Three Roads to Commitment:
A Trimodal Theory of Decision Making

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ABSTRACT

Researchers in different paradigms have concentrated on different narrow slices of the decision making domain, such as *choice* in classical decision theory or *recognition* in naturalistic research. We distill a more comprehensive and fruitful conception based on graded commitments to action at different levels of specificity and scope. Three pathways to commitment – *Choice, Matching,* and *Reassessment* – differ in both their starting points (initial commitment status), the questions they pose, and the normative rationales they confer on conclusions (desirability of consequences, fit between situation and rule, and successful performance, respectively). Levels of uncertainty, understood as obstacles or affordances for commitment, apply within each mode, accounting for cognitive strategies that vary from quick and accurate to slow and exploratory in each mode. Implications for cognitive engineering include adaptation of decision aids and training to both fundamental differences and the need for seamless transitions among decision modes and uncertainty levels.

Keywords: Decision making, intention, commitment, naturalistic decision making, decision aiding, decision analysis, bounded rationality, cooperation, self-control, confirmation bias, escalation of commitment, critical thinking

INTRODUCTION

Rethinking Decision Making

A decision is conventionally defined as a choice between two or more options, or acts, based on reasoning about the desirability of their consequences (e.g., Jeffrey, 1965/1983). A large amount of research has been formulated and carried out within the framework of this definition, with little or no critical consideration of its implicit assumptions. What we will call a standard story has emerged from this work, addressing *normative* issues (how choices ought to be made) by means of decision theory (Savage, 1972; von Neumann & Morgenstern, 1944; Luce & Raiffa, 1989), *descriptive* issues (how in fact they are made) by behavioral decision making research focused on systematic errors (Kahneman, Slovic & Tversky, 1972: Gilovich, Griffin, & Kahneman, 2002), and *prescriptive* issues (how to help real decision makers make better decisions) by means of decision analysis (Raiffa, 1968; Keeney & Raiffa, 1976: Brown & Paschoud, 2005) and cognitive psychology (von Winterfeldt & Edwards, 1986; Bell, Raiffa, & Tversky,1988).

The story is interesting and important, but its plausibility hinges on the assumptions embedded in its starting point – i.e., *selecting* the *best* of *multiple options* by *deliberating* about *consequences*. We will question almost every piece of this definition. We will also question the more basic presupposition that decision making can be subdivided into *stages* corresponding to what happens before, during, and after a discrete event described as *choice*: viz., that *before* this event, options, criteria, and outcomes must be identified, and that only *after* the event has occurred can action be initiated. Our ultimate aim is constructive: to show how a more inclusive framework can dispense with these assumptions.

Choice, when it occurs, is not usually the most important part of the decision process. Simon (1960) observed that managerial decision makers spend a considerable amount of time (i) identifying

problems and opportunities and (ii) assessing the situation. They spend *most* of their time in what he referred to as (iii) the *design* of suitable actions or plans. They spend the *least* amount of time in (iv) comparison and selection of options, or choice. Other researchers (March, 2000; Schön, 1983) have studied processes of (v) adjustment, learning, and innovation that occur *after* plans are adopted, often in the midst of action. (i), (ii), (iii), and (v) are neglected, perhaps, because conventional decision theory does not apply to them, and because of an overly narrow view of what counts as normative (Lipshitz & Cohen, 2005; Cohen, 1993).

As Alexander (1979, p. 383) noted three decades ago, a myopic focus on choice leads to a normative paradox:

> If planners, administrators, and managers are being equipped today with tools and techniques for articulating goals and evaluating projects and programs, how should they develop those alternative solutions which they are to evaluate…? *Are there any normative techniques for systematically designing alternative solutions in a given situation?* If there are, how appropriate are they in the light of actual behavior and perceived constraints in real environments? How crucial these questions are is clear when we realize that *the best evaluation techniques can only be applied to those alternatives which are given*. [italics added]

Compelling as Alexander's point is, it does not state the paradox in full generality. He could have posed the same questions not just about option generation but also about identifying fundamental goals, framing a situation in terms of objects, attributes, and relations, and adhering to or abandoning decisions already made. Standard choice methods must make do with given goals, given ways of describing the situation, and given options, even though agents remain capable of thought as they evaluate and implement actions in a changing and uncertain world. Are there normative principles and methods that apply to *these* processes?

Empirical research in naturalistic environments casts doubt not only on the importance of choice, but on whether, in many cases, it actually occurs. Experienced decision makers often recognize appropriate actions quickly in familiar environments (Klein, 1998); when they do not, they often explore options sequentially rather than concurrently, stopping when they find a satisfactory solution rather than looking for the best (Lindblom, 1959; Mintzberg, 1975; Simon, 1987). Conversely, supposedly distinct processing stages (e.g., situation assessment, goal specification, option generation, option evaluation-and-selection, and action) occur in parallel, or in complex embedded cycles, rather than in a linear series (Schön, 1983; Braybrooke & Lindblom, 1963; Witte, 1972; Mintzberg, Raisinghani, & Théorêt, 1976). As Witte (1972, p. 180) observed, "human beings cannot gather information without in some way simultaneously developing alternatives. They cannot avoid evaluating these alternatives immediately, and in doing this they are forced to a [revisable] decision. This is a package of operations and the succession of these packages over time constitutes the total decision making process."

The standard story attributes this real-world disarray to human capacity limitations, irrationality, or ignorance, to be rectified by decision aids and training. Other researchers suspect that there is an order in naturalistic decision making which the conventional story overlooks or undervalues. Naturalistic Decision Making research (e.g., Klein, Orasanu, Calderwood, & Zsambok, 1993; Hoffman, 2007; Mosier & Fischer, 2010) has rejected the standard story, but has not provided a comprehensive theory to take its place. Yet the search for order across a full range of human decisions should be of paramount concern to cognitive engineers. As we will see, decision support or training may disrupt rather than improve decision making unless it is based on an apt understanding of decision making itself.

Overview

In the following section, we introduce a more comprehensive framework, Trimodal Decision Making, or TDM, which is based on a conceptualization of decision making as *commitment*. In the third section, we explore ways of arriving at commitment from a *normative* point of view, making a case for the indispensability and distinctiveness of three pathways, or modes, of conferring rationality on action. In the fourth section, we elaborate *descriptively* on the three modes, defining uncertainty as low affordance for commitment and showing how each mode varies from intuitive to highly deliberative as it faces and handles different levels of difficulty. In the fifth section, we turn briefly to *prescriptive* implications of the framework for the design of effective decision aids. Each mode applies different cognitive strategies to different aspects of the situation. Cognitive engineers must be sensitive to these distinctions while supporting their integration and reconciliation in particular situations.

As a theory and as a framework for research, TDM has a number of distinctive features: First, it is conceptually unified. A single powerful but general concept, *commitment*, is rich enough to distinguish different modes of decision making along both normative and descriptive dimensions and to generate prescriptive suggestions. Second, TDM organizes apparently disparate research paradigms and findings and shows how they relate to one another. Third, TDM expands the normative basis for decision making beyond conventional decision theory and choice. Fourth, TDM sheds light on patterns underlying apparently disparate cognitive strategies used to handle uncertainty. Fifth, TDM expands the function of cognitive engineering beyond the supporting role assigned to it in the standard story. One of the most important tasks of cognitive engineering is to identify the different sources of rationality associated with commitments in particular domains, to identify the most critical obstacles to those commitments, and develop ways of overcoming them.

PATHS TO COMMITMENT

Intentions

If decision making is not choice, then what is it? We concur with Yates, Veinott, & Patalano (2003), whose definition highlights "committing to a certain course of action." More specifically, we regard decisions as *graded commitments of mental, affective or material resources to courses of action*. Decision making includes any cognitive process that can create or modify such commitments. This definition highlights the invariant output (i.e., sustaining / changing commitment status) while avoiding restrictive assumptions about how it is produced.

When a decision concerns action in the future, the commitment is an *intention* (Brattman, 1987). Intention should be understood very broadly, to include long-term, high level *goals* and *policies*, *plans* to achieve the goals or apply the policies, and specific *tactics* or *actions* to implement the plans. (Thus, an intention may be a constituent of any of the various "images" discussed by Beach, 1990.) "Intended actions" may therefore vary in: (a) specificity and concreteness (e.g., a career goal to help others, to be a doctor, or to practice a particular medical specialty; the action of treating a patient, treating a patient for problem X, or treating a patient for problem X by method Y), and (b) comprehensiveness in temporal scope (e.g., seeing patients every day or seeing a patient today) and in conditions of execution (e.g., a plan for the next treatment or for a series of treatments contingent on results at each stage). These dimensions are independent in principle, but not in practice. The standard story privileges an impossible ideal, i.e., detailed planning far into the future for all conceivable contingencies. In the real world, the longer the temporal scope, the further into the future, and the greater the number of uncertain or unknown contingencies, the less likely an intended action is to be fully and concretely specified in one fell swoop, and the more likely are details and conditions to be filled in – or modified – in future cycles of planning or judgment, often in the midst of action (Mintzberg, 1994: Schön, 1983).

