Logical Strategery

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Abstract

We propose a conceptual framework for explaining logical reasoning in terms of competing strategies. Contrary to previous approaches in which a single theory is suggested to explain all logical reasoning, this framework suggests that the core elements of existing theories constitute strategies, each of which have unique processing demands. A strategy is more likely to be used when its processing demands match a problem's task demands. The framework specifies how each strategy may be distinguished theoretically and empirically.

Overview

The study of logical reasoning has typically proceeded as follows: researchers (1) discover a response pattern that is either unexplained or provides evidence against an established theory, (2) create a model that explains this response pattern, then (3) expand this model to include a larger range of reasoning situations. For example, researchers typically investigate a specific type of reasoning (e.g., deduction) using a particular variant on an experimental task (e.g., the Wason selection task). The experiments uncover a specific reasoning pattern, for example, that people tend to match terms between the premises and conclusions rather than derive valid conclusions (Evans, 1972). Once a reasonable explanation is provided for this response pattern, researchers typically attempt to expand this explanation to encompass related phenomena, such as, the role of 'bias' in other reasoning situations such as weather forecasting (Evans, 1989). Eventually, this explanation may be used to explain all performance on an entire class of reasoning phenomena (e.g. deduction) regardless of task, experience, or age. We term this the *unified approach*.

Unified approaches have traditionally suggested that logical reasoning is either rule-based (application of transformation rules that draw valid conclusions once fired; Rips, 1994) or model-based (creating and searching veridical representations of premises and possible conclusions; Johnson-Laird, 1999). It seems possible, however, given the range of problem types, task demands, experience, and cognitive resources of the reasoner, that there may be more than one approach to solving a class of reasoning phenomena.

Logical reasoning tasks are quite varied, ranging from simple tasks such as statement evaluation (e.g., "Is my cat black?") to complex tasks such as predicate syllogisms (e.g., Some A are not B, Some B are C, Some C are not D, Are some D A?). There is no evidence that logical reasoning occupies a particular region of the brain (cite), that it is a coherent process distinct from the rest of cognition (Johnson-Laird, 1999), or that it involves the same cognitive processes across different tasks. Moreover, cognitive psychology has identified a variety of general cognitive processes that are used to solve a wide variety of tasks (e.g., analogy, retrieval, guessing). Thus, it should not be controversial to suggest a multiple strategy approach- that several, general processes might be used to solve logical reasoning problems in at least some situations, even if there are special logical reasoning processes.

We propose an alternative to the *unified approach* in which a series of simple strategies may be used rather than a single complex theory. Thus, we propose a new framework for explaining logical reasoning performance by incorporating simplified versions of existing approaches as possible strategies for solving logic problems. We list a variety of alternatives that seem highly likely to be used in at least some logical reasoning situations. It is not crucial to the argument here that all strategies are actually used. We will propose conditions under which various strategies may be used, thus proposing a framework through which strategies can be distinguished theoretically and empirically.

The multiple strategy approach has been suggested in the domains of judgment and decision-making (see Bettman, Johnson, Luce, & Payne, 1993, and Todd & Gigeranzer, 1999). Like the logical strategy model, these approaches suggest competition between various strategies in which selection is accomplished, in part, from an evaluation of effort-accuracy tradeoffs. However, the logical strategy model differs from these approaches in their function and goals: (a) the function of the LSM is the creation and evaluation of knowledge (inference) rather than selection and evaluation of knowledge for decision making (judgment), and (b) the goal of LSM is to establish (either through production or evaluation) valid inferences while the goal of other approaches is to return the most adaptive decision (Todd & Gigeranzer, 1999).

The Strategy Approach to Logical Reasoning

What does it mean to think in terms of strategies? A glance at the existing literature suggests that unified approaches have difficulty accounting for differences in performance between individuals and across tasks (for a review see Rips, 1994; Johnson-Laird, 1999). We suggest that differences in performance across individuals and situations are due to the selection of a strategy and that strategy selection is a function of the history of success with each strategy and the match between processing demands of the strategy and the task demands of the problem. We will describe this match between the processing demands and history of success of the strategy and the situation/task demands as the *situational niche*.

