It is not a small irony of our age that even as humans place a telescope millions of miles away from the earth to study the early universe, effortlessly manipulate building blocks of life in the laboratory, and develop artificial intelligence that could fundamentally transform what it means to be human, we have floundered at understanding our own place within the awesome physical and epistemic structures of our design. Amid (and despite) extraordinary advances in science and technology, humans stumble when it comes to understanding the basics that are essential for survival of the species. The conditions that could lead to emergence of cooperation amid widespread conflict; collectively-accepted limits on resource consumption; the tradeoffs between attainment of individual goals and social goods, and—at a very fundamental level—how to negotiate individual and group existence in a world of extraordinary human-made complexity—these are challenges that remain nowhere close to being met even as the second quarter of the twenty-first century looms in the horizon.

"Know thyself." It would have served us tremendously if science paid greater attention to this Delphic exhortation as humans falter at negotiating the Anthropocene, with the specter of large-scale organized violence, and widening inequality that stands to upset already-precarious social orders. To successfully navigate the next pandemic, to stop the next global war, to align intelligence we have created to our own values will all require knowing ourselves much better than we do. It will require a new science of humans, rigorously built from the intellectual tools that study of the physical world necessitated. Having successfully decentered the human in natural philosophy, we must now reconceptualize their central role in the physical world.

But wait, one could argue: we have, after all, made tremendous advances in biology and cognitive science that have vastly improved our understanding of ourselves; we have created social sciences that have informed how we organize societies, allocate resources efficiently, and have even built mental models of bargaining and conflict that have kept (as some theorists of deterrence argue) nuclear annihilation at bay for almost three-quarters of a century. Do considerable advances in biology, psychology, sociology, economics, and political science not obviate the need for another human science? Should we not—instead—work towards a grand synthesis of insights from these various disciplines to address our current predicaments as a species?

Not really. The study of the physical world of inanimate matter has been driven largely by the search of "fundamental" underlying laws (the standards of what constitutes the fundamentals varying from era to era) and closely informed by a concomitant increase in mathematical sophistication and empirical methodologies. However, advances in understanding human behavior both at an individual level and as collectives (of social groups, nation-states, civilizations etc.) have largely happened in fits and starts, with no single overarching cross-generational intellectual program behind it. Unlike physics, say, where working practitioners share a common understanding of what the most important questions of their generation are and how to go about attempting to answer them, what to build on and what to discard, scientists who study human behavior are yet to come to such consensus. A consequent problem that continues to plague social sciences is that of "micro-foundations." For example, it is almost impossible to satisfactorily derive principles of contemporary macroeconomics (of aggregate output growth) from the study of microeconomics (individual utility-maximizing economic agents) outside highly-specific and much contested models. Worse still, economists continue to vigorously debate the very meaning of micro-foundations. To understand just how unsatisfactory this situation really is, imagine we were still debating how to bridge thermodynamics and statistical mechanics, and Boltzmann's H-theorem was nowhere in sight!

This is not all. Consider political science, and security studies in particular. Largely driven by the demands on Cold War American academia, security studies—especially the study of nuclear conflict—grew into a subject of considerable sophistication. Mathematical modelling, in the form of systems analysis and game theory, has played a significant role in understanding incentives and disincentives of striking first, crisis bargaining, and conditions for escalation control in war. And yet, prominent security-studies scholars variously debate basics such as the extent to which rationality assumptions made by many of the formal models are needed to understand the problem at hand, and indeed, the extent to which such assumptions, and models in general, are valid in the first place. Meanwhile, the discipline has made no serious effort to integrate advances in biology of human behavior and cognitive science into the panoply of conceptual tools that define its extant intellectual tradition. Mathematically-minded security studies experts study conflict using tools from microeconomic theory, perhaps not completely internalizing the fact that microeconomic theory itself is grounded in empirically-suspect assumptions.

Decentering Humans in Science

It is not hard to guess how and why human behavior never quite emerged as a fundamental object of study in natural science. The Copernican revolution removed the earth from the center of the human's mental universe, while Newtonian physics—by presenting precise and empirically verifiable laws—demonstrated how the very large and the very far can be understood with the same mathematical language that describe the falling apple and the spinning top. The impact of these developments on the growth of modern science cannot be overstated. Following Newton, astronomy quickly emerged as the most prestigious of sciences. The study of dynamics—as applied to celestial objects—spurred dramatic advances in mathematics which, in turn, contributed to the bright luster of Newtonian science and defining not only a paradigm of doing science that continues till date, but also setting a complex of intellectual priorities that is respected to date. The study of mechanics gave way to the study of heat, light, and electricity to which the 20th century added the study of atoms and subatomic particles. The overarching effect of this intellectual progression culminated in fundamental physics being completely being identified with the study of dynamical particles and fields as they affect the very small and the very big. Along the way, as physics grew in conceptual and mathematical sophistication, the study of humans and their everyday environment—which sits somewhere in the middle of the log-plot of size versus mass-energy that covers the most of the observable universe, as the mathematical physicist Shahn Majid has shown—was left by the wayside. Science, to be worth its salt, had to be quantitative and predictive, its objects of study governed by universal laws.

