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Modularity

Intermediate article

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CONTENTS

What is modularity?
Views and theories of modularity
Empirical evidence concerning modularity
Role of modularity in cognitive science
Summary

Various cognitive and perceptual processes may be separated or isolated from one another. Those processes may be understood as relatively independent subsystems, or modules.

WHAT IS MODULARITY?

A cognitive or perceptual process is said to be modular to the extent that it is an independent sub-process of the overall cognitive architecture. A module is a cognitive or perceptual subsystem whose workings are relatively independent from the rest of the cognitive architecture, and whose functioning can be analyzed and understood relatively independently of the overall system in which it is embedded. This idea is based on the more general engineering notion of 'near-decomposability' (Simon, 1981). According to Simon, a system is nearly decomposable if it is made of components whose behavior is, in most respects, not influenced by anything else going on in the system beyond what is given to the components as input.

Although the modularity of subsystems of perception and cognition has been discussed in various forms throughout the history of the philosophical study of mind, the view that psychological systems are to be understood as systems of interacting modules was particularly popular among the 'faculty psychologists' in the nineteenth century. These theorists typically held (apparently with little empirical justification) not only that there were independent modules governing various skills, abilities, and aspects of intelligence (e.g. a musical faculty, and a mathematical faculty), but that these modules had specific physical locations, and that the strength of a psychological faculty was correlated with the size of bumps on the head in the corresponding location.

The modern notion of modularity is expressed in terms of information processing. Here, the central idea is that various subsystems within the overall cognitive and perceptual system are relatively independent in terms of information processing; that is, they have relatively limited informational interaction with other cognitive subsystems. They are thus taken to be 'informationally encapsulated'.

This informational encapsulation has two 'directional' aspects. Firstly, there may be constraints on what information can get into the module and influence its working. This is sometimes called 'cognitive impenetrability'. A process is cognitively impenetrable to the extent that information that is available to other cognitive and perceptual processes is not available to the modular process, even though it may be relevant to the task being done. This is illustrated clearly by phenomena like the persistence of illusion. In the standard Müller–Lyer illusion (Figure 1), the visual system continues to perceive two lines as of different lengths, even when the viewer (after measuring, say) has available the information that they are in fact the same length. The visual system 'won't listen' to that outside information, and so the illusion persists.

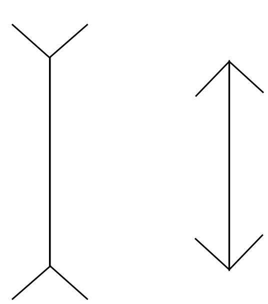

Figure 1. The Müller–Lyer illusion. Even when we know that the vertical lines are the same length, we continue to perceive the line on the left as longer.

Secondly, there may be constraints on the information apparently available to the module but unavailable to the rest of the cognitive system. This is called 'informational opacity'. For example, although a two-dimensional representation of (at least some of) a visual scene is probably computed along the path of visual processing, that two-dimensional representation seems not to be available for making other kinds of judgments. When a subject looks at a table top, the relative lengths and orientations of the two-dimensional projections (from the subject's perspective) of the edges of the table are not easily cognitively available to the subject to make judgments about. It seems that the visual system gives the rest of cognition some 'proprietary' description of visual input – perhaps as three-dimensional shapes – but reveals little of the methods and assumptions it uses to produce the representation that it gives as output.

Another feature commonly ascribed to modules is 'domain-specificity'. This is the idea that modular processes operate on only very specific domains. It is, however, a difficult notion to define precisely. Firstly, the notion of a 'domain' is not well defined; furthermore, domains, which are concerned with content rather than the form of processing, may change according to how we look at the information processed. A process might be seen as 'domain-specific' by virtue of doing only one particular form of calculation, but those calculations might be applied to representations with different sources and different contents.

Other features commonly ascribed to modules include both information-processing features (such as lack of competition for computational resources with other processes, and speed of operation) and features pertaining to the implementation and ontogeny of modules (that they should be innately specified, neurally specific and localized, hardwired, and with a characteristic pace and sequencing of development). But there are wide differences of opinion about which of these are critical to the notion, or should even be expected in modules that may be discovered.

