Made sense and remembered sense: Sensemaking through abduction

C. Gustav Lundberg [a,b,*]

[a] *A.J. Palumbo School of Business Administration and John F. Donahue Graduate School of Business, Duquesne University, 600 Forbes Avenue, Pittsburgh, PA 15282-0180, USA*
[b] *Swedish School of Economics and Business Administration, Arkadiagatan 22, 00100 Helsinki, Finland*

Abstract

The purpose of this article is threefold: to present a general framework for investigating processes of reasoning and problem solving in market-related situations that are not transparent, to present some central processes involved in sensemaking, and to present a set of key elements of abductive reasoning. The paper focuses on the processes involved in making sense, on the on-line generation of explanations, and on logics more suitable for on-line and commonsense reasoning than classical logic. Although some of the roots of experts' reasoning must be aleatory (probabilistic), the focus of the paper is epistemic (causal) reasoning in ill-structured domains. The professional decision maker is seen as equipped with a diverse mental toolbox. The on-line making of new sense is a process that we are only beginning to understand. Likewise, the process involved in strategy shift and the changing of mind are not well understood. Nonmonotonic, abductive reasoning is presented as a framework within which we can start to understand, and possibly re-evaluate on-line and creative economic decision making. © 2000 Published by Elsevier Science B.V. All rights reserved.

PsycINFO classification: 2340; 2343

* Tel.: +1-412-396-6255; fax: +1-412-396-4764.

E-mail address: lundberg@duq.edu (C.G. Lundberg).

1. Introduction

The purpose of this article is threefold: first, to present a general framework for investigating processes of reasoning and problem solving in market-related situations that are not transparent, second, to present some central processes involved in sensemaking and third, to present a set of key elements of abductive reasoning. The argument progresses from general blueprints of reasoning and decision making in rich and ill-structured domains characterized by equivocality, through an exploration of central sensemaking concepts, to a detailed discussion of some central logic building blocks.

Market agents (e.g., traders, analysts, commentators) must make sense of the conditions at hand before possibly taking action. The complexity and pace of markets make multiple explanations, often of diametrically opposite nature, highly likely. At the aggregate level, these divergent views are held by market 'bulls' and 'bears', respectively. On an individual level, it is likely that agents maintain more than one possible explanation of the present, as well as more than one projection concerning future market developments. This paper focuses on the processes involved in making sense, on the on-line generation of explanations, and on logics more suitable for on-line and commonsense reasoning than classical logic. Although some of the roots of experts' reasoning must be aleatory (probabilistic), the focus of the paper is epistemic (causal) reasoning in ill-structured domains (cf. Beach, 1992).

Many of the examples that illustrate the theoretical frameworks presented in the article originate in studies of economic and financial decision making on a micro level: intensive work with a small group of professional commodity traders (Lundberg & Barna, 1992), experiments with larger sets of novice traders (Lundberg & Frost, 1990, 1992), with professional auditors (Lundberg & Nagle, 1999, 2000), and longitudinal studies of the actions of a professional stock broker (Lundberg, 1991, 1992). These studies echo a widely held sentiment that experience and commonsense are important driving forces in professional judgment and thought. Several of these studies

involve experts making on-line (or real-time) judgments. [1] It is clear that real-time traders frequently change their mind. Lundberg and Frost (1990, 1992) argue that being 'fickle' may be the best way for a trader to survive in an environment characterized by terms like 'random walk' and 'efficient markets'. Fickle explanations (cf. Pennington & Hastie, 1988), by their very essence, are explanations that the agents generate 'on the fly' in their effort to try to keep up with and make sense of the barrage of information that faces them. Professional traders and auditors, for example, are forced to make decisions, many of them with great consequences, knowing that the information they base their decision on is incomplete. All the experts that we have studied have acquired and made ample use of tacit knowledge and built implicit theories of varied situations. Many of them seem to generate multiple interpretations and mental representations at different levels of abstraction of the system to be managed.

Two frameworks will be outlined that may complement the current set of methodologies and explanations in economic psychology: research on *sensemaking processes* outlines some avenues for studying real-time genera-tion of 'sense' and explanations, whereas an understanding of *nonmonotonic logics* may allow better modeling of reasoning and explanation generation in environments characterized by ambiguity and equivocality. We need a framework for modeling decision making that is based on more than one potential model. Commonsense reasoning is frequently not monotonic as it allows additional information to invalidate old conclusions. For example, in many situations people draw conclusions which are given up in the light of further information (without withdrawing any of the former premises), gear their reasoning toward different hypotheses, reason again on past inferences without increasing the number of facts to be used, and make default as-sumptions to overcome incomplete knowledge.

Although cognitive science and decision theory have provided a language for dealing with uncertainty, researchers who study recurrent and risky de-cision making, e.g., commodity trading, frequently see a need to go beyond uncertainty. Weick (1995, p. 91) argues that 'in the case of *ambiguity*, people engage in sensemaking because they are confused by too many interpreta-tions, whereas in the case of *uncertainty*, they do so because they are ignorant of any interpretations'. The related concept of *equivocality* covers the

---

[1] Pennington and Hastie (1993) define on-line judgments as reasoning where the value of a piece of evidence is incorporated into a judgment as soon as it is encountered.

confusion created by two or more meanings. Sensemaking involves placing stimuli into some kind of framework. Importantly, having an *accurate* map of the environment may be less important than having *some* map that brings order to the world and prompts action. Economic psychologists have already applied many of the building blocks of sensemaking, notably scripts, frames, and schemata. However, in areas where the emphasis is placed on rapid action, it is important to look closer at the processes that lead to 'sense'.

