THE DRIVE FOR KNOWLEDGE

Humans constantly search for and use information to solve a wide range of problems related to survival, social interactions, and learning. While it is clear that curiosity and the drive for knowledge occupies a central role in defining what being human means to ourselves, where does this desire to know the unknown come from? What is its purpose? And how does it operate? These are some of the core questions this book seeks to answer by showcasing new and exciting research on human information-seeking. The volume brings together perspectives from leading researchers at the cutting edge of the cognitive sciences, working on human brains and behavior within psychology, computer science, and neuroscience. These vital connections between disciplines will continue to lead to further breakthroughs in our understanding of human cognition.

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The Science of Human Information Seeking

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Contents

Figures

Tables

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Preface

Irene Cogliati Dezza, Eric Schulz, and Charley M. Wu

What defines us as humans? Named *Homo Sapiens*, or "Wise Person" by Carl Linnaeus in the eighteenth century, what seems to distinguish us from our nearest primate relatives is our knowledge – or rather, our appetite for knowledge. Indeed, Aristotle begins his volume on Metaphysics with the simple statement "all people by nature desire to know."[1] This central role of human curiosity also permeates life and culture well beyond dusty academic tomes, abounding in the creation myths that define our cultural identities, from Adam and Eve seduced by the fruit of the tree of knowledge to Pandora tempted by the irresistible mysteries of a locked box.

While it is clear that curiosity and the drive for knowledge occupies a central role in defining what being human means to ourselves, an important concern is where this desire to know the unknown comes from. What is its purpose? And how does it operate? These are some of the core questions we seek to answer in this book. These are not new questions, of course, since they have occupied the minds of innumerable thinkers over countless generations. But today, we have new tools and methods for providing answers, from computational models of human information-seeking behavior to peering into the brain using an arsenal of neuro-imaging techniques. With these new tools has come the advent of new theories that unite previously disparate fields: connecting neuroscience with recent advances in artificial intelligence, bridging the psychology of childhood development with mathematical theories of learning, and countless other criss-crossing avenues of interdisciplinary research. Emerging from this hotbed of innovative and collaborative research is a new science of human information-seeking, which we proudly showcase between the covers of this book.

[1] Linnæus, C. 1758. Systema naturæ per regna tria naturæ, secundum classes, ordines, genera, species, cum characteribus, differentiis, synonymis, locis. Tomus I. Editio decima, reformata. 1–824. Holmiæ. (Salvius).

The drive to seek information can come from diverse motives, fulfilling different biological and neurological functions, and producing disparate outcomes when paired in opposition to other drives, such as toward reward or avoidance of pain. Acquiring new information serves the crucial functions of making sense of reality, improving our internal representations of the world, and driving the development of our skills and intellect. In general, acquiring more information empowers us to solve increasingly sophisticated problems, from the mundane "What should I eat for lunch?" to pivotal life-or-death survival scenarios such as "Should I fight or flee?" Yet we do not only desire useful or relevant knowledge; rather, new information and novel sensations seem to be enjoyed for their own sake. Information thus seems to have hedonic value and can induce sadness, joy, or fear. Our drive for knowledge is therefore tangled up in the regulation of emotions and affective states, perhaps providing a key piece of the puzzle for understanding clinical disorders, such as depression and anxiety. Moreover, humans not only engage in information-seeking when interacting with the external world, they also search for information internally, when dredging up an old memory, searching for a prelearned motor sequence (e.g., shooting a basketball after a long absence from the court), or selecting which sensory information to attend to (e.g., at a busy cocktail party). The search for information is thus a crucial process anytime we act, learn, and decide in the world.

Today, with modern advances in global communication through the Internet and social media, people have access to more information than ever before. The sum of scientific and medical knowledge is at our fingertips, and constant updates about world events and insight into the personal lives of friends and celebrities are available to continually ping us on our phones, tablets, and computers. With more information, however, comes more choice about what knowledge we wish to seek out. The current crisis of misinformation and belief polarization on social media may be partly explained by our cognitive mechanisms for information-seeking – tuned over long evolutionary timescales – doing its best to adapt to the new information landscape we now find ourselves in.

One consequence of the complexity and breadth of research on information-seeking behavior is that the research landscape spans a rich but scattered manifold, encompassing diverse disciplines including psychology, economics, neuroscience, and computer science. This means that the terminology can vary widely across and within disciplines. Terms such as "curiosity," "novelty," and "interest" are often used to ground the science of information-seeking in the intuitive

concepts we all share through common experience. These terms are often related to more technical terms, such as "information gain," "entropy minimization," or "prediction error," which provide a mathematical and computational framework for quantifying and comparing the informational value of different behaviors.

