

# Mind and motion: surveying successes and stumbles in looking ahead

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**Abstract:** This concluding chapter is written as an exercise in evaluative and formative outcome assessment for the workshop that produced the individual content chapters in this edited volume (entitled *Mind and motion: the bidirectional link between thought and action*; 29–31 May 2008; Bielefeld, Germany). We go beyond simply summarizing and reiterating the academic progress that was made in each group that is presented in the group reports. Rather, we focus on the obstacles that we encountered along the way in hopes of recognizing what may impede future progress in the study of motor-cognitive links. In particular, we identified three key challenges that arose during our workshop discussions: the limitations of a reductionist tendency, the myopia associated with disciplinary biases, and the threats to inferential validity when dealing with mental phenomena. We offer prescriptive advice about how to overcome these limitations and provide a template for future interaction by interdisciplinary researchers who want to continue scientific research in this domain.

**Keywords:** perception; action; cognition; decision making; interdisciplinary research

## Introduction

The behavioral sciences have a long tradition of pioneers who appreciate a systems approach to the study of behavior. For example, Egon Brunswik stressed the need for considering the environment in which an organism is embedded, noting that individual behavior did not occur — and thus could not be studied — in isolation. This connection between the organism and the environment may be apparent, and has been

incorporated into psychological research in many domains including perception, cognition, and movement science. However, there still exists a relative disregard of the system existing *within* the individual; that is, the relationship between the body and the mind.

Admittedly, the relationship between the body and mind has received considerable attention in some academic disciplines — most notably in the dualist tradition of philosophy. However, in this context, the body and mind were viewed as disjoint, rather than as united components of a system of thought and action (although Kant advocated a more integrated view). Yet, as a result of the contributions of philosophy to

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cognitive science, this blossoming, multidisciplinary field recognizes the importance of the body and mind connection. For example, recent work on the hot topics of “embodied” and “situated” cognition suggests that our cognitive, conceptual frameworks are driven by metaphorical relations to our perceptual structures, both of which evolve in a context-dependent manner.

Researchers in cognitive psychology, neuroscience, psychophysics, movement science, robotics, social psychology, and other disciplines represented in this volume are uniquely positioned to take advantage of their collective expertise in dealing with the study of behavior as a tripartite system involving body, mind, and surroundings. This was the goal of the workshop that produced the chapters in this edited volume. The challenge of the workshop lay in integrating the vast body of knowledge in each domain to develop a systems approach. As representatives of different disciplines, we may possess differences in training or terminology, but as a group, through common interests, we should be concerned with the same issues to understand the same phenomena. However, we can only capitalize on the unique advantages of different disciplines through interaction and collaboration, often with excellent results that are mutually beneficial to all fields involved. The ZiF workshop that motivated the current volume was one example of such an endeavor.

The purpose of this concluding chapter is to summarize the progress that we see as emanating from the days spent together at the Center for Interdisciplinary Research at the University of Bielefeld, Germany. Specifically, we will first briefly summarize the consensus that each group and the workshop as a whole achieved. Second, we will discuss the obstacles that we discovered along the way, and how they allowed us to recognize our individual and collective shortcomings in preparedness to tackle such a broad and foreboding topic. Third, we offer prescriptive advice on how to overcome these complications and hindrances in future work that truly integrates various perspectives and human faculties (cognition and action). Finally, we provide an organizational roadmap that we hope is useful as guidance

for future work in this arena. Throughout, our motivation is to reflect upon our experiences to inform those that would follow in our footsteps in pioneering research into the bidirectional links between the cognitive and motor systems.

### **Advances in knowledge gained from the workshop**

The workshop format posed specific questions to each working group and assembled interdisciplinary groups of experts to construct theoretical and practical answers to these questions. These were framed in the context of a decision facing an agent immersed in a situation that required appraisal and action.

The first group was charged with identifying fundamental principles that could describe how alternative courses of action might be perceived and represented by the agent. For example, maybe these potential actions are represented as cognitive structures, motor programs, or diffuse patterns of activation. Are they represented as a collection of relative or comparative units, or as invariant absolutes? Are they comprised of “basic units” clustered into hierarchies, or as an immense assortment of individual exemplars?