In AI, nonmonotonicity frequently takes the form of *abductive* explanation: the process of searching for a set of assumptions that can prove a given observation. Traders and other actors in high-risk/volatile environments must excel in the process of finding plausible explanations for a given set of data. This leads back to sensemaking.

Before we pursue potential models of sensemaking, however, a brief discussion of some of the general processes of creative, expert decision making and reasoning in intransparent situations is in order. For more complete discussions of the various topics – expertise, problem solving, practical intelligence – see e.g. Newell and Simon (1972), Sternberg (1988), Sternberg and French (1991), Busemeyer, Hastie and Medin (1995), French and Funke (1995).

2. On reasoning in opaque environments

In a recent paper, Turkle (1997) describes the ways the computer users and developers of the future, today's children, interact with and view complex computer simulations. The children Turkle studied were 'able to act on an intuitive sense of what will work even when (they do) not have a verifiable model of the rules underneath the game's behavior' and manage to reason in situations characterized by 'unstable meanings' and 'emergent, evolving truths' (pp. 93, 94). Faced with opaque and interactive simulation objects, children still try to impose order, '*making do* with whatever theory can fit a prevailing circumstance' (Turkle, 1997, p. 102). Cast in terms of information processing, this process of making sense can be viewed as abduction: 'as the sequential comprehension and integration of data into a single situation model that represents the currently best explanation of the data' (Krems, 1995, p. 206). The focus of this paper is on reasoning and problem solving in situations that are intransparent – where only symptoms are available and causes have to be inferred. When problems are not transparent, Sternberg

(1995) argues, the solver must construct a mental model that represents as many of the problem's aspects as s/he is able to grasp.

Gelernter (1997, p. 117) points to the importance of thought style, a superstructure that refers to the way a person strings thoughts together into a 'train of thought' or 'stream of consciousness'. Gelernter envisions a continuum of thought styles ranging from high focus thought (e.g., analytical problem solving) to low focus thought, of particular importance to creativity and analogy formation, and finally sleep. Multifaceted knowledge representation enhances transfer between different contexts and is a crucial feature of both expertise and analogy formation. In Sternberg's (1995) terms, selective comparison involves applying all the information acquired in another context to a problem at hand: an analogy is drawn between the present situation and some situation from the past. Gelernter (1997, p. 125) envisions an experience-based system that reasons as follows 'consider case x, case y, case z; note that this case resembles x in the following ways, suggesting the following conclusions; resembles y in the following ways, and so forth.'

The importance of analogies is evident also in Pennington and Hastie's (1993, p. 196) story construction model of juror decision making. They argue that 'intermediate conclusions are established by converging lines of reasoning that rely on deduction from world knowledge, analogies to experienced and hypothetical episodes, and reasoning by contradiction.' Reasoning by analogy to other experiences is crucial in determining the juror's confidence in the conclusion. In more general terms, prototypic narratives (stories or implicit theories) are 'the epistemic strategies in judges' repertories of judgment strategies' (Beach, 1992, p. 121). An individual, Beach argues, has multiple, context-specific implicit theories and narratives; prototypes that greatly aid her/his sensemaking. To understand reasoning and problem solving in ill-structured domains in general, we may need to pay more attention to metaphors that domain experts live by (Lakoff & Johnson, 1980; Winograd, 1997). To begin to understand real-time, creative economic reasoning and decision making in particular, it may be necessary to create a detailed mapping of the metaphors professionals use in their effort to make sense of markets à la Oberlechner, Slunecko and Kronberger (2000).

Turkle's (1997) observations of how children deal with artificial life's objects suggest that they maintain parallel definitions that they alternate in a way that resembles rapid cycling. This behavior may not be different from what Lundberg and Frost (1990, 1992) and Lundberg and Barna (1992) have observed among expert and novice traders. To behave effectively in a changing environment, Krems (1995) argues, requires a flexible information

processing system that can easily adapt to new tasks and new situations. Krems isolates three task-dependent mechanisms that are important for flexible problem solving: multiple interpretations of data, modification of representations, and modification of strategies; all crucial elements in the on-line process of making sense. Even if it is not clear whether flexibility should be considered a separate genuine factor of intelligence (Sternberg, 1988) or whether flexibility is based on domain-specific knowledge, Vessey (1989) suggests that experts do not generate better initial hypotheses than novices, but are able to modify their error-related assumptions in a much more flexible manner. Krems's (1995) experiments suggest three important generalizations: that experts tend to modify their current diagnostic hypotheses more often during diagnostic reasoning than novices; that experts tend to use a positive test strategy to a lesser degree than novices and that the ability to flexibly change assumptions is based on case-based knowledge and does not appear to be a domain-general ability. Krems argues that cognitive flexibility is positively correlated with expertise. Conversely, Adelson (1984), Frensch and Sternberg (1989), Sternberg and Lubart (1991) and Krems (1995) have shown circumstances in which domain knowledge, especially in highly automated procedures, can interfere with expertise and produce inflexible behavior.

Flexible expert behavior is likely to be based on a diverse mental toolbox that contains sets of solution templates on varying levels of abstraction. This idea of strategic variety is common to three major cognitive frameworks: the view of humans as adaptive, boundedly rational systems, the cognitive heuristics approach, and the cognitive algebra framework. The idea is summarized in Table 1. The table introduces the three main approaches, followed by a brief general description of purpose, and by four examples in each category of well-known choice rules, heuristics, and procedures.

