THE DIVERSITY BONUS

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HOW GREAT TEAMS PAY OFF IN THE KNOWLEDGE ECONOMY

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PRINCETON UNIVERSITY PRESS PRINCETON & OXFORD

Published by Princeton University Press,
41 William Street, Princeton, New Jersey 08540

In the United Kingdom: Princeton University Press,
6 Oxford Street, Woodstock, Oxfordshire OX20 1TR

press.princeton.edu

Cover design by Karl Spurzem

First paperback printing, 2019

Paperback ISBN 978-0-691-19153-9

Cloth ISBN 978-0-691-17688-8

Library of Congress Control Number: 2017938361

British Library Cataloging-in-Publication Data is available

This book has been composed in Sabon and Trade Gothic

Printed on acid-free paper. ∞

Printed in the United States of America

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INTRODUCTION

EARL LEWIS AND NANCY CANTOR

Recently audiences flocked in record numbers to watch *Hidden Figures*, which told the uplifting story of three brilliant African American women who played indispensable but largely unknown roles at NASA in the iconic American success story of John Glenn's launch into orbit and the Apollo missions that followed. These women, products of the segregated South, made lasting contributions to the nation's space program in spite of social strictures that initially limited their inclusion. Their achievements improved the work of NASA's teams of scientists, enriched the space program as a whole, and helped accomplish the national goal of putting a man on the moon. For the team tackling a complex problem, their cognitive skills, grit, determination, and drive proved a plus.

Hollywood's dramatization of a moment of exclusion that begrudgingly transitioned to a moment of inclusion is set against the backdrop of unfolding social and political practices. Recall that segregation was birthed in the late nineteenth century, matured into a hardened system through the middle of the twentieth century, and ended formally in the latter quarter of that century. It didn't end voluntarily, naturally, or completely on its own. It ended because women, men, and children organized, agitated, and fought to end it. The women profiled in the film were agents in the forging of change.

DIVERSITY AND INCLUSION: CONTESTED OR VALUED?

As we prepare this introduction, diversity and inclusion remain highly contested. Americans of all faiths, hues, and histories take to the streets and the airports to protest a hastily configured immigration ban that seems to target Muslims and deny access to the refuge and the opportunities that have defined this country's core values for centuries. In London, a global city if ever there was one, marchers

remind Prime Minister Theresa May that while a majority might have voted for Brexit, they won't tolerate sending their neighbors out of Britain or blocking others' entrance into it. Back in the United States, Native Americans rightfully question the normalization of one version of history: "Let me get this straight: You're afraid of refugees coming to America, killing you, and taking your property?"

At the same time, those who oppose the more restrictive rhetoric cannot ignore the fact that scores of others, in the United States, Great Britain, and across Europe, celebrate the "us" versus "them" viewpoint. Online, at family gatherings, and in the press, they fashion a worldview according to which it is better to exclude than to be victimized by those who are included. They are not all nationalists or on the political fringe; some simply question institutions they deem elite and out of touch with their realities. They seek to preserve advantages and look for ways to pass those advantages on to their children and relatives.

In the first volume in the Our Compelling Interests series, we informed readers that diversity and inclusion would not come easily, but a better understanding of what is to be derived from a fuller embrace would redound to the benefit of the broader society. Invariably the question turned to how. How would we make such a decision? How do we know that diversity and inclusion would benefit the common good? How do we imagine this working in the future? Sometimes the past provides a window into the future. During the height of the Cold War, we imagined that people of integrity and substance, once vetted, could and would enrich the United States. Then as now, we selectively let them enter the country and, once admitted, most became loving, devoted citizens. Along the way, their diverse backgrounds, intellectual powers, and honed skills helped us advance as a nation and people.

Emblematic is the story *New York Times* columnist Nicholas Kristof shares about his father, Wladislaw Krysztofowicz: "A refugee who had repeatedly faced death in the Old Country for not belonging . . . now somehow counted as American even before he had set foot on American soil, even before he had learned English. It

was an inclusiveness that dazzled him, that kindled a love for America that he passed on to his son. . . . The church sponsored Krzysztofowicz even though he wasn't Presbyterian, even though he was Eastern European at a time when the Communist bloc posed an existential threat to America. He could have been a spy or a terrorist."[1] But he wasn't, and, in fact, in 1952 the Oregon farming town that embraced him as one of theirs was bettered for welcoming new talent and new diversity to its community; in time it got to claim the "favorite son" that he fathered.

What stands at the core of the argument in this book series, Our Compelling Interests, is the proposition that diversity is to be valued; that welcoming, inclusive communities are strong communities. This is true even at a time when this country (and many others) looks more insular, xenophobic, and divided than it has in some time. This is true even when the dreams of so many different groups seem similarly at risk and the "recovery" from the Great Recession fails to reach evenly across America, evoking a cry for recognition in a "hillbilly elegy,"[2] offering a stark reminder that black lives matter, and producing a searing look of insecurity on the faces of our student DREAMers. Alas, it is even true when the rise of nationalist movements around the globe, equating Islam with terrorism, scarily evoke Nazism and feed the extremism of the very groups we fear, Al Qaeda and ISIS.

Even now, or perhaps especially now, we have a responsibility to turn to first principles: remembering the inclusive assurance of civil rights in the Bill of Rights, even as it remains unrealized;[3] working neighbor to neighbor on the social connectedness ascribed to *E pluribus unum,* even as strong bonds of similarity remain a precondition for secure bridges across difference;[4] and according due weight to the contributions to economic prosperity from full participation in a flat world,[5] even as we continue to leave on the sidelines of educational opportunity too much of our fastest-growing talent pool[6] in the midst of a diversity explosion.[7] Diversity has tremendous value for democracy and a prosperous nation, and we all need to take a step back from the necessary struggles of actualizing it to unpack its dimensions.

A DIVERSITY BONUS

In this volume, Scott Page starts that unpacking process right at the core of our knowledge economy, examining the diversity bonus as manifest in complex, nonroutine, cognitive tasks, precisely the group problem-solving contexts that virtually define the opportunities for growth and prosperity going forward. The Silicon Valley CEOs knew this well when they all committed to diversifying the high-technology industry.[8] Such group diversity also defined the life and work of the three hidden figures at NASA who helped turn around the space race.[9] It was what educational leaders defended when they asserted, in the affirmative action cases at the University of Michigan, that diversity produces educational benefits for all students.[10] And, in those cases, it was central to the arguments put forward in the amicus brief filed by military generals who stressed the national security risk of not having a cadre of leaders as diverse as the teams under them in taxing conditions of uncertainty.[11]

There is a bonus to be reaped in bottom-line performance when diverse groups function effectively together as teams in the highly charged, competitive, fast-changing work settings we face increasingly in today's world—be it in business or in scientific discovery, in classrooms or on the battlefield. The relevant ability of an individual may not suffice—especially if those in the room share almost the same knowledge and set of approaches to problems that require the flow of all kinds of insights and the application of varied tools. Success may depend on the cognitive diversity that makes for intelligent teams, as Page demonstrates in this volume. What we want today are high-ability people who think in different ways and can function together, playing off each other and maximizing the emergent properties of diverse, inclusive, well-functioning teams.