The second group was charged with illuminating how an agent might recruit, manipulate, and evaluate these representations to derive a preferred course of action. Would such a transformation of input to intended output necessarily be conscious, accessible, and describable? Could it instead be more implicit and associative? Given the apparent complexity of many human actions and movements, would the mechanism(s) that produce a single action in a given situation, and perhaps inhibit others, necessarily then be complex?

Finally, the third group’s task was to focus on the translation of intention into action. Whatever the nature of the representation of potential actions, and however one of these representations or actions was privileged in any sort of mental appraisal algorithm, how does the human body actually enact the physical and mental apparatus necessary to bring the physical world in line with

the preferred representation? Is any sort of cognitive intervention necessary to achieve this result, or would direct perception–action links suffice in producing the same end result (and with more parsimony)?

Admittedly, these are rather lofty questions and given a few days of interaction it is understandable that conclusive, unanimous answers were not readily apparent in any of these groups. The group reports in the current volume provide a glimpse at the intellectual currency that was generated within each group; but none of these provides a definitive answer to their respective question as initially cast. Rather than view this outcome as an underachievement, we herald the progress made within each group at understanding the difficulties inherent in tackling such questions and the unique contributions and perspectives that were brought to bear. To frame the remainder of this concluding chapter, we begin with a brief review of the highlights from the workshop as a whole and the individual groups, in particular.

The first group studying how options are perceived and represented decided to open a broader perspective how the topic of mind and motion should be investigated from an interdisciplinary background. The discussion resulted in a framework that describes the dynamic bidirectional links between perception, decision making, and action. Furthermore it illustrates how personal, task, and environmental constraints may influence these links. Changes of these bidirectional links between perception, decision making, and action were described on a time axis representing short- and long-term adaptations. Finally the framework was applied to current research to convey new ideas for experimental paradigms, data interpretation, and applications (see Chapter 8: The bidirectional links between decision making, perception, and action).

The second group hoped to determine how the motor and cognitive systems necessarily worked together to arrive at decisions that might be cognitively assessed but are motorically enacted. Interestingly, this group realized that there were a number of qualifications that needed to be addressed before the question could be suitably phrased, let alone answered. As a result, the

primary output of this group was an appreciation of the various levels by which decisions could be defined (see Chapter 16: How do motoric realities shape, and become shaped by, the way people evaluate and select potential courses of action? Towards a unitary framework of embodied decision making). With this understanding, one could view the answer to the original question as: “it depends.” Fortunately, this answer is not at all trivial, as the group report outlines a coherent approach to applying several successful frameworks once the appropriate level of analysis is determined.

Finally, the third group tackled the question of how actions are implemented from an interdisciplinary perspective covering both cognitive psychology and neuroscience. Similar to the other two groups, these authors felt the need to first create a common ground by sharpening the questions and by defining central concepts such as what is meant by “action implementation.” While cognitive psychologists agree on the idea that cognitive functions are implemented in the brain, cognitive models do not necessarily refer to biological aspects or principles of brain functioning, but instead concentrate on how information is processed. With the ultimate goal to link ideas on the underlying processes of action implementation taken from different fields, this group introduced four research perspectives and further elaborated these in terms of how they address the phenomenon of action implementation. An important part of this group’s answer to the question at hand was that findings from various fields show the need to abandon serial frameworks of information processing suggesting a step-by-step pattern from perception, evaluation, and selection to execution (see Chapter 24: How are actions physically implemented?).

A common theme that permeated each of these working groups was the challenge of studying a single process — mental or otherwise, observable or unobservable — in isolation. That is, each group found itself necessarily “trespassing” on the domain of the other groups. How can one describe representations in the human mind, without knowing what end these representations serve? How can one determine how a decision is made, without knowing what preceded the

decision and how it will be realized? How can one specify how actions are implemented, without knowing the impetuses and goals of said action? As a result, the group outputs possess great variability, especially in the degree of relatedness to the originally posed questions. Of course, one can consult the individual chapters in this volume for details. The remainder of this chapter, then, will be dedicated to tracking and assessing the procedural quality of our workshop to provide formative input to future similar endeavors.