These standards almost automatically preclude humans as objects of truly-scientific study: outside the laboratory, much of human behavior is extremely hard to quantify (a situation that is somewhat changing now with the rise of ubiquitous wearable "smart" sensors); predicting *individual* human behavior "in the wild" is well-nigh impossible. When humans have occasionally been marshalled back into the physics, the goal has been to resolve two persistent conceptual problems in the physics of the very small and very large: the collapse of the wave-function in quantum mechanics and fine-tuning in cosmology through anthropic principles.

But at a deeper level, much of why human behavior did not emerge as a worthy object of study in its own right unlike, say, electromagnetism or fluid flow, has to do with influential Enlightenment philosophical traditions that grew out of the Cartesian duality strictly separating the mind and body and privileged the position of reason as domain of the former. If the only certainty you have of your own existence is your ability to think, then—as a direct corollary of Cartesian thinking—it is your thoughts that matter and not how they manifest themselves through your behavior. It is therefore not surprising that when leading thinkers between the 17th and 19th centuries like Boole, Hobbes, and Leibniz did turn their gaze towards the mathematical study of human beings, it was to develop logical foundations of thought and reason, ideas that proved to be directly or indirectly influential in the development of computing and automata. The set of ideas that revolve around the notion of a rational mind as a mechanical, *computing*, machine would in turn dominate cognitive science in the 20th century which put a premium on a putative ability of humans to effortlessly manipulate symbols in their head, providing ballast to the notion of a rational human that has so effectively (and problematically) shaped contemporary social sciences.

What is quite ironic is that, with a few notable exceptions, the rise of humanist sentiments across Europe, the French Revolution, and the Reformation did not lead to a greater interest in the scientific study of human behavior. If anything, contemporary beliefs about freedom of choice and will went against the search for lawful patterns in human behavior. As the physicist Geoffrey West writes, the 19th century Belgian mathematician Adolphe Quetelet's studies on what Quetelet termed *social physics* was found by his contemporaries to be rooted in a deterministic worldview, and therefore unsatisfactory. Interestingly, in his statistical quest for an "average man" Quetelet himself was inspired not so much by humans as fundamentally different objects of scientific study but by the tremendous success of contemporary astronomy. Newton continued to cast a long shadow over his successors even when they turned their attention to earthly problems.

The work of André-Marie Ampère—whose father was guillotined by the Jacobins despite being an early supporter of the French Revolution— provides an interesting counterfactual about what might have happened if scientists who had direct experience of the Revolution had drawn lessons from its implications for a putative study of human behavior. Ampère, who first coined the term *cybernétique* as an "art of steering in general," was also a pioneer in the mathematical study of risk and games, thus strengthening his position as the intellectual grandfather of what became cybernetics in the mid-20th century, as the writer George Dyson convincingly claims. Ampère was also a devote of Rousseau, free-will proponent extraordinaire. It is a great missed opportunity of history that Ampère did not find a way to integrate his scientific thoughts with philosophical influence in the backdrop of tremendous political and intellectual ferment.

However, one individual did try to draw up a scientific program from the churn of the French Revolution: the philosopher Auguste Comte. Comte's study of the social group, scholars have argued, drew deeply from the lessons he drew from the Revolution and the changing nature of post-Revolutionary society. More than Quetelet, Comte foresaw the need for a separate science of the social as a requirement of his moment, "[n]ow that the human mind has grasped celestial and terrestrial physics, mechanical and chemical, organic physics both vegetable and animal…"

What Should a Human Science Study?

So far, I have alluded to a science of humans, implicitly equating with a science of individual and collective human behavior. Why did I not define the subject more concretely right away? I did not do so because it is difficult, and much of the difficulty stems from defining humans as a distinctly different class of animals and in a way that distinguishes human behavior from that of the other mammals or even other primates. After all, whales communicate in a way as to resemble language, chimpanzees can do basic arithmetic, gorillas take part in organized violence, and dogs perceive goal-directed behavior. We also know rats dream, ants exhibit remarkable sociality through elaborate interaction networks, and garter snakes behave like teenagers in their acquiescence towards group preference.

