HOMO EFFECTIVUS:
toward a unified model of human cognition for the study of social-ecological systems

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ABSTRACT

Institutional economics and related fields are struggling to reconcile their inherited assumptions about human rationality with the heterogeneous behaviours that are observed in both experimental and real-world conditions. This begs the question: what set of assumptions should we bring to the study of our own species' role in complex systems? In response, we propose HOMO EFFECTIVUS: a model of human cognition, synthesized from various literatures, in which our propensity for *mental efficiency*, achieved mainly through *analogical*—or *case-based*—reasoning, is the primary assumption. This assumption can, in turn, directly inform how we select future objects of analysis.

cognition, social-ecological systems, conceptual metaphor, mental models, rationality

INTRODUCTION

HOMO EFFECTIVUS is the product of comparing mainly two separate, but convergent, literatures. The first is *mental models*[3] research. The second is the study of *conceptual metaphor*[4], which is closely tied to a school of thought known as embodied cognition[5]. Despite different intellectual genealogies, both literatures point to the utility of

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[3] Gentner and Stevens (1983) define mental models research broadly as the "careful examination of the way people understand some domain of knowledge." (1) Johnson-Laird (1983) echoes Kenneth Craik (1952) in defining a 'mental model' more specifically as "an inner mental replica that has the same 'relation-structure' as the phenomenon that it represents." (11)

[4] Lakoff and Johnson (1999) define conceptual metaphor as the cognitive mechanism that allows us to use physical logic to reason about less structured domains. "[Conceptual] metaphor," they write, "allows conventional mental imagery from sensorimotor domains to be used for domains of subjective experience."(45) For a more thorough description, please see the section entitled *Conceptual Metaphor*, in this paper.

[5] Evans, Bergen and Zinken (2007) describe the field as concerned with "investigating the relationship between human language, the mind and socio-physical experience." (2) In particular, "…the neural underpinnings of language and cognition have had longstanding influence on the character and content of cognitive linguistic theories." (2) Núñez, Edwards and Matos (1999) describe embodied cognition as sharing:

> the belief that knowledge and cognition exist and arise within specific social settings, but we go on to ask what it is that makes possible the mutual intelligibility underlying shared social understandings. Our claim is that the grounding for situatedness comes from the nature of shared human bodily experience and action, realized through basic embodied cognitive processes and

thinking about human cognition as an *analogical* process. Namely, they both imply that we reason by drawing on memories of previous, related observations and experiences to help us make educated guesses about the present.[6]

This insight is anything but new. It is further bolstered by parallel research in a range of interconnected fields, from cognitive anthropology (e.g. D'Andrade, 1995; Atran et al., 2002; Atran and Medin, 2008), to philosophy of science (e.g. Nersessian, 1992; Ormart and Brunetti 2008) to psychology (e.g. Kahneman, Slovic and Tversky, 1982; Buchtel and Norenzayan, 2008) to computer science (e.g. Slade, 1991; Kolodner, 1992; Tsallis et al., 2003). We argue that what the study of social-ecological systems needs is a relatively *unified* account of how the mutually-reinforcing findings from each of these fields fit together to inform a helpfully predictive model of the human condition.

While such a comprehensive synthesis is beyond the scope of this paper, we make headway by showing some similarities amongst the findings of these fields. In doing so, what emerges isan instructive synthesized foil to the rational, self-interested, utility-maximizing *HOMO ECONOMICUS.* In contrast to *HOMO ECONOMICUS*[7]*,* the 'new' *HOMO EFFECTIVUS* model will prove a fruitful tool for analyzing the complex, often cross-cultural, real-world scenarios regularly confronted in resource management and social-ecological systems research.

OUTLINE

Before turning to a more thorough discussion of the pragmatic implications of a *HOMO EFFECTIVUS* approach, we will provide a review of the literature it draws from. In the interest of balancing both breadth and clarity, this review will be cursory. However,

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conceptual systems. (46)

[6] As we will see, from this perspective, 'mental models' constitute the web of representations we use to reason about the world (e.g. Johnson-Laird, 1983; Gentner and Stevens, 1983), while 'metaphors' or 'analogies' are the instances of previous, related experience we use to *structure* our thinking about the task at hand (e.g. Lakoff and Johnson, 1980; 1999). This structure, in turn, is what enables us to make usefully predictive inferences about the object of our attention.

To be clear, this approach does not deny the immense importance of rules and rationality. Rather, it simply reminds us that, outside of idealized market- or game-like conditions, properly accounting for analogical, model-based reasoning processes is central to understanding the complexity of dynamic human behaviour, *in-situ*.

[7] Gintis (2002) defines *HOMO ECONOMICUS* as:

> the standard model of the individual in economic theory… [who boasts] several characteristics that are relatively unproblematic in a market setting, but have potentially seriously misleading implications when applied outside this sphere. *H. economicus* comes to a choice situation with exogenously given and determinate preferences. These preferences apply to goods and services that are produced, consumed, and exchanged. *H. economicus* is self-interested, caring only about [a] personal … bundle of commodities, work, and leisure acquired. *H. economicus* is outcome-oriented, caring about social interactions only insofar as they affect his final consumption and wealth. Finally, *H. economicus* has a rate of time preference that allows him to allocate consumption over time in a consistent manner, reflecting his welfare and his concern for the welfare of future generations. Everyday observation attests to the fact that people [often] fail to conform to this model. (312)

some additional context, commentary, and discussion of references can be found in the footnotes.

The first segment of the review will introduce the notion of ‘mental models,’ giving an overview of various authors’ definitions, and some examples of how those definitions have been interpreted and ultimately converted into methodological tools. Next, we will move on to describe contemporary currents in cognitive linguistics[8], with a focus on what is called ‘conceptual metaphor theory.’ We will introduce its component notions of *source domains*, *target domains*, *image schemas*, and *primary metaphors*, as well as the more recent addition of *mental space* and ‘blending’ theory. We will briefly compare this framework with literature on case-based reasoning and related constructs often invoked in cognitive anthropology (i.e. schemas, scripts, prototypes). As this latter field is immense, we reduce a discussion of its relevant constructs to a figure (1.1), which can be used as a shorthand method for navigating the diversity of types of mental representations discussed in the literature.

After providing this overview of the relevant fields, we will demonstrate how the findings can be brought together in the personified form of *HOMO EFFECTIVUS*. *HOMO EFFECTIVUS* is, by necessity, a gross simplification of what it is like to be human, and the model inevitably ignores vast amounts of information. Nonetheless, we present it as a kind of instructive caricature that—however naively—boils the vast soup of contemporary findings on human cognition down to a palatable, and hopefully quite useful, reduction. Finally, having done so, we will conclude by suggesting future uses for the *HOMO EFFECTIVUS* approach in the context of social-ecological systems research.

MENTAL MODELS

Broadly speaking, a ‘mental model’ is a person’s mental representation of the relations between some set of things. In the mental models literature, the objects of representation often include complex, dynamic features of the environment, from a piece of technology, to a physical process, or social system, and so forth. While ‘mental model’ is an increasingly ubiquitous term, there are a range of important axes along which various authors’ usages of the term differ (Schwamb, 1990; Doyle and Ford, 1998). We describe several of these axes here.

One, some authors view mental models as highly *imagistic* representations of the external world (e.g. Funt, 1980). From this perspective, the individual mental representations that combine to form a mental model have an important physical shape in the imaginer’s mind’s-eye. These visualized physical properties are considered crucial for how people draw inferences about future states of whatever is being modeled[9]. This is one, relatively narrow definition of what constitutes a mental model.

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[8] Or alternatively, ‘embodied cognition.’ See the *Cognitive Linguistics and Embodied Cognition*, this paper, for a distinction amongst terms.

[9] E.g. If you are asked to imagine a ball being placed on a sloped surface, the roundness of the ball, and the slope of the surface, imply that the fictional ball will begin rolling downhill as soon as it is released. This seems self-evident. Those who argue for the explicitly ‘imagistic’ nature of mental models insist that this characteristic of simulating physical properties is what gives meaning to the term mental ‘model,’ distinguishing it from other forms of mental representation.

In contrast, other authors, such as Johnson-Laird (1983), argue for a broader use of the term, encompassing mental representations that are also comprised of more abstract, shapeless components. Johnson-Laird (1983) calls these more symbolic representations ‘tokens.’ Tokens may or may not have consequential physical properties, but are nonetheless linked to each other in the thinker’s mind with various kinds of important relations[10]. The nature of these relations determines how practical the model is for making inferences about the world.

A second axis of contention concerns ‘where’ in memory a mental model is stored. Some authors insist mental models reside primarily in working memory while others argue they do, or can, also reside in the brain’s long-term storage. (Nersessian, 1992) On the surface, this debate may seem petty. However, it can have important implications for a given mental representation’s cognitive availability[11] and transparency[12].

In other words, academics are not in agreement over how aware we are of our own clusters of mental representations, or, consequently, how easily we are able to consciously modify them. Phrased another way, while some clusters of mental representations are latent and abstract, others seem to be easily accessed or concrete, and it is contentious which, if any, of these should be labeled ‘mental models,’ as apposed to something else entirely (e.g. ‘schemas’; see Fig. 1.1).

