

Chapter 21

Naturalistic investigations and models of reasoning about complex indeterminate causation

Robert Hoffman*, Gary Klein and Janet Miller

Abstract: This chapter focuses on reasoning about the causal explanation of events and human activities that are indeterminate and complex. We first consider some classical ideas about physical causation from David Hume and John Stuart Mill, who had significant impact on the psychology of reasoning, and we find in their writings some notions that carry over into modern analyses of cause-effect relations and causal reasoning. We then present the macrocognition paradigm, which is empirically grounded in studies of naturalistic decision making, and approaches the analysis of causal reasoning through investigation of the functional purposes of various forms of causal reasoning. This sets the stage for presentation of our research on how people interpret the causal reasoning that is presented in newspaper articles. Findings include new patterns and models of causal reasoning. We conclude with a discussion of some "myths" about causation that characterize theories but that do not match well to our research findings.

Keywords: Causal reasoning, prediction, cause-effect relations, macrocognition, ipsative causal reasoning, projective causal reasoning, indeterminate causation, expertise, causal themes, explanation, models of causal reasoning

1. Introduction

The purpose of this chapter is to describe our research on causal reasoning. We focus on reasoning about events that are indeterminate and complex. That is, we distinguish reasoning about complex human activities from reasoning about physics problems (for instance), which have knowable, single, and definite answers. Sociotechnical systems are all about complex and indeterminate situations: Answers are rarely simple and are always tentative (Hoffman, Norman and Vagners, 2009). Sociotechnical systems have to be understood at the level of "macrocognition", or the analysis of activities such as problem detection, planning, and decision making (Klein et al., 2003). We distinguish such cognitive phenomena from those that are the concern at the "microcognition" level, which focuses on such things as short-term memory access and milli-second-level shifts of attention. Appropriate to its level of analysis, the macrocognition paradigm is empirically grounded in studies of "naturalistic decision making," such as the ones we describe in this chapter.

* Address for correspondence: Robert R. Hoffman, Senior Research Scientist, Institute for Human & Machine Cognition, 40 South Alcaniz St., Pensacola, FL 32502-6008, USA. Tel.: +1 850 202 4462; Fax: +1 850 202 4440; Office: +1 850 202 4418; E-mail: rhoffman@ihmc.us.

First, we consider some ideas about causation from David Hume and John Stuart Mill. They had direct and significant impact on the psychology of reasoning, and we find in their writings some notions that do carry over for the analysis of our brave new world of sociotechnical systems. Next, we discuss in more detail the macrocognition paradigm, and how it approaches the analysis of causal reasoning. This sets the stage for presentation of our research methods and findings, including the models of reasoning that emerged from the studies.

2. A brief history of causation

Our review is necessarily highly selective, converging on core ideas that we pursue in the remainder of this chapter.

The investigation of causality is often traced from Aristotle (384BC–322BC). In his *Physics* (II.3) and *Metaphysics* (A.3), Aristotle considered “effects” as being basic categories of existence, along with substance, quantity, quality, position, and size. Aristotle’s intent was to explain how things come into existence and how a thing can change and yet retain its essential identity (Cohen, 2008). We will not need Aristotle’s analysis of types of causation, although we note that he pointed out that there is no one or simple answer to the question of causation.

A notion of causation that is a focus in this chapter is the temporal “causal chain” idea that was established in the philosophical writings of David Hume (1711–1776) of Edinburgh. To Aristotle, it is substances and objects that have causes (or reasons for their existence) whereas in a Humean view, it is events or occurrences that have causes.

2.1. David Hume

Hume worked as lawyer and for a time was British Undersecretary of State, but was primarily an historian and philosopher, especially interested in the relations of knowledge and belief. His major treatment of things psychological emerged from his reaction to George Berkeley’s 1739 *Treatise on Human Nature*. Hume presented his own version of associationism, which is the general view that knowledge is built up through associations of elemental sensations. Among Hume’s laws of association were the law of cause and effect. That is, a memory of one idea can be stimulated by a memory of another if the two were originally experienced as a cause-effect relation.

The account of causation offered by Hume is in line with our modern notion of cause-and-effect, although it too has been subject to multiple interpretations across the span of modern philosophy. In the Humean view, in order for there to be an objective establishment of a cause-effect relation, certain things must be empirically demonstrated:

1. Priority: The cause always occurs before the effect,
2. Contiguity: The effect occurs close in time to the cause, and
3. Necessary connection: There is some sort of “necessary connection” between the cause and the effect.

Clearly, this third criterion is where the magic lies, especially since the third condition seems to go beyond empirical evidence (that which is directly perceived). Also, the Humean understanding of the first two conditions is by no means simplistic, but takes into account such variations as when a cause continues after an effect has been manifest (e.g., a flood water continues to rise even after a levee has been breached.)

2.2. John Stuart Mill

In his *System of Logic* (1882), J. S. Mill (1806–1873) discussed causation at considerable length, in the context of the known limitations of the method of induction by simple enumeration. To Mill, causation is of paramount importance to scientific experimentation and the discovery of scientific laws. “If we could determine what causes are correctly assigned to what effects, and what effects to what causes, we should be virtually acquainted with the whole course of nature. . . To ascertain. . . the laws of causation which exist in nature; to determine the effect of every cause, and the causes of all effects, is the main business of Induction” (p. 271).

. . . the case in which several agents, or causes, concur as conditions to the production of an effect; a case, in truth, almost universal, there being very few effects to the production of which no more than one agent contributes. . . in which the joint effect of several causes is identical with the sum of their separate effects. . . Most of the uniformities to which the causes conform when separate, cease altogether when they are conjoined (pp. 266–267).

As this passage shows, Mill’s analysis is directly pertinent to the analysis of complex causation. In his discussions of causation (many chapters touch on the topic) we find some very familiar ideas concerning causation.

The necessity of causation. Mill assumed that any apprehended event or phenomenon that has a discernable beginning will have a cause to be found in the circumstances existing at the time of the beginning of the event (Chapter 21). ‘It is more rational to suppose that our inability to assign causes arises from our ignorance, than to suppose that there are phenomena that are uncaused’ (paraphrased from page 405).

Unconditional consequence. Mill had a notion similar to Hume’s notion of necessary connection, that the repetition of cause should always result in the repetition of the effect: “. . . everything which has a beginning must have some cause or other; that among the circumstances which actually existed at the time of its commencement, there is certainly some one combination, on which the effect in question is unconditionally consequent, and on the repetition of which it would certainly again recur” (p. 410).

Causation versus covariation. Mill was very clear about the difference: The fact that two things covary does not mean that there is a causal relation. In fact, much of Mill’s discussion of the “methods of induction” is about methods for determining cause-effect relations based on empirical evidence.

Converging causes. Mill presented a semi-formal analysis of cases in which multiple antecedents cannot be separated or exhibited separately.

Causes influence causes. Causes can serve to amplify the power of other causes, or the addition of an effect onto itself, in a spiraling influence on some effect (“causes that produce a sum of effects”) (pp. 361–363). Mill gave the example of planetary motion, saying “. . . the force grows greater as the planet draws nearer to its perihelion, because as it does to its velocity increases. . . The causes, as they exist at any moment, having produced a certain motion, becoming itself a cause, reacts upon the causes, and produces a change in them” (p. 364).

Causes have causes. Mill noted that one can inquire as to the causes that underlay or compose some other cause, peeling back layers of causation, as it were:

If we inquire further when and how the causes will co-exist, that, again, depends on their causes; and we may thus trace back the phenomenon higher and higher, until the different series of effects meet in a point, and the whole is shown to have depended ultimately on some common cause; or until, instead of converging to one point, they terminate in different points, and the order of the effects is proved to have arisen from the collocation of some of the primeval causes (p. 367).

Non co-termination of cause and effect. Mill noted that a cause can continue after its effect has commenced, and that a cause can show progressive change in its circumstances after it has initiated an effect, a change that can contribute to determining the final course of the effect (p. 363). All of these notions and varieties can be found in modern ontologies of cause-effect relation (e.g., Einhorn and Hogarth, 1986).

Effects can be “emergent.” Mill’s discussion of what we today call emergence is interesting because he illustrates it by references to the complexities of function and causation in living things. Essentially all of his other examples, throughout the book, come from sciences of physics, mechanics, and chemistry. He refers to the fact that the properties of water are not predictable on the basis of knowledge of the properties of hydrogen and oxygen,

Complex causation. Mill takes the notion of emergence a step further, saying: “If this be true of chemical combinations, it is still more true of those far more complex combinations of elements which constitute organized bodies; and in which those extraordinary new uniformities arise which are called laws of life” (p. 267). “The laws of life will never be deducible from the laws of their ingredients” (p. 269). And, “This will be equally true in the phenomena of the mind; and even in social and political phenomena, the results of the laws of the mind” (p. 269).

Cause versus counter-cause. We find in Mill the idea of the counter-cause:

There are thus two different modes of the conjoint action of causes... even if the two causes which are in joint action exactly annul one another, still the laws of both are fulfilled... it will be noticed that we here enlarge the idea of the sum of two effects, so as to include what is commonly called their difference, but which is in reality the result of the addition of opposites (p. 268).

Cause versus enabling condition. Citing an agreement with a point Alexander Bain made in his own book on logic (1870), defined a distinction of cause versus enabling condition. “Causes that merely make good the co-location for bringing a prime mover into action, or that release a potential force” (p. 271). Here we have the question of what counts as a cause or an effect. The listing of Mill’s ideas has taken us progressively closer to the topic of complex indeterminate causation.

3. Modern treatments: What counts as a cause?

In a representative modern treatment, Einhorn and Hogarth (1986) described a number of factors to be considered in the analysis of cause-effect relations: Cause versus enabling condition, plausibility of alternative causes, and likelihood or unusualness of causes. Groetzer (2003) also presented a list of factors for the analysis of cause-effect relations. These, and many others scholars had a notion of causal efficacy (causal power or strength of the cause), and a notion that a cause-effect relation might be deterministic or probabilistic. Groetzer also distinguished cause-effect relations in terms of whether an intentional agent was involved. Many authors have discussed different kinds of cause-effect structures, including converging causes and links or chains of cause-effect relations. See Table 1.

What we see throughout the history of the analysis of causation is:

- 1) A struggle to develop an ontology of causes (what counts as a cause?),
- 2) A struggle to develop an ontology of different kinds of cause-effect relations, and finally,
- 3) A struggle to develop a suite of broadly-applicable measures, factors or variables that can be used to evaluate cause-effect relations (such as causal strength).