Commitments can be unmade as well as made, so they must be less than the physical or even psychological impossibility of doing anything else. At the same time, meaningful commitment to a future action must be more than a private event of "deciding." Intentions are attributed to ourselves and others based on evidence between these two extremes, involving cognitive, physical, and social behavior. Drawing on Bratman (1987), we define the intention or commitment to do A (which may be a goal or action at any level of generality and scope) as a set of dispositions: (a) to stop looking for or thinking seriously about alternatives to A (unless there is specific reason for reassessing it); (b) to attend to information that is relevant for A's implementation or success; (c) to specify and plan A; (d) to take preparatory steps for A (e.g., by allocating resources, creating opportunities for A, or enlisting others' cooperation); (e) to experience negative affect if A is blocked; and (f) to do A at suitable time(s) or place(s).

As illustrated by (a) through (e), intentions not only guide action but provide a *background frame* for subsequent decision cycles. Decision making never starts from scratch. Every decision is framed by a relevantly active subset of the agent's pre-existing intentions (Bratman, 1987; Beach, 1990, 1998). Existing commitments combine with changing circumstances to recruit decision making processes that pick up where earlier ones left off, generating both actions and new intentions. A "plan" is the dynamic product of multiple cycles distributed over time, which continue even as the plan is implemented, rather than the culmination of a straight path from goals to choice. External actions occur opportunistically as *needed* to collect information, prepare, plan, persuade, test the waters, take care of other matters, buy time, or implement, not as endpoints after choice.

Three Modes

This conceptualization of decision making prompts recognition of three prototypical *decision making modes* distinguished by the commitment states with which they begin. As shown in Figure 1, a decision cycle may begin with *multiple, singular*, or *null* commitments at desired levels of

specificity and completeness, and depending on the starting point, it may apply three different transformations: to *select from*, *reduce*, or *expand* the initial commitments, respectively. Ideally, each mode transitions from its distinctive prior commitment state to a *singular intention* at target levels of specificity and scope. (Success in each mode is shown by the shaded boxes and solid arrows in Figure 1.) A rather rich phenomenology of thinking, experiencing, and acting attaches itself to these simple features. In particular, each starting state is associated with a distinctive implicit question, or information objective, and each end state is defended, if challenged, by distinctive types of reasons (Barber, Heath, & O'dean, 2003; Lipshitz, 1993; Shafir, Simonson, & Tversky, 1993).

Insert Figure 1 about here

Concurrent choice (Figure 1C)**.** A decision making cycle may begin with an intention to choose from a set of *two or more* possibilities – corresponding to the implicit question, *Which of these courses of action is best?* The decision process seeks to reduce the disjunctive intention (e.g., *to do A or B or C*) to a singular intention to perform one of the given options (e.g., *to do A*). Options may be at any level of specificity and completeness with respect to times or conditions. They are selected but not altered in content during concurrent choice. Selections are typically justified by reasons that emphasize differences in future consequences: *Do A because it is overall the best available means to the given ends.*

Reassessment (Figure 1B). A decision making cycle may begin with a commitment to a *single* adopted course of action. In response to the implicit or explicit question, *Is my current course of action adequate?*, the decision maker monitors for both obstacles and opportunities. As a result, the course of action may be retained, modified, or rejected. When reassessment concludes with rejection, the set of commitments or constraints is relaxed; the results of rejection are *less* specific or *less* comprehensive in time or circumstances than the original plan. Outcomes are justified by reasons that

emphasize the recent past record of on-going activity: *Continue A because it survived challenges*, or *Do not continue [aspects of] A because it failed to survive challenges*.

Matching (Figure 1A). A decision making cycle may begin with no foreground commitment at desired levels of specificity and completeness, prompting the implicit question, *What should I do in this situation?* Application of the background frame (e.g., general, long-term, or conditional goals, models, and plans) to a current or anticipated situation generates new commitments and elaborates existing commitments. Constraints are added across successful episodes of matching, resulting in outputs that are progressively *more* specific or *more* comprehensive across times and conditions than the pre-existing representation. Conclusions are implicitly or explicitly justified by reasons that emphasize the conjunction of the present situation and the agent: *Do A because it is the appropriate action for someone such as me in situations such a kind.*

Interactions

Matching takes precedence over the other two modes in two ways. First, matching influences when concurrent choice and reassessment occur in lieu of continued matching. Concurrent choice depends on cultural attitudes or personal policies that license calculation of outcomes and deliberate weighing of tradeoffs. Reassessment depends on cultural attitudes or personal policies that license critical reflection, dissent, or changes of mind. Unlike matching, neither concurrent choice nor reassessment is *appropriate* in all situations. Second, matching is the only one of the three modes that is self-sufficient in principle: It begins with no (or less than full) foregrounded commitment and continues by default until appropriate levels of specificity and scope are achieved (Figure 1A). As a result, matching is the ultimate source of the singular or disjunctive courses of action to which reassessment and concurrent choice, respectively, apply.

With the proviso regarding appropriateness, transitions among modes are possible when outputs of one mode match preconditions of another. Thus, new decision making cycles may begin where

previous cycles left off, in the same or different modes. Singular intentions generated by successful matching (Figure 1A) or selected by successful concurrent choice (Figure 1C) may be vetted by reassessment (Figure 1B), and reassessment itself may make iterative adjustments to a singular course of action over time. Each decision making mode may also *fail* to produce a singular commitment under conditions of uncertainty. For example, matching (Figure 1A) can lead to concurrent choice by activating multiple appropriate alternatives and licensing their comparison. Matching may also fail to supply *any* option, prompting a reassessment cycle which foregrounds and then vetts commitments previously in the background (i.e., *assumptions*); relaxing restrictions on the set of possibilities increases the chance that subsequent cycles of matching will be successful. Conversely, reassessment (Figure 1B) may reject a vetted course of action in whole or in part, leading to a null (or less than full) commitment and resumption of matching. Relaxation of constraints during reassessment may also turn up new options that tempt a change of course, leading to concurrent choice. When no options clear evaluative thresholds, concurrent choice (Figure 1C) may prompt reassessment of background assumptions associated with aspiration levels; if too many options clear thresholds, concurrent choice may prompt matching to find additional goals.

All three modes generate intentions that serve in the *background* of future decision making, in any mode. Regardless of its origins, an intention becomes more *central* within a repertoire of commitments through continued successful use in the background of decision making, resulting in an expanding web of connections to new goals, plans, and tactics that it helps generate. As centrality increases, so do obstacles to reassessment, based on the psychological, social or physical constraints of planning and preparation. Commitment produces the stability necessary for effective planning and coordination and timely action. Yet reassessment is necessary to avoid traps, adapt to change, resolve disagreement, and exploit new information.

The traditional story of decision making conceals the fact that many, and probably most, decisions concentrate on the present situation (matching) or past actions (reassessment) rather than

future consequences (concurrent choice). It is a mistake to dismiss these decisions as poor approximations to concurrent choice. The standard story fails to explain where goals, situation frames, and options come from (matching), or why decision making stops, when it resumes, and how learning and innovation take place (reassessment). The three decision making prototypes promise to shed light on the complexity and tensions of real decision aiding.

RATIONALITIES OF COMMITMENT

Each decision making mode uses a different normative backing to confer rationality on action. To the extent that arguments for action can be summarized by simple labels, concurrent choice employs a logic of *consequences* (March, 1994); matching employs a logic of *appropriateness* (March & Olsen, 2006); and reassessment employs a logic of *criticism* (Popper, 1969/2002). In this section, we make a case for the normative *distinctiveness* and *persuasiveness* of each mode. Because they are non-redundant, they may offset one another's weaknesses, and it seems reasonable to consider each of them in the design of decision aids. Because they are sometimes in conflict, however, meaningful synthesis is a far more challenging task. As summarized in Figure 1 and discussed further in this section, the reasoning endorsed by each mode appears *irrational* from the perspective of each of the others!

Insert Figure 1 about here

Logic of Consequences

Concurrent choice is an *instrumentalist* conception of rationality; feasible actions are evaluated *exclusively* in terms of the desirability of their consequences (Hammond, 1988; Wakker, 1999). The question it poses (in expanded form, *Which of the given options best achieves what I want?*) implies no substantive constraints on a person's ultimate goals or values (Hooker & Streumer, 2004).

Because they are not means to further ends, they are relegated to the realm of "passions," where rational standards have no traction.