In everyday parlance, the diversity of a team will likely be described as a function of the social identities, complex and intersectional as they surely are (arrayed along dimensions such as race, heritage, sexual orientation, class, and so on), of its members. Yet in Page's analysis, it is the cognitive diversity of a team—measured by

operate across boundaries of difference in an inclusive society. In that light, Page ends his book by asserting that we have a compelling interest to embrace and engage our differences, and the rhetoric and reality that surrounds us all in these times adds an urgency to this clarion call to action.

THE DIVERSITY BONUS

PROLOGUE

THE CONTRARY ASSUMPTION

We have been wrong. We must change our lives, so that it will be possible to live by the contrary assumption that what is good for the world will be good for us.

—WENDELL BERRY, *The Art of the Commonplace: The Agrarian Essays*

THE VENUE VARIES. I MIGHT BE STANDING IN NORTH DAKOTA STATE University's Memorial Union; the Great Hall of the US Department of Justice; Roper High School's gymnasium in Birmingham, Michigan; or Bloomberg's gleaming auditorium on Lexington Avenue in New York City. The composition of the audience differs even more. I might be speaking to college deans, high school students, NASA engineers, Justice Department lawyers, Wall Street titans, or Silicon Valley disrupters.[1]

The event will have been advertised as a talk on diversity. I am cast in the role of expert based on *The Difference*, a book I wrote a decade ago. The introductions run the gamut. A college administrator might read verbatim from my bio, a Fortune 500 CEO might all but ignore a prepared script and sing the praises of the University of Michigan, or a high school junior might nervously tick off bullet points from a notecard held in her trembling hand.

The next thirty seconds always play out the same. Polite applause (who is this guy again?). I walk on a stage. I shake a hand or accept a hug. I face the audience. All is quiet. I pause, smile, and begin, knowing that the conversation about to take place will not be what anyone expects.

I communicate five points before anyone can take a breath. One: I will focus on the pragmatic, bottom-line benefits of diversity in a knowledge economy. Two: I will not present an ideological argument,

will suffer and people will come to see diversity efforts as counter to the organization's core mission.

The sophisticated diversity practitioner recognizes that diversity bonuses require thoughtful hiring practices, and the creation of a culture that enables meaningful, organic interactions between people with different life experiences, educational backgrounds, and identities. This book provides a framework for achieving those bonuses.

When presenting to an audience, I try to gather information beforehand on how to partition the audience across three groups. The first consists of true believers, the diversity advocates. They want their organization and society writ large to be more inclusive for normative reasons—to redress past wrongs or because it is the right thing to do. The second group consists of the deniers. They believe that diversity and inclusion initiatives hinder performance. Some see these initiatives as affirmative action in disguise. The third group enters the room thinking that they would rather be almost anywhere else. They suffer from what the *Economist* in 2016 called diversity fatigue.[3]

I need all three groups to change how they think. The believers must pull back from the unrealistic, magical thinking that holds that identity-diverse groups perform best on all problems. Wanting something to be true or not true does not make it so. The deniers, many of whom attribute their own success to individual abilities, must open their minds to possible benefits. They must see the shortcomings of hiring people who look just like themselves or come from the same five schools. Those suffering from diversity fatigue must see diversity and inclusion as something other than a waste of time thrust upon them by a compliance officer.

I can only accomplish so much in sixty or ninety minutes. I ask that people set aside their political and normative positions and entertain the contrary assumption that diversity and inclusion can produce bonuses. I ask that they listen with open, skeptical minds. I ask that they challenge the logic and evidence. And challenges do come—whether delivered by a precocious seventh grader wondering how gender could influence the way a person approaches a scientific problem, by a skeptical mid-level executive buying into the logic but

questioning the magnitude of diversity bonuses, or by the chairman of the Joint Chiefs of Staff asking how an organization whose members must follow orders can also be innovative.

Those answers will follow, as will a summary of what I learned on a decade-long tour that has included stops in Houghton, Michigan; Monroe, Louisiana; Frankfort, Kentucky; Redmond, Washington; and Princeton, New Jersey. I learned that rewriting a company or university's diversity and inclusion statement matters far less than changing what people believe and how they behave toward one another. The right culture cannot be imposed from above by a bureaucracy or through elaborate diversity and inclusion strategic plans.

As Wes Pratt, the Chief Diversity Officer at Missouri State, remarked to me, we must be the process. The behaviors that produce diversity bonuses must emerge from the bottom up, organically. Each person who belongs to a diverse team brings a history and set of beliefs shaped by their identity. Those histories and beliefs must be validated and appreciated.

Achieving an organic, bottom-up inclusion requires that people believe in the value of interacting across differences and thus seek diversity bonuses. They must be all in. This more organic form of inclusion will be more likely in teams and organizations with a shared mission or goal. This more bottom-up inclusion will be bolstered by a shared understanding of diversity bonuses because people will see different ideas as worthy of deeper investigation.

In the best cases, people begin to appreciate the resonance between our identities and how we contribute. They see how identity differences add more than pragmatic contributions (more accurate predictions, better policies, more innovative solutions, and so on); they also add beauty, grandeur, and meaning to what is produced.

In my travels, I have been amazed by the depth and breadth of knowledge, skills, and passions people bring to their professions—be it building rockets, designing farm equipment, maintaining quality control in computer cable production, or managing financial portfolios. I have been awed by the kindness and generosity of people and of their dedication to creating more inclusive workplaces, schools,

and societies. And yet, I often hear these same people lament the failures of their diversity groups.

It has been my goal to help people build more productive diverse teams. In each interaction, I could see the large gulf between precise blackboard truths and the messy reality of the world of people. Nevertheless, my experiences reinforced rather than attenuated my belief in the necessity of formal logic and models. I witnessed the power of mathematical rigor to cut through ideologically clouded thinking to reveal truths and guide action. Metaphors and stories can spur emotions and rally the team, but they cannot produce deep understandings or reveal the conditions necessary for bonuses to exist. Those conditions guide proper action, and enable us to take claims to data. That data can then be used to test and improve the theory.