A final point of disagreement is whether mental models are, literally, the representations that exist in people’s heads, or whether the term can, or should, also be used to refer to researchers’ externalized representations of participants’ elicited beliefs. (Examples of the latter could include anything from influence diagrams, to conceptual maps, to interview transcripts in which participants explain their views on the causal relations between things, and so on.) Some authors use the term ‘mental models’ to refer only to the former, while using ‘conceptual models’ to describe the latter. (Norman, 1983) In its extreme, one can think of this particular disagreement revolving around whether mental models are, themselves, an actual system of neural links somewhere in the brain, or, whether the term also has meaning when used to describe the *outputs* of researchers’ efforts to understand how people see things fitting together.

In more applied fields, this distinction becomes less meaningful. For instance, in some risk analysis and public policy literature, there is an acceptance of mental models as researcher-generated representations of peoples’ reported beliefs (e.g. Doyle and Ford, 1998; Morgan, Fischhoff, Bostrom and Atman 2002). Similarly, in the organizational behaviour literature, while mental models feature in authors’ writing, the distinction between a mental model and a conceptual model is not actively debated (e.g. Carley, 1997; Stout, Cannon-Bowers and Salas, 1999; Gibson and Zellmer-Bruhn, 2001).

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[10] E.g. take the ideas: ‘Canadians’ and ‘hockey.’ For Johnson-Laird (1983), even though these ideas are fairly abstract, they could easily serve as valid components of a mental model, in turn allowing for meaningful inferences. For instance: ‘Susan and John are Canadians. Most Canadians love hockey. Therefore Jordan is reasonably certain he’d make Susan and John happy if he gave them tickets to a hockey game.’ For Johnson-Laird (1983) this would comprise a mental ‘model’ of how Susan and John would respond to being gifted hockey tickets. Their characteristics imply certain preferences, which serve as modeling structure for the prediction of future events.

[11] I.e. how easily, or often, it’s recalled.

[12] I.e. how amenable it is to being consciously noticed, and modified.

The most crucial point here, perhaps, is that what counts as a 'mental model' is defined largely by the pragmatic value[13] of using the term to describe a given mental phenomenon. Within the cognitive sciences, such as artificial intelligence and neuroscience, but also extending to psychology and cognitive anthropology, the exact nature and location of hypothesized brain-modules can be highly consequential (e.g. Atran, 1998 and *commentary*; Pinker, 1994). However, in more applied fields, such as risk analysis, public policy, management science and, as we suggest, social-ecological systems[14] research, what the 'mental model' construct allows us to *do* is far more important than whether the chosen working definition has a 'real' one-to-one correspondence with physical structures in peoples' brains. (Allbriton, 1995)

Suffice it to say that what usually distinguishes mental models from other categories of mental representations is that they entail some sort of relational *structure* amongst components, which can, to an extent, be accessed and experimented with by the model-holder. (e.g. Gentner and Stevens, 1983; Johnson-Laird, 1983) The accuracy, or, as we prefer to think, pragmatic value, of a model depends on (a) which components, or 'moving parts,' of a system an individual recognizes and deems important to consider, (i.e. "what's relevant") and (b) the particular nature of the relations between and amongst those components (i.e. how an individual imagines things affecting each other, and why). (Hmelo-Sliver et al., 2007)

From this perspective, examples of mental models can range from the physically concrete—such as what a person imagines when recalling the layout of a specific neighbourhood (e.g. Taylor and Tversky, 1992; Tversky, 1993)—to the more abstract, such as, say, the trophic dynamics of a complex ecosystem (e.g. Bang, Medin and Atran, 2007). Complexity can also differ on a temporal axis. Some mental models are temporally-specific (e.g. Carley, 1997), such as what you draw upon in your mind when trying to determine the fastest route home from work at 5:15pm on a Thursday. Others, however, are so abstract as to be largely unrelated to time, such as how a chemistry student pictures the structure of a hydrogen atom (e.g. diSessa, 1983; Gentner and Gentner, 1983).

To concretize this discussion, we would like to briefly describe some examples of peer-reviewed mental-models studies. The source literature here is quite vast, so we

[13] I.e. the sorts of things it allows us to do.

[14] A definition is helpful, here—Carl Folke (2006) describes the rationale of a social-ecological systems approach in the following terms:

> [W]hy are social–ecological systems not just social or ecological systems? … [D]espite the huge literature on the social dimension of resource and environmental management, most studies have focused on investigating processes within the social domain only, treating the ecosystem largely as a "black box" and assuming that if the social system performs adaptively or is well organized institutionally it will also manage the environmental resource base in a sustainable fashion. A human society may show great ability to cope with change and adapt if analyzed only through the social dimension lens. But such an adaptation may be at the expense of changes in the capacity of ecosystems to sustain the adaptation … and may generate traps and breakpoints in the resilience of a social–ecological system…. Similarly, focusing on the ecological side only as a basis for decision making for sustainability leads to too narrow and wrong conclusions. That is why work on resilience stresses linked social–ecological systems. The efforts to understand such systems are still in an exploratory stage and there is opportunity for creative approaches and perspectives. (260)

focus on examples that (1) demonstrate the importance of mental models as an object of analysis and (2) may be at least tangentially instructive for future social-ecological systems research. We begin below.

An illustrative example of how mental models can affect people's reasoning in observable ways is described by Gentner and Gentner (in Gentner and Stevens, 1983). In this study, the authors examined how different mental models can affect students' reasoning about circuits. Gentner and Gentner found that those participants who imagined electrical current to flow *like a liquid* were more accurate in their predictions about various arrangements of batteries in a circuit than they were about the effects of resistors on a circuit. The exact inverse held true for participants whose mental models characterized electricity as a *density of particles*. Those who reasoned using the flow analogy were best able to distinguish between current and voltage (which are comparable to the flow-rate and pressure of a moving fluid, respectively). Those who preferred a particle analogy were best able to account for the role of resistors, because the latter operate like barriers containing gates, which restrict the number of electrons passing through per unit of time. (Gentner and Gentner, 1983)

Clearly, neither of these two models is comprehensive[15]. Yet, both are helpful in different ways. This illustrates how the implicit physical *structure* of mental-models components can play a central role in our ability to reason about complex situations.[16]

The implications for thinking about social-ecological systems are numerous, here. As one brief example, take the debate over ecosystem service typologies (e.g. Wallace, 2007; Costanza, 2008; Wallace, 2008). Some authors define 'ecosystem services' as all the myriad things that nature provides to people. (Daily, 1997) Others see ecosystem services as countable ecological units, such as lakes or fish. (Boyd and Banzhaf, 2007) Yet others argue ecosystem services are best thought of as flows, or processes, that render benefits. (Levine and Chan, *in press*)

Thinking of ecosystem services as 'flows' versus 'stocks', or as 'processes' versus 'benefits,' can have important repercussions for the goals of management policy. (E.g. Are we trying to amass stocks, or increase rates of flow? Policy prescriptions could differ significantly depending on the answer.) Although they may not be thinking in terms of contrasting mental models, the authors concerned are clearly aware that there are consequences to thinking about abstract systems in one way, versus another, even if there are valid arguments for both.[17]

In a more recent study, Hmelo-Silver, Marathe and Liu (2007) compared expert and novice understandings of both the human respiratory system, and an aquarium ecosystem. Interestingly, in both cases, they found that the locus of difference between experts and novices was not in understanding the *structures* of the systems. Rather, the crucial difference appeared in participants' accounts of the causal behaviours and functions of the various system components. In other words, the authors found that a

[15] Or 'right', in the objectivist sense.
[16] As we will later see, it is conceptual metaphor, broadly conceived, that supplies that particular structure, or what the literature calls 'topography' (e.g. Turner and Fauconnier, 2002; 2007)
[17] I.e. Both the 'stocks' approach and 'flows' approach use analogies that have proven useful in other situations and, by virtue of their familiarity, can help us reason methodically about otherwise ill-defined phenomena. See the section on *Conceptual Metaphor Theory*, this paper, for further detail on this angle.

more nuanced understanding of a system lies not in better identifying all the moving parts, but in understanding the precise *interrelations* amongst components, and the *mechanisms* by which those components interact.

This can be instructive for those of us engaged in researching complex systems. It can help us determine the questions to which we choose to devote our limited resources. This, in turn, will inform the suggestions we may propose for modifying human behaviour (e.g. what a shift towards 'adaptive management' should actually entail—focusing on identifying ever-more system components, or instead experimenting with thinking about different ways the components interrelate).[18]

Citing experiments with schoolchildren, Hmelo-Sliver et al. (2007) also note that teaching people about the function of system components (in their study, human lungs), does not necessarily produce an improved understanding of the actual mechanisms, or 'behaviours,' involved in the system's functioning. If corroborated in a social-ecological systems context, this finding would have implications for the efficient crafting of ecological risk communications and environmental education initiatives.

Finally, foreshadowing our discussion of conceptual metaphor theory, below, Hmelo-Sliver et al. (2007) found that participants drew upon a consistent, limited set of frames to structure their thinking about the systems in question. People with novice understanding tended to hold observer-centric perspectives, in which the system's primary purpose was to fulfill human needs and desires (e.g. an aquarium functioning for its visual appeal, or lungs as existing to allow the participant to breathe). Those with intermediate levels of knowledge structured their thinking about the system around the role and integrity of salient components, in this case either fish, or lungs, themselves.