Instrumental rationality was first conceived in economics (e.g., Jevons, 1871; Walras, 1874) as what Simon called *objective* (1956) or *substantive* (Simon, 1976) rationality – i.e., as the claim that decision makers should, and generally do, achieve the best possible outcomes in the world as it actually is. Simon (1972) strongly criticized such claims in light of *bounded rationality:* limitations on time, information, and processing capacity place objective optimality out of reach in complex problems. Modern instrumentalist rationality, i.e., decision theory (Ramsay, 1926; De Finetti, 1937; Savage, 1954/1972; Jeffrey, 1992/1965; Luce & Raiffa, 1957), reflects a turn toward *subjectivism*, which rejects both an objective measure of value (e.g., money) and an objective definition of probability (e.g., relative frequency). Current models of instrumental rationality localize normative force not in actual outcomes, but in the *coherence* of choices, beliefs, and desires – or more precisely, in the "self evidence" of axioms that define coherence. Since decision theoretic agents maximize utility within the world *as they perceive and value it*, they manifest what Simon (1956) called *subjective rationalit*y. Decision theory imposes a single rational obligation on each agent: chose actions that maximize the subjective expectation of desirable consequences. Decision analysis provides a highly developed set of tools for this purpose.

This subjective turn has both advantages and disadvantages. An advantage is that it moots some of the standard criticisms based on bounded rationality (e.g., Klein, 2001), i.e., that objective optimization is out of reach in complex situations. Reliance on subjective inputs – along with flexibility in the scope and granularity of modeling – finesses the problem of incomplete information by allowing knowledge to be supplemented wherever necessary by judgment, and mitigates time and resource limits by relying on small models (e.g., Brown & Paschoud, 2005). The drawback is diminished normative persuasiveness. The axioms of decision theory seem less than self-evident to ordinary decision makers, who are said to violate them in numerous experimental studies (e.g.,

Kahneman, Slovic & Tversky, 1982; Gilovich, Griffin, & Kahneman, 2002), *as well as to decision theorists*, who have repeatedly relaxed them to fit deviant behavioral results that seem intuitively rationalizable (e.g., Ellsberg, 1988; McClennen, 1990; Wakker, 1999; Luce, 2003; Dubra, Maccheroni, & Ok, 2004). The supposed sanctity of the axioms takes second place to common sense intuitions about instrumental decision making, which are its true source of normativity (Lipshitz & Cohen, 2005).

The gap between formal coherence and reality invites another criticism: strategies that explicitly attempt to maximize expected utility might produce *worse real outcomes* than simple intuitive heuristics. The latter are compatible with the organisms' sensory, neural, and external limitations (*bounded rationality*), and are tuned to statistical regularities in the environments in which they are generally used (*ecological rationality*) (Gigerenzer & Goldstein, 1996; Goldstein, 2001; Gigerenzer, 2000; Payne, Bettman, & Johnson, 1993). For example, satisficing (accepting the first option that clears aspiration levels on all dimensions) performs virtually as well as optimal choice models when there is a stable set of satisfactory options that do not vary much in utility. It works poorly if aspiration levels start too low and a relatively small subset of options is much better than the rest, or if aspiration levels start too high and the population of candidates is decreasing over time. *Take the best* (i.e., choices based only on the most reliable cue) works well when the best cue outweighs any combination of values on other cues, or when cues are positively correlated. When cues are negatively correlated (i.e., trade off against one another) or the number of cues is large, a count of cues favoring each option (i.e., "unit weighting") performs very well (Dawes, 1979). Gigerenzer & Todd (1999) offers a more general argument in favor of "simple" strategies, based on the vulnerability of parameter fitting in complex models to noise in the data (Fiedler & Juslin, 2006; Dawes & Corrigan, 1979). What all these approaches share – whether objective or subjective or bounded and ecological – is the logic of consequences: an assumption that the rationality of an action

is exhausted by considering its consequences. The logic to be considered next presumes a very distinct rationality, based on duty or deontology (Alexander & Moore, 2008).

Logic of Appropriateness

March (1993, p. 58) decomposes the characteristic question of matching (*What should I do in this situation?*) into three queries: *What kind of situation is this? What kind of person am I (or what kind of organization is this)? What does a person such as I, or an organization such as this, do in a situation such as this?* The answers depend on pre-existing social norms (Bicchieri, 2005; Bicchieri, Jeffrey, & Skyrms, 2009), organizational routines (Levitt & March, 1988), standard operating procedures and best practices (Betsch & Haberstroh, 2004), solution patterns in disciplines like medicine or chess (Chase & Simon, 1973; Klein, 1993), scripts for familiar behavior (Shank & Abelson, 1977, 1995), past cases and precedents (Schank, 1990, 1999; Kolodner, 1993), argumentation schemes (Walton,1996), principles and strategies for conversation (Grice, 1989; Sperber & Wilson, 1995; Sacks, 1995), heuristics (Gigerenzer et al., 1999; Simon & Newell, 1958), competitive or cooperative strategies (Axelrod, 1984), culturally modulated emotional dispositions such as anger, guilt, honor, and love (LeDoux, 1996), personal policies (Bratman, 1999; Beach, 1990), cultural maxims and themes (Lakoff, 1987), religious doctrine, moral principles and political ideologies (Etzioni, 1988; Thompson, Ellis, & Waldavsky, 1990), or life trajectories and values (Beach, 1990). For convenience, we will use the term *rules* broadly (e.g., March, 1994) to refer to any general standing commitment or "intention" of this kind. *Rules* (in this very broad sense) are often associated with different social identities or roles that a single individual might take on, related to kin, work, profession, voluntary association, religion, nationality, region, or political ideology (Etzioni, 1988, 2000).

Matching contrasts sharply and profoundly with concurrent choice. Concurrent choice highlights the impact of future outcomes on individual self-interest, although that may include concern for the

welfare of others. Matching diverts attention from the future and highlights duty based on shared or personal rules, i.e., features of the present situation that make an action permissible, appropriate, or obligatory (Etzioni, 1988, 2000). Matching excludes certain goals, options, and even facts from consideration (e.g., the benefits of betraying one's kin or comrades), not because of capacity limitations or irrelevance, but because weighing them is impermissible (Etzioni, 1988; McClennen & Edward, 1998; McClennen, 2004; Elster, 2000). Violations of rules may evoke *appropriate* guilt in the agent and *legitimate* anger or disapproval in those who observe the transgression (Gibbard, 1990).

Matching is different from concurrent choice not because people value others' welfare, but because concurrent choice cannot account for *commitment*, such as promises and threats, either to others or to oneself. By undermining the force of promises in so-called social dilemmas, rational instrumentalist choice diminishes public goods (Elster, 1974). For example, when one party, A, has performed a service for another, B, based on B's promise of compensation, self-interested reasoning by B recommends that he *renege on the promise* to pay unless deterred by external props like legal enforcement or loss of future opportunities. In the absence of such props, A will anticipate this self-interested reasoning by B, will not trust B's "commitment" to pay, and will not provide the service in the first place. As a result, a mutually beneficial transaction does not occur, and both A and B will suffer. A similar problem undermines the deterrent effect of threats, which lack instrumentalist credibility because of the costs of carrying them out. Fortunately, in both experiments and in real life, cooperation and deterrence occur often enough to defy the logic of consequences. (Camerer, 2003; Guth, Schmittberger, & Schwartze, 1982). As Dosi et al. (1998) put it, quoting Kenneth Arrow, "a system of literally maximizing norm-free agents '…would be the end of organized society as we know it' (Arrow 1987, p. 233)."

Decision theory is so inherently "individualistic" that it prevents an individual from making commitments to herself! Common sense instrumentalism suggests that a person might rationally wish to stop smoking in order to avoid lung cancer, go on a diet in order to live longer, work harder to get

ahead, and save money for retirement. But there is no rational mandate in the concurrent choice paradigm for resisting temptation. After adopting a policy (e.g., to stop smoking or to diet), the agent must implement it in a series of separate actions spread over time (Herrnstein & Prelec, 1992). In each of these decisions, the immediate satisfaction may easily outweigh the tiny future harm attributable to a *single* breach of policy. A single cigarette, rich meal, or night on the town has no discernible impact on health, longevity, career success, or lifetime savings. The rational choice is to smoke, eat, and be merry – just this time (Herrnstein & Prelec, 1992; Prelec & Bodner, 2003). On the next occasion, of course, the conclusion is exactly the same, and so the desired outcomes are never achieved. Policy "decisions" based on the big picture – i.e., long-term outcomes – turn out not to have been decisions at all. They carry no *commitment*, since every "time slice" of an agent pursues its own interests. Decision theory cannot account for the fact that we sometimes plan *in order to commit* our future selves, i.e., to create normatively binding personal policies. A real decision maker can anticipate decisions by her future self that she *now* regards as undesirable, and would like, somehow, to bind her future self to do what she may *not* want to do when she actually acts.

Matching must be more fundamental than concurrent choice, so that decisions about policies can be made to stick. In the above example, the result may be better overall outcomes – if persons are defined as agents who are inter-related through commitment with others and with their future selves. Matching mitigates interpersonal conflict within groups who share the same rules. It regulates social interaction, resource allocation, and power within a society. Matching also underlies practices that enable people to make *joint commitments* to coordinated collective action. Verbal and non-verbal communicative exchanges can create rights and obligations associated with a "plural subject", i.e., "*We* agreed to do A" (Gilbert, 1996; Cohen, 2004). By redefining agency, values, and process, matching saves the logic of consequences from itself.