As I look out through the glass walls of Mighty Good Coffee in Ann Arbor, I think of the words of T. S. Eliot: I have ended my exploring by arriving back where I started. The logic holds: cognitive and identity differences can produce bonuses. Achieving them in the real world takes practice. We need to learn the behaviors that make the theoretical bonuses real. I am not talking about just being nice. When making predictions, we have to include less accurate, diverse predictions—because we will do better. When hiring people, we have to see value in difference.

The logic I present, revealing the pragmatic benefits of diversity, intersects with and complements arguments for diversity and inclusion based on social justice. Many people, including colleagues and close friends, have said that though they accept the logic and agree that substantial evidence supports bonuses, they believe that pragmatic logics carry less weight than normative arguments. They question how I can place improvements in economic forecasts, marketing plans, and product offerings on equal standing with considerations of social justice and equity.

I do not dispute that point. One cannot equate a 1 percent increase in a portfolio's return or a 4 percent reduction in shipping costs to the value of creating a world free of discrimination. We should care more about creating a world in which each person has an opportu-

nity to succeed regardless of his or her identity more than we care about the IRS creating a tax form that is 6 percent more readable.

That said, I do not see the social justice frame and the diversity bonus frame as in competition with one another. We need not choose between applying our differences to improve our lot and creating an equitable and just world.[4] On the contrary, I view embracing diversity bonuses as crucial to advancing social justice.

Moreover, if we ignore the pragmatic logic and emphasize only equity and social justice, we all but rule out achieving diversity bonuses. Bureaucratic rules that impose arbitrary diversity without any understanding of how to produce diversity bonuses will result in teams that do not make scientific breakthroughs, develop better health care plans, or write captivating screenplays. An occasional group may get lucky, but most diverse groups will not perform well.[5] As a result, people will see diversity as costly and see a tradeoff in their pursuit of the normative ideal. Those who want a more inclusive society will find themselves climbing uphill barefoot on streets of broken glass. If, on the other hand, we learn the logic of diversity bonuses and learn how to form teams and interact with one another so as to produce diversity bonuses, we align the normative ideal with our self-interest. We skateboard downhill on smooth pavement.

The same logic can be applied to diversity efforts based on compliance with the law and changing demographics—the idea that America will soon be a nation with no majority group, so we must be inclusive. Though each promotes inclusive workforces, each positions inclusion, at least in the short term, as a sacrifice. The diversity-bonus logic does not. It shows that diversity can improve performance.

A KNOWLEDGE ECONOMY PHENOMENON

Historically, diversity bonuses have not been a central reason for promoting diverse interactions. That should be expected. The theory will show that diversity bonuses occur most often within teams of cognitive workers engaged in nonroutine tasks. As we transition to a knowledge economy and as more people work in teams on complex tasks, diversity bonuses become more relevant. We can find diversity

bonuses in scientific research, on investment teams, in groups of neonatal surgeons and script doctors, and among groups of programmers and policy makers

Diversity bonuses were less prominent in the past when most workers were engaged in routine tasks. The logic is straightforward for why routine physical tasks cannot produce large diversity bonuses. Think of a group of Domino's employees folding pizza boxes. The number they fold as a team equals the sum of the boxes folded by the individuals. No bonus exists. Similar logic holds for the number of packages delivered by the fleet of UPS drivers. The total equals the sum. No diversity bonuses arise. However, diversity does exist among the teams of engineers and mathematicians who devise the complex algorithms that route those trucks.

When diversity bonuses exist, the best group will not, as a rule, consist of the best individual performers according to some criterion. Instead, it will be diverse. I am not saying that an organization should hire less talented people. The claim is that talent is multi-dimensional. An organization should hire people with different talents and skills, an insight that I make formal by introducing the concept of a cognitive repertoire.

Similarly, selecting an optimal group requires consideration of the cognitive diversity each person adds. To be clear, a person cannot be diverse, but a person can add diversity. The diversity a person contributes will be relative to an extant group and with respect to a given task. The same person may add relevant diversity to one group on one task and not add diversity to a different group on a different task.

From a diversity-bonus standpoint, choices about whom to hire do not involve a tradeoff between excellence and diversity. If selecting a person to add to a research team or design group, the best choice will be the person who can add the most new ideas or apply the most novel tools. That may not be the person who would perform the best on her own, or who has the highest test scores. The diversity that a person adds to the group will matter as well.

The same logic applies when selecting a cohort. Each year, the University of California–Los Angeles receives over one hundred thou-

strip the capabilities of any one person, so organizations rely on teams. The best of those teams are diverse. They include people with diverse training, experiences, and identities.

The teams that excel achieve diversity bonuses, and that often requires behavioral changes. Those behavioral changes require practice guided by theory. If we understand the logic of diversity bonuses—that is, if we understand the logic and read the evidence—we are better able to identify actions that produce bonuses. Believing that they are there also helps. If we see inclusive actions as in our self-interest, we are more likely to act inclusively, engage diverse ideas, and produce bonuses.[6]

THE MIDDLE OF TOWN

To explain diversity bonuses, I present frameworks, construct models, evaluate empirical evidence, and explore illustrative cases. Together, these enable me to trace the boundaries of the domains in which diversity produces bonuses and those in which it does not.

I first describe the core logic for how diversity creates bonuses. I then unpack that logic by describing cognitive repertoires and linking those directly to better outcomes. Loosely defined, a person's *cognitive repertoire* consists of the different ways in which that person thinks. Having established the logic, I take up the connections between cognitive and identity diversity by presenting three frameworks: icebergs, the timber-framed house, and the cloud.

That discussion lays the groundwork for interpreting empirical studies on diversity and team performance. The evidence of the benefits of cognitive diversity proves strong, bordering on overwhelming.[7] Studies of identity diversity and performance also align with the theoretical models, though not as strongly. I hasten to add that in interpreting those studies, we must keep in mind that the data tell us what we currently achieve. The logic shows how much we could achieve in ideal circumstances. I conclude by embedding the diversity bonus logic within the larger business and societal cases for diversity and inclusion, offering thoughts on how we might better achieve bonuses and highlighting the need for practice and bottom-up integration.

As a preview of the type of claims that follow, one result will be that when a group of people make numerical predictions, the error of their collective prediction cannot be larger than the average of their individual errors. In other words, diverse predictive groups must be more accurate than their average member. Everyone (by that I mean the collective) is above average. Always.

