# Human General Intelligence as a Domain General Psychological Adaptation[1]

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## ABSTRACT

The concept of general intelligence as measured by standard IQ tests has always been a difficult fit for evolutionary psychology. This paper argues that intelligence is a set of domain general abilities which was not designed to solve any specific problem from the human evolutionary past. Rather, general intelligence equips humans to make mental models of the environment and to develop action plans based on these models. It is thus ideally suited to solve evolutionarily ancient problems of survival and reproduction, but also to solve novel problems and to create ideologies (e.g., Marxism) that guide and rationalize behavior. In the human Environment of Evolutionary Adaptedness (EEA), these action plans evolved as means of achieving affective states, such as assuaging hunger, achieving social status, or other evolved goal states. Moreover, it is argued that the most important mechanism underlying general intelligence, the executive processes of working memory, is not tied to regularities in the EEA.

## THE MODULARITY DEBATE IN EVOLUTIONARY PSYCHOLOGY

Early on, the field of evolutionary psychology coalesced around the work of Leda Cosmides and John Tooby (1992) whose views conflicted with two aspects central to the century-long research tradition that has grown up around intelligence. First, the whole point of intelligence quotient (IQ) testing was to provide a measure of individual differences in cognitive ability. Evolutionary psychology, on the other hand, concentrated on human universals. For example, regarding personality research, Tooby and Cosmides (1990) proposed that variation in personality was non-adaptive “noise” (but see MacDonald, 1995, 2012; Penke, Denissen & Miller, 2007).

In the area of intelligence, it is difficult to conceptualize individual differences as noise, since individual differences have a very large number of real world correlates that have been linked to reproductive success. Thus, in contemporary societies, IQ is linked with higher social status, and greater income and education, but negatively with fertility (Gottfredson, 2007). There is also a long tradition linking increasing hominid brain weight (corrected for body size), increasing encephalization, longevity, and a relatively K-style reproductive pattern (e.g., later age of reproduction) (see Rushton, 2004). The linkage between IQ and variation in life history patterns indicates that variation in IQ is an aspect of suite of life history traits and thus unlikely to be simply non-adaptive noise.

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Even more problematic—and the focus of the present essay— has been that research on intelligence has centered around the concept of intelligence as a general purpose problem solver, whereas the emphasis within evolutionary psychology has been to conceive the mind as a set of adaptations designed to solve specific problems encountered in the EEA. The basic logic of evolutionary psychology is that when the environment presents long-standing problems and recurrent cues relevant to solving them, the best solution is to evolve domain-specific mechanisms, or *modules,* specialized to handle specific inputs and generate particular solutions (Geary, 2005).

However, while all parties to the discussion agree that modules designed to solve specific problems have evolved, controversy surrounds the proposal that some evolved psychological mechanisms do not fit standard conceptualizations of modules. For example, Chiappe and Gardner, 2012 emphasize the distinction between systems that utilize implicit processing and systems characterized by explicit processing.

Implicit and explicit mechanisms may be contrasted on a number of dimensions (e.g., Geary, 2005; Lieberman, 2007; MacDonald, 2008; Satpute & Lieberman, 2006; Stanovich, 1999, 2004; see Table 1). Implicit processing is automatic, effortless, relatively fast, and involves parallel processing of large amounts of information. Implicit processing is characteristic of what Stanovich (2004) terms the autonomous set of systems, which responds automatically to domain-relevant information. For example, the visual systems of monkeys and humans contain numerous areas specialized for different aspects of vision (e.g., Zeki, 1993). Areas specialized for color and for motion are sensitive to different aspects of visual stimulation; processing in these different areas occurs in parallel and results in a unitary image. Other modules proposed in the cognitive literature include modules for social exchange (Cosmides, 1989), theory of mind (Baron-Cohen, 1995), fear (LeDoux, 2000), folk physics (Povinelli, 2000), and grammar acquisition (Pinker, 1994).

Although implicit processing is characteristic of evolved modules, it is not restricted to evolved modules. It occurs in a wide range of circumstances, including skills and appraisals that have become automatic with practice or repetition, perceptual interpretations of behavior (e.g., stereotypes), and priming effects (Bargh & Chartrand, 1999). Modules, as defined here, therefore need not be domain specific; they may also result from domain general processes of associative and implicit learning (Stanovich, 2004, p. 39; see below).

On the other hand, explicit processing is conscious, controllable, effortful, relatively slow, and involves serial processing of relatively small amounts of information. Such processing is characteristic of what Stanovich (2004) terms the analytic system characterized by context-free mechanisms of logical thought, planning, and cognitive control. The analytic system is sensitive to linguistic input that allows for explicit representations of the context, including hypothetical representations of the possible consequences of actions. Explicit processing is “typically experienced as an internal linguistic monologue emerging in a freely chosen way from oneself and [is] associated with the experience of agency or will” (Satpute & Lieberman, 2006, p. 88).

The view that general intelligence is domain general has been defended by Chiappe and MacDonald (2005) and attacked by Barrett and Kurzban (2006). Chiappe and Gardner (2012) responded to Barrett and Kurzban who in turn wrote a rejoinder (Barrett & Kurzban, 2012). I summarize the main points of this discussion, and the following section develops a proposal for circumventing a particular argument against domain generality proposed by Barrett and Kurzban (2012).