Table 1
Representative distinctions made in modern literature

Focus of analysis	Categories
Factors in the analysis of cause-effect relations	Einhorn, & Hogarth (1986)
	Cause versus enabling condition
	Causal efficacy or strength (causal power)
	Plausible alternative causes
	Likelihood or unusualness of cause
	Saliency of the cause
	Abnormality or unlikelihood of the effect
	Temporal contiguity of cause and effect
	Spatial contiguity of cause and effect
	Necessity/sufficiency of the cause for the effect, or the effect following the cause
	Congruence of magnitude of cause and effect
	Molar versus molecular analysis: Stopping rule issue
	Typicality vs. unusualness
	Link strength in causal chains
Types of causes or cause-effect relations	Causal chain
	Precipitating versus underlying causes
	Covariation vs. causation
Types of cause-effect relations	Groetzer (2003)
	Link versus chain
	Unidirectional versus interacting
	Simultaneity of effects
	Intervening variables
	Deterministic
	Proximity (spatial, temporal)
Types of causes	Converging causes
	Causal power
	Intentional agents
	Deterministic
	Probabilistic

We doubt that a complete or consistent set of ontologies and evaluative criteria will be developed any time soon. Analysis of matters of complexity can go on forever, perhaps by definition. We present some analysis of each of these three in this chapter.

First, to summarize the historical perspective, we can extract from the classical literature what seems to be a consensus about an ontology of causes. There seem to be four primary criteria to establish what counts as a cause: propensity, mutability, covariation, and manipulability.

The Propensity criterion is that the proposed cause has to plausibly lead to the effect. This is similar to Hume's notion of necessary connection. A hundred years ago a few medical researchers suggested that mosquitoes somehow caused malaria and Yellow Fever. They were ridiculed because no one could see how tiny mosquitoes could contain enough venom to sicken and kill grown men. It was not until viruses were identified that the mosquito link was understood (Parker, 2008). A putative cause has to plausibly result in an effect, and the strength of the cause will depend on the links between it and the effect. The more links, the less plausible. The strength is generally no greater than the weakest plausible link in the chain.

The Reversibility criterion (usually referred to as "mutability" in the literature) is that the effect should disappear if the putative cause disappears. Kahneman and Varey (1990) linked this notion to counterfactual reasoning, where we can imagine that the proposed cause did not happen – perhaps the star basketball player missed his last-second shot instead of making it. Then, the 1-point victory would turn into a 1-point defeat. In domains such as sports, last minute events can gain causal prominence because

they are easiest to mentally reverse. Kahneman and Varey refer to these as “close counterfactuals.” A cause is identified by tracing back from the effect to the nearest plausible candidate in the causal chain. The person responsible is the one whose actions cannot easily be reversed by anyone else. It is possible to imagine reversals that are not close in time to the effects, but the greater the time lag the more complicated (and uncertain) the causal reasoning. Dörner (1986) has shown that participants in a microworld task struggle to make sense of causal connections as the time delay increases. Other than a simple memory problem, time lags permit intervening factors to tangle up the assessment. The reversibility criterion lets us distinguish causes from “enabling conditions.” If someone lights a match and holds it under a piece of paper and the paper begins to burn, we would say that the match caused the burning. We would not say the oxygen in the room caused the burning. Oxygen is necessary for the paper to burn but it is an enabling condition. We can more readily imagine that the match was not held under the paper than the room was void of oxygen.

The Covariation criterion is the observed coincidence of causes and effects. This covariation contingency is discovered through statistical regularities rather than propensity or reversibility. If we set up a matrix of cause (present or absent) and effect (present or absent), we would find many observations in the upper left-hand corner, where both are present, and the lower right-hand corner – that the effect is rarely if ever seen if the cause has not occurred. The other diagonal would be sparsely populated – few, if any, cases where the cause occurred but not the effect, and perhaps no cases of the effect without the cause. This criterion is related to the “method of differences,” described by Mill (1843) as an experimental design for discovering cause-effect relations. Using covariation, we find the biggest difference in situations where the effect occurred or did not occur, and call that the likely cause. (Mill’s Method of Difference was more an all-or-none – if the cause is eliminated the effect goes away – rather than a magnitude relation.) The persistence of medical authorities in Havana in trying to eradicate Yellow Fever by controlling the mosquito population was due to the perceived strength of the relationship between the two, even in the absence of a plausible causal story.

From J.S. Mill’s discussion of methods of induction, the *Manipulability Criterion* states that for something to be regarded as a cause of a certain effect, then by manipulating that potential cause, we can modify or alter the effect in question. The manipulability criterion runs into problems of circularity, but on a psychological level it seems to have clear value for describing what people mean by assigning causal attributions.

In applying such criteria, one must take context into consideration. Einhorn and Hogarth (1986) noted that if we see a hammer strike and shatter a watch crystal, we would say the hammer was the cause of the crystal’s destruction. But if the observation took place in a watch factory where the hammer was used to test the crystals, and this was the only crystal that shattered, we would say the crystal must have been flawed. But, if the test hammer shattered crystal after crystal, we might speculate that the hammer force was set too high. In most cases, shorter delays strengthen our confidence in the causal connection but the interpretation of delay is actually a function of our mental model of the causal chain. Thus, if you begin to smoke cigarettes today and then, at a routine health screen tomorrow, you find out you have lung cancer, the delay is too short for us to ascribe your cancer to the fact that you began smoking.

There are many kinds of distinctions and dimensions that can be used to tease apart cause-effect relations, ranging from the physical to the intentional, and these dimensions and distinctions combine and recombine in diverse and complex ways. Armed with this legacy of ideas, we can approach the topic of complex indeterminate causation.

4. Causal reasoning and macrocognition

Causal reasoning is central to many of the high-level or macrocognitive functions that are crucial in modern sociotechnical work systems.

- Causal reasoning drives *decision making* – the causal models people hold will determine the way they recognize and categorize situations and the kinds of mental simulation they will perform to evaluate courses of action.
- Causal reasoning is central to *sensemaking* – the application of causal reasoning to understand events and to modify their causal models based on what they learn.
- Causal reasoning plays a central role in our *mental models* about how things work and what will happen if we intervene in different ways. In many, if not most, cases our mental models hinge upon sets of causal knowledge and beliefs we summon to make sense of events.
- Causal reasoning is central to *replanning* – diagnosing why a plan might be going poorly and considering what needs to be altered. It is central to coordination – anticipating how the actions of individuals will affect the activities of the team.

These functions are crucial in all sociotechnical domains. Military leaders engage in causal reasoning to select and evaluate courses of action, to gauge their progress, or explain why they are running into trouble. Physicians depend on causal reasoning when they diagnose their patients. Managers engage in causal reasoning to decide whom to blame for failure and who to reward for success, and sometimes get it wrong. For example, Mlodinow (2008) describes the case of Sherry Lansing, the former head of Paramount Pictures. Under her leadership, Paramount had its greatest financial success from movies such as *Forrest Gump*, *Braveheart*, and *Titanic*. Then Lansing hit a slump. Paramount's market share decreased over six years, from 11.4% to 10.6%, to 7.4%, to 7.1% to 6.7%. The Board of Directors could explain Paramount's slide by considering that when Lansing started she had a fresh vision, but inevitably, her vision became less fresh over time and was going to get progressively less successful. The trend was clear and Lansing was fired. Sure enough, Paramount increased its market share the next year to almost 10% with films such as *War of the Worlds* and *The Longest Yard*. That seemed to vindicate the studio's decision to dump Lansing except that these were movies that Lansing had put into production. The causal reasoning had gotten confounded with normal, medium-term variations in box office returns.

The above examples of complex causal reasoning are suggestive of how a macrocognition approach might broaden our understanding. Just as Aristotle built collections of rocks, fossils, plants and other things, we began our research by collecting instances of reasoning about cause-effect relations, to see what lessons, themes, and ontologies might derive therefrom.

5. Purposes of causal reasoning

Klein and Hoffman (2009) conducted an empirical study of how people make causal attributions and find satisfying causal explanations. Our first step was to collect stories from newspapers, magazines and books illustrating causal reasoning about actual events. We collected stories with the goal of sampling varied venues of human activity including sports, politics, world events, and economics. The sub-prime mortgage crisis provided many explanations as the debacle unfolded. The 2007–2008 American football playoffs and Super Bowl entailed different kinds of accounts. The 2008 Republican and Democratic primaries generated ample speculations about the reasons why different candidates succeeded and failed. The changing conditions in Iraq stimulated analyses of what went right and wrong.

Table 2
Some natural purposes of causal reasoning

	Ipsative causal reasoning	Projective ("other")
Prospective	Reasoning about the future (<i>forecasting</i>)	Reasoning about what someone else thinks will happen.
Interventive	Natural experiment or anecdote	Deliberate experimental action to probe the cause-effect relation or test some theory
Inspective	Comprehending the present (<i>nowcasting</i>)	Reasoning about what someone else thinks is happening.
Retrospective	Reasoning about past events (<i>hindcasting</i>)	Reasoning about what someone else thinks has happened.
Reflexive	Reasoning about one's own reasoning, e.g., "Why is this difficult?"	Reasoning to influence someone else's reasoning, e.g., deception
Continuous	When do I have an account? What is the stopping rule?	Reasoning to prevent someone else from engaging in causal reasoning
Corrective	Recognition that there is an explanatory gap. Reasoning about what went wrong in one's causal reasoning. When do I change my explanatory account? How do I know when to change it? Responsive gap-filling (Response to recognition of a Black Swan)	Recognition that there is an explanatory gap. Reasoning about what went wrong in someone else's causal reasoning. Responsive gap-filling (Response to recognition of a Black Swan)
Protective	Reasoning to achieve a justification or rationalization of one's actions, to provide a rationale (e.g., "cover your butt")	Reasoning to achieve a justification of rationalization of someone else's (or some organization's) actions, to provide a rationale (e.g., "cover your butt" and "scapegoating")

One of our first analyses was of a corpus of 74 incident accounts with a focus on the purposes or rationale for the causal reasoning. As it turns out, there are many. Our initial insight came when we encountered a story about the history of a famous prison, turned into a museum. The story was told by a former prison guard who now worked as a museum guide. In the story he discussed a stain in the concrete floor, said to be the spilt blood of an inmate who died swearing revenge on his killer. As the prison guide explained, all attempts to remove the stain failed. He said, in an eerie tone of voice, "No one can explain it." This was an attempt to tell a causal story with the goal of *preventing* the listener from engaging anything but a mystical explanation of cause. The purpose of the reasoning was to influence (prevent) the causal reasoning of someone else, not just to explain something.