The decision maker's limited capacity short-term memory is a central underlying feature in all three approaches. Whereas the focus of the adaptive

Table 1
A sample of possible elements in a person's mental toolbox

Adaptive, boundedly rational	Cognitive heuristics	Cognitive algebra
Conjunctive satisficing	*Heuristics-based reasoning/judgment*	*Information integration*
Dominance rule	Availability	Averaging
Elimination by aspects	Representativeness	Adding
Lexicographic rule	Anchor and adjust	Subtracting
Weighted additive rule	Simulation	Multiplying

approach is on a general reasoning and decision making strategy, satisficing, and cognitively expedient choice rules, the cognitive heuristics approach focuses on general heuristics and biases involved in a human's access and utilization of memory-based knowledge. The cognitive algebra approach focuses on the way humans integrate information, as well as on a belief that many cognitive processes can be modeled in algebraic form. For further detail on each approach, see Hastie and Pennington (1995) for a general overview, Payne, Bettman and Johnson (1990), Kahneman, Slovic and Tversky (1982), and Brehmer and Joyce (1988). For example, it is likely that any professional's reasoning, from time to time, reveals traces of conjunctive satisficing, the availability bias, as well as additive or multiplicative information integration procedures. In addition, it is likely that the toolbox of a professional contains numerous, more or less generalized, procedural templates within her or his task domain. For example, the commonly observed heuristic of consecutively connecting nearest nodes in solving a traveling salesman problem is an example of an overextended, but also generalized, heuristic. The heuristic serves multiple purposes: it provides a solution starting point, it is cognitively simple to perform, and it frequently leads to optimal solutions (for small, common networks).

Similarly, many of the procedures listed in Table 1 have multiple functions. The choice rules listed under the adaptive framework allow a decision maker to solve complex problems without exhausting her/his cognitive capacity. The cognitive heuristics, in turn, also allow the decision maker to expediently solve complex problems, while touching upon the way the decision maker's knowledge is structured; on attention, as well as long- and short-term memory. It is likely that decision makers store templates for how information should be integrated. For example, people are likely to effortlessly switch between multiplicative strategies (e.g., in transportation mode decision making) and compensatory (additive) integration strategies (e.g., when choosing a household product). Likewise, features in the task environment and/or task description seem to influence people's choice of logic. Beach (1992) has found that problems that encourage recognition of chance, repeatability, and sets of persons, objects, or events tend to elicit aleatory reasoning. Problems that involve individual persons, unique objects, or events, on the other hand, tend to elicit epistemic reasoning. In addition, judges use different reasoning strategies for different judgment task encountered in different judgment environments. It is likely that the reasoner/judge categorizes problems and tasks according to her/his benefits associated with making an accurate judgment, whether the task is revisable or not, her/his

relative competence, and the adequacy of the information available. Importantly, most of these well-known elements in the mental toolbox are crucial for the process of everyday sensemaking. Most of these elements also have clear nonmonotonic/abductive characteristics.

3. Sensemaking

In a study of post-decision consolidation processes, Lundberg and Svenson (1993, 2000) examined novice commodity traders. Subjects were asked to decide on which of the four alternative future price developments would follow a historical price trajectory for different commodities, and to rate the importance of each of the chosen alternative's corresponding aspects. Later in the experiment, the subjects were also given information about what was indicated to be the actual development of the market. One group was told that their decisions were correct (irrespective of what the decisions were), another group that they were incorrect but close, a third group that they were incorrect by far, while a fourth group of subjects received no feedback. Following this information, the subjects were again asked to judge the importance of the aspects for their own prior decision on the most likely future development. The results indicated that outcome feedback had an effect on post-decision restructuring of facts. Subjects in the correct condition showed an average consolidation that increased the support, while the wrong conditions lead to negative consolidation (in retrospect indicating that they never found as much support for their decision in the past as they actually did). In other words, there was a considerable difference between the 'sense' that the subjects originally made and their 'remembered sense'. Lundberg and Nagle (1999, 2000) have observed post-decision editing among professional auditors.

Interestingly, regardless of the chosen price trajectory, the novice traders saw certain signals (notably the moving average configurations) as supportive of the choice, suggesting that the aspects underlying the subjects' decisions were mutable. For example, very frequently the same aspect was considered most supportive for subjects as diverse in their views as 'very bullish' and 'very bearish'. In these complex environments, it seems, you see what you want to see. Norman (1997) claims that people are excellent at determining meaning as well as maintaining the spirit of the content. Also, we found evidence of a positive bias both in the choice of future price trajectory and in the attribute ratings. This translates into support for a rather well-known

finding: that people tend to look for supporting and ignore nonsupporting evidence.

In essence, the traders in Lundberg and Svenson's experiments were asked to make sense of a complex situation with limited information: price data (open, high, close readings) leading up to the 'present', and a small set (five or six) (marked) prominent technical signals. The task includes many of Weick's (1995) seven properties of sensemaking: the processes are *grounded on identity construction*, *retrospective*, *ongoing*, *focused on extracted cues*, and *driven by plausibility rather than accuracy*. To complete the list of seven, the Lundberg and Svenson experiments do not directly involve processes that are *enactive of sensible environments*, nor overtly *social*. Enactment means that people produce part of the environment they face. Even if we would have included trading action, there was no mechanism through which the individual trader's actions could have affected the price; a phenomenon that requires a rich organizational context. Neither are the processes revealed in our experiments particularly social. We agree that human thinking and social functioning, in most cases, are intertwined. Our traders are outside any 'network' and do not 'interact socially'. Their sensemaking is, however, to a considerable content based on 'shared meanings' and a 'common language'.