Furthermore, the amount by which the group outperforms its average member depends on diversity: holding the average size of an error constant and making the predictions more diverse makes the group smarter. One analysis of forty thousand predictions by economists found that averaging two predictions reduced the expected error by 8 percent.[8] That error reduction represents a diversity bonus—a significant, quantifiable improvement due to differences in how people think.

I have witnessed, read about, and heard accounts of hundreds of diversity bonuses. I believe that we can build organizations, and even a society, where we achieve them as a matter of course. Doing so requires that we understand how the bonuses occur and that we practice inclusive, productive behaviors. That is why I wrote this book—to help us generate diversity bonuses. If we can, we will improve society and expand opportunities.

My approach brackets social justice and equity-based arguments. That separation has been difficult. Over the past decade, I have met many talented people who have suffered from implicit and outright discrimination. I have met many others who have benefitted from a finger on a scale at key moments. As much as I would like to do so, I do not tell those personal stories. I omit them, not because the normative case lacks merit, but because creating diverse teams based on normative principles alone will produce few bonuses.

People will embrace the move toward a more integrated, inclusive society if they see benefits from doing so. To reach a place where each of us can contribute our unique skills, knowledge, and insights, we need to act with forethought. We need to apply logic, data, and experience in order to build effective, diverse teams capable of achieving bonuses. That type of scientific approach to diversity and inclusion veers neither left nor right. Like Main Street in Sandburg's Kalamazoo, it runs straight through the middle of the town.

CHAPTER ONE

DIVERSITY BONUSES: THE IDEA

The power of a theory is exactly proportional to the diversity of situations it can explain.

—Elinor Ostrom, *Governing the Commons: The Evolution of Institutions for Collective Action*

On April 8, 1865, one week before his assassination at Washington's Ford's Theatre, Abraham Lincoln visited a field hospital near Petersburg, Virginia. To raise morale among the wounded troops, Lincoln picked up an ax and began chopping wood. As a youth, he had split thousands of fence rails to earn money or goods in kind—he was once paid in dyed brown cloth sufficient to make him a pair of trousers. On the day of his visit to the field hospital, he demonstrated to all assembled that the famed "Rail Splitter" could still "make the chips fly."[1]

Suppose that you had to hire a team of people to split rails. You would look for strong, tall people like Lincoln who are best at splitting rails. The logic borders on the tautological: the best team of rail splitters consists of the best individuals.

That logic makes sense because splitting rails is a separable task. The number of rails split by the team equals the sum of the rails split by each person. That logic does not apply for teams of people who work on the complex tasks we confront in our modern, information-rich society. In those settings, a team's performance depends on the diversity as well as the ability of its members. As a result, a policy of hiring the best does not make sense on high-dimensional tasks. The best team will not consist of the "best" individuals. It consists of diverse thinkers.

The idea that diverse ways of thinking can lead to deeper insights is not new. It can be found in the writings of Aristotle. Lincoln himself applied a logic of diversity when appointing his cabinet. He did not create an echo chamber of like-minded people. He chose a diverse cabinet, the famed team of rivals.[2] He opted for diversity partly to build political consensus but primarily because he faced complex problems. As he wrote in his December 1862 message to Congress, "The occasion is piled high with difficulty, and we must rise with the occasion. As our case is new, so we must think anew and act anew. We must disenthrall ourselves."

We too must disenthrall ourselves. We now operate and interact in a complex world in which we work with our minds, not our backs. We must therefore also think anew. We must abandon the narrow and demonstrably false belief that we should admit, hire, and promote those who perform best according to a common standard. As I show later in this book, those who score highest will tend to be similar. Hiring "the best" will reduce the diversity of our scientific teams, our planning commissions, and our boards of directors, and with it their collective potential.

On the complex tasks we now carry out in laboratories, clean rooms, boardrooms, courtrooms, and classrooms, we need people who think in different ways. And not in arbitrarily diverse ways. Effective diverse teams are built with forethought. Not all teams of rivals will succeed. Not all multitudes possess wisdom. To realize the benefits of diversity, we need logic and theory to identify the types of diversity that improve outcomes and to understand the conditions under which they do so. And then we need practice.

Getting the logic correct takes precedence. Otherwise, we cannot compose the best possible teams, and we limit what we can achieve even with practice. That is the main reason for this book: to help us get the logic right. To get us to embrace the contrary assumption and to make our world better.

In this chapter, I sketch the core logic for how diversity produces bonuses. That logic relies on linking *cognitive diversity*, which I define as differences in information, knowledge, representations, mental models, and heuristic, to better outcomes on specific tasks such as

problem solving, predicting, and innovating. Cognitive diversity differs from *identity diversity*—differences in race, gender, age, physical capabilities, and sexual orientation. That said, identity diversity, along with education and work and life experience, will be a contributor to those differences. For the moment, we will keep them separate.

DIVERSITY BONUSES ON COMPLEX TASKS

To sketch the core logic, I borrow a stripped-down model that I developed with Jon Bendor. This model reduces cognitive repertoires to collections of *tools*.[3] Think of these tools as analytic analogues of a carpenter's tools. A carpenter has a chainsaw; a mathematician knows the chain rule. A carpenter attaches boards with a nail gun; a plant biologist inserts DNA with a gene gun.

I use that model to show the logic of how diversity bonuses arise. I then connect assumptions about the diversity of tools that people possess to the complexity of the challenge or opportunity at hand. That second step includes two purposefully incomprehensible graphs.

In the tool-based model, I assign a unique letter to each tool. Figure 1.1 shows three people and their cognitive tools. Define ability of a person to equal the number of tools she knows. Ann possesses five tools, so she has an ability of five. Barry, in the center, has ability four, and Cam has ability three. Ann is the best.