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[18] To provide a sense of how mental models can be elicited, as follows is Hmelo-Silver, Marathe and Liu's (2007) description of their mental model-elicitation method:

> We conducted individual interviews that ranged from 20 to 40 min. All interviews were tape-recorded and transcribed. For the aquarium system, the interviewer presented participants with a piece of paper that had a three-sided rectangular shape (representing an aquarium)…For the human respiratory system, participants were provided with a piece of paper with an outline of a human body. The participants were provided with colored markers and were asked, while thinking aloud, to draw a picture of "anything you think is in an aquarium" or "the parts of your body involved in breathing." If needed, the interviewer asked the participants for further clarifications of their drawings. Once participants had completed their drawings, the interviewer began asking questions… The participants were also given a list of items and asked how these related to an aquarium (e.g., air stone, heater, gravel) or the human respiratory system (e.g., oxygen, alveoli, ribs). In addition, several problems were posed. In these problems, participants were asked what would happen if the system were perturbed…

This approach could quite readily be adapted to assessing various participants' understandings of their local ecosystem, as well as the larger social system they regard as relevant. With a consistent coding scheme, the outputs could be collated and compared, both with each other, and with those of the investigators. The results could render important information on gaps in understanding and perception. These gaps in understanding the links between social and ecological phenomena could then be remedied through communications, educational initiatives, or multi-stakeholder processes. For more examples of adaptable mental model elicitation methods, see: Cox et al. (2003); Mohammed, Klimoski and Rentsch (2000); Bostrom, Atman, Fischhoff and Morgan (2002); Fischhoff, Bostrom and Quadrel (1993). For thorough typologies of mental model methods, see: Carley and Palmquist (1992) and Langan-Fox et al., (2000).

Finally, those with the most knowledge framed their descriptions in terms of how the systems in question were in turn related to higher-level systems, or examples of larger subsuming processes (e.g. energy transfer, or the brain's controlling mechanisms).

For those of us interested in ecological literacy, this poses an important question: whether being prompted to consider connections to higher-level processes can improve people's understanding of social-ecological systems. An alternative explanation is that such explicit awareness of higher-level connections is instead a byproduct—rather than a cause—of increased understanding. This is an empirical question that social-ecological systems researchers could test.

Now switching disciplines, the language of mental models also surfaces in the organizational behaviour literature. Interestingly, much of the focus in that field is on so-called 'team' or 'shared' mental-models. There is empirical evidence (Stout et al., 1999) that suggests the success of groups who are working towards a common goal is dependent on the nature of their shared mental models. Greater similarity of mental models across team members appears to correlate (perhaps unsurprisingly) with more effective teamwork. (Carley, 1997; Stout et al., 1999; Langan-Fox et al., 2000; Gibson and Zellmer-Brahm, 2001)

There are, however, some interesting qualifications. One, it seems that shared mental models themselves may not translate directly into improved teamwork. Rather, what matters may be the team members' willingness to provide useful information to each other without being prompted to do so. (Stout et al., 1999) Also, the early group-planning processes that can help create shared mental models may also allow team leaders to use later 'down-time' to strategize more effectively, rather than continually re-articulate their plans to team members. (Stout et al., 1999; Gibson and Zellmer-Bruhn, 2001) Finally, it appears that it is not merely the similarity between team members' models, or their complexity, which matter. Rather, members of effective groups appear able to articulate their mental models in more than one way—they are able to describe their mental representations more richly. This suggests they have a deeper understanding of the various components of a system, acknowledging that the complex whole cannot necessarily be accounted for using just one kind of imagery or language. (Carley, 1997)

These findings present a wealth of intriguing research questions for those concerned with factors contributing to collective self-organization, and effective common property management within social-ecological systems (e.g. Ostrom, 2007; 2009). For instance, would explicitly fostering shared mental models amongst diverse stakeholders help lead to more robust solutions to commons problems? Alternatively, does the correlation between effective teamwork, and richly descriptive, shared mental models hold in complex social-ecological system settings? Are there cases where multiple stakeholders may share very similar mental models, yet *not* cooperate for common good? How are shared mental-models related to issuesof trust and willingness to engage in reciprocal behaviour? All these are important questions to answer if we truly want to identify the nuanced drivers of success, and failure, in the management of shared resources amongst diverse individuals and groups.

Shifting now to cognitive anthropology[19], Bang, Medin and Atran (2007) note how their comparative study of fishermen from the Menominee Indian Band, and

[19] D'Andrade (1995) defines cognitive anthropology as:

neighbouring fishers from mainstream-culture Wisconsin, exhibited very little variation in their mental models of the ecological factors affecting local freshwater fishing[20]. The differences that they did observe, however, appeared to stem from what the authors call the "framework" theories or "epistemological orientations" of the two groups. Menominee participants appeared to hold a distinctive image of humans' role in nature, which seemed to affect memory organization, and ecological reasoning. Namely, their more nuanced understanding of trophic relationships seemed tied to their highlighting of reciprocal processes amongst organisms in the ecosystem, while mainstream culture participants tended to structure their ecological memory around competitive relationships between fish. Menominees, in turn, tended to describe 'Mother Nature' as a nurturer and sustainer of humans, while their mainstream counterparts were more focused on humans' role in 'taking care' of nature. This is a noteworthy difference.

However, Bang, Medin and Atran (2007) assert that even *more* intriguing was the fact that the two groups had greatly exaggerated misconceptions about each other's mental models and general fishing practices. Mainstream fishers, in particular, posited much greater difference between the practices of themselves and the Menominee than in fact existed. This result was moderated in cases where a fisher from one group had a longstanding social or working relationship with a fisher from the other group. (Bang, Medin and Atran, 2007)

The authors conclude that their mental models analysis points, first of all, to the effect that cultural inheritance can have on cognitive processes—namely, the relative focus that an individual places on context, versus individual objects, when reasoning about a system[21]. Secondly, however, the authors also conclude that acknowledging the effects of subtle, culturally inherited epistemological differences may hold the key to conflict resolution in cases where different groups have negative perceptions of each other's ecological practices. (Bang, Medin and Atran, 2007)

Both these conclusions bear directly on the study of commons management more broadly. They are important factors to consider if we aim to understand how distinct groups can come together to manage shared resources, as well as what approaches may be useful for overcoming misunderstandings that preclude effective management.

In a subsequent study, Atran et al. (2002) found that in one geographical region in the Guatemalan lowlands, three different groups of resource users—lowland Maya, Ladinos[22] and highland Maya—each had notably different practices with respect to the

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> …the study of the relation between human society and human thought. The cognitive anthropologist studies how people in social groups conceive of and think about the objects and event that make up their world—including everything from physical objects like wild plants to abstract events like social justice. Such a project is closely linked to psychology because the study of how particular social groups categorize and reason inevitably leads to question about the basic nature of such cognitive processes. (1)

[20] The authors used what is called a 'cultural consensus model' to determine the degree of inter-participant agreement. (Bang, Medin and Atran, 2007)
[21] This echoes findings in cultural psychology, e.g. Ji, Nisbett, Su (2001); Heine and Renshaw (2002); Buchtel and Norenzayan (2008).
[22] Ladinos are Spanish-speaking people of mixed indigenous and European ancestry.

management of local forests and 'milpas' (a sort of biodiverse corn-garden pivotal to Mayan agricultural practice). Atran et al., (2002) assert their most counterintuitive finding was that, while lowland Maya exhibited the most sustainable practices, which the authors attribute to that community's extended history learning to subsist in the region, the next-most similar group in terms of resource management practices was in fact the Ladino immigrants, not the lowland Maya's highland cousins. The counterintuitive nature of this finding was reflected in the participants' mental models themselves: lowland Maya predicted that highland Maya would exhibit more similarities in their agricultural practice than would the Ladinos. This prediction was apparently completely inaccurate. (Atran et al., 2002)

The authors attribute this initially perplexing result to the different mental models held by highland Maya and Ladinos. Ladinos, it appears, were willing and able to learn resource management techniques from observing and interacting with their lowland neighbours. Although they have not necessarily adopted the lowland Maya's intricate system of belief in forest spirits, which appears to play a significant role in lowland Mayan management practices, the Ladinos have been adept at integrating lowland behaviours into their own practices. Highland Maya, on the other hand, appear to still have spiritual and communal connections to the highland territory from which they originally migrated. Atran et al. (2002) posit that these spiritual and cultural connections preclude the highland Maya's adoption of the lowland Maya's belief-driven management system. Highland Mayan worldview thus plays a crucial mediating role in determining 'rational' behaviour toward the surrounding ecology. Despite this, because the two Maya groups imagine each other as culturally related, they both appear to have mistakenly assumed that they were more similar to each other in agricultural practice than they were to their Ladino neighbours. (Atran et al., 2002)

While this study is instructive on several fronts, perhaps the most salient lesson is that a standard HOMO ECONOMICUS model, with its assumption of unqualified rational utility-maximization, would simply fail to account for how, and why, the various groups manage their resources they way they do. Even when tempered by the cognitive blind-spots so elegantly described by Kahneman and Tversky (1974)[23], HOMO ECONOMICUS is too blunt a tool to capture what is necessary for generating a functional understanding of the situation. Clearly, something else is going on.