Our analysis proceeded to include other forms of causal reasoning related to deception and influence operations. Other purposes include the goal of understanding one's own actions or beliefs (which we call *ipsative* causal reasoning, from the Latin *ipse*, meaning "self"). Some "natural kinds" of causal reasoning are listed in Table 2. These are all forms of Observative Causal reasoning, in which the reasoner is a commentator on or analyst of the to-be-explained events. This is distinguished from Agentive Causal Reasoning in which the reasoner has a causal power in the events that are being explained.

In this taxonomy, we see an example of the benefits of naturalistic inquiry, to look beyond laboratory paradigms and survey the actual natural occurrences of the phenomena of interest. We have revealed a variety and diversity to causal reasoning, significantly broadening the scope of study of phenomena of causal reasoning. The kinds of causal reasoning that have been subject to rigorous empirical investigation would fall only in a few of the cells in Table 2. But clearly the other forms not only occur, but occur widely in daily human experience.

This conceptual analysis was just a first glimpse of the varieties of causal reasoning. But it did make clear a distinction between determinate and indeterminate causality. Compare, for instance, the entries in Table 2 with the prototypical psychological experiment on causal reasoning, in which the participant (typically, a child) is asked whether the water exiting from a curled hose continues to curl. This is a special sort of situation, historically linked to the study of science education. Much of the discussion of causation in philosophy, and much of the research in academic psychology, focuses on understanding physical causation, where effects are clear and determinable. While there is some literature on causal reasoning about human behavior (e.g., attribution theory), there is opportunity for study indeterminate causation in which the goal is to anticipate individual or aggregate human activity.

6. Scales of indeterminate causality

Our initial corpus analysis made it clear that reasoning about complex causality spans a great range of spacetime. Reasoning may be about very particular events that happened moments ago in a particular place, or historical trends spanning decades and have a reach across nations. To model this, we rely on a distinction made by one of the founders of the field of Expertise Studies, James Shanteau (1992). He observed that there seem to be two types of domains. In Type 1 domains it is relatively easy to identify the specific tasks at which the practitioner is proficient, generate operational definitions of what it means for a person to be an expert, and hence relatively easy to identify experts. This includes domains such as music, surgery, electronics troubleshooting, medicine, chess, weather forecasting, and others. In other domains, it is not so easy. Type 2 domains include jurisprudence, mental health counseling, economic forecasting, and others. These are all domains where accurate prediction is difficult or impossible, and it is not always terribly clear what it means for a person to be an expert. Indeed, the expertise may lie in tasks other than those that are assumed to be the principal tasks. The actual skills at which the practitioner is proficient are not necessarily the skills that ostensibly define the expert's profession. Thus, for instance, one would think that to be an expert clinical psychologist one would have to be able to correctly diagnose and then correctly predict the likelihood of recovery, and then correctly treat the client, but the true skill might lie in being a very good listener.

Type 2 domains are ones in which the ostensive principal task goals involve the prediction of individual or aggregate human activity. Human activity fails to provide the needed cues for timely feedback, which is one of the reasons why it can be difficult to achieve expertise. At a collective level, human activity is subject to too many unpredictable events and decisions. The spread of ideas on the Web through such mechanisms as YouTube is an example.

It is sometimes certainly possible for individuals to perform well in predicting events involving human affairs. An on-going study of the forecast accuracy of intelligence analysts (Mandel et al., 2009) is showing that analysts can do a good job if they are working on areas that provide timely, unambiguous feedback on their performance – in other words, in stable domains. Furthermore, intelligence forecasts can be better at point prediction if they are very near-term (National Intelligence Council, 2000; The United States Commission on National Security, 1999). Conversely, the U. S. National Intelligence Council's *Global Trends* report of 2000 suggested that the phenomenon of global climate change was knowable even if the impact was not precisely predictable.

The Economist newspaper regularly publishes predictions about human affairs in areas such as economics, health care, real estate, etc. A survey conducted in 1984 (summarized in *The Economist*, 1995) found greater accuracy in a control group than in the experts in a 1984 to 1994 set of economic point predictions. Of four groups of people – finance ministers, chairmen of multinational corporations, Oxford

University economics students, and, as a control group, four London garbage collectors, every group did poorly. The garbage collectors, as it happened, turned out to be the most accurate, the point being that forecasting is difficult. Kahneman and Klein (2009) noted that “long-term forecasting must fail because large-scale historical developments are too complex to be forecast” (p. 520). The low inherent predictability of specific events, actions, and decisions within a long-term spacetime scale is a feature of decision making and judgment because it is a nasty fact of the world, the inherently low predictability of the actions of individuals or aggregates of individuals.

This is why it makes sense to say that something was “unexpected” and yet in hindsight can be plausibly explained. If one is anticipating specific events and effects (near-term), but is doing so largely on the basis of beliefs about forces and trends (which are long-term), then of course many specific events are left unanticipated, and many of those could have been regarded as “predictable” if one were able to turn back the clock and bring to bear one’s knowledge of the broad forces and trends at work.

This is illustrated by the predictions offered by a number of books published in the 1995–2001 period that addressed the issues of the looming 21st Century, and missed climate change – and more importantly from the U.S. perspective – missed the likelihood of attacks such as those by Al Qaeda on the World Trade Center and the Pentagon on 11 September 2001 (Schwartz, 1996). One could argue that the likelihood of a war on terror was knowable before 2001. At least one intelligence adviser warned of the 9/11 attacks. Undermining a more thorough anticipation was the complexity of the future, which when viewed from afar prevented accurate assessment.

Fallows (2005) speculated of a looming economic crisis. As seen from hindsight, Mr. Fallows had no way of knowing in foresight which parts of his speculative piece would come “true”. It blamed the crisis in part on people using home-equity to buy stocks, but from the point of view of 2005, however, the impending crisis centered around a number of mortgage-related activities and practices. To shrink-wrap these in a package, many simply blamed the economic crisis on “greed”.

Some things can be predicted, if by “prediction” one means that a specific or distinguishable event is forecast to transpire in the future. If the event is close in spacetime it is likely to be a prediction of some specific event, decision, action, or human activity. Some things cannot be predicted but only a range of possibilities can be anticipated. These fall at broader spacetime scales and involve forces and trends more than they involve specific events. This is depicted in Fig. 1.

What occurs when we think about an event or trend lying in the future? Long-term forces and abstractions or near-term events and decisions are projected forward in spacetime towards an effect or event that we are trying to make sense of. Then we envision the reach and consequence of that effect or event further into the future; we extrapolate future forces and abstractions, and events and decisions. We make these considerations from some present moment prior to the effect or event to be made sense of. What counts as an “effect” is predicated upon events and decisions that are themselves influenced by forces and abstractions. They in turn give rise to new (or continuing) events and decisions that are in turn embodied in new (or continuing) forces and abstractions.

What makes some sense out of this complexity of multiple causation is that at each scale, there are particular dynamics having particular space-time parameters. As one progresses from higher scales to lower, each scale provides the “boundary conditions” or forcing events for the scale below it. Each scale requires examination of different kinds of data and emergent patterns as well as differing meanings. Dynamics are coupled to spacetime, and because time is a factor there is an explicit expression of increasing uncertainty the farther one is from the effect or event – either in the past or in the future.

This all occurs in foresight. We subsequently look at events backwards. Someone got onto an airliner with a bomb in their underwear. What explains this? We can reason backwards in actual time from effects

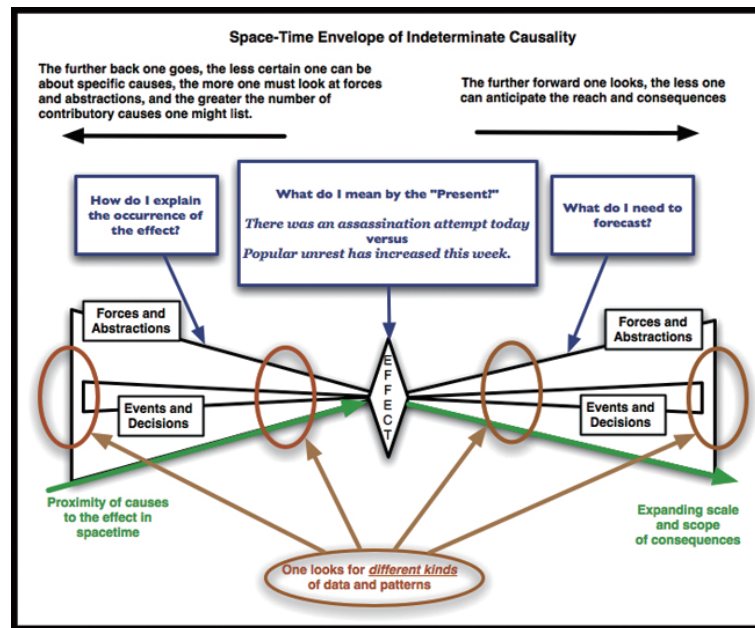


Fig. 1. The Spacetime Envelope of Indeterminate Causality (Reproduced with permission from Moore and Hoffman, 2011).

and after effects (the attempt by the bomber to detonate his explosives and the successful preventative intervention) to causal explanations. And, we *always* find those causal explanations; we're typically certain they're the right ones, or plausible ones, or good ones.

For Type 1 domains, people may be good at this. The very nature of Type 2 domains should preclude any certainty of accuracy on our part about causal explanations. But, as Kahneman and others point out, people are sometimes certain they are right: the "illusion of validity" prevails. Such sensemaking in hindsight is quite rational, the reconsideration of a case after one has obtained more information about it. It works because we only consider what we knew afterwards and what we could or should have known afterwards. We do not consider the event from the perspective of what we knew *before* the event occurred. (And the case of intelligence failures, this feeds into the blame game.)

If one looks to some distant future, then the activities of individuals or groups can only be *anticipated* in terms of general trends and forces: discretions and authorizations for things that individuals might do. On the other hand, if one looks to the near future, one is more able to *predict* specific activities and decisions, things that individuals are obligated to do. The Spacetime Envelope suggests a reconsideration of the customary goal of "predicting behavior." It might be prudent to seek means for *anticipating ranges of activity* of certain kinds and divorce this from any assumption that it would be useful to generate lists of alternative specific actions and assign to each a probability of occurrence. While it may be possible to do that, the efficacy of such prediction is likely to be limited, and to date has proven to be so. In other words, *whether* one can anticipate or predict depends on the spacetime frame of reference, and *what one* can anticipate or predict differs depending on the spacetime frame of reference.

