Extending Ecological Rationality: Catching the High Balls of Disaster Management

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ABSTRACT

The contemporary world is characterized by several large-scale hazards to human societies and the environments we live in, including the impacts of climate change. This paper outlines theories concerning cognitive psychology and complexity dynamics that help explain the challenges of responding to these hazards and the complex systems which create them. These theories are illustrated with a baseball metaphor, to highlight the need for decision-making strategies which do not rely on comprehensive information where comprehensive information is not available. The importance of tools which can support more efficient uses of limited information is also outlined, as is the way that these tools help combine the computational resources and acquired experience of several minds. Existing research has been used to investigate many of the concepts outlined. However, further research is required to coalesce cognitive theories with complexity theories and the analysis of group-level interactions, towards improving important disaster management decisions.

Keywords

decision-making, complexity, macrocognition, computational media, ecological rationality

INTRODUCTION

We live in an epoch which, according to Fiksel (2006) and Patterson, Miller, Roth, and Woods (2010), is characterized by increasingly complex and interdependent human systems. This is an epoch which is often referred to as the Anthropocene: a world marked by many challenges resulting from our unsustainable interactions with surrounding ecosystems. We are to blame to a large extent, for complex ecological degradation that has resulted in the extinction of 52 percent of the world's species between 1970 and 2014 (World Wildlife Foundation, 2014). In the meantime, unprecedented and compounding challenges posed by human contributions to climate change only appear to be accelerating (Intergovernmental Panel on Climate Change, 2014). Urgent mitigation and adaptation decisions are required, to address these dynamics in many parts of the planet.

Ours is also a world marked by ongoing natural hazard impacts that remain relatively un-mitigated. As outlined by Donner and Rodríguez (2008), with particular reference to the Indian Ocean Tsunami of 2004 and Hurricane Katrina in 2005, these impacts are often worsened by expanding human populations that tend to migrate towards large cities and coastal areas. As at 2013 and 2014, financial losses from natural hazard events (140,000 million USD inflation adjusted; 110,000 million USD) were roughly equivalent to inflation adjusted losses suffered over the previous 30 years (Munich RE, 2014). As outlined by Huggins, Hill, Peace and Johnston (2015), these kinds of contemporary challenges mark the need for a dramatic shift in understanding decisions concerning complex phenomena, and a shift in the way such decisions are evaluated and improved.

The current paper makes a case for using a concept of decision-making efficiency drawn from cognitive psychology, to evaluate and improve decisions concerning complex scenarios. It defines the particular complexity of certain scenarios resulting from interactions between human (e.g. urban planning) and non-human (e.g. tsunami causing seismicity) systems. The paper then discusses the need to evaluate and improve decisions concerning these scenarios, that occur over relatively long timeframes and have even longer-term implications; before outlining a novel approach to understanding how decision-making in complex scenarios. A theoretical framework is then outlined, for assessing tools that are located externally to the physical brain[1] but which can form an essential element of these decisions.

The Cognitive Challenges of Complex Scenarios

Interactions within social and social-ecological systems in which the phenomena outlined above are embedded create problem scenarios which are very often ill-defined. Instability and unpredictability mean that there is very rarely enough information to take an elaborate, relatively comprehensive approach to making decisions in these scenarios (Patton, 2011). Furthermore, the breadth of relevant information available often demands the expertise of multiple experts and various other stakeholders before a useful decision can be made. This means that networks of decision makers are being called upon to make relatively time-pressured decisions that will nonetheless have medium and long-term implications. A coherent and cohesive theoretical framework is required, for evaluating and improving the way important decisions are being made in these challengingly complex, modern day scenarios.

For the purposes of the current paper, complexity is defined in terms of *aggregate complexity*: Where interactions between two or more system components create phenomena that is emergent and hard-to-predict. Aggregate complexity can be illustrated in terms of physics, using the example of a double pendulum. Using the example shown in Figure 1, a single pendulum follows a path that is relatively easy to predict in relation to its initial movement. However, it is much more difficult to predict the path of a second pendulum secured to the weight of the second. This is because the path of the second pendulum results from a standard pendulum trajectory combined with the path of the first pendulum. This creates a complex situation, even without considering feedback effects from the second (lower) pendulum on the first (upper) pendulum. According to Christini, Collins and Linsay (1996), the path of the second pendulum is therefore characterized by what they called “high-dimensional chaos” (p. 4824). This high dimensional chaos is what makes the path of the second extremely difficult to predict in any reliable fashion - hence the question mark appearing to the bottom right of Figure 1.

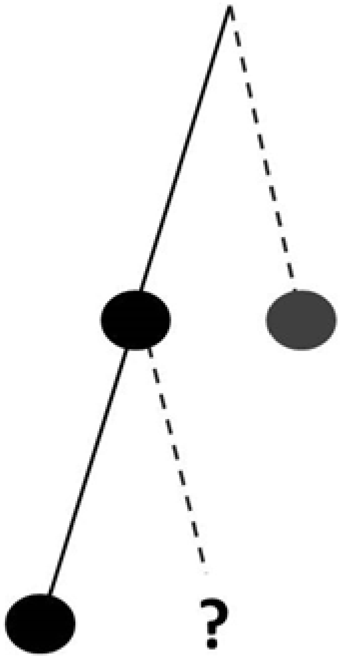

Figure 1. Second Pendulum Creating Aggregate Complexity

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[1] The anatomical brain, located within the human skull.

