Macrocognition

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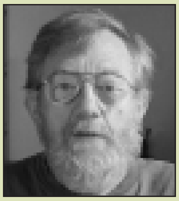
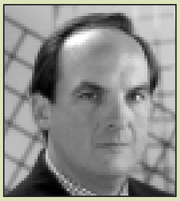
If we engineer complex cognitive systems on the basis of mistaken or inappropriate views of cognition, we can wind up designing systems that degrade performance rather than improve it. The results stemming from the application of any cognitive systems engineering methodology will be incomplete unless they include a description of the cognition that is needed to accomplish the work. The concept of *macrocognition* is a way of describing cognitive work as it naturally occurs.

Definition

Macrocognition is a term coined by Pietro Cacciabue and Erik Hollnagel to indicate a level of description of the cognitive functions that are performed in natural (versus artificial laboratory) decision-making settings.[1,2] Traditionally, cognitive researchers have conducted lab experiments on topics such as puzzle solving, serial versus parallel attentional mechanisms, and other standard laboratory paradigms for psychological research. We term these *microcognition* because they are aimed at investigating the building blocks of cognition, the processes that we believe are invariant and serve as the basis for all kinds of thinking and perceiving.

In contrast, the methodology for macrocognition focuses on the world outside the lab. This includes contexts designated by such terms as the "field setting," the "natural laboratory," and the "real world."[3] Key features of cognition in naturalistic contexts include the following:

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- Decisions are typically complex, often involving data overload.
- Decisions are often made under time pressure and involve high stakes and high risk.
- Research participants are domain practitioners rather than college students.
- Goals are sometimes ill-defined, and multiple goals often conflict.
- Decisions must be made under conditions in which few things can be controlled or manipulated; indeed, many key variables and their interactions are not even fully understood.

In natural settings, domain practitioners rarely focus on microcognitive processes. Instead, they are concerned with macrocognitive phenomena, as Table 1 shows.

These types of functions—detecting problems, managing uncertainty, and so forth—are not usually studied in laboratory settings. To some extent, they are emergent phenomena. In addition to describing these types of phenomena (the left-hand column) on a macrocognitive level, we can also describe them on a microcognitive level. The two types of description are complementary. Each serves its own purpose, and together they might provide a broader and more comprehensive view than either by itself. We do not suggest that the investigation of macrocognitive phenomena will supercede or diminish the importance of microcognition work—just that we need research to better understand macrocognitive functions in order to improve cognitive engineering.

Another way in which the methodology for macrocognition differs from that of microcognition deals with assumptions about cognition's "building blocks." Microperspectives carry with them the notion of reductionism—that explanations come from reduction to a set of basic functions or components. Although we might want to reveal specific causal sequences of various memory or attentional mechanisms, this turns out to be difficult. When we try to describe naturalistic decision making, we quickly realize that it makes little sense to concoct hypothetical information processing flow diagrams believed to represent causal sequences of mental operations, because they end up looking like spaghetti graphs.

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Table 1. Important macrocognitive phenomena and traditional microcognitive lab research.

Degree	Model
Planning and problem detection	Puzzle solving
Using leverage points to construct options	Strategies for searching problem spaces
Attention management	Serial versus parallel processing models
Uncertainty management	Estimating probabilities or uncertainty values

Explaining cognitive phenomena by decomposing or reducing them to hypothetical building blocks might not always be necessary. If anything, supplementary explanatory concepts come from above rather than from below—for example, feedback/feedforward, self-organization, equilibrium, and so on. Macrocognitive functions can be considered as perspectives, but not in the sense that the constituent functions are necessarily elements, or elementary in any way. And they are rarely like the "basic" cognitive functions of microcognition. It is more like the phenomenon you often find in a functional analysis—that is, that function A is a precondition for function B, and function B is in turn a precondition for function A. In that sense, each one encompasses the other, but one is not more elementary than the other. Each description has a value in itself, and the fact that multiple descriptions exist only reflects that you can look at something from different viewpoints and different levels. The linkages we should look for are therefore dynamic ones that can explain how functions or behaviors can emerge and interact.

To some extent, macrocognitive phenomena take place over longer time periods than microcognitive phenomena, but the distinction is not time-linked. Some macrocognitive phenomena happen very quickly, and some aspects of microcognition, such as puzzle solving, can be drawn out. Macrocognition often involves ill-defined goals, whereas microcognitive tasks usually have well-defined goals.

As researchers learn more about macrocognition, they are likely to clarify its relationship to microcognition. However, the two levels might not line up neatly. Microcognitive research has posited a set of distinctions (for instance, the difference between memory and inference) that might not be useful as we study macrocognition. The study of macrocognitive functions will introduce new distinctions that will have to be evaluated on their own merits.

Why study macrocognition?

Some will object to postulating a distinction between micro- and macrocognition. If both levels address cognitive processes, why introduce new terms and a new distinction? One reason is that without it, most researchers would likely continue experimentation on microcognition and ignore macrocognition. Second, the study of macrocognition might require a different approach to research. Third, we believe that the field of microcognition will also benefit by being contextualized by macrocognitive functions.