But matching sometimes overrides the logic of consequences, even when the latter is applied to policy and rules. There are actions that most people in our society regard as *wrong,* which have

consistently more desirable consequences than the *right* actions. For example, most surgeons would consider it a violation of professional and ethical commitments to kill an innocent, healthy patient in order to save five others who need his organs – even though the outcome (four additional lives) is preferred by *everyone* except the unlucky patient. Instrumentalist rationality favors killing one in order to save five, in the absence of legal jeopardy (cf., Baron, 1993). Matching defines a realm where *agency* sometimes excludes the comparison of consequences. From the matching perspective, comparing outcomes in concurrent choice is itself a cultural practice whose applicability is limited by a web of mutual obligations and rights, and which may fit some situations badly (Etzioni, 1988). It is worth noting that the ethos of economic maximization, although certainly consistent with human nature, does not pervade human history; it is, at least in part, a contingent historical and cultural development (Appleby, 2010; Smith, 2008). Nor does it totally dominate modern life. The marketplace itself depends on norms of trust among strangers.

Various proposals have been made to reconcile classical decision theory with cooperation, self-control, and ethical principles: e.g., by positing empathy and altruism as sources of utility (Binmore, 1994; Raz, 1990) or meta-preferences for being a particular type of person (Prelec & Bodner, 2003; Nozick, 1993). These solutions concede that people are rationally justified in following personal policies, social norms, or ethical principles rather than weighing consequences for each action. But the concession is after-the-fact; it provides no guidance for deciding when an apparently irrational choice is rational after all. Moreover, it is not clear that classical decision theory *can* assimilate matching without violating its (currently accepted) axiomatic constraints. Abiding by a policy and being a particular type of person are not easily treated as additional desirable *outcomes*. Decision theory does not apply to matching when it (a) changes the utilities of states of affairs (e.g., four lives, one death) depending on whether or not they are *caused* by an agent, and (b) assigns negative utility to the very method (deliberation about tradeoffs) that decision theory uses to make decisions (Nozick, 1993, p. 55).

Bounded rationality does not help. If matching were a heuristic approximation to rational choice justified by limits on time or cognitive capacity, it would be normatively *necessary* to suspend matching – along with interpersonal commitment, personal policy, and ethical principle – when calculation of outcomes is feasible. But rules decree that an agen*t* should *not* reassess some commitments, even when it costs little to do so.

Matching is not, of course, without pitfalls and problems. For example, it is based on many different rules which vary in function, form, and origin, with no guarantee of mutual consistency. Unlike decision theory, matching provides no overarching mechanism (or unique meta-rule) for resolving intrapersonal conflicts among different rules to which the same individual is committed. And of course, matching on grounds of clan, region, religion, and politics can lead to conflict between culturally diverse groups. Different rules or values often seem incommensurable even in a democracy (e.g., the appropriate tradeoff between liberty and equality), and there is little realistic expectation that such conflicts can be directly resolved by reasoning (Levi, 1986; Schön, 1994; Etzioni, 1988). But this particular problem is not unique to matching. Concurrent choice (e.g., in the form of game theory) provides no assured basis for agreeing on mutually beneficial actions, much less for resolving interpersonal disputes, even within culturally homogenous groups (Bacharach, 2006).

In sum, matching, *but not concurrent choice*, sustains cooperation when self-interest would be served by cheating (Etzioni, 1988; Elster, 2000), sustains self-control over impulsive self-gratification (Prelec & Bodner, 2003; Herrnstein & Prelec, 1992; Nozick, 1993), and excludes calculation about unethical or illegal options (Etzioni, 1988; Schauer, 2009). Matching relies on rules that do not consider consequences, evoke guilt and anger, may be inconsistent with one another, may be collectivistic, and often exclude ostensibly relevant information. These features exemplify mindless habit and superstition from the standpoint of decision theory (cf., Baron, 1993). Yet they are essential to what most of us regard as a rational life.

Logic of Criticism

Reassessment is the backup plan for commitments made on the basis of incomplete information – as all commitments are in real world environments. We decompose the question posed by reassessment (*Is my current course of action adequate?*) into two parts: *Is relevant new information available?* and *What does that information imply about the adequacy of my plan?* Relevant information may involve an empirical sample of performance, e.g., failure of actions thus far to produce the expected or desired outcomes (if the original decision was based on concurrent choice), or a newly revealed mismatch between the situation and the conditions of a rule (if the original decision was based on matching). Reassessment may also involve indirect evidence of emerging problems, e.g., via critical thinking about assumptions (Cohen, Adelman, Bresnick, Freeman, Salas, & Riedel, 2006), mental simulation of future events (Markman, Klein, & Suhr, 2009; Klein, 1993), warnings or dissent from other informed parties (Walton, 1998; van Eemeren & Grootendorst, 1992), or the adventitious discovery of a significantly more promising idea. Reassessment of a general rule can occur any time prior to its use in a new situation. Plan reassessment is possible even after implementation begins, as long as commitments to future parts of the plan are not yet irreversible. The rationale for continued commitment to a rule or plan is that it has been tested – i.e., exposed to the possibility of new, relevant information – and has so far survived; i.e., it *works.*

The normative basis of reassessment is as fundamental as instrumental rationality or matching. It has been argued (Dennett, 1978, 1996) that genuinely new knowledge can *only* emerge from some version of trial and error, or generate and test. Darwin introduced the principle of variation and selective retention to explain the emergence of apparent design in biology (Gould, 1977). Behavioral psychology employs the law of effect to explain the shaping of novel adaptive behavior by consequences (e.g., Sutton & Barto, 1998; Skinner, 1953; Dennett, 1978). Popper's (1994, 1969) evolutionary epistemology asserts that growth in scientific knowledge can only be explained by

processes of conjecture and subsequent refutation by empirical evidence and argument. Mental simulation and critical thinking provide a surrogate, internal environment where, as Popper is said to have said, "we let our hypotheses die in our stead." In sum, *differential empirical success* (which is the basis for reassessment) determines the survival and shape of organisms, behavior, and ideas, respectively.

Matching and reassessment are easily contrasted: While matching seals commitments, reassessment unlocks them. Matching, if taken by itself, assumes that personal and collective experiences embodied in rules are sufficient for the problem at hand. Reassessment assumes the possibility of error and stands ready to learn from it.

Differences between reassessment and concurrent choice are more subtle, but also provide more insight. From the perspective of concurrent choice, a decision problem presents people with (a) multiple options, which they should (b) compare on an equal basis (c) in terms of future consequences. Reassessment is different in all three respects. It privileges a *single* "option" – the current plan – which it assumes will be implemented by default. It does not even require awareness of alternative options; if the decision maker happens to be aware of alternatives, it does not require that they be modeled in detail, seriously considered, or compared with the current plan. Reassessment monitors or probes the recent past for problems with the current plan, makes changes only if necessary, and when change is necessary, makes the most accessible changes first. Concurrent choice starts from scratch and looks only to the future.

The standard story deems reassessment irrational because it violates path independence (Garud & Karnoe 2001): given the same desires, the same current options, and the same evidence regarding outcomes, rational decision makers should make the same choices – regardless of how they got to the choice point. Instead, reassessment manifests a bias toward options that resemble past commitments. Experiments have shown that committed decision makers who experience a single negative consequence or a single piece of disconfirming information (1) are reluctant to change (the *sunk cost*

fallacy: Arkes & Ayton, 1999), (2) ignore or distort the negative information (*confirmation bias*: Wason, 1968; Nisbett & Ross, 1980; Poletiek, 2001; Klayman, 1995; Evans, 2007), and (3) sometimes take actions that deepen commitment (*escalation of commitment*: Staw, 1976; Staw & Ross, 1989). These phenomena produce different actions as a function of different initial views; hence, they are symptoms of irrationality if there can only be one right answer to a decision problem. By contrast, according to TDM, reassessment searches for adequate solutions (e.g., situation interpretations, outcome predictions, and/or courses of action) in a landscape that is not fully known and too vast or ill-defined for exhaustive exploration. Because such a landscape must be constructed one region at a time, it can be searched rationally from different starting points, and rational explorers may end up with different solutions.

In relatively unfamiliar and complex situations, a truly random biological, behavioral, or cognitive mutation has little chance of working (Levinthal, 2008); existing knowledge *must* be used to selectively generate meaningful "trials" (Simon, 1969). Prospects are improved when search begins in the neighborhood of a familiar explanation, prediction, or course of action than when it strikes out blindly (Politeik, 2001). Each mode of decision making generates commitments that express different kinds of existing knowledge, i.e., of types of action that are appropriate (matching), that have worked (reassessment), or that are calculated to maximize desired outcomes (concurrent choice). In response to problems, reassessment exploits this existing knowledge by making small adjustments to peripheral assumptions; if repairs are too numerous or unconvincing, it expands the search space outward, bringing more central assumptions into consideration. The result is *double loop learning* (Argyris & Schön, 1974, 1996; Rudolph, 2003). Second-order surprise, about the difficulty of resolving first order conflicts, motivates the iterative surfacing of more fundamental premises from the background frame (Cohen et al., 1996). The supposed bias in favor of current commitments reflects a reasonable *initial* judgment about where solutions are likely to be found and provides an anchor that improves the prospects of generating new knowledge.