As we analyzed our story corpus, and brought in more stories to attempt to both validate and refine our distinctions and models, we noticed that individual causal attributions sometimes gather together, to form what we came to call "themes".

Table 3
Frequency of occurrence of references to types of causes, in an analysis of news reports

Topic	# Cases	Single causes			Causal structures	
		Reversible event	Abstraction	Condition	List	Story
Sports	38	17	55	29	14	12
Economic	18	20	3	25	2	14
Politics	7	17	5	14	7	0
Military	3	4		4	2	0
Miscellaneous	8	18		8	1	3

7. Studies of indeterminate causal reasoning: Themes of causes

In studying accounts that presented causal analyses and causal explanations, we identified what we perceived to be individual statements of causal attribution, we labeled the statements with identifiers, and we made notes that summarized each attribution. For instance, one story offered an explanation of the increasing cost of products made in China (the effect X to be explained). Some causes led directly to the effect. For example, China reduced and removed tax incentives for exporters of Chinese goods (A), which led to increased costs of exports ($A \rightarrow X$). Product recalls and environmental crackdowns (B) also led to increased cost of products made in China ($B \rightarrow X$). Causes were also indirect. For example, an increase in oil costs (C) led to an increase in the cost of plastics (D), which led to an increase in the cost of Chinese products ($C \rightarrow D \rightarrow X$). Labor shortages and stricter labor rules (E) led to an increase in wages, which (F) led to an increase in the cost of Chinese products ($E \rightarrow F \rightarrow X$).

As we collected and analyzed more accounts, we began to see some themes. In some explanations the cause was seen as a single dramatic event that occurred close in time to the cause, and that might have gone the other way (e.g., a basketball team lost a game because of a basket at the very end of a game), whereas in others there was a critical event but it was not so dramatic, coming earlier in the event sequence. Both of these are a theme of the single critical and reversible event, we found accounts that seemed to boil down to a single condition for how something could happen (e.g., HIV causes AIDS), but we also found stories in which the mechanism was complex, involving multiple causes in which the effects interacted with one another.

In the corpus of 74 incidents we identified the causes as the reasons offered by the writer to explain why the outcome occurred. We tallied 219 individual causes. Only two of the 39 sports incidents referenced 10 or more causes. In contrast, four of the 18 economics incidents included 10 or more causes. None of the political, military or miscellaneous incidents had as many as 10 causes. The data on the themes are presented in Table 3, and are discussed next.

The reversible event. These attributions were to mutable on reversible events, actions or decisions, sometimes referred to in the literature as counterfactuals or close counterfactuals. For example, late in the last quarter of the 2008 Super Bowl between the NY Giants and the New England Patriots, Eli Manning, the Giants' quarterback, seemed almost sure to be sacked by the Patriots but somehow spun away and got off a pass that the receiver caught against his helmet. Most accounts of the game highlighted this miracle play because if Manning had been sacked the game would probably have ended with the Giants losing, and it was very easy to imagine the play failing. Events that are mutable are more convincing causes than routine events – in basketball, winning a game with a free throw in the first quarter is less likely to be cited as an explanation than winning with a 3-point shot. A last minute reversal, such as the winning 3-point shot, appears to be both necessary (the team would have lost if the shot missed) and sufficient (at that point, the game was completely decided by the shot). As might be expected, the sports

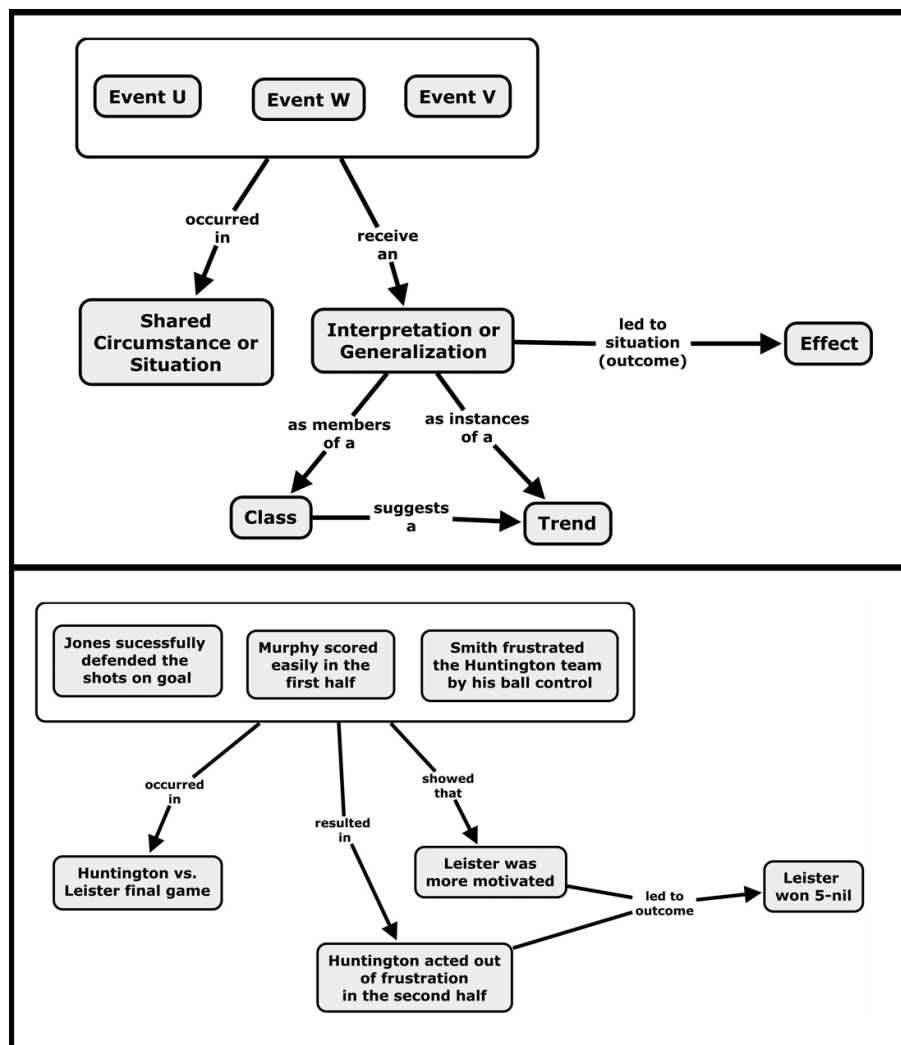


Fig. 2. The “abstraction”.

incidents included a large share of reversal (counterfactual) explanations. In the economics category, the U.S. Federal Reserve decision to keep interest rates low in the period 2002–2004 has been identified as a cause of the housing boom, the housing bubble, and the subsequent recession.

The abstraction. The Abstraction is a generalization over evidence (events or conditions). This causal attribution takes several causes, sometimes including counterfactuals, and synthesizes these into a single-cause explanation. The explanatory statement collects them as sub-events or prior conditions, distills a substantive similarity as a single explanation. The evidentiary events or conditions might be superficially different (e.g., different ways in which team members could make errors) or substantively similar (e.g., all the team members were getting old). In basketball, a series of mistakes by the New York Knicks (a professional sports franchise) were synthesized to explain why the Knicks lost the game – they made too many errors. Table 3 shows the Abstraction theme was more prevalent for sports than for economics. The Abstraction is sometimes offered by itself, with exemplars being implicit, but at other times the Abstraction was used as an additional way to bundle events in which all of the relevant factors

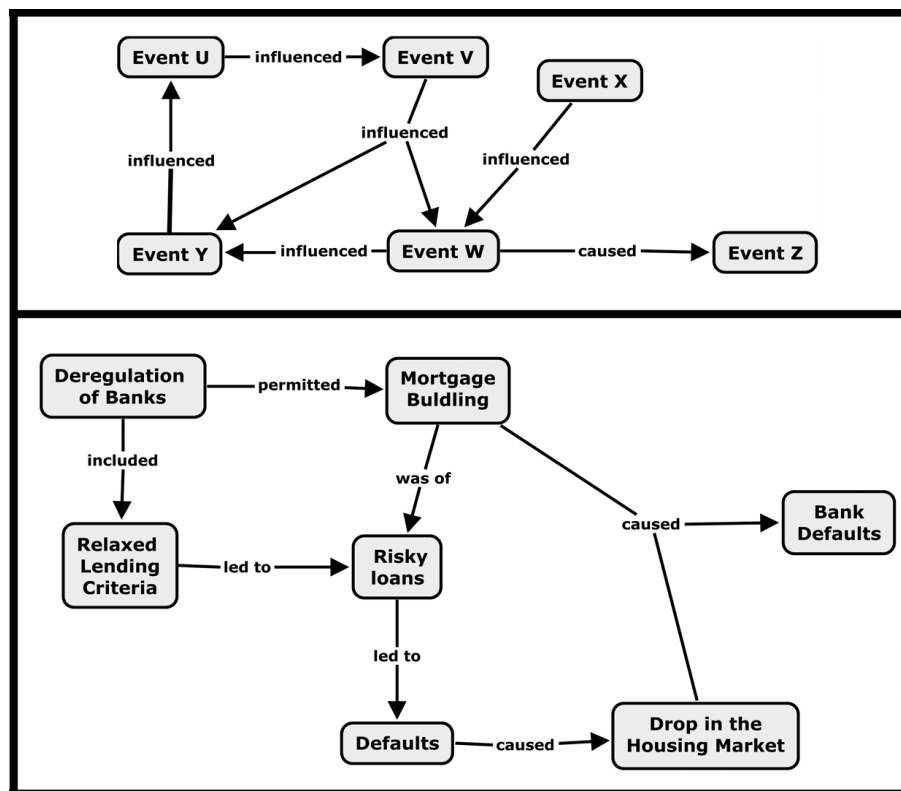


Fig. 3. The “clockwork”.

and events are of the same kind. Most important, an abstraction is usually offered as a single answer to the question of what caused an event, in contrast to lists and stories.

