Causal Reasoning: Initial Report of a Naturalistic Study of Causal Inferences

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ABSTRACT

Motivation – This paper describes the initial results of a naturalistic inquiry into the way people derive causal inferences. **Research approach** – We examined media accounts of economic, political, military, and sports incidents to determine the types of causal explanations that are commonly invoked. **Findings** – We found two interacting processes at work: the identification of potential causes and the framing of these causes into explanations. Explanations took several forms: abstractions, events, lists (undifferentiated collections of partial causes), conditions, and stories (complex mechanisms linking several causes). **Originality** – Causal reasoning in "the real world" is both different from and far richer than the formal causal accounts found in philosophy, and from the determinate search for causes during scientific problem solving. **Takeaway message** – By understanding the way causal reasoning is done in natural settings we should be better able to help decision makers diagnose problems and anticipate consequences.

Keywords
Causal reasoning, causality, mental models, sensemaking.

INTRODUCTION

Causal reasoning has received enormous attention from many different disciplines—philosophers, scientists, psychologists, economists, historians, educators—because of its centrality to the ways we think and make sense of events, the ways we learn from experience, the ways we codify knowledge. Causal reasoning plays a central role in our mental models about how things work and what will happen if we intervene in different ways. Military leaders depend on causal reasoning to select and evaluate courses of action and to gauge their progress or explain why they are running into trouble. Physicians depend on causal reasoning when they diagnose their patients. Managers rely on causal reasoning to figure out who to blame for failure and who to reward for success, and sometimes get it wrong.

This paper describes results of the first phase of a 3 phase effort to investigate causal reasoning, not from the philosophical perspective of what counts as valid causal reasoning, or the scientific perspective of how to unpack causal accounts, but from a naturalistic perspective of how people actually engage in causal reasoning.

The next section describes the defining criteria for what can count as a cause. Next, we consider five widespread assumptions about causal reasoning, discussing the limitations of each of these, and why it seems valuable to take a naturalistic perspective on causal reasoning. The next section describes the findings from a review of written causal accounts, taken from newspapers, magazines, and books, all attempting to explain why events occurred.

WHAT COUNTS AS A CAUSE?

The investigation of causality is usually traced to Aristotle but for our purposes the account offered by Hume (1739-1740) is much more in line with our modern notion of cause-and-effect, although it has been subject to multiple interpretations and criticisms. In the Humean view, in order for there to be an objective establishment of a cause-effect relation, there is some sort of "necessary connection" between the cause and the effect.

Hume's analysis suggests three primary criteria to establish what counts as a cause: propensity, mutability, and covariation.

Propensity. 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

Reversibility. The reversibility criterion (usually referred to as "mutability" in the literature) is that the effect should disappear if the putative cause disappears. Hume argued that causal propositions such as "A caused B" are based on the regular succession of events, i.e., whenever A occurs then B does. 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 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 the causal reasoning. Dörner (1996) 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 that 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.

Covariation. Covariation 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) an experimental design for discovering cause-effect relations. The method of differences is that we can find the biggest difference in situations where the effect occurred or did not occur, and call that the likely cause. The persistence of medical authorities in Havana and then in Panama in trying to eradicate Yellow Fever by controlling the mosquito population was due to the strength of the relationship between the two, even in the absence of a plausible causal story.

In applying these three primary criteria, we need to take a few other considerations into account. Context is one consideration. Einhorn and Hogarth (1986) noted that if we see a hammer strike and shatter a watch crystal, we would say that 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 now say that the crystal must have been flawed. But if the test hammer shattered crystal after crystal, we might speculate that perhaps 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 that you have lung cancer, the delay is too short for us to ascribe your cancer to the fact that you began smoking.

Causal reasoning goes beyond the criteria for considering candidate causes. It involves formulating arguments about the potential causes. The next section reviews some traditional assumptions about causal reasoning.

Claims about Causal Reasoning

We have identified five assumptions about causal reasoning that appear in many forms and we believe they are widely held. We also believe that they are misleading. We do not claim to be the first to voice these objections; we are repeating them because the assumptions are still widely held.

Philosophy 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 criteria for valid causal inferences and the problems they deal with do not fit neatly into manageable packages or fixed structures.

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 in the part of scientists, especially about physical causation (e.g., Gopnik & Schulz, 2007; Sloman, 2005). However, scientists usually undertake investigations into determinate problems where there is a chance of making a discovery. The investigation into the cause of AIDS led to the discovery that HIV causes AIDS. Watson and Crick (1953) figured out the structure of DNA and also explained how DNA could replicate. In contrast, military leaders and organizational managers ponder indeterminate questions. Why did the American military situation

in Iraq improve from 2004 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 fits scientific reasoning does not fit causal reasoning in general.

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) have 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.

