summaries, see Huettig, Rommers, & Meyer, 2011; Huettig, Olivers, & Hartsuiker, 2011; Ferreira, Foucart, & Engelhardt, 2013).

The report that triggered the widespread use of the VWP and that is also viewed as having fatally undermined the idea of a modular sentence processing system is Tanenhaus et al. (1995), reported in more detail in Spivey, Tanenhaus, Eberhard, & Sedivy (2002). This study adapted the Altmann and Steedman (1988) ideas concerning presuppositional support to the domain of visual contexts and spoken sentences that could be evaluated against them. To illustrate the study, consider the imperative sentence *Put the apple on the towel in the box.* At the point at which the listener hears *on the towel,* two interpretations are possible: Either *on the towel* is the location to which the apple should be moved, or it is a modifier of *apple.* The phrase *into the box* forces the latter interpretation because it is unambiguously a location. Referential Theory specifies that speakers should provide modifiers only when modification is necessary to establish reference (e.g., we do not generally refer to a big car if only one car is discourse-relevant). From referential theory, it follows that if two apples are present in the visual world and one of them is supposed to be moved, then right from the earliest stages of processing, the phrase *on the towel* will be taken to be a modifier, because the modifier allows a unique apple to be picked out. The listener faced with this visual world containing two referents should therefore immediately interpret the phrase as a modifier and avoid being garden-pathed, and this is indeed what the data seem to show (Farmer, Cargill, Hindy, Dal, & Spivey, 2007; Novick, Thompson-Schill, & Trueswell, 2008; Spivey, Tanenhaus, Eberhard, & Sedivy, 2002; Tanenhaus et al., 1995; Trueswell, Sekerina, Hill, & Logrip, 1999).

However, in recent work we have argued that the VWP is in many ways highly unsuited to the task of assessing modularity (Ferreira, Foucart, & Engelhardt, 2013). Of course, there are numerous other significant questions concerning sentence processing for researchers to ask, and for those questions, the VWP is quite useful (Huettig, Rommers, & Meyer, 2011). But recall once again the argument in *TMOM* that evaluating modularity requires an experimental approach that allows the measurement of online processing, and it should not encourage subjects to adopt atypical strategies for dealing with the experimental situation that might have little to do with normal sentence processing. Now consider how the original Tanenhaus et al. (1995) study was set up. Subjects were allowed to watch as an experimenter laid out a 2 × 2 arrangement of real objects to be manipulated in response to auditory instructions. Two quadrants contained the target and the distractor object and the other two quadrants contained two potential goal locations. Listeners then heard either a syntactically ambiguous or unambiguous instruction containing a prepositional phrase modifier. With this setup, the amount of time available to preview the visual context could be several seconds, and this time interval was not controlled. It seems likely that, during the preview period, listeners might start to generate fairly specific expectations about the form and content of the upcoming utterance, especially since all the utterances consisted of a transitive verb followed by a noun phrase and at least one prepositional phrase. After experience with some trials, the participant may form a template or underspecified form of the upcoming utterance. Thus, both the visual display and the sentences conform to predictable patterns, which participants can learn after a small number of trials (Fine & Jaeger, 2013).

To address these concerns about the suitability of the VWP for evaluating modularity in language processing, we conducted three experiments examining the effects of depriving subjects of a preview of the visual world, and we conducted a production experiment to determine how accurately naïve participants could guess the sentence likely to occur with a particular visual display (Ferreira et al., 2013). We found that participants were not garden-pathed in any condition when they were denied preview of the visual world prior to hearing the sentences, and we also reported that participants were surprisingly good at anticipating which object they would be asked to move and which objects would serve as potential locations. From these results we concluded that listeners engage in a fairly atypical mode of processing in VWP experiments with visual world previews and utterances that are highly similar to each other over all experimental trials: rather than processing utterances incrementally, they instead form an underspecified representation of what they are likely to hear next based on the content of the visual world. They then evaluate that prediction against the utterance itself. Now, it is certainly possible that humans sometimes process language in this way, but most people would agree that typical processing situations are quite a bit more open-ended.