### **Speed bumps and road blocks**

We are each proud of the production of each of our respective groups, and view the workshop as a success, even if we candidly must admit that the means to the end was sometimes turbulent. Granted, our approach to the workshop was risky in its ambition and format, and the payoff could have been inconsequential. Beyond the content of the group output, we believe that the most useful product of the workshop was in identifying the challenges that faced us — we now realize the speed bumps that may impede progress in this field, and the road blocks that may halt potential theoretical advances altogether. Discovering these obstacles is in itself a very productive result. Now we know the difficulties we must confront if we want to forge ahead in this area, and armed with this awareness we can avoid “treading water” or becoming bogged down with petty misunderstandings or semantic differences, for example. Encouragingly, no impasse surfaced in any of the groups. Therefore, we are confident that ultimately a true understanding of the scope and implications of bidirectional links between cognition and action can be achieved. Our path may be littered with speed bumps and road blocks, but at least we learned enough to realize that it is not a dead end. In this section, we explicitly enumerate the obstacles we encountered along the way.

### ***Reductionism***

As recognized in other chapters in this volume, perhaps the single largest threat to true and

comprehensive understanding of the bidirectional links between cognition and action is the reductionist tendency. In the current workshop, this principle was manifest in many forms, none of which contributed very positively to our ultimate goals. As scientists we are often myopic and focused solely on the problems that face us directly. Even within a discipline, researchers are content, if not encouraged, to study problems limited in scope for the sake of manageability and the development of expertise. Cognitive psychology, for example, has such a broad expanse of topical interests that any single researcher can rarely possess even conversational, let alone expert, knowledge in more than a few constituent fields. To truly understand language, for example, is to understand speech production, speech comprehension, syntax, lexicon, categorization, and many other topics that individually can (and have) fueled entire careers. Directly studying the entire system is the exception rather than the rule, yet phenomena as complex as language or decision making — and indeed beings as complex as humans — are almost certainly greater than the sum of their parts. However, despite our best intentions, as disciplinarily trained scientists the default is to concern ourselves with only our chosen domain of study, and to impose our own unique perspectives on any research question.

The first, and most concrete, problematic instantiation of the reductionist philosophy was our organizing framework and the questions that it posed. In particular, this problem interacted with the disciplinary biases of us as organizers. It was pointed out explicitly in at least one of the working groups that the organizing questions suffered critically by adopting the information-processing assumptions of modern cognitive psychology. That is, by organizing the groups around themes of representation, decision, and implementation, we were *a priori* supposing the ability to reduce behavior into these constituent processes, and thereby assumed that motor-cognitive interdependencies in behavior could still be accurately studied in this manner. Entire approaches represented at the workshop, such as dynamic systems theory, strongly reject such artificial distinctions, which creates obvious

tension. As mentioned earlier, this premise met with disdain in each of the groups. Furthermore, it turned out to be severely limiting and impaired the flexibility of the responses that seemed available to each group. This structure implicitly surfaced other problems as well, such as the assumption of a serial feed-forward progression across these processes. In the end, each group rejected this framework to some degree. In fact, one group report focuses solely on presenting an alternative conceptualization and thereby dismissing their “assigned” question almost entirely. Another group report goes to great length to qualify its response as taking this (disputed) position as the basis for inevitably defining a multilevel response.

The second challenge caused by reductionism is the obstacle to fruitful interaction among interdisciplinary groups. That is, because of our individual reductionist tendencies, there was fertile ground for disagreement concerning concepts that are seemingly straightforward when viewed only through the lens of a single discipline. For example, none of us probably would have predicted an inability to form a consensus on what even characterizes a “decision,” or the target behavior of interest. Is a saccade a decision? In what sense is a reflex a decision? What level of consciousness, or complexity, or import is required to classify a “true decision” as having taken place? When all one studies is the saccades of primates, or a “go/no-go” task, or consumer choice, or jury deliberations, then certainly one naturally defines a “decision” only in the context of one’s own relevant task. Lack of consensus in this sense also raises the issue of disciplinary differences addressed next.

### ***Disciplinary biases***

Few would dispute that a topic such as motor-cognitive interactions not only benefits from, but in fact *requires* perspectives from multiple disciplines. (Of course, if it were not for reductionism, this would not necessarily be the case: a single perspective would suffice if it alone were all-encompassing.) The second major obstacle we encountered was the disciplinary biases that each

of us brought to the meeting. This presents difficulties for a number of reasons, but two of which we see as primarily manifest in the workshop.