Reassessment monitors and probes *committed* performance in order to learn from error; unlike choice, it does not ask decision makers to hold off on commitment or maintain an "open mind" (Klein, Phillips, Rall, & Peluso, 2007). Unlike matching, however, deliberative levels of reassessment do require the ability to maintain a kind of "double vision" (Schön, 1983). Decision makers must acknowledge the *possibility* that their view, however strongly held and passionately pursued, might be wrong. Thus, commitments that are rightfully viewed as genuine knowledge are *simultaneously* viewed as conjectures (or trials) by reassessment, i.e., as informed guesses whose continuing success is, to at least some degree, an open empirical question. The logical gap between past regularities and their continuation is famously known as the *problem of induction* (Goodman, 1965). The gap is inescapable, but larger in unfamiliar or highly complex situations, where it is most reasonable to suspect that important factors have been overlooked (e.g., *black swan* events described by Taleb, 2007). The ability to maintain this kind of double vision is a necessary condition of adaptation and change. Cohen et al. (1998, 2001) describe critical thinking training successfully based on these ideas.

There are many ways search can go wrong – for example, due to rapid changes in the landscape, insufficient sampling of a stable landscape, or fixation in local optima on a hilly surface. Matching, is slow to change, hence, it is most vulnerable to instability. Concurrent choice tends to abandon commitments, hence, tends to rely on limited data. Reassessment can become trapped in local optima, but the risk is offset at least in part by benefits: Reassessment strategies that begin in the vicinity of current commitments reduce the costs of exploration, minimize disruption of on-going practice, and are more likely to find a genuine solution to real problems in large, unknown search spaces.

We have seen that different modes of decision making are associated with different criteria for normatively successful performance: effective means to desirable outcomes (concurrent choice), action appropriate to the agent and the situation (matching), and adaptation of courses of action to

new information (reassessment). An important next step is *descriptive*: to identify some of the factors that causally influence whether decision making in each mode is in fact successful.

OBSTACLES TO COMMITMENT

Uncertainty

Uncertainty is cited frequently – though often rather vaguely – as a cause of problems in real-world decision making. Decision theory offers a precise definition of uncertainty as *probability*, operationalized in terms of choices among gambles. Probability theory, however, does not capture all dimensions of uncertainty even in concurrent choice. For example, probabilities do not reflect the reliability of the *knowledge* underlying the generation of options, the identification of relevant factors and their relationships, or the assessment of probabilities themselves (Cohen, 1993; Cohen, Schum, Freeling, & Chinnis, 1984; Cohen, Laskey, Chinnis, Ulvila, 1986). Several general taxonomies of uncertainty have been developed for cognitive engineering, but they take the form of *ad hoc* lists that lack a theoretical basis. (Lipshitz & Strauss, 1997, and Watkins, 2000, review different approaches.) Uncertainty itself, i.e., what if anything the different types have in common, is seldom defined in a sufficiently comprehensive way.

TDM defines uncertainty simply and comprehensively in terms of its effects on decision making, as *a doubt that tends to block or postpone commitment* (Lipshitz & Straus, 1987). Uncertainty is an obstacle against answering the question posed by a decision mode. This definition provides an *ordering* of instances of uncertainty at least roughly by magnitude: Uncertainty is greater the more time or cognitive effort is required to overcome the obstacle and commit to an answer. At low levels of uncertainty decision makers commit quickly, with little or no experienced uncertainty or cognitive effort, at levels of specificity and completeness necessary for successful performance in the relevant mode; performance is accurate and appears intuitive. At higher levels of uncertainty, performance becomes either more deliberative or less accurate, or both. Norman (1988) and others define

affordances of mechanical devices as readily perceived action possibilities based on properties of the device *and* the user's experience, abilities, and interests. Similarly, *Levels of uncertainty* in TDM are affordances for commitment, which comprise combinations of uncertainty types and tactics for handling them – as determined both by the situation and by the decision maker's knowledge, skills, attention, and motivation. Levels of uncertainty are shown as numbered items in the center of the large triangle in Figure 2.

Insert Figure 2 about here

To identify obstacles to commitment, we draw from the authors' research on decision making by real world practitioners. Lipshitz (1997; Lipshitz, & Strauss, 1997) developed a model of uncertainty types and uncertainty handling tactics in naturalistic decision making, based on analysis of over 100 retrospective reports of real world decisions by military officers (Lipshitz & Strauss, 1997). The model, called *RAWFS* (an acronym for uncertainty handling tactics), was subsequently tested in more detail in the domain of incident management by fire fighting unit commanders (Lipshitz, Omodei, & Wearing, in press). Similarly, Cohen and his colleagues identified different types of uncertainty and mitigating responses in the Recognition / Metacognition (R / M) model, based on critical incident interviews and experiments with Navy and Army officers (Cohen et al., 1996, 1998, 2001) and commercial airline pilots (Cohen, Adelman, & Thompson, 2000; Freeman, Cohen, & Thompson, 1998). Figure 2 integrates findings from RAWFS and R/M within the Trimodal Decision Making framework.

To classify uncertainty types within TDM, we imagine that each primary question (*What should I do in this situation? Is my course of action adequate? Which of these options is the best means to desirable outcomes?*) interacts with the active frame to generate a set of secondary questions, which point to relevant information. Ideally, the secondary questions constitute a *Strong method*, i.e., they

(i) have known possible answers that bear in a clear way on the primary issue (i.e., commitment in the relevant mode), and (ii) there are established routines or practices for getting reliable answers. Strong methods include both immediately accessible perceptual observation, and more extended processes of collecting, retrieving, asking, calculating, looking up, and inferring. Because they reliably respond to the primary question, answers produced by strong methods warrant and receive strong commitment. Six uncertainty types, represented by ovals on the left in Figure 2, are distinguished by the following criteria applied to these secondary questions:

- Is the frame adequate to generate secondary questions that satisfy condition (i) for a Strong method, i.e., do they have known possible answers that bear in a clear way on the primary issue? *No* implies *lack of understanding*, which places the decision maker at **Level 6** of uncertainty, as shown in Figure 2.
- If yes to the preceding, have all the questions been answered? *No* implies *lack of information*.
- If yes to the preceding, are all the answers consistent? *No* implies *conflict*.
- If yes to the preceding, were the answers produced in a manner that satisfies condition (ii) for a Strong method, i.e., by an established routine or practice for getting reliable answers? *No* for a small number of answers implies *Unreliable assumptions*. *No* for a large number of answers implies *Overall implausibility*.
- Yes to the preceding implies *No uncertainty* – i.e., relevant questions have already been answered consistently by established, reliable, relevant methods. This corresponds to **Level 1** of uncertainty, as shown in Figure 2.

Levels of Uncertainty beyond Level 1 are combinations of uncertainty types and *available* methods to handle them, from the perspective of the decision maker. Rounded rectangles on the right of Figure 2 represent three classes of methods that practitioners use to handle uncertainty:

- *Strong* methods, already defined above, involve purposeful, directed information acquisition that produces reliable, relevant answers. If a strong method supplies answers at the same time as the questions (e.g., via direct observation of the current situation), uncertainty is at **Level 1**. Uncertainty is at **Level 2** when a strong method is available but does not yield immediate answers in response to lack of information, conflict, or unreliable assumptions.
- *Assumption-based* methods satisfy condition (i) but not condition (ii) for Strong methods. Meaningful secondary questions can be posed, but established routines or practices for answering them either are not known or are not feasible in the current context. Instead, decision makers must adopt assumptions, i.e., answers not backed by reliable methods. Assumptions may be relatively *central*, i.e., densely connected to other currently relevant commitments, or they may be relatively *peripheral*. Central assumptions resist change more strongly than peripheral ones. Uncertainty is at **Level 3** when adjustments to peripheral assumptions are available in response to Lack of information or Unreliable assumptions. Uncertainty is at **Level 4** when adjustments to peripheral assumptions are available in response to Conflict. Explaining conflict is generally more effortful than filling gaps (Level 3) because it introduces source reliability as a factor and prompts increased future vigilance regarding the sources involved in a conflict. Uncertainty is at **Level 5** when the decision maker sees no way of adjusting peripheral assumptions that plausibly explains conflict; to achieve coherence, the decision maker must change central assumptions.
- *Weak* methods fail both conditions of a Strong method. They involve less directed information seeking, which occurs when it is initially unclear what questions are relevant, what the possible answers might be, or what the implications of the answers would be for

the primary issue. Weak methods can be *top-down* or *bottom-up*. They are top-down if there are general principles (such as decision analysis, political ideology, religious doctrine, a legal code, or a scientific theory) that can be applied in order to deliberatively analyze a novel, complex problem. They are bottom-up if they require relatively open-ended exploration of the current case or domain, or relatively unconstrained extrapolation of ideas from other domains or cases. Both kinds of weak methods seek to leverage existing knowledge in novel and complex situations and ultimately to discover or invent sufficient structure to support Strong methods or well-defined assumptions. Weak methods are necessary in response to lack of understanding, but may also be required in response to overall implausibility, when it is not clear how to go about changing central assumptions. In either case, when weak methods are relied upon, the decision maker is at **Level 6** of uncertainty.