For these reasons, then, we are not convinced that the VWP can provide strong evidence against modularity. Again, the technique is superb for getting at many important questions about how language is processed, but it is not clear

that it is suited for determining to what extent sentence processing is characterized by information encapsulation or domain-specificity.

MODULARITY AND SHALLOW PROCESSING

In the last fifteen years or so, a new framework for thinking about sentence comprehension has emerged. There are many variants with important distinctions among them, but what they share is the idea that comprehenders sometimes end up with an interpretation that differs from the actual input received—the interpretation is either simpler (construal), somewhat distorted (late assignment of syntax theory; good-enough processing), or outright inconsistent (noisy channel approaches) with the sentence's true content. These models have been difficult to pigeon-hole with respect to the modularity thesis. To try to sort out this issue, we feel it is important to shift the emphasis away from the features of modularity having to do with information encapsulation and toward the features that emphasize shallow outputs and limited central access to the internal operations of a module. Typically, psycholinguists have assumed that the output of any parsing or sentence processing module is a syntactic representation, which is turned over to "central" systems that relate to knowledge and belief. But we could assume instead that the output of the module is an interpretation, with structure-building operations being used to create it. If we adopt these assumptions, then we might not be surprised to discover that people can end up with interpretations that are simpler than the input would seem to mandate, and that might even be nonveridical.

To see how this argument works, let's begin with the mildest form of these models—the ones that assume representations that reduce the input in some way. One implementation is to allow representations to be underspecified (Sanford & Sturt, 2002). Consider construal (Frazier & Clifton Jr, 1997): A major assumption of the construal model is that syntactic structures are not always fully connected—adjunct phrases in particular (e.g., relative clauses) may instead simply get associated with a certain processing domain, "floating" until disambiguating information arrives. The parser thus remains uncommitted (Pickering, McElree, Frisson, Chen, & Traxler, 2006; Traxler, Pickering, & Clifton, 1998) concerning the attachment of the relative clause and the interpretation of the noun phrase and sentence that would follow from any particular attachment (see Frisson & Pickering, 2001; Sanford & Graesser, 2006; Sturt, Sanford, Stewart, & Dawydiak, 2004; Frisson S., 2009 for evidence favoring underspecified representations). A more radical possibility is that the attachment decision is strategically postponed, which is what the good enough language processing (henceforth, GE) theory predicts. Swets, Desmet, Clifton, Ferreira (2008) tested this idea by presenting participants with either fully ambiguous sentences (*the maid of the princess who scratched herself was embarrassed*) or disambiguated controls (*the son of the princess who scratched himself/herself was embarrassed*). The twist they introduced was to manipulate whether participants were required

The rationale was that, with easy questions, readers would not be motivated to resolve the ambiguity; with no interpretive consequences, they would be happy to leave the relative clause unattached. In contrast, with challenging questions, subjects would know they were being "called out" on their understanding of the sentences, and therefore attachment decisions were incentivized. The findings supported these predictions: they found a reading time advantage for sentences with ambiguous relative clauses relative to disambiguated controls when they were followed by easy questions, suggesting that they were easier to process due to the omission of the attachment operation. In contrast, when readers expected to receive questions probing their interpretation of the relative clause, critical regions of the sentences were read more carefully, and the ambiguity advantage was reduced. Other studies support the idea of underspecified representations for global syntactic structures (Tyler & Warren, 1987), semantic information (Frazier & Rayner, 1990), and coercion structures (Pickering, McElree, Frisson, Chen, & Traxler, 2006).