The apparently chaotic implications of aggregate complexity range much wider than the physics class-room. Relevant scenarios include, but are not limited to, eventualities such as the environmental degradation and disaster events outlined above. These are definitively complex scenarios because they result from interactions between two or more system components, such as human industrialization and melting sea ice, or interactions between flora degradation and animal populations. According to Manson (2001), such interactions between two or more of system components can lead to other characteristics of a complex system, including:

- changes effected by structures within the system (Allen & Hoekstra, 1992);
- fluid interactions with the surrounding environment (Rugman, 2012);
- learning and memory within the system (Wilson, 1988);
- hard to predict, emergent outcomes (Lansing & Kremer, 1993; Patton, 2011); and
- constant change and evolution (Allen, 1997, Andrade Jr., Wainer & Moreira, 1995; Correig, Urquizu & Vila, 1997; Sanders, 1996).

The current paper makes a case for using a concept of decision-making efficiency[2] drawn from cognitive psychology, to evaluate and improve decisions concerning scenarios resulting from aggregate complexity. These are scenarios affected by high levels of change which can be hard-to-predict or constant, and which therefore constrains information gathering and algorithmic decision-making[3] approaches alike. This understanding of limitations on decision-making efficiency has typically been applied to rapid decisions being made by relatively isolated individuals[4]. The current paper argues that, in order to address challenges highlighted by theories of aggregate complexity, understandings of decision-making constraints need to be extended much further than the mind of any individual making decisions in apparent isolation.

According to Holmes, Trueblood and Heathcote (2016), research into how relatively isolated individuals deal with new information and use it to make a more or less effective decision help us understand important everyday processes such as safely moving between lanes on a freeway. For example, research by Kiani, Hanks and Shadlin (2008) has shown how longer sequences of changing information can lead to a primacy effect, where decision-makers remember earlier information. This effect meant that participants in Kiani et al. (2008) did not remember information received after receiving a certain amount of new information. Both of these research precedents were complemented by Tsetsos, Gao, McClelland and Usher (2012) who also identified a recency effect, where decision makers focused on the most recent information but only when they were given more time to make each decision. This recency effect only occurred when participants were allowed to take up to one second, instead of 300 milliseconds to make decisions.

The research by Tsetsos et al. (2012) exemplifies how pre-existing decision-making research has tended to focus on decisions made within extremely brief timeframes. Holmes et al. (2016) noted this limitation in their own research into decision-making under changeable conditions, because delayed responses pushed the key phenomena of interest (decision accuracy) outside their two second data collection timeframe[5]. While a lot of prior decision-making research appears to have focused on response time as a key measure, there is a need to evaluate and improve decisions occurring over a much longer response time. These are decisions which can often have very long-term consequences, such as decisions concerning urban planning and ecosystem conservation in the face of climate change and other aspects of environmental disruption.

ECOLOGICAL RATIONALITY

Todd and Gigerenzer (2003) used the concept of *ecological rationality* to describe the adaptive fit between short-cut decision-making strategies and the demands of real-world, ill-defined domains. In the absence of sufficient information to take an effective, more elaborate or even algorithmic approach, these domains often require a more abbreviated decision-making strategy or decision-making shortcut (Todd & Gigerenzer, 2003). Ideally, these decision-making shortcuts will form an achievable and effective response to the challenges posed

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[2] The effectiveness and relative speed of decision making.

[3] Approaches to decision-making prompted by a highly detailed, step-by-step flow chart.

[4] For example, sitting alone under tightly controlled laboratory conditions.

[5] The limited timeframe within which research participant needed to respond.

by the extreme form of bounded rationality[6] experienced in complex scenarios.

However, with reference to the ecological nature of ecological rationality, this only applies to certain decision-making shortcuts in certain situations. Decision-making shortcuts do not always make a good fit with a surrounding decision-making context, or ecology. As outlined in seminal papers by Kahneman and Tversky (1972), Tversky and Kahneman (1973) and a large body of subsequent research including Todd and Gigerenzer (2012), abbreviated decision-making processes are often highly flawed and can lead to unfavorable outcomes. Examples include how restricting cognitive processes to recent information exposure disrupts assessment of current, climate-related risks (see Nicholls, 1999). Neglecting the standard occurrence, or base rate frequency, of common life-threatening hazards (see Goodie & Fantino, 1996) forms another challenge for ecological rationality, concerning particularly effective decision-making short-cuts in particular situations.