Frequently, sensemaking researchers base the process of sensemaking in organizations on identity construction: 'any one sense maker is a parliament of selves' (Weick, 1995, p. 18). Every complex environment invites multiple definitions of self. A trader may well be risk averse and risk seeking simultaneously; driven at the same time by fear and greed. Likewise, a trader may be part 'contrarian', part 'trend follower'. Similarly, an auditor in a small company may define him/herself as accountant, as auditor, as tax professional; and within those definitions as a book-keeper, a controller, a watchdog (an active seeker of problems), an observer who attests to the fairness of information contained in financial statements, a forecaster, and/or an advisor (Lundberg & Nagle, 1999, 2000). In Weick's (1995) terms, intentional sensemaking is triggered by a failure to confirm one's self, and occurs in the service of maintaining a consistent, positive self-conception. Also, people learn about their identities by projecting them into an environment and observing the consequences, and try to shape and react to the environments they face. Importantly, '(t)he more selves I have access to, the more meanings I should be able to extract and impose on any situation. Furthermore, the more selves I have access to, the less the likelihood that I will ever find myself surprised ... or astonished ..., although I may find

myself confused by the overabundance of possibilities and therefore forced to deal with equivocality' (Weick, 1995, p. 24).

The Lundberg and Svenson as well as the Lundberg and Nagle studies very clearly involve the retrospectiveness property of sensemaking. However, even in situations where post-diction is not induced experimentally, people create meaning by attending to what has already passed. Researchers have isolated several factors that influence sensemaking: what is occurring at the moment of looking back, general memory processes and limitations, and the ambiguity of the stimulus–response sequence. Weick (1995) suggests that sensemaking stops when the goal of imposing order, clarity, and rationality has been achieved. This process is similar to the cognitive strategy called 'conjunctive satisficing', where people seek 'good enough' options in opaque environments characterized by costly search (Hastie & Pennington, 1995). In trading, this process of finding enough order and clarity frequently must be very rapid. Andreassen and Kraus (1989) have suggested that traders repeatedly shift between very simple extrapolation-based forecasting methods and more complicated methods based on naive econometrics. If the price moves in the direction they predicted, traders see little need for extended search for clarity and order, i.e., for an explanation. The need to make sense of an outcome becomes much more involved when the trader receives counterfactual information. Variables that concurrently are at abnormal levels are generally those which are identified as potential causal mediators for the event. Lundberg (1991, 1992) and Lundberg and Frost (1990, 1992) suggest that traders switch, probably by means of naive econometrics, from one explanation to other explanations in their repertoire. The current most favored explanation is then extrapolated until the trader sees a need for re-explanation. In trading, this process may be exemplified by shifts from technical to fundamental analysis, or vice versa. Again, these processes have clear abductive features.

Sensemaking is an ongoing process. 'To understand sensemaking is to be sensitive to the ways in which people chop moments out of continuous flows and extracts cues from those moments' (Weick, 1995, p. 43). This process of ongoing sensemaking is illustrated in Lundberg's (1991) protocol analysis of a stockbroker's reasoning about the market, his actions and missed actions, and his gradual recovery after the devastating market crash in October 1989. The sequence of protocols shows how the broker utilizes relatively simple, familiar structures – even when he persists to be a contrarian – as building blocks for his more comprehensive sense of what may be occurring. This process of cue extraction is highly

dependent on context, as context both affects what is extracted, and how the cues are interpreted. Lundberg and Frost (1992) have shown that financial data can be highly mutable. [2]

Finally, sensemaking is driven by plausibility rather than accuracy. Having an accurate explanation may be less important than having some explanation that brings order to the world and prompts action. Bruner (1973, p. 30) sums up this argument eloquently: 'The cost of close looks is generally too high under the conditions of speed, risk, and limited capacity imposed upon organisms by their environment or their constitutions. The ability to use minimal cues quickly in categorizing the events of the environment is what gives the organism its lead time in adjusting to events. Pause and close inspection inevitably cut down on this precious interval for adjustment'. The organism in Bruner's discussion, could clearly be any of the financial agents referred to earlier, and maybe equally clearly a firefighter, an emergency room physician, or a chess player in action. Bruner's summary also provides a natural bridge to our discussion of nonmonotonic reasoning and abduction.

4. Nonmonotonic reasoning

Lundberg's and Lundberg and Frost's claim that traders switch from one explanation to other explanations in their repertoire in a predictable fashion, suggests that another process than that of 'stopping when enough sense has been made' must be in operation. It may be that this trader 'fickleness' is an example of abductive reasoning, where experts with vast and highly interconnected knowledge structures will consider multiple interpretations of the situation when confronted with fuzzy or ambiguous information (Krems, 1995).