First, each discipline demands certain ways of tackling problems, and has different criteria for “good” solutions. A persuasive argument to an economic historian might be considered “hand waving” to a biopsychologist. In contrast, compelling evidence to the neuroscientist could be disregarded as “mere correlations” with little theoretical significance to the political scientist. Consider one specific exchange that occurred in one of our groups, concerning topics such as degrees of freedom and model parameterization. To some researchers, a model’s success in explaining, replicating, and predicting phenomena is sufficient grounds for endorsement. Others, however, are always concerned with criticisms regarding model flexibility and lack of parsimony. If a model’s parameters are not uniquely identifiable, such as if the model contains too many parameters relative to the degrees of freedom in the data used to verify the model, it is discarded almost out of hand in some fields. A major challenge lay in reconciling these very disparate viewpoints about the quality of, and constraints on, our explanatory tools. In short, if a group cannot begin by agreeing on what constitutes a good answer, then how would they be expected to go about seeking exactly that?

Second, a discipline’s methods can color how theories are formed as well as what variables and concepts are considered interesting or “worthy.” Again we illustrate the point by criticizing our own development of the workshop’s organizing framework. The information-processing framework of the human mind so popular in modern cognitive psychology is based on the metaphor of the mind as a computer. This stems in no small part from the introduction, evolution, and explosion of computing machines and power since World War II. Furthermore, beyond theory development, this can also play a role in determining which constructs or variables are important and worth studying and accounting for. Economists are engaged in applied settings that deal with markets and institutions; even

microeconomics is concerned with behaviors on the order of the firm or household. Is it any wonder many economists have been reluctant to embrace the importance of the psychology of the individual in their theories? In this context, are human emotion and individual differences not just nuisance variables like the weather and natural disasters that are difficult to predict and beyond the explanatory goals of the models? It is not hard to imagine that the role of, for example, emotions would be of differential importance to cognitive psychology, social psychology, robotics, and neuroscience! Because representatives from each of these particular fields sat around a single table at the workshop, one can imagine the potential barriers to true collaborative and interdisciplinary discussion.

### ***Inferential validity***

The third and final general impediment we saw to achieving immediate and overwhelming progress in detailing the bidirectional links between thought and action is the lack of an ability to validate clearly claims we would make, or solutions that we would endorse. In other words, even if the groups were to have found seemingly “correct” answers to our questions, how would we ever know that we had in fact found them? As largely unobservable phenomena, many of the fundamental, decisive issues with which the groups struggled are difficult if not impossible to study empirically. Furthermore, even in instances where contrasting assertions lent themselves to empirical study, such work had not been undertaken, had not been entertained (to our knowledge), and perhaps had not even been conceived, for reasons raised earlier. Specifically, researchers in any single field might take a certain phenomenon for granted to the point that it is not even considered necessary to verify in the laboratory or the field. Perhaps a specific qualification to a phenomenon or crucial follow-up study was never identified as critically lacking. Only through the intermingling of disciplines were we able to recognize, by the virtue of another discipline’s perspective, the need for addressing these situations.

Another incarnation of the threat to inferential validity arises in the context of generalizing across the specific conditions that might be used to provide evidence for any claim. Many individual chapters in the current volume (as well as many authors outside this collection) recognize and voice the need to consider the domain-specific nature of many phenomena, such as decision making. Granted, it is difficult to generalize from sterile laboratory conditions to many real-world environments, and it is easy to argue why ideally one would like to study the latter to make valid claims about true human behavior. In the limit, however, this dooms the assumption that there are any broader regularities in human behavior, that there are mental and physical mechanisms that can be applied across many situations. Essentially, the question becomes to what degree can we draw valid inferences across various domains, people, environments, time scales, etc.? Are there indeed behavioral invariants that we are trying to discover, or very specific trends?

### **How to overcome these obstacles?**

A quick qualification is probably in order regarding the previous section before we continue. Without a doubt, we think the content outcome of the working groups was meaningful and time well spent. So, following a section that cataloged our most serious shortcomings we should at this point reiterate the purposes of such an exercise. By enumerating our challenges and critically assessing the workshop we hope to play a constructive, functional role in shaping subsequent work. In particular, in this section, we offer prescriptive advice for how to remedy the issues raised above and thereby steer clear of the most frustrating obstacles.