However, humans are different from other animals who may share "human-like" attributes such as the ones mentioned above in one singular way: they are able to marshal many or all these attributes at once, melding one with another in surprisingly interesting ways. For example, when a burglar points a gun at someone to relieve them of their belongings, spelling out his aim in clear understandable speech, he is, simultaneously, exhibiting goal-directed behavior through language and gesture, demonstrating intent, and anticipating a future. If, luckily for the hapless victim, the police do show up in time but the burglar escapes, his intent would have been modified by a unit of social organization that encompasses him, namely legislation that forbids robbery—an excellent example of downward causation.

From such examples and centuries of ethological and social studies, humans can be abstractly defined as:

1. possessing the ability to **anticipate**, **intend**, and generally exhibiting **goal-directed behavior**;
2. characterized by **individuality** that is **contingent** and **history-dependent**;
3. capable of **communicating** and **learning**; and
4. exhibiting **sociality** when considered in aggregate.

A science of human behavior would—and should—take these abstract attributes as a starting point, and try to deduce consequences of their interactions. That science should possess enough explanatory (and not necessarily, predictive) power to map everyday human phenomena at multiple time scales—from simple interactions to complex collective behavior –to a combination of these attributes. Finally, the science should be grounded in natural laws, not in the sense of enunciating a single set of laws that govern all human behavior but in the sense that models of the attributes mentioned should be stated in observable, measurable and conceptually-unambiguous terms.

Missed Opportunities and Close Approaches*

With a (perhaps provisional) definition of what it takes a human to be so, we turn to how close or far we have been in the past when it came to developing a comprehensive physics of human behavior, and how such a science could have enriched physics in turn. Let us start with anticipation, intention, and goal-directed behavior. To my mind, the fact that these aspects of human behavior were not explored in the 19^{th} century for example remains a tragedy, even more so because the conceptual tools to do so clearly existed at that time.

The tools are in the form of certain formulations of Newtonian mechanics, which have an essentially teleological nature making them eminently suitable for the exploration of goal-directed behavior. Consider the extremal principles which led to spectacular success in optics and mechanics, such as the "least" action principles of Hamilton and Maupertuis. The impact of these teleological formulations has extended beyond physics and into the realm of engineering in the form of control theory. To wit, the Bellman theorem can be formulated as a Hamilton-Jacobi theory, a fact that was discovered in the hay days of control theory spurred by military and aerospace concerns. Control engineering, in turn, provided half the motivation for Wiener's cybernetics, a once-promising discipline that not only tried to explain (non-social) human behavior but also put human and artificial systems on the same footing. Feynman's formulation of quantum mechanics in terms of path integrals and sum-over-histories—a direct successor of the extremal principle approach to classical mechanics—have found applications in finance and theory of stochastic processes, and have led some psychologists to view it as providing a template for understanding intentional behavior in conjunction with control-

* Due to space constraints, I must—regretfully—leave out scientific advances over the past century or so that have also contributed to a better understanding of human behavior even when falling short of providing a road map to a complete science. They include Robert Rosen's work on anticipatory systems, Herbert Simon's investigations on complexity, hierarchy and modularity, the work of James Gibson and other ecological psychologists and, last but not least, brilliant contributions by complexity scientists.

theoretic notions. That said, teleological formulations of mechanics have remained under-explored as tools to understand human behavior. Teleology is still taboo.

"Happy families are all alike; every unhappy family is unhappy in its own way." These famous lines from Tolstoy's *Anna Karenina* capture a profound notion characterizing individual humans as well as groups. We are all different, though our differences are some times more pronounced in certain contexts specified by chance as well as history. The former necessitates that any science of human behavior have a strong (but context-specific) stochastic component. The latter forces us to take path-dependence seriously. And both served as formidable obstacles in situating the human within science as a principle objects of study. While statistical physics took chance seriously—interestingly Maxwell used one of Quetelet's theoretical ideas from the study of social physics in his kinetic theory of gases—fundamental physics of the 19th century remained too deeply wedded to Laplacian determinism for probability to permeate deeply into the sciences. Meanwhile, the time-reversible nature of a large scale of dynamical systems meant that history—which is, by definition, an expression of time *asymmetry*—could also not be treated as something that was amenable to serious scientific investigations. In fact, the study of path-dependent phenomena in social science is relatively recent, stemming from the work of Brian Arthur in economics. Taking individuality shaped by contingency seriously would also have meant that physics could have come to grips with how some physical models sensitively depend on initial conditions much earlier.