Barrett and Kurzban cheerfully acknowledge that their position represents a substantial retreat from original formulations of evolutionary psychologists. As originally formulated, evolutionary psychologists proposed that the mind must consist solely of a suite of mechanisms designed to solve specific problems (Tooby and Cosmides, 1992). That is, these mechanisms are activated by particular content domains for which they are specifically designed.

Table 1: Characteristics of Implicit and Explicit Cognitive Systems

| **Implicit System** | **Explicit System** |
|---|---|
| Not Reflectively Conscious | Conscious |
| Automatic | Controllable |
| Fast | Relatively Slow |
| Evolved Early | Evolved Late |
| Parallel Processing | Sequential Processing |
| High Capacity | Limited by Attentional and Working Memory Resources. |
| Effortless | Effortful |
| Evolutionary Adaptation or acquired by practice | Acquisition by Culture and Formal Tuition |

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> Advocates of evolutionary views do not deny that humans learn, reason, develop, or acquire a culture; however, they do argue that these functions are accomplished at least in part through the operation of cognitive mechanisms that are content-specialized—mechanisms that are activated by particular content domains and that are designed to process information from those domains. (Tooby & Cosmides, 1992, p. 166)

Barrett and Kurzban (2006) retreat from supposing that content specificity is the hallmark of a module. Instead, domains are construed as content-free rules that make information able to be processed by the brain: “Domains should be construed in terms of the formal properties of information that render it processable by some computational procedure. In this sense, even the rules of so-called content-independent logics—for example, modus ponens— are domain specific, in that modus ponens operates only on propositional representations of a particular form” (Barrett & Kurzban, 2006, p. 634). Thus, for example, working memory or modus ponens becomes modular simply because the input to working memory must be encoded in a specialized manner.

Since the brain necessarily has formatting requirements for all possible inputs, all psychological mechanisms are necessarily modular by this definition. It should be apparent that this is a radical departure from the original thrust of evolutionary psychology emphasizing content-specialized mechanisms designed to solve specific problems. Modus ponens and working memory are not designed to solve any particular problem; rather they may be used to solve a very wide and undefined range of problems—solving mathematical problems, making analogies, or figuring out the most efficient way to manufacture pianos, all of which involve explicit processing.

As Chiappe and Gardner (2012) note, “if something is ruled out by the Barrett and Kurzban (2006) approach, it certainly isn’t anything that has been taken seriously in psychology.” Since all psychological mechanism are by definition modular, Barrett and Kurzban’s argument would vitiate Cosmides & Tooby (2002) claim that domain-general mechanisms are inherently weak because “jacks of all trades are masters of none. They achieve generality only at the price of broad ineptitude” (p. 170). Chiappe and MacDonald (2005) showed that “jacks of all trades” could evolve, only to have it argued that even jacks of all trades like working memory and modus ponens turn out to be modular and domain specific because they necessarily have formatting requirements for their inputs. One wonders what mechanisms Tooby and Cosmides were attempting to exclude in their rejection of domain generality, since now it turns out that all conceivable psychological mechanisms are necessarily modular and domain specific. Clearly, the view of Tooby and Cosmides (1992, p. 77) that “organisms are integrated collections of problem-solving mechanisms” has been lost in this reformulation. No problem need be specified; since the emphasis has been shifted to the very weak claim that all inputs to the brain must be formatted in specific ways in order to be processed by the brain.

Barrett and Kurzban (2012, pp. 684–685) adopt another definition of module, which, like the definition in terms of formatting requirements, necessarily includes all psychological mechanisms:

> Our view of modularity defines modules in precisely this way: if *X* is a *mechanism,* and if it has a *design* (i.e., has been shaped by the process of natural selection acting over evolutionary time), then it is what we are calling a "module."

Thus anything that evolved must necessarily be modular, including mechanisms such as working memory and modus ponens. Since evolution is the only reasonable way that any mechanism could have come into existence, this definition necessarily includes all psychological mechanisms.

The issue then becomes, are there limitations on what types of mechanisms can evolve? Traditionally, evolutionary psychologists have argued that the concept of evolution by natural selection does indeed place limits on what types of psychological mechanisms can evolve. These limits derive from standard definition of an adaptation as necessarily being tied to environmental regularities:

> An adaptation is (1) a system of inherited and reliably developing properties that recurs among members of a species that (2) became incorporated into the species' standard design because during the period of their incorporation, (3) they were coordinated with a set of **statistically recurrent structural properties outside the adaptation** (within in the environment or in other parts of the organism), (4) in such a way that the causal interaction of the two (in the context of the rest of the properties of the organism) produced functional outcomes… (Tooby & Cosmides, 1992, pp. 61–62; my emphasis)

> It is only those **conditions that recur, statistically accumulating across many generations**, that lead to the construction of complex adaptations . . . For this reason, a major part of adaptationist analysis involves sifting for these environmental or organismic regularities or invariances. (Tooby & Cosmides, 1992, p. 69; my emphasis)

The proposal then is that adaptations can only evolve by tracking regularities. Cues to these regularities are the proper domain of the adaptation; hence all adaptations are domain specific and therefore modular. Barrett and Kurzban (2012) clearly agree that recurrences are essential to the construction of adaptations and they attempt to analyze the ability to solve novel problems within this framework:

> Here, we think, there is a definitional issue: at a certain level, the terms "design" and "novelty" are incompatible with each other, because **adaptation is impossible without *some* environmental signal, even if statistical and fuzzy, to adapt to.** If "novel" means "bears no resemblance to anything in the past," then design to deal with novelty is a priori impossible. … To be clear, we don't think adaptations designed for novelty are impossible, but only if we redefine "novelty" so as to not make adaptation to it impossible. (Barrett and Kurzban, 2012, p. 686; my emphasis)

Thus, according to Barrett and Kurzban (2012), adaptation to novelty would be impossible without recurrences to adapt to. They show that some adaptations may respond to novelty as a byproduct of past selection. Novel tokens of types that recurred over evolutionary time are a paradigmatic example. For example, a novel food item (say genetically modified food, or a novel creation of a chef) would be processed by the digestive system because it has enough similarity to the sorts of food for which the digestive system was designed. Similarly, a novel three-dimensional object will be processed in a functional manner by the visual system because the novel item does not depart substantially from the regularities that resulted in the evolution of the system.

The problem here is that, although such examples are compelling accounts of particular cases, they do not provide an analysis of the actual mechanisms that form the basis of human general intelligence, such as the executive processes of working memory discussed in the following. That is, it would have to be shown that (1) the executive processes of working memory evolved to track a certain environmental regularity and (2) that these processes are then able to solve specific types of novel problems because the novel problems have sufficient similarity to the recurrent features of the EEA that originally resulted in the evolution of the executive processes of working memory. So far as I am aware, this argument has not been made in the literature, and, given the extremely wide range inputs to working memory, it would appear to be a daunting problem to find what environmental regularities the executive processes of working memory were originally designed to respond to.

## HOW ADAPTATIONS CAN EVOLVE IN THE ABSENCE OF ENVIRONMENTAL RECURRENCES.

In the following, I elaborate an argument for how psychological adaptations can evolve in the absence of environmental regularities based on MacDonald, 1991 (see also Chiappe & MacDonald 2005; MacDonald & Hershberger, 2008). The claim by Barrett and Kurzban (2012) that there "must be some environmental signal" in order for adaptations to evolve is an attempt to solve the *frame problem* discussed by cognitive scientists (e.g., Dennett, 1987; Fodor, 1983). The frame problem is the problem of determining which problems are relevant and what actions are relevant for solving them. Environmental regularities effectively frame a problem to be solved and enable the evolution of mechanisms able to respond to the regularity. The regularity provides a built-in sense of relevance—a built-in sense of what the problem is. Input stemming from an environmental regularity is automatically framed by the relevant modules because they are designed to be attuned to a particular environmental regularity.

The above is a compelling argument for the existence of at least some modular, domain-specific mechanisms. Nevertheless, an important aspect of evolution has been to solve the frame problem in a manner that does not rely on environmental regularities for the evolution of psychological adaptations. The proposal is that humans and other animals have evolved motivational systems that solve the frame problem by equipping them with systems that provide signals when their evolved goals are being met. For example, the hunger mechanism provides a signal telling the child to look for food and begin feeding. How the child goes about getting a familiar food item is unspecified and does not depend on environmental regularities. However, the motivational system effectively frames the problem: It tells the child what the problem is (the feeling of hunger), and it tells the child when the problem has been solved (satiation). This signal is not a response to an environmental regularity, but rather signals that an internal goal has been met; further, achievement of this internal goal (e.g., satisfying hunger) must have been linked to reproductive success in the EEA; but there is no need for reproductive success to be linked to any environmental regularity. As described in the following, such a system enables the evolution of mechanisms able to take advantage of ephemeral environmental regularities (classical and operant conditioning) or imitate successful others (social learning). Ultimately, via the elaboration of the domain general mechanisms of general intelligence, affectively grounded systems enable organisms to solve novel problems and (more commonly) to solve ancient evolutionary problems by novel means — means that are more efficient than any possible architecture that is linked to environmental regularities.

From this perspective, a watershed event in evolutionary history was the evolution of psychological signals—positive or negative feelings—that inform the animal when its goals of survival and reproduction are being met or unmet. Imagine a primitive organism equipped only with "if *p,* then *q*" devices, where *p* represents recurrent environmental events and *q* represents an evolved response to the event: If a certain environmental situation *p* occurs (e.g., presence of food), then respond with behavior *q* (eating). Such an organism would completely satisfy the requirements for a psychological adaptation as described by Barrett and Kurzban (2012): The mind is constructed with mechanisms designed to respond adaptively to recurrent environmental events (the presence of *p*'s). The mechanism is entirely modular, designed to deal exclusively with a particular kind of input (domain-relevant information) by encoding the input in a manner that can be processed by the animal's nervous system; and it produces a particular kind of output (e.g., behavior such as eating *p*), thereby solving a very specific problem. Its disadvantage would be that there would be no way to take advantage of nonrecurring information in order to find food—for example, the information that a certain ephemerally available stimulus is a cue for food (classical conditioning), the chance discovery that a certain behavior is a good way to obtain food (operant conditioning), or observing another animal successfully obtaining food (social learning).