As stated earlier, unified approaches have suggested that a single theory can account for the range of human performance. We suggest that the strategy selection approach may explain the same phenomena by proposing a series of specified approaches, each relegated to explaining a subset of the total range of human deductive performance.

What do we gain from this approach? The strategy approach allows established explanations to be incorporated into a single model in which all are possible explanations of behavior differing only in the extent to which the particular strategy has been used in similar situations and matches the task demands. The match between a particular strategy and its situational niche may not be rational, but may help explain individual and situational differences between theories. For example, it is well established that familiar content tends to improve performance on the Wason selection task (Wason & Johnson-Laird, 1972). Hundreds of experiments have investigated this phenomenon and have led to the introduction of a variety of explanations (e.g., matching rules), which differ widely in the range of their applicability. That is, some are specific to a particular set of materials while others seek to explain a larger range of reasoning behavior. What has rarely been investigated is the influence of the situational niche on performance, or, more specifically *how is the task itself contributing to the response pattern*? For example, take two contrasting approaches: in one, specific knowledge is required to solve a problem, and in the other, abstract rules (excluding the influence of knowledge) are used to solve problems. Problem A is given in which a substantial amount of content knowledge is given that is relevant to a solution. In this case, we would expect the knowledge-based approach to be better suited to solving this problem. If however a different problem were given in which no background information is proved, then we would predict that the second solution is more likely to be used. We suggest that a strategy approach allows flexibility in explanation by allowing for an individual to display a range of possible approaches to a problem set.

The logical strategy approach is in stark contrast to unified approaches in which explanations for processing logical statements are confined to one approach. A possible criticism at this point is that that a unified approach is more parsimonious than a strategy approach. That is, why suggest a series of competing strategies, each of which demands cognitive resources, when one approach would suffice? We provide two responses. First, current unified approaches have been unable to account for a range of performance without many ad hoc additions. For example, Mental Logic theory suggests that logical inferences are derived nearly automatically by a set of content-free inferential rules (Rips, 1994; Braine & O'Brien, 1998). In order to explain the effect of familiar content, Mental Logic theory incorporated an additional step in the reasoning process, a pragmatic filter, which determines if a statement is to be considered logical or conversational. In the former, logical inferential rules are applied, while in the latter case less formal conversational inferential rules are applied. The result is that the theory postulates an approach to reasoning that undermines its own primary thesis, that logical inference is a set of content-free rules applied as automatically as syntax.

Second, the strategy selection approach does not require a series of additional resources but can be accounted for by a small set of general-purpose cognitive mechanisms. Within the strategy selection framework a series of strategies can be derived within minimal effort on the part of the cognitive system from the experiences with the environment. For an example, let us return to the example given above. To account for reasoning in situations in which statements are presented without familiar content and reasoning with statements presented with familiar content, a strategy selection framework could account for empirical findings by the use of two strategies. The first does not use formal rules but uses the content to derive a plausible conclusion related to the specific content. In the second (without the presence of familiar knowledge), inferential rules are used because the most salient property of the problem is the relations between elements, not the content of elements. The use of each is specific to the situation in which both are presented.

In the sections that follow we will first outline seven strategies and their corresponding task demands. We will then examine the influence of task demands on their selection. We first state that the following is an incomplete model. There are many possible strategies and we are suggesting a small number in this paper. Second, the description of each is limited by space, thus does not cover the full range of possible applications. Given the nature of these limitations, the model is reasonably articulated for the purposes of the paper.

Token Based (Mental Models)

Overview. The token based reasoning strategy has the following characteristics: 1) information is represented as tokens derived from natural language which correspond to perceptual or verbal instantiations of possible states and 2) "logical" reasoning is achieved not through the application of formal rules but by the creation, inspection, and manipulation of tokens (Johnson-Laird, 1983; Johnson-Laird, Byrne, and Schaeken, 1992).