Macrocognition comprises the mental activities that must be successfully accomplished to perform a task or achieve a goal. Other somewhat related terms have been used in this regard, such as *situated cognition* and *extended cognition*.[4] These terms describe the fact that macrocognitive functions are generally performed in collaboration—by a team working in a natural situation, and usually in conjunction with computational artifacts. The emphasis in macrocognition is on cognitive functions, and teams can perform these. Thus, we can study how the barriers to effective problem detection might be different for individuals than for teams. Macrocognitive functions can be performed using information technology, or without any technology at all, and we can study how technology helps us past some barriers but introduces others. We prefer the term *macrocognition* because in addition to broadening the focus to include the team and technology context, it also broadens the level of description of the cognitive functions themselves. General approaches such as situated cognition are important for explaining why cognitive functions must be studied in natural contexts, but they only point to the need to discover and understand the macrocognitive functions that operate in natural contexts.

Furthermore, one of a macrocognition framework's intended functions is to encourage the development of descriptive models of processes such as decision making, sensemaking, and problem detection. For example, a research program on decision making started by investigating the strategies used by experienced firefighters.[5] This research program used accounts of critical incidents to propose a new model of decision, called the *Recognition-Primed Decision* model. The RPD model tried to explain how experienced decision makers could generate effective courses of action without having to consider more than a single option. Normative models of decision making, such as utility theory, dictate that "good" decision making involves specifying all the action alternatives, all the possible outcomes, and their likelihoods, and evaluating all the alternatives for their costs and benefits. The RPD model postulates that we can use pattern matching to categorize a situation, so that the recognition of familiarity (case type) evokes a recognition of the typical way to respond. Furthermore, experienced decision makers can evaluate a single course of action by mentally simulating it rather than by deliberatively comparing it to other options.

After considerable research on recognition-primed decision making, we realized that the model was basically a combination of three decision heuristics that had already been well-studied from the microcognition perspective: availability and representativeness to identify the typical course of action, and the simulation heuristic to evaluate the course of action.[6] Therefore, in this case it was possible to trace the macrocognitive phenomenon back to hypothetical microcognitive components. However, several decades of research on the availability, representativeness, and simulation heuristics had not led to a discovery of recognitional decision making. That is why we see the macrocognitive functions as emergent. We discover them by investigating cognition in field settings rather than by continually pursuing explanations of lab findings.

A variety of macrocognitive functions

Our current list of the major macrocognitive functions appears in the center of Figure 1.[5,7–12] The circle around the primary functions shows a range of supporting macrocognitive processes.[13–19] We do not include them as primary functions because decision makers, at least those we have studied, do not carry out these processes as an end in itself but rather as a means for achieving the primary functions listed. This distinction is as much for pragmatic as for theoretical purposes: to highlight those functions that repeatedly emerge as ends in themselves across a variety of projects in various domains.

Additional macrocognitive functions and supporting processes will eventually be added to this set; some of the functions in the figure might be subsumed into others as researchers make new discoveries. For instance, we have not included situation awareness[7] in Figure 1 because it is a state rather than a process; it arises through sensemaking and situation assessment. Basically, we are less concerned with presenting an official list than with encouraging research at the macrocognitive level of description.

We considered trying to diagram the relationships between the different functions and supporting processes in the format of processing diagrams—the currency of cognitive science—but decided that such a representation is still premature. In most natural settings, the decision maker must accomplish most or all of these functions, often at the same time. A macrocognitive function such as problem detection can be an end in itself for a mission such as intensive-care nursing or intelligence analysis, or it can be a means toward an end of command and control replanning. Mental simulation and storybuilding are typical strategies for sensemaking but are also supporting strategies for naturalistic decision making. A mental model of a situation must be developed for decision making, sensemaking, effective planning and replanning, coordination, adaptation, and replanning. In other words, everything can be connected to everything. This makes any attempt at depicting a flow diagram either ad hoc or useless because cognition, as it occurs in the world, can't be "frozen."

Some of the functions that Figure 1 depicts have been studied to a level of specificity that enables the creation of specific models, whereas others are still in the early stages of modeling. An example of a specific model is the RPD model, mentioned earlier, which has generated several empirical generalizations about lawful relationships:

- People make most decisions using recognitional strategies, fewer decisions by comparing options analytically. This generalization is based on studies in domains such as firefighting, critical-care nursing, and military decision making and is tempered by the features of the domain.[5]
- Experienced people rely more heavily on recognitional strategies. When people are just learning about a domain, their approach tends to be more analytic and deliberative.
- If people have any experience in a domain, the first option they generate is usually plausible (and certainly not random).
- People typically evaluate options using mental simulation rather than analytical comparison.
- As people gain experience, they spend more time examining the situation and less on contrasting the options, whereas novices spend more time contrasting options and less on comprehending the situation.