The enabling condition. This causal attribution cites a prior condition even before the to-be-explained event began. Thus, in sports, if a key player was so injured that he did not even play, we counted that as an Enabling Condition because it did not occur during the contest. Economics offers many examples of conditional explanations – a market force inexorably at work, such as the development and collapse of bubbles. Often, a conditional theme is used in a simplistic fashion. The economic recession is blamed on greed. The success of a sports team is attributed to better coaching, or the fact that they “wanted it more.” Or consider the cause of World War I. The assassination at Sarajevo explains it as an event, whereas the rise of nationalism explains it as a condition – a feature of the situation. We use this theme of causal reasoning to include lawful relationships and regularities, as well as characteristics of a situation such as an injury to a star player.

In addition to finding that most causal explanations can be parsed into these themes, we also found that the four get combined in various ways into causal structures. A “chain” is a series of causes and effects culminate in the to-be-explained effect. A “swarm” is when multiple and *independent* causes converge or combine to cause an effect. A “clockwork” is when multiple and *interdependent* causes combine to bring about an effect. The Abstraction, Clockwork, and Chain are depicted, with examples, in Figs 2, 3 and 4.

Some of the themes represent ideas presented in the past. What we called swarms and chains were discussed by J.S. Mill. Herbert Simon referred to examples in which a proposed cause was further

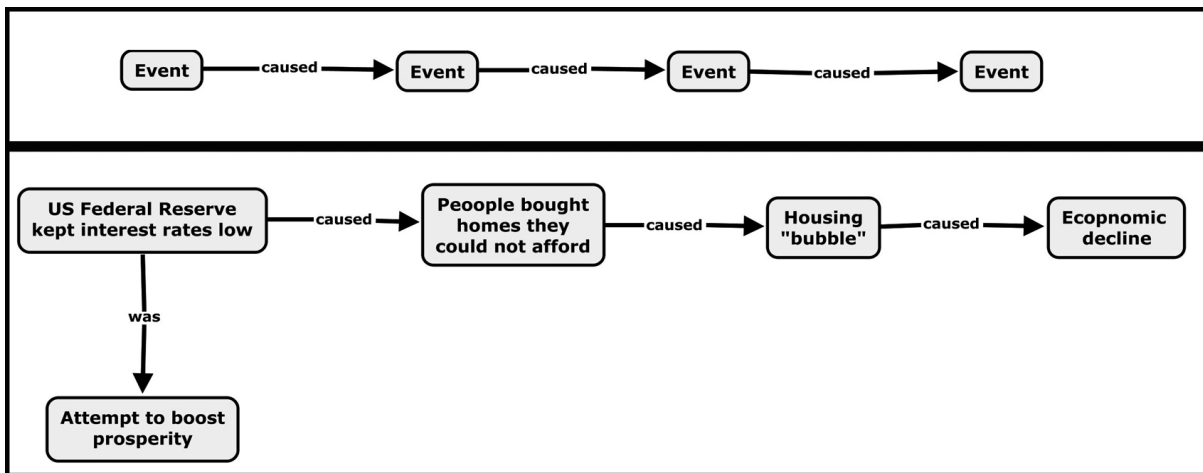


Fig. 4. The “chain”.

analyzed, like peeling apart an onion to find the cause of the cause (1992). These were all causal structures. It was a struggle for us to deal with the problem of multiplication of the categories. We decided that the onion is captured sufficiently by the notion of a chain. In some chains, the causal power progresses as each cause amplifies the subsequent effect. People sometimes refer to this as an upward or downward “spiral”. In looking at cases of causal reasoning where deception might be involved, we considered the metaphor of the “snark hunt”. The snark is a mythical animal that is the object of search. As a form of causal reasoning, the reasoner determines that the causes under analysis might, in fact, not exist. In a variation on this, people sometimes look for a “culprit”. Of a set of alternative causes or explanations, only one is the “true” or the “real” cause. This is similar to “root cause” analysis, when people ask, “Yes, but what *really* caused it was. . .” In waves of reanalysis we tried to reduce the set of themes to a smaller and manageable number, taking into account the fact that some themes were not very frequent in the corpus we analyzed. We finally latched upon a very simple dichotomy, the “Single Causes” versus “Causal Structures” that appear in Table 3, above. We next describe the two main types.

The list theme. This is a list of multiple reasons why something happened and converged. Lists are fairly common in sports – e.g., the reasons the Patriots lost the Super Bowl. For the sports category, 14 of the 38 accounts featured a list. Lists are less common in economics – an example would be an article listing the reasons why the Chinese economy should move into a higher rate of inflation. All of the articles on politics relied on a list – the reasons the political campaigns of John Edwards, Rudy Giuliani, Mitt Romney, or Hillary Clinton folded. A variation on the list theme that we noted is what we called the “counter” theme. This form of causal explanation is simply a tabulation of the number of incidents in which an opposing cause was mentioned – e.g., a good play by someone on the losing side of a sports contest. These counter-explanations emerged fairly often in sports, but were rare in the other categories.

The story theme. This provides a deeper analysis to present a mechanism of how the different causes interacted. Sometimes the stories took the form of a chain or a clockwork. Chains were relatively rare in the sports incidents, and when they were used, the chains were very short. Chain-reaction stories seem more prevalent in economics. In general, economics analyses used the most complex story explanations. For example, one article described how the Federal Reserve worsened the sub-prime mortgage problem. An example of such a story is presented in Table 4, based on a report of the death by asphyxiation of a fireground commander in New York. Each of the elements of this story is a cause – each was a reversible event, each led to the subsequent events/effects.

Table 4
An example of the “story” theme of causal explanation: Firefighting incident

-
- A woman in an apartment was giving baths to her children and wanted the apartment to be warm so they wouldn’t catch colds. The apartment was already adequately heated. She increased the temperature by turning on the gas stove.
 - Her young son, waiting for his turn, started playing with a paper wrapper from a toy. He waved it over the flames and it caught fire.
 - He became frightened and tried to hide it behind a sofa.
 - The sofa caught on fire and the flames spread.
 - The mother came out of the bathroom, saw the flames, gathered up her children and fled the apartment.
 - On her way out, she dislodged the rug by the front door.
 - The rug got stuck in the self-closing door, preventing it from closing.
 - In her rush she didn’t check the door.
 - Because the door didn’t close, the fire and smoke were not contained to the apartment. They spread into the hall.
 - Shattered windows created winds that fanned the flames.
 - The firefighters arrived and were thwarted by low visibility because the hall was filled with smoke.
 - Their progress was so slow that they began to run low on oxygen from their tanks.
 - Accordingly, they had to withdraw.
 - The unit leader failed to withdraw.
 - * Perhaps he was still searching for residents.
 - * Perhaps he wanted to be sure that everyone in his crew had left.
 - * Perhaps he became disoriented.
 - He ran out of air and died.
-

Table 5
An example of the “story” theme of causal explanation: The U.S. mortgage crisis

-
- In January, 2001 the .com bubble was bursting.
 - A recession was starting.
 - After the 9/11 attacks there was a fear of deflation.
 - Therefore, the Federal Reserve cut the rate by 0.5% outside the normal schedule for announcing rate changes, from 6.5% to 6%, followed by 12 more cuts through 2003, dropping the rate 5 points, eventually to 1%, the lowest rate since 1958. The Federal Reserve kept rates at this level for a year. Then the Federal Reserve increased rates by $\frac{1}{4}\%$ increments, to 5.25% in June 2006.
 - However, by 2002 it was clear that rates should be staying neutral or going up, not down.
 - * The Gross Domestic Product was lining up with capacity.
 - * Inflation was low.
 - In addition, the housing market was vibrant, even in 2001.
 - * Housing does not always follow the law of supply and demand. When prices rise, that creates a demand in the form of a bubble as people expect prices to keep rising.
 - * The rise in housing prices created an increase in house building, strengthening the economy.
 - Mortgage rates stayed low even when the Federal Reserve under Bernanke raised the rates.
 - * The reason that Bernanke suggested was the low rates was a global issue. Oil exporters and thriving Asian economies needed places to invest.
 - * This added to the money supplies in the U.S. and kept rates low.
 - Lending standards were reduced, which is typical in a bubble/craze.
 - All of these credit-cheapening forces helped the sub-prime borrowers enter the equation, as looser practices and pressures enticed less-qualified investors.
-

Here we see a set of causes related to the spread of the fire into the hall, and another set about the failure of the lieutenant to withdraw in time. There is no single event or single sequential chain. Table 5 provides a second example.

The mortgage crisis story describes different causes acting in parallel, but also interacting, to produce the conditions for an economic crisis in the U.S. The causal analysis tried to explain why the Federal Reserve made a critical mistake in 2002 when it continued to reduce rates.

The greater complexity of the explanations in economics, as compared to sports, comes with a caveat.

The economics explanations created an impression of inevitability, a sense that this is how the dominos were fated to fall. The mortgage crisis example is an anomaly that suggests the Federal Reserve should have acted differently and might have altered fate. Most economics explanations fail to include any countervailing forces or opportunities for events to unfold differently. They are perceived to be strongly determined. In contrast, many of the sports accounts note countervailing causes. A few of the Super Bowl accounts note the Giants were lucky with their miracle play, a play that changed the outcome of the game. Of the 38 sports incidents, 12 cited some sort of countervailing force. Only 3 of the 18 economics incidents did so. Sports accounts seem to be more sensitive to factors such as luck, and sometimes offer a counterfactual perspective that is usually missing from economics.

Fugelsang, Thompson, and Dunbar (2006) referred to the list theme as “multicausal,” and, within story explanations, distinguished domino chains as “linear” and more complex stories as “interactive.” However, their use of “multicausal” involves only necessary conditions (e.g., for a flower to bloom it must receive sunlight, fertilizer, warm temperature, and moisture), whereas our analysis of lists includes factors whose influence is not fully determined, such as the reasons that Hillary Clinton’s presidential campaign failed.

We are currently replicating this study and extending the set of cases, to ask whether reliance in one or more of the themes depends upon the domain at hand. For instance, we suspect that explanation by Clockwork typifies economics whereas explanation by list and reversible typifies the explanation of outcomes of sporting events.

8. Modeling the results

We culminated these investigations with an attempt to graphically represent how the basic types of cause and the various themes relate to one another. This resulted in what we called the Butterfly model – so named because its shape (sort of) resembled a butterfly. The body of the butterfly was the List theme. From that, one might branch toward single cause explanations or branch toward multiple cause explanations. This is depicted in Fig. 5.