Examples of "if *p*, then *q*" systems are the fixed signaling systems of nonhuman primates and other animals discussed by Oller and Griebel (2005). Such signals occur in particular recurrent contexts (e.g., threat, danger, alarm, greeting) and are coupled to the specific circumstances surrounding their use and the functions they serve. Their meaning is therefore fixed. The breakthrough in human language was the evolution of *contextual freedom,* in which each sound can be produced voluntarily and can be coupled, via learning, to an endless variety of social functions that are not dependent on environmental recurrences. These functions can change quickly over time, making them ideal for dealing with uncertain, novel situations. As in the case of social learning (see below), there is undoubtedly a great deal of specialized neural machinery underlying human language ability. However, like social learning, it functions as a domain-general system, with no evolutionarily fixed inputs or outputs and no fixed relationship to particular environmental regularities. Even infants 3 to 6 months of age are capable of many-to-many mappings between signal and function; there are a wide variety of signals, many with no social function at all (Oller & Griebel, 2005).

The evolution of motivating systems goes a long way toward solving the frame problem. (It is also, quite probably, the evolutionary origin of consciousness, because by definition, the animal must be aware of these motivational cues.) A hungry child may indeed be confronted with an infinite number of behavioral choices, but such a child easily narrows down this infinite array by choosing behaviors likely to satisfy his or her hunger. The motive of hunger, and the fact that certain behaviors reliably result in satiating hunger, give structure to the child’s behavior and enable him or her to choose adaptively among the infinite number of possible behaviors. The child’s behavior is not random because it is motivated by the desire to assuage the feeling of hunger.

Motivational mechanisms can thus be thought of as a set of adaptive problems to be solved but whose solution is underspecified. Learning mechanisms are examples of the evolution of *hyperplastic* mechanisms, mechanisms such as the immune system, which are unspecialized because they are not responsive to recurrent environmental events and because there is no selection for a particular phenotypic result (West-Eberhard, 2003, p. 178). Such systems enable the evolution of any cognitive mechanism, no matter how opportunistic, flexible, or domain-general, that is able to solve the problem. The child could solve his or her hunger problem by successfully getting the attention of the caregiver. The problem could be solved if the child stumbled onto a novel contingency (how to open the refrigerator door); or it could be solved by imitating others eating a novel food; or the child could develop a sophisticated plan based on imagining possible outcomes and relying on mechanisms of general intelligence—the *g factor* of intelligence research. None of these ways of solving the problem need result in solutions that were successful in our evolutionary past. This is illustrated in Figure 2.1. below.

Level 1 EVOLVED MOTIVE DISPOSITIONS

Level 2 PERSONAL STRIVINGS

Level 3 CONCERNS, PROJECTS, TASKS (Utilize Domain-General Mechanisms)

Level 4 SPECIFIC ACTION UNITS (Utilize Domain-General Mechanisms)

EXAMPLE:

Evolved Motive Disposition: Intimacy

Personal Striving: Intimate Relationship with a particular person

Concern, Project, Task: Arrange Meeting, Improve appearance, Get promotion

Action Units: Find phone number, Begin dieting, Work weekends

**Figure 2.1.** Hierarchical Model of Motivation Showing Relationships Between Domain-Specific and Domain-General Mechanisms ; SOURCE: Adapted from Emmons (1989).

Motivation represents a major point of contact between evolutionary approaches and approaches based on learning theory. Learning theories generally suppose that some motivational systems are biological in origin, but traditionally they have tended toward *biological minimalism.* They posit only a bare minimum of evolved motivational systems. For example, traditional drive theory proposed that rats and people have drives to consume food, satisfy thirst, have sex, and escape pain. For an evolutionist, this leaves out a great many other things that organisms desire innately. Personality theory provides a basis for supposing there are several evolved motive dispositions (EMDs), including evolved motives for seeking out social status, sexual gratification, felt security (safety), love, and a sense of accomplishment (MacDonald, 1991, 1995, 2012). Glenn Weisfeld (1997) has expanded on this list by specifying 16 affects that provide positive or negative signals of adaptive significance: tactile pleasure and pain, thirst, tasting and smelling, disgust or nausea, fatigue, drowsiness, sexual feelings, loneliness and affection receiving, interest and boredom, beauty appreciation, music appreciation and noise annoyance, humor appreciation, pride and shame, anger, and fear. One can quarrel with the details of such a list, but there is little doubt that there are a wide range of positive feelings that humans are innately designed to experience and a wide range of negative feelings that humans are innately designed to avoid.

One type of novelty that organisms must adapt to is ephemeral regularities. Whereas longstanding regularities give rise to adaptations as traditionally understood, ephemeral regularities are novel situations with huge benefits for organisms able to exploit them. The quite ancient solution to the problem of exploiting novel regularities has been the evolution of domain general learning mechanisms that are not tied to environmental regularities.

The pursuit of evolved motives allows for flexible strategizing and the evolution of domain-general cognitive mechanisms—learning mechanisms and the mechanisms of general intelligence useful for attaining evolved desires. This fits well with research showing that problem solving is opportunistic: People satisfy their goals, including evolved goals such as satisfying hunger, by using any and all available mechanisms. For example, children typically experiment with a variety of strategies and then select the ones that are effective. Children are *bricoleurs*, tinkerers who constantly experiment with a wide range of processes to find solutions to problems as they occur. Children "bring to bear varied processes and strategies, gradually coming through experience to select those that are most effective. . . . Young bricoleurs . . . make do with whatever cognitive tools are at hand" (Deloache, Miller, & Pierroutsakos, 1998, p. 803).