Another line of work explores psycholinguistic analogues of the so-called Moses illusion. The now-famous Moses illusion involves asking people a question such as *How many animals of each sort did Moses take on the ark*. Amusingly, most people answer "two" instead of pointing out that the presupposition behind the question is incorrect (Erickson & Mattson, 1981). The illusion is presumed to occur because Moses and Noah share a large number of semantic features, and semantic processing is often too shallow to allow the distinguishing features to be activated and integrated (see also Barton & Sanford, 1993). Sanford and Sturt (2002) suggest that shallow processing is linked to the focus-presupposition structure of a sentence: elements that are in semantic focus are processed deeply, but those that are assumed or backgrounded are processed more shallowly, leading to these kinds of semantic illusions. This proposal is reminiscent of one offered by Cutler and Fodor (1979), who found in phoneme monitoring studies that phonemes in words which are part of the focus of a sentence are detected more quickly than those that are in words located in the presupposed portion.

More radical variants of shallow processing models are those that allow the comprehension system to generate an interpretation that is even more discrepant from the input. Researchers in the field of text processing and cross-sentence integration have shown that readers are sometimes remarkably insensitive to contradictions in text (Otero & Kintsch, 1992), and also often fail to update their interpretations when later information undermines a fact stated earlier—for example, a character described initially as guilty of a crime but described later as exonerated remains tainted by the original charge in people's memory representations for the story (Albrecht & O'Brien, 1993). These ideas from text processing were exported to the sentence processing literature in a series of experiments showing that people did not seem to fully recover from garden-paths (Christianson, Hollingworth, Halliwell, & Ferreira, 2001). Participants were asked to read sentences such as *While the woman bathed the baby played in the crib* and then they answered a question such as *Did the woman bathe the baby?*. The surprising finding was that most people answered "yes," even though

the meaning of the reflexive verb *bathe* requires that the object be interpreted as coreferential with the subject in an intransitive structure (see also Slattery et al.; Ferreira, 2013). It appears that comprehenders are not entirely up to the task of syntactic reanalysis, and sometimes fail to revise either all pieces of the syntactic structure or all elements of the semantic consequences of the initial, incorrect parse. In addition, the more semantically compelling the original, garden-path interpretation, the more likely people are to want to retain it rather than revise it to the one consistent with the global grammatical form.

Townsend and Bever (2001) offered up a model of sentence comprehension very different from either the traditional two-stage model or the connectionist models of sentence processing that had become popular in the 1990s. The Townsend and Bever model implements an architecture similar to what has been suggested for decision-making (Gigerenzer, 2004; Kahneman, 2003), which distinguishes between a so-called System 1 and System 2 (or Type 1 and Type 2) for reasoning. System 1 is fast, automatic, and operates via the application of simple heuristics—"quick and dirty" rules that usually deliver a reasonably good result. System 2, on the other hand, is slow, attention-demanding, and that is able to consult a wide range of beliefs—essentially anything the organism knows and has stored in memory. Notice how closely this architecture echoes the one suggested in *TMOM*, where System 1 would map on to modular systems and System 2 would map on to the central reasoning system. Of course, one important difference is that Fodorian modules are assumed to be computational—for example, the modular parser consults a detailed, complex syntactic database when building an interpretation, rather than relying on a small set of simple heuristics. Nonetheless, the points of overlap are intriguing.

In Townsend and Bever's (2001) model, which they refer to as LAST (late assignment of syntax theory), sentences are essentially processed twice: first, heuristics are accessed which yield a quick and dirty meaning, and then syntactic computations are performed on the same word string to yield a fully connected, syntactic analysis. The second process ensures that the meaning that is obtained for a sentence is consistent with its actual form. Townsend and Bever also assume that the first stage is nonmodular and the second modular; this is to account for the use of semantics in the first stage, and the use of essentially only syntactic constraints in the second. However, this type of two-stage model can be construed in such a way that the first stage is modular, as long as the heuristics are essentially "reflexes"—as long as they are simple syntactic tricks that are blindly applied to the input without the benefit of consultation with other sources of knowledge. Two models similar in spirit to LAST but which assume a modular architecture for the first stage are the one offered by Ferreira (2003) and Garrett (2000). The Ferreira model assumes that the first stage consults just a couple of heuristics—a version of the "NVN" strategy, in which people assume an agent-patient mapping of semantic roles to syntactic positions, and an animacy heuristic, in which animate entities are biased toward subjecthood. The 2003 Ferreira model captures the results of a series of experiments in which participants appeared to frequently misinterpret passive sentences, particularly when they expressed an implausible