### ***Beyond reductionism***

We propose that to combat reductionistic tendencies and the trappings they bring to the scientific study of an issue, we need to change both the way we see ourselves as scientists as well as the way we

tackle problems. First, we advocate for a style of “Renaissance researcher” that is versed in multiple disciplines and domains, as is suitable to study particular problems. Much like the drive in secondary education pedagogy to focus on problem-based learning, this emphasis should be beneficial for researchers of both the cognitive and motor systems. We envision a community where scientists are not identified by the label that is attached to their degrees, but rather by the problems with which they are engaged. Thereby researchers formerly known as sport scientists, cognitive psychologists, and neuroscientists could all instead be known as judgment bias researchers, or social-facilitation-in-sports researchers. This focus on distinct problems blurs disciplinary lines in what we believe to be a fruitful manner, and encourages individuals to obtain whatever knowledge is requisite for understanding phenomena, rather than focusing within-discipline. This community should work together daily on the same floor rather than meeting occasionally in workshops. The Center for Interdisciplinary Research in Bielefeld and other centers of interdisciplinary advanced studies should be the rule not the exception.

Second, we propose that the unit of analysis be expanded from a single hypothetical mental process to the broader scope of the behavior under examination; in particular, the largest identifiable chunk of behavior. We must resist the urge to isolate single events demarcated by convenience or academic specialization. In the current context, we must not presuppose discrete, identifiable “decision events” as the proper units of analysis (cf. Chapter 16: How do motoric realities shape, and become shaped by, the way people evaluate and select potential courses of action? Towards a unitary framework of embodied decision making). A decision event may not always have a clear onset or a clear resolution, but represent merely a temporary pattern of mental and physical behavior. We should study an entire stream of behavior to avoid excluding potentially important inputs and outputs of the mental and motor processes under study. In natural settings, we are not typically presented with an explicit set of options in tightly controlled circumstances, as

some of our empirical work does. Rather, life presents itself in all of its splendid, untidy glory for us to parse (or not) and interact upon. Instead of observing, for example, the athlete’s verbalizable decision when faced with a freeze-frame video of an offensive formation at a critical point, we should examine the athlete’s behavior (perceptions, cognitions, and actions) during the entire development of the situation at hand. In doing so, we can follow a behavior from beginning to end to appreciate the interplay of constituent processes — if individually identifiable component processes even exist as such at all.

### *Appreciating disciplinary contributions*

As we mentioned in the introduction of this chapter, the only way to truly foster interdisciplinary perspectives is to continue to interact and include multiple approaches. Some behavioral researchers promote the use of “adversarial collaboration,” where the most enlightening flaws in one’s line of reasoning are raised by one’s fiercest competitors. Of course, only by first identifying shortcomings in our disciplinary modes of thought can we then correct them. We would continue to endorse the interdisciplinary nature of gatherings such as ours, and if anything would expand on this notion to include formal training in one another’s means and methods. By “playing physicist for a day,” we allow ourselves to be informed about the unique challenges and contributions the field of physics has to offer. Then we understand how to incorporate concepts such as dynamics, force, energy, entropy, and inertia into our own work — what are the behavioral and motoric analogs of these concepts? How might a field as seemingly esoteric (to a behaviorist) as quantum mechanics enlighten us to new avenues of thought? Could we apply Heisenberg’s uncertainty principle to the study of, for example, actions and intentions rather than location and momentum? Certainly it is asking quite a lot to assume we will all earn multiple advanced degrees, but the more modest goal of short primers in one another’s fields does not seem prohibitive.

## **A new empiricism**

The toolbox of methods and metrics across disciplines exhibits considerable variability. We support a multimethod protocol for studying complex behaviors such as motor-cognitive interactions. The experimental method may be easily championed by some, but there is much to be gained from other methods such as computer simulation, neuroimaging, and self-report (not to mention introspection), to name only a few of those represented in the current volume. By combining multiple methods in the study of behavior, we can capitalize on the advantages of each method while allowing others to compensate for their shortcomings. Even within a specific field, such as neuroscience, one can use multiple methods to great benefit (e.g., combining high temporal resolution from one method with the greater spatial resolution of another).