Causal reasoning means finding the true cause for an effect/event. As described above, when dealing with indeterminate causes there is no way to identify the true single 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.

Correlation does not imply causality. But of course it does; it was designed to. Correlation as a suite of mathematical techniques was invented precisely to enable the exploration of causal relations or potential ones. Correlation is a major cue to causality. Even in scientific investigations, correlation is required in order for causation to be proved. 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 causality. Further, people do not mentally calculate correlations, but rather are apprehending 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.

In causal reasoning people identify an effect, nominate causes, and select what they believe is the best one. This 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.

Summarizing the limitations of these claims, we see that in many natural settings the causes are often multiple, vague, and indeterminate. Frequently people never figure out actual or final causes. People sometimes stop their investigations at fairly shallow level, demonstrating the reductive tendency. The effects we are trying to explain morph. Time lags between cause and effect are inevitable; they 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 philosophers and scientists of leading to some single, final point where causal reasoning stops because the cause has been determined and the explanation of events is complete.

Causal reasoning can take different forms in natural settings and is rarely amenable to factor analysis of causal chains. So, what are the diverse forms of causal reasoning that a naturalistic inquiry might identify?

MECHANISMS OF ACTION: HOW DO PEOPLE ACTUALLY REASON ABOUT CAUSALITY?

Method

Our first step has been to collect newspaper, magazine and book materials illustrating causal reasoning about natural events. We collected stories from newspapers and news magazines 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 offered different types of accounts. The 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.

In studying accounts that presented causal analyses and causal explanations, we identified the 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—X). Product recalls and environmental crackdowns (B) also led to increase cost of products made in China (B—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—D—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—F—X). This seemed to be a "swarm" of converging effects but it had some chains of effects.

As we collected and analyzed more accounts, we began to see some convergence of themes. In some explanations the cause was seen as a single dramatic event that could 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 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

We should also add some comments about coding the data In an informal check on coding reliability we found that domain knowledge seems critical for reliably identifying the causes mentioned in a media account. However, once the causes are specific, domain knowledge doesn't seem necessary for coding the causes into the explanatory categories shown in Table 1.

Results and Discussion

As shown in Table 1, the pilot study focused on an analysis of 74 incidents. These often referenced more than one cause; 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 even 10 causes. In each account, we identified the causes as the reasons offered by the writer to explain why the outcome occurred. (The column to the extreme right in Table 1 shows the number of cases that mentioned any contrary information – influences that worked in the opposite direction of the outcome. This category was not one of the causal reasoning themes.)

Topic	# Cases	Events	Abstraction	Condition	List	Story	Counter
Sports	38	17	55	29	14	12	12
Economic	18	20	3	25	2	14	3
Politics	7	17	5	14	7	0	2
Military	3	4		4	2	0	1
Miscellaneous	8	18		8	1	3	0

Table 1. Causal reasoning themes.

From these data, we identified five causal explanation themes: Events, abstractions, conditions, lists, and stories.

The Theme of Events. These were mutable, that is, reversible events, actions or decisions, sometimes referred to as counterfactuals or close counterfactuals. For example, late in the last quarter of the 2008 Super Bowl between the N.Y. Giants and the New England Patriots, Eli Manning, the Giants' quarterback, seemed almost sure to be sacked by the opposing team 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 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 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 would be expected, the sports incidents included a large share of these kinds 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 Theme. This form of reasoning takes several causes, including counterfactuals, and synthesizes these into a single explanation. 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. Table 1 shows that the Abstraction theme was more prevalent for sports than for economics.

The Condition Theme. This explanation 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 a Situation 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 are using this category to include lawful relationships and regularities, as well as characteristics of a situation such as an injury to a star player. We suspect this category of "condition" may evolve in the future.

Sometimes, these three types of explanations (an event, an abstraction, a condition) were offered by themselves, but often they were bundled together. We identified several common ways for them to be bundled into a higher-level explanation: the abstraction, the list and the story. The category of 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 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 List Theme is merely 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.

The Story Theme provides a deeper analysis to present a mechanism of how the different causes interacted. Sometimes the stories took the form of a chain. These kinds of 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 2. The story here 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.

• 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 ½% 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 ¼% increments, to 5.25% in June 2006.

• However, by 2002 it was clear that rates should be staying neutral or going up, not down.
     o The Gross Domestic Product was lining up with capacity.
     o Inflation was low.

• In addition, the housing market was vibrant, even in 2001.
     o Housing does not always follow the law of supply and demand. When prices rise, that can create a demand in the form of a bubble as people expect prices to keep rising.
     o 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.   o The reason was the Bernanke suggested that the low rates were a global issue. Oil exporters and thriving Asian economies needed places to invest.

o   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.

Table 2. The story explanation for the U.S. mortgage crisis.