event with reversible semantic roles (e.g., the dog was bitten by the man = the dog bit the man). The application of heuristics in the first stage yields the dog-bit-man interpretation; a proper syntactic parse will deliver the opposite, correct interpretation, but the 2003 model assumes that it is fragile and susceptible to interference from the more frequent interpretation. Garrett (2000) offers a more explicitly analysis-by-synthesis model which incorporates the production system to yield what are widely believed to be top-down effects. A first pass, bottom-up process uses basic syntactic information to yield a simple parse which in turn allows for a rudimentary interpretation; then the language production system takes over and uses that representation to generate the detailed syntactic structure that would support the initial parse and interpretation.

Finally, a family of models has been proposed that assume people engage in rational behavior over what they understand to be a noisy communication channel. The channel is noisy both because listeners sometimes mishear or misread due to processing error or environmental contamination, and because speakers sometimes make mistakes when they talk. Thus, a rational comprehender whose goal is to recover the intention behind the utterance will normalize the input according to Bayesian priors. A body of evidence from research using event-related potentials (ERPs) helped to motivate these ideas (Van Herten, Kolk, & Chwilla, 2005; Kim & Osterhout, 2005). In these experiments, it is reported that subjects who encounter a sentence such as *The fox that hunted the poachers stalked through the woods* experience a P600 rather than an N400 upon encountering the semantically anomalous word, even though an N400 would be expected given that it is presumed to reflect problems with semantic integration. There is still not a great deal of consensus on what triggers P600s, but an idea that has been gaining traction is that it reflects a need to engage in some type of structural reanalysis or revision. The idea, then, is that when a person encounters a sentence that seems to say that the fox hunted the poachers, they "fix" it so it makes sense, resulting in a P600. Other models have taken this idea and developed it further (Gibson, Bergen, & Piantadosi, 2013; Levy, 2011; Levy, Bicknell, Slattery, & Rayner, 2009). These models seem less compatible with modularity than the other "shallow processing" approaches discussed earlier, because the information that is accessed to establish the priors can potentially be anything, ranging from biases related to structural forms all the way to beliefs concerning speaker characteristics (e.g., that a person with an upper-class speech style is unlikely to refer to his tattoo; Van Berkum, van den Brink, Tesink, Kos, & Hagoort, 2008). However, these noisy channel models have not yet been rigorously tested using a methodology that allows early processes to be distinguished from later ones. For example, it remains possible that comprehenders create a simple quick-and-dirty parse in a manner compatible with modularity and then consult information outside the module to revise that interpretation, right down to actually normalizing the input. Indeed, models designed to explain the comprehension of sentences containing self-repairs (*turn left uh right at the light*) assume mechanisms that allow input to be deleted so that the speaker's intended meaning can be recovered in the face of disfluency (Ferreira, Lau, & Bailey, 2004).