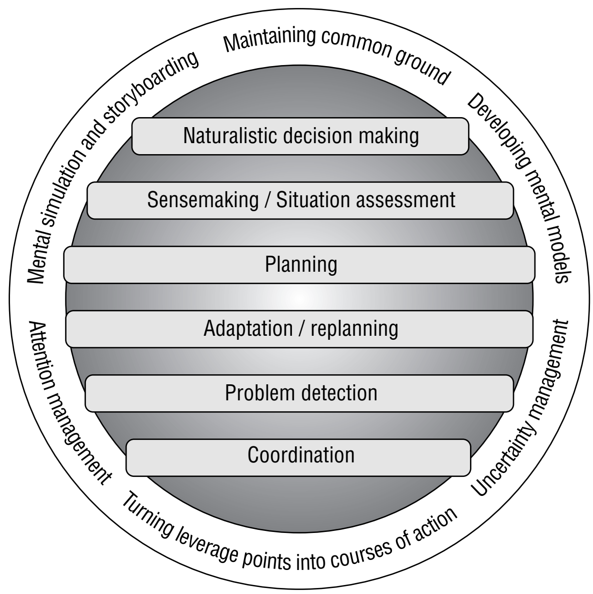

Figure 1. Macrocognitive functions and supporting processes for individuals, teams, and information technologies.

Many of the accounts researchers have provided of macrocognitive functions and processes are preliminary and tentative. Nevertheless, they are the best descriptions currently available—because macrocognitive processes have received so little attention. That is a major reason for calling out macrocognition as a distinct framework. We must study these types of functions and processes, even though they do not fit neatly into controlled experiments. We must find ways to conduct cognitive field research that can improve our understanding of the functions and processes encountered at the macrocognition level.

A natural science research approach

We propose that the naturalistic perspective is appropriate for studying macrocognition.[20,21] Naturalists develop theories, concepts, and methods by observing and interacting with the world. Research for the naturalist is a process—not a single, predefined procedure. The naturalist digs out the nature of the empirical world, continually revising conceptions of it and remaining flexible in methods of discovery and analysis. In the case of complex cognitive systems, the naturalist probes the world in which people actually live and work and the emerging situations in which they find themselves. The approach becomes most salient when contrasted with attempts to abstract or simulate a piece of the empirical world, as is typical in laboratory studies, or to substitute a preset image of it, as in many information processing accounts of cognition.

The naturalistic approach could yield an empirical basis for macrocognition. Yet, when someone proposes it to the research community as an investigative approach, standard methodological objections are often raised: Naturalism does not follow the experimental paradigm, it (therefore) lacks rigor, the procedures are (therefore) soft, and the results are (therefore) not generalizable. From our vantage point, these objections are wrong, a clear case of methodolatry. Many grand figures of science exemplify the naturalist at work—Charles Darwin, Jean Piaget, Galileo Galilei. It would be nonsense to say that Darwin contributed nothing to science because he did not formulate his theory of evolution as a consequence of a series of lab experiments. Nor would it make sense to criticize Galileo because he did not try to hold constant certain variables in the nighttime sky. Leading naturalists created rigorous observation methods, made valuable discoveries, and tested their hypotheses, leading to the conclusion that "more discoveries have arisen from intense observation of very limited material than from statistics applied to large groups."[22]

The naturalistic perspective qualifies as being scientific in the best meaning of that term. The long-held view that the study of cognition must adhere to tightly controlled studies using experimental methods would only serve to limit us in our attempt to study and describe macrocognitive functions. Our focus must turn now to formulating criteria for evaluating naturalistic studies, as other disciplines have done.[23] Our call for more macrocognition research is also a call for this research community to develop the science of understanding human cognition in natural settings.

The more we learn about macrocognition, the better should be the applications. We should be able to design better ways for using information technology, better interfaces, and better training programs. We should be able to discover strategies for enabling operators to control complex and highly dynamic systems, especially systems operated in distributed environments.

Researchers have empirically demonstrated that a range of cognitive functions and processes are central in complex cognitive systems, but these functions and processes have received little or no interest from the pertinent research communities. To a great extent, they are emergent phenomena—only obvious once researchers begin to investigate performance in natural contexts. The systems we would design to support decision making would be very different if we defined decision making as the process of multiattribute utility analysis or the collection of biases that must be continually corrected.

Researchers can probably be more effective working as naturalists to capture and study macrocognitive functions than by trying to impose an experimental structure. Furthermore, macrocognitive functions are linked; attempts to study individual processes in isolation from the others will probably result in distortions.

As we develop better tools and methods for cognitive systems engineering, we will have to gain a clearer sense of the cognitive functions we want to support. The macrocognition framework is intended to clarify what these functions are, so that we can do a better job of studying and supporting them. ■

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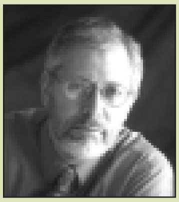

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