Decision-making short-cuts used in a range of decision-making scenarios are commonly referred to as *heuristics*. This term is generally used to describe short-cut cognitive processes which are relatively *fast* and *frugal* (Gigerenzer, Todd and the ABC Research Group, 1999). Cognitive heuristics are fast because they demand few cognitive resources and can therefore be executed rapidly. They are frugal because they require relatively little information to produce a response. Gigerenzer et al. (1999) provided the example of a decision tree used to guide rapid decisions about heart attack patients arriving to an emergency ward. This decision tree was fast because it only required answers to a brief series of three questions. It was frugal because the three questions could be answered using a limited range of readily available information (blood pressure, age, and heart beat).

The term heuristic has also been used to describe decision-making short-cuts constituting ecological rationality. A heuristic process which is ecologically rational focuses on information which directly facilitates what a person wants to achieve, rather than relying on a more detailed representation of the decision-making situation (Todd & Gigerenzer, 2003). The heart attack decision tree epitomizes this efficient application of usefully selective heuristics to a particularly demanding decision context. Rather than attempting to provide a full diagnosis and longer-term prognosis, doctors used this decision tree to determine more immediately life-threatening characteristics.

Several, apparently common heuristics had been identified by the time Todd and Gigerenzer (2003) authored the concept of ecological rationality. These heuristics included the availability heuristic (Kahneman & Tversky, 1972), where decisions are restricted by the information that is most easily recalled by a decision maker. This was the heuristic observed by Nicholls (1999), affecting climate-related decisions. However, and despite the range of contexts where the availability heuristic and many others come into play, the concepts of heuristics and ecological rationality have traditionally been used to describe decision-making by individuals in marginally complex domains such as a baseball player deciding how to run and catch a high ball, alongside financial investment and mate selection (Todd & Gigerenzer, 2012).

Catching a high ball in baseball can be thought of as a marginally complex scenario. However, with reference to the basis of aggregate complexity outlined above, the player’s decision still needs to consider interactions between their own running speed and various aspects of the ball’s trajectory, such as velocity and wind speed. These interactions can pose many challenges for baseball players. Baseball games would be of little interest to players and the public alike if catching a baseball was as simple as running at any speed, in any direction and simply raising a catching mitt. The interactions involved in catching a baseball nonetheless run between two well-rehearsed, fairly constrained, and therefore relatively predictable, system components such as running speed, ground conditions and ball trajectory. Although baseball games can keep many sports fans on the edges of their seats, there are very few genuine surprises involved –especially when decision outcomes are neatly divided between catching, or failing to catch, a baseball.

ECOLOGICAL RATIONALITY AND COMPLEXITY

As outlined in the introduction to this paper, scenarios marked by aggregate complexity are the epitome of an ill-defined problem scenario within a framework of ecological rationality. According to the concomitant theory of complex adaptive systems by Patton (2011), complex scenarios are characterized by fluid instability and emergence which is often unpredictable. As in the overarching theory of aggregate complexity, these characteristics of fluidity and emergence appear to result from interactions between two or more sub-systems constituting a complex system of interest. The terms fluidity and emergence can evoke images of changes in a body of water, such as the river reportedly used by Heraclitus (see Graham, 2015) to illustrate the general

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[6] Where decision making is limited by information available, ability to process that information and other constraints (Simon, 1972).

principle of flux. However, the use of water as a metaphor does not mean that these terms are instantly transparent.

As a technical term, fluidity refers to an overall state of instability which can make system characteristics very hard to define (Patton, 2011). This can result in epistemological challenges concerning knowledge of a system state, for example the movement from one season of a climate to another. Fluidity can also result in ontological challenges, arising from changes in the over-arching structures of a system. For example, climate change may result in radical shifts in the overall patterns of rainfall and temperature which we refer to as seasons. Emergence refers to relatively unpredictable phenomena which can result from the complex adaptive system as a whole (Patton, 2011). Using a climate-related example, an increase in algal blooms has resulted from the interaction of several system components, such as changes in ocean currents, ocean acidity, and rainfall. According to Hallegraeff (2010), the resulting emergence of harmful algal blooms has become a highly unpredictable outcome of contemporary climate change.

These phenomena have important implications for decision-making within complex adaptive systems. According to Patton (2011), fluidity and emergence within a complex system mean that complex scenarios can only be understood in terms of incomplete and uncertain information. This means that, if we accept that complex adaptive systems are fluid, without any stable point of static equilibrium, then we must be highly skeptical of any apparently comprehensive set of information regarding such a system. That set of system information is very likely to be incomplete and even more likely to be out of date.

Given a lack of reliable and comprehensive information, we are unlikely to find a viable non-heuristic strategy for making decisions concerning complex adaptive systems and characterized by aggregate complexity. As a result, most viable decision-making strategies concerning complex scenarios are inevitably heuristic. Under these conditions, heuristic strategies are necessarily, relatively fast and frugal, compared to more detailed analyses of much more exhaustive information sets. More heuristic approaches, such as rudimentary but nonetheless effective analyses of fluctuating financial trends (see Camerer & Johnson, 1991), can allow decision-makers to function effectively. This occurs despite working with substantially incomplete data, under ever-present constraints on time and other resources. The following section expands on this notion, concerning the tools and other interactions used to make such decisions, in contexts affected by fluidity and emergence.