CONCLUSION

We began this chapter on the modularity of sentence processing with a summary of the main features of modules, because it is essential to appreciate that modularity is about more than information encapsulation—other key features include speed, automaticity, shallow outputs, and limited central access. If information encapsulation is treated not as simply one of a cluster of features but rather as "the heart of modularity," then the challenges to the notion that sentence processing is modular will continue to resonate in the cognitive science community, despite the arguments we've made here that many studies purporting to show interactivity can be reconciled with modularity. The key, we argued, is to appreciate two points. First, the so-called "two-stage" model associated with Frazier and colleagues (including the first author) is only one kind of modular model for sentence processing, so evidence against the two-stage model is not evidence against every instantiation of a modular model. And second, whether an influence of some piece of information constitutes a violation of information encapsulation depends critically on what information is contained in the "capsule." If we assume the sentence processing module can consult phrase structure rules only, then effects of even information such as verb subcategorization frames will be construed as disconfirming encapsulation. But if we accept that one of the aims of theory construction in the field of sentence processing is to develop an explanatory model of how the system works, then one key goal will be to determine what sources of information are in fact part of the sentence processing module. The goal would then be to determine what the proprietary databases are that the sentence processing module must consult. Certainly almost everyone would agree that information about what speakers from different social classes are likely to say probably does not belong in a parsing module, but information about verb subcategorization and even animacy are a different matter entirely. Moreover, the assumption of seriality relating to ambiguity resolution should be open to empirical scrutiny and revision as well; as we argued, a system with parallel consideration of alternative parses is compatible with modularity, and indeed mimics the architecture proposed as a bottom-up account of how lexical ambiguity is processed.

We would like to offer a further suggestion, and that is to emphasize the modularity features that cluster around shallowness rather than those that focus on encapsulation. We could assume that the output of the sentence processing module is not a parse in the sense of a detailed syntactic structure, but is rather the conditions for interpretation—a representation that includes information about thematic roles, focus-presupposition structure, and so on, but does not retain highly articulated syntactic forms or traces of movement operations. Complex, detailed syntax might get accessed and used by the module that creates an interpretation, but those detailed syntactic representations also are likely discarded once they serve their role of allowing a propositional interpretation to be built (Sachs, 1967). In addition, the module would be able to consult simple frequency based heuristics such as the NVN strategy (Townsend & Bever, 2001). And if the heuristics deliver a compelling interpretation faster than the

syntactic algorithms do (as in some cases of garden-path reanalysis, which can be time-consuming and often require accessing infrequent forms; MacDonald, Pearlmutter, & Seidenberg, 1994), then the systems subsequent to the sentence processing module may decide to proceed with what they have rather than waiting for more detailed analyses to be performed. These tendencies would result in phenomena such as the Moses illusion, garden-path misinterpretations, and misinterpretations of implausible passives. Moreover, if that interpretation still seems unsatisfactory in a Bayesian sense, then post-sentence processing modules may engage in the sort of normalization and correction that would be expected on a rational view of communication.

We end by returning to our opening observation: Modularity might be out of fashion, but this is not because the evidence against it is particularly compelling. Instead, we suspect that many researchers simply grew weary of the limited set of questions that were being asked in the context of testing modularity against one specific model of sentence processing, and so they decided to shift their energies to broader questions such as dialogue, embodiment, and language-vision interactions. This shift in focus has been positive for the field because so much more is known now than even ten years ago. However, much of what we've learned is not relevant to evaluating modularity, and these new approaches and findings are quite possibly compatible with it.

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4

The Unity of Consciousness and the Consciousness of Unity

THOMAS G. BEVER

Truth is stranger than fiction. . . . because fiction is obliged to stick to the possibilities.

Truth isn't

—Mark Twain, *"Following the Equator"*

A SENTENCE IS LIKE A (MINIATURE) OPERA

Music is often analyzed in relation to language to give perspective on the structural and formal aspects of language. But even the simplest sentence surpasses what music can tell us about it. A sentence in everyday use combines a stream of sound, with rhythm and pitch variations, with memorized units of meaning, an organizing structure that recombines those meaning units into a transcendental unified meaning that includes informational representations, general connotations, and specific pragmatic implications unique to the conversational context.

In other words, each sentence is a miniature opera of nature.

Children grow up surrounded by one opera after another, and miraculously learn to create their own. This is achieved in the context of experiencing only a small number of fully grammatical sentences, many ungrammatical ones, and very little specific feedback on their mistakes. This situation is generally referred to as "the poverty of the stimulus," which is the basis for the argument that much of linguistic structure must be innately prefigured (Chomsky, 1959,1965,1975,1980). Fodor (1981) broadened the implications of this argument beyond language into cognition in general: "The [argument from the poverty