Outline of Processing/Processing Demands. Logical inferences are derived from manipulations of models rather than by using inferential rules. There are three steps in processing token-based propositions: propositional analysis, models generation, and model use. **Propositional analysis**

refers to language processing and is largely analogous to representing the surface structure of a statement and requires sufficient verbal/spatial working memory to encode and parse language. **Model generation** refers to the creation of tokens derived from the propositional analysis and relevant information in the existing knowledge base and in the environment. Generation requires verbal/spatial working memory space to create and hold tokens. **Model Use** is the process of searching and evaluating the set of models created by the procedures outlined above and requires a sufficient processing capacity to create veridical models of the necessary information, creation and search for counterexamples, and evaluations of truth-values. The primary limitation on processing is the working memory space required to create and search models for a solution.

The token-based strategy seems particularly useful in the solution of problems in which there are spatial relations because token-based representations can encode such relations more easily than propositional representations (Johnson-Laird, 1983, 1999). For example, in the transitive problem "Bill is to the right of Fred, Fred is to the right of Sam, Is Sam to the right of Bill?") A token based-representation would easily encode the relevant dimensions as follows:

[Sam] [Fred] [Bill]

An obvious limitation of this strategy is that the number of models needs to remain within the current working memory limitations of the reasoner.

Verbal (Mental Logic)

Overview Verbal logic approaches explain logical reasoning as the result of content-free, logical transformation rules applied to linguistically derived mental structures (Rips, 1994; Braine & O'Brien, 1998).

Outline of Processing in Verbal Theories The core elements of verbal theories share basic processing characteristics. Input is represented and processed in a verbal form (e.g., predicate-argument structures; Braine & Rumain, 1983). Sufficient verbal working memory is required to extract the formal elements and hold the representation in a predicate argument structure. **Application of Transformation Rules** are content-free rules represented as either condition-action pairs (Rips, 1994) or as inferential schemas (Braine & O'Brien, 1997). Once verbal input is represented, the content matches a series of transformational rules that produce an output that is either in the form of a conclusion, a statement that will be operated upon by additional rules, or a statement that does not match additional rules. Errors in processing are attributed to a failure in applying the appropriate rule to the statement.

The verbal strategy is most useful in solving abstract statements in which the focus is on relationships between elements. For example, in a version of the Wason selection task the card content is related only by formal structure, not by content (e.g., If there is a vowel on one side, there is an odd number on the other side).

Knowledge Based Heuristics (KBH)

Heuristics are rules that do not utilize logical algorithms. Such a strategy does not generate a valid conclusion but may generate "logic-like" performance (Cheng & Holyoak, 1985). KBH are easily implemented processing rules that use *content* as the basis for deriving a conclusion. Unlike algorithmic approaches (e.g. verbal strategy), these conclusions are not necessarily valid (often violating logical inference rules), yet are often pragmatically supported. An example is Pragmatic Reasoning Schemas (PRS; Cheng & Holyoak, 1985) in which social (permission rules) and physical (causality) regularities form the basis of a series of inferences schemas.

Outline of Processing in KBH

There are three processing steps in KBH: **parsing sentence**, **detection of relations**, and **solution output**. Sentence parsing refers to sentence comprehension and includes verbal and nonverbal information. The detection of relations occurs when the present content is similar to content for which there are established rules. For example, in permission relations, there are established rules (typically phrased as conditionals) that suggest appropriate responses. Matching content allows rules to be accessed. Once rules are accessed, they are applied to the specific situation and a solution output is produced.

The detection of specific relations determines if a statement matches an existing schema. Cues such as temporal sequence suggest obligatory or causal relations between elements. For example, in the statement "Mow the lawn and I will give you five dollars" the condition is set in the first clause while the consequent is set in the second clause. Previous knowledge of other exchanges (in which transactions are made on the basis of obligations) forms the basis of these inferences.