Although this paper is concerned mainly with general intelligence, mention should be made of mechanisms that channel learning in adaptive directions and allow for the transmission of novel cultural variants in the absence of recurrent cues over evolutionary time. For example, prestige (dominance, power), warmth (prototypically from parents, enabling parents to be effective models for children) and similarity of model to self (e.g., children are biased toward learning from same-sex models) bias social learning; all of these biasing mechanisms allow for the transmission of novel cultural variants that are themselves not tied to recurrences in the EEA (MacDonald, 1991). Barrett and Kurzban (2012) accept this, but argue that biasing mechanisms for social learning (their example relates to prestigious models) allow novel cultural variants to spread only if accepting cultural variants on the basis of the prestige of the model is associated with reproductive success. Thus, instead of learning being attuned to environmental recurrences acting over evolutionary time, they propose that the regularity ultimately is between reproductive success and acceptance of a cultural variant.

Nevertheless, there is no theoretical necessity for biasing mechanisms that are tied to reproductive success in order for domain general learning to evolve. As noted above, it is sufficient if the satisfaction of internal affective states is linked to reproductive success. Thus, humans are able to learn from models that do not have prestige or warmth or any of the other biasing mechanisms uncovered by social learning research if the learner sees the modeled behavior as successful in achieving a desired goal and regards it as useful in some way. Quite often, the utility of socially learned behaviors is measured in quite practical terms—the probable outcome of learning on mundane proximal goals far removed from reproductive success, such as repairing a TV set, baking a cake. Models are attended to if they are successful in producing the desired behavior and if the learner has a motive for learning the behavior. Evolved biasing mechanisms need not enter the picture.

Similar considerations apply to classical and operant conditioning. As an example of a contrary point of view, Tooby and Cosmides (1992; p. 95) claim that support for domain-generality in operant conditioning relies on data from "experimenter-invented, laboratory limited, arbitrary tasks." They criticize traditional learning experiments for not focusing exclusively on ecologically valid, natural tasks—tasks that deal with problems that were recurrent in the animal's EEA.

Such a stance obviously begs the question of whether there are problems that were not recurrent in the evolutionary past that can be solved by learning in the absence of biasing mechanisms. It is certainly true that investigations of learning tasks, especially in animals, have sometimes revealed specialized learning mechanisms (e.g., rats' predisposition to link nausea with recent food intake [Garcia & Koelling, 1966] ). However, an equally remarkable aspect of learning is that, for example, pigeons *can* learn to peck keys to satisfy their evolved goals of staving off hunger even in experimenter-contrived, arbitrary, novel situations without environmental regularities stemming from the animal's EEA. Although pecking for food is undoubtedly a species-typical behavior for pigeons, pigeons, like rats learning to push levers, are also able to learn a variety of arbitrary, experimenter-contrived behaviors that are not components of the animal's species-typical foraging behavior. In other words, they are able to solve a fundamental problem of adaptation (getting food) in a novel and even arbitrary environment that presents none of the recurrent associations between the animal's behavior and obtaining food experienced in the animal's EEA. Similarly, humans are able to learn lists of nonsense syllables—another example highlighted by Tooby and Cosmides (1992), despite the fact that learning such lists was not a recurrent problem in the EEA. People can learn such lists because their learning mechanisms can be harnessed to new affectively tinged goals, such as getting course credit as a subject in a psychology study.

In general, operant conditioning, classical conditioning and social learning did not evolve to link specific recurrent aspects of the EEA with reproductive success. The mechanisms underlying these abilities imply a great deal of evolved machinery, and there are important cases where evolution has shaped learning in ways that depart from domain-generality. However, in general, there are no specified input to these systems linked to environmental regularities in the EEA. The input to associational mechanisms of rats and humans verges on whatever is detectable by the sense organs, and operant behaviors span virtually the entire range of physically possible motor behaviors. Because of their domain-generality, these mechanisms allow humans and animals to solve problems with features not recurrent in the EEA.

Finally, there are examples in nature where animals, like humans, are able to go beyond associative learning mechanisms in solving novel problems that are not connected to regularities in the EEA. Thus New Caledonia crows are able to develop a causal rule that enables them to solve novel problems (Taylor et al., 2010). Further, they quickly process causal information and use it to solve novel problems utilizing new tool types (dropping stones into water so that food items are accessible) that are not utilized in their natural environments and have no relationship to their established behavioral repertoire (Taylor et al., 2011). These results do not appear explicable by the use of associative learning, nor is the causal rule linked to regularities utilized by the crows in their EEA. Rather, the results indicate an ability to develop and utilize an abstract causal rule in order to solve an affective goal—assuaging hunger—by novel means.