Weare not suggesting, here, that the individual Maya and Ladinos of Atran et al.'s (2002) study are not acting in a rational or self-interested manner. However, we also resist the notion that all that tempers their rationality is a set of cognitive 'blind-spots' preventing an otherwise optimal use of their rational faculty. Instead, here we echo authors such as Damasio (1994) and Gintis (2002) in arguing that rational utility-maximization is just one of many heuristic faculties humans possess that help them

[23] Kahneman and Tversky are renowned for their widely cited work on the consistent *biases* that people display when reasoning about probabilities. Their argument hinges on the observation that we tend to use *heuristics* to help us make sense of problems, and that these heuristics, while often efficient, leave us vulnerable to blind-spots in our rationality—such as a susceptibility to what are called 'framing' or 'anchoring' effects, in which the information provided *in context* skews our judgment significantly. (Kahneman, Slovic and Tversky, 1982)

survive and thrive in their social and ecological milieu. Rather, culture—shared mental constructs that can differ remarkably from group to group—plays a central, not peripheral, role in determining what sorts of behaviour are *even within realm of possibility*.

Moreover, what the Ladinos in Atran et al.'s (2002) study point to is that, even if the micro-level beliefs that serve to structure a culture's internal logic are mysterious, foreign, or apparently 'illogical' to outsiders (such as the lowland Maya's forest-spirit pantheon) the *practical outcome* of that belief system can be highly adaptive for a particular ecological context, and thus worthy of emulation. In this sense, diverse cultural systems and individual beliefs are not only interesting as anthropological curios, but, crucially, are important to understand for their *pragmatic value*.[24]

Those of us in mainstream, Western culture are shaped by our own particular social, economic and ideological milieu, which affords us great advantages in understanding, say, how to design faster motherboards, implement successful public health initiatives or build airplanes. However, our particular cultural assumptions may preclude us from understanding the diversity of cognitive approaches—at both individual and group levels—to interacting with our environment, and with others. As argued by Medin et al. (2006), Atran and Medin (2008) and Nadasdy (2007) this can have crucial repercussions for ecological sustainability. And, as argued by Wynne (1992), failing to account for the wealth of pragmatic knowledge held by diverse groups—even if the mental models that relate this knowledge appear, at first, contradictory to standard scientific practice—can have pivotal implications for establishing fruitful working relationships between communities, researchers and policy-makers.

That said, weare not arguing, here, for the post-modern position of an inherent 'arbitrariness' to our cognitive and cultural constructions. Rather, we wish to reflect a theoretical stance drawn from cognitive science[25] that can help us account for these micro-variations in human behaviour in an unromantic, methodical, and usefully analyzable manner. To do so we now turn to the field of cognitive linguistics, with a nod to its broader school of embodied cognition. Despite outward differences, we aim to highlight the important similarities between contemporary mental-models approaches, and the theory and core findings that underlie these latter fields.

COGNITIVE LINGUISTICS AND EMBODIED COGNITION

The philosophical position underlying the field of embodied cognition is controversial. Lakoff and Johnson (1999), Lakoff and Núñez (2000), and Turner and Fauconnier (2002), amongst others, argue rigorously for the need to divorce ourselves from objectivist philosophy, and re-ground the study of the human condition on our neural structure and its connection to our human bodies and environments. This is a bold position, and can be read as unnecessarily provocative.

There are certainly more accessible arguments for the strengths of an embodied perspective (e.g. Slingerland, 2008). However, because of its controversy, we do not

[24] Atran and Medin (2008) echo this thought, in slightly different terms, throughout their book "The Native Mind and Cultural Construction of Nature."
[25] See, e.g., Slingerman (2008), ch. 2.

wish to dwell on the philosophical commitments required by what we would call a stance of 'radical' embodiment.[26] Rather, we simply point to the pragmatic value of looking at human cognition through a lens that highlights how our physical condition helps inform our thinking in ways we may normally fail to notice. This may sound abstract at the moment, but it will come into much sharper focus in the review, below. We begin with a description of the main ideas underlying conceptual metaphor theory, and then go on to describe more recent developments in mental space and blending theory. Where appropriate, we relate examples to our earlier discussion of mental models, and to the theme of social-ecological systems research.

CONCEPTUAL METAPHOR THEORY

For some, the word 'metaphor' evokes associations of literary flourish and emotive, even 'irrational,' thought. In the field of cognitive linguistics, however, the term is used much more broadly. For the purposes of this paper, therefore, we can regard 'metaphor' as virtually identical to the much less controversial 'analogy.' The most salient common feature of these two phenomena is also the most relevant for our discussion: both terms refer to a process that involves the 'mapping,' or 'carrying over' (*meta-pherein*, in Greek), of a mental representation[27] from one domain, to help structure our thinking about a second, often less familiar, domain (Lakoff and Johnson 1980; 1999).[28] This efficient 'borrowing' of neural circuitry from earlier experience, is, we argue, a core feature of human thought, and is precisely what makes HOMO EFFECTIVUS effective.

For example, let us revisit the mental-models experiment conducted by Gentner and Gentner (1983), described above. To recap, the authors wanted to test the effects of students' mental models of electricity on their understanding of electrical currents. Electricity is a difficult concept. We interact with it everyday, but its workings are somewhat opaque to most of us. Notably, Gentner and Gentner (1983) found that participants tended to structure their thinking about electricity in a very limited number of ways: they either thought about electrical current as a *liquid-like flow*, or as a *density of smallround objects*.

An electrical current is actually neither of these things, exclusively. Yet, imagining electricity as a flowing liquid or, alternatively, as a dense cluster of discrete objects, helps structure our thinking[29], and allows us to make useful inferences and predictions about how electricity might behave. By invoking the analogy (or 'metaphor') of liquid, or,

[26] Nunez, Edwards and Matos (1999), for instance, explain cognitions and behaviours as contributions to interactive systems. They explicitly contrast this with what they call 'cognitivism,' which they argue entails an unreflective commitment to the notion of transcendental ontological truths. They go on to contrast cognitivism with *radical* constructivism, essentially the extreme post-modern position. This is finally contrasted with a position of *embodied* constructivism—in which all human experience, mental and physical—is inseparable from our shared embodiment, which the authors assert is the only plausible position to assume.

[27] Or 'habit of mind,' e.g., Atran (1998)

[28] Shimko (1994) provides a useful distinction between metaphor and analogy, identifying the former as, simply, "between-domain" comparisons, and the latter as "within-domain" comparisons. (660)

[29] Here we mean humans more broadly, not just the participants in the study.

alternatively, what amounts to a bunch of moving balls, Gentner and Gentner's (1983) participants were able recreate in their minds a *human-scale* model of this abstract phenomenon called 'electricity.'

Because we directly observe flowing liquid (e.g. water), and moving spheres (e.g. pebbles, grapes, marbles, billiard balls, etc.) on a daily basis for virtually our entire lives, thinking about electricity *in termsof* these things is second nature. Phrased another way, it is cognitively efficient to think about new ideas in terms of things most familiar to us, precluding a need to 'reinvent the wheel.' (Allbriton, 1995; Tsallis et al., 2003), It is simply easy for us to use our rich, preexisting life-knowledge to make educated guesses about things with which we are less viscerally familiar[30]—in this case, electricity.

This is the simple premise behind conceptual metaphor theory, and virtually all the ideas to follow below: the fact that we tend to think about abstract things in terms of more familiar things. Phrased differently, it is also the notion that we reason about complex scenarios using tried and true heuristics and, ultimately, that we tend to use well-rehearsed established clusters of neural connections to do our thinking, rather than continually expend the considerable time and energy required to think about new things entirely 'from scratch.'

This may seem unremarkable. Yet, in fact, it is a source of considerable explanatory and predictive power. From this perspective, what allows for the rich complexity of cognitive representations and cultural constructs that we observe in our daily lives is not a mysterious entity inhabiting a 'black box' between our ears. Rather it is our remarkable ability to *intelligently map* elements of our preexisting knowledge (such as—in the case described above—our practical experience with water, or with round things like grapes or pebbles) onto less familiar domains, which allows us to invent ever-more nuanced, ever-more useful 'blends'[31] of what are otherwise quite mundane ideas (e.g. deriving a powerful theory of electricity by selectively blending our knowledge of fluids and particles).

This penchant for creative re-combination leads to staggering cultural diversity. Crucially, however, despite said diversity, by virtue of our shared genome we all experience the world using a very similar set of sensory inputs (human eyes, ears, fingers, tongues, etc.). This shared experience of *human-scale* physical interaction with the world affords us a broad swath of shared spatio-temporal experiences. We draw upon these experiences to help structure our understanding of more complex, abstract domains not easily observable with our unaided senses.

As argued by Slingerland (2008), this renders our human bodies a sort of "universal decoding key" (218) for understanding how other individuals and other cultures experience life, build their worldviews and structure their societies. The potential uses of this perspective in social-ecological systems research are vast and

[30] Note the similarity between this propensity for thinking in terms of easily recalled previous experience, and Kahneman and Tversky's (1974) *availability heuristic*. Both imply we tend to reason about a problem by drawing on the most accessible analogue in our memory, even if there are nonetheless important differences between the analogue and the target. As Kelly (2001) argues, the pitfall of metaphorical, or analogical, thought is the tendency to assume more similarity between domains than actually exists. We tend to mistake the imperfect model for the thing being modeled, which can lead to impractical inferences.

