The SPLIT PERSONALITY of COGNITION

By Matthew Blakeslee

LEFT: BECKER MEDICAL LIBRARY, WASHINGTON UNIV. SCHOOL OF MEDICINE; NEURONS: CRESTOCK.COM; COMPOSITE: PAULA EASTWOOD

SCIENTISTS AT THE SANTA FE INSTITUTE ARE HAVING A FRESH THINK ABOUT COGNITION OUTSIDE THE BOX—THE BOX, IN THIS CASE, BEING THE INDIVIDUAL BRAIN.

"Most cognitive science still emphasizes the individual brain," explains Professor and Faculty Chair David Krakauer. "But there are two directions cognitive science can move that are quite different from the focus on individuals."

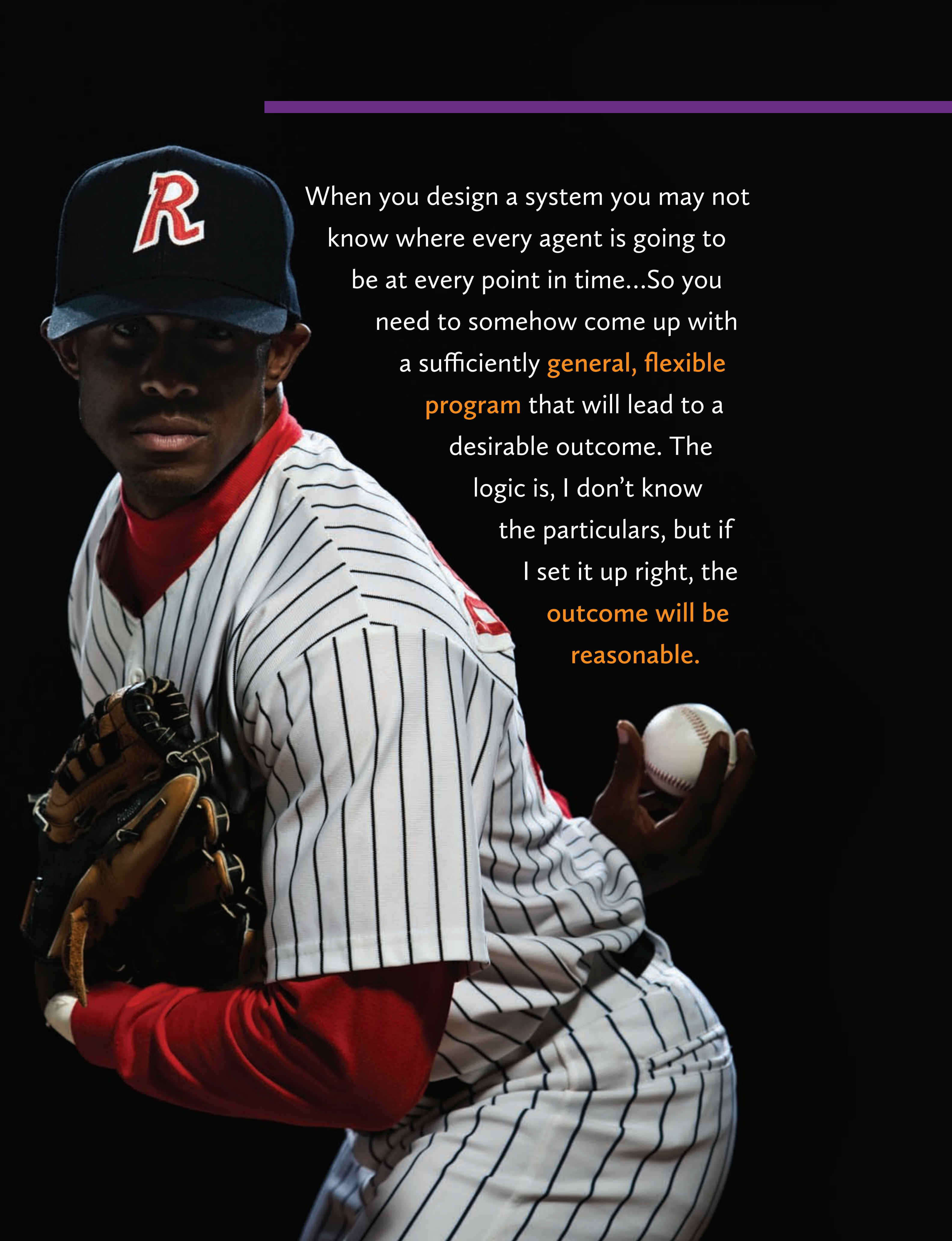
One direction is to expand its scope up, toward the social level, Krakauer says. The term for this is "distributed cognition," something that occurs wherever knowledge, skills, and decision making are distributed across populations of individuals in societies and organizations.