There has been considerable debate on what evolutionary pressures resulted in human general intelligence: rapid climactic change, ecological maximization, social competition or some combination of these (see Geary, 2005 for a review). Note that the above argument is compatible with all of these scenarios. That is, the solution of novel problems is not central to the argument. Rather, the affective basis of domain generality is evolutionarily ancient, resulting primitively in simple associative learning mechanisms (classical and operant conditioning), social learning, the ability to form abstract causal rules (in New Caledonia crows), and finally human general intelligence as a suite of mechanisms, particularly the executive processes of working memory (see below) underlying the ability to manipulate information from a variety of sources in order to achieve goals that may or may not be linked with affective motivational systems derived from the evolutionary past (i.e., EMD's; MacDonald, 1991]). Besides solving novel problems, human general intelligence is adept at finding novel, more efficient ways to solve old problems of survival and reproduction (e.g., finding better ways to extract resources from the environment or developing more effective military tactics).

## DOMAIN-GENERAL MECHANISMS UNDERLYING GENERAL INTELLIGENCE: WORKING MEMORY CAPACITY AS A PARADIGM

Perhaps the most obvious way that general intelligence is domain general is that the *g* factor of general intelligence correlates with a very wide range of mental abilities. Individuals who are good at mathematical reasoning also tend to be relatively good at verbal comprehension and rotating figures in space. It seems unlikely then, that general intelligence evolved to solve particular problems tied to regularities in past environments. Indeed, common models of general intelligence propose that the *g* factor is at the top of a hierarchy of a set of modular processes, such as verbal and spatial reasoning, that have unique inputs with very specific formatting requirements and unique outputs (e.g., MacDonald & Hershberger, 2005).

For example, Case, Demetriou, Platsidou and Kazi (2001; see also Demetriou, Elklides, and Platsidou, 1993) proposed a model of intelligence in which general processes—“core capacities,” including working memory and processing speed—are able to process information from a variety of more specialized, domain-specific content areas as inputs. The general processes are proposed to constitute the fundamental processes underlying stage changes in cognitive development. That is, relatively rapid changes in the general processes constitute transition zones between stages of cognitive development. Similarly, Case (1998) describes domain-general central conceptual structures (CCS) that serve to integrate and organize information from modular systems of number, space, and theory of mind: “Although the content that they serve to organize is modular, the structures themselves reflect a set of principles and constraints that are system wide in their nature, and that change with age in a predictable fashion” (p. 770).

A conceptually similar model of general intelligence is provided by Geary (2005; see Figure 2.2 below). A central executive is able to direct attention and manipulate information that it receives from inputs from highly specialized, domain-specific mechanisms. These inputs, in addition to information typically associated with intelligence tests (e.g., spatial and verbal information), include a very wide range of information (visual object recognition, face recognition, auditory, olfactory, kinesthetic and gustatory). The central executive can amplify attention to particular areas as needed and is able to manipulate the information to create mental models and other goal-relevant representations as well as inhibit information that is irrelevant to the goal.

General intelligence is the result of the fundamental revolution in brain design by which the primate brain moved away from massively parallel implicit processing “with widely converging and diverging connections between individual neurons” to a more serial, hierarchical design (Striedter, 2005, p. 340). The result of this revolution was that information came to localized in one central area which could then be appraised and acted on by a central executive via explicit processing as opposed to a multitude of reflexive, implicitly processed connections acting subcortically and in parallel. Thus, for many animals, conflicts between approach and withdrawal are resolved simply by the summed strength of the competing implicitly processed action tendencies (thirst versus pain avoidance)—a standard ethological account (e.g., Goetz & Walters, 1997). For humans and some other animals, information is routed to the prefrontal cortex where it may be held in working memory and acted on by the executive processes of working memory. (Humans also retain implicitly operating modular connections, resulting in two pathways for many stimuli, such as loud noises that activate the fear system—the ancient evolutionary route directly to the amygdala which operates very quickly and results in reflexive fear, and a more recent, slower pathway to the cortex where it is evaluated and acted upon by the central executive via explicit processing [LeDoux, 1996, 2000].)