[31] See *Mental space and blending theory*, below.

exciting. In the meantime, however, we will continue by briefly describing the basic building-blocks of conceptual metaphor theory, as they appear in the literature.

The most fundamental constructs at the root of conceptual metaphor theory are the *source domain* and the *target domain*. For any given instance of metaphorical mapping, the target domain is, quite simply, the thing we are trying to understand, or describe (e.g. in Gentner and Gentner (1983), electricity). The source domain, in turn, is the more viscerally-familiar body of knowledge (e.g. flowing liquid, or small round objects) that we draw upon to help us structure our thinking about the target.

A crucial tenet of conceptual metaphor theory[32] is the *invariance principle*. This is the notion that, all things being equal, we conserve the *structure* of the source domain when using it to think about a target domain. (Turner, 1990) This is why analogies and metaphors are actually useful—they allow us to map, or project, the salient properties of one domain onto another. This, in turn, allows us to make better-educated guesses about the less familiar thing being described.[33]

To put it once again in terms of Gentner and Gentner's (1983) electrical current example, students who thought about electricity as a *flowing liquid* intuitively *mapped* the physical characteristics and propensities of the source domain, *liquid*, onto their notion of the target domain, *electricity*. This enabled them to make the helpful distinction between voltage—which is analogous to water pressure—and current, which is analogous to the speed of water flow. The source domain of *small, uniform spheres* likewise helped inform the other group about the role of resistors, which they were able to conceive of as 'gates'—again structuring the target domain to fit human-scale experience.

That, in short, is the invariance principle. It is our innate propensity to usefully map features of a source domain onto a target domain. It is also so intrinsic to our thinking that we rarely, if ever, pause to contemplate it. Nonetheless, it is a remarkable ability. It also serves as a useful theoretical construct for understanding how we build our mental models. This tendency to preserve, or 'project,' inferences from analogous cases is a core feature of *HOMO EFFECTIVUS,* which we elaborate on, below. Presently, we continue by describing the notion of *image schemas*.

Image schemas are our minds' stored knowledge of the patterns of spatial relations that we all experience as humans. They are our intuitive understandings of basic-level phenomenology; simply put: in-out, up-down, ahead-behind, and so on. (Lakoff and Johnson, 1999) Image schemas are the foundational basis of conceptual

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[32] Principally in its early form—e.g. Lakoff and Turner (1989). In more recent texts focused on our ability to *recombine* the topography of various source domains into new blends, the notion of total invariance has been de-emphasized (e.g. Turner and Fauconnier, 2002; 2007; Lakoff and Johnson, 1999)

[33] For instance, if we say "John's apartment is a pig sty", we likely do not mean that a pig actually occupies John's apartment. Rather, we mean that the internal organization of John's apartment resembles that of a pig sty. (In this case, we likely mean to say there is a conspicuous *lack* of organization.) It is the known, structured relationship amongst objects in a pig sty (i.e. conspicuous disarray) that helps you imagine what being in John's apartment is like. If, instead, we were to tell you something like "Our friend's house is virtually a museum," you would likely make certain inferences about how organized and clean our friend's place is. Assuming you and we share some common cultural knowledge, you may also infer that our friend is a bit neurotic about keeping and displaying his art or memorabilia in pristine condition.

metaphor. They are also what make conceptual metaphors ‘conceptual’—that is, pervasive and largely unnoticed—rather than obvious or literary.

To ground this idea, let us briefly examine two examples laid out explicitly in Lakoff and Johnson (1999). The first is the *container schema.* A container schema is eminently simple: it has an inside, an outside and, thus, a boundary between the two. That is all. This is perhaps the most basic distinction we, as humans, are able to make about the world we live in; that it is comprised of distinct entities, rather than one undifferentiated whole. Importantly, we are able to project this notion of an entity that contains some things, but excludes others, onto all sorts of less structured domains of thought and behaviour. This grants us a very useful cognitive tool.[34]

Crucially, it is worth repeating that conceptual metaphor theory argues the *container schema* is anything but an arbitrary cultural construct. Rather, it is the direct, inescapable artifact of experiencing and learning about the world from within a human mind and body, and thus is a reasoning tool accessible to all human beings. (Lakoff and Johnson, 1999; Lakoff and Núñez, 2000; Slingerland, 2008)

Another example of such a phenomenon is the *source-path-goalschema*. Each of us develops this schema by virtue of our experience of moving through space. It consists of a starting point, a mobile object (what Lakoff and Johnson (1999) call a ‘trajector’), and an end-point, or goal. The trajector, in turn, may follow the most direct route to the goal, or it may stray. It may eventually arrive at the designated end point, or it may miss its goal. Finally, at any given time, the trajector will have a particular location and direction relative to the beginning, and presumed end, of its path. (Lakoff and Johnson, 1999).

It can be cumbersome to describe in abstract, but cognitive metaphor theory asserts that our grasp of the *source-path-goal schema* is in fact a fundamental precondition for a huge chunk of our linguistic repertoire (e.g. Talmy, 2000). Yet it is so deeply ingrained in our physical and mental experience that we never need to think about it in such explicit terms. The same applies to what Lakoff and Johnson (1999) call bodily projections, which are a sort of variation on the source-path-goal theme. For Lakoff and Johnson (1999), such schemas are:

> …especially clear instances of the way our bodies shape conceptual structure. Consider examples such as *in front of* and *in back of*. The most central senses of these terms have to do with the body. We have inherent fronts and backs … [and we also] project fronts and backs onto objects. What we understand as the front of a stationary artifact, like a TV or computer or a stove, is the side we normally interact with using our fronts… We project fronts onto stationary objects without inherent fronts such as trees or rocks. English speakers project fronts onto such

[34] As Lakoff and Johnson (1999) write:

> Container schemas, like other image schemas, are cross-modal. We can impose a conceptual container schema on a visual scene. We can impose a container schema on something we hear, as when we conceptually separate out one part of a piece of music from another. We can also impose container schemas on our motor movements, as when a baseball coach breaks down a batter’s swing into component parts and discusses what goes on “inside” each part. (32)

objects so the front faces the speaker. In other languages (e.g., Hausa), speakers project fronts onto such objects in the opposite direction, facing away from the speaker. (34-35)

Lakoff and Johnson (1999) go on to describe how different languages in fact have varying degrees of specificity when projecting human bodily experiences onto other objects. English, it turns out, has a somewhat impoverished repertoire, relatively speaking. What is central for our purposes, however, is that, *despite* this vast linguistic diversity, studies have shown that there are, in fact, a limited number of these so-called *primary schemas* shared by all languages, and which serve as the basis for virtually all other, more complex cognitive and linguistic relational constructions. (Lakoff and Johnson, 1999; Talmy, 2000; Slingerland, 2008)

Lakoff and Johnson (1999), identify the following basic-level schemas in addition to those we have already examined here: *part-whole, center-periphery, link, cycle, iteration, contact, adjacency, forced motion* (e.g., pushing, pulling, propelling), *support, balance, straight-curved*, and *near-far*, as well as *vertical*, *horizontal* and *front-back* orientation schemes. (35) Lakoff and Johnson (1999) argue these spatial concepts are common to all languages, and are therefore universally commensurable across cultures. This finding presents an important challenge to the radical relativism of some post-modern thought. (Lakoff and Johnson, 1999; Slingerland, 2008)

Interestingly, this commensurability continues into the realm of *primary metaphors*, in which we use basic-level image schemas to structure our thinking about realms of experience with which they regularly co-occur. Take, for instance, the metaphor MORE IS UP. Because we have virtually all observed, many times over, from a very young age, how adding objects to a pile, or pouring liquid into a container, makes the quantity of the observed substance ‘rise,’ the notion that ‘more’ can be expressed as ‘up’ is so commonplace as to be almost unnoticeable. Yet it is at once pervasive, and fundamentally metaphorical (or, if you prefer, analogical) in nature. (Lakoff and Johnson, 1980) Other widely pervasive primary metaphors, apparently rooted directly in our experience of these things co-occurring with the image schemas and sensations they draw upon for structure, include IMPORTANT IS BIG, DIFFICULTIES ARE BURDERNS, CATEGORIES ARE CONTAINERS, SIMILARITY IS CLOSENESS, KNOWING IS SEEING, and so forth[35]. (Lakoff and Johnson, 1999)

A willingness to entertain the hypothesis that these primary metaphors and image schemas are key to human cognition is crucial for understanding the potential of conceptual metaphor theory[36]. According to the theory, it is these image schemas and

[35] A more comprehensive list of primary metaphors as laid out in Lakoff and Johnson (1999) includes: AFFECTION IS WARMTH, HAPPY IS UP, INTIMACY IS CLOSENESS, BAD IS STINKY, LINEAR SCALES ARE PATHS, ORGANIZATION IS PHYSICAL STRUCTURE, HELP IS SUPPORT, TIME IS MOTION, STATES ARE LOCATIONS, CHANGE IS MOTION, ACTIONS ARE SELF-PROPELLED MOTIONS, PURPOSES ARE DESTINATIONS, PURPOSES ARE DESIRED OBJECTS, CAUSES ARE PHYSICAL FORCES, RELATIONSHIPS ARE ENCLOSURES, CONTROL IS UP, UNDERSTANDING IS GRASPING, AND SEEING IS TOUCHING. (50-54)

[36] In addition to cross-cultural linguistic analysis, there have been rudimentary empirical studies showing that using conceptual metaphors to reason does activate the neural networks associated with the physical movement or gestalt that they draw upon for implicit structure. (Slingerland, 2008) Findings such as these cannot be regarded as ‘proof’ for the theory, but they do provide important supporting evidence.

primary metaphors, which we in turn combine with each other, and with new target domains, to form a range of diverse, elaborate conceptual metaphors that constitute our complex cognitive and cultural framework. To again relate this back to the mental models literature, it is these basic-level mental representations (i.e. image schemas and primary metaphors) which provide the *structure* for our dynamic models. The accuracy of our inferences depend on the internal spatial and causal logic of the schemas and metaphors we use to construct our mental models.