To make sense of these different approaches, this book is organized according to three simple questions: **What** drives humans to seek information? **How** do humans search for information? **Which** machinery supports the drive for knowledge? Each question is targeted in three separate parts, but with plenty of spillover and connections across parts.

Part I aims to answer the question "What drives humans to seek information?" Humans are internally driven to make sense of the world in the same fashion as they are driven to seek primary rewards such as food, water, sex, etc. Wojtowicz et al. (Chapter 1) explore the motivational factors that drive humans to make sense of the world through acquiring novel information. Acquiring novel information is also achieved at different time scales. Donnellan et al. (Chapter 2) discuss a novel framework of knowledge acquisition which unifies one-time information-seeking (i.e., curiosity) and long-term development of information-seeking motivations (i.e., interest). Information-seeking is also key to autonomous learning in the real world. By facilitating faster, more efficient learning, intrinsically motivated curiosity prepares both artificial and biological agents to perform better in future problems. Ten et al. (Chapter 3) focus on the functions, mechanisms, and usage of intrinsic motivation as a mechanism to promote information-seeking and boost the rate of learning. Lastly, De Simone and Ruggeri (Chapter 4) provide an overview of how different forms of information-seeking behaviors develop over the lifespan. They plot a developmental trajectory of active learning, unified by the three core capacities of "sensitivity" to environmental inputs, "competence" in selecting and generating informative queries, and "adaptiveness" in tailoring learning strategies to the structure of the environment.

Part II attempts to answer "how" people search for information. In particular, different theoretical frameworks are presented to describe the computational principles underlying information-seeking. Meder et al. (Chapter 5) provide an overview of different formalizations for quantifying the value of information based on the principles of Bayesian experimental design. This provides an organizational layout for different probabilistic models and heuristics used to model human information acquisition, based on different approaches for characterizing uncertainty. Sajid et al. (Chapter 6) further bridge domains by exploring how active inference

unifies Bayesian experimental design with Bayesian decision theory: when removing prior outcome preferences, active inference reduces to Bayesian experimental design, while in the absence of ambiguity and relative risk, active inference reduces to Bayesian decision theory. Brändle et al. (Chapter 7) discusses the limitations of traditional decision-making tasks (i.e., multiarmed bandits) used to study human information seeking, and proposes a shift toward more real-world problems, where empowerment-based exploration strategies can expand the study of human exploration to a richer repertoire of scenarios. Lastly, since most of what we learn is from other people, the study of information-seeking must also consider how information is exchanged both between and within minds in a social context. Wu et al. (Chapter 8) present a novel framework for studying human social learning, oriented around the representations involved (e.g., behavioral policies, values, and beliefs). This framework provides new insights into how people select from different social learning strategies and combine socially acquired information with their own mental representations.

Part III seeks to answer "Which machinery supports the drive for knowledge?" Since information is valuable, similar to primary or monetary rewards, the neural machinery used to process information may mimic that of reward processing. However, by exploring the neural mechanisms and motives underlying information-seeking behaviors, Charpentier and Cogliati Dezza (Chapter 9) review recent discoveries showing two different neural networks involved in information-seeking: one network sharing similar neural codes with reward processing and another independent of it. Furthermore, since the brain has resource-limited capacity, it has to select only information relevant for behavioral benefits. Gottlieb (Chapter 10) explores the neural mechanisms underlying the selection of relevant information, suggesting that these processes are modulated by learning, individual goals, biological constraints, and behavioral contexts. Another indication of neural machinery shared between different cognitive systems is when comparing commonalities of search behavior in internal and external spaces. Hills et al. (Chapter 11) argue that the strategies adapted for search in external spatial environments are similar to those used to seek information internally from memory, as demonstrated by the use of classic models of spatial foraging used to predict internal search in memory. This framework suggests that the representational structure of inner space may be shaped by the processes people apply to search within it. Lastly, information-seeking is not only a drive to acquire new knowledge, but also to connect ideas and relate knowledge about different things

in the world. Zurn et al. (Chapter 12) discuss a novel framework that moves away from an acquisitional account of curiosity to a connectional one. In doing so, this chapter describes how humans build their own network of knowledge and how both personal traits and states influence this building process.

In the conclusion of the book, we discuss the open questions and future challenges the field may face in the coming years. For example, how is information-seeking related to reward-seeking? What are the principles that enable us to acquire useful information with computational efficiency, despite possessing limited cognitive capacities and knowledge? Which aspects of our neural machinery are unique to information-seeking, and what is shared across other cognitive systems? We conclude by discussing how the science of information-seeking informs important societal issues. Just as limitless as our appetite for knowledge, so too is the science of information-seeking bounded only by the limits of our curiosity.