Here is another example of a story, from the Miscellaneous Topics group of incidents. The effect was the death by asphyxiation of a fireground commander in New York. How did it happen? This story is presented in Table 3. Each of the elements of this story is a cause – each was reversible, each led to the subsequent events/effects.

•   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.
    o   Perhaps he was still searching for residents.
    o   Perhaps he wanted to be sure that everyone in his crew had left.
    o   Perhaps he became disoriented.

•   He ran out of air and died.

Table 3. The story for the fatal blaze incident.

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 simple sequential chain. Moreover, confidence in a causal chain or interaction depends on the plausibility of each transition. In this regard, it is not clear how to treat violations of expectancies. If a transition is highly plausible then it should add to confidence but also diminish the information value of the account. Transitions that violate immediate expectancies but seem to be well-justified may increase confidence in the account.

The greater complexity of the explanations in economics, as compared to sports, should be caveated somewhat. 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 in that it suggests that 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 that the Giants were lucky with their miracle play which 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 et al. (2006) have 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),
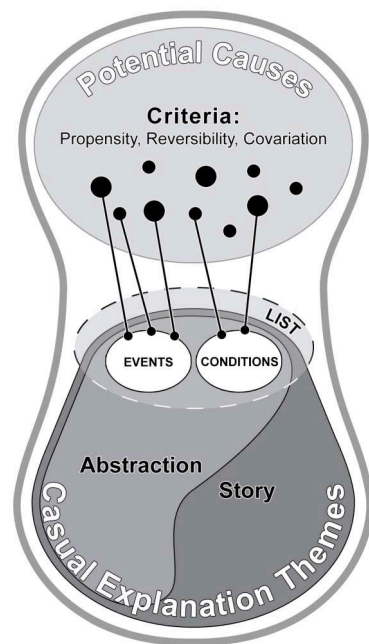
whereas our analysis of lists includes factors whose influence is not fully determined, such as the reasons that Hillary Clinton's presidential campaign failed.

CONCLUSIONS

What we have found is that we could identify certain kinds of explanations that seem more common – people seem to find them more useful or comfortable, in explaining different kinds of events. This is a major finding from our investigation, and we will return to this point later.

After reviewing portions of the copious and historical literature on causal reasoning, we have adopted a naturalistic inquiry into the question, "What forms of causal reasoning do we actually see when we look out at the world of human activity and argument? What we see are styles of kind of causal reasoning that have not previously come under much analytic scrutiny, such as the use of abstraction themes.

Causal reasoning is a form of sensemaking and might be better understood as such rather than simply branded with the single word "cause.". It may be instructive to apply the Data/Frame model of sensemaking (Klein et al., 2007), which asserts that explanations are frames that get built out of data and that data are defined by the frames being used to fashion explanations. If we apply this perspective, we get a Reciprocal Model of causal reasoning, depicted in Figure 1. The causes identified in a situation (based on propensity, covariation and reversibility) generate the explanatory frames presented in Table 1. At the same time, these explanatory frames (events, abstractions, conditions, lists and stories) guide the search for causes. Both processes are occurring simultaneously, as the process of causal reasoning. For example, the physicians in the U.S. and Europe who were detecting the onset of AIDS were noticing coincidences across their patients, but these coincidences were not simply a matter of matching patterns because the features hadn't been discovered before, and each case showed different symptoms (because AIDS is an opportunistic infection). Rather, the detection of coincidences was conditioned by the types of mental models and explanations that the physicians had learned.

Figure 1: Data Frame model revised to feature the causes and the frames.

Figure 1 shows that the events and conditions are the primary forms of causal explanations. They are sometimes combined by forming them into lists, synthesizing them into abstractions, or connecting them into stories. The form of the explanation may affect the way potential causes are identified and selected.

One of the limitations of our initial research effort is that it was based on passive onlookers rather than participants in the to-be-explained events, such as decision makers in mortgage banking industry. The causal reasoning is heavily analytical and not grounded in the context of making choices. Our next step, for Phase 2 of this project, is to understand how decision makers achieve closure in their causal explanations of events in which they themselves have causal powers, and prevent themselves from a never ending spiral into further depth. We seek to understand how decision makers notice coincidences and reject those that seem less useful. We suspect that decision makers learn by action as much as by analysis—they take some actions in order to see how the situation changes. We will investigate how decision makers simplify the causal stories they formulate, and how they determine whether an account is plausible and

sufficient. Therefore, part of our plan for the research project is to interview and study military and corporate leaders, as opposed to outside commentators.

The five assumptions regarding causal reasoning that we have criticized seem questionable in settings that feature complex and ambiguous conditions. We believe that a naturalistic investigation can provide a useful perspective of the process, perhaps by elaborating the reciprocal model of causal reasoning.

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