The processes outlined in Figure 2 are highly iterative. In response to one type of uncertainty, e.g., lack of information, a Strong method such as collecting relevant information may lead to other types of uncertainty, such as inconsistent answers. These may prompt other tactics, such as adopting assumptions to explain the conflict, which lead to other problems if they are over-utilized, e.g., overall implausibility of assumptions (taken all together). Overall implausibility in turn may prompt a change in fundamental assumptions, which makes better sense of conflicting information without the need for as many ad hoc adjustments, but at the same time raises new questions corresponding to gaps in information. (For examples of these kinds of moves, see Cohen et al., 1996, 1998). Regardless of the level of uncertainty at which one begins, the aim is not to cycle endlessly but to climb "up" the triangle in Figure 2 to the state of *No uncertainty* within constraints of time and other costs, hence, with as few spirals or switchbacks as possible.

Figure 2 identifies three control tactics that apply to all kinds of uncertainty in all modes. They become increasingly important at lower levels of affordance, which demand more time and effort to

achieve a given level of accuracy. One tactic prolongs deliberation and another cuts it short. The first is to *Forestall* commitment or buy time by mitigating the consequences and reducing the costs of continued delay. The second, *Suppression*, is to act or commit regardless of remaining uncertainty, because the costs of delay outweigh potential benefits and cannot be sufficiently mitigated (Cohen, 2010, discusses this in more detail). A third control tactic, which emerges from the present framework, is to change modes.

Our definition of uncertainty applies across all three modes of decision making. It thus highlights similarities across modes in both the difficulties they encounter and the tactics they use to manage them, despite differences in the normative definition of success. Nevertheless, different decision making modes pose questions about different aspects of a decision, hence, each is most affected by a different *object* of uncertainty: i.e., the relative value of action outcomes (Concurrent choice), problems with the current course of action (Reassessment), and satisfaction of rule conditions (Matching). Thus, a situation that offers high affordance for matching (e.g., by means of well-known rules for traditional behavior) may be difficult to parse in terms of outcomes and their values (concurrent choice). In another situation, it may be easy to identify the most advantageous option (concurrent choice) but difficult to decide if it is ethical (matching). Finding a successful action by experimentation (i.e., reassessment) may be easier than concurrent choice or matching if the situation is novel and actions are reversible, but concurrent choice or matching are easier when actions are costly and the domain is well understood. These affordances almost certainly influence which mode is used first. For the same reasons, decision makers may find themselves changing modes if uncertainty becomes excessive; for example, a decision maker may decide to follow the usual practice rather than trust an assumption-laden analysis of outcomes. Whether this happens depends not only on uncertainty but on dispositions to favor different modes, which may vary with individual experience, personality, social context, task, domain, and cultural background.

A more specific hypothesis about the relative difficulty of the three modes is suggested by the embedded triangles at the top center of Figure 2. These associate decision making modes with different functionally defined cognitive representations. Concurrent choice is associated with a *decision model*, defined simply as any representational process with sufficient structure to distinguish multiple alternatives, their respective outcomes, and evaluations. Reassessment is associated with a *mental model*, defined as the representation of a *single* possible state or event sequence (Johnson-Laird, 1983) – including, for example, observations and inferences about the situation, an action plan, and the unfolding of its future consequences. As we have already seen, matching involves the emergence or elaboration of a mental model for action by application of a *frame*, defined as a set of accessible tacit or explicit rules for interpreting, predicting, and acting in situations of particular types. Frames, mental models, and decision models are dynamic processes rather than static states or objects. They are continuously constructed, applied, and transformed by cognitive strategies like those in Figure 2. Mental models presuppose a frame that supplies the relevant elements and relationships. A decision model presupposes at least rudimentary mental models of options. The three representational processes thus correspond to increasingly differentiated activity in an underlying long-term memory system that is itself undergoing continuous change. It seems plausible that concurrent choice *tends* to be intrinsically more effortful than reassessment, and reassessment *tends* to be intrinsically more effortful than matching – despite gradations of difficulty corresponding to levels of uncertainty within each mode.

A Taxonomy of Decision Processes

When researchers recognize different modes of decision making, they tend to associate them with specific cognitive strategies. For example, in naturalistic decision making, Matching tends to be addressed primarily as intuitive recognition without uncertainty. Reassessment is associated with monitoring of action outcomes to detect conflict with goals or expectations and verify assumptions.

Concurrent choice is sometimes equated with decision analysis, a top-down weak method involving deliberate calculation. TDM suggests that such associations are misleading. Despite any intrinsic differences in difficulty, the modes themselves are broader than individual cognitive strategies. In particular, there is variation *within* each mode along dimensions corresponding to the familiar contrast between rapid, automatic "intuitive" processing and slower, controlled, analytical processing (Hammond, Hamm, Grassia, & Pearson, 1997; Sloman, 2002; Chaiken & Trope, 1999). In all three modes, *metacognition* (i.e., cognition that monitors and regulates features of other cognition) helps compensate for lack of affordance in the environment, by identifying sources of uncertainty and activating corrective methods at different points on the intuitive-deliberative spectrum (Cohen et al., 1996; Dunlovksy & Metcalf, 2009; Overschelde, 2008). Table 2 is a "periodic table" of decision research areas, based on the six levels of uncertainty crossed with the three modes of decision making. Each mode of decision making is represented by examples at *every* level of affordance and effort.

Insert Table 2 about here

The most effortful levels in *each* mode involve Weak methods for leveraging existing knowledge and discovering new possibilities. In other words, decision analysis is not alone. Strategies are also available in matching and reassessment to supply frames for unfamiliar situations and define consistency of commitments across cases. There are important differences, however. Decision analysis, which formalizes concurrent choice, purports to provide a universal grammar and standard of coherence for instrumental decisions. Matching, by contrast, must be systematized one domain at a time, whether scientific, religious, legal, or political. Reassessment is codified not by assertions but in *practices* that institutionalize critical thinking about current practices and foster innovations to improve them.

SUPPORT FOR COMMITMENT

Principles of Interface Design

The TDM framework provides a basis for decision support that is more comprehensive than current variants of decision theory, naturalistic decision making, or critical thinking. We have space here to sketch a handful of high level design guidelines suggested by the framework. We discuss them under five headings: compatibility, focus, uncertainty, transitions, and control.

Compatibility. Our most basic proposition is that decision aids support modes of decision making that *match* the decision maker and situation. This follows from the principle that matching is fundamental among the three modes. For example a decision model for comparing multiple alternatives should almost never be the default or initial representation. Rather, it should be available as a tool if the situation turns out to be framed, through matching, in terms of multiple competing alternatives whose values depend on their outcomes. Reassessment displays should support modification of aspects of the current course of action that are permitted to change under ethical, organizational, or other constraints.

To support judgments of compatibility, the system should provide templates based on past cases, practices, precedents, norms, or doctrine. Such resources can be used to help users determine when evaluation of consequences is appropriate, and when it is not. Similarly, they can be used to help users determine which elements of the current plan it is appropriate to reassess and which not.

Focus. Displays should support the appropriate focus of attention for the current mode: i.e., (a) situation awareness and option generation for matching, (b) course of action monitoring and modification for reassessment, and (c) comparison of outcomes and selection of actions for concurrent choice.

Within each focus, the aid should compare the current state of commitment, or intention, with the targeted state, e.g., by highlighting missing details or incompleteness of scope in matching, the

number of options to be eliminated in concurrent choice, or problematic aspects of the current course of action in reassessment.

The aid should facilitate achieving the desired commitment state by supporting different types of comparisons in each mode. For matching, the aid should compare the actual situation with the conditions of relevant rules. For concurrent choice, the aid should compare projected action outcomes with desired features, or alternatively, compare outcomes of one course of action with outcomes of another. For reassessment, the aid should compare actual events and actions with those expected according to the current plan.

Uncertainty. Aids should support the levels of uncertainty likely to be encountered by decision makers in particular domains. Almost always, this means that both intuitive and deliberative tactics should be available for a supported mode. Aids should highlight types of uncertainty likely to be significant in determining rule fit (matching), option superiority (concurrent choice), or course of action adequacy (reassessment), i.e., information needed; information with conflicting implications; unreliable assumptions, and overall implausibility.

Transitions. Given that any one mode may create initial conditions for any other, displays for different modes should support seamless transitions when appropriate. For example, displays for generating options and goals, for comparing options in terms of goals, and for monitoring goal achievement in the course of option implementation should relate transparently to one another.