The other direction for cognitive science is to narrow its scope down to the sub-components of the individual brain—to the level of cells, molecules, and circuits. Cognitive scientists can then ask at what points, and by what degrees, do the collective actions of mindless neurons and small-brain structures increasingly add up to a full-fledged, intelligent self.

Krakauer is organizing five groups that will interact over the coming year. The theme of these groups is captured under the umbrella of *Emergence in Decision Making and Cognitive Systems,* one of four focus areas at SFI. (The other three focus areas are scaling, risk, and conflict.) Krakauer's workshops will explore various ways to understand cognition when it is distributed across scales both higher and lower than the individual brain. Three of the groups will be based at SFI; the other two will be centered at other institutions in California.

Two of the working groups are devoted to game theory, a behavior-oriented branch of mathematics that analyzes strategy, decision making, and reward seeking. Game theory has found applications in many fields, notably in economics, international relations, and evolutionary science. Game-theoretic analysis can illuminate optimal strategy, the expected payoff of a given action, and predictions about the likely strategies of competitors and allies.

Game theory is an elegant edifice, Krakauer says, but it is sometimes criticized as being too rarefied and abstract. At its core, it posits an idealized decision-making agent who has a highly streamlined and optimized psychology. This model is sometimes mockingly referred to as *Homo rationalis,* the Platonic ideal of a fully rational, self-interested, utility-maximizing individual. *Homo rationalis's* ability to derive and execute the mathematically optimal strategy for any given "game" is all well and good, but as everyone knows, flesh and blood *Homo sapiens* often deviate from it. They might buy lottery tickets, invest in socially responsible mutual funds (which do not maximize their profits), get swept up in dot-com and housing-bubble manias, dash the chess board to the ground and sulk home.



When you design a system you may not know where every agent is going to be at every point in time…So you need to somehow come up with a sufficiently **general, flexible program** that will lead to a desirable outcome. The logic is, I don't know the particulars, but if I set it up right, the **outcome will be reasonable.**

The game theory working group **Reasoning and Beliefs in Strategic Settings: New Foundations from Empirical Data** is led by former Omidyar Fellow and extramural fellow Willemien Kets, from Tilburg University, the Netherlands. The group aims to modify game theory to make it more psychologically realistic—to bring it more in line with how decision making actually happens in the real world.

"One of their questions," Krakauer explains, "is whether within the existing framework of Bayesian game theory [the branch of game theory concerned with how agents learn and adapt their strategies] there might be ways to incorporate elements of real neuroscience, psychiatry, and cognitive science into the mix. In a sense, to make it more complicated"—but in a good way.

As part of their contribution to this workshop, Krakauer, SFI Professor Jessica Flack, and SFI Omidyar Fellow Simon DeDeo are approaching the problem with a slightly more radical method. Rather than attempting to fix game theory with tweaks and half-measures, they plan to cast the whole edifice aside and rebuild it from scratch.

"Game theory never came out of social data," says Krakauer. "It came out of the mathematics of parlor games—poker—and then was generalized to real-world situations in a kind of abstract, toy-model sense. So our question is, what if we started again, but this time with the social data itself? Could we do any better [than classical game theory] at making sense of how strategic interactions are carried out by real people?" The new edifice they hope to build has been dubbed *inductive* game theory.

The second working group with a game-theoretic orientation, **Decentralized Control in Systems of Strategic Actors,** is being organized by David Wolpert (NASA's Ames Research Center), SFI Professor D. Eric Smith, and Robert Ecke, Director of the Center for Nonlinear Studies at Los Alamos National Laboratory. This group uses as its springboard the work of SFI Science Board member Eric Maskin, who is based at the Institute for Advanced Study in Princeton and who won the Nobel Prize in Economics in 2007 for his development of mechanism design theory.