ECOLOGICAL RATIONALITY WITHIN THE EXTENDED MIND

For the purposes of research into these heuristic decision-making processes, it can be useful to conceptualize mental processes involving input to, processing within, and output from, the human brain. However, the decision-making heuristics outlined above are unlikely to operate solely within the mind of any individual. Fast and frugal human thought has been encoded, recorded and clarified both within and beyond the brain, at least since humans made rudimentary sketches on the walls of caves and other surfaces. These sketches were used to record the characteristics of animals being hunted, rather than relying on brain-based memory or rudimentary story-telling alone. Clark and Chalmers (1998) incorporated the consideration of these types of media into an *extended* approach to cognition, encompassing cognitive processes that include, but are by no means limited to, the brain alone.

Seals used by the ancient Sumerians circa 8000 BC (see Schmandt-Besserat, 1992) form a more elaborate example of extended cognition. These objects were created and then iterated outside of the human brain, to help calculate the value of animals and food being traded. Relevant, contemporary examples of extended cognition include the process of deciding whether to apply for a costly real estate mortgage. Even if we do not consider interactions between the potential mortgagee, banking consultants and real estate agents, the resulting decision will depend on at least one calculation extending largely outside of the brain. To help consider the interacting effects of compound interest, moving interest rates, fee structures, and other costs, banks often provide an online mortgage calculator to help clients decide whether they can afford to repay a particular amount of debt.

Even prior to the widespread influence of internet-based decision support tools, these types of processes have been performed using calculator devices, pen and paper, or other components external to the physical brain. Extending cogitation to incorporate these components requires processes extending beyond the physical brain, including perception and action. As outlined below, these aspects of extended rather than brain-based cognition are a focus for research into the use of external cognitive tools in scenarios marked by fluidity and emergence.

Macrocognitive Precedents

The extended mind approach has been reflected in innovative approaches to cognitive analysis. This includes research into distributed cognition[7] (Hutchins, 1995, 2000) which has been taken up within the over-arching field of *macrocognition* (Cooke & Gorman, 2010). According to Schraagen, Klein and Hoffman (2008), macrocognitive research analyses how human cognition adapts to meet the challenges posed by complex systems and scenarios therein. In other words, macrocognition addresses the way that human thought processes change in response to non-linear interactions between two or more system components and to the implications of those interactions (Cooke, Gorman, Myers & Duren, 2013). As outlined by Patton (2011), scenarios marked by these kinds of scenarios are particularly challenging when one of the system components is distinctly social, such as a human settlement or some other kid of social grouping.

As briefly outlined in the previous section, the demands posed by complex scenarios often exceed the capabilities of an individual decision maker. A wider range of expertise and computational capacities can be required. This means that, as outlined by Kozlowski and Chao (2012), macrocognition typically addresses decision-making made by and within groups, rather than by relatively isolated individuals, within complex scenarios. Examples include decisions made by the crew of an ocean-going vessel (Hutchins, 1995; Cooke & Gorman, 2010), or by a team of emergency managers working to organize water storage and mitigation activities in a geographic region prone to earthquakes, storms and tsunamis (Huggins, Hill, Peace & Johnston, 2015). Both of these examples illustrate how macrocognitive dynamics nearly always involve a division of labor, between many minds. According to Kozlowski and Chao (2012), this division of labor occurs through the pooling, configuration, acquisition and variability of existing knowledge, alongside the intra-team and between-team emergence of new knowledge. For example, an emergency management team often share the expertise of members trained in diverse fields such as rescue, engineering or communications. Team members may also generate new knowledge and expertise as a result of working with each other to develop practical disaster risk management solutions.

The value of shared expertise highlights how, although macrocognition encompasses individual decision-making processes, decisions made by a group, or groups, become paramount. The *distributed cognition* approach to macrocognition highlights how groups collaborating in such complex scenarios use a range of tools to generate their shared decisions. The term *node* is typically used to describe discrete human actors at the center of collaborative activities. For the purposes of distributed cognition, external cognitive tools become essential nodes between networks of problem solving individuals. Hutchins (1995) provided the example of charts, instrument panels and other tools which help the crew of an ocean-going vessel to safely navigate from one port to another. Hutchins (1995) referred to each of these tools as a *computational medium* and this term has since been used as part of macrocognitive analyses, to describe the vital role played by information displays and similar cognitive extensions, in arriving at effective decisions in complex scenarios.