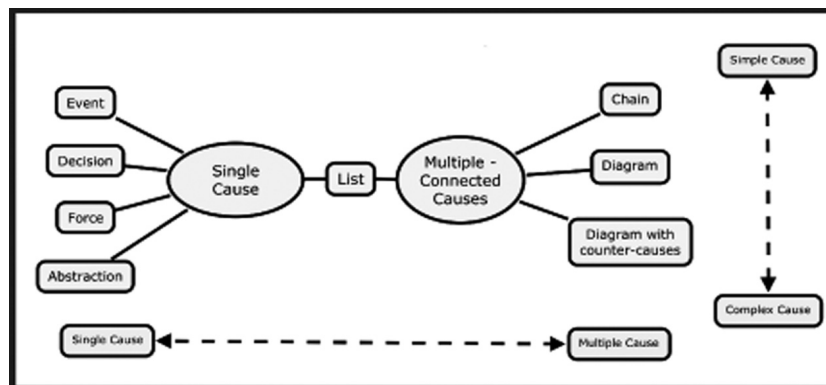


Fig. 5. The initial butterfly model.

People do not always prefer the most complex explanations, such as the Clockworks that show multiple interactions of causal variables. It seems from our results that as people begin the process of sensemaking by causal analysis, they initially latch on to simple, single causes (sometimes Reversibles and sometimes

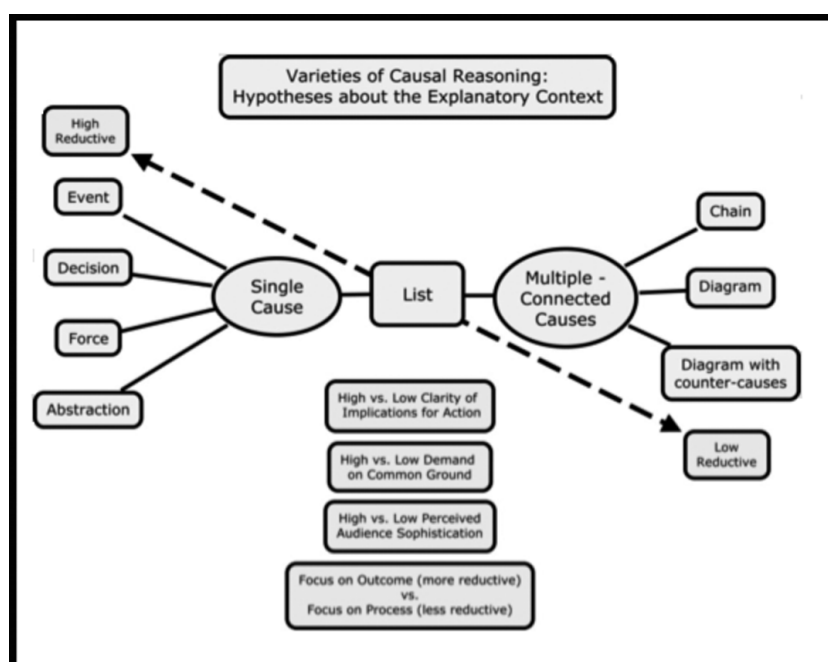


Fig. 6. Using the butterfly model to capture preference factors.

Abstractions), then they expand and deepen the analysis, but only to the point where they feel a need to re-simplify. It did not escape our notice that this pattern characterized our own struggles in trying to develop robust and broadly applicable ontologies for cause, effect, and cause effect relations. We would see instances that suggested a type of cause or a theme, and build upon the list of themes, but then feel a need to reduce and simplify.

We attempted to graphically represent how preferences and context dependence might fit with the Butterfly Model in light of our own struggle at ontologies for causation, and our waves of analysis and synthesis, which largely reflected the tendency of one of us to split the categories and the tendency of the other one of us to struggle to merge categories. It occurred to us that the Butterfly Model might be used to capture preference factors. This is depicted in Fig. 6.

We next conducted an investigation that asked about themes in another way. We presented people with explanations that represented the types and structures that we had described. If left to their own devices, would people themselves apprehend the sorts of themes that we found (as in Figs 2, 3 and 4)?

9. Do you see what I see?

Five news articles were selected, from the larger corpus we discussed previously, representing the domains of sports, world events, history, and economics. Each article was one page or less, and they spanned several different domains.

1. Economics. "How Did Madoff Get Away With it?" *The Week*, January 2009.
2. History. "Supply and Demand: The Industrial Revolution Explained and Why Britain Got There First." *The Economist*, Fall 2009.
3. Sports. "Patriots Not So Perfect After All." *Pensacola News Journal*, January 2008.

4. Business. "Inside Every Chief Exec There is a Soviet Planner." *The Observer*, 2009.
5. World Events. "Can Obama Tame North Korea?" *The Week*, November 2008.

Sentences, clauses, or phrases in each article that represented causal attributions were identified and underlined by the Researcher, using the conceptual terminology of the causal themes: abstraction, enabling conditions, counter-cause, reversible event or decision, list, or chain. Examples are:

- "*The SEC got multiple warnings but failed to uncover Madoff's activities.*" (Counter-cause)
- "*The Industrial revolution began in Britain because it was profitable there and it fit a demand.*" (Abstraction)
- "*Steam engines had been designed to pump water, watchmakers provided high-quality gears. . .*" (Chain/List)
- "*Why did Britain have high wages and cheap energy in the first place?*" (Abstraction)
- "*The Patriots won the Super Bowl because their receivers kept catching Manning's last-ditch passes.*" (Abstraction)
- "*Relations with North Korea worsened because Bush tried to bully Kim.*" (Reversible)

The labeling was an emergent process, as the preparation of materials of this study also fed into our continuing development and refinement of the themes. For instance, in our initial appraisal of the process of causal reasoning we discussed the phenomenon of "onioning" in which the reasoner asks about the cause of a cause, but we had not included that in our brief list of themes because it seemed to rare, and could be counted as a type of Reversible Event or a type of Abstraction. Also, we had included the Chain as one of the themes but the examples we found in articles were typically lists of factors rather than chains of cause-effect relations.

The experiment was run as a self-administered booklet, presented to 11 psychology majors at the University of West Florida. Each article was printed on a separate page, and written at the top was the effect to be explained (e.g., "*What causes the U.S.-North Korea hostility?*"). Instructions were to read the article and then go back and underline what were seen as causal attributions. Next, each underlined attribution was to be rationalized by answering the questions: "How does this explain the cause?" "Is the story-teller's explanation simple or complex?" "What is your level of prior knowledge and interest in this topic?"

After reading a relatively simple worked-out example, the participants worked through their booklets, time-stamping the turn of each page. It generally took participants about an hour to an hour-and-a-half to finish the booklets. Table 6 shows the results with respect to the articles: The statements that participants underlined were also statements the researcher had underlined and categorized. These might be thought of as "hits." This shows that for all of the articles, the researcher identified more causal attributions than all of the participants.

Table 7 shows the results with respect to the participants, the average proportion of statements each participant underlined that were also statements the researcher had underlined and categorized. Participants tended to notice this only about one-third to one-fifth of the number of potential ("seeable") causal attributions.

Table 8 shows the results with respect to the types of causal attributions, the "Seeability Proportions." Seeability was the total number of times that participants underlined an attribution relative to the total number of times the attribution was presented to participants. Thus, if an article had two Reversibles, and there were 10 participants, the total number of opportunities for seeing would be 20. All of the participants "saw" Reversibles and Abstractions. (We place scare quotes on "saw" because the participants did not rely on our conceptual terminology.) All but two of the 11 participants "saw" Enabling Conditions.

Table 6
Results on participants' underlining of causal attributions that were also noted as causal attributions by the researcher

Story	Total # of attributions seen	Total # of opportunities to see	Mean (over participants) proportion of attributions seen
Industrial revolution	29	165	0.24
Madoff	37	77	0.51
North Korea	41	154	0.36
Patriots win	28	99	0.18
Planners	41	231	0.18

Table 7
Average proportion of hits for each participant, averaged over attributions within articles

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
Sum	42	28	19	13	20	12	19	33	17	21	21
Mean	0.43	0.29	0.25	0.20	0.20	0.10	0.30	0.30	0.18	0.34	0.24

Table 8
Seeability results

Causal theme	Occurrences (number of attributions in all the articles)	Opportunities (participants x occurrences)	Average (over participants) of the proportion seen
Enabling condition	23	253	0.15
Reversible	30	330	0.30
Counter-cause	7	77	0.21
Abstraction	30	30	0.37
List/chain	2	22	0.32

Only two of the 11 Participants underlined Counter-causes. There were only seven Counter-causes in the articles, and hence 77 opportunities. Six of the participants did not underline the List/Chains. There were only two lists/chains in the articles, but going into the study, we thought these were salient and obvious. For instance, in the article on the causes of the Industrial Revolution there was the Chain: *"The Black Death raised the price of labor and boosted trade, for English sheep grew longer fleece, and local cloth improved. As Britain traded more. . . other cities expanded."* We expected all participants to underline such obvious chains, but only six of the 11 did, and even then they did not uniformly underline all of the elements within in the chain or list.

One possible outcome was that participants could underline statements, regarding them as causal attributions, that the researcher had not highlighted and labeled in the master scoring key. Out of 245 underlinings by all the Participants, there were only 19 such additions, which contrasts with the total of 92 attributions identified by the Researcher. Of the 19 additions, eight were from just one of the articles. Most of the additions were either restatements of the effect that was to-be-explained or were causal attributions only by inference. An example of an effect restatement is *"Madoff stole money,"* which was regarded by one participant as a causal explanation. Arguably, it could be thought of as an enabling condition and, thus, we would consider it a causal attribution that the researcher missed. An example of attribution by inference is the statement *"We played them like they were any other team,"* which was interpreted by one participant to mean that *"They were not intimidated."* While this could be regarded as an Enabling Condition, we did not count it as a "Researcher miss" because the attribution was by inference, that is, it was not explicit in a statement in the article.