Abduction is the process of finding plausible explanations for a given set of data; the possible cause of manifestations (Davis, 1990; Sombé, 1990). The consequence of using abduction in learning, in conjunction with a causal model, is that the acquired knowledge can be justified (plausibly). Also,

---

[2] Starbuck and Milliken (1988) distinguish noticing from sensemaking, noticing consisting of the activities of filtering, classifying, and comparing, while sensemaking refers to interpretation and the determination of meaning. Weick (1995), in turn, relates the processes of noticing and sensemaking to problem sensing.

abduction allows a significant restriction of the search space. These effects are particularly important in noisy domains because the causal model suggests which phenomena are meaningful and relevant (Botta, Saitta & Ravotto, 1992). Abduction can also be viewed as inference to the *best explanation*, a process that paradoxically seems very effortless to humans, but that often has been computationally intractable. Examples of abductive processes have been recorded in diagnosis, plan recognition, hypothesis formation, explanation/consequence finding, natural language parsing, and probabilistic justification (Lin, 1992). In Brewka's (1991, p. 12) terms, 'the diagnosis we are looking for consists of a minimal set of assumptions which, together with the background knowledge, entail the observations'. Plan recognition, similarly, can be seen as a kind of hypothetical reasoning, where the recognizer tries to find some plan whose execution would entail the performance of the observed actions (Charniak & McDermott, 1985; cf. Allen, Kautz, Pelavin & Tenenberg, 1991). A simple example may help clarify the basic idea:

Like deduction, *abduction* makes use of major and minor premises.

Major premise:	IF my daughter's temperature is over 38°C, THEN I will not allow her to go to school.
Minor premise:	She did not go to school today.
Conclusion:	Her temperature was over 38°C.

The 'opportunistic' nature of abduction is evident when we realize that there may have been other reasons why she did not go to school. However, we have been provided a plausible starting point; a hypothesis has been generated. Davis (1990, p. 101) defines the monotonicity of deductive inference as follows: 'If a sentence Φ is a valid conclusion from a set of sentences Γ, and if Γ is a subset of Δ, then Φ is a valid conclusion from Δ'. Clearly, plausible inference does not have this property.

More generally, monotonic reasoning is 'based on the assumption that once a fact is determined, it cannot be altered during the course of the reasoning process ...' (Rosenberg, 1986, p. 119). Nonmonotonic reasoning, in turn, can be described as the process of drawing commonsense conclusions which may be invalidated (retracted) by new information (Lukaszewicz, 1990). 'In deductive logic, the addition of new axioms to a set of axioms can never decrease the set of theorems. At most, the new axioms can give rise to new theorems, so that the set of theorems grows monotonically with the set of axioms. In nonmonotonic logics, the set of theorems may lose members as

well as gain members when new axioms are added' (Cohen & Feigenbaum, 1982, p. 115). An inherent property of commonsense reasoning is its non-monotonicity: a larger set of *initial assumptions* does not necessarily imply a larger set of *consequences*. For example, when a cardiologist tries to find a diagnosis for a patient's symptoms, s/he excludes some models knowing that they are possible but unlikely. Pruning, Beach (1992) argues, is an epistemic, not an aleatory process. [3] In addition to the resultant diagnosis and treatment action, it is likely that the cardiologist maintains in her/his memory a set of (implicitly or explicitly ranked) alternative 'explanations' or differential diagnoses. *Restricting the class of models* leads to nonmonotinicity. Also, in commonsense reasoning, we often include in our belief set statements which have no justification in our initial assumptions beyond the fact that we have no evidence in our belief set to contradict them: we jump to conclusions (if there is no evidence that would contradict φ, conclude φ). Importantly, abductive reasoning is nonmonotonic as there is no general algorithm that guarantees truth-preserving conclusions.

The classic papers of Reiter (1978, 1980) on *default logic*, McDermott and Doyle (1980) and McDermott (1982) on *modal nonmonotonic logic*, and McCarthy (1990) on *circumscription* – three frameworks that correspond well to first-order, modal, and second-order logics in the classical setting – 'went against the accepted opinions of logicians and philosophers who often claimed that classical logic in its various manifestations is the ideal logic of reasoning' (Marek & Truszczynski, 1993, p. 3). They introduced the possibility of a logical theory of *educated and justifiable guesses*. The following inference is a typical example of default reasoning: *assume X unless $\sim X$ can be proved*: believe a statement, unless and until otherwise demonstrated. Defaults also enter into many knowledge-representation systems implicitly through what is known as the *closed-world assumption*: that all relationships not explicitly stated to hold do not hold (Cohen & Feigenbaum, 1982, p. 115). *Autoepistemic* reasoning, a form of modal nonmonotonic logic, involves reasoning about one's own knowledge (Moore, 1984, 1985, 1988), and follows the following pattern:

1. If statement X were true, I would know it.
2. I do not know whether X is true.
3. Therefore, X is not true.

---

[3] Epistemic strategies require that element-specific knowledge not be ignored as it is central to the judgment, and set membership is merely one aspect of it (Beach, 1992, p. 111).

The nonmonotonicity of autoepistemic reasoning stems from the fact that the meaning of statements about one's knowledge is context-sensitive, i.e., indexical (Moore, 1985).

McCarthy (1990, p. 83) describes the idea of *circumscription*, or parsimonious reasoning, as follows: 'We know some objects in a given class and we have some ways of generating more. We jump to the conclusion that this gives all the objects in the class. Thus, we *circumscribe* the class to the objects we know how to generate'. McCarthy also suggests that cicumscription, with an adequate formalism, may turn out to be the key to inferring nonknowledge.