The human ability to communicate and learn is another area which would prove stubborn to examine as modern science, spurred by physics' success, was taking shape. Part of that has to do with implicit equations of communication, reason, and thought that have dominated thinking about language for a long time which, in turn, pivoted around Cartesian beliefs I have explored earlier in this essay. But the irony is that it was not for the lack of empirical material about how meaning was encoded into, and decoded from, optical, electrical, and radio signals. The heliograph, telegraph, and radio could all have been subject of scientific study as providing touchstones to test ideas about the nature of human communication especially as probability theory and statistics was taking roots through studies of games of chance and social measurement. Could at least aspects of Shannon's information theory have been anticipated much earlier?

The study of social behavior in terms of networks is also something that should not have waited as long as did before emerging as a trending topic in 21st century quantitative social science.

Recall that graph theory found its earliest applications, in chemistry, in the work of James Joseph Sylvester and Arthur Cayley, with atoms being vertices and bonds edges. In modern sociology, individuals are represented as vertices and relations between individuals, edges. This remarkably simple idea can often shed considerable light on aggregate human behavior including malign ones such as acts of terrorism. To be sure, modern computing has enormously aided with the linear-algebraic calculations that are needed to generate interesting measure of "nearness" or "influence." But conceptually, a lot of the work that has been done with social networks relatively recently could have been done a long time ago albeit much more laboriously.

A last observation about missed opportunities. It is deliciously ironic to note that—whether it be goal-directed behavior, individuality, communication, or sociality—the tools that we now identify as being key to a science of human behavior arose not through its study but by the demands placed by human-made constructs. The problem of control rose to the fore for Wiener through his study of fire control systems for aircraft guns, and earlier, for Maxwell from the problem of controlling steam engine speeds. Probabilistic thinking grew out of gambling and games of chance. The study of communication as a mathematical science had to wait for the emergence of large-scale telecommunication systems. And finally, social networks came to prominence much later—in the late twentieth century—as the Internet grew to a planetary scale. It seems the study of the human as a scientific object must be preceded by humanity reaching a certain level of technological sophistication. This bodes well for the future. Will the rise of sophisticated robotics and machine-learning techniques inspired by the layered structure of the human brain finally enable us to make the leap to a new science?

Recentering Humans in Science

If humans are to be treated as fundamental objects of study—at par with particles and fields—what conceptual bridges must we first build? I would argue that it involves (1) obtaining a clearer understanding about the relationship between models and the objects who provide the representations that form them, and (2) getting a better grip on two fundamental "cuts" that frame the endeavor.

Currently, mathematical models of human behavior often pertain to collective behavior (in the sociophysics framework of Galam and others). In many ways, this is a useful research strategy, allowing for judicious applications of concepts from statistical physics to social problems. But absent a conceptually clearer picture of what the fundamental "atomic" units of the problem constitute—that is, an unambiguous understanding to what makes a human human—there is a real risk that physicists would shoehorn their favorite statistical-physics techniques (phase transitions, renormalization group, etc.) to model a given phenomenon. The very success of this approach can also be misleading in that by focusing exclusively on models of collective behavior (and implicitly assuming course-graining), the social facet of human behavior becomes divorced from the others (goal direction, contingent individuality, and communication). This is bound to eventually lead to the micro-foundations problem that so plague contemporary economics, for example.

At the same time, there are models of collective human behavior that rely techniques from other disciplines, such as nonlinear dynamics: how different ways of looking at similar problems can be reconciled within a single mathematical framework remains an extremely vital task. At the same time, as mathematical scientist and public policy expert Joshua Epstein points out by way of showing how social science must eventually become a part of biology, different models of human behavior *can* emerge as special cases of a single formal system (illustrating this with the Lotka-Volterra equations which specialize to both the Richardson and Lancaster models of conflict). A large part of a new science of human behavior should revolve around the judicious study of general domain-independent formal systems. But most importantly, one must keep in mind that models inspired by physical phenomena would form only a subset of models of human behavior. A science of human behavior will require certainly require more ideas than what is available in contemporary physics texts.

The second observation pertains to the two "cuts". While one is straightforward ("the map is not the territory"), one needs to keep in mind that there is no straightforward strategy to decide the criterion of parsimony in building models of human behavior. Modelers who do so can attest to the real temptations of curve-fitting by introducing large number of parameters which have (at best) tentative links with the problem at hand. But it is the other cut that is philosophically more significant resembling, as it does, Heisenberg's *schnitt* (that demarcates the observer and the observed in quantum mechanics). The *schnitt*, in Howard Pattee's formulation, is an epistemic cut, demarcating two completely different—and apparently irreconcilable—regimes of knowing and the knowable. A new science of human behavior has so far not materialized because we have, for a variety of reasons this essay has described, treated human and inanimate-physical behavior in completely different terms; hence the oft-touted distinction between "hard" and "soft" sciences, for example. Science can be what it should be only by finding a way to square the two within a single conceptual frame.