Contemporary examples of a distributed cognition approach include analyses summarized by Cooke and Gorman (2010), of communications within and between collaborating groups. Other examples include research by Huggins, Peace, Hill, Johnston and Cuevas (2015b), and Huggins, Hill, Peace and Johnston (2015), into decisions made among emergency managers and their diverse collaborators. These examples, together with the original examples provided by Hutchins (1995), show how computational media support a division of labor that enhances decision-making effectiveness beyond the limited capabilities of an individual, micro-level of brain-based cognition. The use of computer networks for meta-computing instead of individual computers (Foster & Kesselmann, 1997) illustrates how combining capacities enhances computational power in a largely synthetic[8] manner. This kind of division of labor operates between human and non-human components of extended cognition by:

- off-loading information, to reduce the load on working memory (Tversky, 2011);
- decomposing large tasks into subtasks (Hutchins, 1995)
- acting as a mechanism for transforming information through computation and calculation (Hutchins, 1995);
- re-presenting or rearranging information so that it is better understood and more natural to use (Norman, 1994);
- providing more effective approaches to interacting with the information sources (Kirsh, 2013), and;
- facilitating the flow of information and decisions between collaborators (Cooke & Gorman, 2010; Kozlowski & Chao, 2012).

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[7] Where decision-making and other thought is distributed between different people, devices and media.

[8] In this context, non-human.

As outlined in Huggins, Peace and Hill et al. (2015), the latter characteristic of computational media appears to be supported by focusing on active intentions. Rather than trying to provide a faithful description of all surrounding phenomena of interest, computational media may be a more effective element of decisions when they focus on the phenomena which users aim to influence. Huggins, Peace and Hill et al. (2015), like Taket and White (1996), suggest that taking this *pragmatic* approach may help mitigate potential friction between collaborators with very different knowledge and expertise. In support of theory from Sherif, Harvey, White, Hood, and Sherif (1961) concerning the value of superordinate goals[9] for mitigating inter-group conflict, pragmatic computational media appear to focus on objectives that collaborators hold in common. This avoids directing users' attention to points of fact which are likely to cause friction between collaborators.

As outlined by Kirsh (2013), the effectiveness of abbreviated approaches may be largely due to what is being modelled. Kirsh (2013) provides the example of a mechanic's sketch. The sketch is not an accurate and definitive description of the machinery the mechanic aims to repair. However, this highly practical approach to sketching certain system dynamics aligns with surrounding into the effectiveness of modelling approaches to learning complex tasks. The mechanic's sketch, together with the value of non-sequential practice (Kirsh, 2012), illustrate the potentials for using relatively rough-grained models as computational media. It seems that conceptual models incorporating a certain level of abbreviation may lower the cognitive demands[10] faced by users while improving their cognitive outcomes (Kirsh, 2013).

THE HEURISTIC ROLE OF COMPUTATIONAL MEDIA

There is an important question to be asked, considering the concept of ecological rationality within the domain of macrocognition: What is the role played by computational media, as part of effective heuristic approaches to high levels of aggregate complexity? In partial answer to this question, computational media used in highly complex decision-making scenarios appear to share certain fast and frugal characteristics of heuristic processes they are incorporated within. For example, consider the information displays and other tools used to make a timely decision to avoid a collision between a large ship and a largely submerged iceberg. These tools may be restricted to a highly selective set of information which can be rapidly displayed and incorporated into the time-pressured decisions required to avoid the iceberg.

However, frugal information and rapid incorporation are not sufficient to ensure that computational media are used as part of effective decision processes in complex scenarios. Computational media do not need to mimic human heuristics in order to become part of extended heuristic processes. Ideally, computational tools accommodate rather than replace humans' heuristic capabilities (Norman, 1994), to support decisions which are usefully integrated as part of lived experience (Clark, 1998; Hutchins, 1995; Kirsh, 2013; Norman, 2008). This is where ecological rationality becomes particularly important, by drawing attention to the comparative usefulness, rather than just the characteristics and functions, of particular computational media.

The concept of ecological rationality helps to highlight that heuristic decisions made using certain computational media can be more useful than a more elaborate, relatively comprehensive approach to the same decision in the same context. There have been many elaborate approaches to decision-making under complex conditions which have made this kind of comparison, to assess the comparative ecological rationality of a more heuristic approach. Professional share market evaluations serve as one example here, where detailed stock market evaluations have been outperformed by much more rudimentary predictions (Grove & Meeh, 1996). Regarding the use of computational media in the same sort of financial contexts, detailed stock market evaluations have been outperformed by basic trend analysis (Camerer & Johnson, 1991).

Like the comparison between detailed stock market evaluations and much more rudimentary models of analysis, computational media designed as part of a relatively non-heuristic decision process can be compared with components of a faster and more frugal, heuristic, approach. These comparisons can be performed by using a range of measures to gauge the effectiveness of resulting decisions. Examples of relevant outcome measures include a range of macrocognitive performance metrics used by the United States Naval Sea Command (NAVSEA) (2005), including both decision accuracy and situation awareness variables. Strategic awareness scales developed by Huggins, Hill and Peace et al. (2015) form another example of gauging the quality of decisions using heuristic approaches to complex scenarios.

Situation awareness is a theoretical construct which was originally used to define the quality of *in situ* decisions made by fighter pilots in combat scenarios, involving complex interactions between friendly and enemy

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[9] Goals shared by more than one person or group.