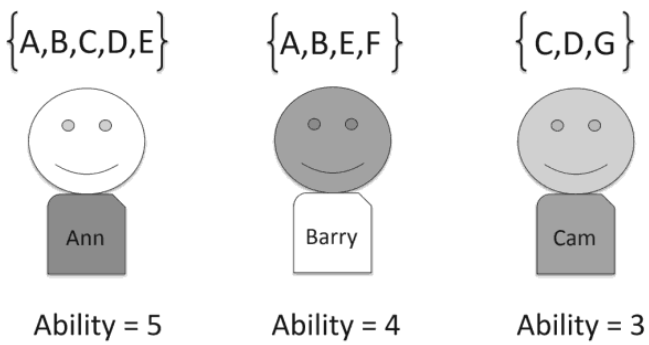

Figure 1.1 Three People and Their Cognitive Tools

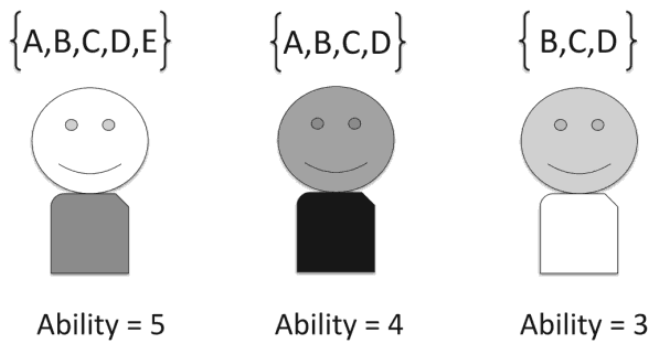

Figure 1.3 Three People Who Produce No Diversity Bonus

As an analogy, think of people riding on a train from Chicago to Los Angeles. At each stop along the way, the conductor tells the history of the station. If one person stays on the train longer than another, that first person learns about more stations than the second. She necessarily knows about every station that the second person knows about.

The cognitive tools shown in figure 1.1 do not satisfy that condition. Here, the person with the fewest tools knows tools the most talented person does not. For this configuration to occur, it must be that tools need not be acquired in a single order. Instead of a train trip, a trip to the zoo would be a more appropriate analogy. One person might spend a full day at the zoo and visit five exhibits (Alligators, Bears, Camels, Ducks, and Elephants). A second person might leave midafternoon after taking in only three exhibits (Camels, Ducks, and Gorillas). The second person learns less, but she gains knowledge of gorillas that the first person does not have. The first person does not know everything the second person knows.

Figure 1.4 represents these two possibilities in network form. Assume that a person must first learn a tool on the left edge and then can follow any path. The upper path corresponds to the train ride. Diversity doesn't matter. The best team consists of the best person. Ability rules.

The lower path represents the trip to the zoo. As shown in figure 1.5, the tool sets in the first example can be constructed within this network. Ann can follow a path that leads to A, B, C, D, and E. Barry can learn A, B, E, and F, and Cam can learn tools C, D, and G.

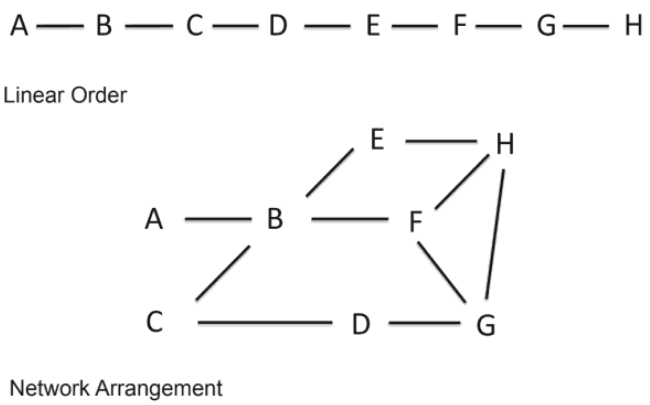

Figure 1.4 Linear and Network Arrangements of Cognitive Tools

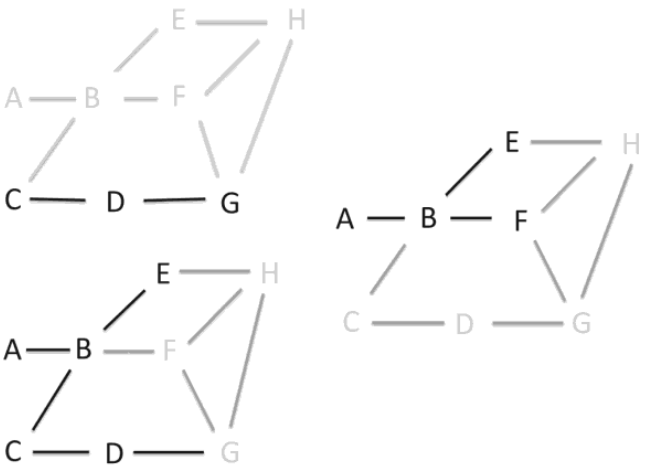

Figure 1.5 How Tool Structure Influences Cognitive Diversity

The fact that a person can know fewer but different tools means that someone can have less measured ability than the people already in a group but still contribute.

The remaining step in the logic connects the value of diversity to complexity. The intuition will be straightforward: Our accumulation of knowledge, representations, techniques, and models produces elaborate networks of what I am calling tools. This allows people to construct distinct tool sets. That need not be the case for less developed bodies of knowledge, which often create linear orders.

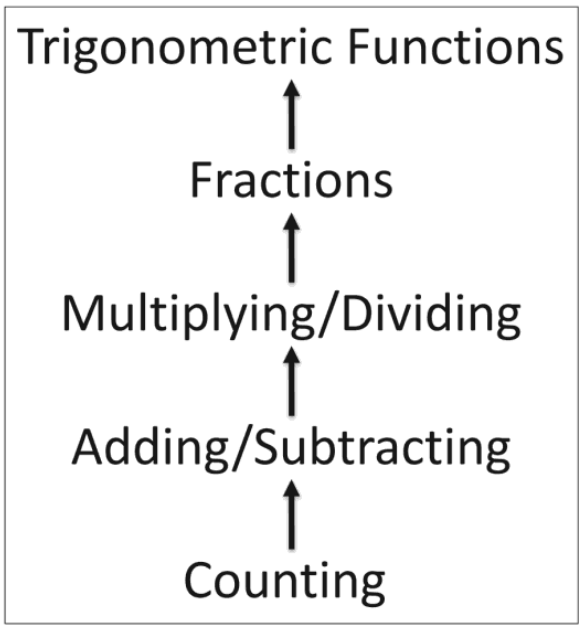

Figure 1.6 Relationships among Topics in Elementary School Mathematics

As an example, consider topics in mathematics. Figure 1.6 shows the relationships between the topics covered in elementary school mathematics. The topics build on one another in a linear fashion. You need to be able to count in order to add, to add in order to multiply and divide, to multiply and divide in order to understand fractions, and to understand fractions in order to define the trigonometric functions sine and cosine. These topics can be represented in a linear order.

In contrast, the advanced mathematical topics in figure 1.7 connect in multiple ways. This is the first incomprehensible graph. To approach a network of this complexity, ignore the technical terms and focus on the many boxes and arrows. Notice that there exist multiple paths a student could pursue. Parts of the network can be understood by anyone. For instance, in the middle of the figure, the integers (1, 2, 3, and so on) point to the rational numbers $\left(\frac{1}{2}, \frac{1}{3}, \cdots\right)$, which in turn point to the real numbers ($\pi = 3.1415\ldots$). To know the real numbers, a person must first understand integers and fractions. That portion of the network looks like the linear elementary school network.