A crucial point to make here is that, according to conceptual metaphor theory, reasoning based on primary schemas and metaphors is not limited to the physical realm. Rather, these same schemas and metaphors are what structure the foundations of our *metaphysical* and *moral* reasoning, as well. (Johnson, 1994; Lakoff and Johnson, 1999)

This assumption can prove an insightful methodological tool for bridging gaps of understanding amongst cultures with otherwise very distinct ethical or philosophical frameworks. A clear example of such an approach in use is Slingerland's (2004) analysis of the conceptual metaphors at work in the discourse on human rights in China.

Briefly, Slingerland (2004) argues that the Western notion of human rights is in fact premised on an underlying conceptual metaphor of MORALITY AS ACCCOUNTING and specifically, RIGHTS AS IOUS. The internal logic of this metaphor entails that a person's well-being can be thought of as *property*, or wealth. Certain acts can affect the status of that wealth: infringing on someone's well-being is equivalent to stealing property. Thus, differences must be resolved through restitution or compensation.

In contrast to this schema of *property*, Slingerland (2004) argues that conceptions of morality in Chinese culture are traditionally structured around a *spatial* metaphor, in which MORALITY IS BOUNDED SPACE*.* From this perspective, moral behaviour is human action that occurs within a certain boundary. The pinnacle of moral conduct is remaining perfectly centred, or balanced, within that space. Conversely, transgressing, overstepping or overflowing that space is tantamount to immorality.

Identifying such underlying schemas creates discursive space for improving cross-cultural understanding. Phrased differently, metaphor analysis can facilitate inferences about how other societies are structured, how the individuals who make them up relate to the world, and the way people with a certain cognitive inheritance, absorbed via culture, education and experience, are likely to perceive and reason about given events. In other words, examining metaphors can help us grasp the internal logic of people's mental models.

MENTAL SPACE AND BLENDING THEORY

Multiple examples in the literature demonstrate the strength of metaphor analysis for demystifying, and possibly overcoming, gaps of perception and understanding amongst culturally diverse stakeholders (i.e. Shimko, 1994; Slingerland, 2004). They also remind us of the role metaphor can play in legitimizing and perpetuating power structures and certain elements of social systems (i.e. Shimko, 1994; Kelly, 2001;

Slingerland, 2004). The prospects for applications to social-ecological systems research are therefore promising.[37]

That said, conceptual metaphor theory is not without its limitations. Particularly in the narrow sense first articulated by Lakoff (Glucksberg and McGlone, 1999; McGlone, 2007), conceptual metaphor theory presents a rather serious conundrum. If we make the mistake of thinking about this phenomenon as a strict one-to-one mapping of *all* the features of just one source domain onto a single target domain, we risk glossing over the fact that many of our most creative theories—or mental models—are in fact the product of innovative recombinations of various parts of various metaphors into new systems that allow for novel inferences. For instance, returning to the Gentner and Gentner (1983) example, it is indeed interesting that we often think about electricity in terms of a flowing liquid or a density of particles, and that those particular metaphors affect the inferences we are able to make about electrical currents. What is equally interesting, however, is that, with proper reflection, we are able to think about electricity as *both* a flow of liquid *and* as a density of particles, resulting in a more nuanced, predictive conception of the variety of ways electricity behaves.

How do we do this? How is it that we avoid taking metaphoric projections too literally, and thus ensure ample room for the creation of novel constructs and, hence, new knowledge? The apparent absence of a coherent answer to this question is a major criticism of first-generation conceptual metaphor theory (e.g. Gluckberg and McGlone, 1999; McGlone, 2007).[38] It has, however, been addressed by the concepts of mental space, and blending theory.

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[37] Consider, for example, the pervasive use of economic metaphors throughout both conservation biology and sustainable development: e.g., ecosystem services, natural capital, human capital, social capital, the 'portfolio' effect, carbon 'banking,' biodiversity 'banking,' and so on (e.g. Economist, 2005; Katoomba Group, 2010) Given a certain set of goals, and a certain cultural context, there is undoubtedly great practical utility in talking about people and ecology this way. But doing so uncritically risks forgetting that we are, ultimately, making decisions about people, and other highly complex living things—not perfectly interchangeable units of value that we trade at a currency exchange kiosk, or on the floor of a stock market.

Each organism, human being or ecological process is *not* actually perfectly replaceable, given some set of capital and labour input. And unlike currency, living things and ecological processes have very specific characteristics and contextual roles which make theme unique and, assuredly, *not* fungible. It may, in some cases, be helpful to think about certain elements of the world in such terms, but mistaking the metaphor for reality can lead to dangerously maladaptive inferences.

[38] Another criticism of simple conceptual metaphor theory is that it is unable to account for why, or how, different individuals within the same culture are liable to use different source domains from each other when structuring a given target domain. Put another way, conceptual metaphor theory does not make it clear why some people find a given metaphor apt, while others do not. Eubanks (1999) chose to investigate this question in a study of cognitive metaphors of competition in business. By running and observing focus groups, Eubanks (1999) came to the intriguing conclusion that people tend to judge, and then grant or reject, the aptness of certain metaphors by virtue of what he calls 'licencing stories.' These stories are essentially narratives that people evoke to reminisce on previously observed cases, which individuals then go on to use as evidence for whether a given metaphor is an accurate way of making sense of a target domain. In our opinion, although his particular account risks passing the locus of explanatory responsibility on to the murky realms of personal political motivation, the spirit of Eubanks' (1999) observation ties in well both with the notion of case-based reasoning (see below), as well as with the synthesized model we propose in *HOMO EFFECTIVUS.* Regarding the latter, we propose that surrounding context, cognitive availability, and personal case history each play a role in selecting for the aptness of some analogical mappings over others.

As described by its progenitors Turner and Fauconnier (2002; 2007), mental space and blending theory can quickly get prohibitively turgid for non-cognitive linguists. However, it is entirely possible to describe the ideas underlying the theory in accessible language (e.g. Slingerland, 2008). Here, we aim to do so by briefly summarizing Turner and Fauconnier's centrally relevant ideas. In the interest of space, our survey is very brief. However, it should shed light on how conceptual metaphor theory has evolved, and in turn how it helps account for our construction of complex mental models.

For our purposes, we can think of the core concepts of blending theory as follows: *mental space*, *selective projection*, *emergent structure*, and *completion*. (Fauconnier and Turner, 2007) *Mental space* is a category created by generalizing from the notion of source and target domains, to encompass what Fauconnier and Turner (2007) describe as:

> …the small conceptual packets constructed as we think and talk… [They] are very partial assemblies containing elements, and structured by frames and cognitive models. They are interconnected, and can be modified as thought and discourse unfold. Mental spaces can be used generally to model dynamical mappings in thought and language. (363)

Using this terminology, a *mental model* can be thought of as one refined, complex mental space that is in fact the product of *selectively projecting* elements of other, more structured mental spaces to form a *blended space* that demonstrates *emergent structure*. This *emergent structure* is essentially a set of characteristics that exists only by virtue of the recombination that occurs as a product of blending. (Fauconnier and Turner, 2007)

For instance, let us imagine this in terms of Hmelo-Silver et al.'s (2007) study of mental models of complex systems, described above. The *emergent structure* of the aquarium system participants were asked to describe can be thought of as the habitable, self-sustaining environment for fish, provided by combining the components of a filter, tank, water, heater, and so forth, together into one blended whole. None of those components could, itself, sustain life. However, when combined to form one blended whole, they serve a new, emergent function.

To further ground this idea, let us return to Gentner and Gentner's (1983) study on mental models of electricity. For demonstrative purposes, let us imagine ourselves as students trying to learn how to reason about electrical current as *both* a flow, *and* as a density of electrons. In this case, *flowing liquid* constitutes what Fauconnier and Turner (2007) would call an '*input' space*. Thinking about electricity as a liquid amounts to *selectively projecting* elements of the input space—liquid—into the new '*generic' space* we are building for electricity. The projection is *selective*, because we do not imagine electricity as, for instance, wet, or thirst quenching, or subject, like a waterfall, to gravitational pull. Rather, only the flowing behaviour of liquid is assumed to apply[39].