[10] Requirements for information seeking, encoding, manipulation, and decision-making in addition to other thought-related tasks.

combatants, alongside environmental and mechanical components of a combat system. Situation awareness was originally defined as: "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1988, p.1). This construct has since been developed into a distributed variant, *distributed situation awareness*, which is shared between collaborating individuals and teams (Stanton et al., 2008). The strategic situation awareness scales from Huggins et al. (2015) form variants which help gauge longer term implications of the decisions being evaluated. As outlined in the section below, these scales can be used to gauge the higher utility of certain distributed approaches.

Operationalizing the Impact of Computational Media in Ecological Rationality

Huggins et al. (2015) developed scales for assessing the role of computational media in demanding emergency management decisions, concerning the aggregate complexity of interacting social and environmental sub-systems. The scales were adapted from NAVSEA (2005) to gauge: current situation awareness, or the perception of relevant information; prospective information seeking quality, or the quality of plans to seek further information; and prospective amendment quality, or the quality of planned actions. These three aspects of situational awareness were used to rate decisions in response to heuristic or relatively non-heuristic computational media, concerning pre-emptive disaster risk reduction activities (Huggins et al., 2015).

Under design parameters[11] used by Huggins et al. (2015), the type of (heuristic or non-heuristic) computational media became the key independent variable of interest, affecting emergency managers' recommendations. The emergency managers' recommendations were then rated by recognized experts in the field of interest using the current situation awareness, prospective information seeking quality, and prospective amendment quality scales[12]. Each of the situation awareness scales achieved good inter-rater reliability even though they were rated by two quite different groups of experts (operational personnel and disaster research academics). This suggested that these scales could be used to gauge both the immediately practical, and more analytical, usefulness of decisions made using certain computational media. Data from these scales is therefore particularly relevant when other key aspects of the same decisions, such as individual participant differences, remain relatively constant between computational media conditions.

Huggins et al. (2015) applied these scales to responses from participants from operational participants who received a request for their opinions regarding an emergency management group's strategy for pre-emptive disaster risk reduction in the face of storm, earthquake and tsunami hazards. This means the scales were used to focus on aspects of group level macrocognition.

Huggins et al. (2015) and Huggins et al. (2015b) operationalized[13] an extended concept of ecological rationality for evaluating computational media such as that illustrated in Figure 2. The research examined professional emergency managers' decisions regarding real world interactions between environmental elements such as earthquakes, storms and tsunami hazards and community-based preparedness activities. Case study (Huggins et al., 2015b) and experimental (Huggins et al., 2015) stimuli were developed through interactions with practical and academic professionals who had little overlap in their expertise.

The lack of expertise overlaps between participants had been identified in prior research by Huggins, Peace, Hill, Johnston and Cuevas (2015a) which identified different patterns of opinion held by practitioners and the academic researchers seeking to assist them. Participants' comments in response to Figure 2 were then compared with comments in response to a text-based table designed to promote a much less heuristic approach to the decisions of interest. Participants in both conditions were asked to suggest amendments to the computational media, as a form of iterating a manipulatable computational medium. Results from Huggins et al. (2015) and from Huggins et al. (2015b), suggest that the comparative usefulness of computational media for facilitating relevant decisions in complex scenarios could be augmented by having the following characteristics:

- time-stamped information, updated at regular intervals
- piloted colors and symbols
- clearly structured layouts
- limited use of text-based information

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[11] Aspects of the experimental design.

[12] Indices for measuring these characteristics.

[13] Incorporated into an experimental design.

- displaying a limited number of elements and element groups at any one time
- causal linkages drawn between prioritized media elements

(Huggins et al., 2015b; Huggins et al., 2015)

Other methods for assessing group level decisions concerning complex scenarios have been developed for assessing decision support systems, including research by Eguchi et al. (1997) and by McDaniels, Chang, Colec, Mikawozc and Longstaff (2008). Taken together with the research by Huggins et al. (2015), these provide a substantial opportunity for further research seeking to improve the way computational media support decisions concerning complex phenomena. Considering that relevant phenomena include contemporary climate change dynamics, natural hazard risk, fragile human interdependencies, and the sustainability of ecosystems encompassing human life on Earth, these assessments of computational media represent an important role for contemporary cognitive research.

Research in this area needs to help ensure that computational media can be updated and reconfigured, to mimic the continual development and re-development of human neural tissue. This is how manipulatable components can be external to the brain but nonetheless form an active, rather than inert, part of extended cognitive processes (Clark, 2011). Literature regarding human-computer interactions highlights several other characteristics of effective computational media, such as: reliable information (Prasanna & Huggins, 2016); document formatting standards (Huggins et al., 2015b; Magee & Thom, 2014); and culturally specific adaptations to become more intuitive for diverse users (Reinecke & Bernstein, 2011). There is also a need for further research to identify the characteristics of cognitive tasks and contexts that benefit from using these kinds of external cognitive aids (Kirsh, 2010, 2013). In addition, as outlined throughout this article, there is a need for more research comparing the use of computational media against use of media supporting a less heuristic approach to aggregate complexity.