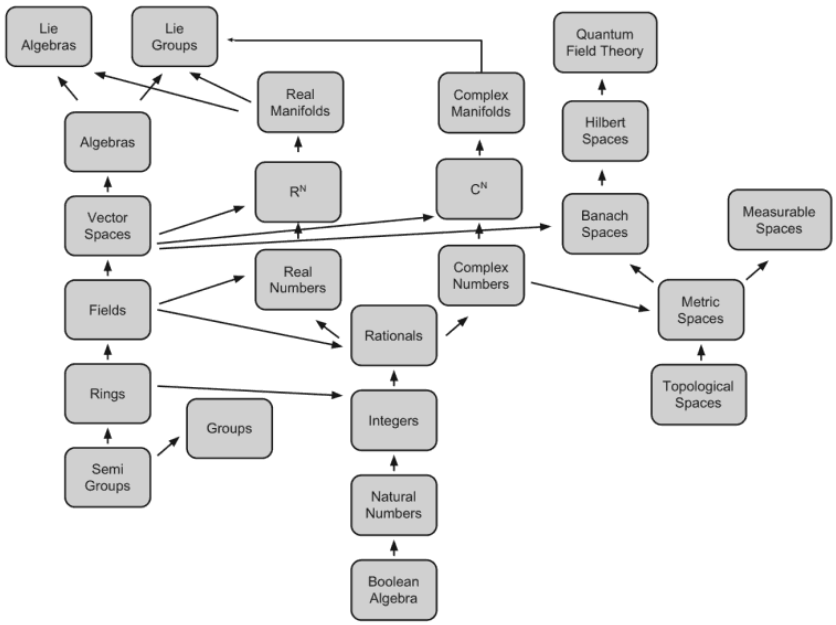

Figure 1.7 Relationships among Topics in Graduate Mathematics (courtesy Tegmark, "Ultimate Ensemble Theory?")

Making sense of other parts of the network requires deeper technical knowledge. The graph implies that a person could master Lie groups (in the upper left) without knowing Hilbert spaces, distributions, or quantum field theory (in the upper right). The implication is that the tool sets of professional mathematicians would look like those in our first example. And each mathematician would add diversity to the group.

Making breakthroughs in mathematics often involves combining different tools. A report by the National Academy of Sciences describes "an increasing need for research to tap into two or more fields of the mathematical sciences."[6] Tapping into two fields implies a diversity bonus. Something that could not be proved using either field alone can be solved with tools from two fields.

That same report notes the growing connections between mathematics and other fields including defense, entertainment, physics, economics, computer science, linguistics, manufacturing, finance, and

biology. These connections reflect a broader trend toward multidisciplinary inquiries. That can be explained by the complexity of modern challenges and opportunities.

Consider the rise of obesity. Some call it an epidemic. Fifty years ago, we might have placed the challenge of reducing obesity within the domain of nutritional sciences. We now understand that it has myriad causes that cross disciplines.

Figure 1.8 characterizes one attempt to explain the obesity epidemic with arrows denoting causal forces from the Foresight Group in the UK.[7] It is meant to be overwhelming. (Yes, this is the second incomprehensible graph.) The disciplinary knowledge embedded in the graph crosses economics, nutrition, physiology, sociology, biology, media studies, advertising, transportation and infrastructure, and genetics.

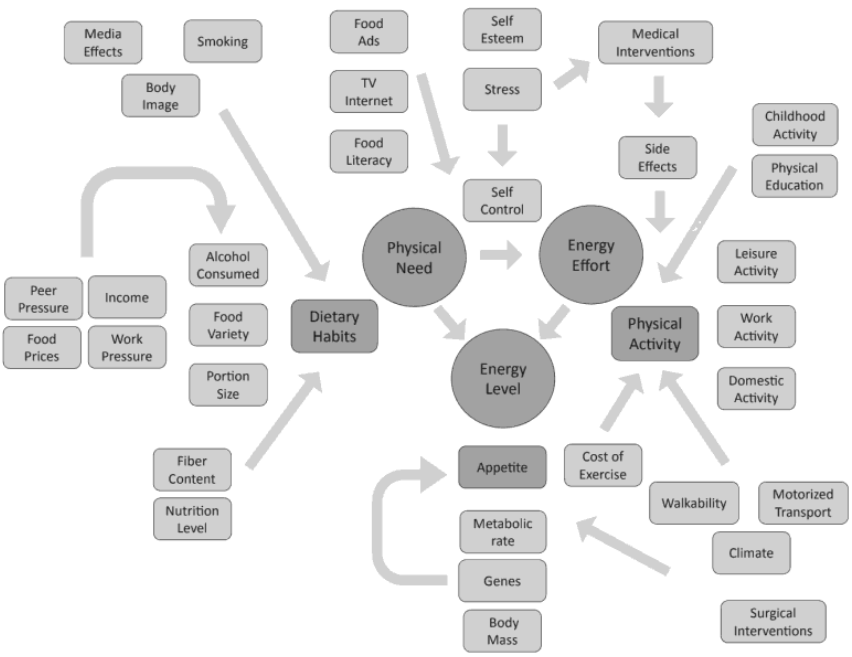

Figure 1.8 Obesity Knowledge Structure (based on Vandenbroeck, Goossens, and Clemens, *Foresight Tackling Obesities: Future Choices—Building the Obesity System Map.* Government Office for Science, UK Government's Foresight Programme, 2007, http:www.foresight.gov.ukObesity12.pdf. Accessed June 16, 2009)

mathematics problem as well as the problems she chooses to tackle. That's truer for the frontiers of math, where mathematicians often rely on analogies and knowledge from other experiences.

The lack of an obvious logic linking identity diversity to germane cognitive diversity in fields like math or physics does not mean that those fields do not need to be inclusive. On the contrary, because mathematics community confronts hard problems, it needs cognitive diversity.

Permit me a slight digression to make a larger point linking inclusion to cognitive diversity. Define the capacity of a mathematician as the number of tools she can acquire. We can think of her career as traversing a path in figure 1.7. A great mathematician might learn about twenty topics, a good one only fifteen. Excluding some identity groups from being mathematicians or making the field less attractive to some groups results in a cohort of mathematicians with lower overall capacity. If a woman with a capacity of twenty opts out of mathematics, and a man with capacity sixteen replaces her, then mathematics suffers. The profession loses talent because she has more capacity, and it loses diversity because of her larger capacity.