Tying the discussion to a set of general modeling tools, it is clear that the popular *frame* system is nonmonotonic. 'The frame may be in error, but until feedback or some other form of information makes the error evident, the frame is the foundation for undertstanding the situation and for deciding what to do about it' (Beach, 1997, p. 24). Similarly, inhertiance with exceptions in semantic networks is nonmonotonic (Russell & Norvig, 1995), as is the programming language PROLOG. One feature that distinguishes PROLOG from first-order logic is the treatment of negation. NOT P is true in PROLOG whenever P cannot be derived: negation as failure (Brewka, 1991). Continuing the technical connection, several modern expert systems shells offer two or more knowledge representation methods, so called hybrid systems: rules and objects (Nexpert), rules and frames (KEE), and rules, frames, and objects (Kool) (Klein & Methlie, 1990). Finally, nonmonotonic reasoning is relevant for natural language understanding and for vision, as well as for law; a great part of law being written in the form of rules with exceptions (precedence).

In groundbreaking research on expert as well as novice abductive reasoning among physicians, computer programmers, and automobile mechanics, Krems (1995) has isolated a number of generalizable features. Experts modify the mental representation of a task less often than intermediates do (frequently relying on case-based representations of their knowledge), develop more coherent explanations, and modify their diagnostic assumptions earlier. When confronted with disconfirming data, the experts change assumptions earlier than novices do, and generate a larger number of plausible explanations in their concluding (summarizing) diagnostic decisions. Experts also showed a shorter search path to the correct solution than did novices, focusing their search for information on the most specific level (depth first). Importantly, however, Krem's generalization attempts, as well as the arguments outlined throughout this paper, do not suggest that experts

consistently perform better than novices (Ayton, 1992; Bolger & Wright, 1992; Adelson, 1984; Frensch & Sternberg, 1989). However, they allude to very interesting differences.

At this point, I would like to reconnect with Bruner's (1973) argument concerning the importance of organisms' ability to use minimal cues quickly, with the idea of a mental toolbox presented above, and with the notion of a repertoire of explanations available to the agent proposed by Lundberg (1991, 1992) and Lundberg and Frost (1990, 1992). In the first case, it is possible that these agile agents use default reasoning. In the latter case, the maintenance and use of several competing explanations is related to abduction. Nonmonotonic reasoning opens up avenues to processes that our standard research methods and philosophies in economic psychology may not be suitable for.

5. Discussion

A case has been made for viewing business and economic reasoning through the lens of how professionals produce sense. A person actively involved in economic decision making is likely to be well adjusted to environments characterized by unstable meanings, and uniquely able to handle emergent, evolving truths. Business expertise, maybe more so than most areas of expertise, is based on rapid pattern recognition and matching. In general, people in business and economics may be viewed as meaning-finding 'systems'. Often, humans are considered compulsive sensemakers; sense being much easier to deal with cognitively than life's random elements.

The arguments presented in this paper start with a broad, yet biased look at what it means to be a decision maker, a reasoner, and a sensemaker. The argument focused on processes involved in the making of sense that may have been overlooked in the economic psychology literature. For example, the role of analogy formation on everyday reasoning has been widely studied and acknowledged, yet we have few studies focusing on the role of analogies in sensemaking in narrower, professional domains. It may be time to go beyond the most celebrated metaphors, e.g., the 'bulls' and 'bears' of the market, to a more detailed mapping of the use of metaphors and analogies. These constructs may be part of the reason why professionals, often with quite successful consequences, are seen as jumping to conclusion (making justifiable guesses), after quickly having restricted the search space and generated plausible starting points. On a related note, sense and cause are

naturally related. Causal models suggest which phenomena are meaningful, and help decision makers generate 'best', although frequently quite fickle, explanations.

The professional decision maker is seen as equipped with a diverse mental toolbox. It is tempting to suggest an eclectic borrowing of tools from three major cognitive frameworks: the view of humans as adaptive, boundedly rational systems, the cognitive heuristics approach, and the cognitive algebra framework. In an interesting parallel development, this idea of strategic variety is gaining a foothold both in knowledge management and in data mining (Groth, 1998). In both environments, there is an active interest in developing sets of solution templates which can be leveraged to solve specific business problems.

Weick's (1995) outline of the fundamental processes involved in sense-making is matched with a number of examples originating in trading and auditing decision making. Although the examples were results generated outside of Weick's framework, they provide support for several of the most central claims, and suggest extensions to some. The studies of Lundberg and Svenson (1993, 2000) and Lundberg and Nagle (1999, 2000) suggest that people are excellent at determining meaning as well as maintaining the spirit of the content. Like earlier studies, these studies show that memory of past decisions is a dynamic process; that remembered sense is not always identical to the originally made sense. The on-line making of new sense is a process that we are only beginning to understand. Likewise, the process involved in strategy shift and the changing of mind are not well understood. Nonmonotonic, abductive reasoning is presented as a framework within which we can start to understand, and possibly re-evaluate on-line and creative economic decision making.

As professionals, economic psychologists have utilized tools and concepts that have clear nonmonotonic characteristics. For example, we have modeled human knowledge structures using frames and scripts, built semantic networks that allow exceptions, and sometimes formalized our models in PROLOG code. All three examples have distinct nonmonotonic features. Having taken those, in retrospect intuitive methodological steps, we may benefit further by taking a closer look at the building blocks of abductive reasoning. For example, it is likely that the tendency to jump to conclusions is related to the way people reason about their knowledge. It is also likely that the process of expediently making enough sense, the central idea of satisficing, has several nonmonotonic features. While nonmonotonic reasoning may be flawed in its opportunism, it can help explain the rapid

generation of reasoning starting points and initial hypotheses. For example, the 'tendency to believe a statement unless and until otherwise demonstrated' may provide the reasoner a convenient and often productive starting point.