Displays should also seamlessly track uncertainty levels as they change in response to uncertainty handling tactics. For example, different levels of abstraction in situation interpretation (matching), in value hierarchies (concurrent choice), or in planning (reassessment) should be displayed in relation to one another (e.g., Bennett & Walters, 2001; Bennett, Posey, & Shattuck, 2008: Rasmussen, Pejtersen, & Goodstein, 1994), affording users the opportunity to identify, vett, and modify either narrow peripheral assumptions (at the bottom) or more general central ones. (at the top)

Control. Each mode is subject to obstacles which require different amounts of effort and time to overcome. As a result, each mode faces tradeoffs between the benefits of reducing uncertainty (hence, improving the accuracy or completeness of commitments) versus committing sooner and avoiding costs of delay. Aids should help users adapt their decision processes to the available time. This includes the ability to stop and act on the current best solution when benefits of further processing are outweighed by risks (the *Suppress* tactic in Figure 2). Conversely, aids can sometimes also help users adapt the available time to decision making processes. This includes identifying ways to buy time before irreversible commitment is necessary (the *Forestall* tactic in Figure 2). Aids should also help users identify opportunities afforded by changing decision modes, if permissible (the *Change Modes* tactic in Figure 2).

CONCLUSION

We argued for a conceptualization of decision making not as choice, but more simply and generally as *change in commitment*. This led to a Trimodal Decision Making theory, based on recognition that three modes of decision making both complement and conflict with one another:

- *Matching* generates an action that fits the agent in the current situation. Reasons refer to features of the current setting that link it to an appropriate action via a *rule* based on social customs, organizational routines, expert strategies, personal traits, or moral principles.
- *Reassessment* monitors, evaluates, and adjusts existing practice to deal with unexpected problems, resolve disagreement, or take advantage of opportunities. Reasons for action refer to its having *survived* testing thus far.
- *Concurrent choice* chooses among given alternatives by weighing the degree to which they achieve given, desirable goals. Reasons for choice are based on an explicit *comparison* of action outcomes.

Different modes are associated with different criteria for successful performance: i.e., appropriate action (matching), timely adaptation to new information or events (reassessment), and desirable outcomes (concurrent choice). Each mode applies to commitments created by the others and creates commitments to which the others can be applied. Yet they represent competing visions of rationality, which in the most difficult cases directly conflict.

From a descriptive point of view, the TDM framework defines *uncertainty* as *a doubt that tends to block or postpone commitment*. Based on the authors' empirical research, we have identified types of uncertainty and tactics for handling them. Combinations of uncertainty types and tactics constitute six levels of affordance for commitment that apply to all three modes of decision making. Therefore, they highlight similarities across modes in both the difficulties they encounter and the strategies they use to manage them, despite differences in the focus of attention and the normative definition of success. Relationships among existing decision making research paradigms are clarified by locating them in a matrix of levels by modes.

The TDM framework suggests a rich agenda for cognitive engineering practice and research. We sketched a number of top level design principles under the headings of compatibility, focus, uncertainty, transitions, and control. Some current decision aiding work (Cohen et al., 2008) attempts to apply these principles, and has achieved significant acceptance from end users in the field. The first item on the research agenda should be an empirical investigation of the compatibility rule, that effective aiding depends on the compatibility of the decision aid with a decision making mode that is *appropriate* for the decision maker and situation, as determined by matching. This testing can proceed in parallel with the development and refinement of decision aiding technologies that implement, integrate, and reconcile the three decision making modes.

The standard story, which identifies decision making with concurrent choice, derives from an Enlightenment ideal congealed into a cultural myth. It encourages people to make retrospective sense of their actions to themselves and others as deliberate and optimal (March, 1979) – and to allege

errors when even when the actual process is nothing of the kind. The standard story has proven to be a trap for designers, who are frequently surprised by the low level of user acceptance even for well-engineered decision support, when it focuses exclusively on deliberative comparison of options. Trimodal Decision Making provides the normative basis for three paths to commitment, describes six levels of affordance for those paths, and prescribes five principles of decision aiding. It fleshes out and corrects the standard story and other overly narrow approaches to decision making, and generates important implications and challenges for decision aiding, training, and research.

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Table Captions

Table 1. Normative perspective of each decision making mode (left column) on itself and on each of the other decision making modes (top row).

Table 2. Examples of cognitive strategies and associated research paradigms corresponding to each combination of uncertainty level and decision making mode.

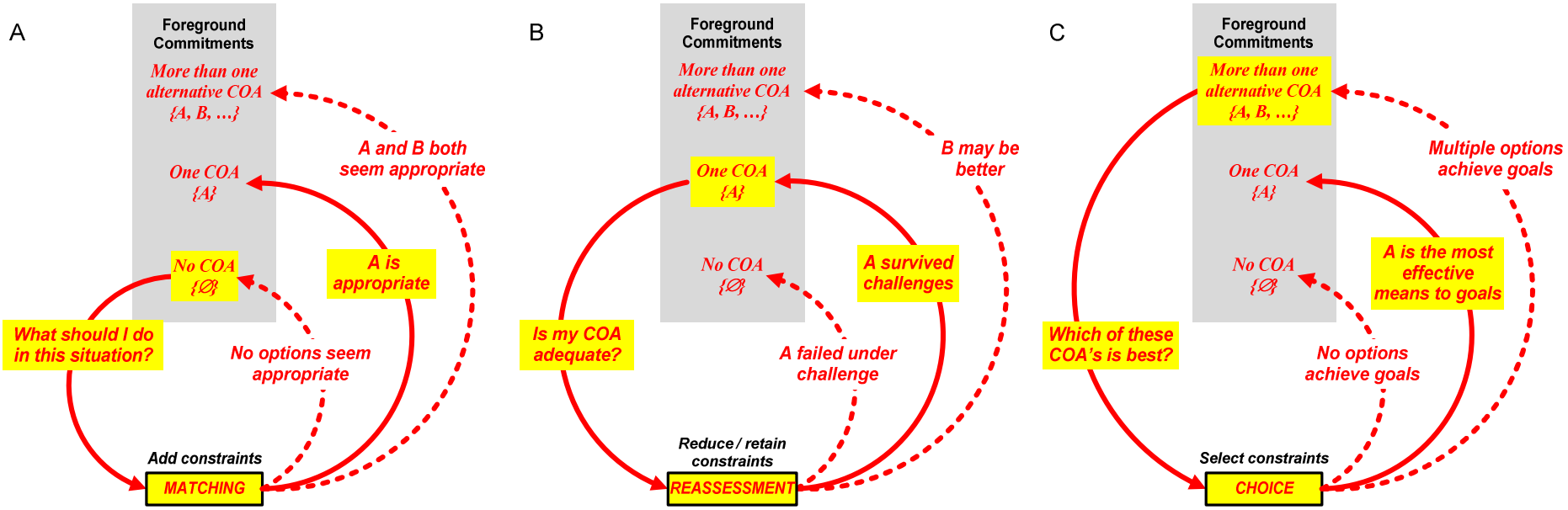
	…on Concurrent Choice	…on Matching	…on Reassessment
Perspective of Concurrent Choice…	*Rational calculation only applies to the efficiency of means for achieving given ends*	**Matching is superstitious rule following:** 1. Blocks consideration of relevant information and options. 2. Blocks rational calculation.	**Reassessment is biased in favor of current option:** 1. Highly selective in information use. 3. Does not consider other options seriously.
Perspective of Matching…	**Concurrent choice undermines civilized life:** 1. Favors cheating over cooperation and self-control. 2. Is inappropriate in ethical contexts. 3. Overestimates individual calculation relative to inherited wisdom.	*Some actions and values are obligatory, appropriate, or permissible for a particular person in a particular situation.*	**Reassessment disrupts organized activity:** 1. Favors riskier changes over exploitation of existing knowledge. 2. Disrupts coordination and causes interpersonal conflict.
Perspective of Reassessment…	**Choice suppresses uncertainty:** 1. Assumes options and goals are given, and that parameters can be reliably quantified. 2. Bounded rationality depends on assumptions about statistical properties of the environment.	**Matching does not adapt to change.** 1. Imposes a static solution that excludes possible changes in the social and physical environment. 2. Presupposes large amounts of experience, which may not be available.	*Genuinely new knowledge can only be produced by some form of generate and test, or trial and error.*