VIEWS AND THEORIES OF MODULARITY

The most prominent and influential view on modularity has been that of Fodor (1983). According to Fodor, there is a fundamentally trichotomous architecture to cognition: 'transducers', which just convert stimuli directly into signals to be used in processing; 'input systems', which are informationally encapsulated modules that make inferences about the sources of those inputs; and 'central systems', which are non-modular ('holistic') processors responsible for general inference, reasoning, and the fixation of beliefs. Input modules are constrained and encapsulated subsystems, but, unlike transducers, they engage in real nondemonstrative inference that goes beyond the information given in the stimulus alone: for example, in the case of perception, generating hypotheses about the distant environment.

The linguistic and visual domains were suggested by Fodor as likely to involve significant modularity, and much subsequent research on modularity has focused on these two domains. The views of Marr (1982) and his followers on visual processing have also been influential in encouraging a modular view of the visual system. Marr (for whom the boundary of the visual module is defined by the representation he calls the 'two-and-a-half-dimensional sketch') insists that within the visual module 'the processes can be influenced little or not at all by higher-order considerations' (Marr, 1982, p. 351). Marr further encourages a view of the visual module as largely decomposable into submodules (e.g. for stereopsis, and for constructing the 'raw primal sketch'), each of which is more or less informationally encapsulated even from the rest of the activity in the visual module.

Similarly, in language processing, many theorists have looked for significant modularity. For example, in Jackendoff's analysis, 'syntax … has *no* direct interface with the articulatory–perceptual system; rather, it interfaces with phonological structure, which in turn interfaces with articulation and perception' (Jackendoff, 1997, p. 30).

Much broader and more ambitious accounts of mental modularity have also been proposed. For example, Gardner (1983) suggests that much of higher cognition and intellectual skill is modular. This is in contrast to Fodor's view that higher cognition is generally a holistic and non-modular central system. Other accounts have suggested modules ranging from the perceptually driven (e.g. Lerdahl and Jackendoff's (1983) modular account of musical cognition), to modules in higher cognition specified in much more abstract terms such as the 'theory of mind' module (Scholl and Leslie, 1999), which has been postulated to explain the apparent nonpervasiveness of the cognitive disturbances involved in autism. In the last decade of the twentieth century, some more extreme modularist hypotheses about the mind appeared. Prominent among these is Sperber's (1994) suggestion of 'massive modularity', where a great variety of modules are seen as permeating the structure of the cognitive architecture. Such views have typically been coupled with evolutionary accounts of these allegedly ubiquitous modules (e.g. Cosmides and Tooby, 1987), and have suggested modules whose 'domains' of operation are much more abstract than domains such as visual processing (e.g. Cosmides and Tooby's suggested 'cheater-detection module').

EMPIRICAL EVIDENCE CONCERNING MODULARITY

There has been significant experimental investigation of the kinds and degrees of informational encapsulation that various cognitive subsystems might exhibit. Much of this work has focused on the cognitive impenetrability of the systems of visual and linguistic perception. But some of the most obvious empirical evidence for at least some degree of modularity in such systems is phenomenological. For example, in the Müller–Lyer illusion, the phenomenological assessment of the stable output of visual processing (roughly, 'how it looks') strongly suggests that the output of visual processing is unaffected by (or cognitively impenetrable by) the information we have about the actual lengths of the lines.

In general, empirical investigation of the possible modularity of these systems has focused on what would appear to be relatively intelligent interpretation of stimuli, and considering whether information for solving such problems is likely to come from generally available (non-encapsulated) cognition about the domain (which would contradict the claim of impenetrability) or from constraints plausibly built into the subsystem itself. Cases in which general background knowledge is actually in conflict with the apparent inference made by the purported module are particularly salient. Thus, with the Müller–Lyer illusion, the background knowledge of a typical subject includes the knowledge that this is a familiar illusion and that the lines are actually the same length. But the apparent lack of penetration of the visual system by this information, combined with the fact that the actual stimuli (both as objects and as retinal stimulations) are lines of the same length, seems to imply that while the visual system is making an inference that goes beyond the stimulus in interpreting the input, it uses only its own limited information in the processing leading to that inference.

Perhaps the best evidence of modularity comes from early processes in vision. Much of this evidence concerns perceptions of illusions, like the Müller–Lyer illusion, and rules and strategies apparently used in visual perception but which are hidden from our notice. Rock (1983) has compiled a catalogue of such data, including facts about non-obvious completions of hidden and illusory visual contours, lightness constancy across illumination changes, and many others. Marr's (1982) analysis of the visual extraction of depth information from stereoscopic images also gives a clear illustration of powerful inferences made within the visual system using rules which the subject would seem to have neither access to nor the ability to override.