The problem of domain specificity versus generality is a more challenging and complicated one. This is not simply a matter of basic versus applied research, or laboratory versus field research. The easiest recommendation would be to suggest including all of these types of research in our investigation of motor-cognitive links. We can study the athlete in the field to identify important environmental variables, and then target these variables in laboratory work. We can understand basic underpinnings of behavior that can then be used in worldly applications. These propositions are not novel, and are practiced everyday in many of the parent disciplines represented at the workshop.

Beyond this suggestion, however, we propose that considerable effort should be invested in a taxonomy of environmental characteristics or decision types where motor and cognitive systems are involved. Imagine if we could specify six or seven environmental primitives that could serve as orthogonal bases for constructing the majority of everyday situations. If we can accomplish this, then there is no pressing need to study a behavior in every possible application imaginable. We could then focus on these primitives and their interactions, and use interpolation and extrapolation methods to derive testable hypotheses for

environments of direct interest to our individual research programs (or funding agencies!). In the interplay of thought and action, however, we are only at the initial steps of achieving something similar to the table of elements in chemistry or the laws in physics.

## **The road ahead**

We would like to conclude this chapter by formalizing the preceding discussion into a concrete vision to organize future work in this area. We begin by summarizing from the group reports the open questions that face research on bidirectional communication and dependence between motion and cognition. Then, we offer an organizational framework for continued study in this area.

### ***Recognizing what we have not learned***

Each of the working groups contributed to the identification of outstanding issues and open questions that could not be resolved in the limited opportunity of the current workshop. The first group provided a global framework, however more specific assumptions were not yet achieved such as when do we assume sequential versus parallel processing? When are deterministic versus probabilistic models sufficient? How static or dynamic are interactions between components of the framework? The second group proposed different levels of decision, but could only speculate as to how the mind-body link influenced each absolutely and/or relatively (see Chapter 16: How do motoric realities shape, and become shaped by, the way people evaluate and select potential courses of action? Towards a unitary framework of embodied decision making). For example, in what sense do motoric realities influence very high-order, deliberate, preferential choice tasks, and how is this influence different than the influence on transient, intuitive tasks? The third group did an excellent job of formally phrasing open issues that arose in their discussions (see Chapter 24: How are actions physically implemented?): how can we define and measure

knowledge structures? What role does cognition play, *per se*, beyond the explanatory power of direct perception-action links? And what about the role of emotions?

### ***Practicing what we have learned***

In this final section, we describe a potential framework that would incorporate the recommendations from the preceding discussion to “correct flaws” in the way we approach the mind–body linkage, and “break down barriers” to allow for its interdisciplinary investigation. We draw heavily on the principles described in the first group report (Chapter 8: The bidirectional links between decision making, perception, and action) and the task conceptualization of the second group report (Chapter 16: How do motoric realities shape, and become shaped by, the way people evaluate and select potential courses of action? Towards a unitary framework of embodied decision making).

We argue for a stance that is described by the four principles introduced in the first group report. First, it is necessary to truly consider the *bidirectional* nature of motor-cognitive influences. In particular, the majority of progress made up to this point has focused on how the motor system may influence the performance of mental (cognitive) processes. Much less attention has been paid to the other important arrowhead — how higher-order processes influence motoric processes in a top-down fashion. By analogy, consider that the role of top-down influences has been very productive in the study of perception and classification, but has not been extended further down to the level of sensation. More ambitiously, rather than remembering to study both mind–body and body–mind links, we should realize the constant interplay of the two in a single system. Second, we believe that the joint motor-cognitive system architecture that we are studying is necessarily parallel or nonconsecutive. We learned that it is not profitable to assume a progression of activity that places differential emphasis on thought and action. Rather, at any moment in time, the whole of human activity (mental and motor) is engaged. Third, and related to the nonconsecutive tenet, is

the fundamentally dynamic nature of behavior. We need to study streams, not segments, to determine how the mind and body interact over time. Finally, we must appreciate the constraints that exist on both the mind and the body. Only by understanding the realities of the limits on human mental function and physically conceivable action will we understand more than just *how* human behavior arises, but *why* it occurs the way it does.