Table 9
Examples of attributions and the participants' explanations

P	Article	Underlined statement	Researcher's categorization	Participant's explanation
1	Industrial Revolution	<i>"... the conditions were not sufficient or exclusive to Britain. . ."</i>	Counter-cause	<i>"These explain why the author thinks that previously considered factors are insufficient."</i>
1	Industrial Revolution	<i>"The Black Death raised the price of labor and boosted trade, for English sheep grew longer fleece, and local cloth improved. As Britain traded more. . . other cities expanded. . ."</i>	Chain/List	<i>"Long series of cause-effect statements to explain why wages were high and energy cheap."</i>
4	North Korea	<i>"North Korea fears that it has become a low priority for an incoming Obama administration that will have to deal with other issues."</i>	Abstraction	<i>"NK knows that the Obama administration has too many problems to tackle and that they are towards the bottom of that list. So they are creating hostility with the USA for attention."</i>
5	Patriots Win	<i>"When Eli Manning put up last-ditch pass after last-ditch pass, and his receivers kept catching them. . ."</i>	Abstraction	<i>"Explains how Giants QB made many last ditch long passes, causing Giants to gain momentum."</i>
6	Planners	<i>"If anything, overhead costs are increasing as work breeds more work. In less effective organizations, of course, hidden indirect costs are much higher."</i>	Enabling Condition (Spiral)	<i>"Overhead increases as work breeds more work – hidden indirect costs are much higher."</i>
7	Industrial Revolution	<i>"The industrial revolution occurred in Britain in the 18th and early 19th centuries for one overwhelming reason, he argues: it was profitable there and then. It met a demand."</i>	Reversible	<i>"Profit caused the IR to occur in Britain."</i>

Combined with the results on "hits," it seems clear that the Researcher not only identified many more attributions than the Participants but identified most of the attributions that people might find. Most people can "see" Reversibles, Abstractions, and Enabling Conditions. The participants' explanatory comments show that they apprehend the justification (or explanatory value) of an attributions in ways that accord with our conceptual terminology. Examples are presented in Table 9.

Many of the participants' justification statements were explanatory elaborations, a good example being row three in Table 9. Also frequent were justifications that essentially restated article statements. A good example is the last row in Table 9.

We noticed some interesting individual differences, constituting one of the findings that motivate further investigation. We pointed out above that participant performance ("hit" rate) ranged from about 50% down to about 10%. There are many explanations for this, and for the discrepancy of 245 vs. 92 comparing the participants and the researcher. Many of the possibilities will involve individual differences. That it is possible using this experimental paradigm to observe a range of performance means this paradigm could be used to explore the individual difference factors. For example, one participant did not see any causal attributions in one of the articles (the sports article) and yet this participant saw all of the different themes in other articles. This same participant said that a causal explanation in one of the articles was "too complex for most people" and yet also said that there were explanatory gaps.

A key finding seems to be that practice at causal analysis, and the unpacking of complex causality, leads to an increased ability to notice causal attributions. In other words, while people can see what we saw (i.e., the themes), they did not see nearly as much as we saw.

Our research next expanded from textual analysis to structured interviewing. We wanted to understand how decision makers engage in causal reasoning under conditions of time pressure and uncertainty. And we were particularly interested in how people reason about complex indeterminate causation.

10. The myths of causation

We conducted 10 two-hour interviews, using the Critical Decision Method (Crandall, Klein, and Hoffman, 2006), with specialists in logistics, intelligence, and command and control. Each interview was conducted by a team of two to three researchers, and one subject-matter expert at a time. The interviews were primarily conducted at the offices of the Klein Associates Division of Applied Research Associates in Fairborn, OH, but some were conducted at Wright-Patterson AFB, and at the Institute for Human Machine Cognition in Pensacola, FL.

The interviews revealed additional phenomena of causal reasoning; in particular, our interviews with the logistics specialists. We expected them to grapple with the question of when to stop probing for more information about causal relationships, and we were surprised to find that we were off by 180 degrees. Rather than struggling with a stopping rule, they seemed to lack a starting rule. That is, they usually did not initiate any investigation into causal dynamics even in cases where such an investigation would be useful and enlightening. As we described it to ourselves, the decision maker would be in a situation where, to the inquiring mind, there was a clear smoking gun. But the decision maker never asked who or what pulled the trigger.

In one example, an Air Force logistics specialist was responsible for maintaining safety at an Air Force base; which included maintenance of the fire trucks. He had two larger tankers for spraying water on a fire. One was in poor mechanical condition and the other was in good condition. The one in good condition was scheduled for routine depot maintenance. He and his staff agreed the other one should go in for the routine maintenance, but when they requested this shift, the depot staff turned it down. End of story. We asked him why they turned him down, and he admitted that he did not know. It never occurred to him to try to find out. We speculated that this lack of curiosity may stem from inexperience – he did not see any value of finding out the reason why his request was rejected. In the interview we noted that if the depot did not want to extend themselves, perhaps his colonel might have been able to intervene, whereas if the rationale was a concern over legal repercussions in case the fire truck originally scheduled for maintenance was to run into mechanical difficulties then it might be harder to convince them otherwise. He agreed that at this point in his career, with a better appreciation for how to get things done, he might have pushed further. At the time, however, he was insensitive to any value of trying to learn why the request was denied. In virtually all of the interviews with logistics specialists we encountered the same phenomenon – a disinclination to pursue an inquiry into the causes for decisions.

The logistics interviews also surfaced an issue we had not encountered before but had anticipated in our analysis of the “natural purposes” of causal reasoning (See Table 5, above) – the need for causal inquiry into the reasons for the decisions and actions of other people. Our interviews suggests that the reason for the actions and decisions of others may stem from: lack of information, competing priorities, organizational constraints, and/or lack of motivation.

As we found these interesting and unexpected phenomena of causal reasoning and sought to culminate all of our investigations, we found it possible to couch some key findings with reference to what seem to be myths about causal reasoning. Some of the phenomena we found seem to be genuinely new to the analysis of causation. The clearest examples are:

- 1) The finding that indeterminate causal reasoning is not a single process with clear-cut beginnings and endings, and
- 2) The finding that the main issue for satisficing in continuous causal reasoning is not determining a stopping rule (e.g., when to stop the search for a causal explanation), but the condition under which the search for a causal explanation does not even start.

We do not claim to be the first to voice objections to other myths of causation; we are repeating them because the assumptions are still widely held and we believe they are misleading.

10.1. Myth #1: Correlation does not imply causation

We list this one first because of the widespread recognition that it is in fact a myth. Correlation, as a statistical technique, was developed by Galton and Pearson specifically for the purpose of suggesting that there might be a causal relation between the variables that define two sets of data. In scientific investigations, correlation is required in order for causation to be proved, as J.S. Mill argued. The source of confusion here is the term “implies” which can mean “suggests” or “requires.” Correlation certainly suggests causality, but it does not require a conclusion of simple causality. Further, people do not mentally calculate correlations, but rather apprehend co-occurrences and covariations. Sharp observers use coincidence to speculate about causality. The coincidence of prevalence/absence of mosquitoes and presence/absence of Yellow Fever helped control and then understand the disease. It is true that correlation does not prove causation, and that additional factors may be operating and causing both the putative cause and the effect. But correlation definitely suggests causation. It often initiates a fruitful causal investigation.

10.2. Myth #2: Logic is the basis for understanding causal reasoning

Legions of philosophers have helped to illuminate the nature of causal reasoning. However, these illuminations generally center on the necessary conditions for valid or rational causal reasoning, with rationality set in terms of the standard of logic. In real-world settings, the evidence for causation is typically too ambiguous to permit valid (i.e., deductive) reasoning, so this is not a generally useful standard. Our goal is to describe how people such as military leaders and managers actually engage in causal reasoning. They are rarely in a position to satisfy the logical criteria for valid causal inferences and the problems they deal with do not fit neatly into manageable packages or fixed structures.

10.3. Myth #3: The analysis of physical causation is the model or template for the understanding of all forms of causation

Researchers in the so-called ‘hard’ sciences usually undertake investigations into determinate problems where there is a chance of making a discovery. On the other hand, military leaders, organizational managers, and researchers in the ‘soft’ sciences ponder indeterminate questions. Why did the American military situation in Iraq improve from 2005 to 2008? Why did Hillary Clinton lose the contest to become the Democratic candidate for president in 2008? Why did a certain sports team (name your favorite example) beat another in a championship game? There are no single or uniquely correct answers to such questions, and no amount of research would discover the “real” cause. A model of causal reasoning that might explain physical causation does not fit causal reasoning in general.

10.4. Myth #4: The scientist is the ideal for causal reasoning

Much of the literature in cognitive psychology and in the psychology of science focus on causal reasoning on the part of scientists (e.g., Gopnik & Schulz, 2007; Sloman, 2005). Scientists are driven by curiosity and are always looking for deeper explanations and further mysteries, whereas managers have to stop at a certain point and make decisions. Feltovich et al. (2004) described a “reductive tendency” to chop complex events into artificial stages, to treat simultaneous events as sequential, dynamic events as static, nonlinear processes as linear, to separate factors that are interacting with each other. Scientists are on the lookout for these tendencies, whereas managers, leaders, and other kinds of decision makers depend on the reduction to avoid some of the complexity that might otherwise be unleashed. Therefore, the scientist, working on deterministic problems and searching for deeper and deeper explanations, is an inappropriate model for naturalistic causal reasoning.

10.5. Myth #5: Causal reasoning means finding the one true cause for an effect/event

As described above, when dealing with indeterminate causes there is no way to identify a single or “true” cause. Further, researchers such as Reason (1990) have shown that accidents do not have single causes, so the quest for some single “root” cause or a culminating cause is bound to be an oversimplification and a distortion. Nevertheless, in order to take action we often need to engage in such simplification.

10.6. Myth #6: The “effect” that is to-be-explained is always clear

This also is a widely-held belief. In Einhorn and Hogarth’s (1986) example of the hammer and the watch, one might say that the hammer strike was the cause of the crystal’s destruction. But if the observation took place in a watch factory where the hammer was used to test crystals, and this was the only crystal that shattered, we would now say that the cause was a flaw in the crystal that cracked. But if the test hammer shattered crystal after crystal, we might speculate that perhaps the hammer force was set too high. The nature of the effect that is to be explained often changes as the investigation of cause-effect proceeds. The original AIDS “effect” to be explained was why homosexuals were dying of infectious diseases. As the investigation continued, and non-gay to include intravenous drug users manifested the disease, then also people who had received blood transfusions, the perceived effect changed from infectious disease to immune disease. Cases such as these show that the initial effect may be re-framed and re-cast during the investigation into its causes.