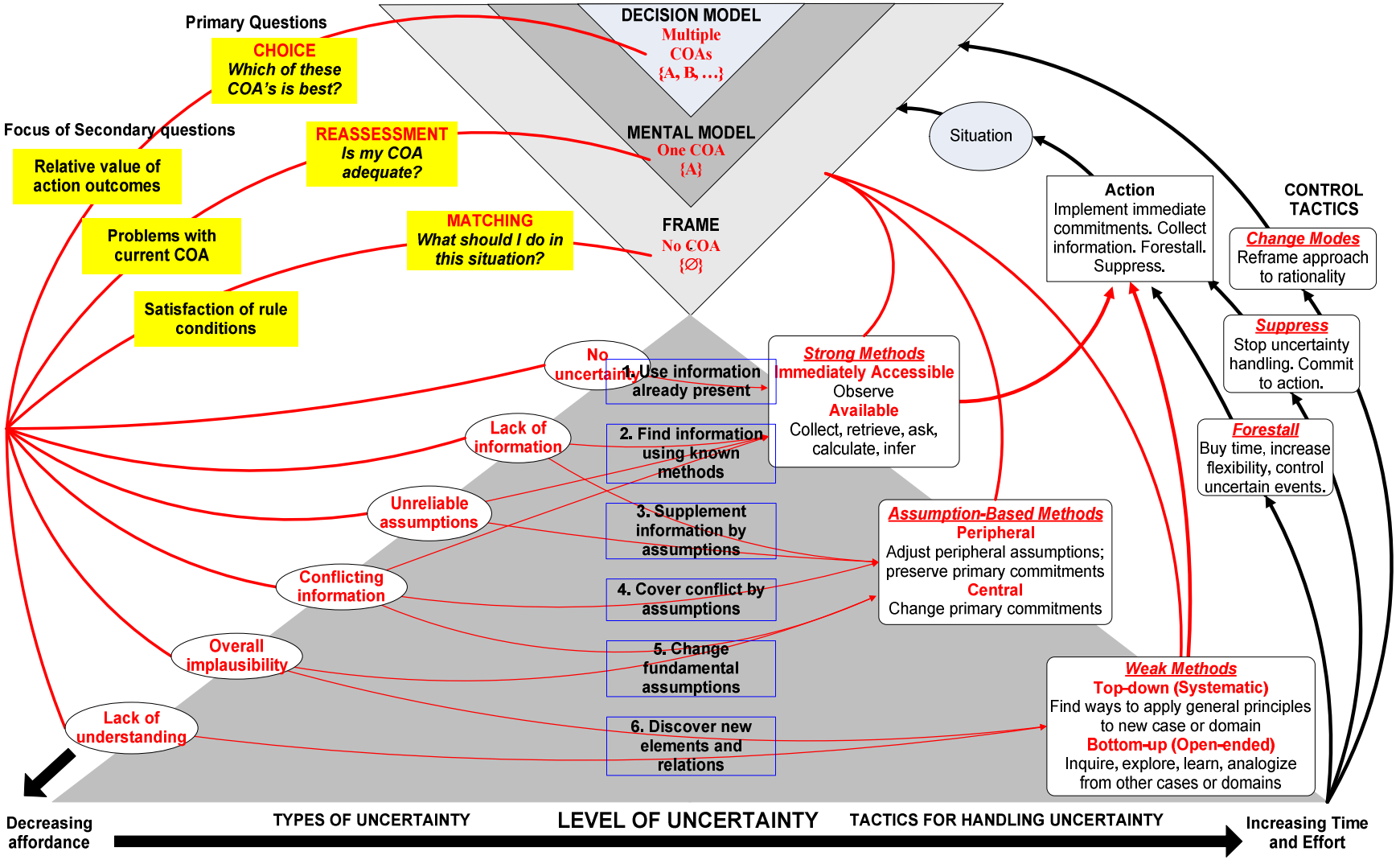
UNCERTAINTY LEVEL	DECISION MODE		
	Matching	**Reassessment**	**Choice**
1. Use immediately available information	**Recognize that a rule fits the situation.** Expert pattern recognition (Chase and Simon, 1972), Rapid Recognition Primed Decision Making (Klein, 1998), scripts (Schank & Abelson, 1977, 1995).	**Natural feedback shapes on-going action.** Implicit learning (Berry & Dienes, 1993), reinforcement learning (Herrnstein & Prelec, 1992).	**Allocate time proportional to reinforcement rates.** Choice behavior (Herrnstein, 1997).
2. Find information to handle gaps, assumptions, and conflict	**Actively scan for information to determine fit of rules.** Situation awareness (Endsley, 1995, 2000), Data Frame theory (Klein et al., 2007). Judgment policy, lens model (Hammond, Shanteau).	**Actively monitor for problems with current course of action** Reflection in action (Schön, 1983), Recognition / Metacognition (Cohen, et al. 1996).	**Predict outcomes and compare to cutoff criteria.** Elimination-by-aspects (Tversky, 1972), satisficing (Simon, 1955, 1987).
3. Supplement information by assumptions	**Fill gaps in situation awareness by assumptions based on normal / default values.** Schemas (e.g., Mandler, 1984), scripts (Schank & Abelson, 1977, 1995).	**Use models to interpret outcomes and choose remedial actions** Action theories (Argyris & Schon, 1996), stories (Cohen, et al. 1996) .	**Employ heuristics that depend on assumptions about options and criteria** One-reason decision making (Gigerenzer & Goldstein, 1996, 1999), satisficing (Simon, 1955, 1987).
4. Cover conflict with assumptions	**Explain or ignore conflicts between rule conditions and situation.** Explanation based reasoning (Pennington & Hastie, 1992); legal, moral, and political reasoning (Gunther, 1993; March, Schultz, & Zhou, 2000); normal science (Kuhn, 1996).	**Modify peripheral assumptions to explain anomalies.** Recognition / Metacognition (Cohen, et al. 1996, 1998), sunk costs (Arkes & Ayton, 1999), escalation of commitment(Staw, 1976), confirmation bias (Poletiek, 2001)	**Revise aspiration levels or reorganize evaluation criteria.** Dynamic satisficing (Simon, 1955, 1987), dominance structuring (Montgomery, 1993).
5. Change fundamental assumptions	**Shift assumptions regarding nature of situation, self, or rules.** Gradual or rapid change in group identities. ethical, legal, or political values; paradigm shift in science (Kuhn, 1996).	**When ad hoc explanations cause strain, consider changes in central assumptions.** Recognition / Metacognition (Cohen et al., 1998, 2001, 2006); theory change (Popper, 1995; Quine & Ullian, 1970).	**Generate new options or new evaluation criteria.** Value-focused thinking (Keeney, 1992).
6. Discover new elements and relations	**Explore application of experience-based knowledge or abstract principles.** Case-based reasoning, analogical reasoning, creativity (Weinreb, 2005, Holyoke & Thagard, 1995; Gentner, Holyoak, & Kokinov, 2001);domain theories.	**Institutionalize practices of reassessment and innovation.** Incremental planning (Braybrooke & Lindblom, 1963), mixed scanning (Etzioni, 1988), skunk works (March, 1994), scenario-based planning (Shoemaker, 2007).	**Impose structure on unfamiliar problems by decomposing them into simpler choices.** Decision analysis (von Winterfeldt & Edwards, 1986; Keeney & Raiffa, 1976; Raiffa, 1968).

Figure Captions

Figure 1. (A) Matching, (B) Reassessment, and (C) Choice are shown as transitions from their respective initial states of commitment. Solid arrows indicate culmination in a single commitment.

Figure 2. The three decision making modes differ in the structure of knowledge representations and the focus of uncertainty (upper part of figure). They address similar types of uncertainty by similar tactics, and are subject to similar control methods (lower part of figure).


A
Foreground Commitments
More than one alternative COA {A, B, …}
One COA {A}
No COA {∅}
A and B both seem appropriate
A is appropriate
No options seem appropriate
What should I do in this situation?
Add constraints
MATCHING
B
Foreground Commitments
More than one alternative COA {A, B, …}
One COA {A}
No COA {∅}
B may be better
A survived challenges
A failed under challenge
Is my COA adequate?
Reduce / retain constraints
REASSESSMENT
C
Foreground Commitments
More than one alternative COA {A, B, …}
One COA {A}
No COA {∅}
Multiple options achieve goals
A is the most effective means to goals
No options achieve goals
Which of these COA's is best?
Select constraints
CHOICE


Primary Questions
CHOICE
Which of these COA's is best?
Focus of Secondary questions
Relative value of action outcomes
REASSESSMENT
Is my COA adequate?
Problems with current COA
MATCHING
What should I do in this situation?
Satisfaction of rule conditions
DECISION MODEL
Multiple COAs
{A, B, …}
MENTAL MODEL
One COA
{A}
FRAME
No COA
{∅}
Situation
Action
Implement immediate commitments. Collect information. Forestall. Suppress.
CONTROL TACTICS
Change Modes
Reframe approach to rationality
Suppress
Stop uncertainty handling. Commit to action.
Forestall
Buy time, increase flexibility, control uncertain events.
No uncertainty
Lack of information
Unreliable assumptions
Conflicting information
Overall implausibility
Lack of understanding
1. Use information already present
2. Find information using known methods
3. Supplement information by assumptions
4. Cover conflict by assumptions
5. Change fundamental assumptions
6. Discover new elements and relations
Strong Methods
Immediately Accessible
Observe
Available
Collect, retrieve, ask, calculate, infer
Assumption-Based Methods
Peripheral
Adjust peripheral assumptions; preserve primary commitments
Central
Change primary commitments
Weak Methods
Top-down (Systematic)
Find ways to apply general principles to new case or domain
Bottom-up (Open-ended)
Inquire, explore, learn, analogize from other cases or domains
Decreasing affordance
TYPES OF UNCERTAINTY
LEVEL OF UNCERTAINTY
TACTICS FOR HANDLING UNCERTAINTY
Increasing Time and Effort