Ideally, as introduced in the introduction, further research will use experimental protocols extending beyond a few seconds of available reaction time. This will examine the processes involved when people make decisions made over substantial periods of time, longer than the 10 second timespans or less that are typical of most experimental research. Rather than focusing on rapid reaction time as a key variable, decisions incorporating extended response times may produce better outcomes in scenarios affected by aggregate complexity. The value of information seeking in situation awareness (Endsley, 1988) mark the need for several delays in response time while searching for further information in complex scenarios. A considerable body of relevant research, for example by Prasanna (2010) and by Sinclair, Doyle, Johnston and Paton (2012), has used a model of situation awareness based on Endsley (1988) to research emergency management scenarios, involving multiple interactions between human and environmental sub-systems. At the group level of macrocognitive decisions, many delayed responses may occur well outside of a standard experimental timeframe - due to the communications needed to facilitate an effective division of decision-making labor. It follows that, while reaction time may help analyze micro-cognitive operations within wider macrocognitive processes, this is unlikely to deliver insights from relatively new research concerning macrocognition.

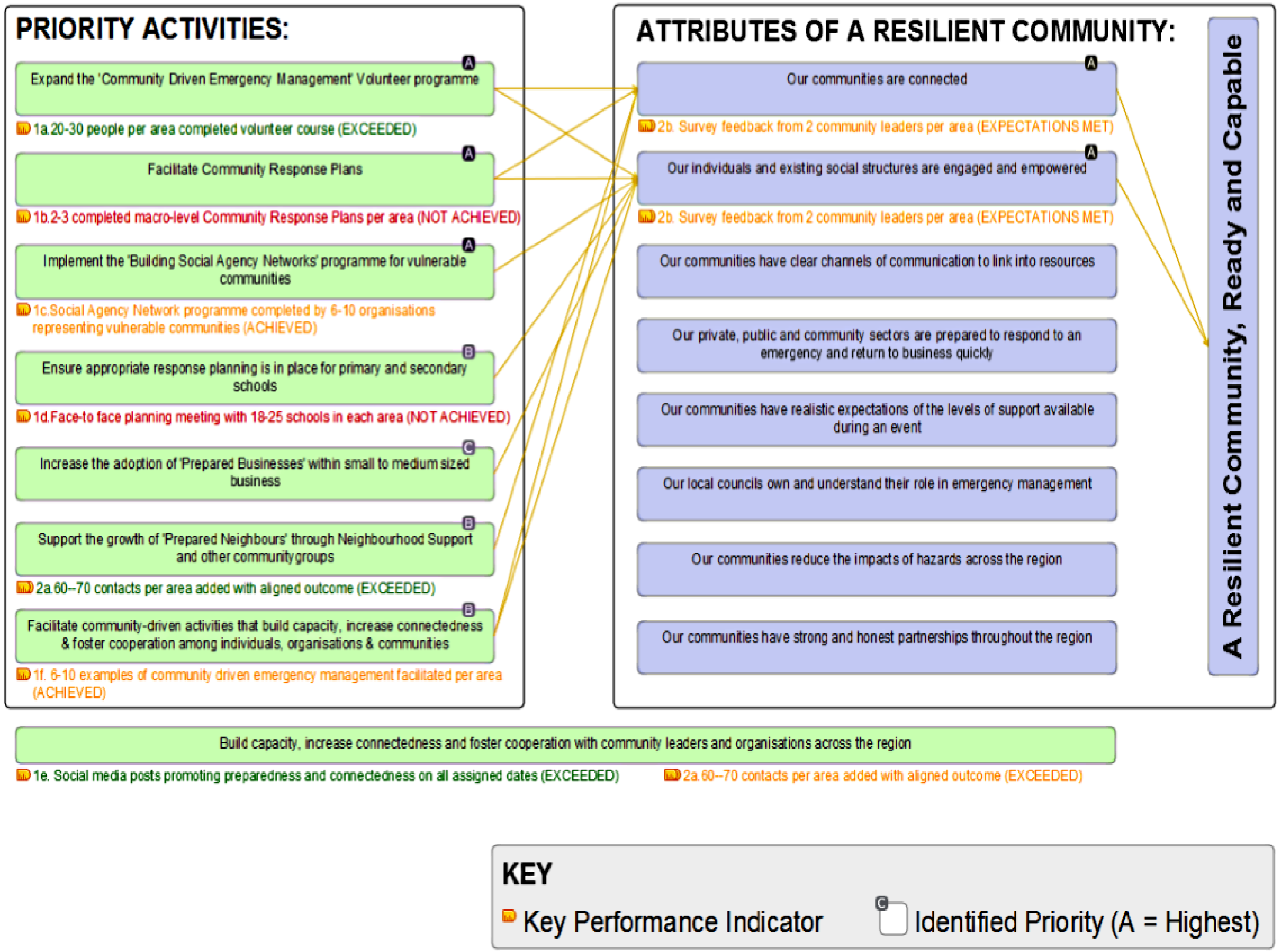

Figure 2. Key performance indicator display for Wellington Region Emergency Management Office.