Acknowledgements

References

Adelson, B. (1984). When novices surpass experts: The difficulty of a task may increase with expertise. *Journal of Experimental Psychology: Learning Memory and Cognition*, *10*, 483–495.

Allen, J. F., Kautz, H. A., Pelavin, R. N., & Tenenberg, J. D. (1991). *Reasoning about plans*. San Mateo, CA: Morgan Kaufmann.

Andreassen, P. B., & Kraus, S. J. (1989). Judgmental extrapolation and the salience of change. *Journal of Forecasting*, *9* (4), 347–372.

Ayton, P. (1992). On the competence and incompetence of experts. In G. Wright & F. Bolger (Eds.), *Expertise and decision support* (pp. 77–105). New York: Plenum Press.

Beach, L. R. (1992). Epistemic strategies: Causal thinking in expert and nonexpert judgment. In: G. Wright & F. Bolger (Eds.), *Expertise and decision support* (pp. 107–127). New York: Plenum Press.

Beach, L. R. (1997). *The psychology of decision making – people in organizations*. Thousand Oaks, CA: Sage Publications.

Bolger, F., & Wright, G. (1992). Reliability and validity in expert judgment. In G. Wright & F. Bolger (Eds.), *Expertise and decision support* (pp. 47–76). New York: Plenum Press.

Botta, M., Saitta, L., & Ravotto, S. (1992). Use of causal models and abduction in learning diagnostic knowledge. *International Journal of Man–Machine Studies*, *36*(2), 289–307.

Brehmer, B., & Joyce, C. B. R. (Eds.) (1988). *Human judgment: The SJT view*. Amsterdam: North-Holland.

Brewka, G. (1991). *Nonmonotonic reasoning: Logical foundations of commonsense*. Cambridge: Cambridge University Press.

Bruner, J. S. (1973). *Beyond the information given*. New York: Norton.

Busemeyer, J., Hastie, R., & Medin, D. L. (1995). *Decision making from a cognitive perspective*. San Diego: Academic Press.

Charniak, E., & McDermott, D. (1985). *Introduction to artificial intelligence*. Reading, MA: Addison-Wesley.

Cohen, P. R., & Feigenbaum, E. A. (Eds.) (1982). *The handbook of artificial intelligence*, Vol. III, Stanford, CA: HeurisTech Press.

Davis, E. (1990). *Representations of commonsense knowledge*. San Mateo, CA: Morgan Kaufmann.

French, P. A., & Funke, J. (1995). *Complex problem solving – the European perspective*. Hillsdale, NJ: Lawrence Erlbaum.

Frensch, P. A., & Sternberg, R. J. (1989). Expertise and intelligent thinking: When is it worse to know better? In R. J. Sternberg (Ed.), *Advances in the psychology of human intelligence*, Vol. 5 (pp. 157–188). Hillsdale, NJ: Lawrence Erlbaum.

Gelernter, D. (1997). The logic of dreams. In P. J. Denning & R. M. Metcalfe (Eds.), *Beyond calculation – the next fifty years of computing* (pp. 117–126). New York: Springer.

Groth, R. (1998). *Data mining, a hands-on approach for business professionals*, Upper Saddle River, NJ: Prentice-Hall.

Hastie, R., & Pennington, N. (1995). Cognitive approaches to judgment and decision making. In J. Busemeyer, R. Hastie & D. L. Medin (Eds.), *Decision making from a cognitive perspective* (pp. 1–31). San Diego: Academic Press.

Kahneman, D., Slovic, P., & Tversky, A. (1982). *Judgment under uncertainty: Heuristics and biases*. Cambridge: Cambridge University Press.

Klein, M., & Methlie, L. B. (1990). *Expert systems: A decision support approach*. Addison-Wesley: Wokingham, England.

Krems, J. F. (1995). Cognitive flexibility and complex problem solving. In P. A. French & J. Funke (Eds.), *Complex problem solving – the European perspective* (pp. 201–218). Hillsdale, NJ: Lawrence Erlbaum.

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. Chicago: University of Chicago Press.

Lin, D. (1992). Obvious abduction, PhD Dissertation. Edmonton: University of Alberta.

Lukaszewicz, W. (1990). *Non-monotonic reasoning: Formalization of commonsense reasoning*. New York: Ellis Horwood.

Lundberg, C. G. (1991). Explanation-based financial decision making. Paper presented at the Joint Conference of the International Association for Research in Economic Psychology (IAREP) and the Society for Advancement of Socio-Economics (SASE), Stockholm.

Lundberg, C. G. (1992). On the utilization of multiple hypotheses in financial decision making. Paper presented at the Joint Conference of the International Association for Research in Economic Psychology (IAREP) and the Association for Experimental Economics (GEW), Frankfurt am Main, Germany.

Lundberg, C. G., & Barna, A. C. (1992). Modeling commodity trading expertise. In D.E. O'Leary & P. Watkins (Eds.), *Expert systems in finance* (pp. 65–88). Amsterdam: North-Holland.

Lundberg, C. G., & Frost, D. E. (1990). Exploring the dynamics of strategy shifts: Experimental evidence from futures trading. Paper prepared for the Annual Meeting of the Southern Finance Association, Savannah, GA.

Lundberg, C. G., & Frost, D. E. (1992). Counterfactuals in financial decision making. *Acta Psychologica*, *79* (3), 227–244.