10.7. Myth #7: In causal reasoning people identify an effect, nominate causes, and select what they believe is the best one

This identify-nominate-select approach fits scientific investigations. It does not always fit medical investigations. After all, the original AIDS “effect” to be explained was why gay men were dying of infectious diseases. As the investigation continued, the perceived effect morphed to include intravenous drug users, then also people who had received blood transfusions, and other at-risk populations. Cases such as these show that the initial effect may be re-framed and re-cast during the investigation into its causes. In many natural settings involving human activity, the causes are often multiple, vague, and indeterminate. Frequently people never figure out actual or final causes. People sometimes stop their investigations at a fairly shallow level, demonstrating the reductive tendency. The effects we are trying

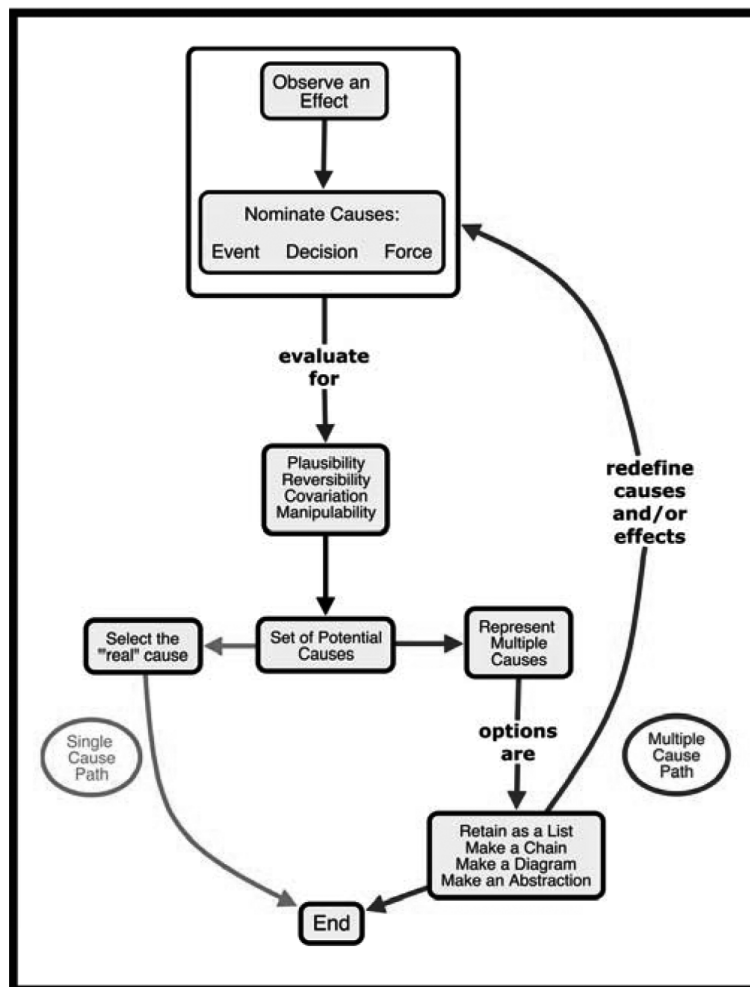


Fig. 7. A macrocognitive model of indeterminate causal reasoning.

to explain morph. Time lags between cause and effect are inevitable and create an additional layer of complication (Dörner, 1989), not simply because of the time but because of intervening events that cloud the picture. People still have to engage in causal reasoning under these conditions, but their reasoning will not follow the models of logicians and scientists, that insist on culminating at a final point. Causal reasoning stops because the cause has been determined and the explanation of the caused events is complete.

10.8. Myth #8: Cause-effect reasoning is an identifiable process, with determinable beginnings and endings

This myth shares the spirit of Myth #7, but makes a somewhat different point. The standard view is that people identify an effect they want to explain, then they start by nominating possible causes, they evaluate each of these causes, and they select the best one. Our interviews with U.S. Air Force logistics officers revealed cases where some event or circumstance was a clear invitation for causal reasoning to enable effective action. There was some sort of “trigger.” And yet, causal reasoning was not engaged.

Causal reasoning often does not end with some judgment that an event has been made sensible by an understanding of its causes. Sometimes, people never try to get closure by figuring out actual or satisfying causes.

We culminated our investigations by taking the myths a step further in an attempt to develop a macrocognitive model of causal reasoning.

11. A macrocognitive model of causal reasoning and explanation

Our culminating effort was driven by: (1). Our main consideration that causal reasoning, as a form of sensemaking, should conform to the general structure provided in the Data-Frame theory of sensemaking (Klein, Moon & Hoffman, 2006a,b; Klein et al., 2006), and (2). Our specific finding that people first latch onto single explanations, then generate lists, then stories or clockworks, and then retreat back to something simpler and more actionable. The model we developed is presented in Fig. 7.

Macrocognitive models such as this, and the Spacetime Envelope model in Fig. 1, do not look much like the sorts of models that would derive from a logical (or “rational”) analysis in the tradition of microcognition. Of course, this fits with our discussion of the myths, and specifically the myth that scientific/rational causal analysis is to be regarded as a prototype (normative or otherwise) for causal reasoning in general and indeterminate causal reasoning in particular. Our initial “Butterfly Model” (Fig. 5) is preserved in Fig. 7, although metamorphosed, in the lower part of the figure where single versus multiple cause explanations branch off.

The material and ideas we have presented here are obviously not a complete analysis. No analysis of complexity can be complete, by definition. But we hope that a main take-away is valuable: The idea that simply “looking to see what’s out there” can expand one’s empirical horizons and theoretical reach. Even for something that has been debated and studied as much as causation and causal reasoning.

Future directions for research stem from the claim that in indeterminate situations there is not a “right” answer, but rather a range of different potential forms of explanation. We described these forms when we distinguished different themes. Some themes involve single cause explanations such as a reversible event, action or decision, or a single condition, or a single abstraction across single causes. Other themes involve multiple cause explanations such as a list, chain or story/diagram. Figure 6 above presents some factors that we hypothesize might affect preferences for forms of causal explanation, such as the need for action (single causes should have clearer implications for action) and perceived audience sophistication (single causes should be seen as more appropriate for less sophisticated audiences). We can test these hypotheses by manipulating these variables to see if there is a corresponding change in preferences. We can also examine cultural differences in preferences for causal explanations to see if members of some cultures have different preferences for forms of causal explanation than Western populations. To the extent that we understand why people would prefer one type of explanation over another we should be able to manipulate that preference.

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Authors' Bios

Robert R. Hoffman is a Senior Research Scientist at the Florida Institute for Human and Machine Cognition. He is a Fellow of the American Psychological Society, a Fulbright Scholar, and an Honorary Fellow of The British Library (Eccles Center for American Studies). He received his B.A., M.A., and a Ph.D. in Experimental Psychology at the University of Cincinnati, where he received McMicken Scholar, Psi Chi, and Delta Tau Kappa Honors. After a Postdoctoral Associateship at the Center for Research on Human Learning at the University of Minnesota, Hoffman joined the faculty of the Institute for Advanced

Psychological Studies at Adelphi University. There, he received multiple awards for outstanding research and service, and also served as Chair of the Institutional Review Board and as the University Grants Officer. He joined the IHMC in 1999. Hoffman's early research was in the area of psycholinguistics, where he helped pioneer the experimental study of the comprehension of figurative language (metaphor, proverbs). His first book, *Cognition and Figurative Language* is now regarded as a classic. Hoffman went on to found the journal, *Metaphor and Symbol*, for which he remains Associate Editor. Another focus of Hoffman's early work, an interest that continues to this day, is the psychology and history of science. Hoffman has published analyses of the use of metaphor and analogy in science, the history of cognitive psychology and applied psychology, and the philosophy of contextualism. Hoffman is widely regarded as one of the pioneers of the field of "Expertise Studies" and the study of human performance, with seminal and widely-cited publications spanning a quarter century. He has conducted extensive research on the knowledge and reasoning skills of expert remote sensing scientists, weather forecasters and utilities engineers. Hoffman has been recognized internationally for his fundamental contributions to the field of Human-Centered Computing, for his pioneering research on the psychology of expertise, his contributions to the methodology of knowledge elicitation, and his research on human factors issues in the design of workstation systems and knowledge-based systems. Hoffman is a member of The Human Factors & Ergonomics Society, The American Association for Artificial Intelligence, The American Meteorological Society, and the Institute of Electrical and Electronics Engineers. His current research focuses on the psychology of intelligence analysis, and methodological issues in the analysis of complex systems. He has spearheaded the development of a new branch of statistics called "Range Statistics" to solve some outstanding measurement problems. He is Series Editor for the book Series, "Expertise: Research and Applications." He has also worked as a Ranger/Naturalist in the Green Mountains of Vermont and is an accomplished blues drummer.

Gary Klein, Ph.D., is a Senior Scientist at MacroCognition LLC. He was instrumental in founding the field of Naturalistic Decision Making. Dr. Klein received his Ph.D. in experimental psychology from the University of Pittsburgh in 1969. He was an Assistant Professor of Psychology at Oakland University (1970–1974). Then he worked as a research psychologist for the U.S. Air Force (1974–1978). In 1978 he founded his own R&D company, Klein Associates, which grew to 37 people by the time it was acquired by Applied Research Associates (ARA) in 2005. Dr. Klein developed a Recognition-Primed Decision (RPD) model in 1985 to describe how people actually make decisions in natural settings. In 2007 he developed a naturalistic model of sensemaking, the Data/Frame model. He has written: *Sources of Power: How People Make Decisions* (1998); *The Power of Intuition* (2004); *Working Minds: A practitioner's guide to Cognitive Task Analysis* (Crandall, Klein, and Hoffman, 2006); and *Streetlights and Shadows: Searching for the keys to adaptive decision making* (2009).

Janet E. Miller is a senior electronics engineer and program manager in the US Air Force (USAF) Research Laboratory's Sensors Directorate at Wright-Patterson Air Force Base, Ohio. Dr. Miller received a PhD. in Industrial and Systems Engineering from The Ohio State University in 2002 with emphasis on cognitive aspects of human factors. Since receiving her degree, she has focused her efforts on addressing various cognitive challenges of work, including team work, in US Air Operations Centers (AOC) in particular but in other USAF settings as well. To support that work, she has visited AOCs worldwide documenting the challenges of socio-technical systems in the current dynamic, complex USAF environment. Recently, she has turned the center of her attention to the issues of teams working with small/micro-unmanned air vehicles. Dr. Miller co-edited a book providing an overview of the theoretical foundations of macro-cognition and macro-cognitive metrics to evaluate and measure the performance of real-world teams. Additionally, she has published numerous journal articles and conferences papers in areas of human factors.