Some aspects of language processing also appear to be modular. Competence in learning a language appears to be quite independent of general problem-solving skills – an observation that goes back at least to Descartes, and that has been supported by recent research (e.g. Karmiloff-Smith *et al*., 1997), including brain lesion studies that suggest that localized lesions can affect language skills without significantly affecting other aspects of cognition (e.g. Caramazza *et al*., 1983). And careful chronometric studies of the 'phoneme restoration effect' – one of the most widely-recognized contextual effects on early language processing – have shown it to be plausibly a result of biases introduced by the postperceptual judgments of the subjects, and so perhaps not after all in violation of modularity (Samuel, 1981).

The evidence concerning modularity in other domains is more mixed and controversial; and in all domains, there are some threads of evidence that seem at least to limit the modularity. Farah (1994) has argued that lesion and deficit studies do not support, and sometimes even refute, the suggestion of neurological localization of speech functions. The presence of various sorts of top-down effects on perceptual recognition (e.g. in gestalt shifts) suggests that information flow into perceptual modules is not completely constrained (e.g. McClamrock, 1989). And the 'McGurk effect' (McGurk and MacDonald, 1976) seems to suggest that the process of recognition of even relatively low-level features of language like phonemes is penetrated by information coming from the visual modality, so that the face movements that are seen can influence which phoneme is heard.

ROLE OF MODULARITY IN COGNITIVE SCIENCE

The idea of modularity has had two distinct roles in contemporary cognitive science: one descriptive, the other methodological. In its descriptive role, modularity – and especially its notion of informational encapsulation – is one of many information-processing concepts used for constructing explanatory cognitive models. Empirical results such as those considered above seem to imply the need for a model of the relative separation of, say, perception of (apparent) length and judgments about the properties of objects. Determining the extent to which such results demand modular models of processing is a difficult but not unusual problem of theory construction and testing.

The methodological role of the notion of modularity is more subtle. Modularity is supposed to provide a kind of 'divide and conquer' strategy for the study of cognition: by defining subsystems whose behavior in relative isolation is similar enough to their behavior in the real, embedded context, we might hope to come gradually to understand the complex working of a system. Conversely, unchecked top-down information flow into perceptual processes would make them difficult to analyze. As Marr puts it, the information-processing approach would be likely to fail with 'systems that are not modular … that is to say, complex interactive systems with many influences that cannot be neglected' (Marr, 1982, p. 356). And as Fodor puts it, 'the limits of modularity are also likely to be the limits of what we are going to be able to understand about the mind … [because] the condition for successful science (in physics, by the way, as well as psychology) is that nature should have joints to carve it at: relatively simple subsystems which can be artificially isolated, and which behave in isolation in something like the way that they behave *in situ*' (Fodor, 1983, pp. 126–128).

As Marr puts it for the case of vision, '[if] we can experimentally isolate a process and show that it can still work well, then it cannot require complex interaction with other parts of vision and can therefore be understood relatively well on its own' (Marr, 1982, p. 101). However, even where this experimental isolation can be achieved, the fact that such an isolable subsystem 'cannot require complex interaction with other parts' does not entail that it can 'be understood relatively well on its own'. The subsystem might still roughly accomplish its task under informationally impoverished conditions, but it might do so in a way that is not a good indication of its normal pattern of working. For example, it might take longer and resort to less efficient means to solve a problem than it would under conditions of normal informational access, where it might work more quickly, with less effort, and with fewer resources. Or it might work as quickly, but with greater error. The case of isolation would then give a misleading view of how the process normally works.

It may be useful to isolate processes in order to study them, but there is a concern that decomposition of the cognitive system has more to do with hopeful simplifying assumptions about cognition than with its actual structure. The accounts of 'massive modularity' mentioned above are perhaps the most optimistic but least empirically grounded of the current modularist views. And Fodor (2000) has recently suggested that assumptions of modularity and related strategies of decomposition have been applied too freely in the cognitive theorizing of the last years of the twentieth century, and are of much more limited applicability than is often suggested.

SUMMARY

Modularity, taken as the decomposability of cognition into components that can be considered in relative isolation from one another, is both a methodological ideal and, sometimes, an assumption that has influenced and guided research in cognitive science. Although there is some evidence to support the idea of modularity, especially in the early stages of processing involved in language and vision, the application of the idea currently exceeds the evidence for it. Modularity is sometimes more an optimistic guess, intended to guide explanation, than a conclusion of experiment and completed theory. Its soundness is a subject of widespread debate, and one of the central metatheoretical issues that cognitive science currently confronts.

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