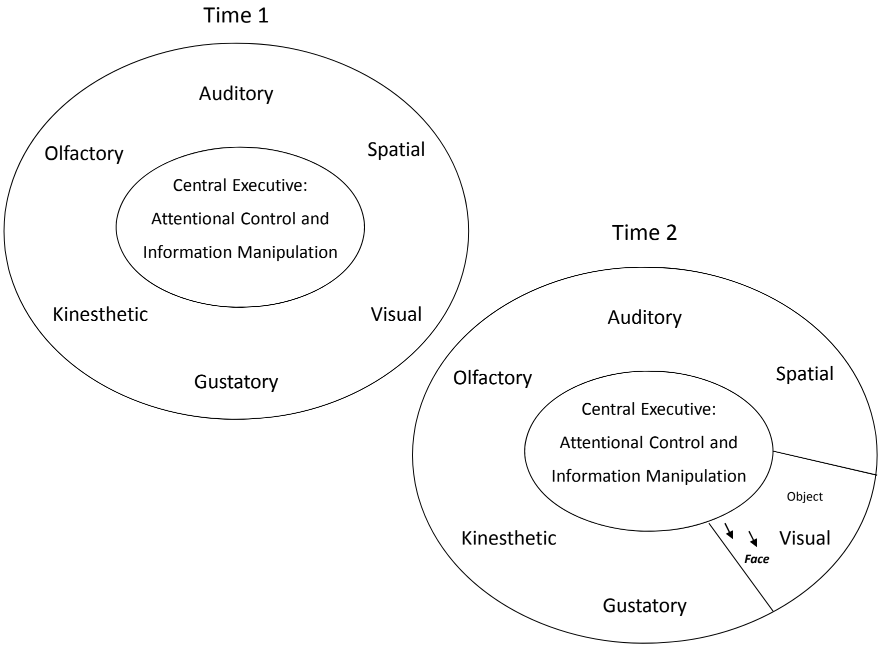

**Figure 2.2.** An illustration of the proposed relationship between the central executive and a partial list of inputs: auditory, spatial, visual, gustatory, kinesthetic, and olfactory. The central executive directs attention to particular domains (e.g., spatial), resulting in a conscious representation of the information from that domain. At Time 1 there is no specific focus of attention, but at Time 2 attention is focused on a face, resulting in conscious awareness of the face. (From Figure 7.1 of Geary, 2005)

The processing of this disparate information by the central executive is a prime example of explicit processing. As noted above, a fundamental divide among psychological mechanisms is the distinction between implicit and explicit processing, with implicit processing characteristic of modules as traditionally understood in evolutionary psychology. Explicit processing is intimately related to general intelligence. And, although necessarily having formatting requirements for inputs, explicit processing is domain general in the sense that its inputs can include the ability to make mental models taking in a wide range of information that is not tied to recurrences in the EEA, including all aspects of human culture (MacDonald, 2008, 2009). These explicit mental models can then be used to achieve the EMD's described above, including an immense variety of sub-goals that may be involved in plans to achieve EMD's but which require navigation through the complexities of modern life far removed from the EEA (e.g., figuring out the best way to finagle a job promotion or develop a winning strategy for getting elected to a political office). Whereas dedicated modules evaluate costs and benefits implicitly, such sub-goals require explicit analysis of costs and benefits of a wide array of cultural information (e.g., likelihood of legal consequences, financial considerations).

Explicit analyses of costs and benefits are able to override implicit, prepotent responses that have evolved in response to evolutionary regularities. The control processes associated with explicit processing are centered in the prefrontal cortex (PFC). The PFC is involved in top-down processing utilized during attempts to match behavior to intentions or internal states. It is especially important when previous connections between inputs, thoughts, and actions are not well established, as in confronting novel problems, rather than either innate or well-established learned connections (Miller & Cohen, 2001). Executive control permits "goal-directed override of primitive and inflexible reactions to environmental stimuli" (Gazzaley & D'Esposito, 2008, p. 188).

Explicit processing is called into play when confronting nonroutine tasks that require flexible responses, retention of information over time, and planning future courses of action (Dehaene & Naccache, 2001; Miller & Cohen, 2001)—all of which are central to intelligent behavior. Further, explicit processing implies conscious awareness (Stanovich, 2004), and theories of conscious awareness have converged on the proposition that they are adaptive because they allow consideration of different kinds of information from systems with different functions and phylogenetic origins (Morsella, 2005). Because the PFC is widely connected to sensory, cognitive, affective, and motor modalities, it is well suited to integrate information useful for making plans and for the production of skilled, intentionally controlled movements (Gazzaley & D'Esposito, 2008; Striedter, 2005).

The control function of explicit processing over implicit processing has become well established in the area of intelligence research. Unlike the vast majority of animals, humans can control automatic, heuristic processing and make decisions that depend on explicit processing. Controlling heuristic processing requires effortful, controlled problem solving and makes demands on attention and working memory resources. Stanovich (1999) provides evidence that people with higher general intelligence are better able to selectively control heuristic, automatic, socially contextualized processing. An example is evaluating a valid syllogism with a false premise. Consider the following:

All blue people live in red houses.
John is a blue person.
John lives in a red house.

Drawing the correct inference requires decoupling from experience in which there are no blue people and forming a mental model of a hypothetical situation in which there are blue people, all of whom live in red houses. The mental models involved in explicit problem solving include explicitly represented information involving language or images (Johnson-Laird, 1983).

Constructing mental models utilizes working memory. As noted above, models of intelligence feature central executives with access to input from a wide range of information, much of it the output of implicit processing. The information is held in working memory and may be utilized to create plans and evaluate possible outcomes prior to enacting the plan.

Research on human general intelligence has implicated working memory capacity as a key domain general intellectual ability (Engle, Tuholski, Laughlin, & Conway, 1999; Kyllonen & Christal, 1990). Thus Kane, Hambrick and Conway (2004) reanalyzed 10 studies with over 3000 subjects, finding a mean correlation of 0.72 between working memory capacity and fluid intelligence. Engle et al. (1999) showed that the executive functions of working memory (assessed by tasks involving attentional control) predicted general intelligence (i.e., *g*), but that short-term memory capacity (assessed by tasks such as memory for sets of words) did not. Working memory capacity thus consists of capacity (e.g., how many items can be held in memory) and also executive control (the ability to direct attention and keep it focused on some input while not being distracted by other input).