Matching Heuristics

Overview- Matching heuristics are selective processing strategies in which solutions are derived based on superficial elements such as terms or common elements (rather than on content as in KBH). Two well-known examples of matching heuristics are Matching biases and Atmosphere effects (Evans, 1989; Woodsworth & Sells, 1935).

Outline of Processing in Matching Heuristics

Matching heuristics specify rules of *selective processing* differ from all previous strategies in that no specific inferential content is accessed. These rules follow a basic processing model as follows: 1) **encode surface structure**, 2) **find key elements**, and 3) **match key elements**. For example, in the Wason selection task, subjects prefer to choose cards named in the rules rather than cards that are not named in the rules (Evans, 1972). In the first processing step, the subject encodes the surface structure focusing on the elements in the rule. Most likely this involves encoding an IF→ THEN rule. The key elements are identified. For example, given "If an odd number on one side, then a vowel on the other side" the subject may focus on "odd number" and "vowel" as key elements. Then, when searching possible solution states, the subject will attend to those solution states that contain the key elements. Continuing with the example above, the subject may be more likely to select a card with an odd number and a card with a vowel because they match elements in the rule. This general processing model also applies to atmosphere effects.

Task-Specific Procedures

Overview- Like heuristic strategies, Task-specific procedures are non-logical procedures that achieve correct solutions on logical tasks without the use of formal inferential rules. Task-specific procedures are reasoning "short-cuts" that produce procedural solutions without declarative understanding. The limitation of TSP procedures is that they do not generalize beyond the specific type of reasoning format in which they were induced. Logical training (education and training studies) may produce these procedures leading to an understanding of logical reasoning analogous to the understanding of Chinese attributed to the occupant of the Chinese room (Searle, 1990).

Outline of Processing in Task-Specific Procedures

The processing demands in task specific procedures can be defined as two steps: (1) encoding the relevant problem features and (2) implementing the appropriate algorithm. For example, in a syllogism evaluation subjects concluded that any syllogism with two "somes" in the premises was invalid (Gallotti, Baron, & Sabini, 1986). Implementing a solution algorithm requires sufficient working memory to hold the encoded premises and to fire the appropriate algorithm.

Pragmatic Acquiescence

Overview- Pragmatic acquiescence (PA) refers to response patterns that are attempts to match the expectations of the questioner. In a situation in which someone has little prior knowledge, they may be inclined to seek social cues from the questioner as to how to respond to a novel situation. Rather than matching the conceptual features of the problem as in matching heuristics, PA-based solutions are based on the pragmatics of the problem/testing situation.

Outline of Processing PA- The PA strategy is used when (1) the pragmatic cues are most salient or (2) other strategies fail to produce a definitive solution.

The first step is encoding relevant cues. We suggest at least four such cues: a) speaker status, b) language cues, c) intonation cues, and d) gesture cues. Speaker status should influence acquiescence in the following ways: the validity of the response should increase as the authority of the speaker increases. This also suggests an informal metric for calculating the status of self and speaker. Language cues may be the most obvious and suggest the type of response that is expected (e.g., "don't you agree"). The second step is inferring possible solutions based on relevant cues. Selecting the PA strategy should occur when other strategies fail to match or when the pragmatic cues are most salient. In both cases, this suggests that the reasoner lacks the knowledge necessary to solve the problem at hand.

The final step is producing a solution. In this case, the reasoner has encoded relevant cues and determined the cued response. This response is given under any of the following conditions: 1) if no other strategy matches, 2) if a strategy produces a solution that is in conflict with the cued response and fails to override this solution, or 3) if the cued response is so highly activated that it overrides all other strategies.