[39] There are multiple explanations for how our minds determine which elements of a mental space to selectively project, and which to leave aside. This is sometimes discussed in terms of the 'motivation' for various kinds of metaphorical mapping. For our purposes, it is sufficient to say that it is largely a function of *context*, and *associative reasoning*. Both are intimately informed by how our mind categorizes and

Next, we are also told that electricity can be thought of as a *density of small round objects*. This constitutes a second input space. We then selectively project elements of that space into our generic space for electricity. The projected elements might include the notion of discrete individual spheres, but will not include every single one of the normal physical behaviours we would attribute to, say, marbles or grapes. Namely, we are likely not going to project the same tendency to fall when dropped, or break when smashed, and so forth, into our generic space. Rather, it is the abstract shape, and discreteness, of prototypical 'round things' that we are projecting, and hence *blending* with our abstraction of liquid, to create a new mental space. When combined, this new, *blendedspace*, can be said to comprise our'mental model' of electrical current.

To continue with the example, the *emergent structure* of our mental model is our knowledge that electricity both flows, like a liquid, but is *also* responsive to resistors in ways that reflect its micro-scale structure as a density of individual electrons. Finally, Fauconnier and Turner's (2007) ultimate *completion* stage translates to the *predictions* we can now make about how electrical current will behave under given conditions (e.g. flow through a conductor, be regulated by a resistor). Phrased differently, *completion* (or 'running the blend') is synonymous with our ability to now dynamically model electrical current in our minds, and thus make new inferences about what was previously opaque.[40]

This is a very basic account of how authors Fauconnier and Turner (2002; 2007) conceptualize cognition, combined with our own take on how their typology feeds into the broader notion of mental models. There is, in fact, far more depth to the theory, which Fauconnier and Turner (2007), have developed into a more comprehensive account of what they call *cognitive integration networks*. Their account includes a typology a different kinds of blends, as well as a preliminary theory as to what motivates our selection of input spaces and specific projections. This quickly becomes dense to navigate without reading the full account, but for the moment, it is worth noting that Fauconnier and Turner (2007) regard *context* as a crucial factor in determining which elements of a given input space we choose to project onto a generic space.[41]

CONVERGENCE WITH OTHER FIELDS

Fauconnier and Turner's (2002; 2007) approach to understanding cognition is, of course, just one of many. Many others exists, each operating at various levels of abstraction (e.g. Tsallis et al., 2003; Pinker, 1994; Nersessian, 1993; Slade, 1991), and each starting with a different set of disciplinary tools and assumptions. However, that

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stores information, as well as how that stored information is related to emotional and somatic states or 'somatic markers' (e.g. Damasio, 1994; Eubanks, 1999; Grady, 2007; Slingerland, 2008).

[40]Using blending theory terminology, our new mental model of electricity would constitute a 'double-scope' blend. This implies that the structure of two separate input domains are projected into a third, generic space. Simple, conceptual metaphor-like blending, in which there is only one source domain, mapped onto a target domain, is generally characterized as a 'single-scope' blend. (Fauconnier and Turner, 2007; Slingerland, 2008)

[41] This overlaps rather elegantly with the availability heuristic, and related framing, priming and anchoring effects, demonstrated by Kahneman and Tversky (1974; 1982), and now ubiquitous in cognitive psychology. See below for more details.

said, there is conspicuous convergence from multiple fields toward the notion of *analogical* or *case-basedreasoning*[42]. It is not always, or even frequently, articulated as such, but a survey of the literature makes this convergence unmistakable.

Briefly, psychologists Kahneman and Tversky (1974; 1982) highlight the *availability heuristic*, in which people have a tendency to make judgments based on the information most readily accessible to their memories[43]. Many of the biases they describe as ‘bounding’ our inherent rationality (e.g. the anchoring bias, our susceptibility to framing effects, the gambler’s fallacy, and so forth) can be attributed to the far-reaching influence of this particular heuristic tendency.

Turning now to cognitive anthropology, this field has, over the course of decades, developed a detailed, if still hotly debated, typology of the various mental representations that people draw upon to reason about the world around them (e.g. D’Andrade, 1995; Atran, 1998 and *commentary*). These bear striking resemblance to—and often explicitly overlap with—the various constructs that have developed in both cognitive linguistics, and cognitive and cultural psychology (e.g. Pinker, 1994; Buchtel and Norenzayan, 1998). Figure 1.1 places these diverse types of representations on a spectrum, which we portray as differing on two main axes: the relative abstraction or, conversely, concreteness of (a) the temporal and/or causal structure; and, (b) the physical, material structure, of a given type of mental representation.

Figure 1.1 also contains ‘cases,’ which we regard simply as examples of highly concretized mental representations. The notion of ‘cases’ reflects findings from computer science, in which *case-based learning* (CBL, or alternatively, *case-based reasoning*) programs have shown to be much better analogues of human cognition that strictly linear, rule-based ones. (Slade, 1991; Kolodner, 1992; Tsallis et al., 2003)

Continuing briefly with case-based reasoning, although there is also diversity in this field, the main thematic gist is the notion that it is far more efficient, and allows for far more recombinatorial complexity, to solve problems by comparing cases, which are ‘indexed’ (described, stored and ordered) according to their component characteristics, than it does to reason about each new problem from scratch by deferring to a lengthy set of highly developed rules. Rather, by using only a small number of relatively global rules pertaining to the analysis, storage, retrieval and modification of cases, researchers are able to construct what appear to be much more faithful models of complex cognitive processes (e.g. Slade, 1991; Kolodner, 2002; Tsallis et al., 2003).

Similar trends are also apparent in the philosophy of science. Authors such as Nersessian (1993; 2003), Rosch (1999), and Carey and Spelke (1996) have built on Kuhnian (1962) foundations to elaborate a growing body of work on what they call *model-based reasoning.* In this school of thought, analogy, mental models, and the ability to run simulations, or mental experiments, based on the inferred characteristics of a model’s component parts, comprise the fundamental engine of conceptual change in science. (Ormart and Brunetti, 2008) Although the terminology differs, the process they

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[42] This could also be regarded, more broadly speaking, as ‘heuristic’-thinking.

[43] In other words, they found we have a penchant to reason about a given problem using whichever analogue is most easily accessible to our minds. (Kahneman and Tversky, 1974; 1982) This is in stark contrast to the assumption that we reason with abstract logic, or nuanced statistical awareness, by default. (Gintis, 2002)

describe (what Carey and Spelke (1996) call 'bootstrapping') is virtually identical to the process of recursive blending proposed in Fauconnier and Turner's (2002; 2007) theory of conceptual integration, as well as in Johnson-Laird's (1983) account of mental models.

Finally, as expounded at length by Mark Johnson (1994), the 'co-founder' of conceptual metaphor theory, the metaphorical (or 'analogical') nature of normative reasoning is eminently compatible with the school of American pragmatist philosophy, epitomized by the writings of John Dewey. (Alexander, 1993) According to Johnson (1994), normative reasoning can be usefully described as the exercise of *moral imagination*, in which we experiment with extending a variety of schemas, analogies and metaphors into realms of ethical thought in order to determine what constitutes right action.[44]

This philosophical approach views moral thought as operating within a pluralistic context rather than through a "unifocal theoretical stare" (Alexander, 1993: 378). It identifies our imaginative (or, alternatively 'modeling') capabilities as allowing for normative thought experiments, which in turn enable us to create a "context from which present values may be criticized, thus liberating the course of action itself." (Alexander, 1993: 384) Crucially, from this view, values are *generated*, not static. By starting from an assumption of analogical reasoning, which entails our ability to recombine mental objects to produce emergent structure, this stance provides us with a conceptual framework for understanding the plurality and dynamism of values often glossed over by more rationalist, static models of human behaviour (i.e. *HOMO ECONOMICUS* and its correlates).

HOMO EFFECTIVUS: A PERSONIFIED SYNTHESIS OF THE LITERATURE

Having reviewed a diversity of contemporary literature on human reasoning, we are now in a position to synthesize (or, in the vocabulary of conceptual integration theory, 'compress') what we have learned into a human-scale model. The intent is not to perform the impossible and somehow include everything we have observed in a perfectly comprehensive manner. Rather, here we aim to reduce the relevant findings in the literature to a series of core, representative characteristics. The intended product is a revision to Kahneman and Tversky's (1974) bounded rationality thesis, or the *HOMO ECONOMICUS*model before it, that will enable us to make useful inferences about human behaviour under particular conditions.

For our purposes, we are interested in a model that can account for the individual- and group-level scale of human behaviour in complex, real-world systems. As such, our model will have to be more nuanced than *HOMO ECONOMICUS*, even though the latter does serve a useful purpose for more abstract, or controlled, analyses, particularly of idealized market behaviour.

[44] As we see in Slingerland's (2004) analysis of the Chinese human rights debate, this theoretical stance can guide us toward useful methodologies for analyzing, and possibly defusing, otherwise intractable metaphysical or legal conflicts. Werhane (2000; 2002; 2008) has applied a version of this approach to the field of business ethics, complex adaptive systems and the behaviour of multinational corporations, specifically.