Lundberg, C. G., & Nagle, B. M. (1999). Post-decision editing of auditors' judgment. In P. Lenca (Ed.), *Proceedings of 10th Mini EURO Conference, Human Centered Processes, HCP'99* (pp. 45–51) Centre de Reserche Public, Centre Universitaire, ENST, Brest, France.

Lundberg, C. G., & Nagle, B. M. (2000). Post-decision inference editing of supportive and counterindicative signals among external auditors in a going concern judgment, *European Journal of Operational Research*, forthcoming.

Lundberg, C. G., & Svenson, O. (1993). Pre- and postdiction of commodity prices. In *Proceedings of the IAREP (International Association for Research in Economic Psychology) Conference* (pp. 346–357), Moscow, Russia.

Lundberg, C. G., & Svenson, O. (2000). Postdecision consolidation in a trend prediction task. *Scandinavian Journal of Psychology*, *41* (2), 159–168.

Marek, V. W., & Truszczynski, M. (1993). *Nonmonotonic logic: Context-dependent reasoning*. Berlin: Springer.

McCarthy, J. (1990). Epistemological problems of artificial intelligence. In V. Lifschitz (Ed.), *Formalizing common sense* (pp. 77–92). Norwood, NJ: Ablex Publishing Corporation.

McDermott, D. V. (1982). Non-monotonic logic II: Non-monotonic model theories. *Journal of ACM*, *29*, 33–57.

McDermott, D. V., & Doyle, J. (1980). Non-monotonic logic I. *Artificial Intelligence*, *13* (1–2), 41–72.

Moore, R. C. (1984). Possible-world semantics for autoepistemic logic. In *Proceedings of the First International Workshop on Nonmonotonic Reasoning*, New Paltz.

Moore, R. C. (1985). Semantical considerations on nonmonotonic logic. *Artificial Intelligence*, 25.

Moore, R. C. (1988). Autoepistemic logic. In P. Smets, E. H. Mamdani, D. Dubois & H. Prade (Eds.), *Non-standard logics for automated reasoning*, New York: Academic Press.

Newell, A., & Simon, H. A. (1972). *Human problem solving*. Englewood Cliffs, NJ: Prentice-Hall.

Norman, D. A. (1997). Why it's good that computers don't work like the brain. In P. J. Denning & R. M. Metcalfe (Eds.), *Beyond calculation – the next fifty years of computing* (pp. 105–116). New York: Springer.

Oberlechner, T., Slunecko, T., & Kronberger, N. (2000). Surfing the money tides: Understanding the foreign exchange market through metaphors. In E. Hölzl (Ed.), *Fairness and Cooperation, IAREP/SABE 200 Conference Proceedings* (pp. 314–319), Baden, Vienna, Austria.

Payne, J., Bettman, J., & Johnson, E. (1990). The adaptive decision maker: Effort and accuracy in choice. In R. Hogarth (Ed.), *Insight in decision making*. Chicago: University of Chicago Press.

Pennington, N., & Hastie, R. (1988). Explanation-based decision making. Effects of memory structure on judgment. *Journal of Experimental Psychology (Learning)*, *14*, 521–533.

Pennington, N., & Hastie, R. (1993). The story model for juror decision making. In R. Hastie (Ed.), *Inside the juror the psychology of juror decision making* (pp. 192–221). Cambridge, UK: Cambridge University Press.

Reiter, R. (1978). On reasoning by default. In *TINLAP-2*, pp. 210–218.

Reiter, R. (1980). A logic for default reasoning. *Artificial Intelligence*, *13* (1–2), 81–132.

Rosenberg, J. M. (1986). *Dictionary of artificial intelligence and robotics*. New York: Wiley.

Russell, S. J., & Norvig, P. (1995). *Artificial intelligence – a modern approach*. Upper Saddle River, NJ: Prentice-Hall.

Sombé, L. (1990). Reasoning under incomplete information in artificial intelligence – a comparison of formalisms using a single example. *International Journal of Intelligent Systems*, *5*(4), 323–472.

Starbuck, W. H., & Milliken, F. J. (1988). Executives' perceptual filters: what they notice and how they make sense. In D.C. Hambrick (Ed.), *The executive effect: concepts and methods for studying top managers* (pp. 35–65). Greenwich, CT: JAL.

Sternberg, R. J. (1988). *The triarchic mind: A new theory of human intelligence*. New York: Viking.

Sternberg, R. J. (1995). Expertise in complex problem solving: A comparison of alternative conceptions. In P. A. French & J. Funke (Eds.), *Complex problem solving – the European perspective* (pp. 295–321). Hillsdale, NJ: Lawrence Erlbaum.

Sternberg, R. J., & French, P. A. (Eds.) (1991). *Complex problem solving: Principles and mechanisms*. Hillsdale, NJ: Lawrence Erlbaum.

Sternberg, R. J., & Lubart, T. I. (1991). An investment theory of creativity and its development. *Human Development*, *34*, 1–31.

Turkle, S. (1997). Growing up in the culture of simulation. In P. J. Denning & R. M. Metcalfe (Eds.), *Beyond calculation – the next fifty years of computing* (pp. 93–104). New York: Springer.

Vessey, I. (1989). Toward a theory of computer program bugs: An empirical test. *Journal of Man–Machine Studies*, *30*, 23–46.

Weick, K. E. (1995). *Sensemaking in organizations*. Thousand Oaks, CA: Sage Publications.

Winograd, T. (1997). The design of interaction. In P. J. Denning & R. M. Metcalfe (Eds.), *Beyond calculation – the next fifty years of computing* (pp. 149–161). New York: Springer.