CONCLUSION

The contemporary human world is marked by a range of eventualities that challenge the survival of human societies and our surrounding ecosystems. Many of these eventualities are a result of complex adaptive systems such as global and local climate change, ecosystem degradation, and relatively un-mitigated natural hazards. It can be useful to accept that these complex adaptive systems and many others are characterized by fluidity and emergent outcomes, resulting from the interaction of two or more sub-systems. It follows that such systems have no state of static equilibrium. Once these notions are accepted, we can accept that, in the moment we think we have a comprehensive set of information about a complex adaptive system, that information is probably incomplete and likely out of date.

Heuristic approaches to making decisions concerning complex adaptive systems may be the best we can hope for under these kinds of decision-making conditions. According to the concept of ecological rationality summarized following the introduction to this paper, these fast and frugal approaches to making decisions based on substantially limited information often out-perform more elaborate approaches to the same decision scenario even when more elaborated information is available. However, ecological rationality is also more of a potential phenomenon than a universal rule. As outlined by Todd and Gigerenzer (2003), this phenomenon characterizes some heuristic approaches to some decision-making contexts.

The current paper outlined a case for extending individualistic, brain-based applications of the ecological rationality concept, to better understand decisions made by two or more people. As outlined in in the preceding section, these decisions are often made by sharing cognitive tools located outside of the brain. The broadened notion of ecological rationality outlined in the latter section marks a substantial extension from the example provided by Todd and Gigerenzer (2012), of a baseball player running to catch a high ball. Decisions using computational media can still be relatively heuristic, even though they may not be as fast and frugal as this simple sporting metaphor. The heuristic use of computational media seems especially relevant when decision-makers may have access to a much more elaborate, and apparently comprehensive, approach to the same decision being made.

Limitations

The proposed approach to extending the concept of ecological rationality is not without limitations. The foremost limitation concerns the challenges of taking a macrocognitive approach to analyzing the usefulness of shared decision-making heuristics. Usefulness is the key criterion for establishing the ecological rationality of a particular decision-making heuristic in an ill-defined, decision-making context (Todd & Gigerenzer, 2003). This criterion is easy to apply to the usefulness of the heuristic used by a baseball player running to catch a ball. The baseball player either catches the ball, which is useful to them, or they do not, which is not useful. However, the usefulness of shared decisions concerning complex scenarios can be much harder to define. Parties to the same decision may aim to achieve very different objectives through making the same shared decision.

As a result of these pluralistic objectives, it may be very difficult to define a unitary measure or set measures for usefulness in some decision contexts. This has resulted in the use of process quality measures rather than measures of outcome quality for much of the research outlined in the current paper. Situational awareness and distributed situational awareness scales do not specifically address the quality of immediate decision outcomes. Nor do they address the downstream implications of those outcomes. For future research, these constructs would ideally be replaced by context specific measures of decision outcome quality.

The current paper has highlighted the aggregate complexity of decisions concerning complex human interdependencies, climate change, ecosystem degradation and natural hazard risk. It is assumed that each of these challenges exist within complex dynamic systems, which demand a relatively novel approach to analyzing and improving decisions about aggregate complexity. However, decisions surrounding the most challenging complexities of modern day human existence can also be characterized by severe political constraints. Even when a broadly useful decision can be made through a relatively heuristic approach, there is no guarantee that such a decision will be developed or implemented through the intricacies of multi-lateral, bi-lateral, or even sub-national political interests.

Implications for Research into Interface Design and Development

Kirsh (2012) wrote that: “Once we understand the complex coordination between external and internal simulation… …we will begin to reach new heights in design, and create a cognitively better world of physical-digital coordination” (p. 28). Although there have been several relevant precedents, new research is required to further operationalize and exploit the role of computational media as part of ecological rationality in complex scenarios. Applying the concept of ecological rationality to shared decisions in complex scenarios has many benefits for cognitive psychology and the populations participating in cognitive psychological research. In the absence of an extended notion of ecological rationality, cognitive research into decisions concerning complex adaptive systems may be left without coherent criteria for evaluating effectiveness. Although decision usefulness can be a difficult concept to operationalize in many decision contexts, this is a challenge that is worth tackling in some decision contexts. Even imperfect or plural[14] measures of decision usefulness are a marked improvement on measures that may have little coherence or explanatory potential.

Failure to operationalize an extended notion of ecological rationality may also mean that research into relevant decisions and the information technology supporting them lacks a coherent point of comparison. Arbitrarily comparing one decision making process to another would be a very *ad hoc* approach to making structured scientific explanations, especially when there can be so much at stake. Areas such as disaster risk reduction, marked by substantial risks to lives, livelihoods and surrounding societies, exemplify one area requiring substantial improvements to decision-making tools and processes. In this area, as in many other domains affected by aggregate complexity, research operationalizing an extended notion of ecological rationality can make profoundly positive impacts on the world we live in. This research will benefit from collaborations with engineers and designers tasked with creating the many interfaces which humans use to interact with each other and with synthetic computational capacities. Such an approach to relevant research would substantially improve the ability of heuristic computational media to support decisions with a more profoundly positive affect on our lives and on the environment with which we interact.

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[14] Interpreted differently by different groups and individuals.

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