The various storage buffers of working memory are indeed domain specific (e.g., phonological loop, visual/spatial). Nevertheless, "the available evidence suggests that, although performance on complex [memory] span tasks may be influenced by domain-specific processing competencies, they have a commonality in their measurement of a domain-free ability to control attention (Feldman Barrett, Tugade, & Engle, 2004, p. 556). This conclusion is based on evidence that even though the various tasks do indeed require the use of domain specific memory buffers, performance strongly covaries across domains of performance—exactly as expected on the hierarchical model of general intelligence described above in which a general factor is at the highest level over a variety of specific ability factors, and where performance on the specific ability factors are correlated with performance on other specific ability factors. Further, Feldman Barrett et al. note that capacity in domain specific processing spheres is unrelated to the speed and accuracy of computation using information from the specific capacity spheres—also highly compatible with the importance of a domain general processor responsible for speed and accuracy across domains.

Similarly, Engle (2010, p. S17) notes that "The domain-general aspect of working memory—attention control … has established reliability and validity of measurement. Individual differences in domain-general working memory capacity have been shown to be important to a wide range of both speech-based and visual/spatial-based tasks." As noted, it is the domain general aspect of working memory capacity rather than domain specific capacity spheres that is highly correlated with general intelligence.

Further illustrating the domain generality of WMC, Engle (2010, S20) reviews data indicating that individual differences in WMC are correlated with "a wide range of higher-order cognitive tasks," including tasks related to reading and listening comprehension, reasoning, bridge playing, and learning to perform a complex task such as computer programming. People with higher WMC are also better able to block out a very wide range of intrusive, irrelevant thoughts and representations—another indication of domain generality.

The attentional processes of WMC are critical to goal management, which involves constructing, executing, and maintaining a mental plan of action during the solution of a novel problem (Carpenter et al., 1990). For example, the Raven's Progressive Matrices fluid intelligence test and the Tower of Hanoi problem (in which participants must develop a long-term plan with multiple subgoals) require one to be able to activate multiple goals and keep track of the satisfaction of each of them (Carpenter et al., p. 413).

Performance on these tasks in the study by Carpenter et al. was highly correlated ($r$ = .77), which suggests that substantial goal management was necessary in both tasks. Executive functions underlying general intelligence are thus involved when problems call for substantial planning and keeping track of various subgoals without distraction.

## IDEOLOGY AND THE CREATION OF EVOLUTIONARILY NOVEL GOALS

Although general intelligence is clearly useful for creating novel means of achieving ancient evolutionary goals in any environment, it is worth pointing out that humans are also able to create novel goals that are unrelated to human evolved motive dispositions. That is, there are many goals in addition to the evolved feeling states described above whose satisfaction or avoidance are desired by humans.

I have noted above that the input to the attentional processes of WMC may span a very wide range of inputs and that a characteristic outcome of such processes is the construction of mental models useful in solving problems in evolutionarily ancient and modern environments. A particularly interesting input (or output in the case of creators of ideologies) consists of what one might term “big picture” mental models of how the world works or ought to work—what is usually termed ideology (MacDonald, 1991, 2009, 2010). Ideologies are the result of explicit processing; they are explicit belief systems, and they may motivate behavior in a top-down manner. Examples are Marxism, liberal democracy, capitalism, religious views of creation and an afterlife, and moral idealism (i.e., moral principles that apply independently of human interests and thus may act to channel behavior in a non-self-interested manner; see MacDonald, 2010).

A paradigmatic mental model of this type are the various utopian models of ideal human behavior, such as Marxism. Marxism not only proposed an explanation for human behavior and the patterns of history, it also envisioned a post-revolutionary world without social classes or other hierarchical relationships between human groups, and it energized and rationalized extreme violence against perceived class enemies.

It goes without saying that throughout history there have been many ideologies that have been highly motivating. The basis for this claim is the control function of explicit processing described above. That is, explicitly held beliefs are able to exert a control function over behavior and over evolved predispositions (including EMD’s), and they are able to exert this control function independently of external processes of social control (e.g., punishment). For example, a person may refrain from engaging in a particular behavior to which he is predisposed as a result of evolved modules (e.g., various forms of aggression [Buss, 2005]), and he may do so because of he believes that he would be sent to prison, or because of he believes that he will be punished for it in an afterlife, or because he believes that it violates an important moral principle or God’s law. The success of Calvinism in 16th-century Geneva depended not only on the threat of externally applied sanctions, but also on the persuasiveness of the explicit beliefs that constituted Calvinist religious ideology (Wilson, 2002).

## CONCLUSION

Human general intelligence is a highly limited but extremely powerful domain general ability. It is able to take in a very wide range of inputs, including cultural and linguistic input, focus attention on these inputs and create plans for action. At the apex of this evolutionary process, human general intelligence is able to create powerful scientific mental models able to provide explanations and predictions of processes in the natural world. The mental models created by general intelligence are fallible. In particular, ideological mental models produced by explicit processing may often result in maladaptive behavior, as when ideologies without rational foundation motivate behavior that is not in the interests those who accept the ideology (see MacDonald, 2009, 2010).

Human general intelligence is the evolutionary outcome not of responding to regularities in past environments, but rather of natural selection for ever more sophisticated ways of achieving ancient evolutionary goals of survival and reproduction. As it has become elaborated in humans, it is able to create and accept ideologies that go beyond evolutionary goals by create goals that are far removed from evolutionary regularities and only tenuously related to evolutionary fitness.

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