Future study in the realm of motor-cognitive interactions will best be served, we believe, by a task-based division different than the one attempted in the current workshop. In particular, we propose that the functional division introduced by DeCaro et al. (Chapter 16: How do motoric realities shape, and become shaped by, the way people evaluate and select potential courses of action? Towards a unitary framework of embodied decision making) is a far more appropriate division of labor. Rather than have research teams study information-processing hallmarks such as representation, decision, and implementation, these processes should be jointly studied across three different decision styles. First are lower-order decisions that are almost exclusively sensory driven, where the decision representation is sensorimotor and/or proprioceptive, the decision (as such) is almost reflexive, and the enactment is served by stable motor programs. Second are associative decisions driven by representation as recognition and decision by classification, such as “if-then” rule-based learning. Finally, third are the higher-order, abstracted decisions such as preferential choice (consider voting in a presidential election), where the decision may be very deliberate, conscious, and algorithmic.

An important contribution will be to map these different types of decisions to corresponding neural systems. It is tempting to speculate that these may be ordered phylogenetically. Decisions on the lower levels may rely more on phylogenetically ancient structures such as the striatum, while higher-order, abstracted decisions will involve more recently evolved neocortical structures, such as the prefrontal cortex (PFC), to a greater degree.

What might these visions look like for a reprisal of the workshop that spawned this volume? In short, we would propose research teams guided by principles outlined by de Oliveira et al. (Chapter 8: The bidirectional links between decision making, perception, and action), consisting of disciplinary traditions reviewed by Zentgraf et al. (Chapter 24: How are actions physically implemented?) assigned to each of the three decision levels proposed by DeCaro et al. (Chapter 16: How do motoric realities shape, and become shaped by, the way people evaluate and select potential courses of action? Towards a unitary framework of embodied decision making). Specifically, we would organize a follow-up workshop by first recruiting from the same fields that contributed to the current workshop, thereby acknowledging the disciplinary diversity that produced the excellent results collected in this volume. As Zentgraf et al. (Chapter 24: How are actions physically implemented?) point out, the combination of these approaches is pleasingly complementary. Additionally, we would expand the concept of the current workshop by proposing a few days of tutorials and short courses in an attempt to better educate extradisciplinary researchers about the benefits and unique insights to be gained from each discipline. Finally, we would foster a sense of community by engaging in discussions for some length of time prior to a face-to-face workshop. In this, we envision something like a biweekly, global, technologically mediated reading group, where individual researchers would suggest papers that exemplify the relevant readings from their own field to the topic of motor-cognitive bidirectional links. This would greatly expand the preparation for the next workshop and provide a solid, common knowledge base across research teams.

With the proper mix of interdisciplinary scientists, and the foundation of a broad comprehension of the interdisciplinary literature, these teams would be prepared to work together in the antireductionist and crossdisciplinary spirit that we advocate. Of course, these teams need to work on a proper set of problems; we have learned the

perils of mis-specifying the target questions. Rather than organize around an information-processing view of artificially segmented processes, we propose that each of three teams focus on one of the decision levels put forth by DeCaro et al. (Chapter 16: How do motoric realities shape, and become shaped by, the way people evaluate and select potential courses of action? Towards a unitary framework of embodied decision making). Specifically, we would propose that each group selects two specific tasks or situations that represent their particular decision level, and study these two tasks in their entirety, including the context of the task initiation, the consequences of the actions deployed to bring about resolution, and the full range of processes in between. This appreciation of the entire stream of behavior stands in stark contrast to the functional group divisions undertaken in the current workshop. Furthermore, by selecting two distinct tasks, each group could also then perform a comparative analysis to begin to understand the prospects for a domain-general versus domain-specific approach at each level.

Ultimately, we may find that disjoint, even if annual, workshops may be too transient to make the kind of consistent progress that is required to study motor-cognitive links. Even with extensive preparation, there is only so much that can be accomplished in a few days' or weeks' time. Ideally, we would propose a long-term, fully integrated and immersed working group to spend a considerable amount of consecutive time on these issues. Such a group would epitomize the ethos that we put forth in the discussion of this chapter by crossing disciplinary lines and resist carving a problem up into pieces that, while maybe convenient, preclude a true understanding of the relevant behaviors. Whichever route is taken, we highly anticipate continued interaction and persistence in pushing the bounds of our limited understanding. The journey on which we have embarked has only just begun, but we hope to here have helped provide a road map by which the bidirectional links between the mind and body, the motor and cognitive aspects of behavior, can be discovered.