Retrieval

Overview- Retrieval is accessing a previous solution from long-term memory. Retrieval differs from all other proposed strategies in that it is the only strategy that does not create an on-line solution. We include this strategy because solutions, once discovered, can be accessed from memory rather than creating a new solution each time the same problem is presented. Access to solutions will vary by the time interval between discovery and access (recency), the number of times the solution is accessed (frequency), and the degree to which the current problem state is similar to the problem state associated with the solution (fit). Guessing is a loosely constrained form of retrieval in which a response is produced on the basis of inaccurate or irrelevant information.

Outline of Processing in Retrieval- As suggested above, retrieval of previous solutions depends on a variety of factors. The most crucial is the number of possible matches to the current problem. IF there is only one match, then retrieval is simple. Because there are often several possible solutions to a particular problem, in order to retrieve a solution, there must be a mechanism to determine which of these possible solutions will be accessed at any given time, or conflict resolution. We suggest three mechanisms. The first is recency, or the time between when a solution has been discovered and the time it is accessed (Anderson & Lebiere, 1998). The second factor is the frequency of access. The number of times a solution is accessed increases the base activation level of the solution. The higher the base level of activation, the more likely it is that a particular solution will be accessed. The third factor is the degree to which the problem state linked to a solution state is similar to the current problem state, or fit. The degree of fit will determine which of a set of possible solutions is most similar to the current problem state.

Task Characteristics and Situational Niches

The previous section outlined the processing steps for each strategy. As stated in the introduction to the paper, the probability of a particular strategy being used is a function of the processing demands of the strategy and the situational niche. The following section will outline possible task demands, processing demands and how these factors may be related to the application of specific strategies.

The situational niche is similar to Todd & Gigeranzer's (1999) notion of ecological rationality. Both approaches are derived from Simon's (1957) concept of bounded rationality in which reasoning proceeds on the basis of limited information and both are content-sensitive, in that the type of reasoning response is a function of the task demands. While ecological rationality seeks the most adaptive decision/judgment within an open system (i.e., one in which a correct decision is indeterminate), a situational niche represents the current context in which reasoning is occurring and is a match between the processing demands of the system and the task demands of the problem within a closed reasoning system. Thus in a situational niche a correct solution is possible.

The degree to which a problem is familiar will influence the use of a particular strategy. Familiarity is contrasted on two dimensions, the familiarity of the content and experience with a particular problem type. The degree to which content is familiar should increase the probability of knowledge-based strategies. For example, it is a well-documented finding that an invalid syllogism with a believable conclusion is more likely to be accepted as true than a valid syllogism with an unbelievable conclusion (Evans, Barston, & Pollard, 1983). In this case the familiarity of the conclusion may be the most salient element, thus the element most likely to elicit a strategy match. In the case of less familiar materials, for example a syllogism with two "somes" in the premise, a reasoner may rely on a task-specific heuristic to derive a conclusion (Gallotti, Baron, & Sabini, 1986). When given a series of unfamiliar, abstract materials a reasoner may rely strictly on the formal elements of inference. For example given the abstract version of the Wason task, a reasoner may be unable to derive a series of valid conclusions (e.g. modus tollens) but only able to infer modus ponens (Wason & Johnson-Laird, 1972). In each of these cases the familiarity of content may change the problem's situational niche, resulting in different probabilities of matching a given strategy.

In the second sense of familiarity, strategy selection may also depend on the degree of experience a reasoner has with the specific problem type. If a reasoner has a great deal of experience with the specific problem type, they are more likely to retrieve a solution or use the same strategy as used on previous trials. As experience decreases, strategy selection is more likely to be a function of other factors in the situational niche (e.g., presentation format). Strategy selection will be influenced by previous experiences with the problem type and the nature of their outcome associated with the use of priori strategies.

The presentation format also may influence the strategy selected for a particular problem. Presentation formats may be verbal, written, or visual. The type of representation may illustrate or obscure problem characteristics crucial to a correct solution (Larkin & Simon, 1987). Perhaps differences in solutions differ as a function of both the situational niche and the strategy that matches this niche.