As follows, then, is a short description of what we choose to call *HOMO EFFECTIVUS*: a simplified account of the human condition, pieced together from the findings discussed above. (A more iterated description of this model is presented in Fig. 1.2, below). Broadly speaking, we have seen that multiple fields of research now view humans as largely *analogical*, or *case-based*, reasoners. Namely, this entails that we intuitively access memories of earlier experiences most analogous to the current object of our attention, and use those recalled memories as the starting point for reasoning about the issue at hand. Generalizing from the inherent structure of the memories invoked (e.g. remembering what happened when, what caused what, what the relations were between the parts, what features a given item had, or what characteristics a given person exhibited, etc.), an individual is able to make useful inferences—essentially, educated guesses—about aspects of their current object of attention that are yet unclear. In other words, we match our present situation with previous experience, and proceed to fill in the blanks, as it were.[45]

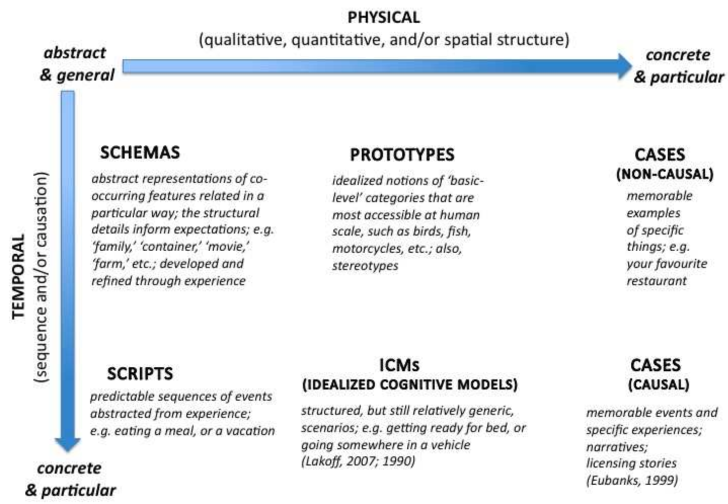
The 'cases' of previous experience we draw upon are not always clear-cut instances of exactly one kind of complete event. Rather, they are clusters of associated features, causes and correlations (e.g. D'Andrade, 1995; Lakoff and Johnson, 1999; Lakoff, 2007), including whatever emotional or somatic states we associate with them. (Slingerland, 2008) These clusters of mental interconnections go by various monikers depending upon both the disciplinary approach, and scale at which they are being discussed.

It can be helpful to think of this diversity of representations as lying on a spectrum of relative abstraction, versus relative concreteness (see Figure 1.1). As we have seen, general terms for the various representations along this spectrum include *source domain*, *mental space*, *schema, primary metaphor,* and *case*. (Slade, 1991; Kolodner, 1992; D'Andrade, 1995; Lakoff and Johnson, 1999; Lakoff, 2007) Other terms, such as *script, prototype* and *idealized conceptual model* (Lakoff, 2007), are also briefly described and pictured in the Figure 1.1.

[45] For instance, Joanna hears a baby crying. Joanna knows that her younger brother used to cry as an infant whenever he was hungry. Therefore, Joanna infers that if someone were to feed this poor baby, he would probably stop crying; *just like* her brother would have responded when he was young.

Take another example: chess. It has been shown that great players become great not by power of sheer reason, but by familiarizing themselves with a wide breadth of particular scenarios with predictable outcomes. When they play, chess masters draw on this rich depth of stored experience to guide their choice of moves.

Figure 1.1 – a typology of mental representations from diverse disciplines



(Slade, 1991; Kolodner, 1992; D'Andrade. 1995; Eubanks, 1999; Lakoff and Johnson, 1999; Lakoff, 2007; Atran and Medin, 2008)

These, in turn, can be thought of as component parts of the more globally familiar *mental model* (or, as Tversky (1993) suggests, sometimes closer to mental, or 'cognitive,' *collages*). How meaningful it is to talk about any one of these mental entities as a distinct unit, or object of memory, depends on the relative *strength* and *nature* of the connections amongst its components.[46] (D'Andrade, 1995; Tsallis et al, 2004; Fauconnier and Turner, 2007) Importantly, these entities are never completely independent from each other. Each shares categories, or 'labels' (often called 'indices' in case-based reasoning literature) with components of other entities.

We echo Fauconnier and Turner (2007), Grady (2007), Tsallis et al. (2003) and others, in arguing that it is the *nature* and *strength* of the relations shared amongst the entities that affect what cognitive linguistics calls the 'motivation' for mapping; namely, why we choose to invoke some analogies, and some of their components, rather than others in any given situation.

In other words, the components of all these mental entities are, to a degree, interrelated. What matters is not whether they are, or are not, interconnected, but, rather, the particular *quality*, *strength* and, in cognitive linguistics terms, *topology* (i.e. causal and structural relations) of their interconnectivity, at any given time. For that reason, here we suggest a new term—mainly for our own purposes—which captures the common characteristics shared by this wide range of mental representations: *Qualified-Interconnectivity Clusters*, or QUICS.

[46] It is worth repeating that these connections include the emotional and somatic markers that we associate with them. (Slingerland, 2008)

With this construct in mind, human reasoning begins to looks like a proclivity toward the *recursive recombination*[47]of QUICS. When we observe, or wish to reason, about something new, we draw upon QUICS that, by virtue of the quality of their interconnections, our mind deems relevant to the task at hand. By conducting mental experiments (e.g. blending, metaphorical mapping, etc.) with those QUICS, we are able to infer information about the less familiar domain—that task—that we are trying to understand. Of course, our individual ability to succeed at this analogical reasoning process depends on our repertoire of QUICS, as well as our innate ability to experiment with them in a *pragmatic* way.

According to cognitive anthropology and cultural psychology (e.g. Buchtel and Norenzayan, 1998; Atran et al., 2002), an individual's repertoire of what weare calling QUICS seems to largely be a function of cultural learning[48]. However, as argued by cognitive linguistics (e.g. Lakoff and Johnson, 1999), our shared physiology as humans, and hence our shared spatio-temporal experience with the world, endows us with a set of primary, basic-levelQUICS that serve as a common denominator of understanding across individuals and groups.

This is, clearly, a highly simplified view of how we reason about ourselves and the world the around us. Nonetheless, we argue it can offer a useful lens through which to select objects of analysis for study. This is particularly true for the interdisciplinary field of social-ecological systems research, in which a functional account of how and why people behave the way they do in specific, local cases, is a requirement.

CONCLUSION: FUTURE PROSEPCTS

While quantitatively-inclined social sciences struggle to reconcile new behavioural findings with outdated behavioural theory (e.g. Gintis 2000), the more qualitatively-inclined social sciences struggle to excise themselves from the mire of radical post-modern relativism[49]. We believe*HOMO EFFECTIVUS*is uniquely suited to simultaneously aid both these efforts. Embracing a framework that explicitly focuses on humans' propensity toward analogical reasoning, which leaves ample room for cultural diversity, yet rests on a firm foundation of an assumed common vocabulary of image schemas and primary metaphors, could provide great insight into how various groups and individuals work from within the basic human condition to reason about their local social and natural environments. With a shared theoretical framework, such studies could render data that would be broadly comparable across study sites. Some examples of how this could be applied include:

- investigating which characteristics of people's mental models of their local social-ecological system correlate with certain behaviours—e.g. if cooperative behaviour correlates with certain kinds of mental models or conceptual metaphors (e.g. Ross, 2002; Atran et al. 2002; Gibson and Zellmer-Bruhn, 2001)

[47] This notion of recursive construction has been proposed in a range of converging fields, from mental models research (e.g. Johnson-Laird, 1983), to cognitive psychology (e.g. Pinker, 1994), to computer science (e.g. Tsallis et al., 2003).
[48] I.e. via socialization, which may or may not include formal education
[49] E.g. see Atran and Medin's (2008) clarion call to fellow anthropologists (9, 10)

- investigating whether the *similarity* of mental models or their composite conceptual metaphors *across* stakeholders is correlated with trust, cooperation, or formal institutions for managing local ecology (Following Schluter and Koch 2009; Denzau and North 1994)

These are just a few specific examples of the many possible applications of *HOMO EFFECTIVUS* to a resource management or social-ecological systems research context.[50] The primary tool that *HOMO EFFECTIVUS* grants us is a coherent set of assumptions about how people think and behave. These *particular* assumptions—namely, that we reason by drawing upon, and recombining, the most salient and accessible relevant instances of past experience, and that we all share a common repertoire of primary experiential schemas—can account both for deep cultural variation, and for the underlying commensurability of human experience that is a requisite for making useful inferences from individual studies of social-ecological systems.

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[50] Others could include:

- testing whether, as implied by Hmelo-Silver et al. (2007), communications aimed at enriching particular aspects of participants' mental models are more effective at improving system understanding, or fostering constructive behaviours, than focusing communications on building participants' knowledge of other elements—e.g. whether 'teaching' people to be able to identify, say, a wider range of species, is more or less effective at promoting cooperative behaviour than is 'teaching' people to think about how the local ecosystem is a sub-set of a larger ecosystem, or a local instantiation of a global process;
- determining whether facilitating participants' proclivity to think about a system using one conceptual metaphor (e.g. ECOSYSTEMS ARE SERVICE PROVIDERS) has any effect on participants' openness or inclination to think about the same system using other conceptual metaphors (e.g. ECOSYSTEMS ARE LEGAL ENTITIES or ECOSYSTEMS ARE HOMES.);
- conducting discourse analyses to develop a typology of the various source domains people draw on to reason about ecology and related subjects; this can help clarify the underlying cognitive processes at work in environmental debates, both within the literature and in the public sphere, and could lead to improved understanding, or reduced conflict, if articulated from a *HOMO EFFECTIVUS* frame (e.g. Slingerland, 2004)

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