The interest here is in designing behavioral settings that channel agents' collective behavior in desired directions. In a sense, Krakauer says, it inverts the usual way game theory gets applied: Rather than analyzing the behaviors and strategic incentives of the agents engaged in a given game, mechanism design seeks to construct a set of game rules and a game environment up front that, once set in motion, guarantees certain group dynamics or kinds of outcome. Mechanism design theory has broad application, including to auction systems, voting systems, market regulation, industrial processes, and emergency procedures.

"When you design a system," Krakauer explains, "you may not know where every agent is going to be at every point in time, what goals each one will be pursuing, or what information each one is going to have access to. So you need to somehow come up with a sufficiently general, flexible program that will lead to a desirable outcome. The logic is, 'I don't know the particulars, but if I set it up right, the outcome will be reasonable.' "

The third working group, **The Role of Entropy in Language, Communication, and Behavioral Sequencing,** is co-organized by Krakauer, philosopher and linguist Mark Johnson from the University of Oregon, and linguist Katherine Demuth of Macquarie University in Sydney. This group is interested in exploring human communication and behavior in terms of information theory (the mathematics of encoding and transmitting information), entropy (ambiguity or information loss during communication), and formal grammars (rule sets for manipulating information-bearing symbols such as numbers, words, gestures, and actions).

Its ultimate achievement, Krakauer says,

A baseball pitcher provides a strong metaphor for the complexity of cognition. The whole game centers on his interaction with the other players as well as his physical skill in handling the ball.

would be to build a bridge between classical Chomskyan linguistics and the motley hoard of language-related neuroscience data that are still in search of a strong unifying theory. These two approaches still stand largely at odds. The Chomskyans have an elegant and rigorous logico-mathematical theory of grammar, but their theory is completely silent on (as well as historically indifferent to, and even contemptuous of) the question of how the living brain might actually instantiate it. In another camp are cognitive scientists who demand a biologically grounded, neurodynamical account of human language and social behavior. At present, Chomsky is Chomsky and neurons are neurons, and never the twain have met. By forcing these estranged bedfellows together, the scientists will address a host of difficult questions about how language, communication, and decision making work at the neural, individual, and social levels.

The last two working groups are collaborations with cognitive scientists in California.

Krakauer is co-organizing the working group Distributed Computation and the Emergence of Mind with neuroscientist Mike Gazzaniga at his home institution, the University of California at Santa Barbara. Gazzaniga is best known for his longtime study of split-brain patients—people who have had severed the major fiber tract that connects the left and right halves of the cerebral cortex. Such patients become split into two quasi-selves that are no longer quite unified, and neither of which is quite whole. The severed selves can have different skills and opinions, and can even hold contradictory beliefs. Yet they will often go to absurd lengths to rationalize and claim credit for the behaviors and choices of the other hemisphere—as though they were striving to hold on to a sense of undiminished free will.

"His whole career, Mike has been very interested in the problem of the unitary sense of consciousness," Krakauer says. "If there is no homunculus [no "pilot" controlling the brain from a central command center], how is it that cells in a distributed network somehow conspire to make a decision that they all seem to agree with—and that you, as a sensible conscious entity, think you made?"

This is a huge and enduring puzzle in neuroscience: Coherent thoughts and coordinated behaviors arise from the noisy chatter of billions of nerve cells, and there is no central controller anywhere to be found. The group will examine this problem through a couple of approaches. One is to look at how neural activity gets coordinated over multiple scales of space and time. The other is to look at brain development, and try to see how coordination mechanisms get established while the system is first setting itself up.

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The last working group, The Road to Cognitive Dynamical Systems, will be held at the Salk Institute in La Jolla, California. In addition to Krakauer, its organizers are Josh Bongard of the University of Vermont, Simon Haykin of McMaster University, Canada, Jose Principe of the University of Florida, Terry Sejnowski of the Salk Institute, and Steve Zucker of Yale University. Their aim is broad and deep, says Krakauer: "If we think of decision making in dynamical systems terms—feedback loops, interacting sub-assemblies, coordination over different time scales—can we find a *unified framework* for studying all things cognitive, everything from robotics and neuroscience to behavior and social science?" The agenda is "explicitly general" and highly ambitious, Krakauer admits, but that is all in keeping with the spirit of the Santa Fe Institute. ◀

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