In order to illustrate possible links between strategy selection and situational niche, we present the following example. Imagine a transitivity problem in which the basic instructions are given as follows:

> Four people are waiting in line at a movie theater with a new seating policy. The new policy states that in order to allow everyone to see the screen, all patrons have to be seated by height. That is, shorter patrons are seated near the front while taller patrons are seated near the back. Five people, Homer, Marge, Bart, Lisa, and Maggie are going to the theater. Based on their relative height (including hair), place them in proximity to the screen.

Knowledge of the source material may influence the type of strategy used. A reasoner with a great deal of knowledge of the source material (The Simpsons®) may simply retrieve a solution (high content familiarity). One who cannot simply retrieve a solution may use their knowledge to match the task constraints as in a knowledge-based heuristic. In this case, the reasoner may be able to place a few members of the family in order without a transitive inference.

Those with no knowledge of the television show may need to solve the problem using different strategies that may depend on the presentation format. If presented pictorially, the representational format reduces the amount of information in working memory and allows a solution to be derived from scanning the relative heights from the visual array (see Figure 1).

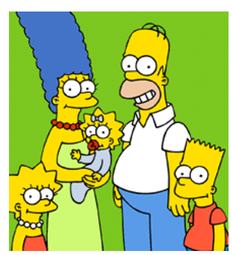

Figure 1

If presented verbally, the task can be simplified by ordering the information to align with task demands. For example, if presented in an ordered format (as in Example 2), a simple scan of relations may allow a solution to be derived. In this case, a matching heuristic may be devised in which the tallest person is only on the left side of the text. From here relations are structured after the tallest has been identified.

Example 2
Homer is taller than Lisa.
Marge is taller than Bart.
Homer is taller than Bart.

Bart is taller than Lisa.
Lisa is taller than Maggie.
Marge is taller than Homer

When terms are randomly distributed in text (i.e., ordering is not aligned with task demands) then each element must be encoded and compared to all other components requiring greater working memory resources (see Example 3). Such a presentation format may best match a token-based strategy, in which pictures are easily represented spatially as a series of tokens.

Example 3
Homer is taller than Lisa. Bart is taller than Lisa. Marge is taller than Bart. Homer is taller than Bart. Lisa is taller than Maggie. Marge is taller than Homer

The previous examples suggest a link between task demands and processing resources. But how do task demands and processing demands produce strategy selection? Differences in processing demands and task demands will lead to differences in the salience of problem elements. Previous strategy use influences the probability that a given strategy will be used. Using this framework, we may be able to explain both inter- and intra-individual change. For information about competition between existing strategies, we will examine data one example of errors in logical reasoning: performance differences based on the presence of familiar content. In verbal strategies, errors in processing are attributed to a failure in applying the appropriate rule to the statement. There are at least two conditions under which a rule is unavailable for processing. **Failure to retrieve** a rule suggests that although the rule is present in long-term memory, it is not retrieved for processing the current information. **Failure to match** a rule is typically explained by the presence of content effects (Braine & O'Brien, 1998). That is, when the content is either familiar or supports an inference beyond that of the statement's form, then rule matching is either suppressed or may match a different rule (Rips, 1994). Although failure to match has been cited as a condition under which abstract rules fail to apply, it is plausible that under these conditions knowledge-based heuristics are more likely to be applied, resulting in slightly different conclusions. Conversely, knowledge-based heuristics rules often fail to fire when given abstract elements (e.g., If A, then B) and are restricted to induced relations (i.e., obligation and permission) (Cheng & Holyoak, 1985; Rips, 1994). In both cases, there are ranges of results that cannot be explained by each unified theory, however, viewing each as a strategy allows the inclusion of the seemingly conflicting empirical findings into a single model.

The strategy approach maintains the explanatory power of each theory while increasing the scope of explanation. The strategy approach accounts for a range of results by suggesting that each strategy possesses distinct processing demands that are likely to match the task demands of specific problem. By allowing multiple approaches within individuals across time the strategy approach is maximally flexible allowing the possibility of explaining differences across tasks and individuals.

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