Fifty years ago, people chalked up the low representation of women and some racial groups in mathematics, and science generally, to a lack of interest—"Women do not want to become physicists." As recently as twelve years ago, some attributed the low numbers in these professions (offensively, I might add) to a lack of cognitive ability. Current thinking points to the effects of limited opportunities and exposure, the lack of role models, and the effects of noninclusive behaviors and discrimination.

Personal accounts of women who entered school with the interest and ability to excel at mathematics and science but pursued other paths reveal the accumulated dampening of interest produced by repeated acts of discrimination. Some actions were overt and direct. Others were subtler. Combined, they made science an unwelcoming place.

As an undergrad, I took a two-year math sequence listed as Honors Track II that students referred to as "math for gods." Lacking any training in calculus, I struggled during the first two courses. Recently, I looked up three students who had excelled in those classes.

All three have enjoyed successful careers. One works as the chief actuary and risk officer at a large insurance company. A second serves as a chaired professor of law at the University of Chicago. The third, the only woman of the three, began her career in engineering, rose to become a senior software engineer, and now works as a life coach, facilitator, and counselor.

Personal accounts of women who tried to pursue scientific careers reveal any number of obstacles, both direct and indirect.[8] The fact that the two men remain in technical fields and the one woman opted out is not surprising, but it is disheartening. We lose talent and diversity when environments are not inclusive.

Data gathered by the National Science Foundation reveal low representation of women and minorities in many technical fields, and we cannot but infer lost diversity bonuses. In 2013–2014, 1,200 US citizens earned PhDs in mathematics. Of these scholars, 12 were African American men and just 6 were African American women. From 1973 to 2012, over 22,000 white men earned PhDs in physics, as compared to only 66 African American women and 106 Latinas. Those numbers translate into over 550 white men and fewer than 2 black women earning PhDs each year. Over that same time period, about 15 Asian American women earned physics PhDs each year.[9]

In addition, recall how mathematics connects to other disciplines and how those connections can produce bonuses. A person may apply his mathematical tools to a problem that leverages identity-based knowledge or interests.

Thus, even if we see no obvious direct links between identity and relevant cognitive diversity within a technical field, diversity and inclusion produce bonuses by increasing the pool of talent and the range of problems studied. Think back first to the complicated graph of mathematical knowledge. People with greater capacity can trace out longer paths in that graph. Their talent adds diversity. In addition, on cross-disciplinarity complex tasks like the obesity epidemic or rising opioid use, identity-based knowledge or perspectives become germane, and identity brings relevant cognitive diversity.

LESSONS FROM THE TOOLBOX MODEL

The toolbox model reveals how complexity, whether within a field like mathematics or in the context of a problem like obesity, creates the potential for diversity bonuses. If the domains were not complex and tools were arranged linearly, the smartest person would know everything that everyone else knows. When tools can be acquired in any number of orders and there exist a large number of relevant tools—that is, when the domain is complex—the potential for diversity bonuses exists.

Complexity and Diversity Bonuses

If cognitive tools must be accumulated in a particular order, like the stations on a train trip, then the best team consists of the highest-ability person and no diversity bonuses exist. If cognitive tools can be accumulated along multiple paths, that is, if the field (mathematics) or the challenge (reducing obesity) is complex, then diversity bonuses can exist because different people master different relevant tools.

The toolbox model represents people as possessing a collection of tricks or techniques to solve problems. If a person possesses different tools, then she produces bonuses. The same logic described with respect to these tools can be applied to the various parts of a person's repertoire: her information, knowledge, models, representations, or heuristics. When there exist only a few tools that must be acquired in a specific order, then we should not expect bonuses. A single person could master all the tools necessary. We need not build teams or seek diversity bonuses. When repertoires can be accumulated along multiple paths and when there exist an abundance of relevant ways of thinking for some task, then diversity bonuses will exist.

Like any model, this tool model oversimplifies. It assumes that everyone trusts and understands one another, that people can recognize improvements, and that no communication costs (or other costs, for that matter) arise when enlarging the team. Without any costs to scaling, the model implies that we should make teams

as large as possible. Larger teams would possess more tools and be more likely to excel at a task. In real situations, communication and coordination costs rise with team size, so even though more people would mean more cognitive tools, larger teams need not perform better.

THE (INAPT) PORTFOLIO ANALOGY

I have found that the most common explanation that people give for the benefits of identity diversity rests on a *portfolio analogy* from finance. That analogy is inapt and unfortunate. Diversity bonuses are not at all the same as portfolio effects. Not only does portfolio thinking offer little guidance for how to hire employees or assemble teams, it also systematically understates diversity's contribution.

The portfolio analogy can be stated as follows: Fund managers invest in a variety of diverse stocks to earn robust returns. By analogy, organizations should create identity-diverse and cognitively diverse teams. For the analogy to be useful, the benefits fund managers receive from diverse investments must be analogous to the benefits organizations receive from diverse people. That is not true.

Fund managers select diverse investments to reduce variation in returns—to lessen risk. Organizations want diverse employees for different reasons. Why they want diversity and the type of diversity they want depends on the task. For example, organizations want diverse problem-solving teams because those teams come up with more ideas that they can recombine to produce bonuses. They want diverse forecasting teams because those teams make more accurate predictions. In both cases, diversity produces bonuses. It does not reduce risk.

A more detailed comparison of investment portfolios and teams of people reveals that the mechanisms through which diversity operates also differ. When building an investment portfolio, a fund manager wants high return and low risk. As a rule, higher-return investments come with higher risk. That follows from economic logic: if high-return, low-risk investments were available, they would

attract many investors. This would raise the price of those investments and lower their returns.

A fund manager therefore must accept risk to earn high returns. A manager can earn (relatively) high returns with low risk by investing in negatively correlated stocks, that is, a diverse portfolio. Figure 1.9 shows a portfolio containing four stocks: a technology stock that returned 4 percent, an oil stock that returned 9 percent, an airline stock that lost 4 percent, and an automobile stock that earned 3 percent.

When the fund manager made these investments, she did not know what their returns would be. The returns depend on what financial analysts call the *state of the world*. No one can know the state of the world a year ahead of time. The idea is to select a portfolio of stocks that pays well regardless of what happens in the economy.

In our example, perhaps the airline stock lost money because of high energy prices. Airline stocks suffer under those conditions. Luckily, in that same state of the world, oil stocks perform well. Had

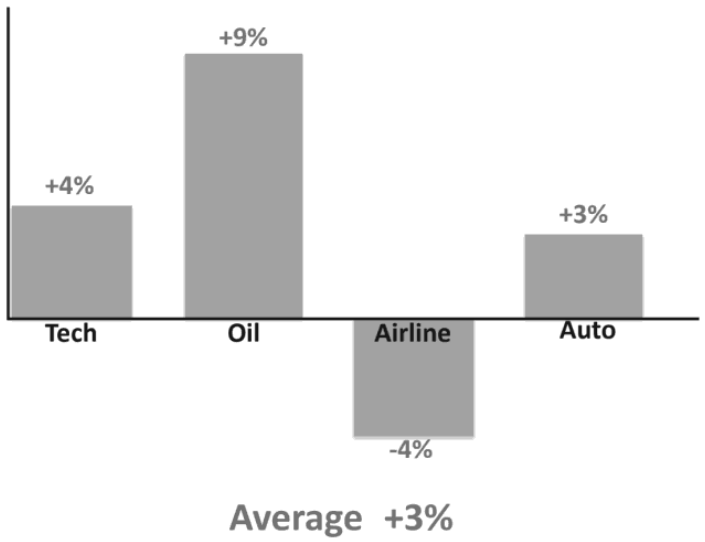

Figure 1.9 A Diverse Portfolio and Risk Reduction

nearly half million users—the largest data set ever made available to the public. Contest rules were as follows: any contestant who could predict consumer ratings 10 percent more accurately than Netflix's proprietary Cinematch algorithm would be awarded a $1,000,000 prize.[10] Netflix had poured substantial resources into developing Cinematch. Improving on it by 10 percent would not prove easy.

The story of the Netflix Prize differs from traditional diversity narratives in which a single talented individual, given an opportunity, creates a breakthrough because of some idiosynchratic piece of information. Instead, teams of diverse, brilliant people competed to attain a goal. The contest attracted thousands of participants with a variety of technical backgrounds and work experiences. The teams applied an algorithmic zoo of conceptual, computational, and analytical approaches. Early in the contest, the top ten teams included a team of American undergraduate math majors, a team of Austrian computer programmers, a British psychologist and his calculus-wielding daughter, two Canadian electrical engineers, and a group of data scientists from AT&T research labs.

In the end, the participants discovered that their collective differences contributed as much as or more than their individual talents. By sharing perspectives, knowledge, information, and techniques, the contestants produced a sequence of quantifiable diversity bonuses.

Winning the Netflix Prize required the inference of patterns from an enormous data set. That data set covered a diverse population of people. Some liked horror films. Others preferred romantic comedies. Some liked documentaries. The modelers would attempt to account for this heterogeneity by creating categories of movies and of people.

To understand the nature of the task, imagine a giant spreadsheet with a row for each person and a column for each movie. If each user rated every movie, that spreadsheet would contain over 8.5 billion ratings. The data consisted of a mere 100 million ratings. Though an enormous amount of data, it fills in fewer than 1.2 percent of the cells. If you opened the spreadsheet in Excel, you would see mostly blanks. Computer scientists refer to this as *sparse data*.

The contestants had to predict the blanks, or, to be more precise, predict the values for the blanks that consumers would fill in next. Inferring patterns from existing data, what data scientists call *collaborative filtering*, requires the creation of similarity measures between people and between movies. Similar people should rank the same movie similarly. And each person should rank similar movies similarly.

A team knows it has constructed effective similarity measures if the patterns identified in the existing data hold for the blanks. Characterizing similarity between people or movies involves difficult choices: Is Mel Brooks's spoof *Spaceballs* closer to the *Airplane!* comedies or to *Star Wars*, the movie that *Spaceballs* parodied?

Early in the competition, contestants' similarity measures of movies emphasized attributes such as genre (comedy, drama, action), box office receipts, and external rankings. Some models included the presence of specific actors (was Morgan Freeman or Will Smith in the movie?) or types of events, such as gruesome deaths, car chases, or sexual intimacy. Later models added data on the number of days between the movie's release to video and the person's day of rental.

One might think that including more features would lead to more accurate predictions. That need not hold. Models with too many variables can overfit the data. To guard against overfitting, computer scientists divide their data into two sets: a *training set* and a *testing set*. They fit their model to the first set, then check to see if it also works on the second set.[11] In the Netflix Prize competition, the size of the data set and the costs of computation limited the number of variables that could be included in any one model. The winner would therefore not be the person or team that could think up the most features. It would be the team capable of identifying the most informative and tractable set of features.

Given a feature set, each team also needed an algorithm to make predictions. Dinosaur Planet, a team of three mathematics undergraduates that briefly led the competition in 2007, tried multiple approaches, including clustering (partitioning movies into sets based on similar characteristics), neural networks (algorithms that take features as inputs and learn patterns), and nearest-neighbor methods (algorithms that assign numerical scores to each feature for each movie and compute a distance based on vectors of features).

At the end of the first year, a team from AT&T research labs, known as BellKor, led the competition. Their best single model relied on fifty variables per movie and improved on Cinematch by 6.58 percent. That was just one of their models. By combining their fifty models in an ensemble, they could improve on Cinematch by 8.43 percent.

A year and a half into the competition, BellKor knew they could outperform the other teams, but also that they could not reach the 10 percent threshold. Rather than give up, BellKor opted to call in reinforcements. In 2008, they merged with the Austrian computer scientists, Big Chaos, a team that had developed sophisticated algorithms for combining models. BellKor had the best predictive models. Big Chaos knew better ways to combine them. By combining these repertoires, they produced a diversity bonus. However, that bonus was not sufficient to push them above the 10 percent threshold.

In 2009, the team again went looking for a new partner. This time, they added a Canadian team, Pragmatic Theory. Pragmatic Theory lacked BellKor's ability to identify features or Big Chaos's skills at aggregating models. Pragmatic Theory's added value came in the form of new insights into human behavior.

They had developed novel methods for categorizing distinct users on the same account. They could separate one person into two identities: Eric alone and Eric with a date. These two Erics might rank the same movie differently. Pragmatic Theory also identified patterns in rankings based on the day of the week—some people rated movies higher on Sundays. They found that for some movies, rankings depended on whether people rated the movie immediately or after having time for reflection. As the credits roll, the hilarity of *Snakes on a Plane* or *Anchorman* results in high rankings. With time for reflection, most people no longer consider a flaming flute or a burrito in the face to be hallmarks of quality films and assign fewer stars.[12]

The combined team, now called BellKor's Pragmatic Chaos, had thought up a jaw-dropping eight hundred predictive features.[13] More diversity meant more ideas. Recall that the goal was not to come up with the most features. Not all the features would improve accuracy. The team had to select from among them to create powerful combina-